DC MACHINES

* It common name given two types:-
  (1.) DC genʳ (2.) Dc motor.

① Dc genʳ → * A m/c which is designed to take the advantage of electromegnatic indⁿ. in order to convert mech. movement into electricity (dc vol.)

***Faraday's law of electromegnatic indⁿ →** *whenever a condʳ cuts megnatic flux a dynamicaly induced emf is produced in the condʳ. The induced emf is directly proportional to rate of change of flux linkage.

flux → The amount of megnatic field around the megnat represent by lines of force. In generaly it is indicated by ϕ & unit is wb.

flux linkage → The extent of interaction between the flux & condʳ ~~or~~ condʳ & flux.

* It depandns on the nature of flux time varying or time invarying.
* If the flux is time invarying in nature it require a relative motion between the flux & condʳ for the flux linkage.
* If the flux is time varying it automaticaly links with stationary condʳ.
* According to Faraday there are 3 modes of flux linkages

$$\lambda = N \times \phi$$

$$e \propto \frac{d\lambda}{dt} \propto \frac{d(N\phi)}{dt} = N\frac{d\phi}{dt}\ V$$

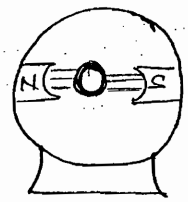
$$e = N\frac{d\phi}{dt} \times \frac{di}{di} \text{ Volts}$$

$$e = N\frac{d\phi}{di} \times \frac{di}{dt}$$

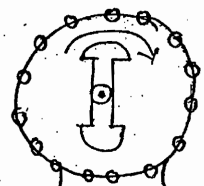
$$\boxed{e = L\frac{di}{dt}}$$

3 modes →

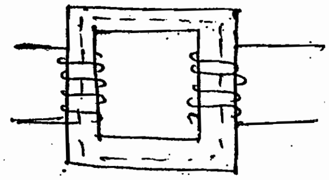
(1.) Conductors (Rotating) Flux (stationary) }
(2.) Conductors (stationary) flux (Rotating) } (Time invarying)
(3.) Conductors (~~stationary~~) flux (stationary)



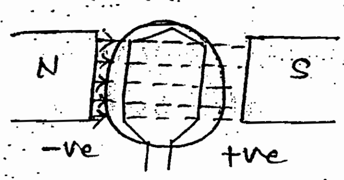
Dc m/c
mode(1)

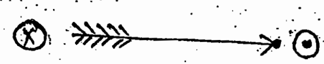


syn. m/c
mode(2)

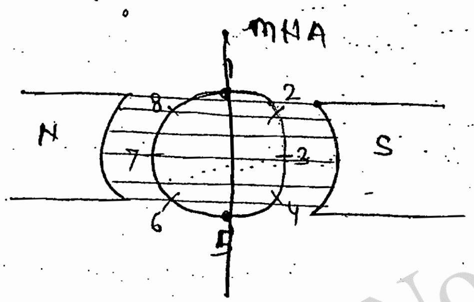


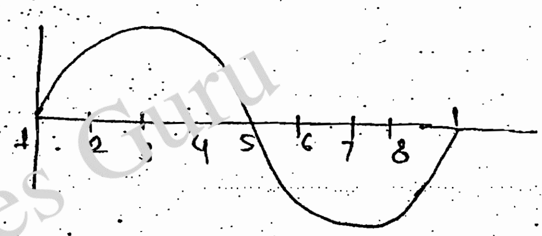
T/F
mode(3)





(DC)
1880 Thomas Alva Edison
1886 (AC) Nicolas Tesla





$$e = N\frac{d\phi}{dt} \text{ volts}$$

$$e = Blv\sin\theta \text{ volts}$$

θ = Angle b/w condr rotation & flux line

FRR
Fore – Dirn of flux
Thumb – Dirn of Rot/motion
Middle – Dirn of emf/current

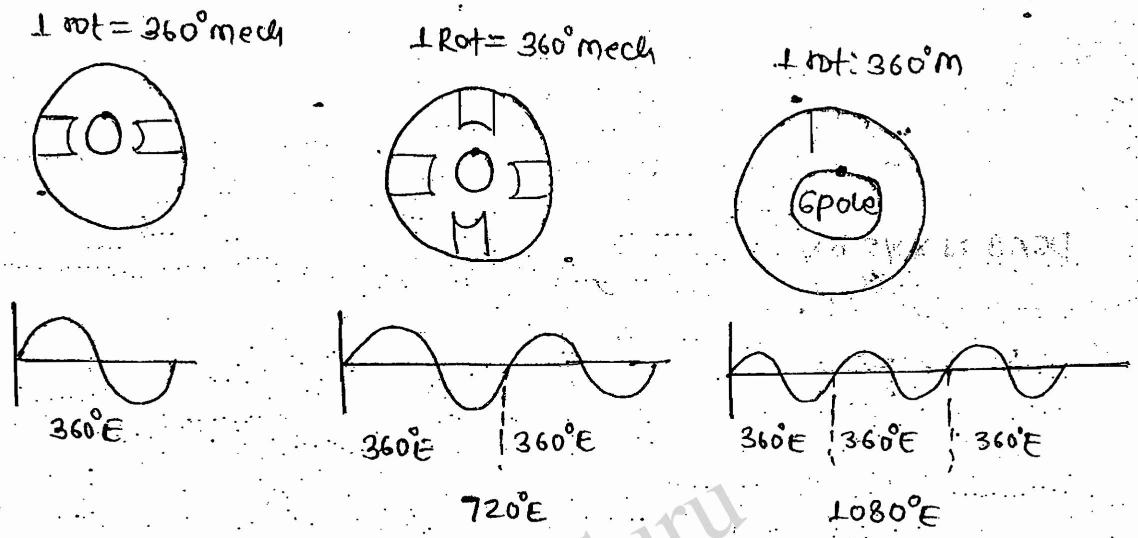
* Consider a simple coil rotating clockwise between 2 poles N & S. In one complete rotation it will produce 1 +ve half cycle & -ve half cycle which is periodic in nature known as alternating vol. or current.
* In positions 1 & 5 the condr movement is exactly parallel to the flux lines ($\theta = 0$)

* Due to this which there is no rate of change of flux linkage & the induced emf is 0. The axis along 1 & 5 where the emf induced is 0 is called as Magnetic Neutral axis.

* At positions 3 & 7, $\theta = 90°$ & the cond^r movement is exactly $\perp$ to the flux lines.

* Concequently max^m induced emf.

* MNA will be always 90° with the flux lines.



* Under a pole there are always 180 ele. degree.

$$\boxed{\begin{aligned}\theta_m &= \theta_e/(P/2)\\ \theta_e &= \theta_m \cdot P/2\end{aligned}}$$

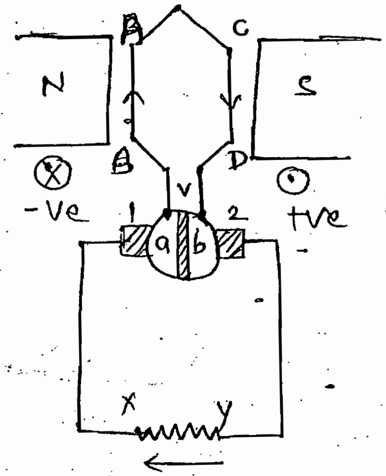
* In AC or DC gen^r there will be alternating vol. induced in the cond^r (AC)

* In AC gen^r AC is directly taken but in a dc gen^r it will be converted into dc using a rotating commutator.

Action of Rotating Commutator →

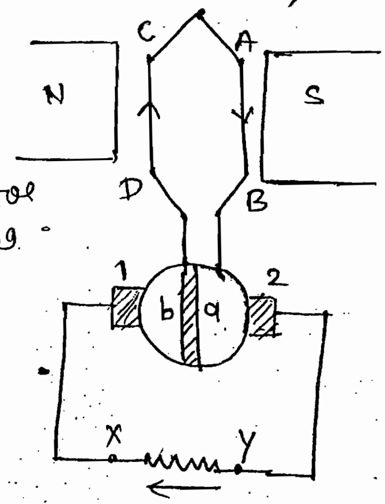
$1 \to 5, 0 \to 180°$

BA CD b2 $\overrightarrow{YX}$ 1a B



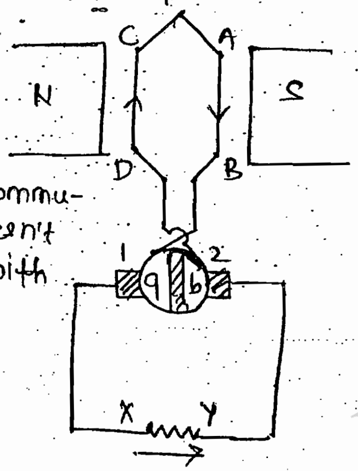
$5 \to 1, 180 \to 360°$

DCABa2 $\overrightarrow{YX}$ 1bD

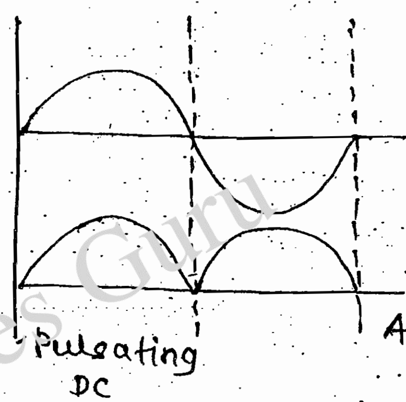


Commutator is rotating with coil

DCABa1xy2bD



when commutator doesn't rotate with coil



* By virtue of its rotation the commutator converts bydirectionaly induced emf into unidirectional (Ac into dc) therefore it is called as mech. rectifier.
* In AC genʳ or dc genʳ the induced emf is ac.
* In dc genʳ the construction will be always rotating condʳ with the stationary field in order to make commutator action possible.
* when a coil rotates across the brushes there is pulsating dc which is not used for commersial dc operation.

In order to improve the shape of waveform there are many no of coils connected in series uniformly distributed known as arm. wdg.

Constructional Details →

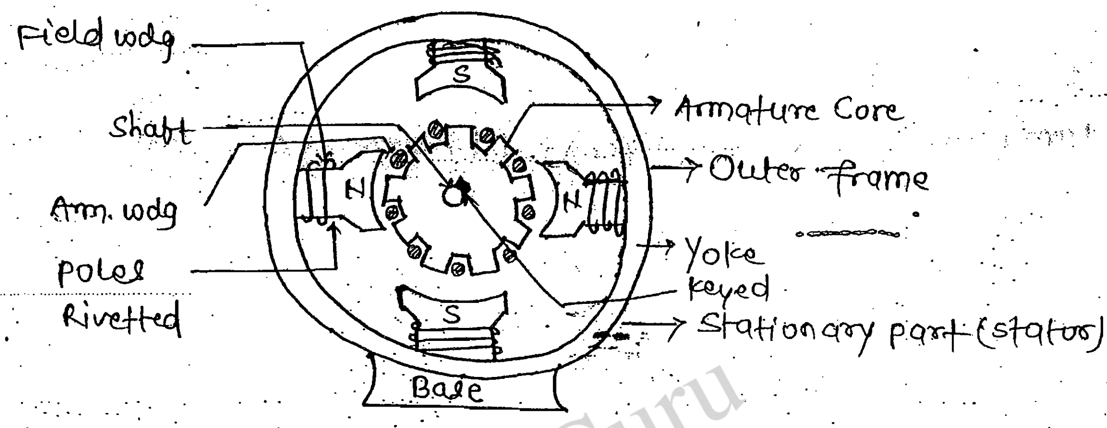
(1) Common features for all rotating ele m/c →

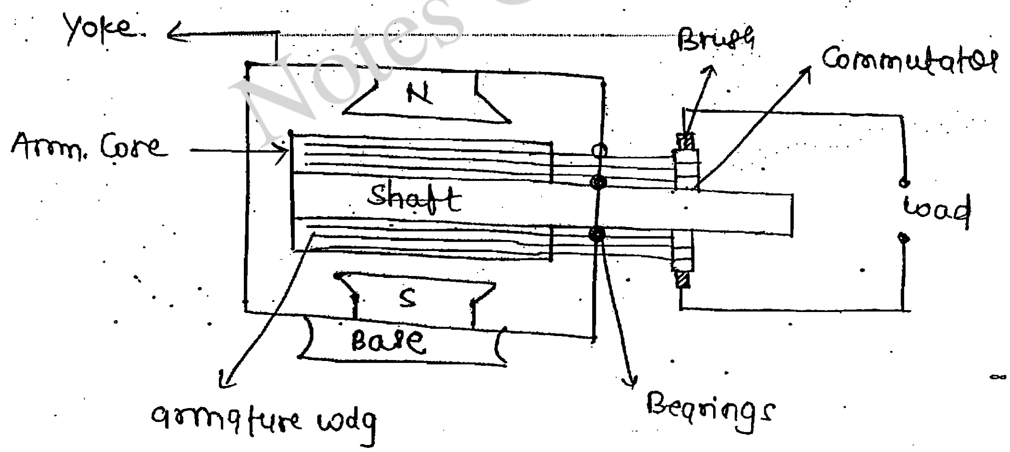
(i) The poles contains Hetropolar st. (alternate North & South poles of even no.)

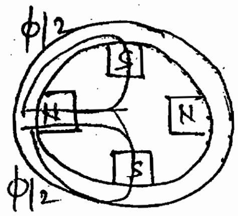
(ii) Excitation should be essentialy in dc.

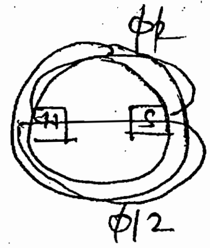
(iii) There will be stator (stationary part) & rotor (rotating part) with a least possible air gap between them.

Air gap → 0.5–2mm



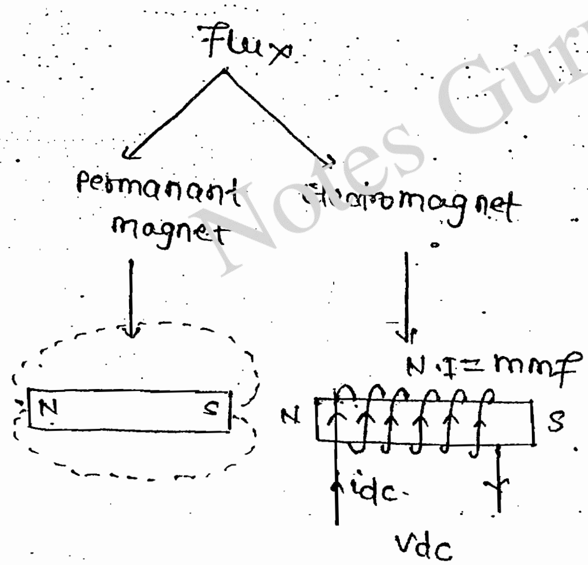


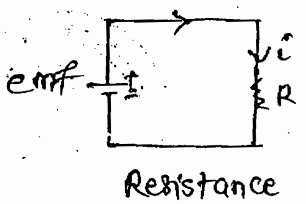


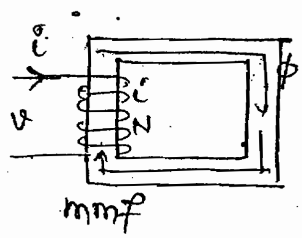


<u>Yoke →</u> * It acts as protective covering to the entire m/c.
* It supports the poles as the poles are directly rivetted to it.
* It offers flux path complition of $\phi/2$ (if ϕ is flux/pole flux passing through yoke is $\phi/2$) . Therfore yoke should be good megnatic material.
* For small m/c <u>cast iron</u> is used, large m/c – <u>Fabricated</u> ~~rote~~ steel.
* If the dc-m/c are operating across power electronic converter laminated yokes are prefered. (to reduce eddy current loss)

<u>Pole →</u> * It has to prdduces working flux in the m/c.
* The basic s





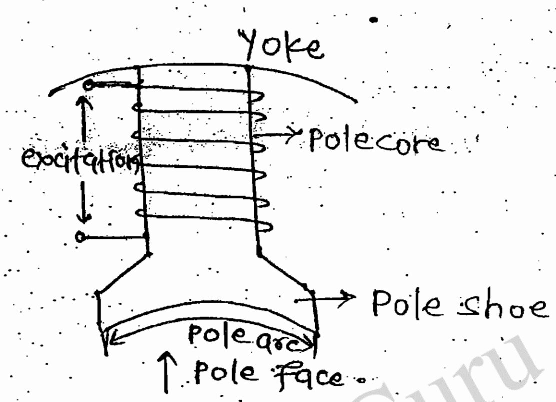


Reluctance

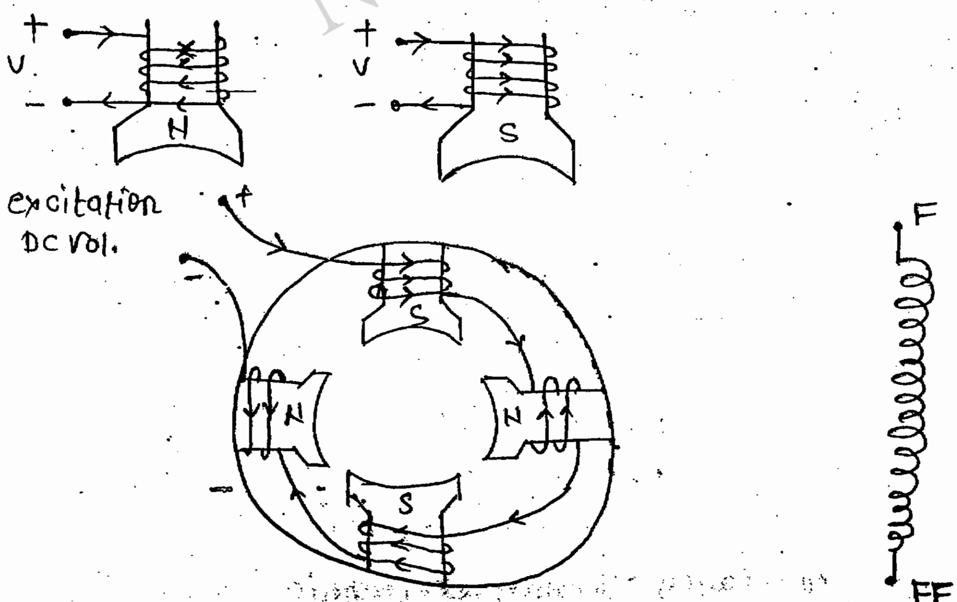
permeability → permit to flow the flux.

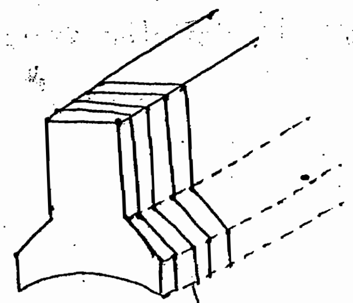
* Excitation should be always dc for the field wdg.

* The funⁿ of the pole is to produce the working flux in the m/c.
* The basic source of flux is permanent magnet which is uncontrolable.
* In order to control the m/c flux need to be controllable. Therefore electromagnets are prefered which requires wdg & a dc vol. across it called as excitation.
* Excitation is essentialy dc because it produce fixed poles polarity.
* The pole is spread out as phole shoe.
* In order to reduce the reluctance in the air gap & to spread flux uniformly on the arm. condⁿ



* The polarity of a pole depands on the polarity of excitation & orientation or sense of wdg.





* Poles are also made up of steel laminations.
* In order to reduce eddy current loss when the flux is not idealy dc.

3) Armature Core → * Arm. core is a cylindrical drum like st. punched into slot on the peripheral.

* The arm. wdg is placed in this slot with the suitable insulation.
* It is mounted & keyed to the shaft. It should be seperior magnetic material.
* As all the electromech. energy conversion happens in this rotating part of m/c (motor or genr), generat.
* Generaly si is used as it has superior megnatic property.
* Due to its high conductivity it will also produce eddy current.
* Therefore solid cores are not prefered but cores are laminated with thin laminations 0.4-1mm thickness.
* Each lamination act as individual core to form single core & the eddy current in each lamination will be considerbly reduced.

Si + steel

↓

-- low hysteris coefficient

Reduce the conductivity of steel

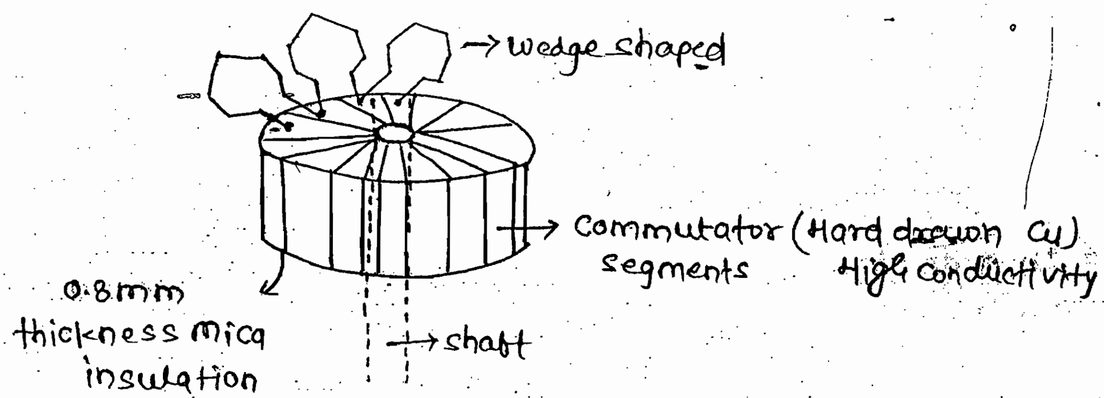
$x = 1.5 - 2.5$

Reduce eddy current & hystesis loss

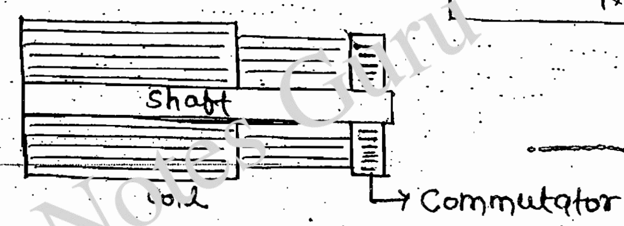
Also called ~~electrosteel~~ technic

* 3.5–4% Si is added to steel which reduce the losses occuring at core known as iron loss.
* Adding Si reduce the conductivity of steel without destrying its megnatic property as well as it has low hysteris cofficient as 1.6 to reduce it Hysteris loss.
* If more Si is added it will destroy mech. property of steel.

* Commutatore →



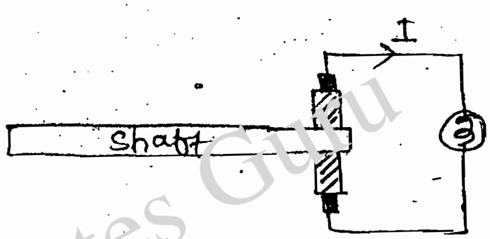
Commutator segments = No. of coils



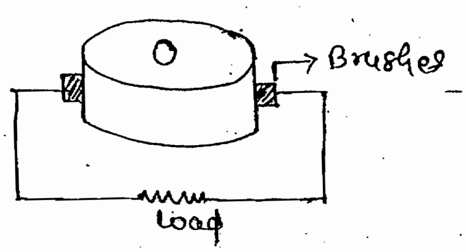
* Commutator is split ring which is segmented through 0.8 mm thickness mica insulation.
* The segments are made up of hard drawn Cu.
* It converts by directional emf or current inside the coil into unidirectional.
* It is the ~~ar~~ image of arm. wdg inside.
* The no of commutator segments are equal to no. of coil.
* Commutation plays the vital role in the operⁿ of dc m/c

Brushes → * Bruches offer ele. connection b/w rotating commutator & stationary load.

* They collect current from the wdg placed on the commutator through brush holders & spring.
* This are stationary sliding contacts.
* If the brushes collect current without any sparking then the commutation is successful.
* If there exist any spark while collecting current then the commutation is not successful.
* Due to high peripheral speed any spark will spread into two or 3 segments & sc the coil inside to & produce large current in them.
* In order to insure succesful commutation mech. as well as ele. condn should be proper.



* In order to insure good mech. condn the brush is placed in a brush holder & placed on the commutator through spring.
* In order to insure good ele. condn & successfull commutation the brushes should be always placed on MNA (Neutral zone).
* The brush materials used are cu, c & electrogrephaite.
* C brushes are used generaly to improve commutation. (refer commutation topic).



small dc	C
All dc m/c	Electro-graphite
LVHC dc	cu graphite

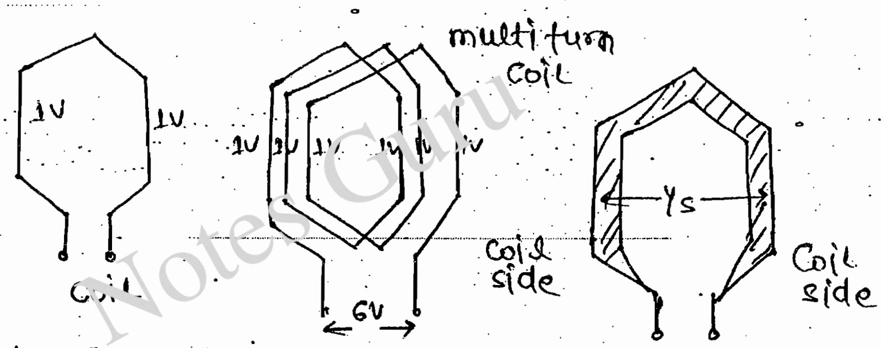
Shaft & bearing → * The purpose of a shaft is to provide mech. o/p.
* when the m/c operate as a genʳ & to collect mech o/p then the same m/c operate as a motor.
* It is hold through bearings which offer rotation.

For large m/c →	Rolar bearing
Small →	Ball bearing

***
Armature wdg → * Condʳ may be made into terns & multiturns to form coils which are connected in series & distributed uniformly throughout the entire peripheral of the arm.

Condʳ → (Z) The length of the wire lying in megnatic field where emf is induced.

Turn → Two condʳ made 1 turn; if there are Z condʳ there will be Z/2 turns.

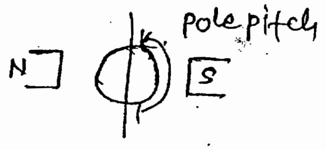


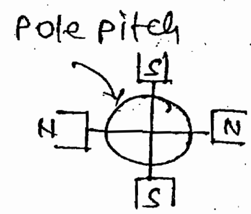
* If a coil consist of 1 turn it is known as 1 turn coil.
* If if there are two are more turns then it will be multiturn coil.
* Practicaly multiturn coil are used, as the provide more voltage
* A multiturn coil consist of two coil sides which are placed in the slots with a coil span.

Coil span → (Ys) Distance b/w 2 coil sides of a coil

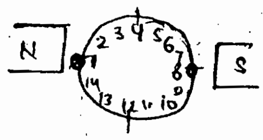
Pole pitch → (Yp) The peripheral distance b/w 2 adjcent poles expressed in no. of slots or condʳ.

$\boxed{\text{slots/pole or } Z/P}$



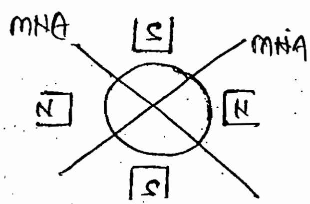


$\boxed{1 \text{ Pole pitch} = 180^\circ \text{ ele degree}}$



* For obtaining max^m vol. the coil side must kept at point 1 & end will be at 8.

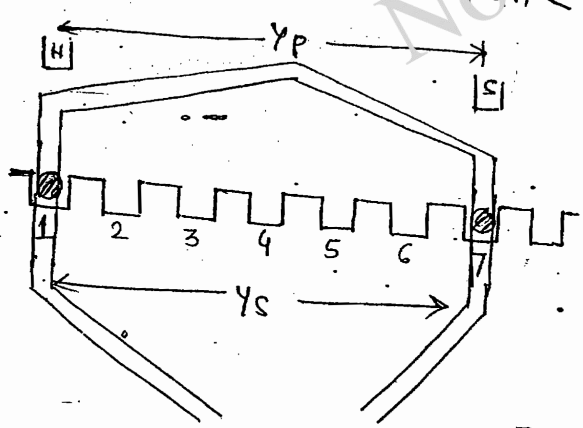
slots/pole $= \frac{14}{2} = 7$ (Hence put a 8)
(maintain 7 slots gap)



Between the two adjcent pole there is one MNA

* If the coil span ~~is exactly~~ equal to pole pitch then it is known as full pitch coil & wdg. known as full pitch wdg.
* Dc m/c arm. wdg are full pitch wdg only.
* In order to get max^m induced emf

Coil span < pole pitch



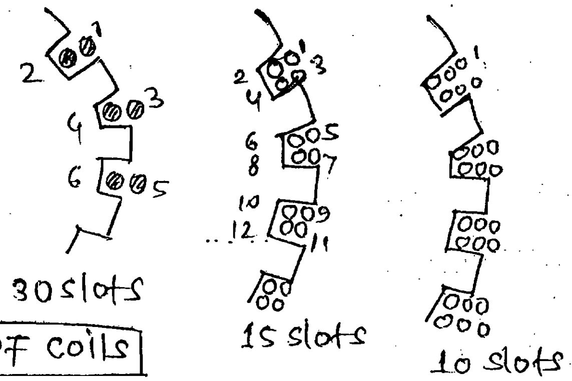
Single layer wdg → One coil side placed in one slot.

60 coil side
30 coil
60 slots

(small m/c)

Double layer or Two layer → Two coil side placed on one slot.

large m/c

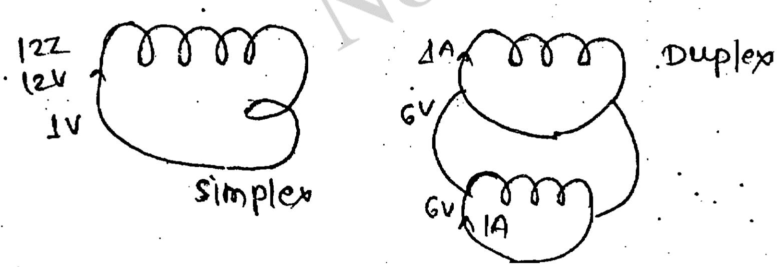


$\boxed{\text{No. of slots} = \text{No. of coils}}$

multiplex wdg →

$\boxed{\text{multiplicity 'm'}}$

* If dc wdgs are closed wdgs if there is one completely closed set of wdg it is known as simplex wdg with multiplicity factor $m=1$.
* If there are 2 such completly closed sets of wdgs connected in parallel it is known as duplex, $m=2$
* similarly 3 sets triplex, $m=3$
* 4 sets = Quadruplex, $m=4$



* Multiplex wdg increase the current rating or loading capability of m/c.
* This are more advantageous in wave wdg then lap wdg.
* For a given no. of Condr multiplicity is increase the current rating while decreasing its vol. rating.

Back pitch → (Y_b). The no. of cond^r spanned by one coil at the back end of arm.

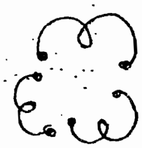
Front pitch → (Y_f) The no. of cond^r spanned by one coil at the front end of arm. (Front end is commutator end)

Resultant pitch → (Y_R) The begining of one coil & its next successive coil (Distance between then.

Commutator pitch → (Y_c) No. of commutator segments connected to 2 successive coil.

Types of arm. wdg → The basic classification is done depandind on the closure.

Closure :
- Open (ac gen^r) / AC ⓖ arm. wdg
- close (dc gen^r)



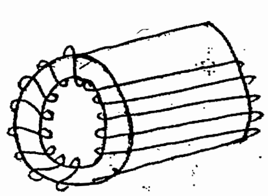
open wdg

close wdg

Closed
- → Grainme Ring
- → Drum
  - → Lap
  - → wave
  - → Frogk leg (mixer)

* DC gen^r wdg should be closed type as there is a commutator

Gramme Ring →

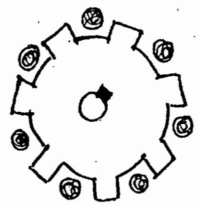


* This is the 1st form of arm. wdg which has been totaly replaced with drum type due to the following disad:-

(1.) Half of the turn is wasted which is lying inside the arm. core.

(2.) Insulating maintanance, repairs & design is costly.

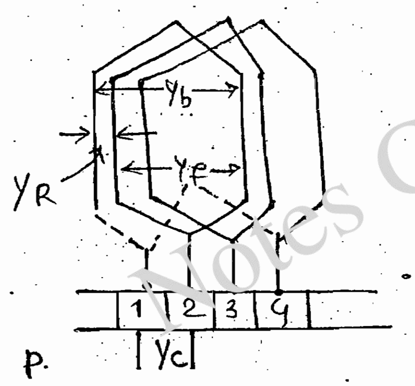
Drum→



* The arm. core is a cylindrical drum which is slotted on the periphery where the wdg is placed in that.

* No turns are wasted, designed maintance & repaire is comparitively easy.

Lap wdg→



$$\boxed{y_R = y_b - y_f}$$

Z P.

(1.) Calc y_b, y_f

(2.) Develop wdg. ~~dia~~ table

(3.) Wdg dia

(4.) Polarity mark brush positions

$$y_s = y_p \simeq y_b \simeq y_f$$

$$\boxed{y_A = \frac{y_b + y_f}{2} = \frac{Z}{P} \text{ avg. value}}$$

* In order to support lap wdg format Y_f, Y_b should be opposite signs.
* Therefore $Y_b \neq Y_f$
* Both Y_b, Y_f should be odd no. in order to have symmetric double layer wdg.
* Therefore $\boxed{Y_b - Y_f = \pm 2m}$ $\boxed{Y_c = \pm m}$

$$Y_b > Y_f \rightarrow +2m$$

* It also called RHS wdg / progessive wdg.

$$Y_b < Y_f \rightarrow -2m$$

* So it called as Retrogressive / LHW.

Eg. → Design simplex progressive lap wdg for 24 Cond^r 4 Poles.

soln →

$$\frac{Y_b + Y_f}{2} = \frac{Z}{P} = \frac{24}{4} = 6$$

$$Y_b + Y_f = 12,$$

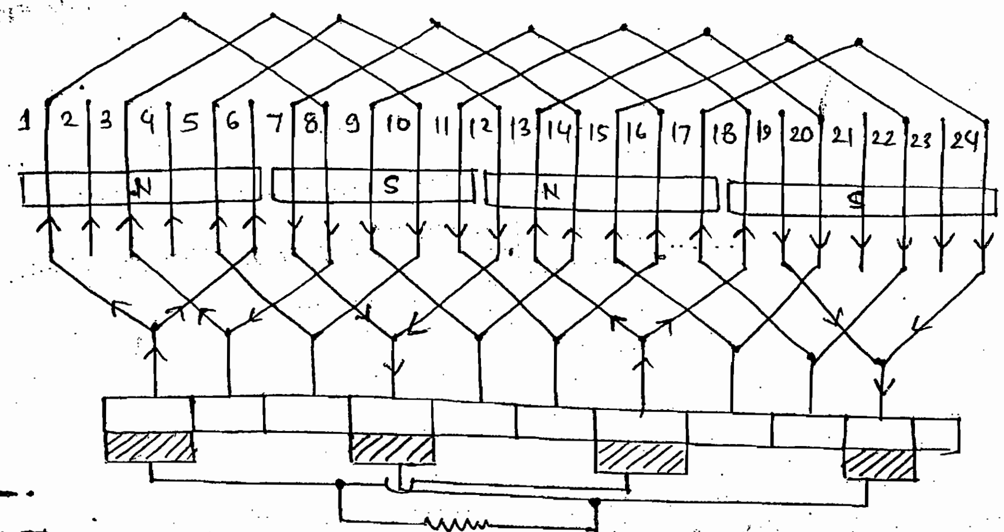
$$Y_b - Y_f = 2$$

$$Y_b = 7, \quad Y_f = 5$$

wdg table →

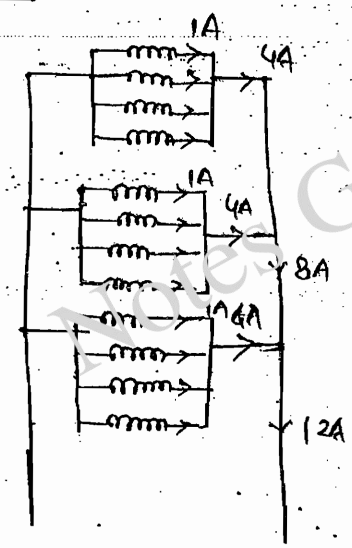
$Y_b = 7$	$Y_f = 5$
1+7 = 8	8-5 = 3
3+7 = 10	10-5 = 5
5+7 = 12	12-5 = 7
7+7 = 14	14-5 = 9
9+7 = 16	16-5 = 11
11+7 = 18	18-5 = 13
13+7 = 20	20-5 = 15
15+7 = 22	22-5 = 17

wdg. diagram →



* The no. of parallel paths are always equals to the no. of poles.
* Multiplexcity also increases the no. of parallel path.

Therefore $\boxed{A = Pm}$



$A = Pm$
$= 4$

$A = Pm$
$= 4 \cdot 2$
$= 8$

$A = Pm$
$= 4 \cdot 3$
$= 12$

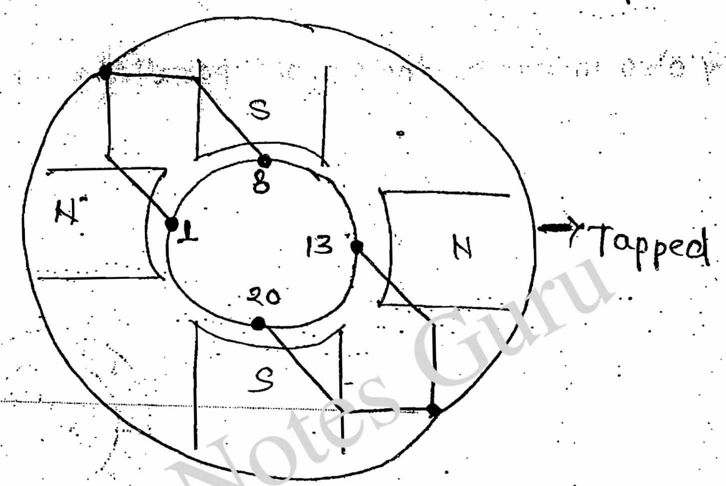
* It is also known as parallel wdg as there are more parallel path in it.
* Consequently no. of cond^r in series per parallel path is less.

Therefore it is emplyoed for high currents low vol. ratings.

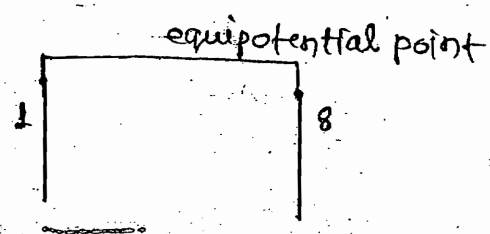
Equilizer rings → This are thick cu condr located at the backend of arm, which has low resistance.

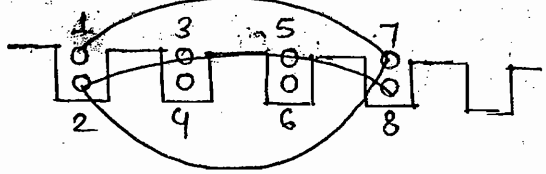
* Equipotential coils are tapped individualy to respective equilizer rings.
* Any circulating current will be bypassed & circulates within the equilizer rings at the back end & doesn't enter into the commutator at front end.

Equipotential coil → * These are exactly located twice the pole pitch distance or 360°E apart.



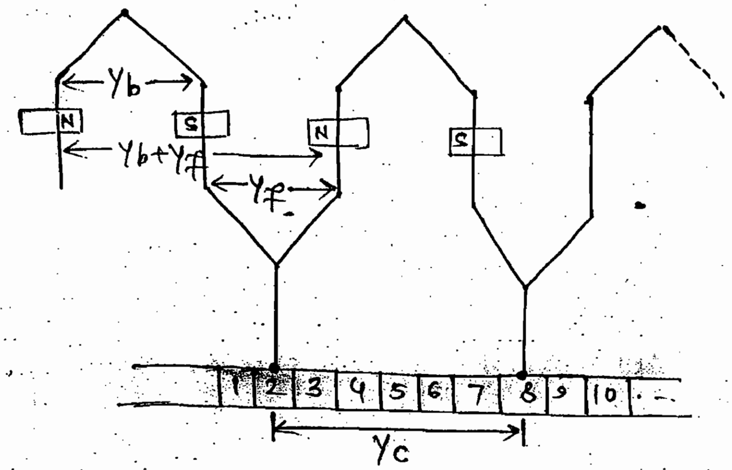
* Any unbalance in the induced emfs in the parallel paths will create a circulating current which interfare with commutation when it flow through the bus
* Therefore any circulating current will be bypass through the equlizer ring at the back end & doesn't enter into the commutator at front end.





→ Unsymmetric wdg.

Wave winding →



* The tech. Cons. diff. b/w lap & wave is in the commutator pitch.
* In wave it is twice the pole pitch.

$$\boxed{Y_A = \frac{Y_f + Y_b}{2} = \frac{Z \pm 2}{P}}$$

* Y_A should be integer

* Y_B, Y_f have same sign to support wave format

$$\boxed{Y_b = Y_f}$$

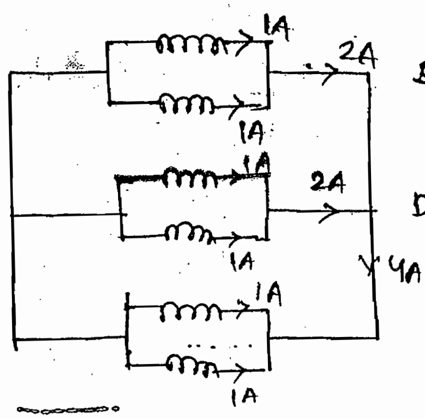
(OR)

$$\boxed{Y_b - Y_f = \pm 2m}$$

$$\boxed{A = 2m}$$

* The no. of parallel paths are indepandant of no. of poles & always = 2 as the multiple wdgs increase the no. of parallel path.

$$\boxed{A = 2m}$$



Simplex $A = 2 \cdot 1 = 2$

Duplex $A = 2 \cdot 2 = 4$

Poles	Lap	Wave
2	2	2
4	4	2
8	8	2
⋮	⋮	⋮
10	10	2
⋮	⋮	⋮
20	20	2

* Multiplex wdgs are advantageneous in wave then Lap.
* As there are less no. of parallel path it is employed for high voltage low current ratings.

*Dummy Coil →

Q→ Design wave wdgs for 60 Condr 15 slots 4 pole simplex.

Soln →

$$Y_A = \frac{Z \pm 2}{P} = \frac{60 \pm 2}{4} \quad 58 \quad 2 \rightarrow \text{missed}$$

$$Y_A = \frac{62}{4} \text{ or } \frac{58}{4} \qquad \frac{60}{4} \text{ or } \frac{56}{4}$$

$$14 \times 4 = 56$$

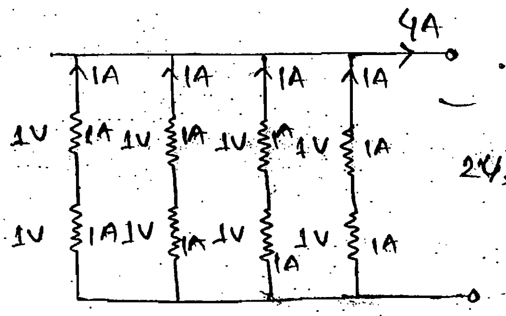
But in 15^{th} slot = ?

* For some set of data Y_A will not be integer in order to make is integer value the nearest possible condr will be considred.
* Due to which some condr are missing in any one of the slots

In order to maintain mech. balance the missing condr are well insulated & placed in the missing slot as dummy.

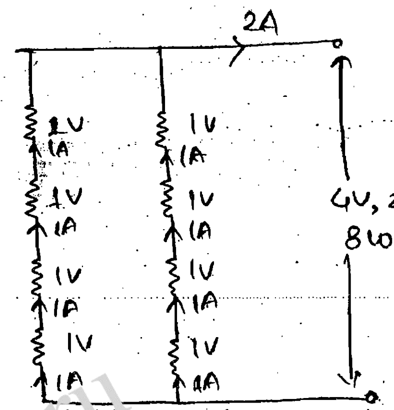
* It is not connected to the rest of the wdg.
* As there are only 2 parallel path any unbalance will become a balanced condn.
* Therefore no need of equilizer rings.

Eg → Consider a 4P simplex lap wound genr arm. with 8 condr is reconnected as wave.



Lap wound

A_L, V_L, I_L, P_L, R_L



wave wound

A_W, V_W, I_W, P_W, R_W

$$\boxed{I \propto A \rightarrow \frac{I_L}{I_W} = \frac{A_L}{A_W} \qquad V \propto \frac{1}{A} \rightarrow \frac{V_L}{V_W} = \frac{A_W}{A_L}}$$

$$\boxed{P_L = P_W \qquad I_L^2 R_L = I_W^2 R_W}$$

Eg. → A 4P dc genr with lap wound arm. is reconnected as a wave what will be the change in V, I & P.?

Soln →

$$\frac{I_L}{I_W} = \frac{A_L}{A_W} = \frac{4}{2} \; ; \quad \frac{I_L}{I_W} = 2 \quad \boxed{\frac{I_L}{2} = I_W}$$

$$e = \frac{P\phi}{60/N} = \frac{\phi PN}{60} \text{ voltz}$$

emf induced per parallel path $\frac{\phi PN}{60} \times \frac{Z}{A}$

$$e = \frac{\phi PN}{60} \times \frac{Z}{A}$$

$$\boxed{e = \frac{\phi ZNP}{60A}}$$

$$\boxed{E_g = \frac{\phi ZNP}{60A} \text{ volts}}$$ gen/induced emf

$$E_g \propto \phi N$$

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

(OR)

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

If N is constant

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

If ϕ is constant

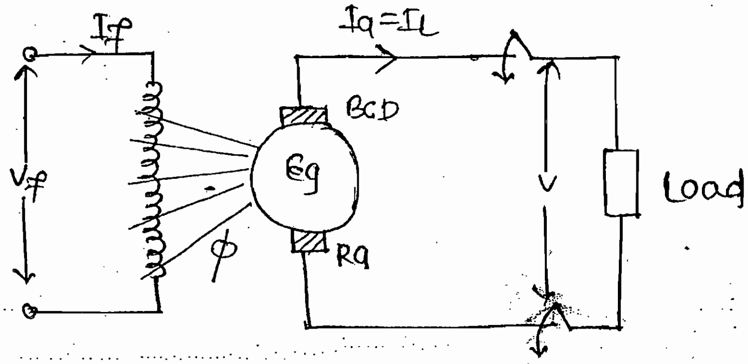
$$\frac{E_{g2}}{E_{g1}} = \frac{N_2}{N_1}$$

* Classification of dc. gen^r → * In order to control the m/c electro-magnets are prefered as poles which required a dc vol. excitation across it.

* The classification of gen^r is according to method of excitation:-

Excitation
- → seprate Excitation
- → self excitation
  - → Shunt Excitation
  - → Series Excitation
  - → Compound Excitation

* Seprate Excitation →



* It requires a seprate dc source for its excitation.
* Its field & arm. wdg are isolated electricaly.
* The terminal voltage (V) across the load doesn't affect its excitation.
* Due to additional voltage source requirement it is rarely used genʳ around 95% dc genʳ used are self excited only.

gen/Ind emf

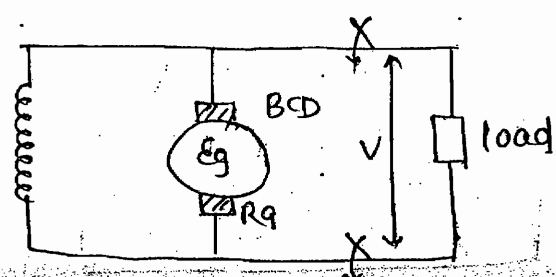
$$E_g - I_aR_a - BCD = V \text{ Terminal V}$$

$$I_a = I_L$$

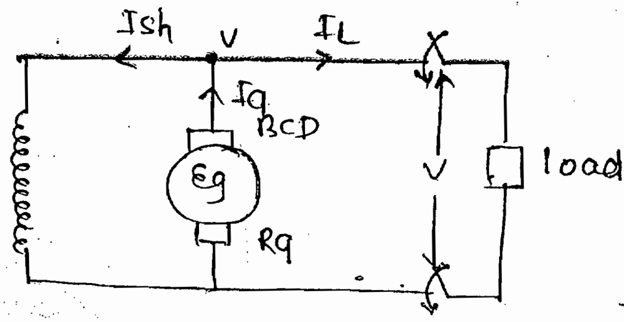
* Self Excitation →

* The field wdg will be excited by its own arm. which requires some essential condⁿ

Starts with residual flux.



Shunt excitation →



$$E_g - I_a R_a - BCD = V$$

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

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

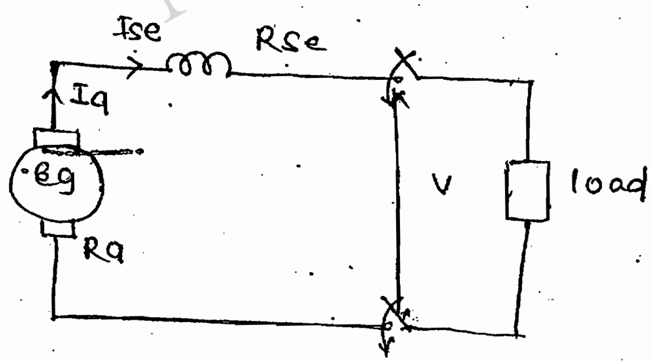
* The field wdg is connected in parallel with arm. through brushes.
* The terminal vol. itself act as excitation.
* Shunt field turns are very large in no. due to its resistance is high with thin condr.

  Range 50–250Ω

$\boxed{\text{Loading any m/c = Reducing the ~~cu~~ resistance}}$

* The field ~~turn re~~ current remains approx. same from NL to rated value.
* Consequently flux is approx. same in the operating region.
* In this mode it is known as shunt genr & vol. operated field.

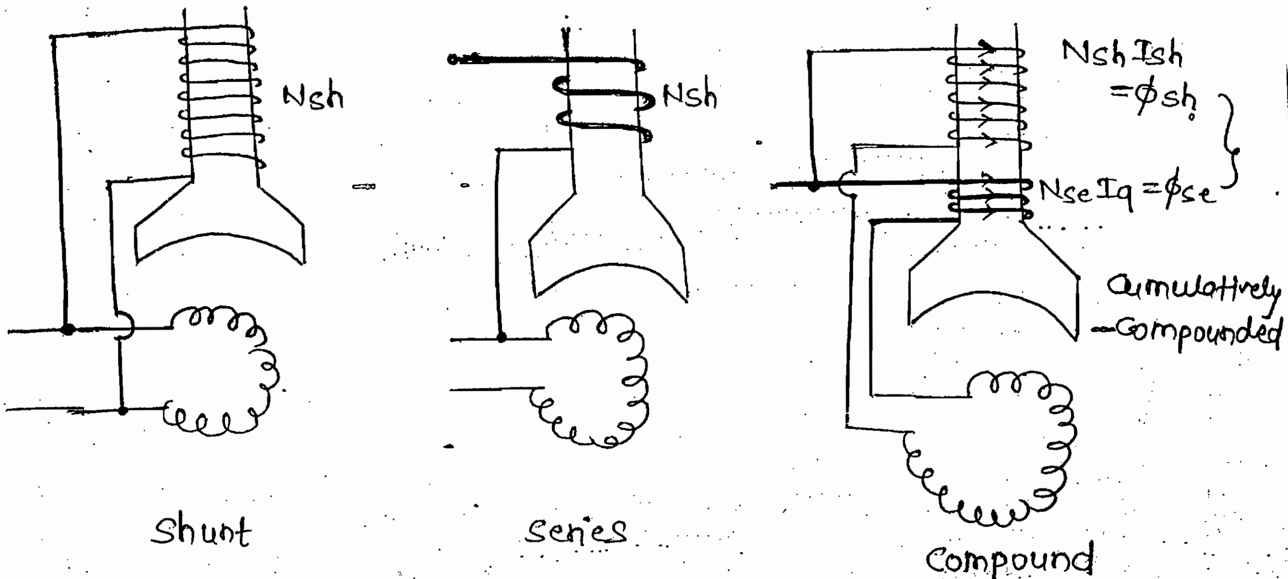
Series Excitation →



* In this mode it is known as series genr & current operated field.

$$\boxed{\begin{gathered} E_g = I_a(R_a + R_{se}) - BCD = V \\ I_a = I_L = I_{sh} \end{gathered}}$$

* The series field wdg contain less no. of turns with thick cond.



* Shunt flux always dominate series flux.
* If series field wdg is reversed than $\phi_{sh} - \phi_{se}$: Differently

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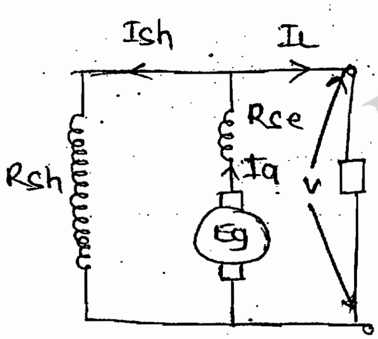
Long shunt →

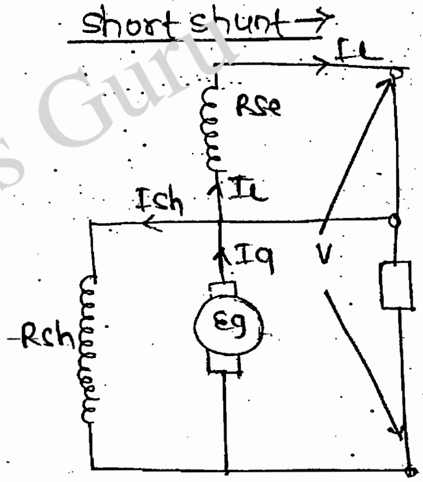


$$E_g = I_a(R_a + R_{se}) - BCD = V$$

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

$$I_{sh} = V/R_{sh}$$

Short shunt →

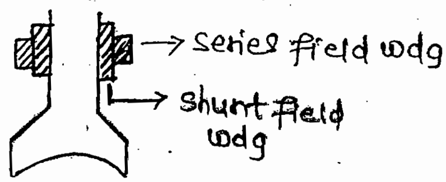


$$E_g - I_a R_a - I_L R_{se} - BCD = V$$

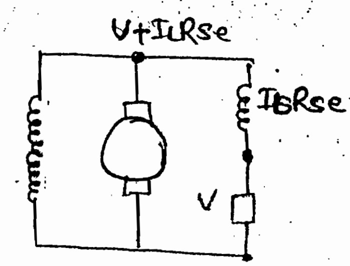
$$I_a = I_{sh} + I_L$$

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

~~* There is no~~



Short shunt



* There is no distinctive diff. b/w long shunt & short shunt genr.
* The induced emf in long shunt is slightly greater than that of short ~~short~~ shunt ($I_a > I_L$)
* If the series field wdg is reversed than the cumulative mode becomes differential.

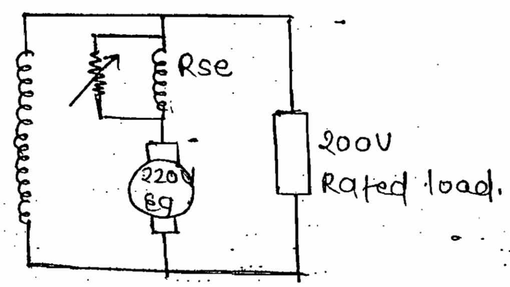
Cumulative: currents in both field wdg same dirn on the pole core. Therefore both fluxes add each other. and the net flux increases with load.

In differential the series flux oppose the shunt flux & the net flux decreases with load.

- Exc.
  - Seprately
  - Self-excited
    - Shunt
    - Series
    - Compound
      - long shunt
        - Differential
        - Cumula.
          - Over
          - Flat/level
          - under
      - short shunt
        - Differential
        - Cumulative
          - over
          - Flat/level
          - under

Compounding → * Adjusting the terminal voltage of cumulative compound genʳ by varying its series field ampere turns by connecting a diverter across its series field wdg.

* Depending on the degree of compounding a cumulative compound genʳ can act as under, flat, over compound genʳ.
Compounding is done at rated load. to adjust the terminal vol. below rated, exactly rated & above rated respectively.



* By varying the diverter resistance from 0 to maxᵐ value a cumulative compound genʳ can be acted in 4 other modes.

(i) Rd = 0 (shunt)
(ii) Rd ↑ Basic cumulative
(iii) Rd ↑↑ Under
(iv) Rd ↑↑↑ Flat/level
(v) Rd ↑↑↑↑ Over

* Compounding can't be done with differential compound genʳ as its series flux opposes shunt flux.

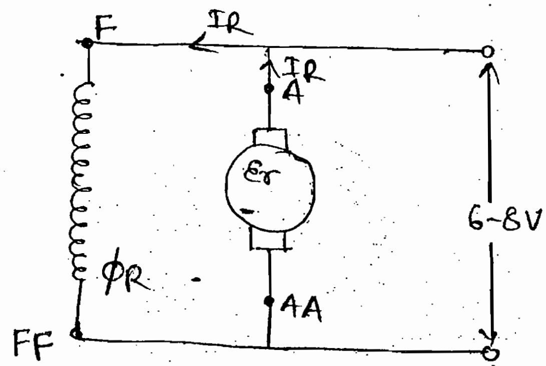
* NL induced emf of flat compound genʳ is exactly equal to rated voltage at rated load.
Since series flux is adjusted to compensate all the drops at rated load.

Voltage build up → [In self excited genʳ]

* In a separately excited genʳ there is a seprate source to exite the field & Produce flux.

* In a self excited genʳ there is no such source to exite the field wdg. Therefore in order to buildup voltage in self excited genʳ the poles should contain the residual flux.

Shunt genʳ →



1.* Consider a shunt genʳ made to run at rated speed with residual flux in its poles small voltage is induced in the arm. (6-8V) which produces small current.

* If the genʳ is on NL, all the initial current will flow into field wdg. to produce initial mmf with field wdg turns.

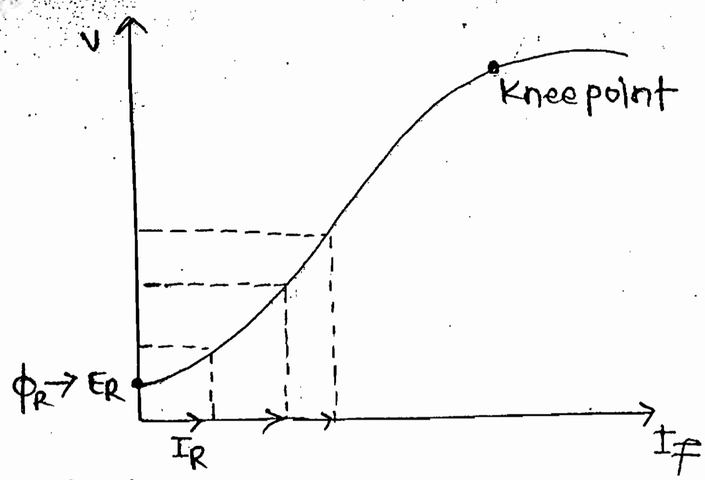
2.* The field should be properly connected to the arm. in order to make initial mmf at the residual flux.

* It is a cumulative process as the current increases the flux out of the pole increased & the induced voltage also increases after saturation of poles even though the current increase. flux doesn't increases. Concequently voltage becomes constant

$$\phi_R \rightarrow E_R \rightarrow I_R$$

$$I_r N_{sh} \rightarrow \phi_1 + \phi_2 \rightarrow E_1 + E_R \rightarrow I_1 + I_{R_1}$$

$$(I_1 + I_R) N_{sh} \rightarrow \phi_2 + \phi_1 + \phi_R \rightarrow E_2 + E_1 + E_R \rightarrow I_2 + I_1 + I_R$$



(3.) The operating speed ~~condn is~~ of the genr should be greater than critical speed.

(4.) The resistance of field wdg should be less than critical resistance value.

(5.) The best condn for a shunt genr to build up voltage successfully is it should be on NL.

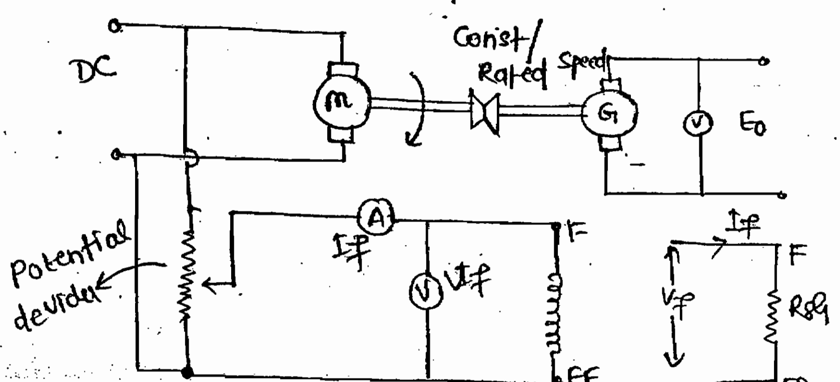
(6.) In-spite of all the above 5 condn satisfied if the vol. doesn't build up it may be due to improper contact across brushes & commutator.

Determination of critical resistance & critical speed →

OCC (open circuit c/s)
NLS (No load saturation)
magnetisation c/s

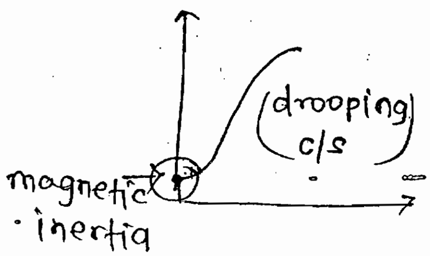
} Eo Vs I_f

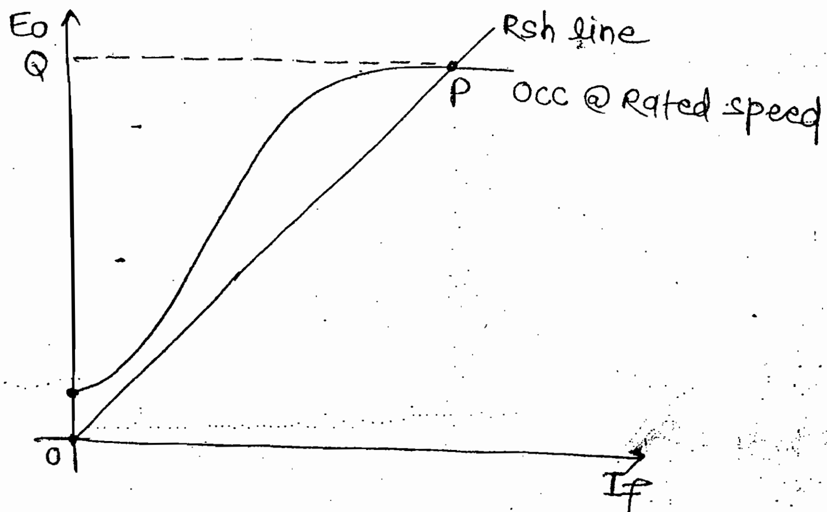
* In order to plot OCC to determine R_c & N_c of a self exc. shunt genr it requires to be seprately excited.



S.N.	V_f	I_f	E_o
1	0	0	6-8
2	10	0.1	30
3	20	0.2	60
4	30	0.3	80
⋮			

linear



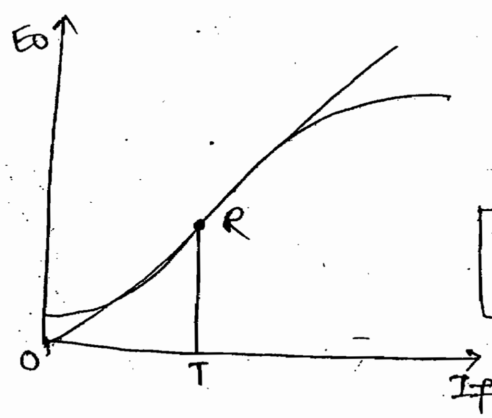


Critical Resistance → The resistance of the field wdg ~~about~~ which the genʳ doesn't build up voltage ~~this is~~.

Critical speed → The speed of genʳ below which the genʳ doesn't build up voltage.

Determination of critical resistance →

* The field resistance line intercepts OCC at a point P.
* Length of OQ in volts is the maxᵐ emf induced in the genʳ.



$$\boxed{R_C = \frac{RT_V}{OT_A}}$$

Sagar Sen
8871453536

Steps:- (1) Draw the occ line.

(2) Plot a tangent through occ.

Critical speed ~~Determination~~ →

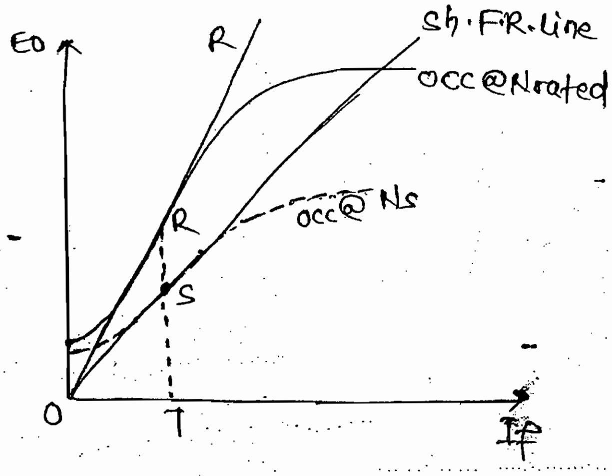
Steps → (1) Draw original shunt field resistance line.

length of (ST) ∝ N_c

length of (RT) ∝ N_{rated}

$$\frac{ST}{RT} = \frac{N_c}{N}$$

$$\boxed{N_c = \frac{ST}{RT} N}$$



* The critical resistance of a given gen^r depands on the operating speed. from critical speed & above.
* It varies praportionaly with speed.
* when the m/c is running at critical speed its field resistance value itself is critical resistance.

Eg. → A shunt gen^r building up vol. normaly. If the field wdg is reversed & operated ~~that~~

(a) Build up vol. normaly
(b) Build up vol. with −ve polarity
(c) No build up of vol.
(d) GV across the arm.

Ans. → (c)

Eg. → Same above que. Dire^n of rotation of gen^r is reversed. options same.

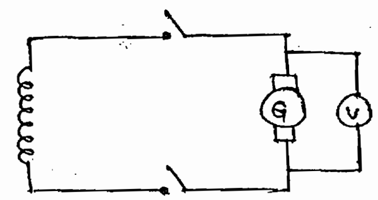
Ans. → (c) $-E_g \propto \phi(-N)$

e.g. → If both dir^n of rotation as well as field wdg is reversed.

$E_g \propto (-\phi)(-N)$; E_g (+ve)

ans. (a)

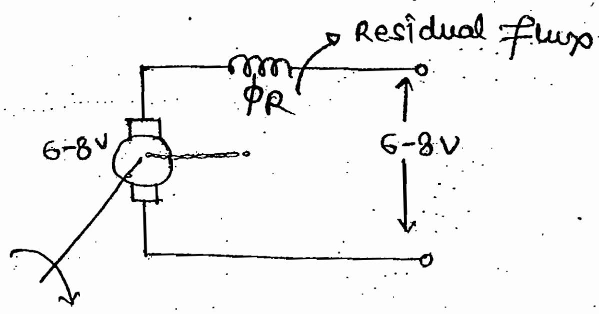
(2/1)



	switch open	switch close
A.	8V	8V
B.	8V	12V
C.	8V	0V

1. Critical Resistance
2. load resistance
3. Field polarity

✱ Voltage build up is series genʳ →



(1.) It require residual flux.

(2.) The terminals should be closed with some load. As the load current flows into the field wdg the initial mmf is considerably good value & no need of large series field wdg terms.

(3.) The total resistance $(R_a + R_{se} + R_L)$ should be less than its critical resistance.

$$\boxed{(R_a + R_{se} + R_L) < R_c}$$

(4.) Its speed should be greater than critical speed.

Cumulative Compound genⁿ →

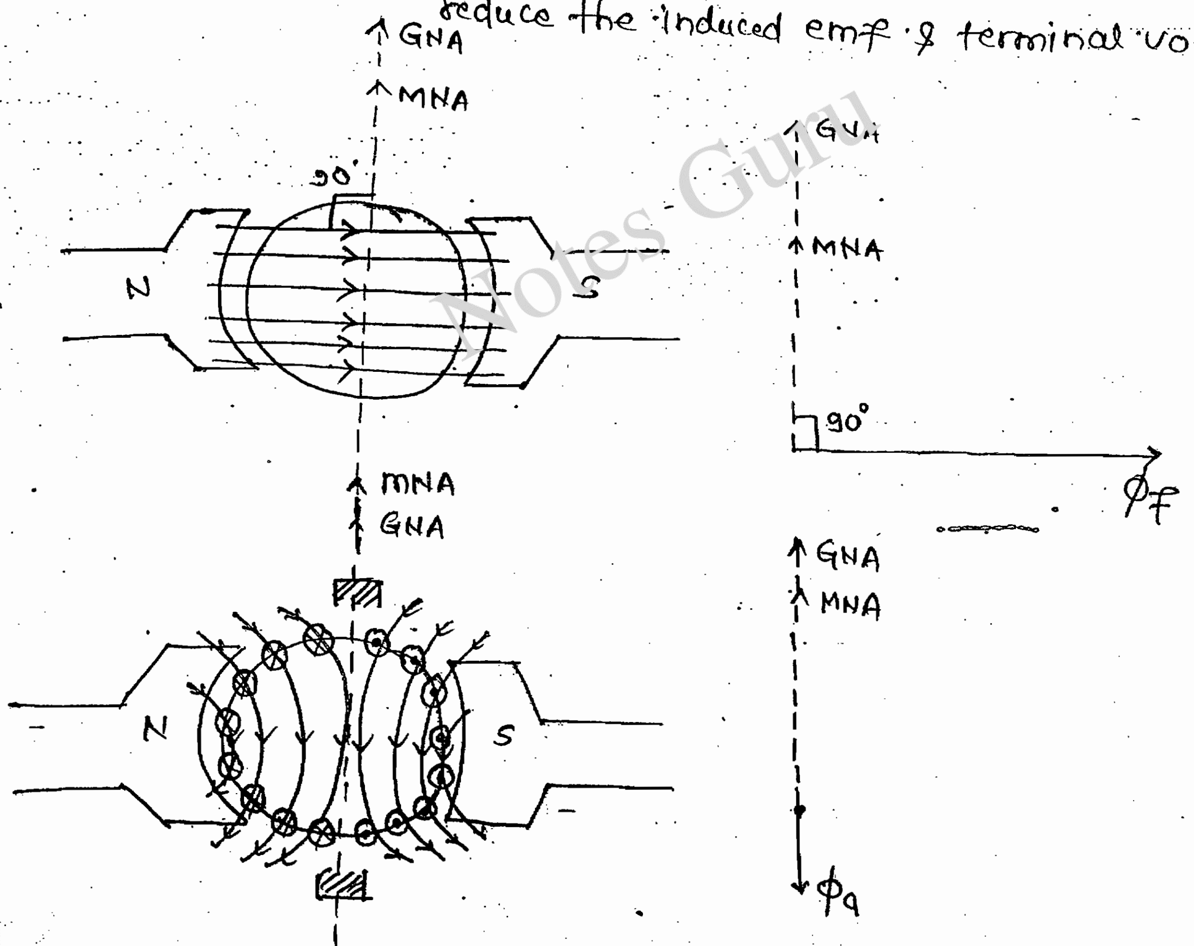
✱ A compound genʳ is eq. to a shunt genʳ on NL. Therefore its vol. build up is eq. to shunt genʳ.

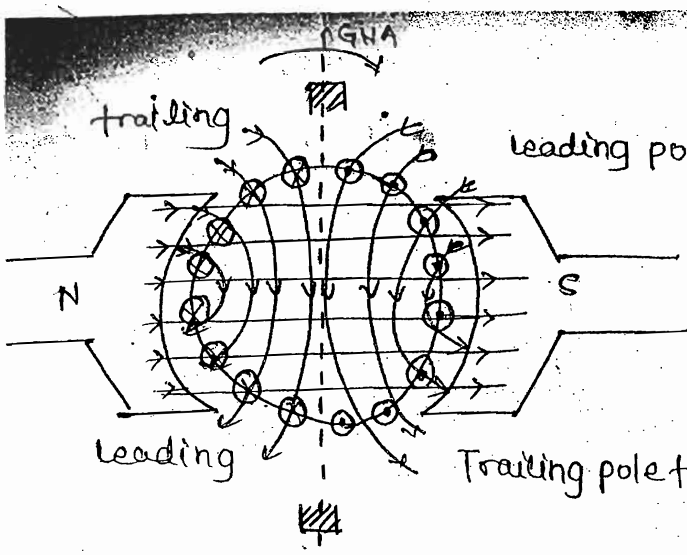
Armature Reaction →

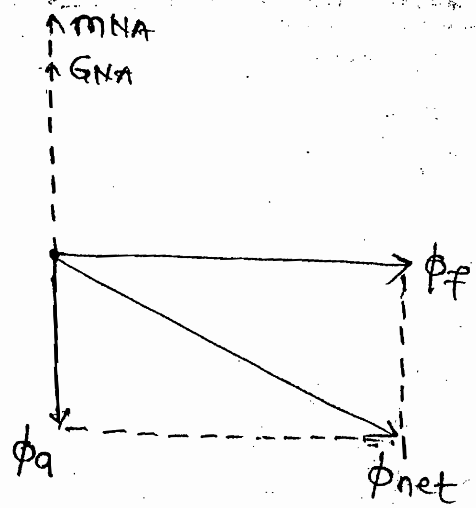
* On NL the arm. current is negligible. Concequently there is only main flux in the air gap distributed uniformly in flat topped nature.
* As the arm. is loaded load current flows in the arm. condr or turns which produce arm. mmF & arm. flux which is also distributed uniformly throughout the arm. peripheral in the air gap.
* The arm. flux will take an action on main flux distribution which is called as arm. reaction.
* The effect of the arm. flux on main flux produce :-
  (1.) Cross magnetisation.
  (2.) Demagnetisation.

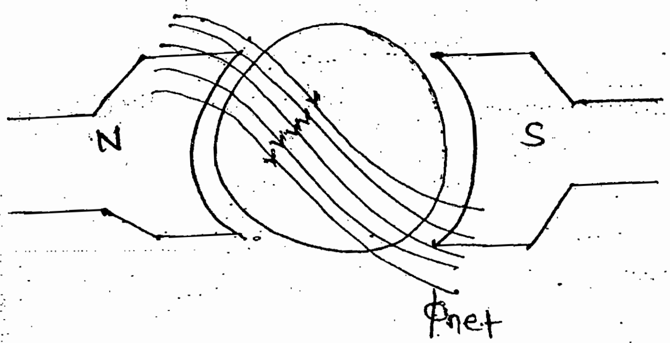
<u>Cross magnetisation</u> → It is distortion of main flux due to which MNA is shifted. & the commutation will not be successful due to sparking.

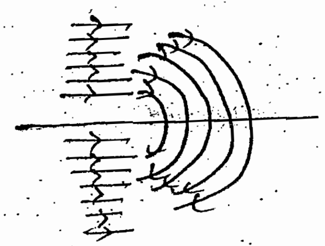
<u>Demagnetisation</u> → It is Reduction in the main flux which reduce the induced emf & terminal voltage.



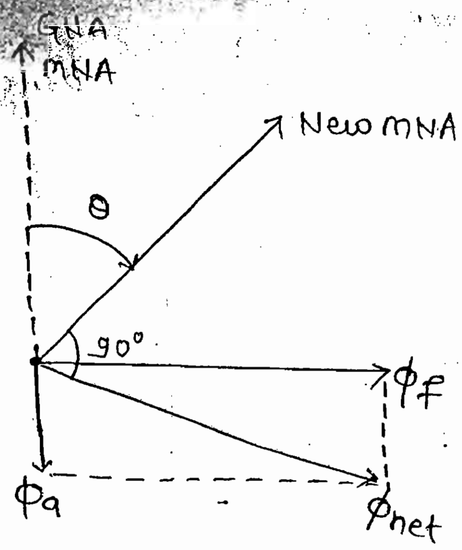






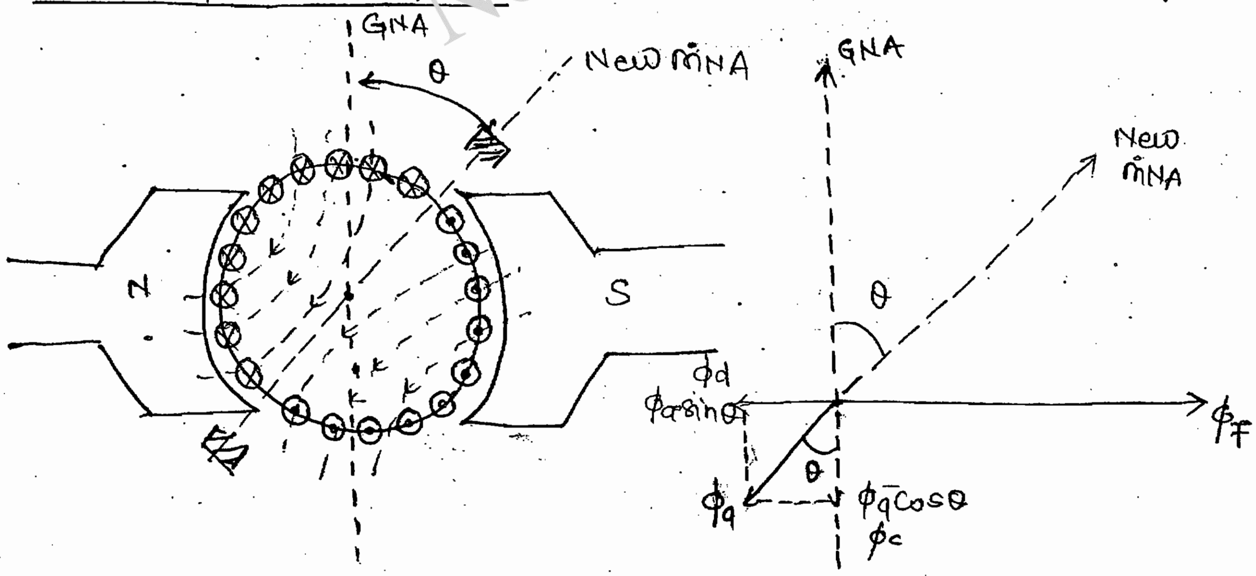


* Depanding on the dirn of rotation the pole tips are named as leading & trailing.
* The arm. flux under the trailing pole tips of genr will increase the flux density as it is in the same dirn. with the main flux.
* The arm. flux under the leading pole tips will demagnetise the main flux as it is in the opposite dirn.
* If the amount of magnetisation & amt of Dm are equal than there is no net reduction in main flux but only distortion.
* Under practical condn the poles get magneticaly saturated & concequently the increase in flux density under trailing pole tips is comparitively less than that of decrease in the flux under leading pole tips.

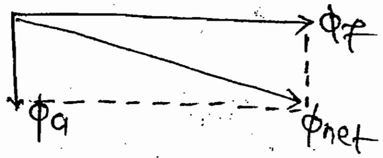


* Due to arm. flux which is also called as cross flux the main flux is distorted. known as cross magnetised due to which MNA is shifted in the dirn of rotation of genr.
* In order to improve commutation the brushes also need to be shifted in the dirn of rotation of genr.
* Due to the affect of brush shift to an angle θ there exist additional demagnetisation.
* Brush shift is not done generally. It has been replaced with interpole as it is not reliable method & also produce additional demagnetisation.

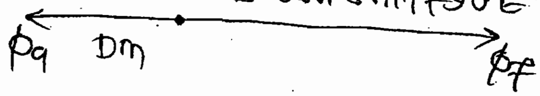
Affect of brush shift →

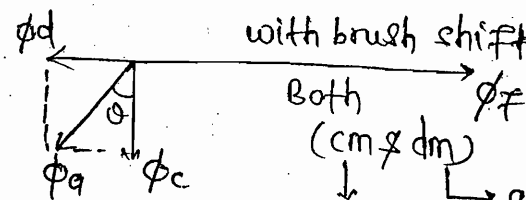


No brush shift



Brush shift 90°E





with brush shift of θ

Both (cm & dm)

↓ Arm. flux ↓ $\phi_a \cos\theta$

→ arm. flux → $\phi_a \sin\theta$

ϕ_c ~~or~~ $= \phi_a \cos\theta$ is cross magnetisation of arm. flux

$\phi_d = \phi_a \sin\theta$ is Demagnetisation of arm. flux

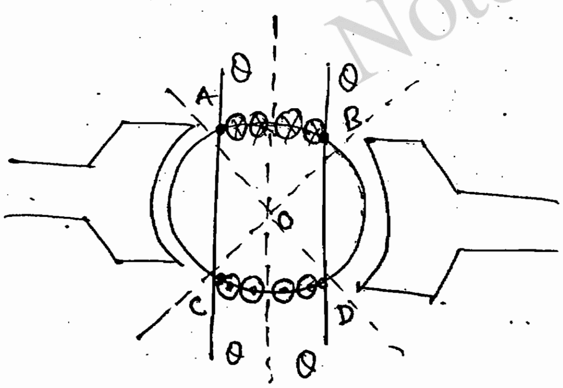
when $\theta = 0$

$\phi_d = 0,\ \phi_c = \phi_a$ (arm. flux is cm in nature)

when $\theta = 90°$

$\phi_d = \phi_a,\ \phi_c = 0°$ (arm. flux is demagnetisation in nature)

De-magnetising Amp-turns/pole A_{id}/p →



$\frac{2\theta}{180°}$

OAB
OCD } Dm

OAC
OBD } cm

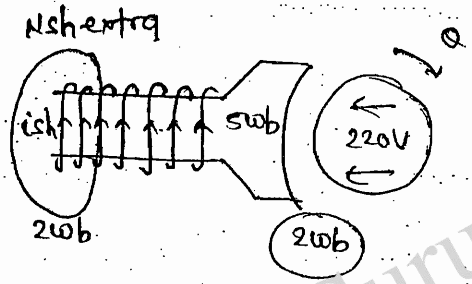
$$\boxed{\frac{2\theta°}{180°} \times \frac{I_a}{A} \times \frac{Z}{2P}}$$

Cross-magnetising Amp-turns/pole →

$$\boxed{ATc/p = \frac{180-2\theta}{180^\circ} \times \frac{Ia}{A} \times \frac{Z}{2P}}$$

$$\boxed{\text{Total arm. mmf} = \frac{Ia}{A} \times \frac{Z}{2P}}$$

* ATd/p is representing the arm. flux which produce addiotional demagnetisation.
* In order to compensate this additional demagnetisation extra amp-turns need to be provided on each pole.



$$\boxed{Nsh\,extra \times Ish = ATd/p}$$

$$\boxed{Nsh\,extra = \frac{ATd/p}{Ish}}$$

$$\frac{AT}{A} = T$$

* The no. of extra turns to be added on each pole of shunt genr in order to compensate additional demagnetisation produced by the brush shift is equal to ATd/p/Ish.
* Similarly in a series genr $\boxed{Nse\,extra = \frac{Atd/p}{Ia (\text{or}) Ise}}$

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* Other effects of arm. reaction →

(1) Decrease in efficiency due to increased iron loss →

The increased flux density under the pole tips will increase iron loss in the core as iron loss is directly proportional to flux density.

(2) Increased maintenance & repair →

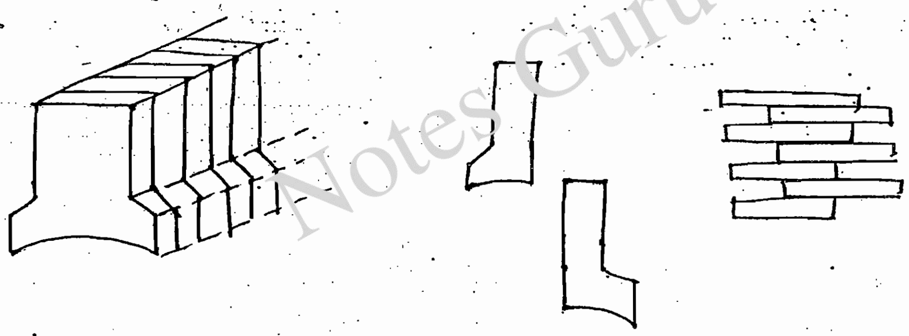
Due to CM Commutation is not successful & there will be unacceptable sparking which damage the brush surface.

(3) Increased design cost →

* methods to reduce armature reaction & its effects →

(1) Pole stacking
(2) pole chamfering
(3) Pole core slotting
(4) ** Compensating wdg.

(1) Pole stacking →



* The pole laminations are alternately stacked to introduced air gap under the pole tips.

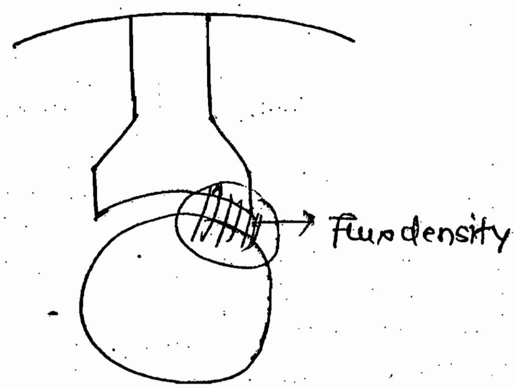
* The increased reluctance will reduce the flux density & reduce the iron loss but the net reluctance in the m/c increased which demands more mmf which increase the size & cost of m/c.

-stacking → ↑ Reluctance

② Pole chamfering →

minm reluctance at the center & increased reluctance towards the pole tips.

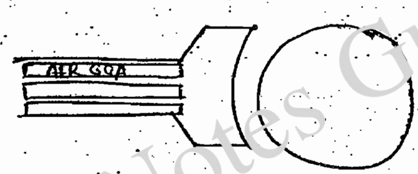
Concept is same as pole stacking.



③ Pole core slotting →

* The pole core contanin rectangular slots to introduce air gap to some part of the flux, & reduces it to some extent.

$$\text{Flux} = \frac{\text{mmf}}{\text{Reluctance}}$$



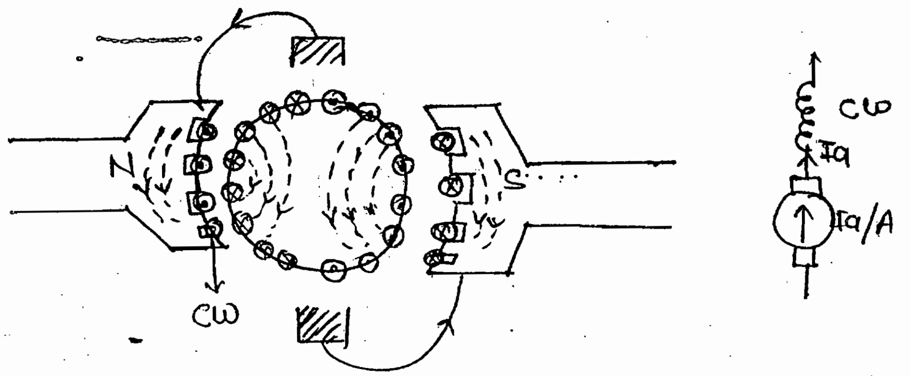
*** (4.) Compensating winding →

* In large rating dc m/c operating at variying load condn running at high speeds compencating wdgs are essential in order to reduce flashover on the commutator.

* As the load vary arm. current vary & produce a varying flux on the arm. links with arm. condr. & produce staticaly induced emf, which results in circulating currents which interfare with commutation & produce sparking.

* Due to high speeds if the spark spreads it will become a flash over to damage the wdg. Compensating wdg in provided in the pole shoe or pole face by cutting into teeth or slots.

* It is always connected in series with arm wdg. through brushes
* In order to automatically neutralise the arm. flux under the pole.



* The current flowing in the CW under any pole should exactly opposite dirn to the arm condr current dirn under the pole. in order to cancel out the arm. flux

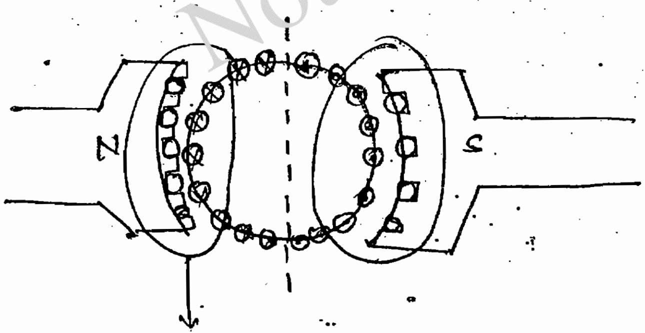
Let Z_c be CW condr , Z be AW condr

$$I_a \cdot \frac{Z_c}{2} = \frac{I_a}{A} \cdot \frac{Z}{2}$$

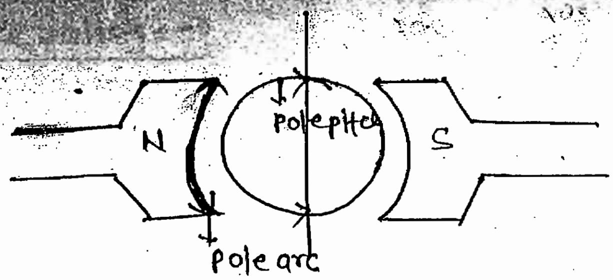
$$\boxed{Z_c = Z/A}$$

No. of compensating wdg under each pole

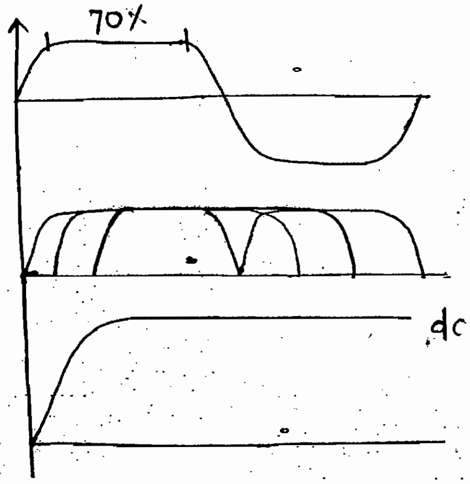
$$\boxed{Z_c = Z/AP}$$



$$\boxed{\frac{\text{Pole arc}}{\text{Pole pitch}}\ \text{factor} = 0.7 \text{ or } 70\%}$$



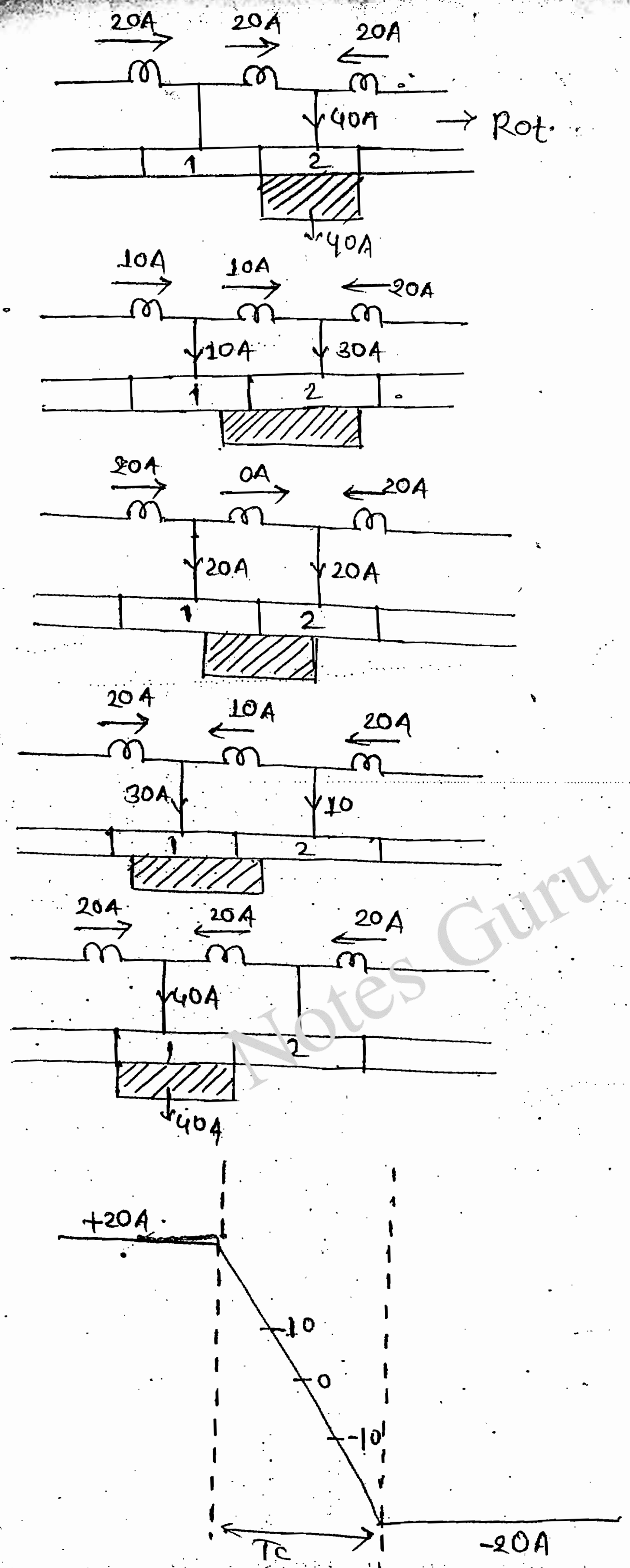
* Flux distribution under the pole in dc m/c is flat topped nature.



$$\boxed{Z_c = \frac{Z}{A_p} \times \frac{\text{Pole Arc}}{\text{pole pitch}}}$$

Because Z_c is placed on pole arc region, thats why multiplying with pole arc / pole pitch.

* COMMUTATION → The process of current reversal in the coil when it passes through a brush is known as commutation.
* The time taken for the brush to span from 1 segment to the other is known as commutating time.
* If the current reverses completely within the commutation time in the coil undergoing commutation then commutation is successful also called as linear, ideal or straight line commutation.
* There will be no sparking at the brush.
* If the current doesn't reverse completely within the commutating time in the coil undegoing commutation there will be sparking at the brush & the commutation is unsuccessful known as delayed commutation or non-linear.

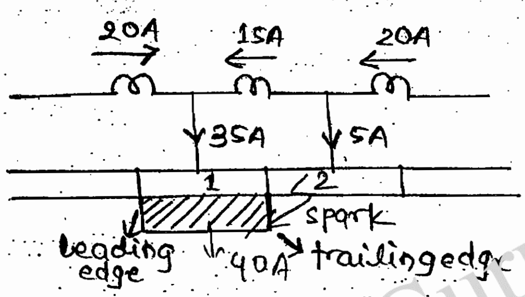


20A
20A
20A
40A
Rot.
1
2
40A
10A
10A
20A
10A
30A
1
2
20A
0A
20A
20A
20A
1
2
20A
10A
20A
30A
10
1
2
20A
20A
20A
40A
2
40A
+20A
10
0
-10
Tc
-20A

Reactance voltage →

$$e_r = N\frac{d\phi}{dt} = \underbrace{L}_{Self}\,\frac{\overbrace{di}^{2I}}{\underbrace{dt}_{T_c}}$$

* In the coil undergoing commutation there is a total change of current from I_a/A to $-I_a/A$ within commutating time T_c which produce the reactance voltage due to self inductance property of the coil.
* According to Lenz law it will oppose the cause i.e. change in current. Therfore by the end of commutating time T_c the current will not be reversed completely.



* Any unchanged current by the end of commutating time will jumped into the brush through spark at the trailing edge of brush.

* Methods to improve Commutation →

(1) Resistance Commutation

(2) Voltage Commutation → Brush shift; → * Interpole

① Resistance commutation →

* Replacing low resistance Cu brush with high resistance C brush to improve commutation by reducing the chances of sparking to some extent.
* C brushes have high resistance compare to Cu.
* Due to its high resistance C brush doesn't incourage sparking at trailing edge & improve commutation.

* The added ad. of c brush are:-

(1) It is not hard material as cu.

(2) It is self lubricating (polishing) in nature which offers good mech. condⁿ with the comm. surface.

(3) If any spark occurs it will gets less damaged than cu.

disad. →

① more brush contact drop.

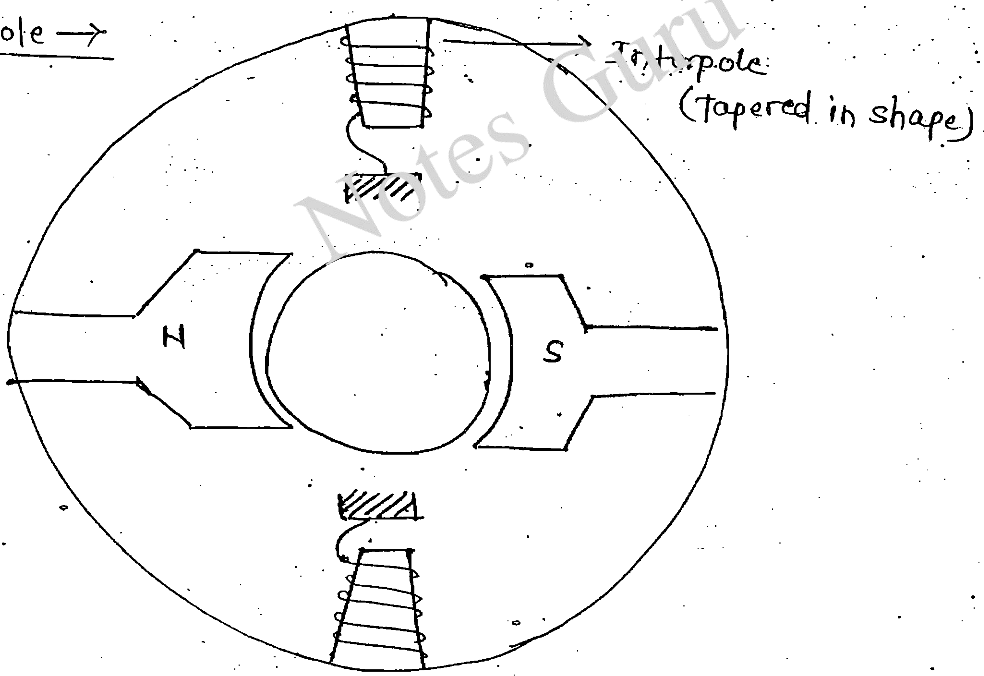
② Low current density, requires larger brush.

* Brush shift → * It is the 1st method of improving comm. which is complecated & not reliable because MNA changes with loads contineously & after the design brushes can't be changed.

* Due to brush shifting there is addiotional Dm.

* It is not done after the invention of interpole.

* Interpole →



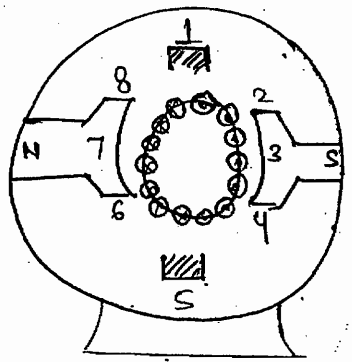
* Interpoles are small poles compare to main ploes placed in the inter polar region between the main poles on the yoke.
* These are also electromagnets with interpole wdg which is connected in series with arm. wdg through brushes in order to have automatic neutralisation of arm. flux in the interpolar region.
* It performs 2 funⁿ :-

(1) Produce a counter flux on the coil undergoing commutation to nullyfy the reactance voltage (2) It also remove the inequality in the flux densities on the top & bottom region of arm.

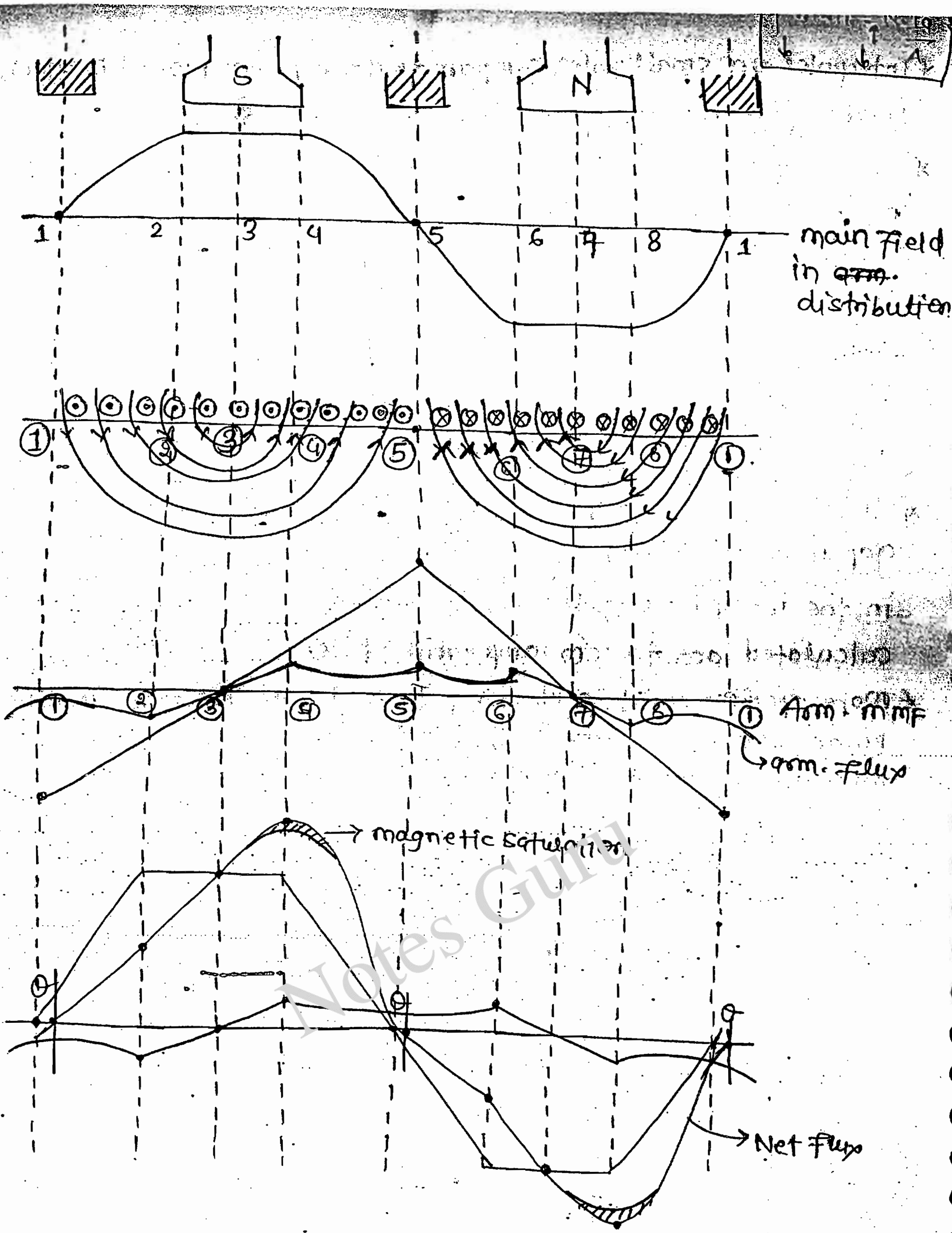
* The interpoles are tapered in shape with comparetively more air gap in order to avoid easy saturation as the load current flows in the interpole wdg. The no. of turns on the interpole are calculated acc. to CW amp turns / pole.
* More specificaly it is the amp turns in ~~th~~ of arm. in the inter-polar region. & some additional turns are also required in order to produce reactance voltage.

CW → Reduces arm. reaction
IPW → Improve commutation

Interpole are directly improve comm. & CW indirectly improve comm.



	turns (or) mmf	
1-3	↓	-ve
3-S	↑	+ve
5-7	↓	+ve
7-1	↑	-ve
3-1	↑	-ve


S
N
1
2
3
4
5
6
7
8
1
main field in ~~arm.~~ distribution
Arm. mmf
arm. flux
magnetic saturation
Net flux

(Reluctance)

* In the m/c if air gap is uniform then the arm. mmF & arm. flux follow the same shape but magnitude may vary.

$$\boxed{\text{Armature Flux} = \frac{\text{Arm. mmF}}{\text{Reluctance (Air gap)}}}$$

	Reluctance	
1-2	↓	-ve
2-3	↓ min^m	-ve
3-4	↑	+ve
4-5	↑ max^m	+ve
5-6	↓	+ve
6-7	↓ min^m	+ve
7-8	↑	-ve
8-1	↑ max^m	-ve

* For drawing arm. ~~flux~~ arm. ~~flux~~ mmF is taken as ref.

(1.) main field flux distribution is having flat topped shape. or trapezoidal.

(2.) Arm. mmF is triangular in shap : increasing or directed towards
* the brush axis.

(3.) Net flux due to arm. reaction is having peaky (If not given peaky then Δ).

(4.) Arm. flux is saddle shape (If not given then prefer Δ).

*** The main flux & arm. flux are always 90°E wrt each other (quadrature or ⊥)/ orthogonal.

* Without arm. flux the main flux is exactly 0 along GNA.

* with arm. flux the neutral (MNA) has been shifted in the dirn of rotation of genr. ~~to/mmor~~

* To improve comm. the brushes need to be given a forward shift.

* The arm. flux stationary wrt poles.

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$$\frac{I_a}{4} = \frac{50}{6} \times \frac{\cancel{720}}{\cancel{2\times 6}}$$ AT/P

$\cancel{\frac{I_a}{4}}$ $T = \frac{720}{2}$

$P = 6$

$$AT/P = \frac{50}{6} \times \frac{720}{2\times 6} = 500\,AT$$

* Factors affecting terminal voltage of dc generator →

* When the genr is on NL the NL induced emf is E_0. When it is loaded there is voltage drop due to arm. reaction demagnetisation.

$$E_0 - E_g = \text{Arm. reaction drop.}$$

* Due to arm. resistance there will be arm. resistance drop I_aR_a.
* These drops are proportional to load.
* In a seprately excited generator there are only above two drops effecting the terminal voltage.
* In a shunt genr its excitation is the terminal vol. Therefore reduction in V in turn reduces the terminal vol. itself
* This will be a cumulative effect when the genr is loaded beyond its rated value known as break down point.

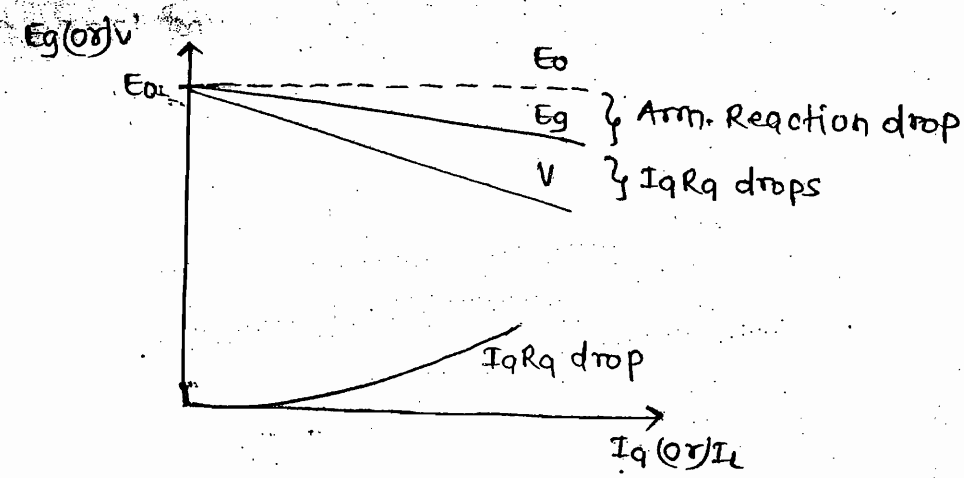
* Characterstics →

* This are the graphical representation of the key parameters which are plotted to know the suitability of appln.

→ No load → E_0 vs I_f

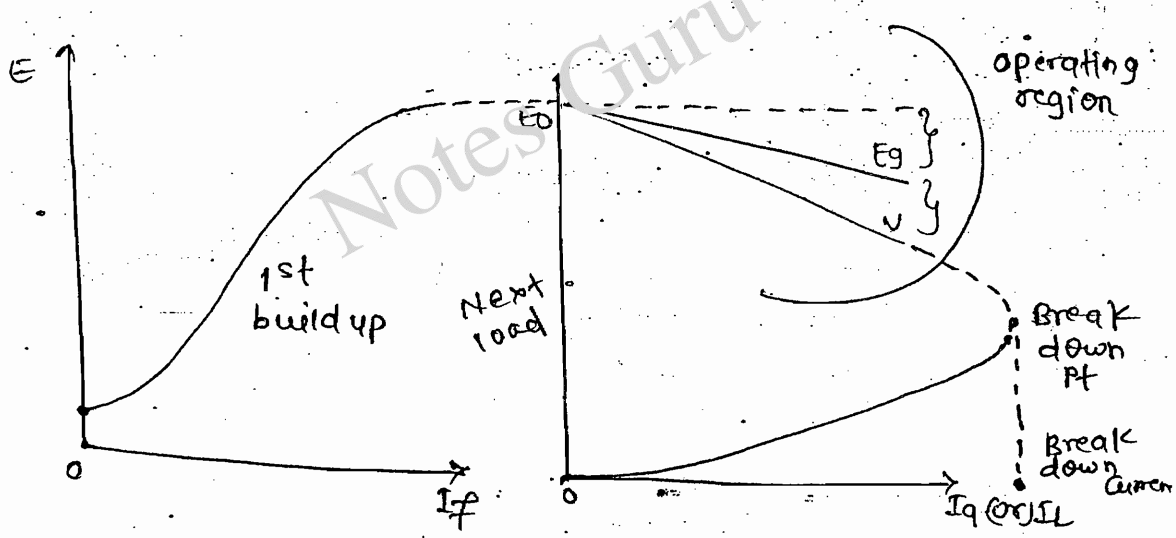
→ load → Internal (E_g vs I_a)
→ External (V vs I_L)

* Separately excited genʳ →



* This are not commertialy used for normal power supply because it requires addiotional dc vol. source.
* It was used in excitation sys. of power plant genʳ.
* Dc supplies in air crafts / ships.
* Used in a speed control method known as ward-leonard method.

* Shunt genʳ →

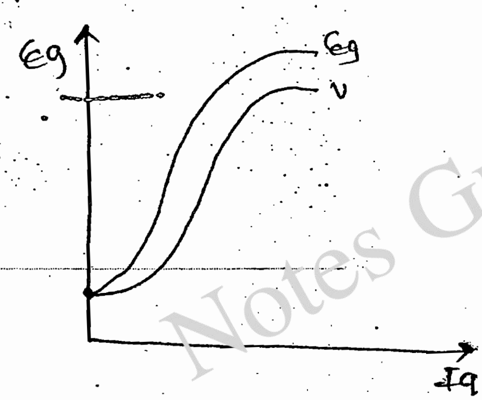


* In its operating region its flux remains approx. same, but beyond breakdown value a cumulative reduction of vol. happen reduce the terminal vol. to 0 drasticaly.

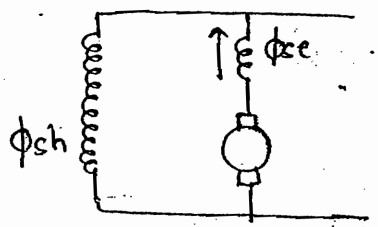
* Generaly the operating region will be around 125% of rated load.
* It is used as small dc power supply & exclusively used for battery charging.
* It was also used in excitation sys. of power plant genr. along with seprately excited genr.

* Series Genr →

* As the field wdg is in series with arm. & load as the load increases flux increases to inturn increase the voltage. Therefore in its operating region it has rising vol. c/s also called as variable vol. genr. not suitable for ordinary power supplies but used as boosters in long feeders. perticularly in dc distribution sys.

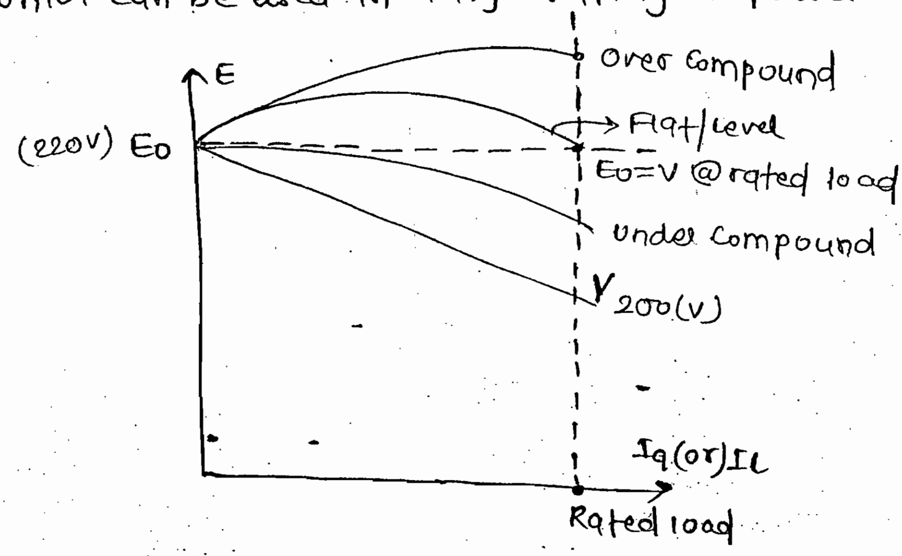


Cumulative →

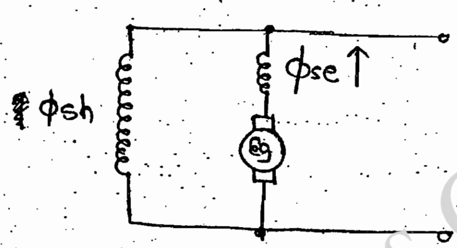


* As the series flux add its shunt flux the net flux increases with load. Concequently it has better vol. c/s. then seprately & shunt genr.

* It can be compounded to adjust its terminal voltage.
Therefore it is widely manufactured dc genr due to its flexible c/s which can be used in large rating dc power supplies.

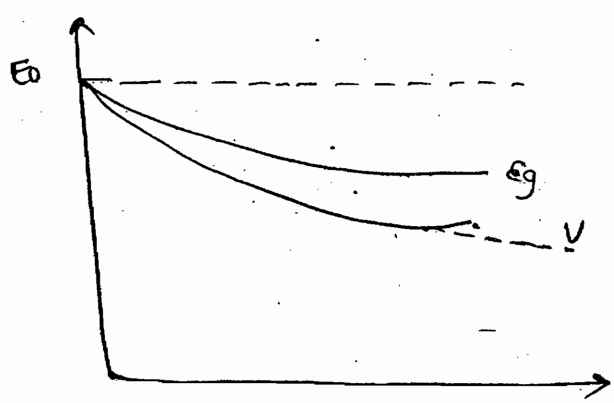


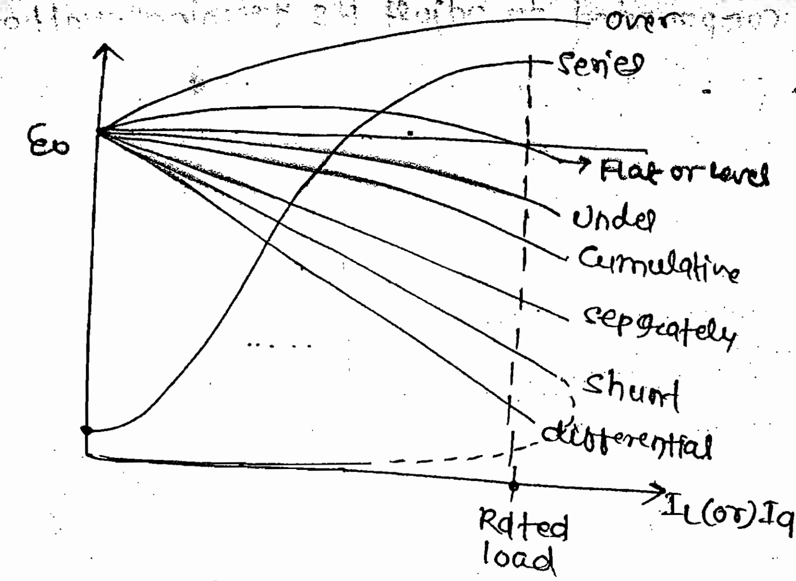
Differentialy →



* Arc weldings

* The net flux decreases with load to decrease the terminal vol.
This is not use for ordinary power supply but specifically used in welding purposes to limit the welding currents.





Voltage Regulation → * It is the change in terminal vol. when the full or rated load across the terminal is disconnected. keeping the flux & speed constant.

$$\boxed{\% VR = \frac{E-V}{V}}$$

E → NL induced vol.

V → Rated terminal vol. @ rated load

* VR is % drop in the m/c.

$$\boxed{VR = \frac{V_{drop}}{V}}$$ V_{drop} ↓ as possible

* It should be as minm as possible, best / ideal value is 0. which happens for only flat / level compound genr.
* For series & over compound VR becomes -ve. not suitable for ordinary load purpose.

DATE - 08/07/14

* PARALLEL OPERATION →

Operating genr in parallel across the common terminals known as bus bars provide the following ad. :-

(1.) High ele inertia across the busbars (constant voltage sys.)

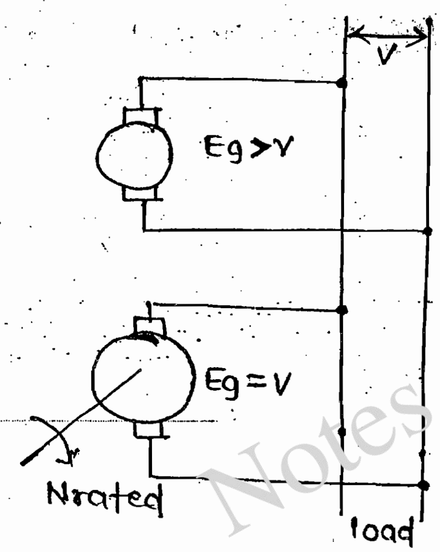
(2.) High reliability.

(3.) Efficiency. (η)

(4.) Future expansion.

(5.) Continuety of supply during maintanence & repairs.

Due to this reasons universaly the genr in the power plants & all the power plants are operating in parallel to form a grid st.



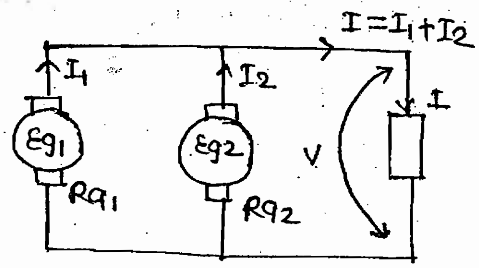
Eg > V	Generating mode
Eg = V	Floating mode
Eg < V	motoring mode

* In order to connect 2 dc genr in parallel it requires 2 essential condn :-

(1.) Terminal vol. should be same.

(2.) Palarity should be matched.

* Consider 2 dc genr operating in parallel at a common terminal vol. V & sharing a common load with induced emfs E_{g1}, E_{g2} respectively.



$E_{g1} - I_1 R_{a1} = V$

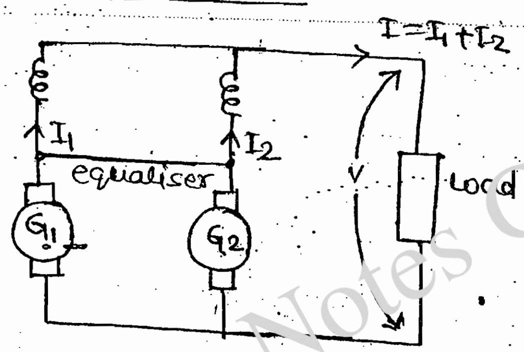
$E_{g2} - I_2 R_{a2} = V$

$\boxed{I_1 = \dfrac{E_{g1} - V}{R_{a1}}}$. $\boxed{I_2 = \dfrac{E_{g2} - V}{R_{a2}}}$

*** The load sharing of genr operating in parallel is significantly depanding on induced emf (directionaly praportional).

* In order to have stable or proper parallel operation the voltage c/s should be slightly drooping in nature but not rising.

* <u>series genr in parallel →</u>



$I_2\uparrow$ $\phi_{se2}\uparrow$ $E_{g2}\uparrow$ (gain load sharing capability)

$I_1\downarrow$ $E_{g1}\downarrow$ (It goes in motoring mode)

* If we connect an equaliser with the both series genr then only it operate in parallel.

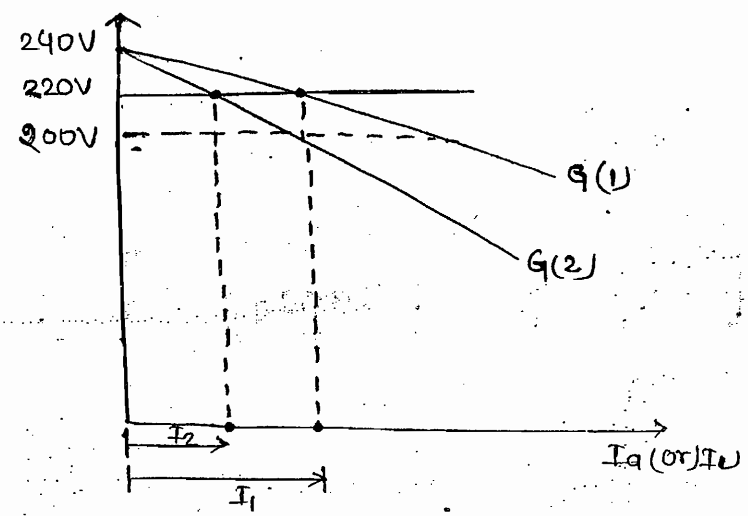
* If any one genr share more load the increase in its current will increased its flux & induced emf.

* Concequently its load sharing capability will increase in a cumulative manner & that genr gets overloaded leaving the other.

* This is due to the rising c/s of series genr.

* In order to make them in parallel an equaliser is required.
* The increased current will bypass into both field wdg to increase there flux & induced emf equaly.
* Equalisers are required for cumulative compound genr also.

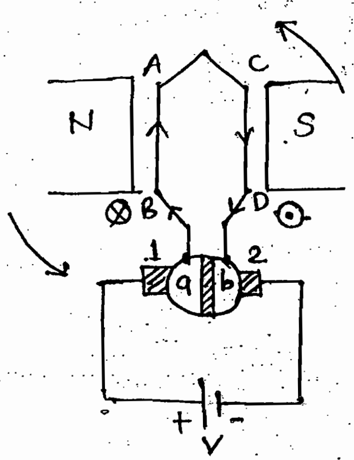
* Shunt genr in parallel →



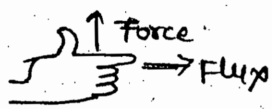
* shunt genr are best suitable for parallel operation due to there drooping c/s.
* The genr which is more drooping will share less load (viceversa)
* By adjusting the c/s the genr can be loaded according to there ratings.

DC MOTORS

* This are more popular because of there highest starting torque & wide range of accurate, simple & efficient speed control.
* The same dc genr can be operated as a motor.



Flemings L.H. Rule



$F = BIl$ Newtons.

$T \propto \phi I_a$

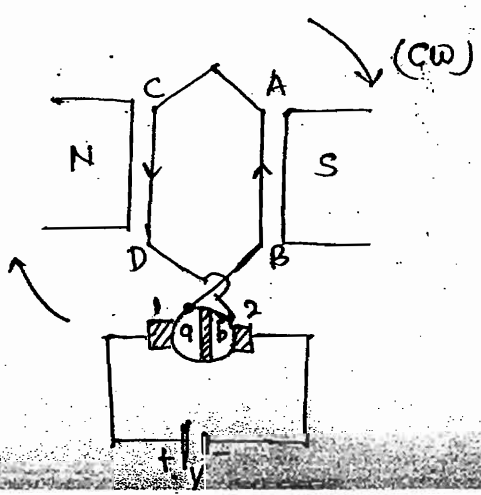
Principle →

* when a current carrying condr placed in a magnetic field it will experience a mech. force which magnitude is given by

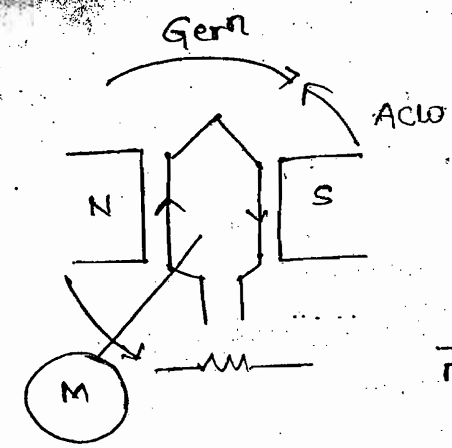
$$F = BIl \text{ Newtons}$$

& the dirn acc. to FLH Rule also called as motor Rule. For the same rotation in case of a genr. if it is rotated clockwise the motor will rotate anticlockwise.

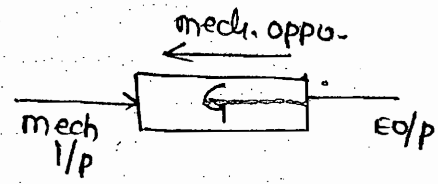
* The funn of commutator is to produce unidirectional torque.



Motor Action in a Gen^r →

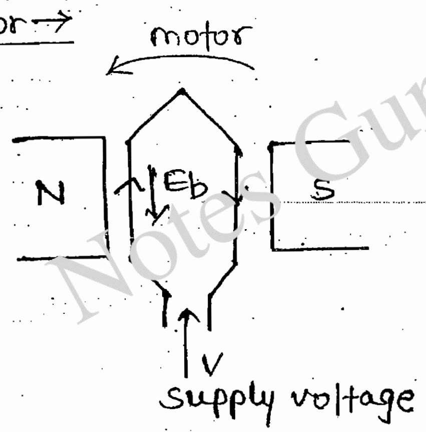


Gen^r → CW
Motor → ACW



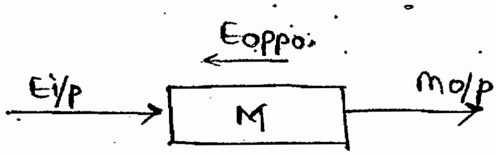
* Energy conversion from one form to other occurs through an opposition acc. to basic fundamental laws of nature.
* In a gen^r mech. to ele energy happens through mech. opposition known as motor action in gen^r.
* The prime mover which is rotating the gen^r should be capable of rotating the gen^r against the backward force or torque.

Gen^r Action in motor →



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

E_b = Back / counter emf



* In the motor arm. Cond^r when they rotate voltage is induced which is acc to Fleming's Right hand Rule & the induced emf is

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

* By applying right hand rule in motor the dirn of induced emf is exactly opposite to supply vol.
Therefore it is known as back emf or counter emf.

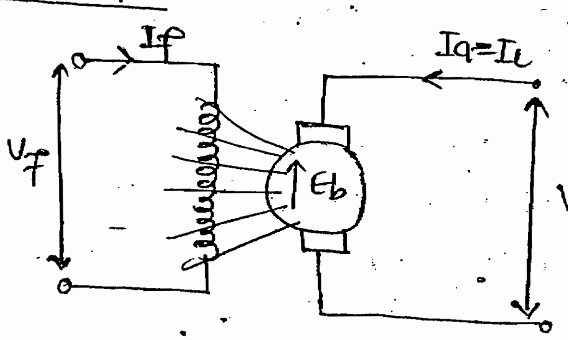
$$\boxed{E_b = \frac{\phi Z N P}{60 A}}$$

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

* The construction of dc motors are identical to genr therefore the classification is similar.

DC motor
- Seprately Excited
- Self excited
  - Shunt
  - Series
  - Compound
    - long shunt
      - Cumulatively compounded
      - Differentia compounded
    - Short shunt
      - Cumulatively compounded
      - Differentialy

1) Seprately excited →

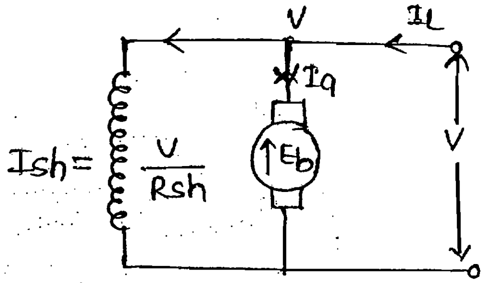


$$\boxed{V = E_b + I_a R_a + BCD}$$

$$\boxed{I_a = I_L}$$

* It basically used in servo motor.

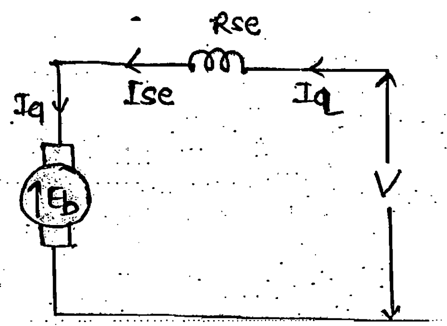
② Shunt motor →



$V = E_b + I_a R_a + BCD$

$I_L = I_a + I_{sh}$

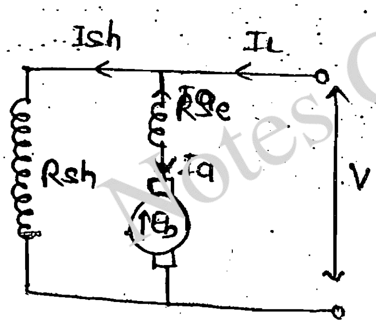
③ Series Motor →



$V = E_b + I_a(R_a + R_{se}) + BCD$

$I_a = I_{se} = I_L$

④ Long shunt →

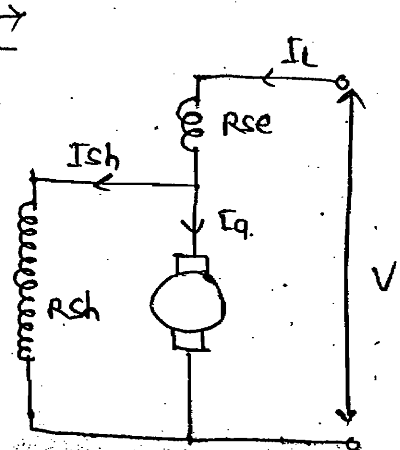


$V = E_b + I_a(R_{se} + R_a) + BCD$

$I_L = I_a + I_{sh}$

$I_{sh} = V/R_{sh}$

⑤ Short shunt →

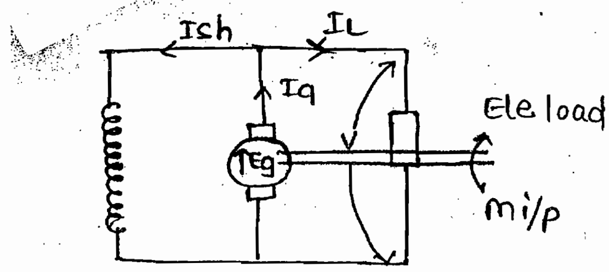


$V = E_b + I_L R_{se} + I_a R_a + BCD$

$I_L = I_{sh} + I_a$

$I_{sh} = \frac{V - I_L R_{se}}{R_{sh}}$

Shunt Gen^r



(1.) Gen^r delivers

$I_a = I_L + I_{sh}$

(2.) $E_g > V$

(3.) $E_g \rightarrow$ Gen/Ind. emf

(4.) $V \rightarrow$ Terminal vol.

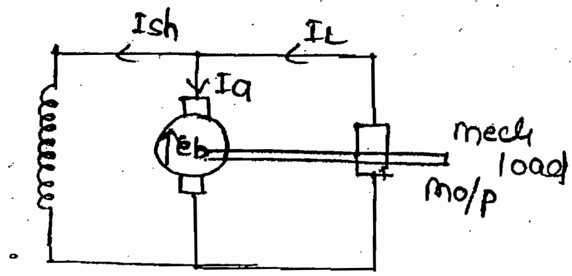
(5.) $E_g I_a \rightarrow$ Ele. power generated in arm.

(6.) $V I_L \rightarrow$ Power delivered to the load.

(7.) $E_g I_a - V I_L$ = Total cu loss

(8.) Electrical loading

Shunt motor



(1.) Motor draws

$I_L = I_a + I_{sh}$

(2.) $E_b < V$

(3.) $E_b \rightarrow$ Induced/Gen Back emf

(4.) V : supply vol.

(5.) $E_b I_a$:- Ele. eq. of mech. power developed in arm.

(6.) $V.I_L \rightarrow$ Ele. power I/p

(7.) $V.I_L - E_b I_a \rightarrow$ Total cu loss

(8.) Mechanical loading

* Significance of Back emf →

(1.) It is playing a role of opposition in electromech. energy conversion in motor.

(2.) The η of motor is depanding on its back emf (directly proportional)

$$V = E_b + I_a R_a$$

$$V I_a = E_b I_a + I_a^2 R_a$$

$$i/p = o/p + loss$$

$$\eta = \frac{o/p}{I/p} = \frac{E_b I_a}{V I_a} = \frac{E_b}{V}$$

$$\boxed{\eta = \frac{E_b}{V}}$$

③ Mech. power developed :—

max^m cond^n → $P_m = V I_a - I_a^2 R_a$

$$\frac{dP_m}{dt} \Rightarrow 0 = V - 2 I_a R_a$$

$$\boxed{I_a R_a = V/2}$$

If $I_a R_a$ (drop) is $V/2$ then the

$$V = E_b + I_a R_a$$

$$V = E_b + V/2$$

$$\boxed{E_b = V/2}$$

Now when Ⓜ P_m max then Ⓜ

$$\eta = \frac{E_b}{V} = \frac{V/2}{V} = 1/2 = 50\%$$

$$\boxed{\eta = 50\%}$$

Now;

$$V = E_b + I_a R_a$$

$$I_a = \frac{V - E_b}{R_a} = \frac{V - V/2}{R_a} = \frac{V}{2R_a}$$

$$\boxed{I_a = \frac{V}{2R_a}}$$

Here value of current increases ($I_a \uparrow$).

* The mech. power developed will be max^m if the back emf is half the supply vol.
* Under such cond^n the η of the motor is only 50%. Therefore dc motors are not designed for such cond^n but they are designed to give max^m η near rated load cond^n.

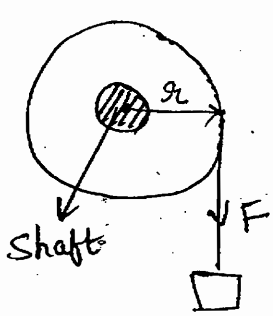
(4) Back emf makes the motor self regulating in nature.

* When the motor is loaded it has to develop the electromagnetic torque which equals the load torque.
* It will do the same by reducing its speed, back emf & increasing the current proportionaly.
* When the electromagnetic torque develop is exactly equal to the load torque the speed will not reduce further & the motor run at new speed.
* If the load is removed the speed increase but do not rise because the back emf will regulate the current & torque.

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

* TORQUE → * It is the turning/twisting movement of force about an axis expressed in N-m.

$$\boxed{T = F \times r \quad N\text{-}m}$$



$$P = \frac{\text{Work done}}{\text{time}} = \frac{\text{Force} \times \text{distance}}{\text{time}}$$

$$P = \frac{2\pi r \times F}{60/N}$$

$$P = \frac{2\pi N (Fr)}{60}$$

$$\boxed{P = \frac{2\pi NT}{60} \text{ watts}}$$

Power developed in the arm.

$$P = E_b \cdot I_a$$

$$E_b I_a = \frac{2\pi NT}{60}$$

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

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

$$\boxed{T = \frac{1}{2\pi} \cdot \frac{\phi Z P I_a}{A}}$$

$$T = \frac{1}{2\pi} \times \phi I_a \times \frac{ZP}{A}$$

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

$$\boxed{\frac{T_2}{T_1} = \frac{\phi_2}{\phi_1} \times \frac{I_{a2}}{I_{a1}}}$$

Flux constant :-

$$\boxed{\frac{T_2}{T_1} = \frac{I_{a2}}{I_{a1}}}$$

If flux constant shunt motors.

$$\boxed{\frac{T_2}{T_1} = \left(\frac{I_{a2}}{I_{a1}}\right)^2}$$ For series motor upto saturation ($I_a \propto \phi_{se}$)

After saturation again shunt motor

$$\boxed{\frac{T_2}{T_1} = \frac{I_{a2}}{I_{a1}}}$$

$$E_b \propto N\phi$$

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

$$N \propto \frac{V - I_a R_a}{\phi}$$

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}}$$

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}}$$ If flux constant.

Armature torque:-

$$\frac{2\pi N T_a}{60} = P = E_b I_a = \text{Rotational losses}$$

↓
IRON & mech.

$$T_a - T_{sh} = \text{Lost torque}$$

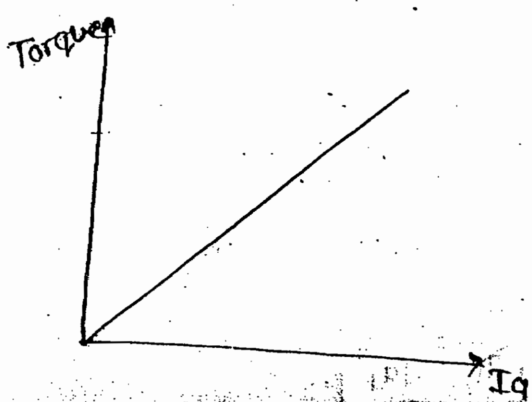
Characterstics →

(1.) Torque vs I_a
(2.) Speed vs I_a } same
(3.) Speed vs T

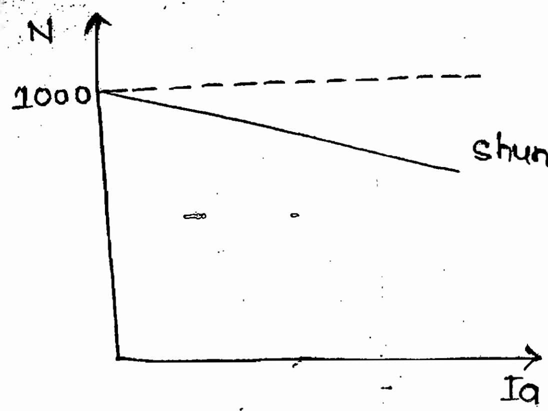
① Shunt motor →

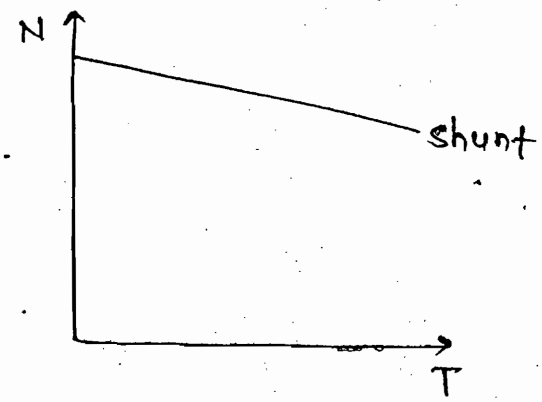
① Torque vs I_a

$T \propto I_a$



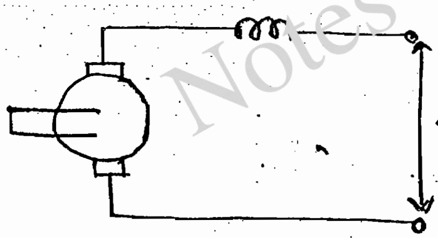
$N \propto V - I_a R_a$





* Shunt motors have excellent speed c/s. & they are approx. as constant speed motors.
* They have low or medium starting torque.
* These are best suitable for manufacturing purposes like steel rolling, Al rolling, lathe's, m/c tools.
* The c/s of shunt motors are identical to indn motors. but shunt motors are prefered for there superior speed control.

(2) Series Motors →



$N \propto \frac{E_b}{\phi_{se}}$

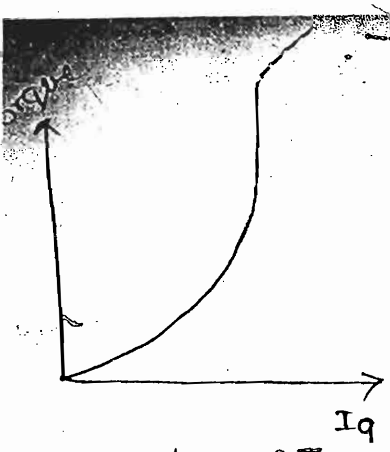
at NL the $I_{a0} \downarrow$ then $\phi_{se} \downarrow$ & speed $\uparrow$.

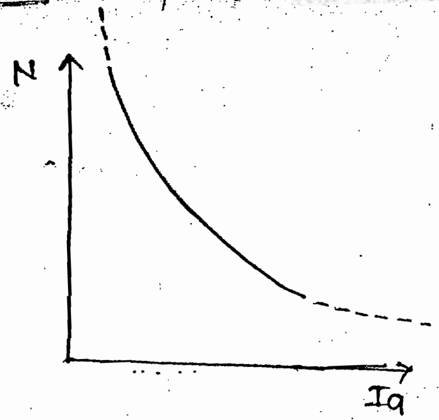
$$I_a = \frac{V - E_b}{R_a}$$

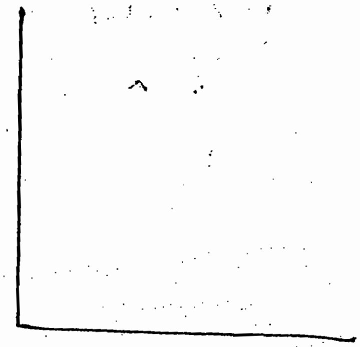
$I_a \downarrow$ E_b will max^m

$$\uparrow E_b \propto \phi_{se} N \uparrow$$

Never start series motor at NL because speed becomes dangerous.







$T \propto \phi_{se} I_a$

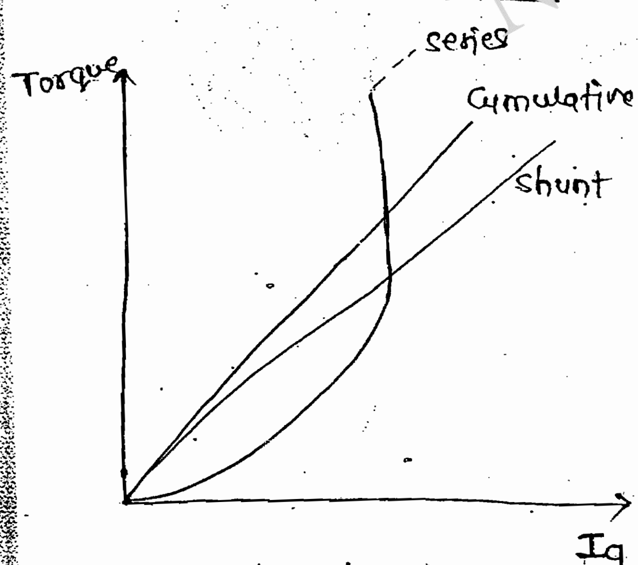
$T \propto I_a^2$ Before Satu.

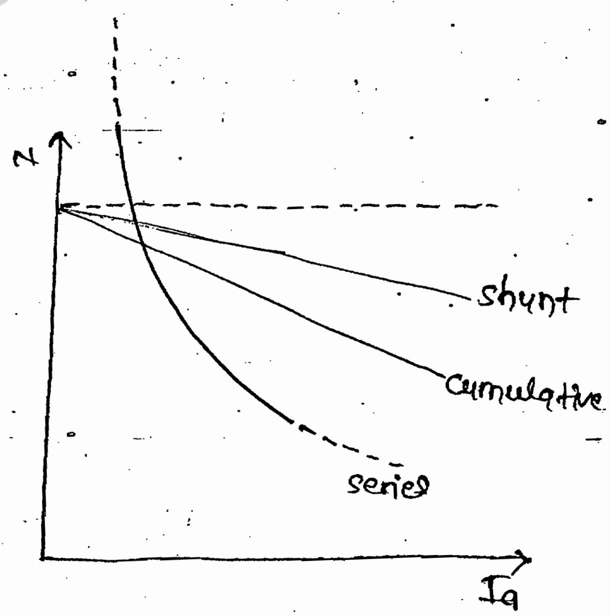
$T \propto I_a$ After saturation.

$\downarrow N \propto \dfrac{(V - \uparrow I_a R_a)\downarrow}{\phi_{se}\uparrow}$

* The series motors have highest starting torque. Therefore used in electric traction, cranes, Hoists etc.
* This are not suitable for belt drives.
* Never start a series motor at NL its speed becomes dangerously high & motor damages mechanically.
* They have variation in speed with load due to series flux & dangerous speed on NL.

Cumulative Compound motor





$T \propto (\phi_{sh} + \phi_{se}) I_a$

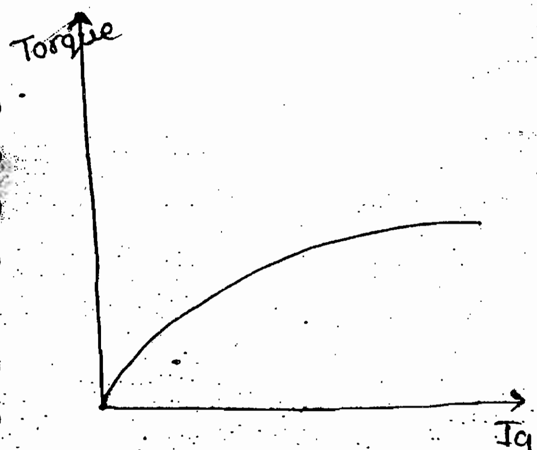
* It is best suitable for high torque intermittent load cond^n.
like shears & punches, presses, compressors.
* They have definate NL speed.

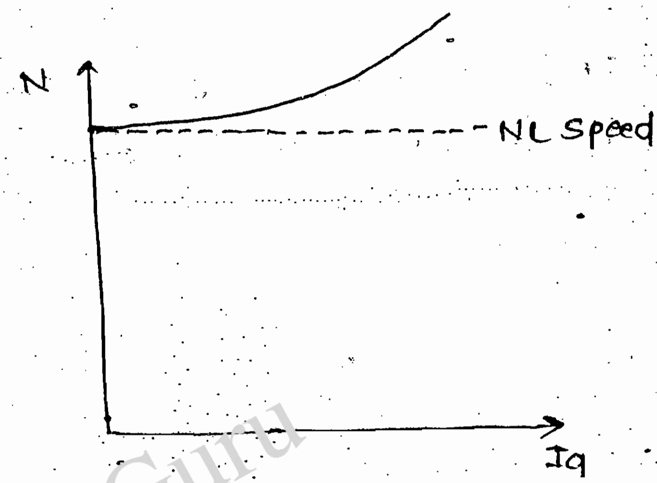
* The shunt flux regulates the speed on NL cond^n & the series flux increases the torque with load cond^n

(4.) Diffrentially Compounded →

$$T \propto (\phi_{sh} - \phi_{se}) I_a$$

$$I_a \uparrow \quad \phi_{se} \uparrow \quad (\phi_{sh} - \phi_{se}) \downarrow \quad T \downarrow$$





$$\uparrow N \propto \frac{V - I_a R_a}{\downarrow(\phi_{sh} - \phi_{se}\uparrow)}$$

* Due to unstable torque & speed c/s they don't have practical app^n

* Speed Regulation →
* The change in speed when the Full load across the motor is disconnected expressed in % of rated speed.

$$\boxed{\%SR = \frac{N_0 - N}{N} \times 100}$$

* Shunt motors have best SR.

* Differtial motors have -ve SR. & these motors may have 0 speed regn without any external control.

(26/6)

$T \propto \phi_{sh} I_a$ (shunt)

$T \propto \phi_{se} I_a$ (series)

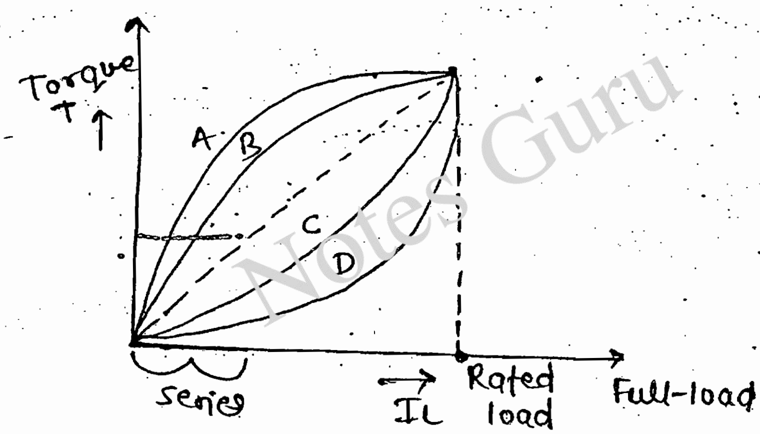
$T \propto (\phi_{sh}+\phi_{se}) I_a$ (cumu.)

$T \propto (\phi_{sh}-\phi_{se}) I_a$ (Diff.) $I_a \uparrow$ $\phi_{se} \uparrow$ $(\phi_{sh}-\phi_{se})\downarrow$

Ans. (d)

** During starting diff motors may run in the reverse dirn if the series flux dominates shunt flux due to large starting current flowing through arm.

(29/6)



At Rated load each motor give same o/s

$T \propto \phi_{sh}$ (Because I_a same No comparision)

$T \propto \phi_{se}$

$T \propto (\phi_{sh}+\phi_{se})$

$T \propto (\phi_{sh}-\phi_{se})$

D → Series motor (Because in series motor negligible value of flux at NL)

Ans 2. A → Differential (Because in option)
B → shunt (Because constant flux)
C → Cumulative

09/07/14

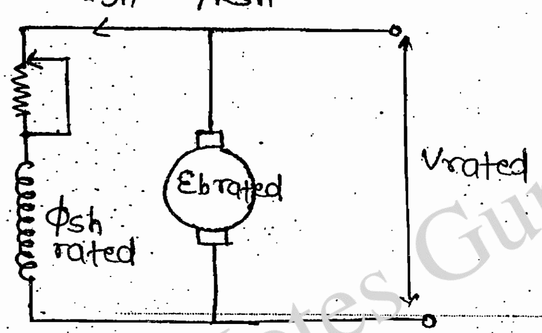
* SPEED CONTROL →

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi} \rightarrow \text{Vary the speed}$$

(1.) Flux – Field weakning
(2.) Ra – Arm. Resistance / Rheostat
(3.) V – Voltage Control.

* Speed control of shunt motor →

(1) Field weakning / Field current →

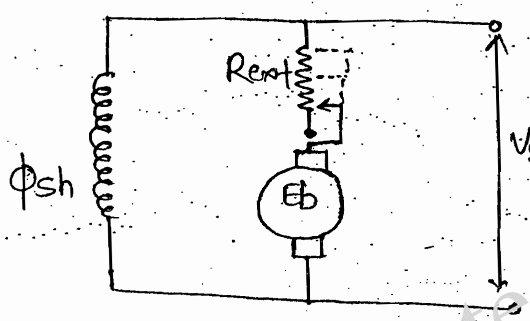


R↑ Ish↓ φsh↓ N↑

* By connecting an external resistance in series with field wdg & by increasing it from its min^m to max^m the field current will reduce & reduce its flux & increase its speed.
* The min^m speed in this method is only rated.
* It is efficient speed control method.
* Because here we decrease the value of flux (Field weakning)
* Loss associated with external resistance in the field ckt is small
* No need of large rheostat
* No need of additional cooling.

* Requires 4-Point starter specialy to control speed over wide range.
* Additional arm. reaction as the main flux is reduced. Therefore it requires interpoles, compensating wdg etc.
* Also called as variable torqe constant power speed control.
* Field resistance should be in the min^m resistance position during starting.
* There is a limit to decrease the field current or to increase the field resistance as the speed of motor becomes dangerously high.

(2) Rheostatic / arm. Resistance Control →



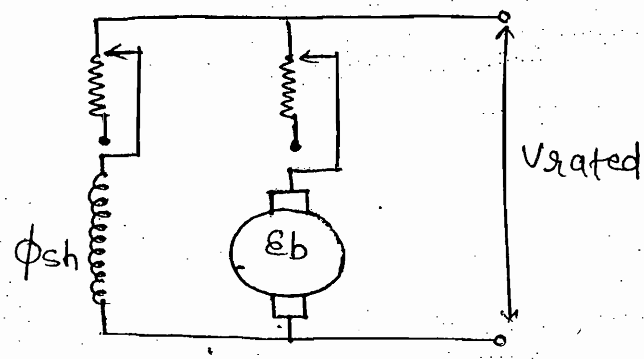
$$\downarrow E_b = [V - I_a(R_a + R_{ext}\uparrow)] \downarrow$$

$$\downarrow E_b \propto N \downarrow$$

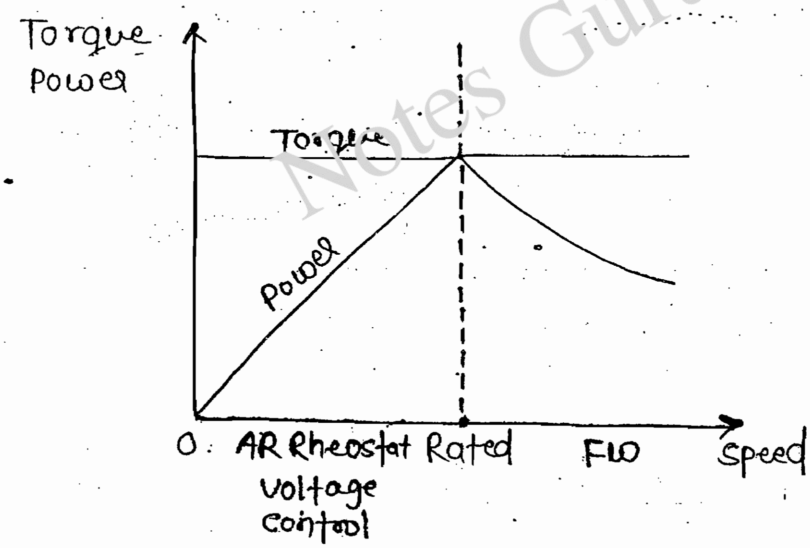
* By connecting an external resistance in series with arm. the voltage across the motor arm. is varies concequently the speed is vary.
* It is basicaly the vol. control without varying supply vol.
* It includes resistance & produce more cu loss. Therefore less efficient method.
* It is to control speeds from rated to below.
* No need of 4 point starter & there is no additional arm. reaction effect
* Requires additional cooling methods.

* Also called as constant torque variable power.
* The arm. Rheostat should be at its max^m position during starting.

Both above Speed control →



FWSC	ARSC
* Variable torque Constant power	Constant torque Variable power
* Nrated to above	Rated to below



Que → A shunt motor is running at rated speed 1000rpm with Rated voltage V. if the voltage becomes half (V/2) then the speed will

① 1000 ② 500 ③ 250 ④ 2000

Soln →

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\frac{N_2}{N_1} = \frac{\cancel{E_{b1}}/2}{\cancel{E_{b1}}} \times \frac{\cancel{\phi_1}}{\cancel{\phi_1}/2}$$

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

$$\boxed{N_2 = 1000\ RPM}$$

$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$

$E_b \propto \frac{V}{\phi}$ ($I_a R_a$ small)

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

If $V = V/2$, $I_{sh} = I_{sh}/2$

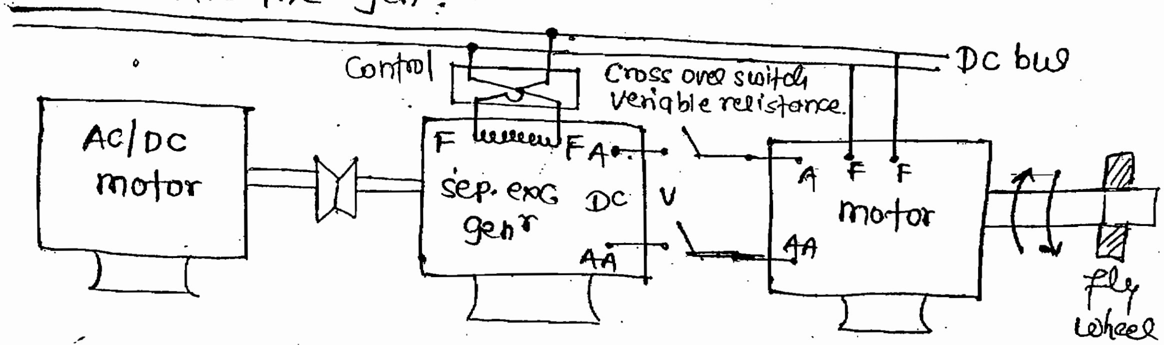
then $\phi = \phi_{sh}/2$

Case② If the flux is constant

$$\boxed{N_2 = 500\ RPM}$$

* multiple voltage control →

* self excited shunt motor should be seprately excited in order to apply the speed control tech.
* It requires a multiple vol. dc source.
* For large rating motor specially used under steel rolling voltage control method known as ward-leonard speed control is used which requires seprately excited dc genr. & the motor to rotate the genr.

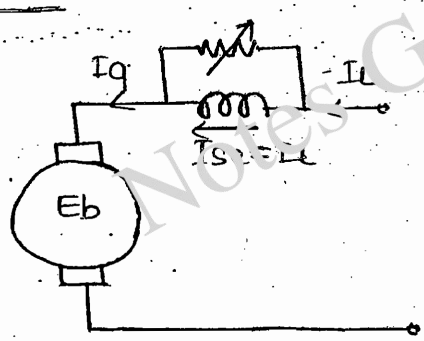


* This is exclusively use to control the speed from rated to below rated efficiently without inserting the resistance in series with arm. & to control speed in both dirn.
* The control is through a cross over switch which varies the excitation of seprately excited genr.
* As it requires two additional m/c it is very expensive.
* A fly wheel is connected across the shaft.
* In order to control the speed fluctuations due to varying loads & to improve overall ~~ffeq~~ efficiency known as Ward Leonard Ilgner method.

* Speed control of series motors →

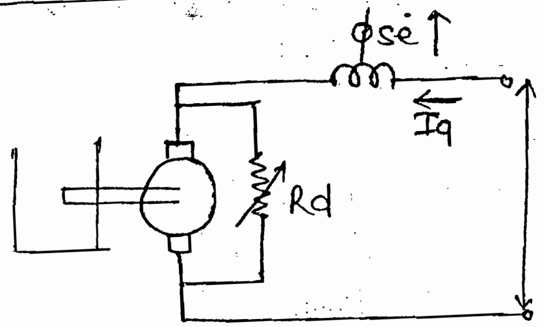
(1.) Field diverter
(2.) Armature diverter
(3.) Tapped Field
(4.) Paralleling Field coils
(5.) Armature Resistance
(6.) multiple voltage.

(1.) Field diverter →



* By connecting a diverter the current flowing through the field wdg gets diverted, flux reduce & conceqently speed ↑.
* Diverter resistance should not reduce below a minm value as the speed becomes dangerously high.

② Armature diverter →

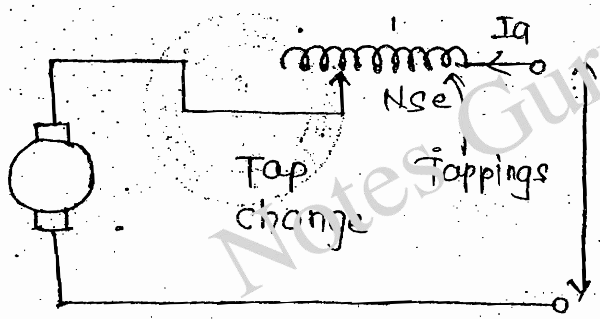


N ↓

$T \propto \phi I_a$

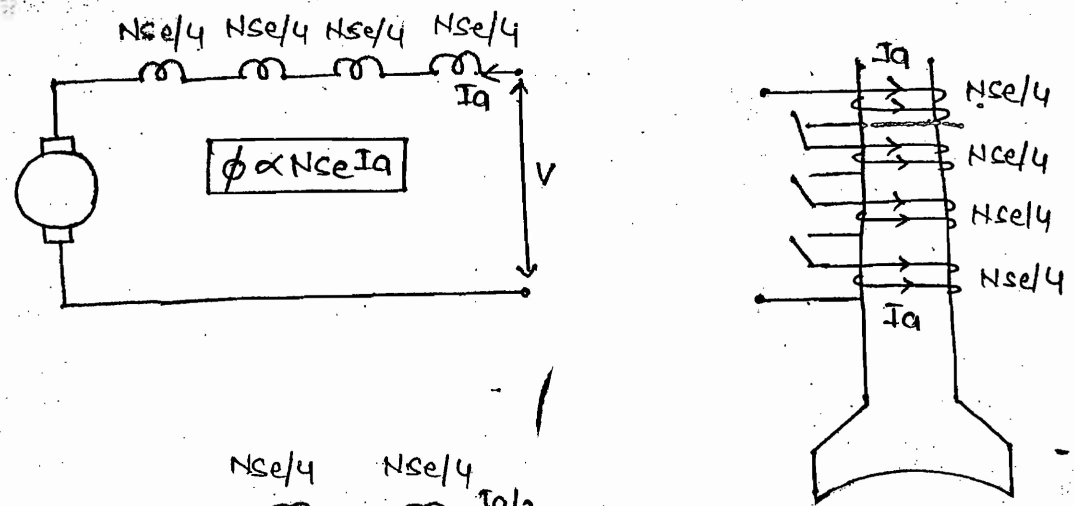
* By connecting diverter across arm., arm. current gets diverted due to which the torque is reduced.
* In order to maintain the torque the motor draws more current from supply which comes through the field wdg flux ↑ speed ↓.

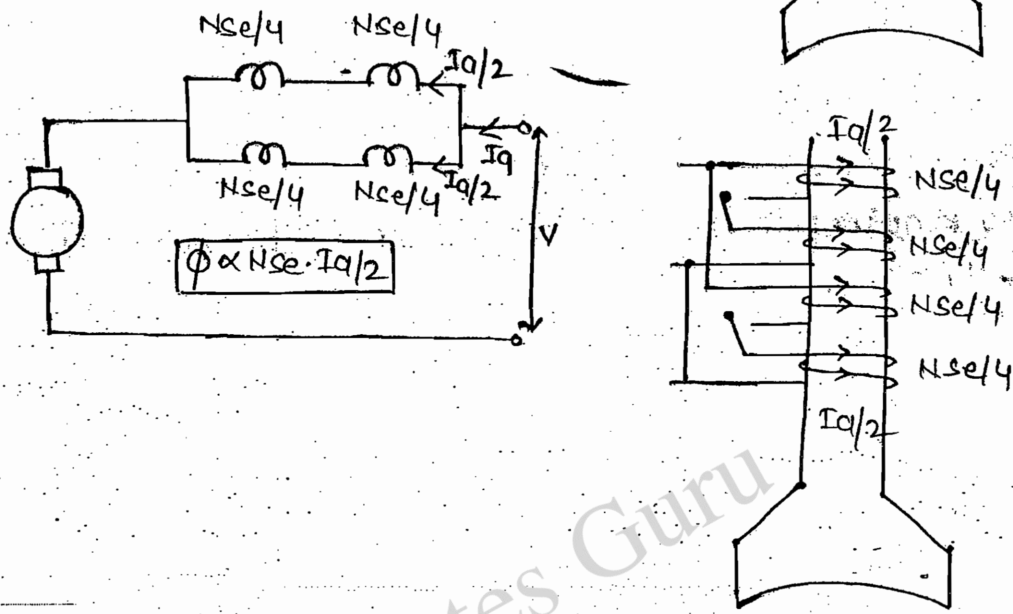
③ Tapped Field →



* If the tappings are more, then turns are more & Hence by increasing the value of turns the value of flux increases & the speed may decreases.

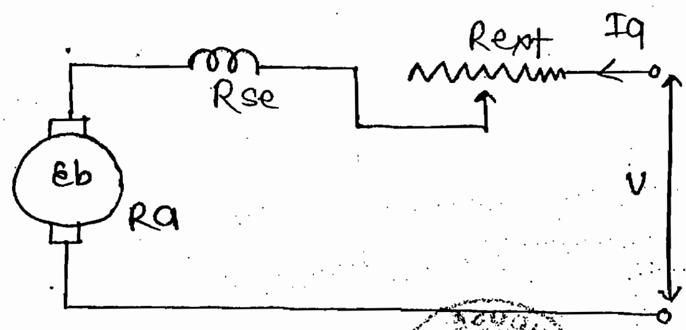
(4) Paralleling Field Coils →





* The field wdg is arranged in the form of coils which can be externaly switch in series & parallel.
* In order to gets speeds b/w the steps a diverter may be connected

⑤ Armature Resistance Control →

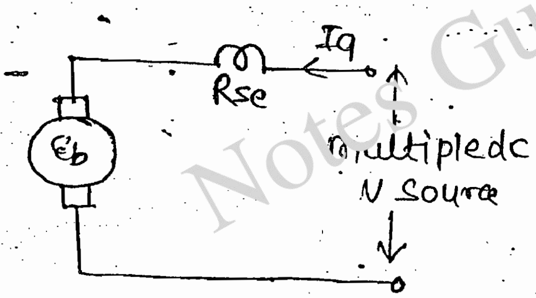


$$\downarrow Eb = [V - I_a(R_{se} + R_{ext}\uparrow + R_a)]\downarrow$$

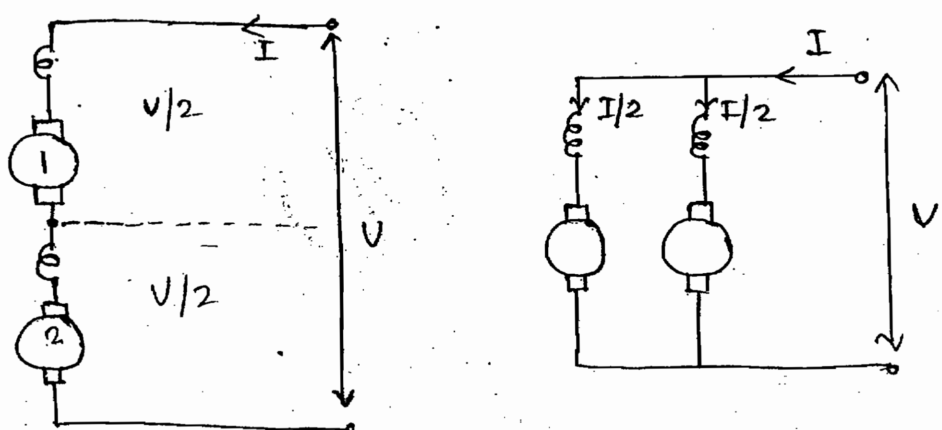
$$N\downarrow$$

* By adjusting the resistance, vol. across the arm. is vary to vary the speed. which involves huge power loss.
* It also requires a multiple vol. source. Therefore these are rarely used.

⑥ multiple vol. control →



* Traction motors in series & parallel →



$N \propto \frac{E_b}{\phi}$ $N \propto \frac{E_b}{\phi}$ $\boxed{\begin{matrix} E_b \propto V \\ \phi \propto I \end{matrix}}$

$N_{se} \propto \frac{V/2}{I}$ $N_{sh} \propto \frac{V}{I/2}$

$N_{se} \propto \frac{V}{2I}$ $N_{sh} \propto \frac{2V}{I}$

*** $\boxed{N_{sh.} = 4 N_{se}}$

$T \propto \phi I_a$ $T \propto \phi I_a$

$T_{se} \propto I^2$ $T_{sh} \propto \frac{I}{2} \cdot \frac{I}{2}$

$T_{sh} \propto I^2/4$

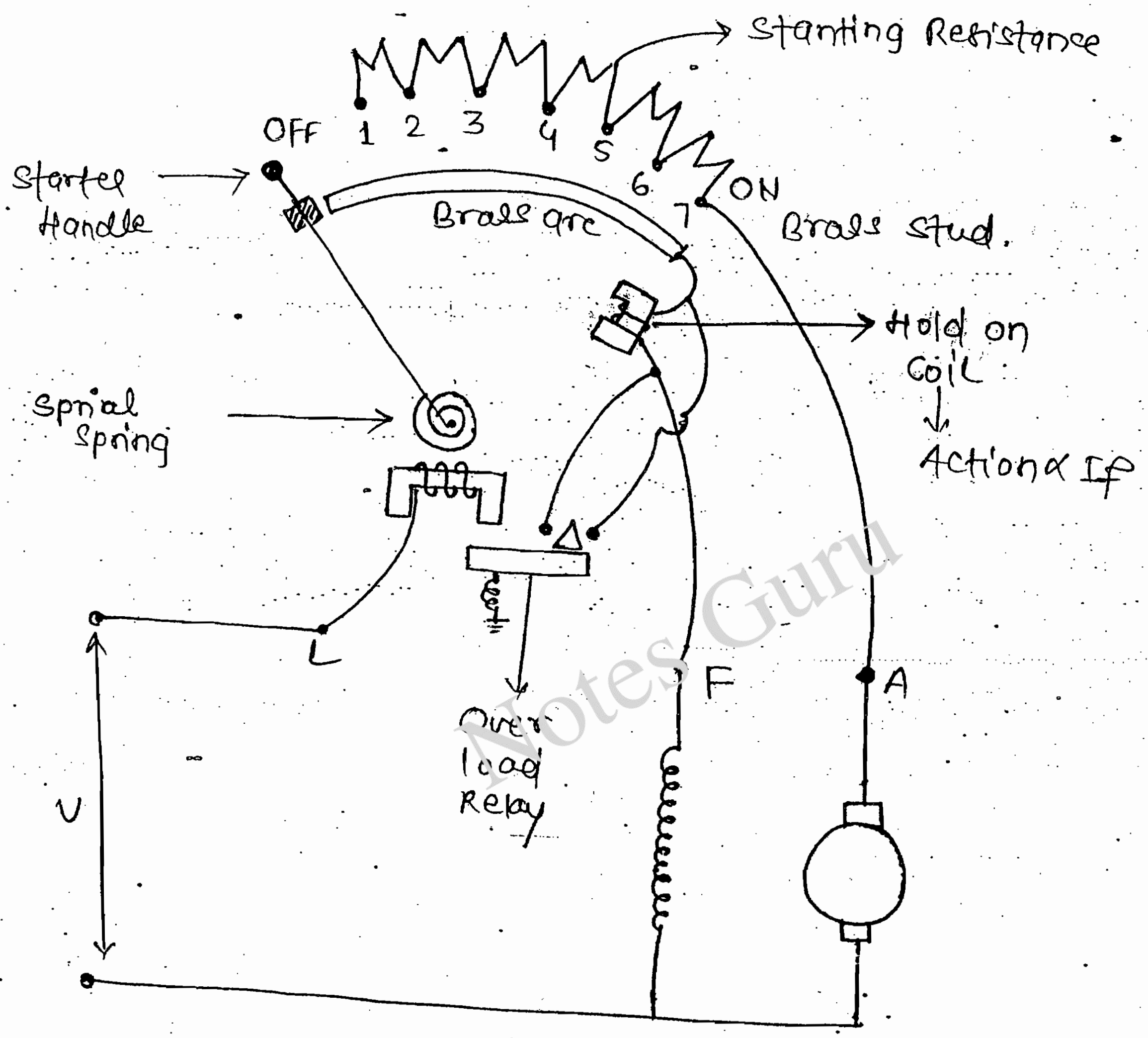
*** $\boxed{T_{sh} = \frac{T_{se}}{4}}$

* STARTERS →

* If a dc motor started directly with rated vol. across the terminal it will draw excessively high current.
* If the motor starts quickly this will be inrush current which may not damage the motor.
* Large motors which have small acceleration time comparitively draw huge current which produce vol. dip in the supply where it is connected & also damages the commutator & brush. Therefore starting resistance resistance should inserted in series with arm. which should be cut down in steps.
* A starter insure this starting resistance to limit the starting current to a desired value.
* There are 3 more protective schemes :-
  1. No volt release
  2. Over load release
  3. Field faliure prevention

* There are 3 types of starters:-
  - 3 point starter } shunt + compound
  - 4 point starter }
  - 2 point starter → Series

* 3 Point Starter →



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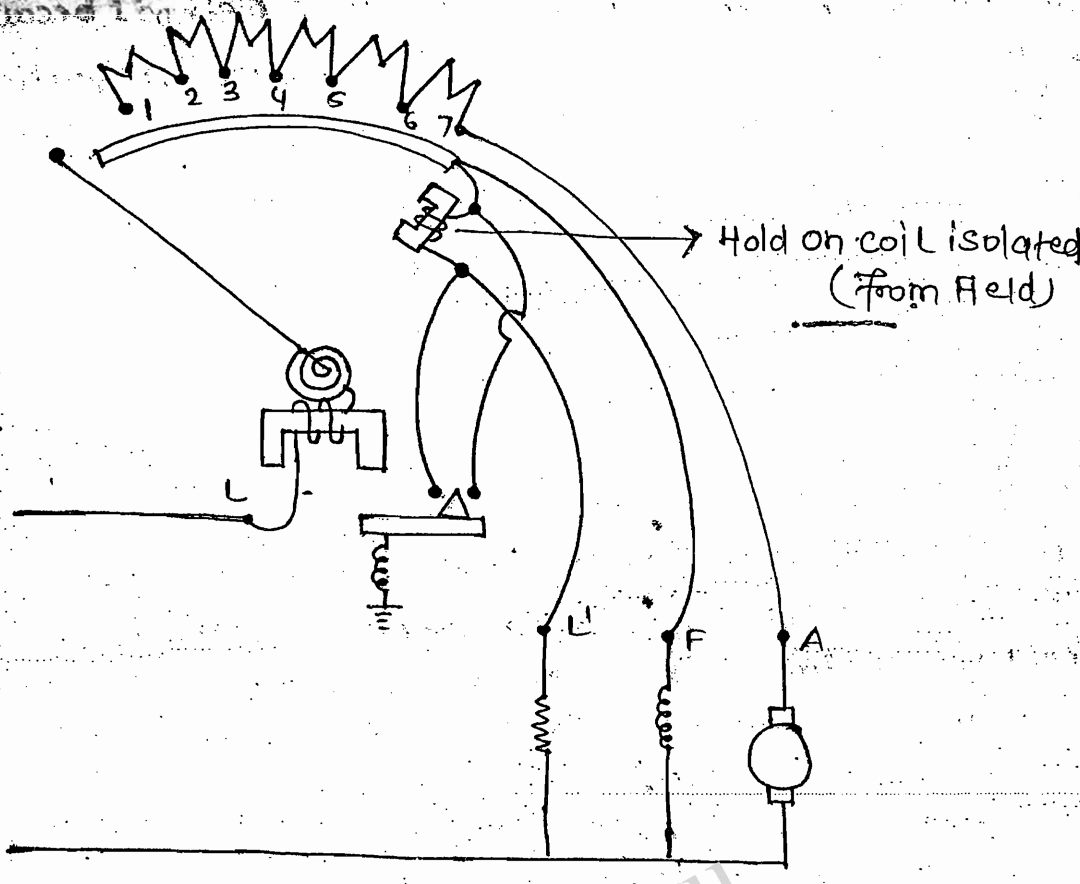
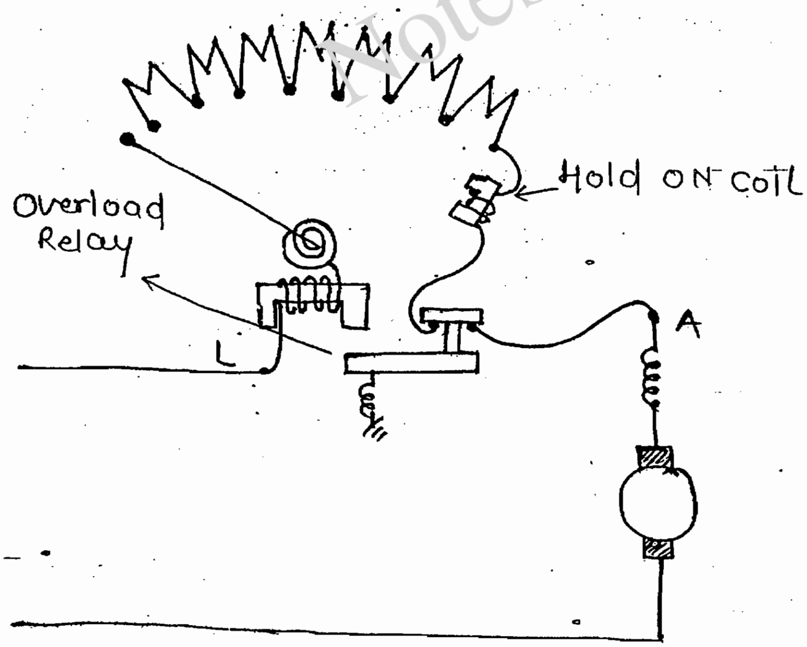
* 3 point starter →



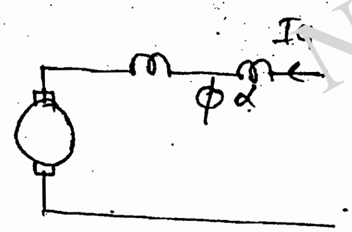
* 2 point starter →

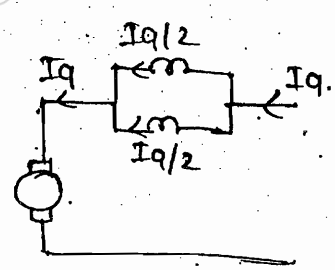


- 3 point starters are not suitable for shunt & compound motor when they are subjected to FWSC methods because the Hold on coil magnetic action is directiotry proportional to its field current.

* For such appl^n 4-point startar should be used.
* Its Hold on coil is isolated from field wdg even though field current decreased. it won't effect Hold on coil action but there is no field faliure prevention.
* 2 point starters are specialy used for series motor only which contains all the 4-schemes.
* Apart from them it also protect the motor at any dangerous speeds (racing cond^n) when the load across its shaft is suddenly disconnected because the Hold on coil is in series with field wdg & arm.
* A 3 Pt. starter can be used to start a series motor but with a slight modification.
* Its F terminal should be closed through -ve to offered a closed path for current to flow in the Hold on coil.

24/6





$T \propto \phi . I_a$

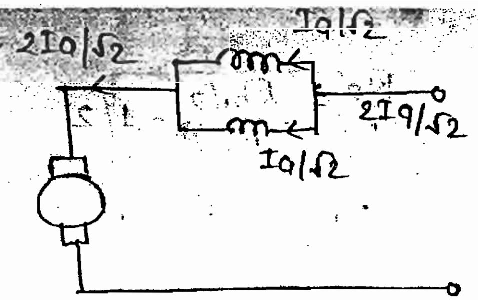
$T \propto I_a . I_a$

$T \propto I_a^2$

$T \propto \phi I_a$

$T \propto \left(\frac{I_a}{2}\right)(I_a)$

$T \propto \frac{I_a^2}{2}$



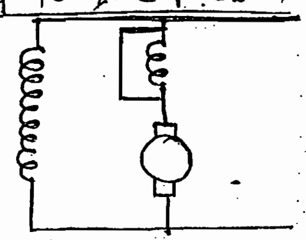
$T \propto \phi I_a$

$T \propto \frac{I_a}{\sqrt{2}} \times \frac{2I_a}{\sqrt{2}}$

$T \propto I_a^2$

If flux is $\phi/\sqrt{2}$ then speed $N\sqrt{2}$.

(9/1) Rated torque prob. →



For cumulatively

$\phi_{sh} + \phi_{se}$ $\quad \phi \uparrow$

series gets SC

ϕ_{sh} $\quad \phi \downarrow$

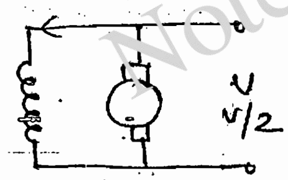
$\uparrow N \propto \frac{E_b}{\phi \downarrow}$

$T \propto \downarrow\phi I_a \uparrow$

Flux reduce & to maintain constant torque motor will draw current high.

(34/7) Rated power →

$I_{sh} = V/R_{sh}$



$I_{sh} = \frac{V}{2R_{sh}}$

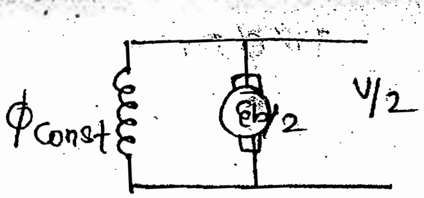
$\phi \to \phi/2$

$\frac{N_2}{N_1} = \frac{E_{b1}/2}{E_{b1}} \times \frac{\phi_1}{\phi_1/2}$

$N_2 = N_1$ speed 1 PU

$P = E_b I_a$

$E_b = E_b/2$ then $I_a = 2I_a$ then power constant



$$\frac{N_2}{N_1} = \frac{E_{b_1}/2}{E_{b_1}} = 1/2$$

$$N_2 = 0.5N \ PU$$

$$P = E_b I_a \qquad I_a = 2 PU$$

DATE-10/07/14

* **BRAKING →** * It is done to intensanaly stop the motor or to control its speed.

* There are 2 basic brakings

(i) Mech. braking → The KE of the rotating parts is dissipated in brake which includes noise, wear & tear high maintenance repair & the braking is not smooth.

(ii) Ele. braking → Isolating the motor from supply is basic electric braking but the motor doesn't stop.

In order to stop the motor at the required instant quickly additional braking methods are used.

(a) Dynamic/ Rheostatic braking

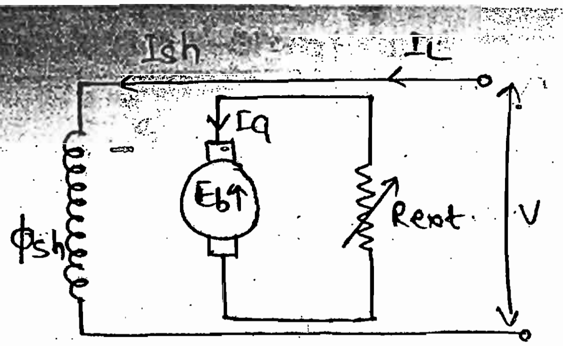
(b) Plugging

(c) Regenerative braking.

(a) Dynamic/ Rheostatic braking → * The basic principle involved in ele. braking is to develop a -ve torque in a running motor with the reversal of arm. current.

* In this braking the arm. of a running motor is disconnected from supply leaving ~~the~~ field connected to supply,

* At the instant of braking the induced back emf will circulate a current in the opposite dirn to reverses the torque & motor stops quickly.

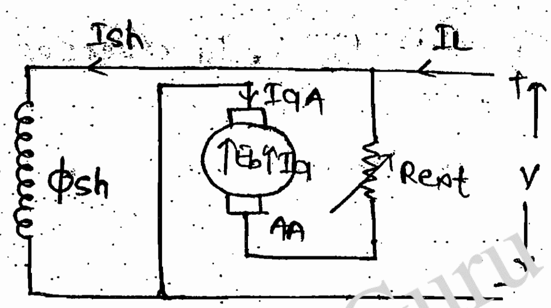


$$I_b = \frac{E_b}{R_a + R_{ext}}$$

(2) Plugging → * Reversing the arm. terminals or arm. polarity only which will directly reverse the arm. current & torque.

* Due to which the motor want to run in opposite dirn.

* Concequently it come near 0 speed where the mech. braking will be applied otherwise the motor continues to run is opposite dirn.



$$I_a = \frac{V + E_b}{R_a + R_{ext}}$$

93/9

$E_b = V - I_a R_a$

$I_L = 15A, \quad R_{sh} = 80\Omega, \quad V = 240V$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{240}{80} = 3A$$

$I_a = I_L - I_{sh}$

$I_a = 12A$

$E_b = V - I_a R_a$

$= 240 - 12(0.5)$

$= 234$

$V + E_b = 234 + 240 = 474V$

$$I_a = \frac{E_b + V}{R_a + R_{ext}}$$

$$\cancel{I_a}(1.25)(12) = \frac{240+234}{0.5+R_{ext}}$$

$$\boxed{R_{ext} = 31.1\Omega}$$

(3) Regenerative Braking → * This is not intantional & it won't stop the motor. it occurs naturaly.

* ~~It occurs naturaly~~ due to the inherent property of motor when it is subjected to over hauling load condn like a train moving down a gradient a crane lowering its load etc.

* Due to increased speed if $E_b > V$, I_a reverses & the torque reverses & the speed is reduced.

* Concequently the motor regains its original mode ($E_b < V$)

* During braking it is acting as genr simultaneously.

* In series motor in order to acheive this braking its field wdg need to be separately excited.

For series motor

$$T = (-\phi)(-I_a)$$
↓
+ve

* So in series motor we brake the arm. & a series field.

* This are so advantage in the mountain Railway.

★ Genʳ across busbar operating as motor →

Genʳ → CW

motor $T \propto \phi I_a$! ← ACW

$T \propto -\phi I_a$ → CW

$T \propto \phi(-I_a)$ → CW

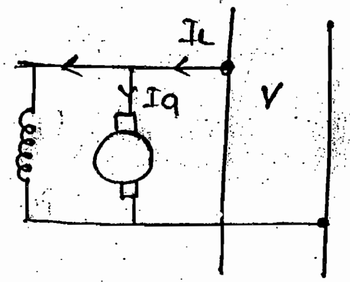
$T \propto (-\phi)(-I_a)$ ← ACW

⊗ A shunt genʳ supplying power across bus bar when the prime mover fails it will act as

(a.) shunt motor running at same dirⁿ.

(b.) Shunt motor running in opposite dirⁿ.

(c.) It will stop.

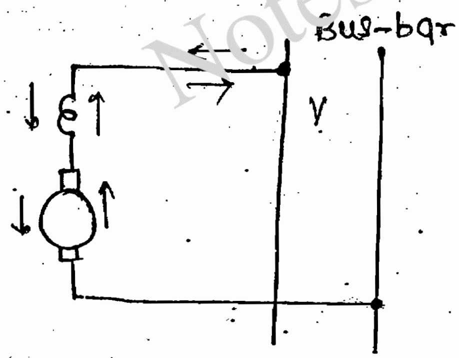


Ans. (a.) (Only I_a dirⁿ change)

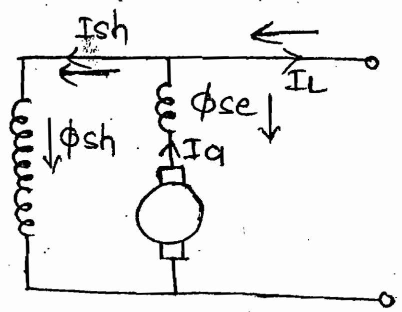
⊗ Series genʳ supplying power to a bus bar, when its prime move fails it will act as

(a.) Series motor running at same dirⁿ

(b) Series motor running at opposite dirⁿ



Ans → (b) (Both ϕ & I_a change)



So by reversing the supply or failure of prime mover there is a reverseal of Ia & cumulatively compound becomes diff compound because ~~of the same dirn in the~~ change in dirn.

21/5

$$\phi_1 \rightarrow \phi_1 \ , \ \phi_2 \rightarrow 1.1\phi_1$$

$$E_{b1} = V - (I_a R_a) \text{ (drop)}$$

$$E_{b2} = 0.95 E_{b1}$$

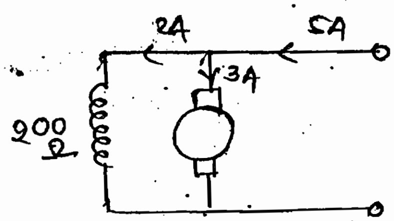
$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\frac{N_2}{1000} = \frac{0.95 \cancel{E_{b1}}}{\cancel{E_{b1}}} \times \frac{\cancel{\phi_1}}{1.1\cancel{\phi_1}}$$

$$N_2 = 863 \text{ rpm}$$

54/10

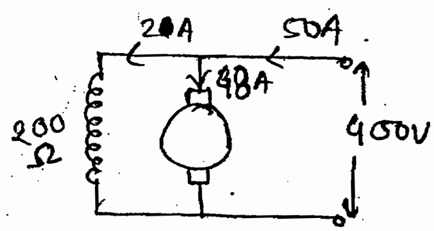
$$N \propto \frac{E_b}{\phi}$$



$$N \propto E_b \propto V - I_a R_a$$

$$E_b \text{ at NL} = 400 - 3\times(0.5+\cancel{200}) = 398.5V$$

$$E_b \text{ at FL} = 400 - 48(0.5)$$
$$= 376V$$



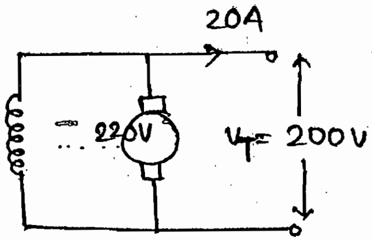
$$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}}$$

$$\cancel{\frac{398.5}{376}} \quad \frac{N_2}{N_1} = \frac{376}{398.5} = 0.94$$

68/13 const: $E_b \propto \phi N \uparrow$ $\quad \downarrow T \propto \phi I_a$

69/13

46/9



$\phi_2 = 1.1\phi_1$

$E_g = V + I_a R_a$

$= 200 + 20(0.2)$

$E_g = 204V$

$E_b = V - I_a R_a$

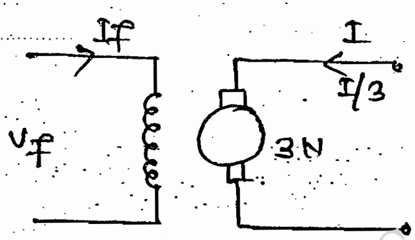
$= 200 - 20(0.2)$

$= 196V$

$$\frac{N_2}{N_1} = \frac{196}{204} \times \frac{\cancel{\phi_1}}{\cancel{\phi_1} 1.1}$$

$$\boxed{\frac{N_2}{N_1} = 0.87}$$

40/8



$P = 3 E_b \cdot I_a/3$

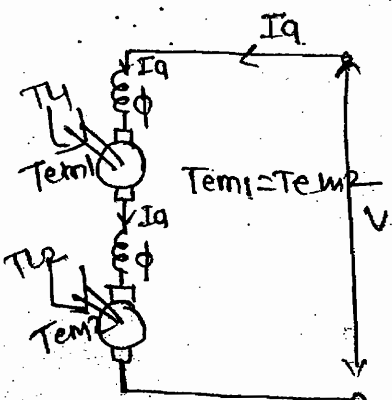
Constant power

$T \propto I_a \phi$

1/1

$N \propto \frac{E_b}{\phi}$ $\quad T \propto \phi I_a$ $\quad T\uparrow \; N\uparrow$

11/4



$P = \frac{2\pi N T}{60}$

$P \propto NT$

Because same T

$P \propto N$, $P_1 \propto N_1$, $P_2 \propto N_2$

$T_{L1} = T_{L2}$, $T_{em1} = T_{em2}$

$\boxed{1:1}$

Tem – Electromagnet torque

TL = load torque

If in ques given two diff motor then ans. $N_1 : N_2$

Losses, η, testing →

Losses →

(1.) Iron loss / core loss.
(2.) Cu loss / ohmic loss.
(3.) mechanical loss.

- The losses will reduce the o/p & η and also increase operating cost.
- Any loss will produce temp. rise in m/c which is proportional to time of operation & damages insulation & also vary the operatinge constrains of m/c.

① Iron / Core loss →

(1.) Eddy current.
(2.) Hystenisis.

Cycles per ~~rotation~~ = P/2

Rotation per seconds = N/60

$$C/R \times R/s = C/s = \frac{PN}{120}$$

$$\boxed{f = \frac{PN}{120}}$$

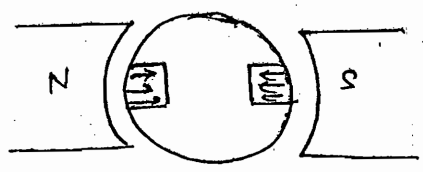
- As the core rotates the core will cut the flux, emf is induced a circulating currents known as eddy current will flow to produce eddy current loss.
- Acc. to steinmetz's eqn

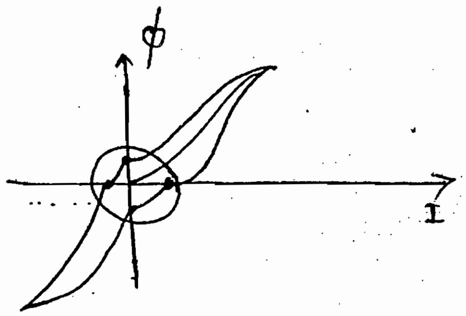
$$\boxed{W_e = K_e f^2 B_m^2 t^2 V}$$

B_m = flux density
t = thickness
V = volume

* It significantly depends on speed of rotation & flux density.

* Hysteresis loss →





* When the core rotates it is subjected to magnetic flux reversal.
* Due to retaintivity property it requires additional coercive current during the flux passing 0 condⁿ which produce Hysteris loss.
* It is also praportional to speed & flux density.

$$\boxed{W_h = K_h B_m^x f V}$$

* If the flux & speed is approx. constant with load then the iron losses are also approximated as constant losses.
* Due to arm. reaction flux density increases with load under the pole tip which increase iron loss. This is generaly neglected.

② Cu loss / ohmic (I^2R) →

* When a current flows in condʳ it produce a temp. rise due to its resistance. Known as cu loss.
* Various cu losses in dc m/c are :-
  (1.) Arm. cu loss ($I_a^2 R_a$)
  (2.) Shunt field cu loss. $I_{sh}^2 R_{sh}$ (or) $V.I_{sh}$
  (3.) Series field cu loss
  $I_a^2 R_{se}$ (series m/c (or) long sh.)
  $I_L^2 R_{se}$ (short sh.)
  (4) cpw cu loss, IPW cu loss, cu loss due to brush resistance.

The cu loss vary as the sq. of current & consequently with load but the shunt field cu loss is constant loss as it doesn't vary with load.

5) Mechanical loss →

(1) Friction loss → Due to brush, Bearings

(2) Windage loss → Air friction.

* The rotational losses in a dc m/c are iron & mech. losses

$$\boxed{\text{mech. loss} \propto \text{speed}}$$

Total losses = Constant loss + Variable loss

I, F (or) W — cu loss.

$I_{sh}^2 R_{sh}$

Condition for max^m η →

$$I/P = O/P + \text{loss}$$

$$\eta = \frac{O/P}{I/P} = \frac{O/P}{O/P + \text{loss}}$$

$$\eta = \frac{O/P}{O/P + \text{constant loss} + \text{variable loss}}$$

$$I/P = VI_L + \underbrace{I_a^2 R_a + W_c}_{\text{loss}}$$

$$\eta = \frac{VI_L}{V \cdot I_L + I_a^2 R_a + W_c} \quad (I_a \simeq I_L)$$

$$\eta = \frac{1}{1 + \frac{I_a^2 R_a}{VI_L} + \frac{W_c}{VI_L}}$$

$$\eta = \frac{1}{1 + \frac{I_a R_a}{V} + \frac{W_c}{V I_a}} \quad (I_L \simeq I_a)$$

$$\frac{d}{dI_a}\left[1 + \frac{I_a R_a}{V} + \frac{W_c}{V I_a}\right] = 0$$

$$\frac{R_a}{V} - \frac{W_c}{V I_a^2} = 0$$

$$\frac{R_a}{\cancel{V}} = \frac{W_c}{\cancel{V} I_a^2}$$

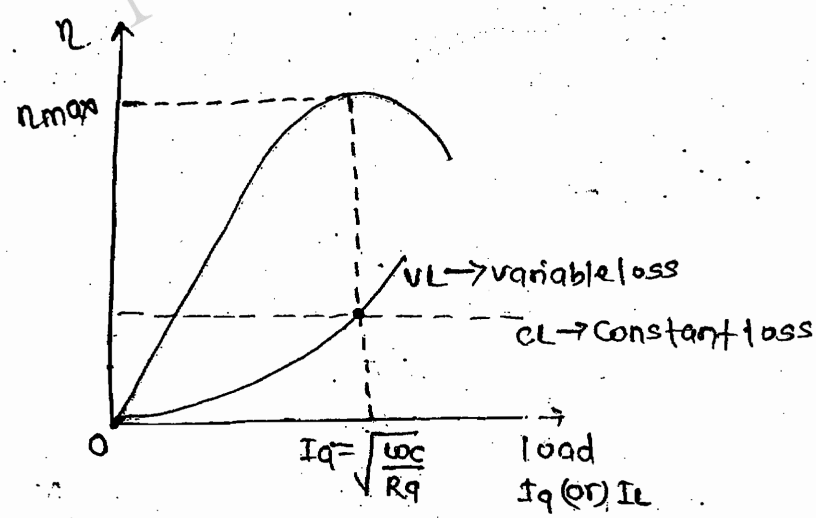
$$\boxed{\begin{array}{c} \therefore I_a^2 R_a = W_c \\ \text{variable loss} = \text{constant loss} \end{array}}$$

$$I_a^2 R_a = W_c$$

$$I_a^2 = \frac{W_c}{R_a}$$

$$\boxed{I_a = \sqrt{\frac{W_c}{R_a}}}$$

* The current or load corresponds to max^m η can be decided by the designer with proportional amount of iron & cu ~~used~~ in m/c design.



Testing → * It is done in order to ~~no~~ know the performance & the operating η of m/c.

It is done in 2 methods :-

(1.) Direct → The m/c is loaded directly, o/p I/p is measure & the η is calculated.

$$\boxed{\eta = \frac{o/p}{I/p}}$$

* This is accurate which includes all losses & also accounts temp. rise & sparking prob.
* But it can't be done to large rating m/c because of loading & metering constrains.

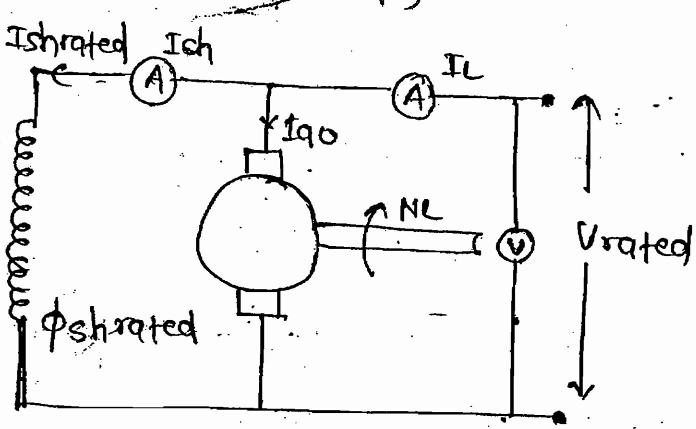
2.) Indirect → * The m/c is not loaded directly but the η is free determined by determining losses.

$$\boxed{\eta_g = \frac{o/p}{o/p + loss}} , \boxed{\eta_m = \frac{I/p - loss}{I/p}}$$

* Comparitively it is not accurate.
* It doesn't account temp. rise & practical arm. reaction, sparking problems.

1.) Swinburne's test →

(constant loss, NL test, sh & comp.)



* Run the sh. m/c on NL as a motor with rated vol. applied at rated speed.
* Note the NL current, field current & the arm. current.

* The NL i/p consist of all losses, inorder to determine const loss the arm. cu loss at NL need to be calculated & subtracted from NL i/p.

	V	I_L	I_{sh}	I_a	Constant loss	variable loss	Total loss	I/p	$\eta = \frac{I/p - loss}{I/p}$
FL	220	11	1	10	45	$10^2 \times 1 = 100$	145	220×11	$= \frac{220 \times 11 - 145}{220 \times 11}$
$\frac{1}{2}$L	220	6	1	5	45	$5^2 \times 1 = 25$	70	220×6	$= \frac{220 \times 6 - 70}{220 \times 6}$

$\boxed{\text{motor: } I_L = I_a + I_{sh}}$

	V	I_L	I_{sh}	I_a	Constant loss	variable loss	Total loss	o/p	$\eta = \frac{o/p}{o/p + loss}$
FL	220	9	1	10	45	$10^2 \times 1 = 100$	145	220×9	$\frac{220 \times 9}{220 \times 9 + 145}$

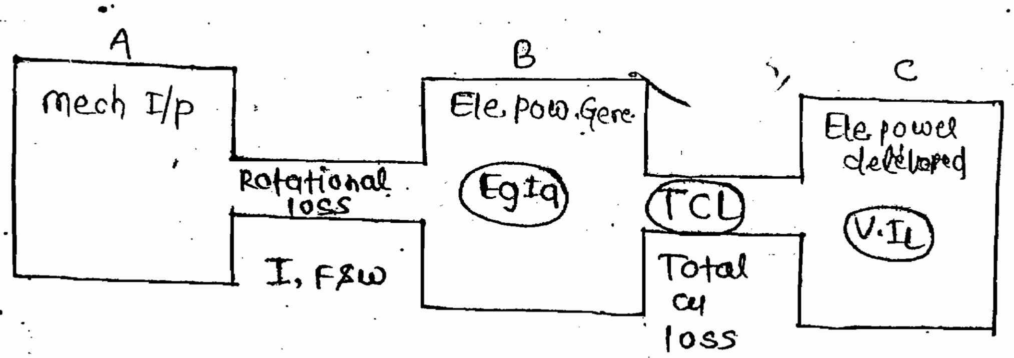
$\boxed{\text{Gen}^r\text{: } I_a = I_L + I_{sh}}$

~~* Power stages of Gen^r →~~

The iron losses are considered as strictly cons. but they practically vary with load due to arm. reaction.

The temp. rise & the sparking prob. are not accountable.

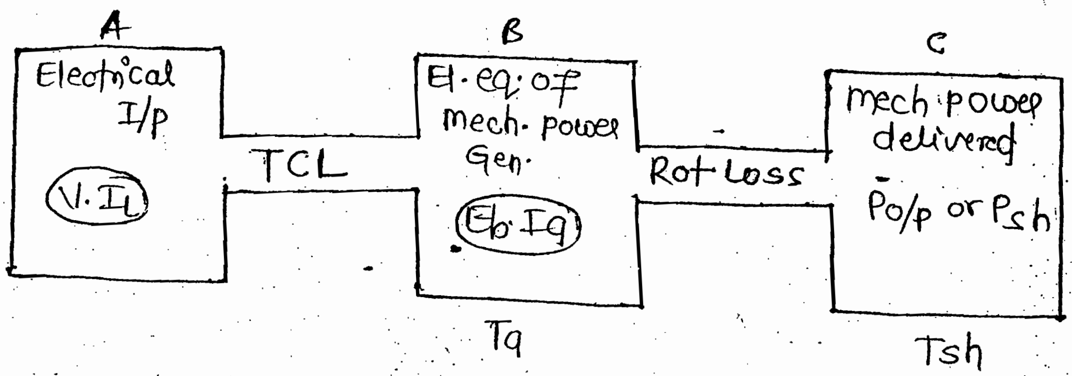
Power stages of gen^r →



$$\eta_{mech} = \frac{B}{A} = \frac{E_g I_a}{\text{Mech. } I_a} \quad ; \quad \eta_{ele.} = \frac{C}{B} = \frac{V I_L}{E_g I_a}$$

$$\eta = \eta_m \times \eta_E = \frac{B}{A} \times \frac{C}{B} = \frac{C}{A} = \frac{\text{Ele. power delivered } (VI_L)}{\text{mech. I/p supplied}}$$

Power stages of motor →



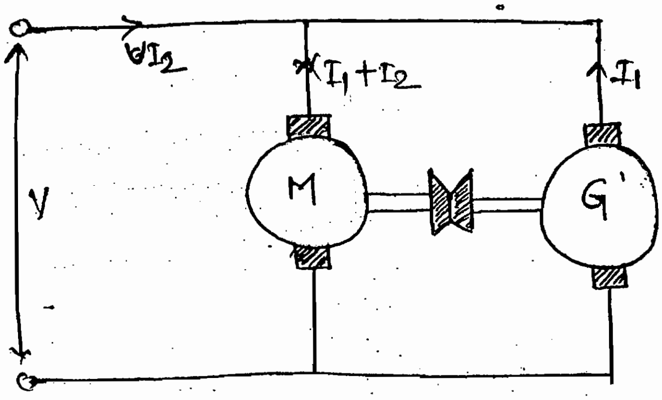
$$\eta_{ele} = \frac{B}{A} = \frac{E_b \cdot I_q}{\text{Ele. I/p } (V \cdot I_L)}$$

$$\eta_{mech} = \frac{C}{B} = \frac{\text{Mech o/p } (P_{sh})}{E_b \cdot I_q}$$

$$\eta = \eta_E \times \eta_m = \frac{B}{A} \times \frac{C}{B} = \frac{C}{A} = \frac{\text{mech. power delivered } (P_{sh})}{\text{Ele. I/p supplied } (VI_L)}$$

$$\boxed{\begin{array}{l} T = \dfrac{60}{2\pi N} \cdot P \qquad T_q = \dfrac{60}{2\pi N}(E_b \cdot I_q) \\[2ex] T_{sh} = \dfrac{60}{2\pi N}(E_b I_q - \text{Rotational loss}) \end{array}}$$

* HOPKINSEN'S TEST →
(OR)
BACK TO BACK



* It requires 2 identical shunt / compound m/c connected back to back & a
* An additional current is drawn & VI_2 represents the total losses in both motor & Genr.

Approximate η →

$$O/p \text{ of gen}^r = VI_1$$

$$I/p \text{ to motor} = V(I_1+I_2)$$

$$\eta_{gen} = \frac{O/p \text{ of } G}{I/p \text{ to } G} = \frac{O/p \text{ of gen}^r}{O/p \text{ of } m}$$

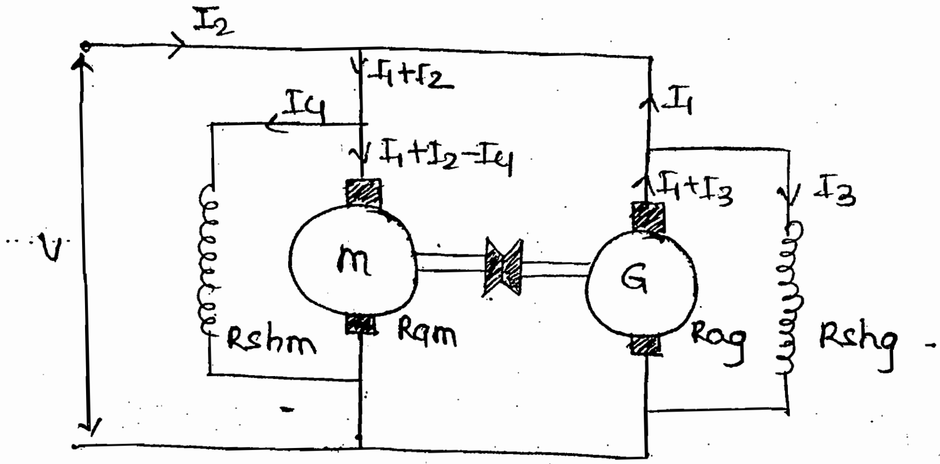
$$\eta_{mot} = \frac{O/p \text{ of motor}}{I/p \text{ of motor}} \Rightarrow O/p \text{ of motor} = \eta_{mot} \times I/p \text{ of } m$$

$$\text{So } \eta_{gen} = \frac{O/p \text{ of gen}^r}{\eta_m * I/p \text{ of } m}$$

$$\eta_g \times \eta_m = \frac{VI_1}{V(I_1+I_2)}$$

$$\eta = \sqrt{\frac{I_1}{I_1+I_2}} \qquad (\eta_g = \eta_m = \eta)$$

Accurate →



* In the above approximation there is inaccuracy as the cu losses are not same in both m/c
* Eliminating all the cu loss from VI_2 gives iron & mech. loss of both m/c which is same approx.

$$\text{Rotational loss } (P_R) = VI_2 - \left[(I_1+I_3)^2 R_{ag} + I_3^2 R_{shg} + (I_1+I_2-I_4)^2 R_{am} + I_4^2 R_{shm}\right]$$

$$\text{Rotational loss of each m/c} = P_R/2$$

$$\eta_g = \frac{o/p}{o/p + \text{loss}}$$

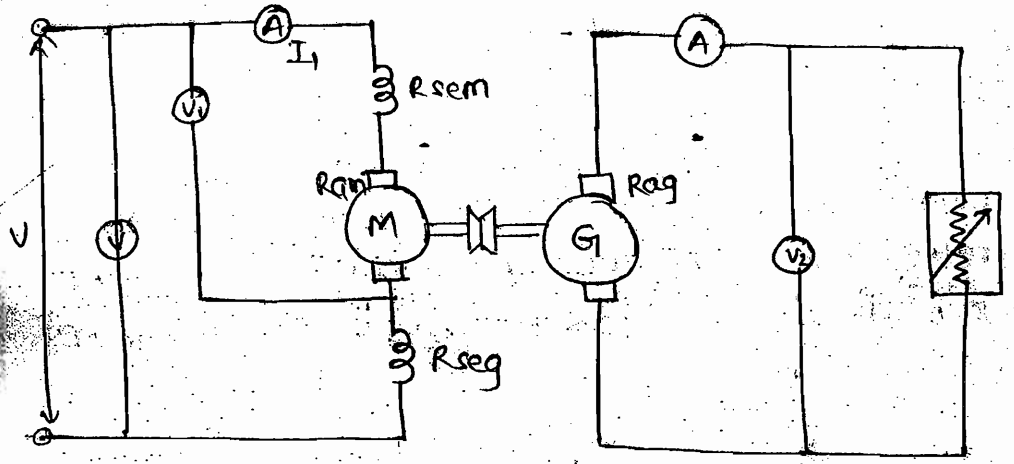
$$\boxed{\eta_g = \frac{VI_1}{VI_1 + \left[P_R/2 + (I_1+I_3)^2 R_{ag} + I_3^2 R_{shg}\right]}}$$

$$\eta_m = \frac{I/p - \text{loss}}{I/p}$$

$$\boxed{\eta_m = \frac{V(I_1+I_2) - \left[P_R/2 + (I_1+I_2-I_4)^2 R_{am} + I_4^2 R_{shm}\right]}{V(I_1+I_2)}}$$

Field's test ⇒

* This test is for series m/c.
* It is not back to back test.
* The genʳ o/p is dessipated in the load resistance.
* It requires two identical series m/c which ~~are~~ easily available.
* Both the Field wdg are connected in series essentialy.



I/p M-G set $= VI_1$

O/p M-G set $= V_2 I_2$

$I/p - O/p =$ Losses in both m/c $= VI_1 - V_2 I_2 = P_T$

$$P_T - \left[I_1^2(R_{sem} + R_{am} + R_{seg}) + I_2^2 R_{ag}\right] = P_R$$

Rotational loss in each m/c $= P_R/2$

$$\eta_M = \frac{I/p - loss}{I/p} = \frac{V_1 I_1 - \left[P_R/2 + I_1^2(R_{sem} + R_{am})\right]}{V_1 I_1}$$

$$\eta_g = \frac{o/p}{o/p + loss} = \frac{V_2 I_2}{V_2 I_2 + \left[\frac{P_R}{2} + I_1^2 R_{seg} + I_2^2 R_{ag}\right]}$$

* In this test the genʳ is acting as separately excited

DATE- 11/07/19

* Retardation Test / Running down test →

* The motor is run slightly above its rated speed.
* When it is isolated from supply it will run down against over coming rotational loss.
* The KE is lost while over-coming the rotational loss. Therefore rate of change of KE. is considered as rotational losses.
* This test is to determine rotational loss as well as to seprate iron loss & mech. loss by conducting in 2 methods:-

Method 1 → * Isolate the arm. from the supply leaving the field connected.

* As there is rated flux as the arm. run down it is overcoming iron, friction & windage losses. Therefore the rate of change of KE is the total iron & mech. loss.

Method 2 → * Run the motor slightly above rated speed. & disconnect arm. as well as field.

* As there is no flux the motor run down only against mech. losses. Therefore rate of change of KE is only mech. loss
* The diff. of losses from 2 methods is iron loss.
* By calculating cu losses η can be determine at any load.

$$KE = \frac{1}{2} J\omega^2$$

J = Moment of inertia

ω = Angular velocity $\left(\frac{2\pi N}{60}\right)$

$$\frac{d}{dt}(KE) = \text{Rotational loss} = \frac{d}{dt}\left(\frac{1}{2}J\omega^2\right)$$

$$= J\omega \cdot \frac{d\omega}{dt}$$

$$= J \times \left(\frac{2\pi N}{60}\right) \frac{d}{dt}\left(\frac{2\pi N}{60}\right)$$

$$\boxed{\text{Rot. loss} = \left(\frac{2\pi}{60}\right)^2 J N \frac{dN}{dt} \text{ watts}}$$

Eg → Retardation test is done on a shunt motor which rated speed is 1000 rpm. During the test the change of speed is from 1030 to 970 rpm in 15 sec. The MI of motor 75 kg m². Calculate the rotational loss.

Sol^n →

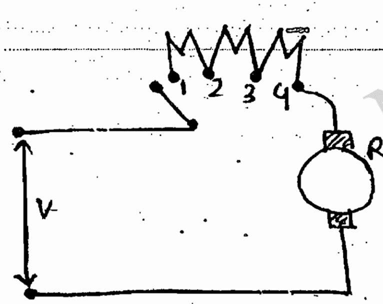
$$\text{Rot. loss} = \left(\frac{2\pi}{60}\right)^2 \times 75 \times 1000 \times \left(\frac{60}{15}\right)$$

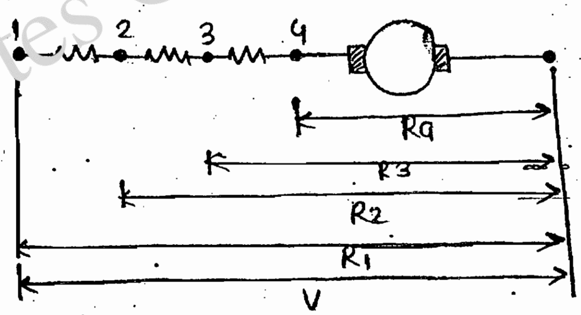
$$\text{Rot. loss} = 3289.868\,W \qquad \text{Ans.}$$

* GRADING →

Starter resistance grading → * In order to design starter resistance the starting torque requirement should be essentialy considered.

* Generaly as the starting torque is more than rated torque 1.5 times rated current will be the general limit of starting current
* Depanding on this value starting resistance is calculated.



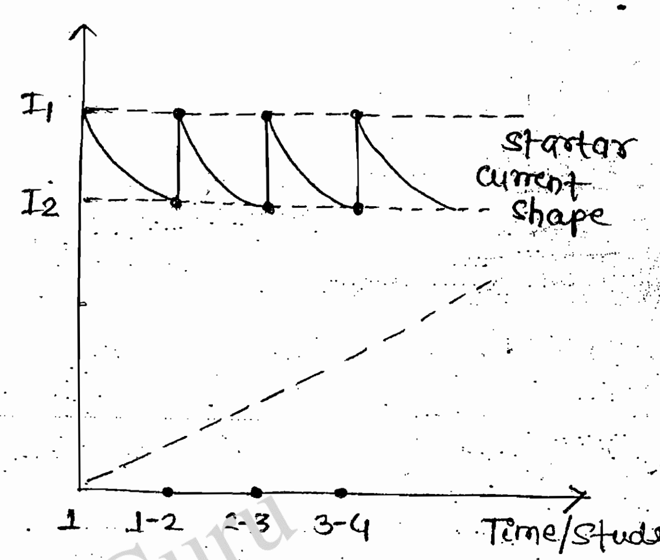


$\left.\begin{array}{l}1-2\\2-3\\3-4\end{array}\right\}$ movement of starter Handle.... Resistance cut down

- The starting current will vary between a max^m & min^m value before reaching its normal value as the motor reaches normal speed.
- The value of starting resistance also depends on the acceleration time requirement depending on the motor appl^n.

At stud ① $I_1 = \frac{V}{R_1}$

After some instant $I_2 = \frac{V - E_{b1}}{R_1}$



①—② $\quad I_1 = \frac{V - E_{b1}}{R_2}$

$$\frac{I_1}{I_2} = \frac{V - E_{b1}}{R_2} \times \frac{R_1}{V - E_{b1}} = \frac{R_1}{R_2}$$

At ② after some instant

$$I_2 = \frac{V - E_{b2}}{R_2}$$

②—③ $\quad I_1 = \frac{V - E_{b2}}{R_3}$

$$\frac{I_1}{I_2} = \frac{V - E_{b2}}{R_3} \times \frac{R_2}{V - E_{b2}} = \frac{R_2}{R_3}$$

At ③ After some instant

$$I_2 = \frac{V - E_{b3}}{R_3}$$

③—④ $\quad I_1 = \frac{V - E_{b3}}{R_a}$

$$\frac{I_1}{I_2} = \frac{R_1}{R_2} = \frac{R_2}{R_3} = \frac{R_3}{R_a} = K$$

$R_3 = KR_a$

$R_2 = KR_3 = K^2 R_a$

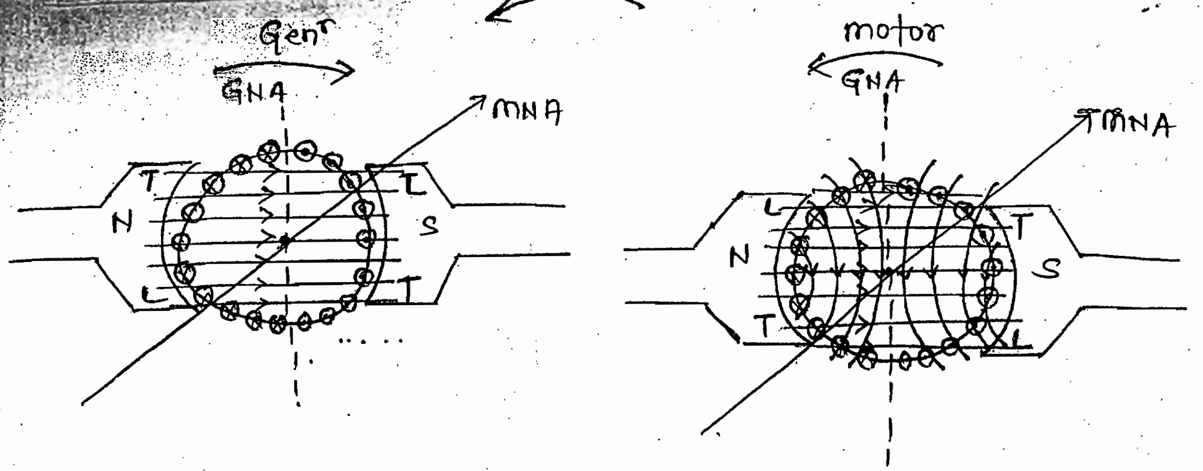
$R_1 = KR_2 = K^3 R_a$

$$\boxed{\frac{R_1}{R_a} = K^3}$$

If the starter contains N studs there will be N-1 sections.

$$\boxed{\frac{R_1}{R_a} = K^{n-1}}$$

Armature Reaction in dc motors →



* The arm. reaction in dc motors is similars to ~~that of~~ genr. but depanding on dirn of rotation terminalogy will change:-

(1.) The trailing pole tips of genr becomes leading pole tips in motor (vice-versa).

(2.) The flux density will increase under the leading pole tips.

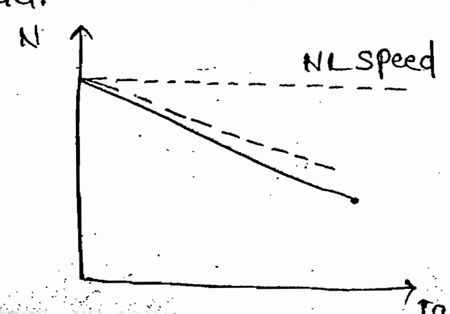
(3.) Shifting of MNA is in the opposite dirn to that of motor rotation.

(4) In order to improve commutation the brushes need to be shifted opposite to the dirn of rotation of motor. This leads to additional Dm. Concequently flux decrease, speed increase & torque decrease.

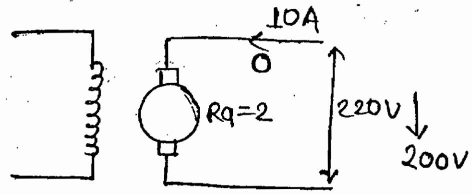
(5) The polarity of interpole is equal to polarity of mainpole behind motor rotation.

Note:- similar to genr there is a slight Dm due to magnetic saturation of poles which will increase the speed & reduce torque capability of motor.

Note:- Therefore in shunt motor with arm. reaction the speed may increase with load.



9/1



$E_b = V - I_a R_a$

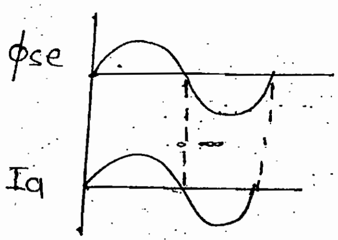
$= \cancel{200} - 10 \times 2$

$= 200V$

Because the source reduce to 200 vol. & the $E_b = 200V$ then there is no change. Hence current goes to 0 1st.

And then N↓ E_b↓ then it set to 10 A

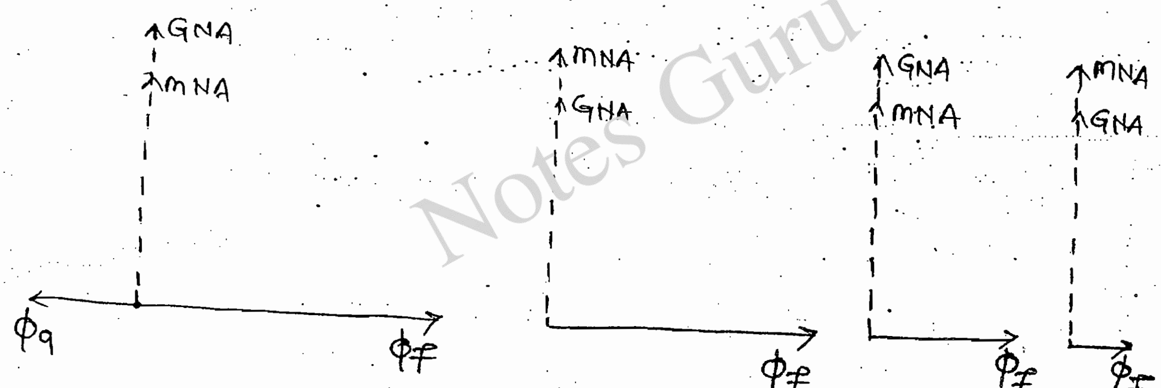
9/4



$T \propto (-\phi)(-I_a)$

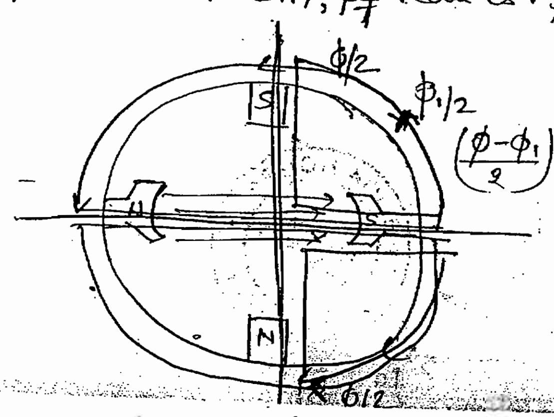
* Because the torque is +ve then it can use in both.
* But shunt motor can't operate on ac because they have huge wdg.

19/5



If there is a shifting of 90°E of brush then there is only DM. & the due to DM, ϕ_f reduces. & GNA is at MNA.

20/5



51/10

Sh.

$T \propto I_a$

$\frac{T_2}{T_1} \propto \frac{I_{a2}}{I_{a1}}$

$\frac{T_2}{T_1} = \frac{12}{10}$

$T_2 = 1.2 T_1$

20%

Series

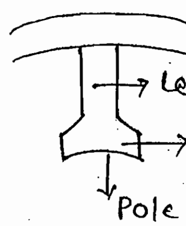
$T \propto I_a^2$

$\frac{T_2}{T_1} = \left(\frac{12}{10}\right)^2$

$T_2 = 1.44 T_1$

44%

52/10



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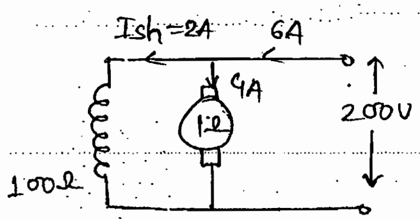


$Cu\ loss = I_{sh}^2 R_{sh} + I_a^2 R_a$

$= 4^2 \cdot 1 + 2^2 \times 100$

$= 416\ W$

74/13

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

$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$

$E_{b1} = V - I_a R_a = 220 - 10(1) = 210V$

$\phi_2 = 0.9 \phi_1$

$E_{b2} = 189$

$T \propto \phi I_a$

$\frac{T_2}{T_1} = \frac{\phi_2}{\phi_1} \cdot \frac{I_{a2}}{I_{a1}}$

torque same

$\phi_2 = 0.9 \phi_1$

$I_{a1} = 10A$

$I_{a2} = 11.11A$

$E_b = V - I_a R_a$

$189 = 220 - 11.11(1 + R_{ext})$ $\qquad R_{ext} = 1.79\Omega$

Q→ A 24 slot 2P dc genʳ has 18 turns/coil with double layer wdg. Flux density/P 1 Tesla, length of arm. 20cm, radius 10cm. Poles are designed to cover 80% of pole pitch. If the arm. angular velocity is 183.2 rad/s. Determine induced emf.

Solⁿ→ 2P, 24 slots, double layer, 18 T/coil, $B = 1$ Tesla/P

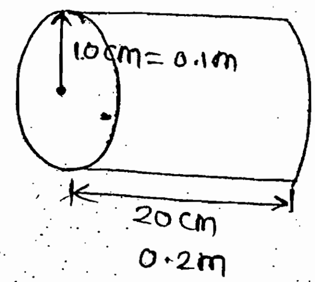
$l = 20$ cm, $r = 10$ cm, 80%, $\omega = 183.2$ rad/s.

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

Calⁿ of ϕ →

Total area $= 2\pi r l$

$= 0.1256\ m^2$



Total area / P $= \frac{2\pi r l}{P}$

$= 0.0628$

Effective area under a pole $= 0.8 \times \frac{2\pi r l}{P}$

$= 0.05\ m^2$

$\phi = B \cdot A = 1 \times 0.05 = 0.05$ wb

Calⁿ of Z →

No. of coil = 24 (double layer).

Total no. of turns $= 18 \times 24 = 432$ turns.

No. of condʳ $= 432 \times 2 = 864$

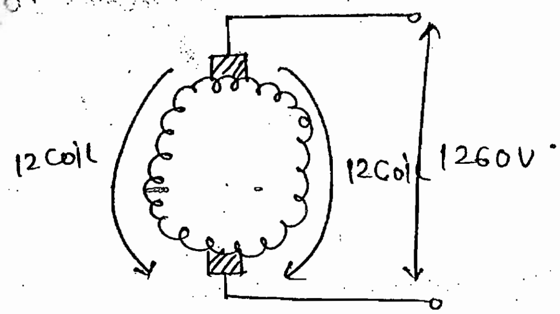
Calⁿ of N →

$$N = \frac{60}{2\pi} \times 183.2 = 1750\ \text{rpm}$$

$$E_g = \frac{\phi Z N P}{60A} = \frac{0.05 \times 864 \times 1750 \times 2}{60 \times 2}$$

$$\boxed{E_g = 1260\ V}$$

- Induced emf per parallel paths

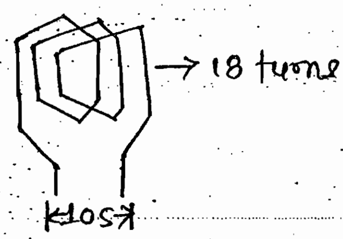


Total 24 Coil

12 coils in each path are producing 1260V as the coils are in series.

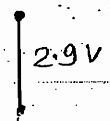
$$\text{voltage per coil} = \frac{1260}{12} = 105V$$

Because of 18 turn coil



$$\text{Voltage / turn} = 105/18 = 5.83V$$

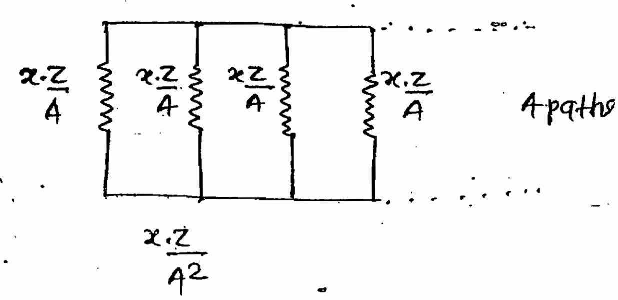
$$\text{Voltage / cond}^r = 5.83/2 = 2.9V$$



Q.→ A 4P Lap wound dc sh. gen^r arm. wdg. consist of 220 turns. Each of resistance 0.004. What is the arm. resistance.

Sol^n→

$$R_a = x \cdot \frac{Z}{A^2}$$



220 turns = 440 cond^r

$$\frac{0.004\Omega}{\text{turns}} = 0.002\,\Omega\ \text{cond}^r$$

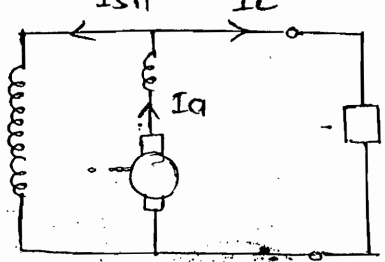
$$R_a = 0.002 \times \frac{440}{4^2}$$

$$\boxed{R_a = 0.055\Omega}$$

Que→ A Compound genʳ is to supply 250 lamps each rated 100W at 250 Volt. Arm. resistance 0.06, series resistance 0.04Ω, $R_{sh}=50\Omega$ determine the generated emf when m/c is connected as long & short shunt (BCD = 1V/brush).

Solⁿ→

1



$$I_L = \frac{25000}{250} = 100A \qquad I_{sh} = \frac{250}{50} = 5A$$

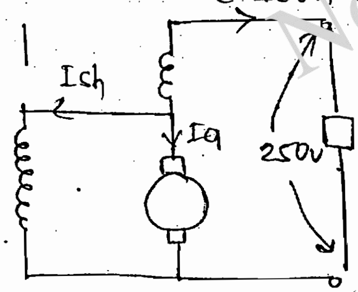
$$I_a = I_L + I_{sh} = 100+5$$

$$I_a = 105A$$

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

$$= 250 + 105(0.06+0.04)+2$$

$$E_g = 262.5V$$



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

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

$$= \frac{250+100(0.04)}{50}$$

$$= 5.08A$$

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

$$= 100+5.08$$

$$I_a = 105.08A$$

8871453536

$E_g = V + I_a R_a + I_L R_{se} + BCD$

$= 250 + 105.08(0.06) + 100(0.04) + 2\times10$

$E_g = 262.3V$

Q.→ In a long shunt compound genʳ the terminal vol. is 230 when the genʳ delivers 150A. Determine the power generated & distribution of this power.

Soln: Given → $V = 230V$ $\quad R_{se} = 0.015\Omega$

$I_L = 150A$ $\quad R_a = 0.032\Omega$

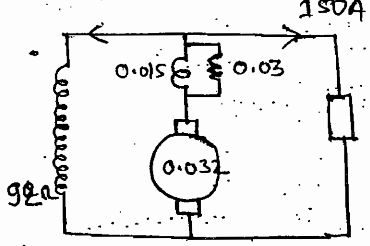
$R_{sh} = 92\Omega$ $\quad R_d = 0.03\Omega$

& a diverter of resistance 0.03 is connected.

Soln→

$P_g = E_g I_a \; , \; P_d = V.I_L$

$230/92 = 2.5A$



$R_d \| R_{se} = \dfrac{0.015\times0.03}{0.015+0.03}$

$= 0.01\Omega$

$E_g = V + I_a R_a + I_a(0.01)$

$= 230 + 152.5(0.032) + 152.5(0.01)$

$= 236.405V$

Power generated in arm $P_g = E_g I_a$

$= 236.405 \times 152.5$

$= 36051.762W$

Total cu loss→

① $I_a^2 R_a = (152.5)^2(0.032) = 144.2W$ $\quad$ * $V.I_L = 230\times150 = 34500W$

② $I_{sh}^2 R_{sh} = (2.5)^2(92) = 575W$

③ $I_a^2(R_d \| R_{se}) = (152.5)^2(0.01) = 232.56W$

$P_g - TCL = P_{delivered} = 36051.762 - 1551.76$

$= *34500.002\ W$

Que. → A 220V dc sh. motor takes a current of 80A runs at 800 rpm

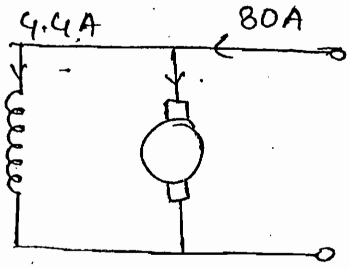
$I_L = 80A$, $N = 800$ rpm, $R_{sh} = 50\Omega$, $R_a = 0.1\Omega$

Rot loss = 1600W

① Cu loss ② T_a ③ T_{sh} ④ η

Soln →

① $\cancel{I_a = I_{sh}}$ $I_{sh} = \frac{V}{R_{sh}}$



$I_a + I_{sh} = I_L$

$I_a = I_L - I_{sh}$

$= 80 - 4.4$

$I_a = 75.6A$

* Cu loss $= I_a^2 R_a + I_{sh}^2 R_{sh}$

$= 1539.536 W$

② $T_a = \frac{60}{2\pi N} E_b I_a$

$= \frac{60}{2\pi \times 800} E_b I_a$

$E_b = V - I_a R_a = 220 - 75.6 \times 0.1 = 212.44V$

$T_a = \frac{60}{2\pi \times 800} \times 212.44 \times 75.6$

$T_a = 191.707$ N-m

* $V I_L - E_b I_a = 220 \times 80 - 16060.464$

$= 1539.536 W$

(3)
$$T_{sh} = \frac{60}{2\pi N}(E_b I_a - \text{Rot. loss})$$

$$= \frac{60}{2\pi \times 800}(212.4 \times 75.6 - 1600)$$

$$= 172.6 \text{ N-m}$$

(4)
$$\eta = \frac{o/p}{I/p} = \frac{P_{sh}}{V I_L} = \frac{(212.4 \times 75.6 - 1600)}{220 \times 80}$$

$$\eta = 82.14\%$$

Q.→ An 8P dc gen^r has 480 arm. cond^r with wave wdg. Arm. current 200A. Find arm. reaction DM & CM amp-turns/P. If ① The brushes are on GNA.
② Brushesh are shifted by 6°E from GNA.
③ Brushes are shifted by 6° mech. by GNA.

Sol^n→

$$\text{Arm. amp-turns/p.} = \frac{I_a}{A} \cdot \frac{Z}{2P} = \frac{200}{2} \times \frac{480}{2\times 8}$$

$$= 3000 \text{ AT/p}$$

① For $\theta = 0$ (Brush are are GNA)

$$AT_d/p = \frac{2\theta}{180} \times \frac{I_a}{A} \times \frac{Z}{2P} = 0$$

$$AT_c/p = \frac{180 - 2\theta}{180} \times 3000 = 3000 \text{ AT/p}$$

② $\theta = 6°$

$$AT_d/p = \frac{6 \times 2}{180} \times 3000 = 200 \text{ AT/p}$$

$$AT_c/p = \frac{180 - 6 \times 2}{180} \times 3000 = 2800 \text{ AT/p}$$

③ $\theta_e = \frac{P}{2}\theta_m$

$= \frac{8}{2} \times 6 = 24^\circ E$

$AT_d/p = \frac{2 \times 24}{180} \times 3000 = 800\ AT/p$

$AT_c/p = \frac{180 - 2 \times (24)}{180} \times 3000 = 2200\ AT/p$

Q.→ In 8P lap wound dc m/c has 720 arm. condr. Pole covers 70% of pole pitch. Cal. the no. of condr of CW under each pole.

Soln→

$Z_c = \frac{Z}{AP} \times \left(\frac{\text{Pole arc}}{\text{Pole pitch}}\right)$

$= \frac{720}{8 \times 8}(0.7)$

$Z_c = 8$

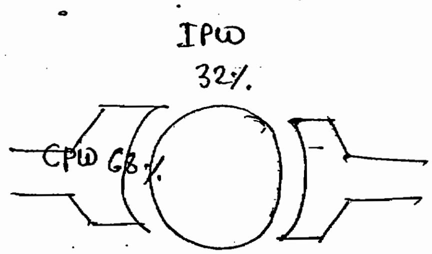
Q.→ A dc m/c has arm. amp-turns/p (AT/p) 15000, ratio of pole arc/pole pitch 0.68, interpolar airgap length 1cm. & additional flux density required 0.25 T/p. Rated arm current 850. Cal. CW turns/p & IPW turns/p.

Soln→ CW $AT/p = 0.68(15000)$

$= 10200$

IPW $AT/p = 0.32(15000)$

$= 4800$



$$flux = \frac{mmf}{Reluctance}$$

To calculate turns $\frac{AT}{A} = T$

$$CW\ AT/p = AT/p/I_a = \frac{0.68(15000)}{850} = 12 \text{ turns}$$

$$IPW\ AT/p = \frac{4800}{850} = 6 \text{ turns}$$

$$\phi = \frac{AT}{l/\mu_0 \mu_r a}$$

$\mu_r = 1,\ \mu_0 = 4\pi \times 10^{-7}$

$$AT = \frac{\phi l}{\mu_0 a}$$

$$\boxed{\frac{Bl}{\mu_0} = AT}$$

Additional turns req: $AT = \frac{0.25 \times 0.01}{4\pi \times 10^{-7}} = 1989\ AT/p$

$IPW\ AT/p = 4800 + 1989$

$= 6789$

$$IPW\ AT/p/T = \frac{6789}{850} = 8 \text{ turns.}$$

$\frac{98}{9}$ As brush shift angle $\alpha \uparrow$ interaction angle b/w the field decrease. Consequently torque decrease

$\alpha \uparrow\ T \downarrow$

ans. $\rightarrow \cos\alpha$

14/4) when the brushes are shifted 90° interaction angle b/w field is 0. Concequently torque is 0.

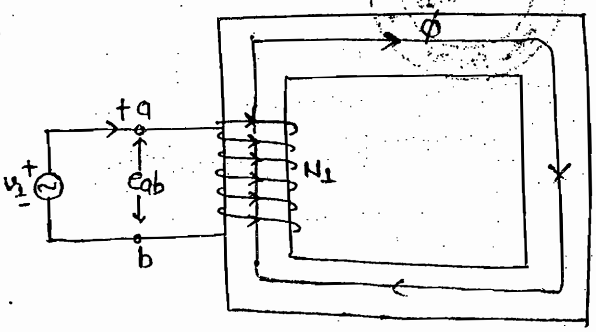
ans- (d)

DATE 03/11/14

Transformers

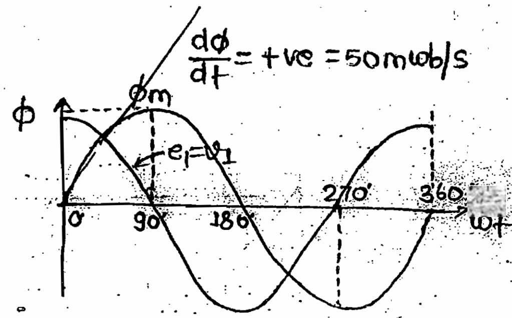
Sagar sen
887145356

* TF is not an ele. m/c



* Core provides → low reluctance path
→ mech. support

$$\boxed{\phi = \phi_m \sin \omega t}$$
(time expⁿ)

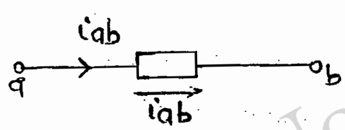


(timing dia)

Flux linkage $(\lambda) = NI$

* whenever there is a flux linkage there is a flux.

V_{ab} – vol. of a wrt b



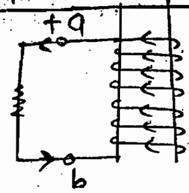
$$e_{ab} = \pm \frac{d\lambda}{dt}$$

* **Lenz law** → According to this law the dirⁿ of induced emf is such that it is allowed to cause a current (by short circuiting the coil). then the current so produced would have an effect that opposes the cause.

$$\text{Thus } e = \pm \frac{d\lambda}{dt}$$

where the sign depends on Lenz law & which terminal is taken as +ve.

Testing of ~~flux~~ in lenz law→

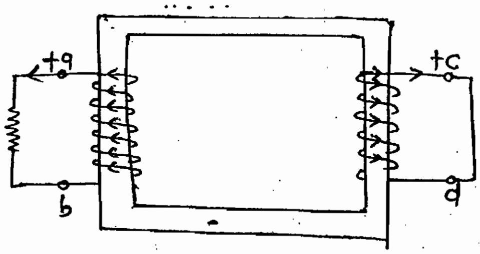


$$e_{ab} = +\frac{d\lambda_1}{dt}$$

$$= +N_1\frac{d\phi}{dt}$$

$$= 100 \times (50\times10^{-3}) \text{ volts}$$

$$= 5 \text{ volts}$$

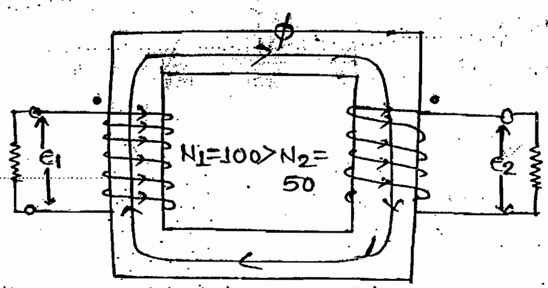


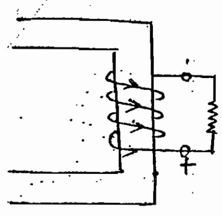
$$e_{cd} = \pm\frac{d\lambda_2}{dt}$$

$$= +\frac{d\lambda_2}{dt}$$

$$= +50\times(50\times10^{-3})$$

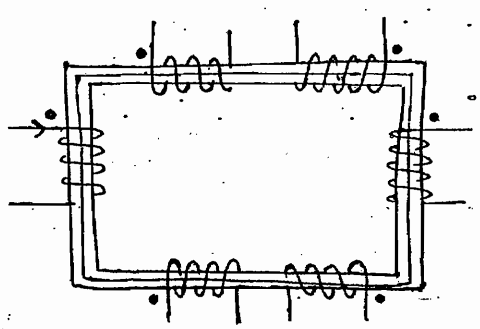
$$= +2.5 \text{ volts}$$





Dot conve→ If the currents enter (or) leave through the dots simultaneously then the fluxes are additive.

*Only the 1st dot is assigned. The remaining dots follow automatically depending upon the sense of winding.



* As applied to Xmer therefore if the currents enter through the dot in the 1° wdg, then it should leave through the dot from 2° wdg in order to satisfy the lenz law.

In other words the dots have the same instantaneous polarity.

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

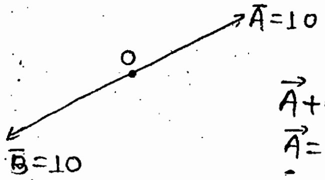
$$e_1 = N_1 \frac{d\phi}{dt}$$

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

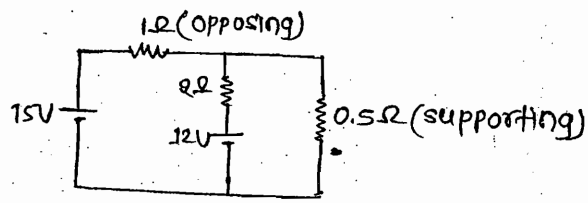
$$= N_1 \phi_m \omega \cos\omega t$$

$$\Downarrow$$

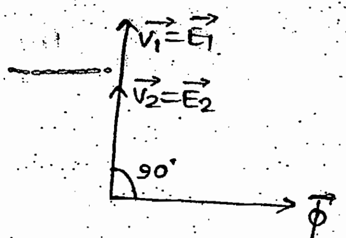
$$\sin(\omega t + 90^\circ)$$



$$\vec{A} + \vec{B} = 0$$
$$\vec{A} = -\vec{B}$$



*** Phasor diagram →** This diagram must come with circuit diagram.



$$\text{Rms } E_1 = \frac{N_1 \phi_m \omega}{\sqrt{2}} = \frac{N_1 \phi_m (2\pi f)}{\sqrt{2}}$$

$$\boxed{E_1 = \sqrt{2}\pi f \phi_m N_1}$$

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

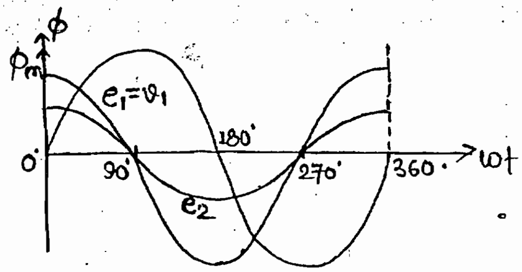
$$= N_2 \frac{d}{dt}(\phi_m \sin\omega t)$$

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

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

$$E_2 = \frac{N_2 \phi_m \omega}{\sqrt{2}} = \frac{N_2 \phi_m (2\pi f)}{\sqrt{2}}$$

$$\boxed{E_2 = \sqrt{2}\pi f \phi_m N_2}$$



$*$ Ideal transformer → (No losses, $\mu = \infty$)

↓

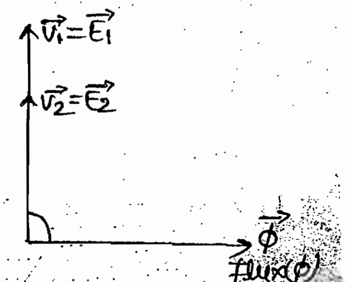
$*$(Flux will establish without any exciting current)

$$\phi = \frac{mmf}{Reluctance}$$

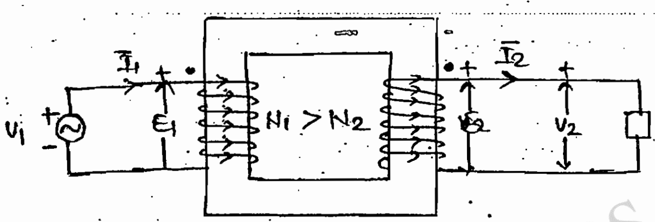
$$\phi = \frac{NI_0}{l/\mu A}$$

$$\phi \times \frac{l}{\mu A} = NI_0$$

$$I_0 = \phi \times \frac{l}{\mu A} \times \frac{1}{N} \quad *(\mu = \infty,\ I_0 = 0)$$



Phasor dia. of ideal Xmer on NL



mmf Balance on load of ideal transformer

$$N_1\vec{I_1} - N_2\vec{I_2} = 0$$

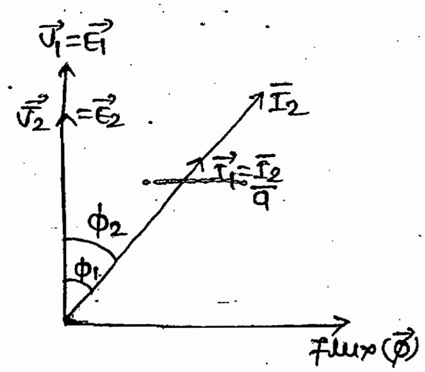
$$N_1\vec{I_1} = N_2\vec{I_2}$$

$$\vec{I_1} = \frac{N_2}{N_1}\vec{I_2}$$

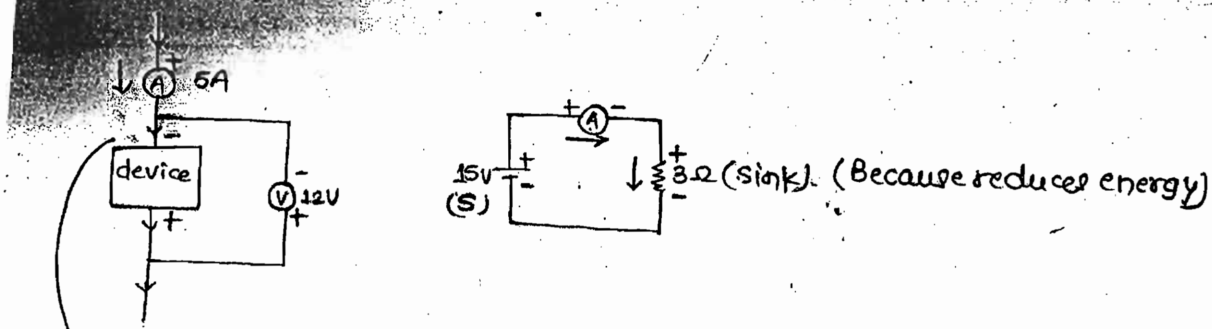
$$\boxed{I_1 = \frac{I_2}{a}} \qquad \boxed{I_1 = I_2'}$$

$$\boxed{\frac{V_1}{V_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = a} \rightarrow \text{Turn Ratio}$$

$I_2' =$ 2° current refered to 1°



Phasor dia. of an ideal TF on lagging PF load.



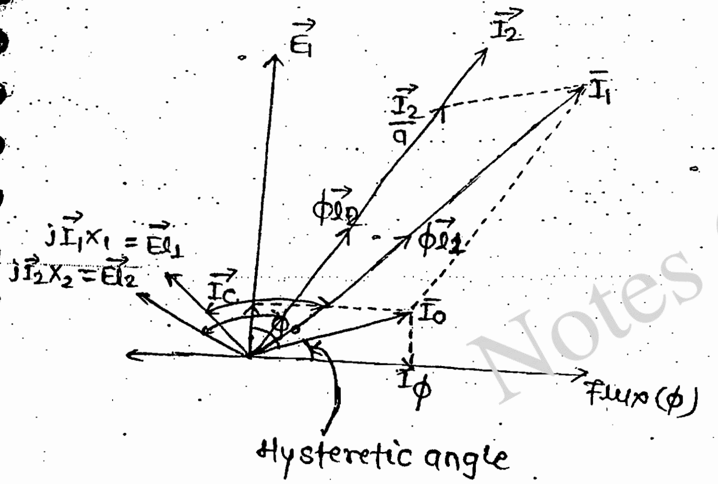
Current enter at lower potential & exit from higher potential. Then the device is <u>source.</u>

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

$$V_1 I_1^* = V_2 I_2^*$$

$$\& \quad E_1 I_1^* = E_2 I_2^*$$

* <u>Hysteretic ~~current~~ angle</u> → It is the angle b/n sinsusoidal flux & sinusoidal current.



I_c = Core loss component of exciting current (I_0)

I_ϕ = Magnetising current of exciting current

$$\boxed{\begin{array}{l} I_c = I_0 \cos\phi_0 \\ I_\phi = I_0 \sin\phi_0 \end{array}}$$

$(\phi_0 = 80^\circ)$

E_{l1} = 1° leakage flux voltage

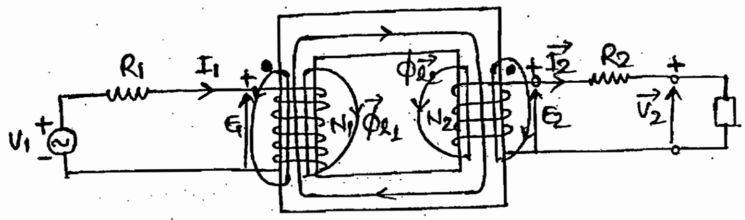
E_{l2} = 2° leakage flux voltage

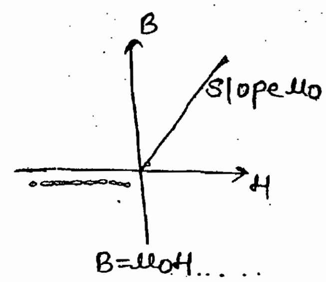
$x_2 = \frac{E_{l2}}{I_2}$, $x_1 = \frac{E_{l1}}{I_1}$

<u>MMF balance of practical TF →</u>

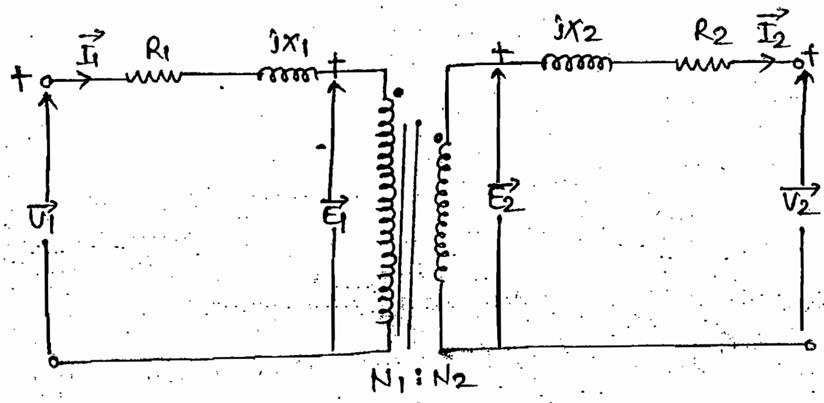
$$N_1 \vec{I_1} - N_2 \vec{I_2} = N_1 \vec{I_0}$$

$$\vec{I_1} = \frac{\vec{I_2}}{a} + \vec{I_0}$$





ϕ_ℓ = leakage flux.

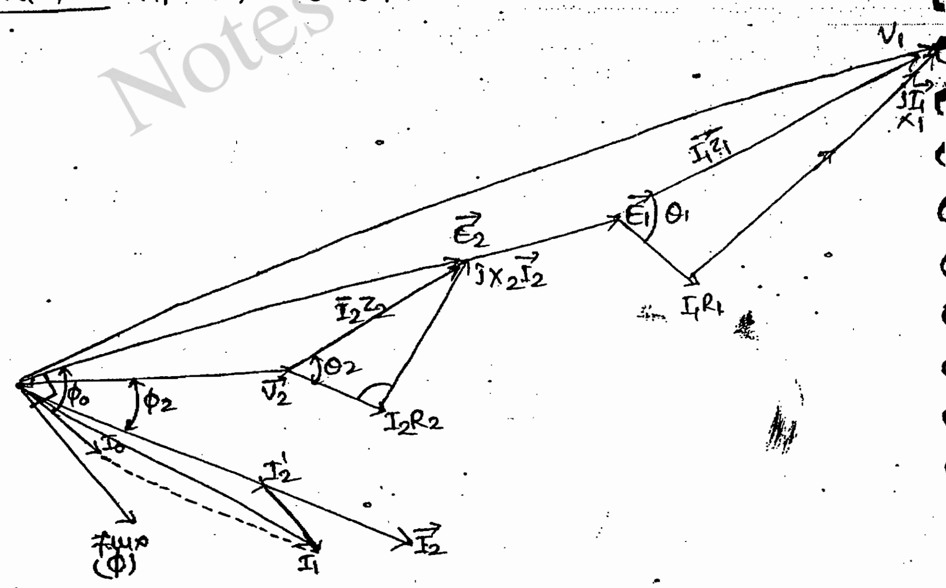


Representation of a practical 2wdg TF

$\vec{E_2} = \vec{V_2} + \vec{I_2}R_2 + j\vec{I_2}X_2$ $\qquad$ $\vec{I_1} = \dfrac{\vec{I_2}}{a} + \vec{I_0}$ $\qquad$ $\vec{V_1} = \vec{E_1} + \vec{I_1}R_1 + j\vec{I_1}X_1$

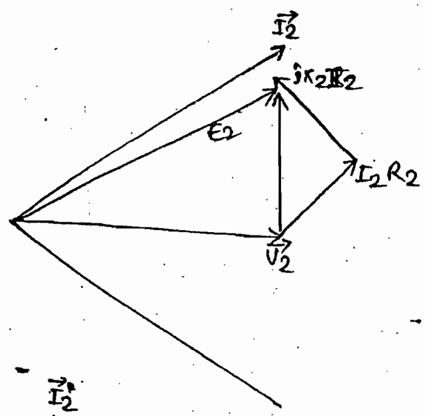
$\vec{E_1} = a\vec{E_2}$ $\qquad$ $= \vec{I_2'} + \vec{I_0}$

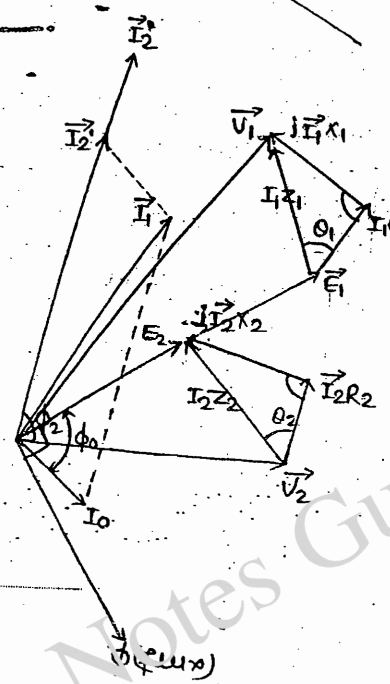
Complete phaser diagram → $N_1 > N_2$, lagging pf operation.



Tight coupling by iron core.

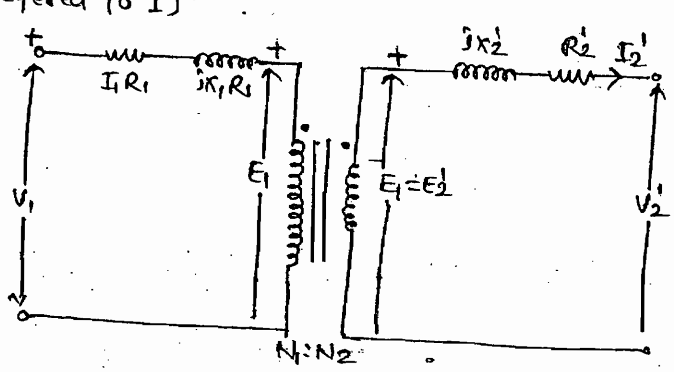
$N_1 > N_2$, Lagging PF operation →





Equivalent circuit → Representation of any device with the help of passive & active ~~elements~~ devices that can be used to analysis & predict the performance of device is called its equivalent circuit.

$\boxed{\text{DATE-04/11/14}}$ (Refered to 1°)



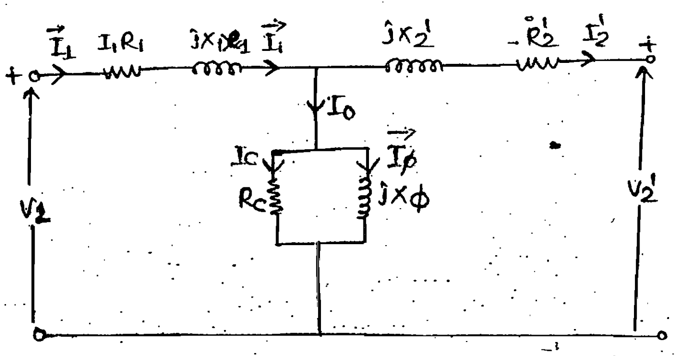
$$\vec{E_2} = \vec{V_2} + \vec{I_2}R_2 + jX_2\vec{I_2}$$

multiplying by $a = \frac{N_1}{N_2}$

$$a\vec{E_2} = a\vec{V_2} + a\vec{I_2}R_2 + ja\vec{I_2}X_2$$

$$E_2' = V_2' + \left(\frac{I_2}{a^2}\right) \times a^2 R_2 + j\left(\frac{I_2}{a}\right) a^2 X_2$$

$$\vec{E_1} = \vec{E_2'} = \vec{V_2'} + \vec{I_2'}R_2' + j\vec{I_2'}X_2'$$



R_c = Core loss eq. resistance.

fig → Exact equivalent ckt
"T" equivalent

Que → The parmeters of a eq. ckt of a 1ϕ is 150kVA, 2400V/240V Xmer are

$R_1 = 0.2\Omega$, $X_1 = 0.45\Omega$, $R_2 = 2m\Omega$

$X_2 = 4.5m\Omega$, $R_c = 10k\Omega$, $X_\phi = 1.55k\Omega$

Using ~~this ckt refered~~ to 1°, determine the 1° i/p vol., i/p current & i/p PF of the Xmer operating at rated load with 0.8 lagging PF.

Solⁿ → FL must be delivered (Rated kVA) at the cost of raded voltage & rated current both.

Rated voltage - Rated Flux

1000W, 200V

↓

180V

then $1000 \times \left(\frac{180}{200}\right)^2 = 810W$

taking V_2 as ref.

$V_2 = 240\angle 0°$; $I_2 = \frac{150 \times 10^3}{240} \angle -\cos^{-1}(0.8)$

$= 625\angle -36.87° A$

$V_2' = aV_2 = 10 \times 240\angle 0^\circ$

$a = \frac{2400}{240} = 10$

$V_2' = 2400V\angle 0^\circ$

$I_2' = \frac{I_2}{a} = \frac{625\angle -36.86^\circ A}{10}$

$= 62.5\angle -36.86^\circ A$

$Z_2' = a^2 Z_2$

$= (10)^2[(2+4.5j)\times 10^{-3}]$

$= (0.2+0.45j)\Omega$

$E_1 = E_2' = V_2' + Z_2' I_2'$

$E_1 = 2400\angle 0^\circ + 62.5\angle -36.86 \times (0.2+0.45j)$

$\boxed{E_1 = 2426.92\angle 0.35^\circ V}$

$I_\phi = \frac{E_1}{R_C} = \frac{2426.92\angle 0.35}{10k} = 0.2427\angle 0.35^\circ A$

$I_\phi = \frac{E_1}{jX_\phi} = \frac{2426.92\angle 0.35}{j1.55\times 10^3} A = 1.56\angle -89.64 A$

$I_0 = I_c + I_\phi$

$= 0.2427\angle 0.35^\circ + 1.56\angle -89.64$

$\boxed{I_0 = 1.5845\angle -80.84^\circ A}$

No load PF angle $\rightarrow 80.84 + 0.35 = 81.19^\circ$

$\frac{I_\phi}{I_0} = 0.98\angle -8.8$

$I_1 = I_2' + I_0$

$= 62.5\angle -36.86 + 1.5845\angle -80.84$

$\boxed{I_1 = 63.65\angle -37.86^\circ A}$

$V_1 = E_1 + I_1 Z_1$

$= 2426.92\angle 0.35^\circ + 63.65\angle -37.86^\circ \times (0.2+0.45j)$

$\boxed{V_1 = 2454.68\angle 0.691}$

I/P PF = Angle of V_1 − angle of I_1

$= 0.691 - (-37.86^\circ)$

$= 38.55^\circ$

PF $= \cos(38.55) = 0.7821$ lagging $\boxed{PF = 0.7821 (lag)}$

* FIRST approximate equivalent circuit →

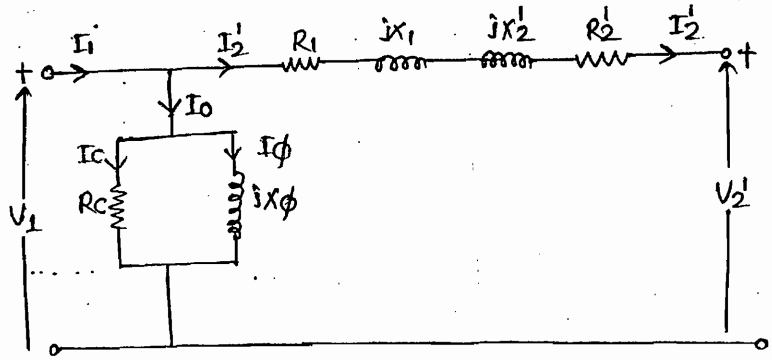
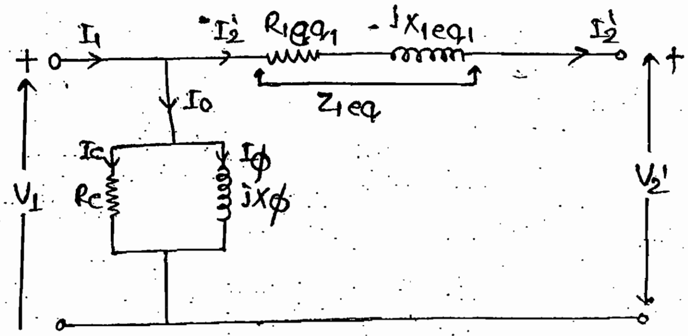


Fig- Cantilever eq:



For η calⁿ it is best suitable

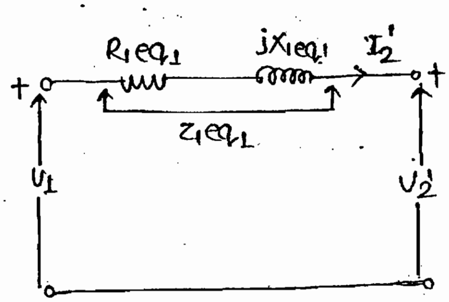
$$V_1 = 2400\angle 0^\circ + 62.5\angle -36.87^\circ \times (0.4 + 0.9j)$$

$$= V_2' + I_2'(Z_1 + Z_2')$$

$$V_1 = 2453.66\angle 0.69^\circ V$$

$$\boxed{V_1 = 2453.66\angle 0.69^\circ V}$$

* 2nd & Final approx eq. ckt →



Open circuit Test & Short circuit Test

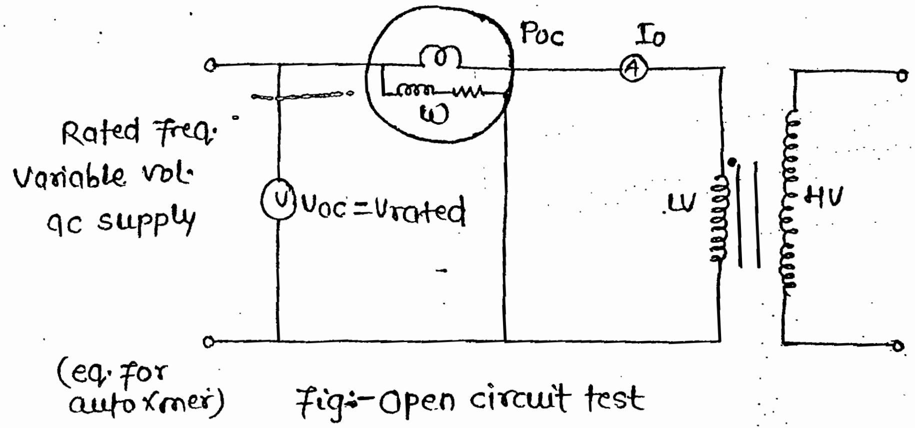


Fig:- Open circuit test

"To predict the performance without actual loading is the main purpose of performing above test."

* The aim of these two test is to predict the performance of Xmer without actual loading.

OC Test →

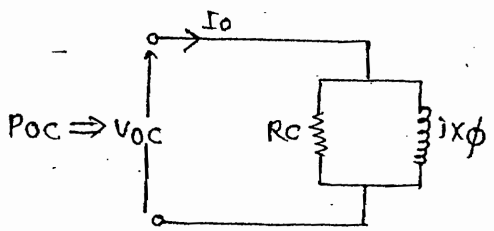
* This test is carried out at rated freq. & rated vol. to determine the core loss.

  The core loss thus determined is then treated as constant despite minor variation in freq. & voltage during actual operation.

* This test is carried out with the instruments placed on the LV side while the HV side is left open circuited.

  This is because it is easier to arrange rated vol. supply at the low vol. level rather then at high vol. level.

* Also the instruments used are in economic in cost at LV level & it is safer to carry out the test.



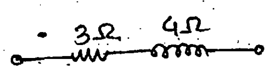
eq. ckt under oc test

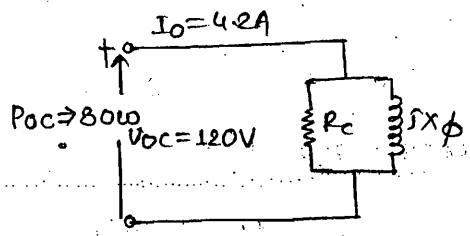
* Since the NL current is limited to 5% of FL value, the 1° cu loss during OC test is ignored.
Also the 1° impedance vol. drop at such low current is neglected.
* Since the NL PF is very low it is recommended that a low PF watt-meter is used in this test.

Que.→ With the instruments connected on LV side OC readings are 10 kVA 450/120V 50 Hz, 1-ϕ Xmer are 120V, 4.2A, 80W

Find the resistance & reactance of parallel eq. exciting ckt refered to HV side.

Soln→





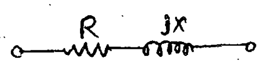
$$Y = \frac{1}{Z} = \frac{1}{3+4j} = \frac{1}{5\angle 53.13°}$$

$$= 0.2\angle -53.13° \text{ semeins}$$

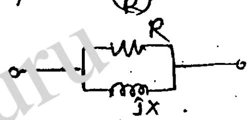
$$= 0.2(0.6 - 0.8j)$$

$$G - jB = 0.12 - 0.16j$$

$$G = 0.12, \; B = 0.16$$



$$\phi = \tan^{-1}\left(\frac{X}{R}\right)$$



$$\phi = \tan^{-1}\left(\frac{R}{X}\right)$$

$$\frac{1}{Z} = Y = \frac{1}{R} + \frac{1}{jX} = \frac{1}{R} - \frac{j}{X}$$

$$\tan\phi = \left(\frac{\frac{1}{X}}{1/R}\right)$$

$$\tan\phi = \frac{R}{X}$$

$$P_{oc} = \frac{V_{oc}^2}{R_c}$$

$$R_c = \frac{(120)^2}{80} = 180\Omega$$

$$P_{oc} = V_{oc} I_o \cos\phi_o$$

$$= 120 \times 4.2 \cos\phi_o$$

$$\phi_o = 80.87°$$

$$\tan\phi_o = \frac{R_c}{X_\phi}$$

$$\tan(80.87) = \frac{R_c}{X_\phi}$$

$$X_\phi = \frac{R_c}{\tan(80.87)}$$

$$\boxed{X_\phi = 28.93\Omega}$$

Ohmic value must be high on HV side & low on LV side.

HV side ⇒ [illegible]

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8871453536

$$a = \frac{450}{120} = 3.75$$

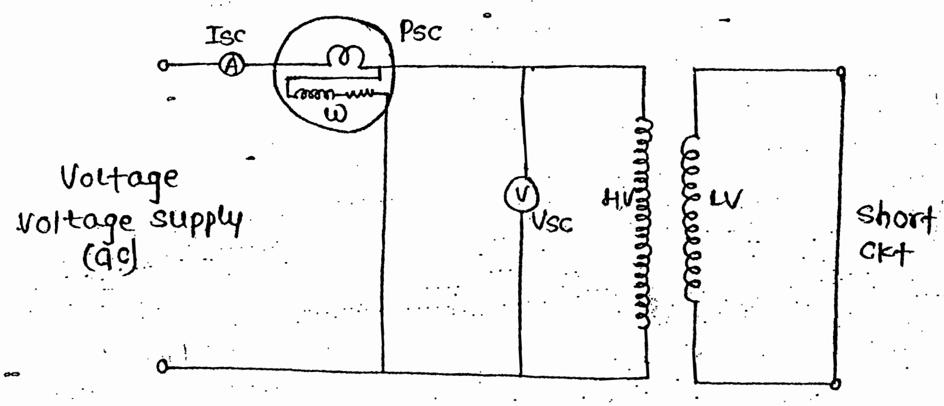
$$R_{C(HV)} = (3.75)^2 \times 180$$

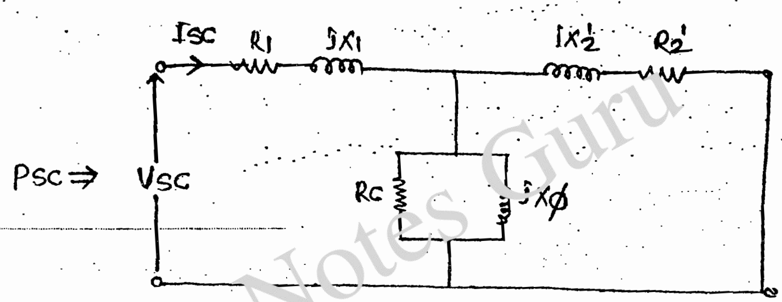
$$= 2.531\ k\Omega$$

$$X_\phi = (3.75)^2 \times 28.93$$

$$X_\phi = 406.83\,\Omega$$

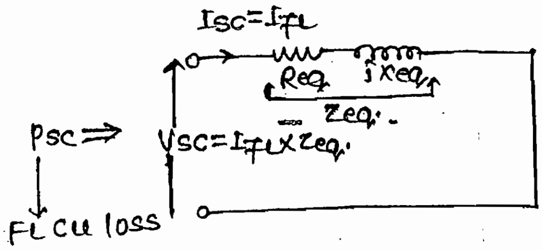
Short circuit Test →





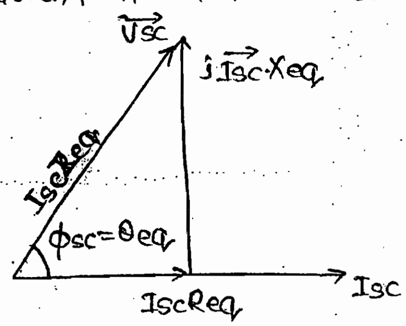
* This test is carried out by rated current to determine FL cu loss.
* Since the resistance of the wdg in Xmers is not affected much by the variation in power freq. band, this test need not be carried out strictealy at rated ~~freq.~~
  Although it would be recommended to conduct the test at rated freq.
* This test is carried out with the instruments placed on the HV side while the LV side is short circuited by a thick condr.
  This is because the rated current on the HV side is less then on the LV side.

And therefore economicaly cheap Instruments may be used in the test.



Since the applied vol. required to circulate FL current at SC would be limited to about 5% to 10% of the rated vol., the core loss at such reduced vol. is ignored.

Also the exciting current at such low vol. may be neglected.



$$Z_{eq} = \frac{V_{sc}}{I_{sc}} \angle \cos^{-1}\frac{P_{sc}}{V_{sc}I_{sc}}$$

$$Z_{eq} = R_{eq} + jX_{eq}.$$

Que.→ with the ins. conneted in HV side the sc test readings for 50kVA 2200V/240V TF are 48V, 20.8A & 617W. Find the ~~leagal ime~~ leakage impedance, effective resistance. & leakage reactance refered to LV side.

Sol→

$$\phi = \cos^{-1}\frac{P_{sc}}{V_{sc}I_{sc}}$$

$$= \cos^{-1}\frac{617}{48\times 20.8} = 51.83$$

$$Z_{eq} = 2.30 \angle 51.83$$

$$Z_{eq} = 1.421 + 1.808j \approx 1.426 + j1.814$$

$$\boxed{Z_{eq} = 2.31\angle 51.83^\circ\,\Omega}$$

LV side→

$$a = \frac{2400}{240} = 10$$

$$(R_{eq})_{LV} = \frac{1.426}{(10)^2} = 14.26\,m\Omega \qquad (X_{eq})_{LV} = \frac{1.814}{(10)^2} = 18.14\,m\Omega$$

$$(Z_{eq})_{LV} = \frac{2.31}{(10)^2}\,\Omega = 2.31\,m\Omega$$

Que (a) A 2200/240V, 50Hz, 1ϕ Xmer has exciting current of 0.6A has a core loss 361W, when its HV side is energised at rated voltage. Calc. the 2 componants of exciting current.

(b) If a Xmer of part a supplies a load current of 60A at 0.8 PF lag on its LV side than cal. the 1° current & its PF. Ignore leakage impedance drop.

Sol^n → (a) $I_0 = 0.6A$, $I_{c_1} = ?$, $I_\phi = ?$

$$P_{oc} = \frac{V_{oc}^2}{R_c} \qquad P_{oc} = V_{oc} I_0 \cos\phi_0$$

$$361 = 2200 \times 0.6 \cos\phi_0$$

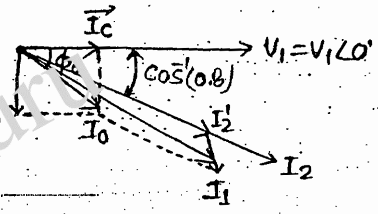
$$\cancel{\cos}\,\phi_0 = 74.13°$$

$$I_0 = I_c + I_\phi \qquad I_c = I_0 \cos\phi_0 = 0.164$$

$$I_0 = \frac{V_{oc}}{R_c} + \frac{V_{oc}}{X_\phi}$$

Because always lag

$$I_0 = 0.6 \angle -\cos^{-1}\frac{361}{2200 \times 0.6}$$



$$I_0 = (0.1641 - j0.577)A$$

$\downarrow I_c$ $\quad \downarrow I_\phi$

$$I_1 = I_2' + I_0$$

$$= \frac{I_2}{a} + \vec{I_0}$$

$$= 6\angle -\cos^{-1}(0.8) + (0.1641 - 0.577j)$$

$$= 6.488\angle -40.08°A$$

I/P PF = $\cos(40.08)$ lagging

= 0.7651 lagging

Interpretation of pu system →

$$R_{pu} = \frac{R_{eq}(\Omega)}{Z_{base}}$$

$$= \frac{R_{eq}(\Omega)}{V_{rated}/I_{rated}}$$

$$= \frac{I_{rated} \cdot R_{eq}(\Omega)}{V_{rated}}$$ = Full load resistance drop in %

Resistive drop = ohmic drop = effective drop

$$= \frac{(I_{rated})^2 \cdot R_{eq}(\Omega)}{(S_{rated})}$$ = Full load cu loss in per unit.

$$X_{pu} = \frac{X_{eq}(\Omega)}{Z_{base}}$$

$$= \frac{X_{eq}(\Omega)}{V_{rated}/I_{rated}}$$

$$= \frac{I_{rated} \cdot X_{eq}(\Omega)}{V_{rated}}$$ = Full load reactive drop in %

$$= \frac{(I_{rated})^2 X_{eq}(\Omega)}{S_{rated}}$$ = Full load reactive loss in per unit.

$$Z_{pu} = \frac{Z_{eq}(\Omega)}{Z_{base}}$$

$$= \frac{Z_{eq}(\Omega)}{V_{rated}/I_{rated}}$$

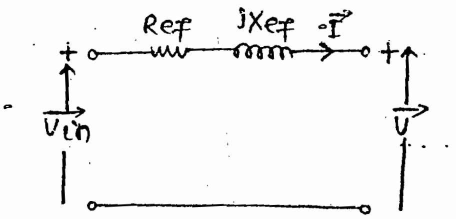
$$= \frac{I_{rated} \cdot Z_{eq}(\Omega)}{V_{rated}}$$ = Full load impedance drop in %

$$= \frac{(I_{rated})^2 \cdot Z_{eq}(\Omega)}{V_{rated}}$$ = Full load Apparant loss in per unit

DATE-05/11/14

VOLTAGE REGULATION

* VR of the Xmer is defined as the rise in o/p vol. expressed as a fraction of FL rated vol. when FL at a specified PF is reduced to 0, keeping the 1° i/p vol. constant.



$$\boxed{VR^n = \frac{V_{in} - V}{V}\ pu}$$

Note:- Use magnitude only

where; $V = V_{rated}$

$$\vec{V_{in}} = \vec{V} + \vec{I}\,\vec{Z_{eq}}$$

$$VR^n = \left(\frac{V_{in}}{V} - 1\right) pu = (V_{in})_{pu} - 1\ pu$$

Que→ The TF has pu imp. of 0.10 pu & pu resistance of 0.01. Calc. the phase diff. betn the o/p vol. & i/p vol. of FL on
(a) 0.8 PF lag (b) Unity PF (c) 0.8 PF lead
And hence determine the VR^n under the above condn.

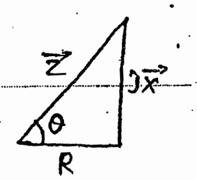
Soln→

$$Z_{eq} = 0.10 \angle \cos^{-1}\frac{0.01}{0.10}$$

$\cos\theta = \frac{R}{Z}$

$\sin\theta = \frac{X}{Z}$

$\tan\theta = \frac{X}{R}$



$$Z_{eq} = 0.01 + 0.095j$$
$$= 0.1\angle 84.26°\ pu$$

(i) $V_{in} = 1\angle 0° + 1.0\angle -\cos^{-1}0.8 \times 0.1\angle 84.26°$

$= 1.0702\angle 3.94°\ pu$

$VR^n = 1.0702 - 1\ pu$

$= 0.0702\ pu$

$\boxed{VR^n = 7.02\%}$ (MORE)

(ii) $V_{in} = 1\angle 0° + 1.0\angle \cos^{-1}(1) \times 0.10\angle 84.26°$

$= 1.015\angle 5.63\ pu$

$VR^n = 1.015 - 1$

$= 0.015$

$\boxed{VR^n = 1.5\%}$ (IMPROVES)

(iii) $V_{in} = 1\angle 0° + 1.0\angle \cos^{-1}0.8 \times 0.1\angle 84.26$

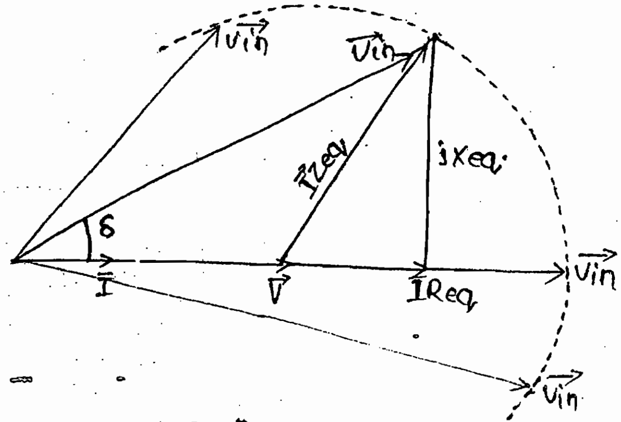
$= 0.9522\angle 5.157$

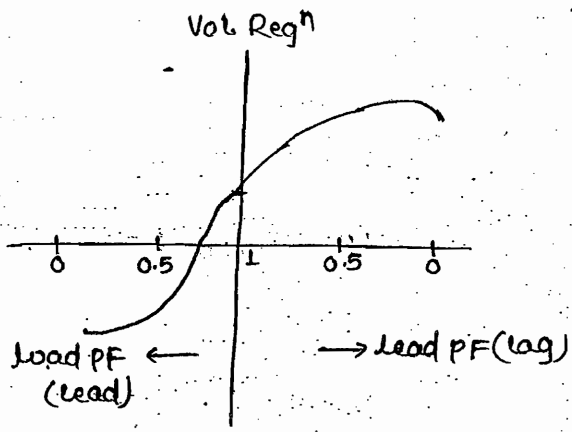
$VR^n = 0.9522 - 1$

$VR^n = -0.0478$

$\boxed{\%VR^n = -4.78\%}$ (LESS)

Locus of Vin at diff PF





$0.8\ PF\ Reg^n = Vin = 1.0702\angle 3.94$

$Vin\cos\delta = 1.0702\cos(3.94)$

$= 1.0675$

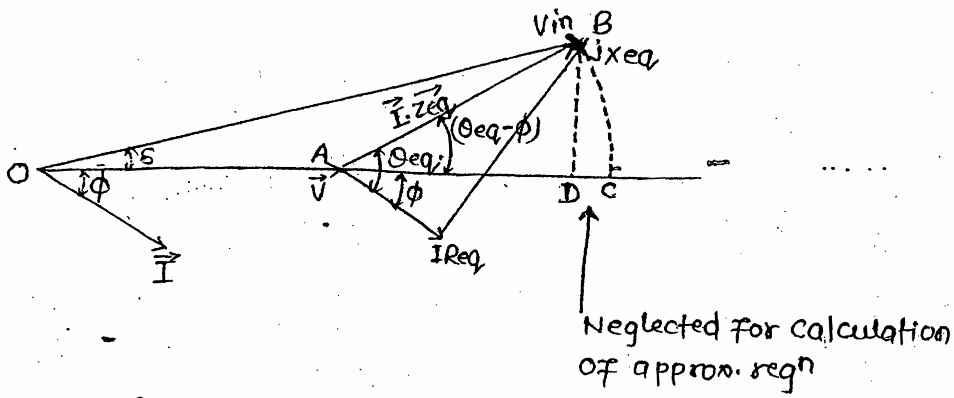
$VR^n = 1.0675 - 1$

$\% VR = 6.75\%$ → Previous value (0.8 PF lag)

$\%\ error = \dfrac{7.02 - 6.75}{7.02}$

$= 3.44\%$

* Approximate Regulation → (Graphical approach)



$$\text{Actual VR}^n = \frac{OB - OA}{OA}$$

$$= \frac{OC - OA}{OA}$$

Since δ is very small; $V_{in}\cos\delta \simeq V_{in}$

i.e. $OD \simeq OC$

$$\text{Then approximate VR}^n = \frac{OD - OA}{OA} = \frac{AD}{OA} = \frac{AB\cdot\cos(\theta_{eq} - \phi)}{OA}$$

$$\text{Approximate VR}^n = \frac{I\cdot Z_{eq}\cos(\theta_{eq} - \phi)}{V}$$

$$= Z_{pu}\cos(\theta_{eq} - \phi)$$

where ϕ is the +ve for lagging PF.

Analytical approach →

$$V_{in}\angle\delta = V\angle 0^\circ + I\angle{-\phi} \times Z_{eq}\angle\theta_{eq}$$

$$= V + IZ_{eq}\angle(\theta_{eq} - \phi)$$

$$V_{in}\cos\delta + jV_{in}\sin\delta = V + [IZ_{eq}\cdot\cos(\theta_{eq} - \phi)] + j[IZ_{eq}\cdot\sin(\theta_{eq} - \phi)]$$

equating Real parts

$$V_{in}\cos\delta = V + IZ_{eq}\cdot\cos(\theta_{eq} - \phi)$$

Since δ is very small

$V_{in}\cos\delta \simeq V_{in}$ for cal^n of approx Reg^n

Then; $V_{in} = V + IZ_{eq}\cos(\theta_{eq} - \phi)$

$$V_{in} - V = IZ_{eq}\cos(\theta_{eq} - \phi)$$

$$\text{approxi Reg}^n = \frac{V_{in} - V}{V}$$

$$= \frac{IZ_{eq}\cos(\theta_{eq} - \phi)}{V}$$

i.e. approx Reg^n = $Z_{pu}\cos(\theta_{eq} - \phi)$ (where ϕ is +ve for lagging PF)

*** Maximum Regulation →**

where $\theta_{eq} - \phi = 0$

$$\phi = \theta_{eq}$$

& max^m reg^n = Z_{pu}

& Corrosponding PF = $\cos\phi$

$= \cos\theta_{eq}$ (lagging)

$= \frac{R_{ef}}{Z_{ef}}$ (lagging)

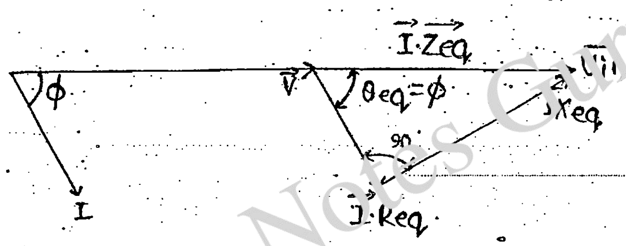


Fig:- Phasor dia. at max^m Regulation

$\boxed{\text{(No approximation is involved } \because \delta = 0)}$

*** Zero Reg^n (approxi cond^n) →**

when $\theta_{eq} - \phi = 90°$

$\phi = (\theta_{eq} - 90°)$ lagging

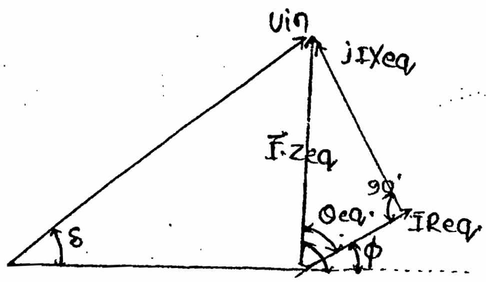
$= -(90 - \theta_{eq})$ lagging

$= (90 - \theta_{eq})$ leading

$\therefore$ Corresponding PF $= \cos(90^\circ - \theta_{eq})$ leading

$= \sin\theta_{eq}$ (leading)

$= \dfrac{X_{eq}}{Z_{eq}}$ (leading)



*** min^m Regulation (approximate cond^n) →**

Approximate cond^n $= Z_{pu}\cos(\theta_{eq} - \phi)$

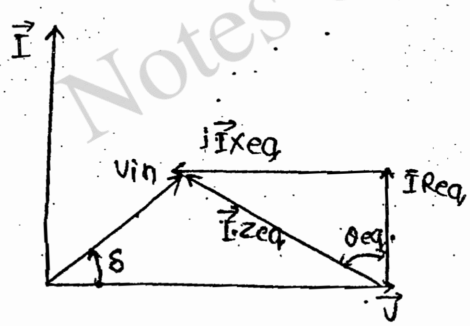
min Reg^n at $\phi = 90^\circ$ leading i.e. at zero pF leading

min^n Reg^n $= Z_{pu} \cdot \cos[\theta_{eq} - (-90^\circ)]$

$= Z_{pu} \cdot \cos(\theta_{eq} + 90^\circ)$

$= -Z_{pu}\sin\theta_{eq}$

$= -X_{pu}$



* VR is a figure of merit of a TF & its low value is desired.

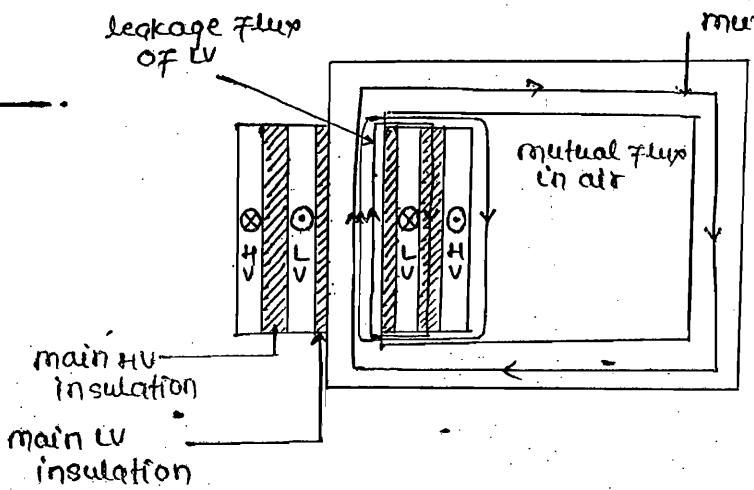
* VR may be reduced by reducing the pu impedance of TF.

* Z_{pu} can be reduced by reducing $(R)_{pu}$ &/(or) $(X)_{pu}$.

* R_{pu} is already kept at an optimaly low value. because of η consideration.

* This leaves X_{pu} to be reduced for reducing the value of pu impedance.

* X_{pu} can be reduced by reducing the leakage flux.

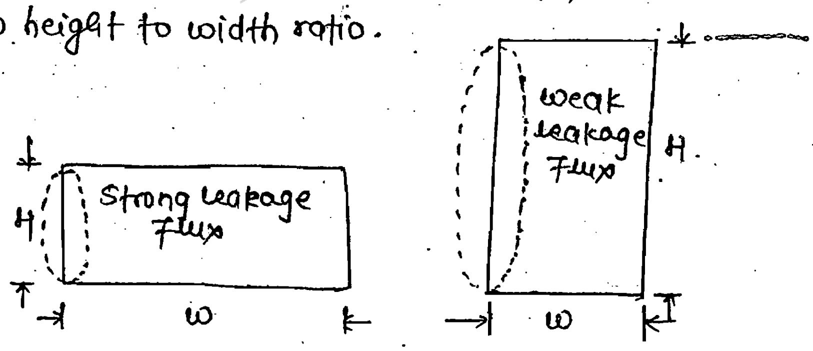


mutual flux → link with both wdg

1/2 wdgs on each limbs

* Leakage flux can be reduced by keeping the wdgs physicaly close together.
This is obtain in core type Xmer by using concentric cylindrical wdgs.
In shell type TF the physical proximity bet/n wdg is obtained by using sandwich wdgs; also called pancake wdsg (or) interleaved wdgs.
Infact the leakage reactance of shell type TF may be graded as per requirement by adjusting the thickness of each layer &/or) arranging the layers of HV & LV sections.

* In core type Xmer the leakage reactance may also be reduced by increasing the window height to width ratio.



Power TF ON → Always on FL

* A power TF operates on FL (or) is switched off.
Therefore VR^n as a performance index is not a significant factor in Power TF.
However the load on a distribution TF depends upon the consumers demand. And therefore may vary from FL to NL.
Obeously therefore VR^n is a very significant factor in distribution TF & should therefore kept low.
Accordingly the pu impedance of the distribution TF may be as low as 0.015 pu while for a power TF it may be as high as 0.15 pu.
A high value of pu impedance in power TF has the advantage that it reduces the fault MVA level of the power sys.

As compare to a TF of low voltage rating, a leakage reactance of a high voltage rated TF is greater because its thicker insulation makes the wdgs further apart.

$\otimes \quad \otimes$ (attractive) $\qquad \otimes \quad \odot$ (Repulsive)

EFFICIENCY

$$\eta \triangleq \frac{\text{output}}{\text{Input}}$$

$$= \frac{o/p}{\text{output}+\text{loss}} \quad \text{(OR)} \quad \frac{\text{Input}-\text{losses}}{\text{Input}}$$

$$\left(1-\frac{\text{losses}}{\text{Input}}\right)$$

TF has 25% loss then η is 80%

$$\eta = \frac{o/p}{o/p + 0.25\, o/p}$$

$$= \frac{o/p}{1.25\, o/p}$$

$$\boxed{\eta = 80\%}$$

100% loss then $\eta = 50\%$

$$\eta = \frac{o/p}{o/p + \cancel{0.25}\ 1\ o/p}$$

$$\eta = \frac{o/p}{2\cancel{.25}\, o/p}$$

$$\boxed{\eta = 50\%}$$

Losses

- Core loss
  - Hysteresis loss
    - $HL \propto f B_m^n$
    - n = steimention exponant (1.5 to 2.5)
  - eddy current loss
    - $EL \propto f^2 B_m^2 t^2$
    - t = thickness
- Cu loss (wdg, resistive, effective loss) (I^2R_{eq})
  - Cu loss $\propto I^2$
  - Cu loss $\propto V^2 I^2$ (proportionality does not change)
  - $P_{cu} \propto (VI)^2$
  - $P_{cu} \propto S^2$

$P_c = P_i$ = constant
(when V & f are constant)

$$\boxed{\eta = \frac{VI\cos\phi}{VI\cos\phi + I^2R_{eq} + P_i}}$$

Sagar sen
8871453536

max^m efficiency →

$$\eta = \frac{VI\cos\phi}{VI\cos\phi + I^2 R_{eq} + P_i}$$

If the load current is constant but the load PF is variable then the max^m η of TF is obtained when the load PF is UNITY.

However if the load PF is constant but the load current is variable then the $cond^n$ for max^m η is obtained as follows:-

Deviding the numerator & denominator by 'I'

$$\eta = \frac{V\cos\phi}{V\cos\phi + IR_{eq} + \frac{P_i}{I}}$$

The η is max^m when the denominator is min^m.

i.e. $\frac{d\eta(\text{denominator})}{dI} = 0$

$$\frac{d}{dI}\left(V\cos\phi + IR_{eq} + \frac{P_i}{I}\right) = 0$$

$$0 + R_{eq} - \frac{P_i}{I^2} = 0$$

$$R_{eq} I^2 = P_i$$

$$\boxed{\text{Cu loss} = \text{Core loss}}$$

$$\boxed{I_{\eta max} = \sqrt{\frac{P_i}{R_{eq}}}}$$

$$VI_{\eta max} = V\sqrt{\frac{P_i}{R_{eq}}}$$

$$S_{\eta max} = V \cdot I_j \sqrt{\frac{P_i}{I_j^2 R_{eq}}}$$

$$= S_j \sqrt{\frac{P_i}{P_{cu(j)}}}$$

S_j = Any kVA at which the cu loss is already available.

$$\boxed{S_{\eta max} = S_j \sqrt{\frac{P_i}{P_{cu(j)}}}}$$

Example:-

(i) $S_j = S_{FL}$

Then $S_{\eta max} = S_{FL} \times \sqrt{\frac{P_i}{P_{cu(FL)}}}$

(ii) $S_j = S_{(13\%)}$

Then $S_{\eta max} = S_{(13\%)} \times \sqrt{\frac{P_i}{P_{cu(FL)}}}$

Alternative for $S_{\eta max}$ →

$$P_{cu} \propto S^2$$

$$\frac{P_{cu(\eta max)}}{P_{cu(j)}} = \left(\frac{S_{\eta max}}{S_j}\right)^2$$

$$\sqrt{\frac{P_i}{P_{cu(j)}}} = \frac{S_{\eta max}}{S_j}$$

$$\boxed{S_{\eta max} = S_j \sqrt{\frac{P_i}{P_{cu(j)}}}}$$

$$\boxed{\eta_{max} = \frac{S_{\eta max} \cos\phi}{S_{\eta max} \cos\phi + 2P_i}}$$

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All Day efficiency (OR) Energy efficiency

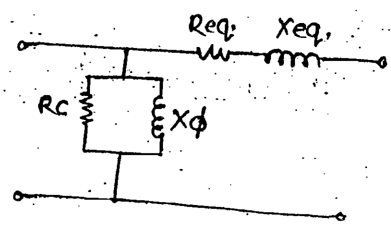
$$\eta_{all\text{-}day} \triangleq \frac{\text{o/p kwh in 24 hrs}}{\text{I/p kwh in 24 hrs.}}$$

$$= \frac{\text{o/p kwh in 24 hrs.}}{\text{o/p kwh in 24 hrs.} + P_{cu}(\text{kwh}) \text{ in 24 hrs.} + P_i(\text{kwh}) \text{ in 24 hrs.}}$$

(OR) $P_i(\text{kW}) \times 24$

1.16 (39)

Que.→ For a 200kVA 4000/1000V 1-ϕ TF draw the eq. ckt refered to LV side & insert all the values.



It is given that the TF η at UPF is 97% both at FL & at 60% of FL. The NL PF is 0.25 & FL reg^n at a lagging PF of 0.8 is 5%.

Sol^n→

$$0.97 = \frac{VI}{VI + P_c + P_i} \qquad 0.97 = \frac{(0.6)^2 VI}{(0.6)VI + P_c + P_i}$$

$(0.6)^2$

$$0.05 = \frac{V_{in} - V}{V}$$

$$\frac{0.97}{200k} = \frac{1}{200k + P_c + P_i} \qquad \frac{0.97}{0.6 \times 200 \times 10^3} = \frac{1}{0.6 \times 200 + 0.36 P_c + P_i}$$

$$P_c + P_i = 6.186 \times 10^3 \qquad 0.36 P_c + P_i = 3.711 \times 10^3$$

$$P_c = 3865.625\,\text{w}$$

$$P_i = 2319.375\,\text{w}$$

$$0.97 = \frac{1 \times 1.0}{1 \times 1.0 + P_{c(FL)} + P_i} \qquad P_{c(FL)} + P_i = 0.0309 \text{ PU} \text{ ---(i)}$$

$$0.97 = \frac{0.6 \times 1.0}{0.6 \times 1.0 + (0.6)^2 P_{c(FL)} + P_i} \qquad 0.36 P_{c(FL)} + P_i = 0.0186 \text{ PU} \text{ ---(ii)}$$

Solving eq^n (i) & (2)

$P_i = 0.0117\ PU \qquad P_{c(FL)} = 0.0192\ PU$

$P_{c(FL)} = R_{PU} = 0.0192\ PU$

$\boxed{R_{PU} = 0.0192\ PU}$

$VR^n = 0.05\ PU = R_{PU}\cos\phi + X_{PU}\sin\phi$

$0.05 = 0.0192 \times 0.8 + X_{PU}\ 0.6$

$X_{PU} = 0.0577\ PU \qquad \boxed{X_{PU} = 0.577\ PU}$

$$P_i = \frac{V^2}{R_{C(PU)}}$$

$$R_{C(PU)} = \frac{V^2}{P_i}$$

$$0.0117 = \frac{1^2}{R_{C(PU)}} \qquad \boxed{R_{C(PU)} = 85.47\ PU}$$

Given; $\cos\phi_0 = 0.25$

$\phi_0 = 75.5224^\circ$

$$X_{\phi(PU)} = \frac{R_{C(PU)}}{\tan\phi_0} \qquad \because \tan\phi = \frac{R}{X}$$

$$X_{\phi(PU)} = \frac{65.47}{\tan(75.52)^\circ} = 22.07\ PU \qquad \boxed{X_{\phi(PU)} = 22.07\ PU}$$

$$Z_{Base(LV)} = \frac{(100)^2}{200 \times 10^3} = 5\Omega$$

Actual Ω = PU value $\times$ Base impedance

$X_{\phi}(act) = 22.07 \times 5 = 110.35\Omega$

$R_c(act) = 85.47 \times 5 = 427.15\Omega$

$R_{eq}(act) = 0.0577 \times 5 = 0.2885\Omega$

$R_{eq}(act) = 0.0192 \times 5 = 0.096\Omega$

Que → The max^m η of 500kVA, 3300/500V 50Hz 1-ϕ TF is 97% & occurs at 75% FL UPF. If the TF impedance is 10%, calc. the reg^n at 0.8 PF lagging.

Sol^n →

$$\cancel{0.97} = \cancel{0.75} = 0.97 = \frac{0.75\times 1}{0.75\times 1 + 2\times P_c}$$

$$P_i = P_c = 0.0115\,PU = P_{c(75\%)}$$

$$I_{\eta max} = \sqrt{\frac{P_i}{R_{eq}}}$$

$$\cancel{S_{\eta max} = 0.01}$$

$$P_{cu(FL)} = \frac{P_{cu(75\%)}}{(0.75)^2}$$

$$= \frac{0.0116}{(0.75)^2}$$

$$= 0.0206\,PU$$

$$Z_{pu} = 0.1 \angle \cos^{-1}\frac{0.0206}{0.1}$$

$$Z_{pu} = 0.10\angle 78.11^\circ\,PU$$

$$Reg^n = Z_{pu}\cos(\theta_{eq} - \phi)$$

$$= 0.10\cos[78.11 - \cos^{-1}(0.8)]$$

$$Reg^n = 0.0752\,PU$$

$$= 75.2\%$$

Que. → A 500kVA TF has a max^m η of 98.6% at 350kVA UPF. During the day it is loaded as follows:-

(1.) 6hrs : 300kVA, 0.8 PF lag

(2.) 4hrs : 240kW, 0.6PF lead

(3.) 5hrs : No load

(4.) 9hrs : 225 kVA, UPF.

Cal. the all day η of TF.

Sol^n →

$$0.986 = \frac{350 \times 1.0}{350 \times 1.0 + 2P_i}$$

$$P_i = 2.4848 \text{ kW} = P_{cu}(350)$$

6hrs:-

$$\text{O/p kWh} = (300 \times 0.8) \times 6\text{hrs} = 1440 \text{ kWh}$$

$$P_{cu}(\text{kWh}) = \left[2.4848 \times \left(\frac{300}{350}\right)^2\right] \times 6$$

$$= 10.953 \text{ kWh}$$

4hrs:-

$$\text{O/p kWh} = 240 \times 4 = 960 \text{ kWh.}$$

$$P_{cu}(\text{kWh}) = 2.4848 \times \left[\frac{(240/0.6)}{350}\right]^2 \times 4$$

$$= 12.982 \text{ kWh}$$

5hrs:-

$$\text{O/p kWh} = 0; \quad P_{cu}(\text{kWh}) = 0$$

9hrs:-

$$\text{O/p kWh} = (225 \times 1.0) \times 9 = 2025 \text{ kWh.}$$

$$P_{cu}(\text{kWh}) = \left[2.4848 \times \left(\frac{225 \cdot 12}{350}\right)\right] \times 9$$

$$= 9.242 \text{ kWh.}$$

Total during the day (24 hrs.)

$$\text{O/p kWh} = 442.5 \text{ kWh}$$

$$P_{cu}(\text{kWh}) = 33.177 \text{ kWh}$$

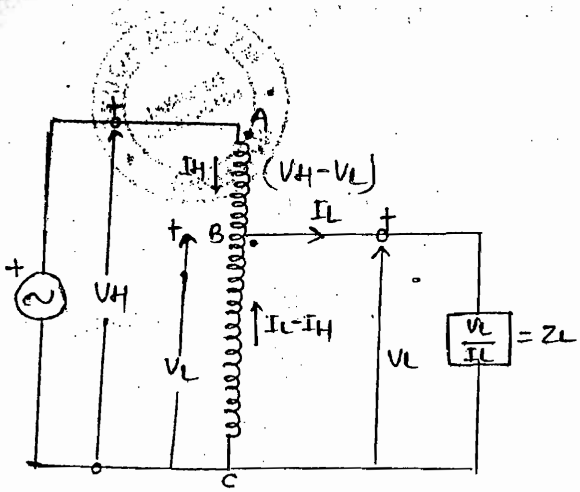
$$P_i(\text{kWh}) = 2.4848 \times 24 = 59.6352 \text{ kWh}$$

$$\eta_{\text{all-day}} = \frac{442.5}{442.5 + 33.177 + 59.6352}$$

$$= 0.9795 \text{ pu}$$

$$\boxed{\eta_{\text{all-day}} = 97.9\%}$$

Auto Transformer



Provided →

$I_L - I_H < I_H$

Total wdg (AC) : N_H

Common wdg (BC) : N_L

Series wdg (AB) : $N_H - N_L$

$\because I_L - I_H < I_H$

$I_L < 2I_H$

$\frac{I_L}{I_H} < 2$

$a < 2$

$\boxed{a_{(auto)} < 2}$

Since the flux is common;

$$\frac{V_H}{N_H} = \frac{V_L}{N_L}$$

$$\frac{V_H}{V_L} = \frac{N_H}{N_L} = a_{(auto)} = \frac{I_L}{I_H}$$

mmF balance (neglecting I_0)

$$(N_H - N_L) I_H = N_L (I_L - I_H)$$

$$N_H I_H - N_L I_H = N_L I_L - N_L I_H$$

$$N_H I_H = N_L I_L$$

$$\boxed{\frac{N_H}{N_L} = \frac{I_L}{I_H}}$$

220V, 100W

110V; P=?

$P = \frac{V^2}{R}$

$P \propto V^2$

$\frac{1}{4} \times 100 = 25W$

Copper Comparision →

Copper weight = Copper Volume × Copper density

$\propto$ Volume

$\propto$ Cond^r c/s × Cond^r length

$\downarrow$ $\propto I$ $\qquad$ $\downarrow$ $\propto N$

$\propto NI$

$\propto$ mmF

$$\therefore \frac{Cu(auto)}{Cu(2wdg)} = \frac{(N_H - N_L) I_H + N_L (I_L - I_H)}{N_H I_H + N_L I_L}$$

$$= \frac{N_H I_H - N_L I_H + N_L I_L - N_L I_H}{2 N_H I_H}$$

$$= \frac{2 N_H I_H - 2 N_L I_H}{2 N_H I_H}$$

$$= \frac{N_H - N_L}{N_H}$$

$$= 1 - \frac{N_L}{N_H}$$

$$\boxed{\frac{Cu(auto)}{Cu(2wdg)} = \left[1 - \frac{1}{a(auto)}\right]}$$

$$Cu\text{-}saving = \frac{Cu(2wdg) - Cu(auto)}{Cu(2wdg)}$$

$$= 1 - \frac{Cu(auto)}{Cu(2wdg)}$$

$$= 1 - \left[1 - \frac{1}{a(auto)}\right]$$

$$\boxed{\% Cu\ saving = \frac{1}{a(auto)} \times 100\%}$$

Componants of power TF →

$$S_L = V_L I_L$$

$$= V_L [(I_L - I_H) + I_H]$$

$$= \underbrace{V_L (I_L - I_H)}_{\text{Inductive Xfer}} + \underbrace{V_L I_H}_{\text{Conductive Xfer}}$$

Inductive Xransfer = A transfer due to tranformer action.

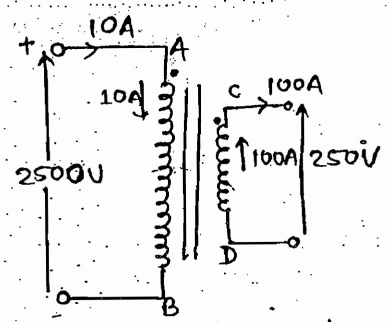
$$S_{BC} = V_L(I_L - I_H)$$
$$= V_L I_L - V_L I_H$$
$$= V_H I_H - V_L I_H$$
$$= (V_H - V_L) I_H$$
$$S_{BC} = S_{AB}$$

Ratio →

$$\frac{S(\text{cond})}{S(\text{Total})} = \frac{V_L I_H}{V_L I_L} = \frac{I_H}{I_L} = \frac{1}{a(\text{auto})} = \text{Cu (saving)}$$

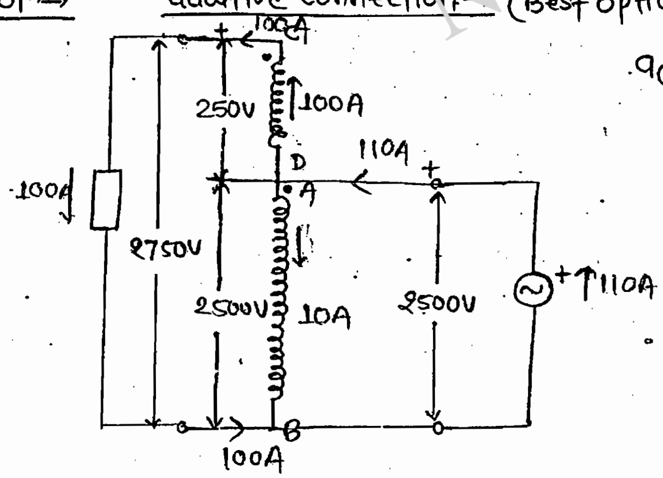
$$\frac{S(\text{ind})}{S(\text{Total})} = 1 - \frac{1}{a(\text{auto})}$$

Que.→ A 25 kVA, 2500/250V 2wdg TF is to be reconnected as auto TF.



Determine the vol. Ratio & the kVA rating as auto TF for all possible connection.

Soln →   additive connection (Best option)



$$a(\text{auto}) = \frac{2750}{2500} = 1.1$$

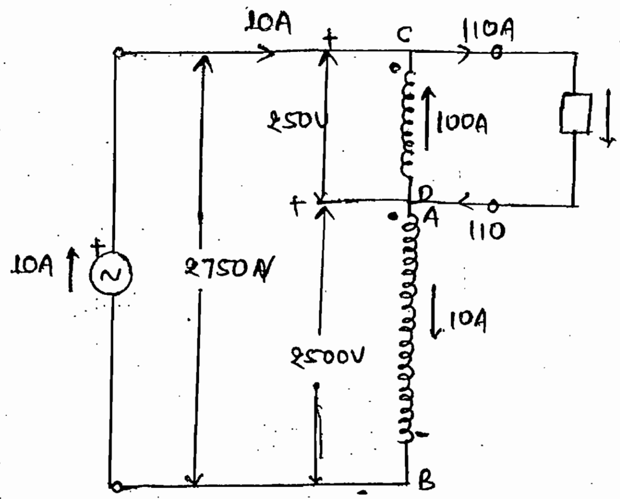
$S_{auto} = 2750 \times 100$ (OR) 2500×110

$= 275$ kVA

Given → 25 kVA → Inductive tra

~~275~~ 250 kVA → ~~Capacitive~~ Conductive

(Bad option)

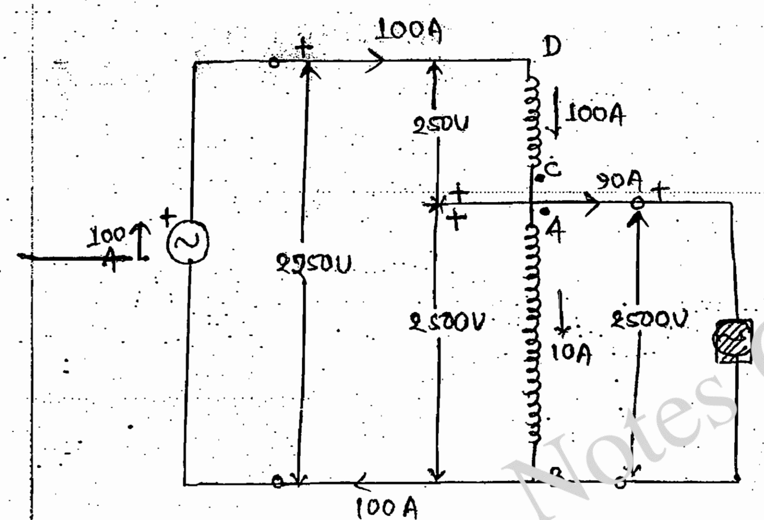


$a_{(auto)} = \frac{2750}{250} = 11$

$S_{(auto)} = 2750 \times 10$ (OR) 250×110

$= 27.5\,KVA$

Subtractive connection → (Good option)



$a_{(auto)} = \frac{2500}{2250} = 1.111$

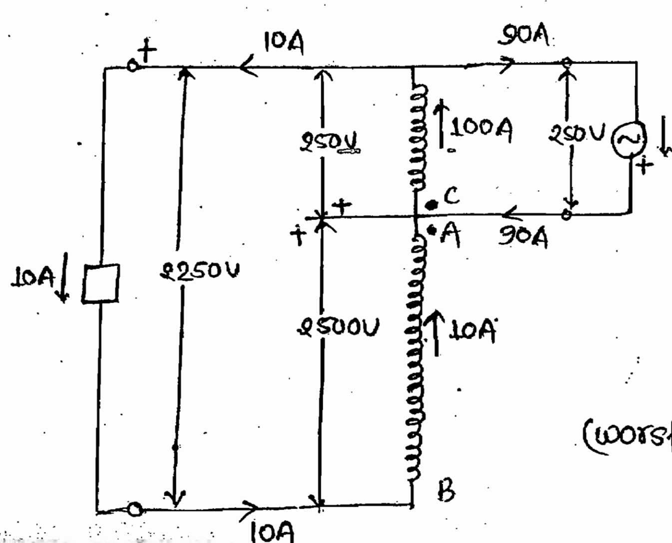
$S_{auto} = 2500 \times 90 \approx 2250 \times 100$

$= 225\,KVA$

Conductive = 200 KVA

Inductive Xfer = common Xfer

Cond. Xfer = ~~Com~~ Total I/p − IT



$a_{(auto)} = \frac{2250}{250}$

$= 9.$

$S_{auto} = 2250 \times 10$ (OR) 250×90

$= 22.5\,KVA$

Conductive = $-2.5\,KVA$

(worst option)

$$a_{(auto)} \simeq 1 \rightarrow S_{(auto)} = \left[a_{(2wdg)} \pm 1\right] \times S_{(2wdg)}$$

$$a_{(auto)} > 1 \rightarrow S_{(auto)} = \left[1 \pm \frac{1}{a_{(auto)}}\right] \times S_{(2wdg)}$$

- An auto TF is a TF in which a part of wdg. is common to 1° & 2° ckts both.
- Unlike a 2-wdg TF where there is only inductive Xfer, an auto TF provide inductive Xfer as well as conductive Xfer.
- As compare to a 2-wdg TF for the same duty an auto TF uses less cu & less iron.

  Its exciting current is lower & η is higher.
- Its pu impedance & therefore its VR^n is lower as compare to the 2wdg. Xmer.

  However a lower pu impedance results into higher SC currents.
- The cu saving is directly related to the ratio of cunductive Xfer & to total Xfer & infact equals this ratio.

  Hence auto TF are usualy prefered when the vol Ratio as auto TF is close to 1.
- Practicaly therefore auto TFs are used where Voltage Ratio is limited to 2.
- In exceptional circumtances vol. Ratio of 3:1 may be used.
- If a 2wdg TF has to be reconnected as auto TF then the insulation of its LV wdg should be strengthen to with stand the HV expected during operation as auto TF.
- Auto TF has the disad. that it is not provide electrical isolation between the 2ckts.

  And therefore the disturbance on one side may quickly spread to other side.

Also if in the stepdown modes, the common wdg developes an oc then the load may be subjected to the full HV of the source limited only by the vol. drop across the sereis wdg.

Applications →

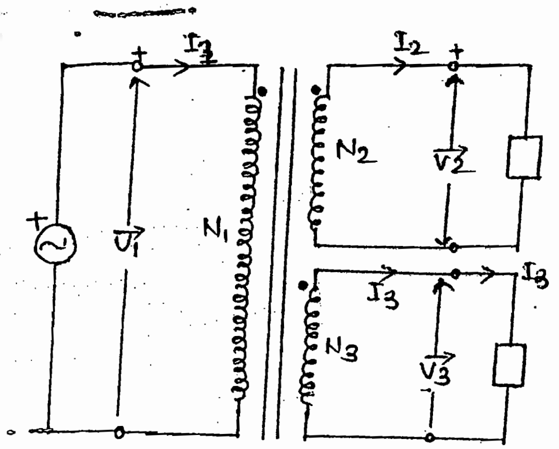
(1.) To connect 2 power sys. at diff. vol. levels where the vol. ratio is close to 1 & usualy limited to 2.
eg:- 765kV/400kV, 400/220kV & 220kV/132kV etc.

(2.) As Booster for line drop compensation in electric traction supply systems.

(3.) To start large 3-ϕ induction motors usualy th of the squarral cage type.

(4.) In manual, automatic & servo-voltage stablizers for domestic, commersial & industrial use.
As contineouly variable vol. TF (or) Lab. applications (variac)

...tiary winding →



$$\frac{V_1}{N_1} = \frac{V_2}{N_2} = \frac{V_3}{N_3}$$

mmf balance in load →

$$N_1\vec{I_1} - N_2\vec{I_2} - N_3\vec{I_3} = N_1\vec{I_0}$$

$$I_1 = \frac{N_2}{N_1}\times\vec{I_2} + \frac{N_3}{N_1}\times\vec{I_3} + \vec{I_0}$$

Taking conjugate

$$I_1^* = \frac{N_2}{N_1}\times I_2^* + \frac{N_3}{N_1}\times I_3^* + I_0^*$$

multiplying by $\vec{V_1}$

$$\vec{V_1}I_1^* = \left(\vec{V_1}\times\frac{N_2}{N_1}\right)\times I_2^* + \left(\vec{V_1}\times\frac{N_3}{N_1}\right)\times I_3^* + \vec{V_1}I_0^*$$

$$\vec{V_1}\vec{I_1}^* = \vec{V_2}\vec{I_2}^* + \vec{V_3}\vec{I_3}^* + \vec{V_1}\vec{I_0}^*$$

$$\vec{S_1} = \vec{S_2} + \vec{S_3} + \vec{S_0}$$

Que. → The ratio of the no. of turns per phase in 1°, 2° & 3° wdg. of TF is 10:2:1 with lagging currents of 45A with PF 0.8 in the 2° & 50A at PF 0.71 in the 3° wdg., find the 1° current & PF. (Neglect losses & exciting currents)

Soln →

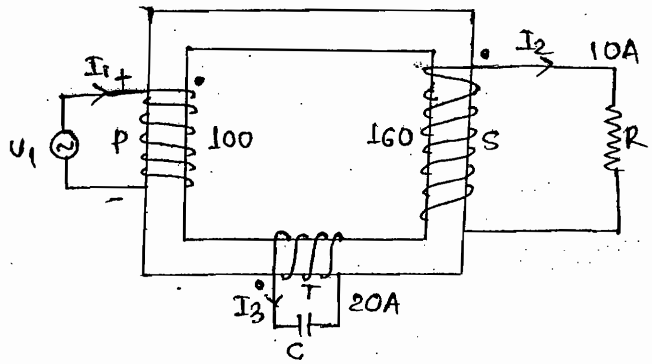
$$\vec{I_1} = \frac{N_2}{N_1}\vec{I_2} + \frac{N_3}{N_2}\times\vec{I_3}$$

$$= \frac{2}{10}\times 45\angle\cos^{-1}0.8 + \frac{1}{10}\times 50\angle\cos^{-1}(0.71)$$

$$= 13.97\angle{-39.69°}A$$

1° PF = $\cos(39.69) = 0.7695$ (lagging)

Que→



An ideal TF has 3 wdgs :-
100 turns on 1° wdg P, 160 turn on 2° wdg S & 60 turns on 3° T. wdg is feeds 10A to a resistive load whereas a pure capacitive load across wdg T takes 20A.

(i) Calculate the current in 1° wdg & its PF in case TF magnetising current is neglected.

(ii) With the polarity marking on P as shown mark the polarity on wdg S & T also.

Soln→ Taking vol. V_1 as ref vol.

C→ leading VARs supply – leading

$$I_1 = \frac{N_2}{N_1} I_2 + \frac{N_3}{-N_1} I_3$$

$$= \frac{160}{100} \times 10\angle 0 - \frac{60}{100} \times 20\angle 90^\circ$$

$$I_1 = 20\angle 36.869 \text{ A}$$

$$1^\circ PF = \cos(36.869)$$
$$= 0.8 (\text{leading})$$

DATE- 02/11/14

Tertiary wdg (CONTD) →

* It is the 3rd wdg in addition to usual 1° & 2° wdgs.

* It is provided to give a 3rd vol level for the special requirements such as :-

(1.) To interconnect 3 power sys at different vol levels.

(2.) To provide 2 diff. auxiliary vol. levels in unit auxiliary TF of power substations.

(3.) To connect reactive power compensating equipment in substations.

(4.) To provide low vol. supply for water, lightning, air conditioning & heating. (or) operating personal in high vol. substations.

* A tertiary delta wdg is provided in star by star TF to overcome prob. related to magnetising current phenomenon; unbalanced load & unbalanced faults.

Such a, 3°Δ wdg if unloaded is called stabilising wdg.

$\boxed{3\text{-}\phi \text{ transformers}}$

$v = V_m \sin\omega t$; $i = I_m \sin(\omega t - \phi)$

$P = \frac{dw}{dt}$ $\quad w = qv$

$= v\frac{dq}{dt}$

$= vi$

$P_{(1-\phi)} = v.i$

$= V_m \sin\omega t . I_m \sin(\omega t - \phi)$

$= \frac{V_m I_m}{2} . 2\sin\omega t . \sin(\omega t - \phi)$

$= \frac{V_m}{\sqrt{2}} . \frac{I_m}{\sqrt{2}} \left[\cos(\cancel{\omega t} - \cancel{\omega t} + \phi) - \cos(\omega t + \omega t - \phi)\right]$

$= V.I\left[\cos\phi - \cos(2\omega t - \phi)\right]$

$$\boxed{P_{(1-\phi)} = V.I\cos\phi - VI.\cos(2\omega t - \phi)}$$

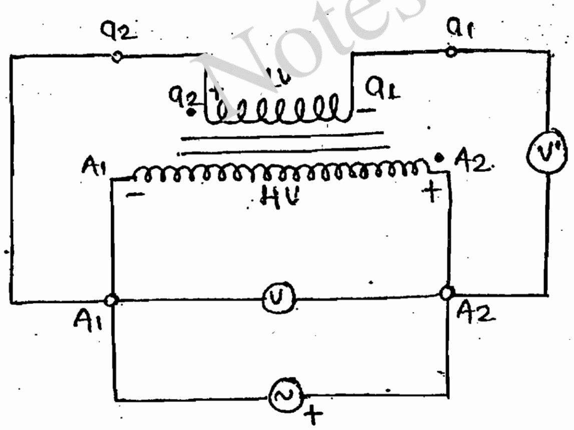
So; a $1\text{-}\phi$ power suffers from double freq. component.

3000 kVA

option 1: 1×3000 kVA, $3\text{-}\phi$ unit

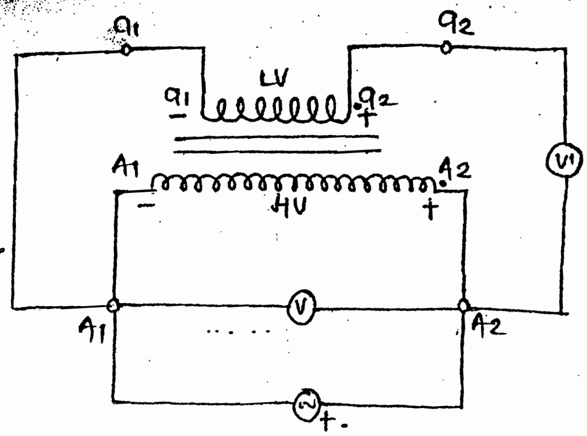
option 2: 3×1000 kVA, $1\text{-}\phi$ TF connected in $3\text{-}\phi$ bank

POLARITY TEST



$V' > V$

Fig:- additive polarity



V'<V

Fig :- Subtractive polarity.

* Phasor Groups →

Group (1) :- 0° → Yy0, Dd0, Dz0

Group (2) :- 180° → Yy6, Dd6, Dz6

Group (3) :- 30°(lag) → Yd1, Dy1, Yz1

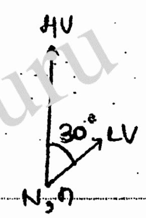
Group (4) :- 30°(lead) → Yd11, Dy11, Yz11

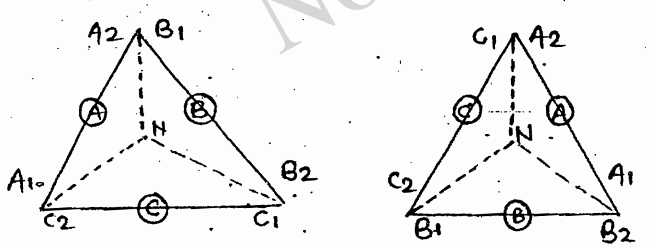
Y d 1

HV is star

LV is delta

Face of the clock





* British Practise for phasor groups →

(1.) Phasor seq. in ABC.

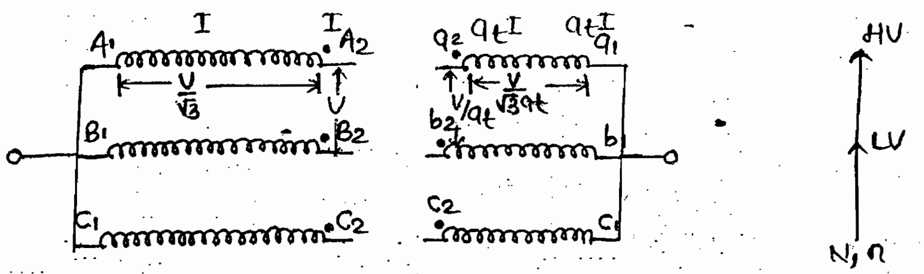
(2.) HV line (A-N) phasor always at 0 o'clock.

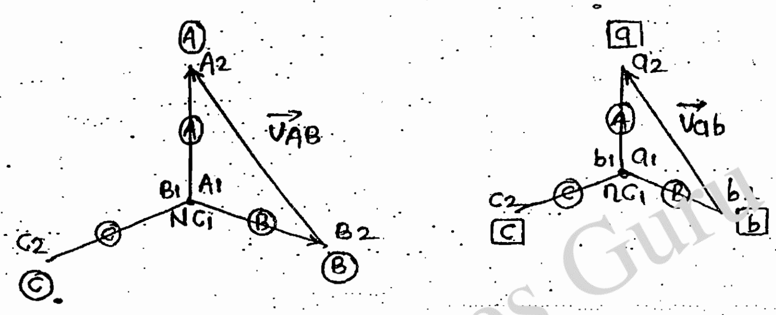
(3.) HV line 'A' terminal to be taken from A_2

(4.) $\vec{V}_{a_2a_1}$ is in phase with $\vec{V}_{A_2A_1}$.

Yy0 →

$$a_t = \frac{N_{HV}}{N_{LV}}$$





$V_{AB} = V_{AN} - V_{BN}$

$V_{AN} = V_{AB} + V_{BN}$

Phase vol. transformation Ratio $= \frac{V}{\sqrt{3}} : \frac{V}{\sqrt{3}a_t} = a_t : 1$

line vol. transformation Ratio $= V : \frac{V}{a_t} = a_t : 1$

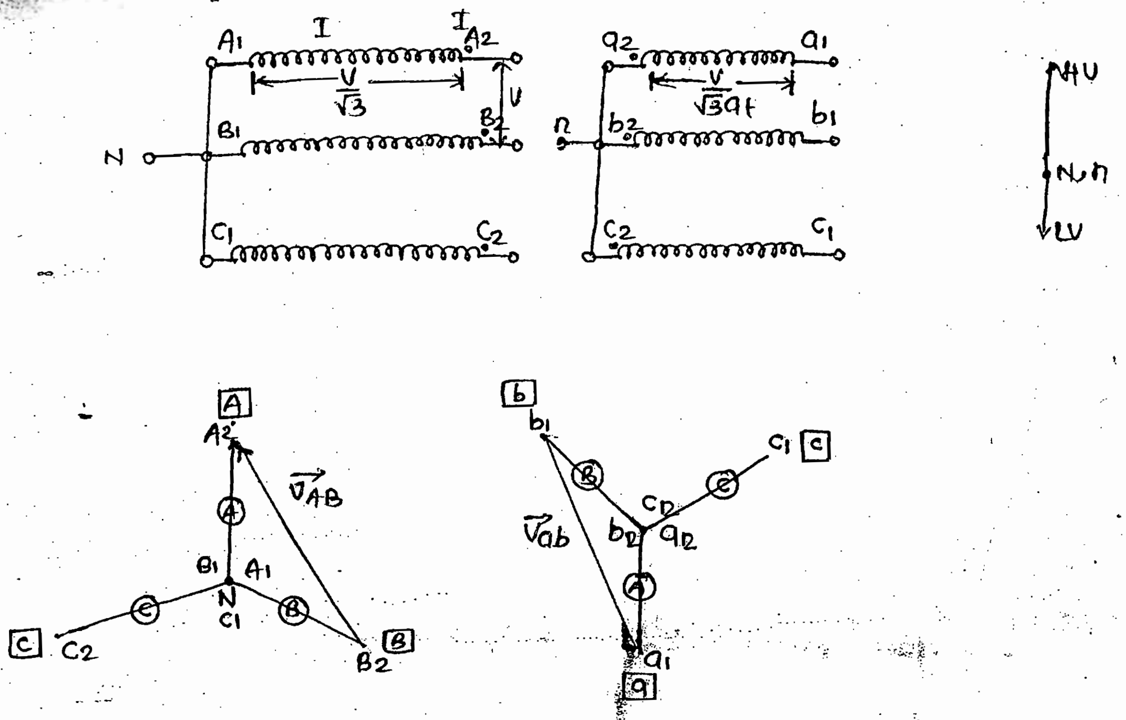
$S_{HV} = \sqrt{3}VI$ $\qquad S_{LV} = \sqrt{3}\left(\frac{V}{a_t}\right)(a_t I)$

$= \sqrt{3}VI$

$= S_{HV}$

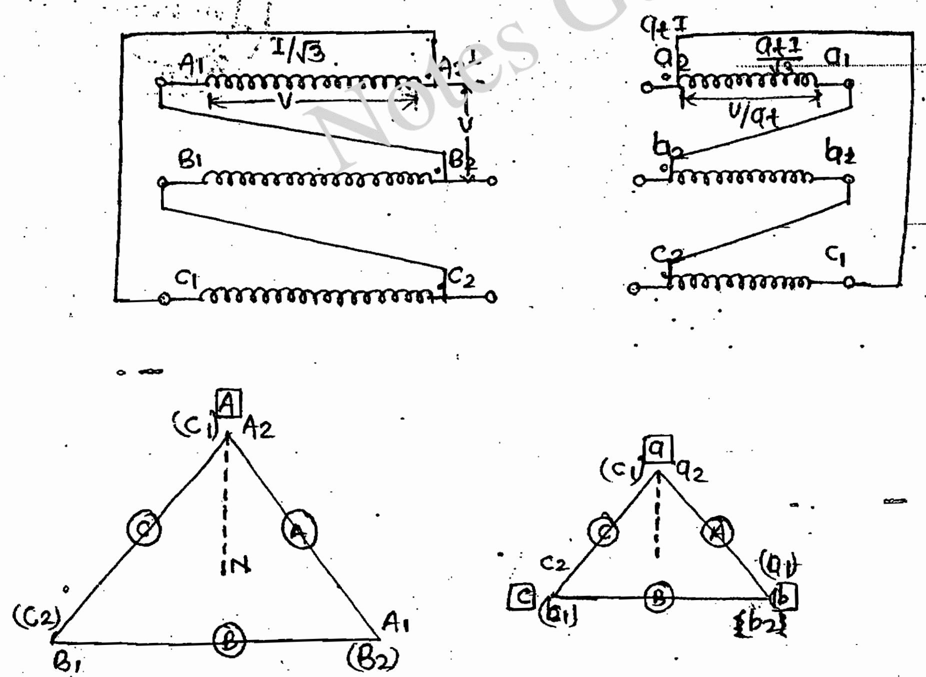
$$\boxed{S_{LV} = S_{HV}}$$

Yy6 →



Dd0 →

* The British convection for Δ-Δ connection is that the HV side Δ & LV side Δ with the same combinations, this shows that a_1b_2, b_1c_2, c_1a_2



phase vol. Xmation ratio $= V : \frac{V}{a_t} = a_t : 1$

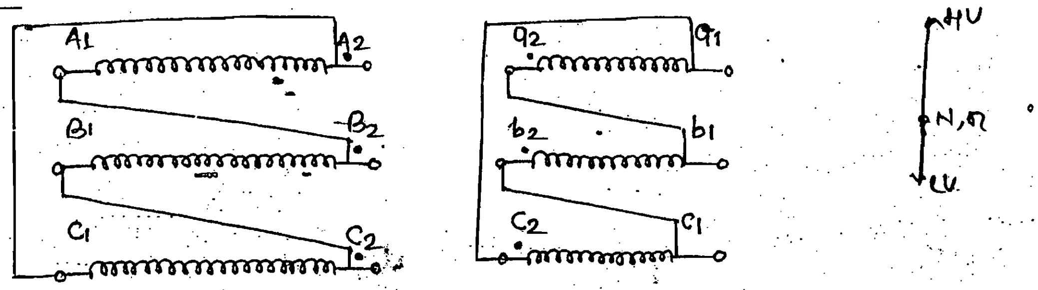
line vol. Xmation ratio $= V : \frac{V}{a_t} = a_t : 1$

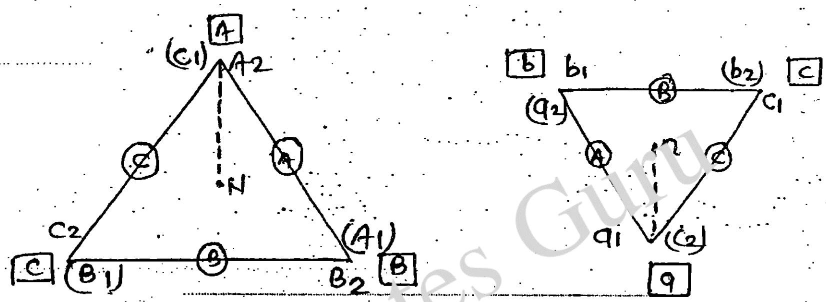
$S_{HV} = \sqrt{3} V I$ $\qquad$ $S_{LV} = \sqrt{3}\left(\frac{V}{a_t}\right)(a_t I)$

$$= \sqrt{3} V I$$

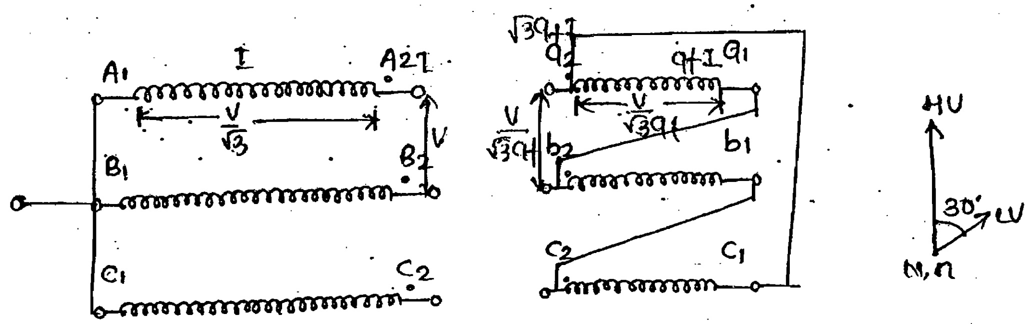
$$\boxed{S_{LV} = S_{HV}}$$

Dd6 →





Yd1 →



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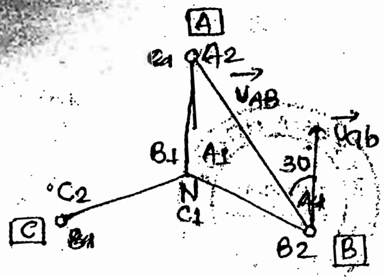
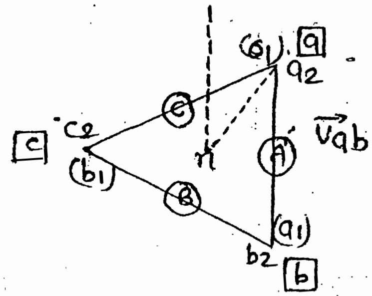




Phase vol. Xmation Ratio = $\frac{V}{\sqrt{3}} : \frac{V}{\sqrt{3}a_t} = a_t : 1$

line vol. Xmation Ratio = $V : \frac{V}{\sqrt{3}a_t} = \sqrt{3}a_t : 1$

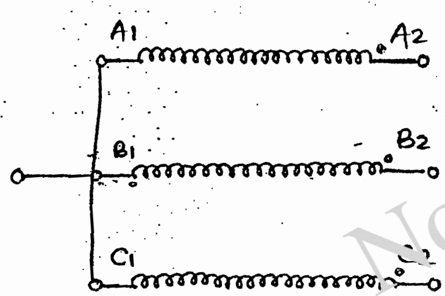
$S_{HV} = \sqrt{3}\,VI$

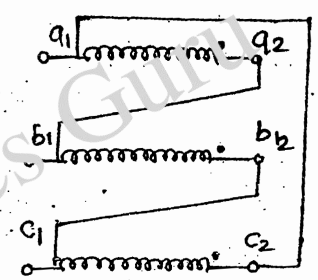
$S_{LV} = \sqrt{3}\left(\frac{V}{\sqrt{3}a_t}\right)\cdot(\sqrt{3}a_t I)$

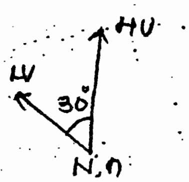
$= \sqrt{3}\,VI$

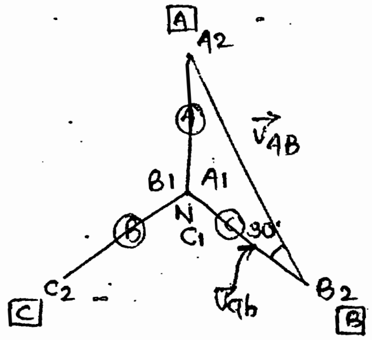
$S_{LV} = S_{HV}$

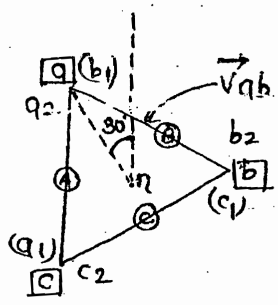
Yd11 →



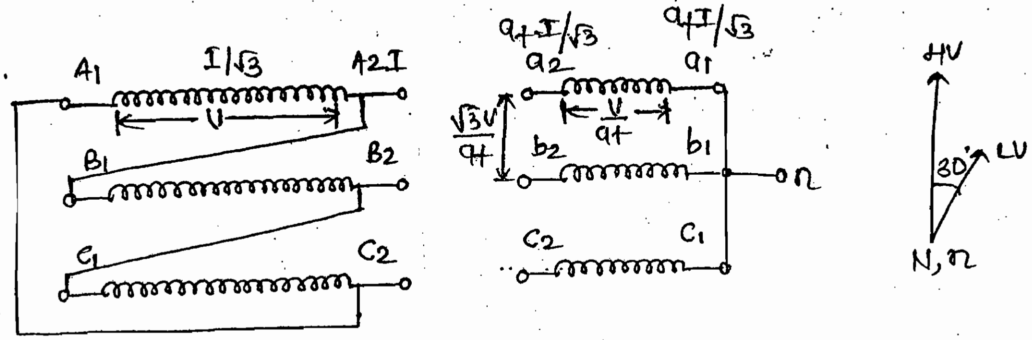


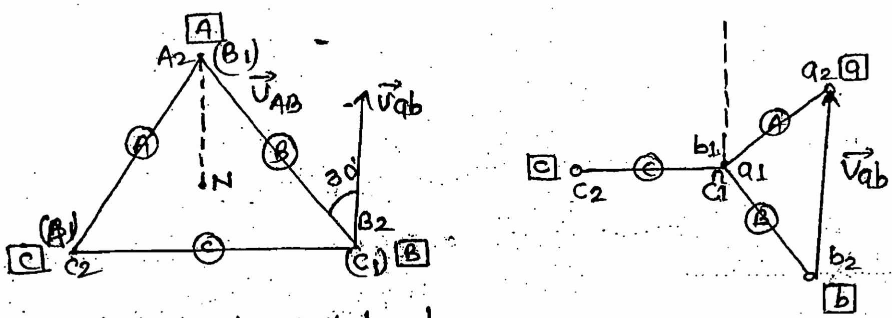






Dy1 →





Hint → Δ limb is decided by λ

Phase vol. Xmation Ration $= V : \frac{V}{a_t} = a_t : 1$

line vol. Xmation Ratio $= V : \frac{\sqrt{3}V}{a_t} = \frac{a_t}{\sqrt{3}} : 1$

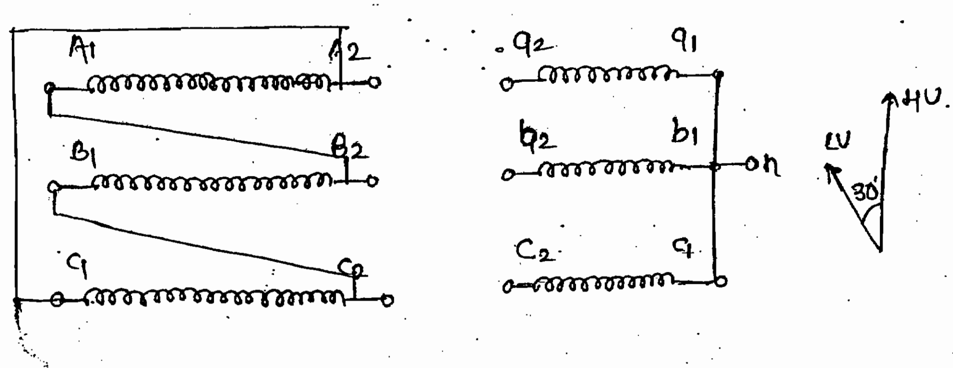
$S_{HV} = \sqrt{3}VI$

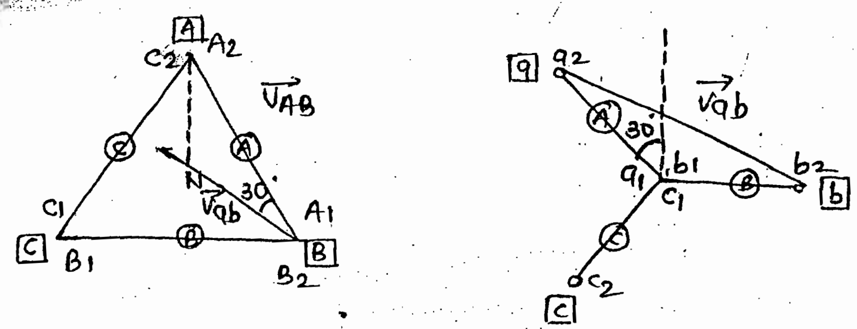
$S_{LV} = \sqrt{3}\left(\frac{\sqrt{3}V}{a_t}\right)\cdot\left(\frac{a_t I}{\sqrt{3}}\right)$

$= \sqrt{3}VI$

$S_{LV} = S_{HV}$

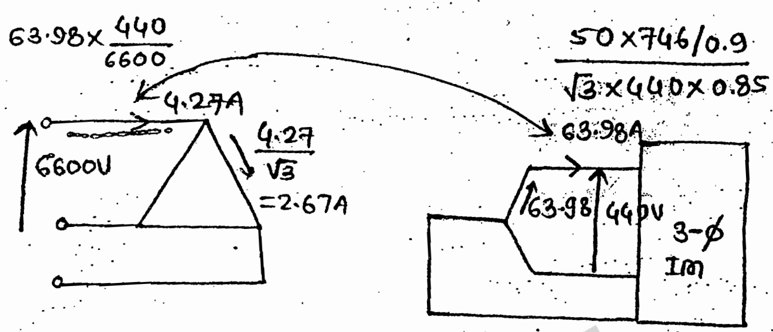
Dy11 →





Que.→ A 50HP 440V 3ϕ-Ind^n motor with an η of 0.9 at a PF of 0.85 on FL is supplied from a 6600/440V Δ-Y connected Xmer. Ignoring the magnetising current cal. the currents in the HV & LV windings of TF when the motor is running at FL.

Sol^n→



Que→ A λ-λ-Δ Xmer with 1°, 2° & 3° voltages of 11kV, 1kV & 0.4kV has a magnetising current of 3A. There is a balance load of 600kVA at 0.8 PF Lagging on the 2° wdg & a balance load of 150 kW on the 3° wdg. Neglecting losses, find the 1° & 3° phase current if the 1° PF is 0.82 lag.

Sol^n→

$$I_1 N_1 = I_2 N_2 - I_3 N_3 - I_0 N_1$$

$$I_1 = I_2 \frac{N_2}{N_1} - I_3 \frac{N_3}{N_1} - I_0$$

$$\vec{S}_1 = \sqrt{3} \times 11 \times I_1 \angle \cos^{-1}(0.82) \text{ kVA}$$

$$\vec{S}_2 = 600 \angle \cos^{-1}(0.8) \text{ kVA} = 600 \angle 36.87 \text{ kVA}$$

$$S_3 = \frac{150}{\cos\phi_3} \angle \phi_3 \text{ kVA} \quad (\text{assuming lag. PF } 3^\circ \text{load})$$

$$S_0 = \sqrt{3} \times 11 \times 3 \angle 90^\circ \text{ kVA}$$
$$= 57.158 \angle 90^\circ \text{ kVA}$$

$$S_3 = \frac{150}{\cos\phi_3} \angle\phi_3$$

$$= \frac{150(\cos\phi_3 + j\sin\phi_3)}{\cos\phi_3}$$

$$S_3 = 150(1 + j\tan\phi_3)$$

$$S_1 = S_2 + S_2 + S_0$$

$$\sqrt{3}\, 11 \times I_1 \angle \cos^{-1}(0.82) = 600 \angle \cos^{-1}(0.8) + (150 + j150\tan\phi_3) + \sqrt{3} \times 11 \times 3 \angle 90^\circ$$

$$15.623 I_1 + j10.905 I_1 = 630 + j\left[360 + 150\tan\phi_3 + 33\sqrt{3}\right]$$

equating real parts;

$$I_1 = \frac{630}{15.623} = 40.325A$$

Equating imaginary parts;

$$10.905 = 360 + 150\tan\phi_3 + 33\sqrt{3}$$

$$\phi_3 = 8.56^\circ$$

$$150 \times 10^3 = \sqrt{3} \times (0.4 \times 10^3) \times I_3(\text{line}) \times \cos(8.56^\circ)$$

$$I_3(\text{line}) = 218.945A$$

$$I_3(\text{ph.}) = \frac{218.945}{\sqrt{3}} = 126.41A$$

$$\boxed{I_1 = 40.32A,\ I_3 = 126.41A}$$

* Star is used for HV, low capacity.
* Δ is used for LV, high capacity.

Applications of diff. 3-ϕ TF connections →

* According to the general recommandation a λ connection is used for High vol., low capacity (kVA) appliⁿ where as a Δ connection is favoured for Low vol. High capacity appliⁿ.

* Since the kVA capacity of a TF is same on both sides, the natural choice would be a λ connection for HV side Δ connection for LV side.

* Accordingaly a λ-Δ Connection is used for a step down appliⁿ where-as a Δ-λ connection is used for step up appliⁿ.

* However there is an exception. In 2° distribution sys. a neutral connection is req. to feed 1-ϕ loads as there are mixed (3ϕ & 1ϕ) loads connected to the system.

Therefore a Δ-λ connection is used in the step down mode in 2° distribution TF.

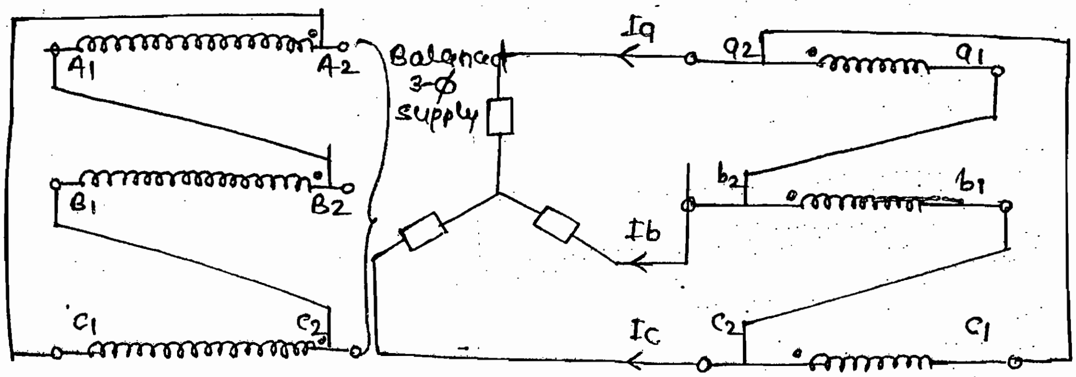
* A Δ-Δ Connection is quite suitable to feed 3-ϕ loads of high capacity at LV levels.

If a 3-ϕ bank of 1-ϕ TF is used in Δ-Δ & a if one TF has to be removed then the remaining 2 TF may still be used in open Δ (or V) connection to continue to supply 3-ϕ loads although at a reduced capacity of 57.7%.

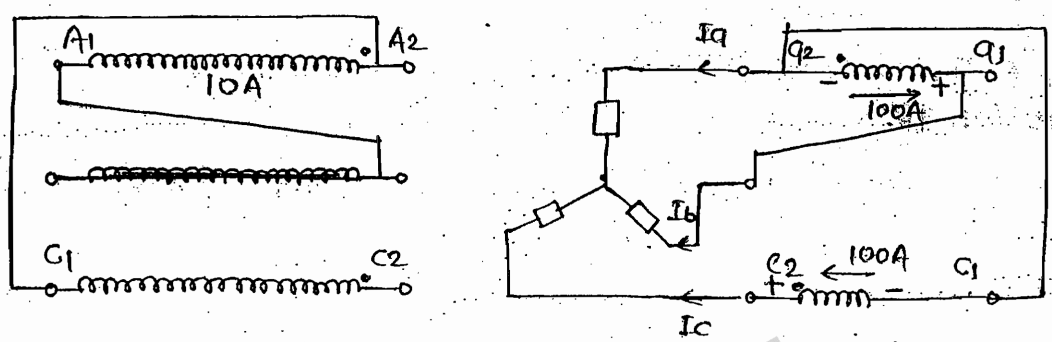
* Although a λ-λ connection appears to be quite attractive for HV appliⁿ it is seldom used without a 3° Δ wdg because of prob. related to magnetising current harmonics, unbalanced loads & unbalanced faults.

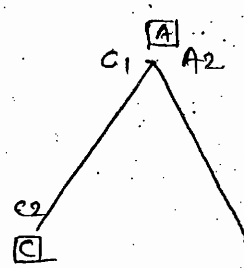
Vee (or) Open Δ-connection

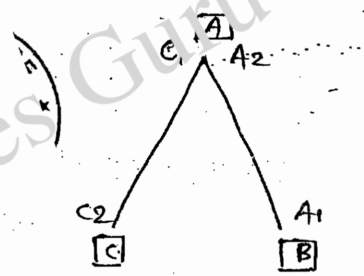
$I = \sqrt{3} \times 100A$



$I = 100A$







$$S_{\Delta\text{-}\Delta} = \sqrt{3}\, V \cdot I$$

$$S_L = \sqrt{3} VI \angle\phi$$

$$S_{Vee} = \sqrt{3} \cdot V \left(\frac{I}{\sqrt{3}}\right)$$

$$= VI$$

$$\frac{S_{Vee}}{S_{\Delta\Delta}} = \frac{VI}{\sqrt{3} VI}$$

$$= \frac{1}{\sqrt{3}} = 0.577$$

$$\boxed{\frac{S_{Vee}}{S_{\Delta\Delta}} = 57.7\%}$$

$$\vec{S_C} = VI\angle\phi+30^\circ = \frac{S_L}{\sqrt{3}}\angle\phi+30^\circ$$

$$\vec{S_A} = VI\angle-(30-\phi)$$

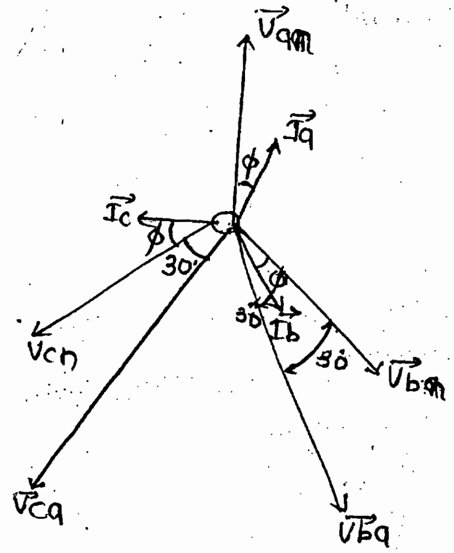
$$\vec{S_A} = VI\angle\phi-30^\circ = \frac{S_L}{\sqrt{3}}\angle\phi-30^\circ$$

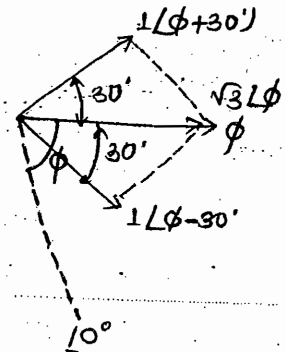
$$\vec{S_C}+\vec{S_A} = VI[1\angle\phi+30^\circ + 1\angle\phi-30^\circ]$$

$$= VI[\sqrt{3}\angle\phi]$$

$$= \sqrt{3}VI\angle\phi$$

$$\boxed{S_C+S_A = \vec{S}_{load}}$$





Que.→ A 3ϕ 1000 kVA 0.866 lag PF load is supplied by V connection at 400V. Determine the kVA o/p & operating PF of each TF. Neglect exciting current & all losses.

Sol^n→

$$\phi = \cos^{-1}(0.866)$$

$$= 30^\circ \text{ lag}$$

$$\vec{S_C} = \frac{1000}{\sqrt{3}}\angle 30+30^\circ$$

$$= 0.577\angle 60^\circ \text{ kVA}$$

at PF 0.5 lag.

$$\vec{S_A} = \frac{1000}{\sqrt{3}}\angle 30^\circ-30$$

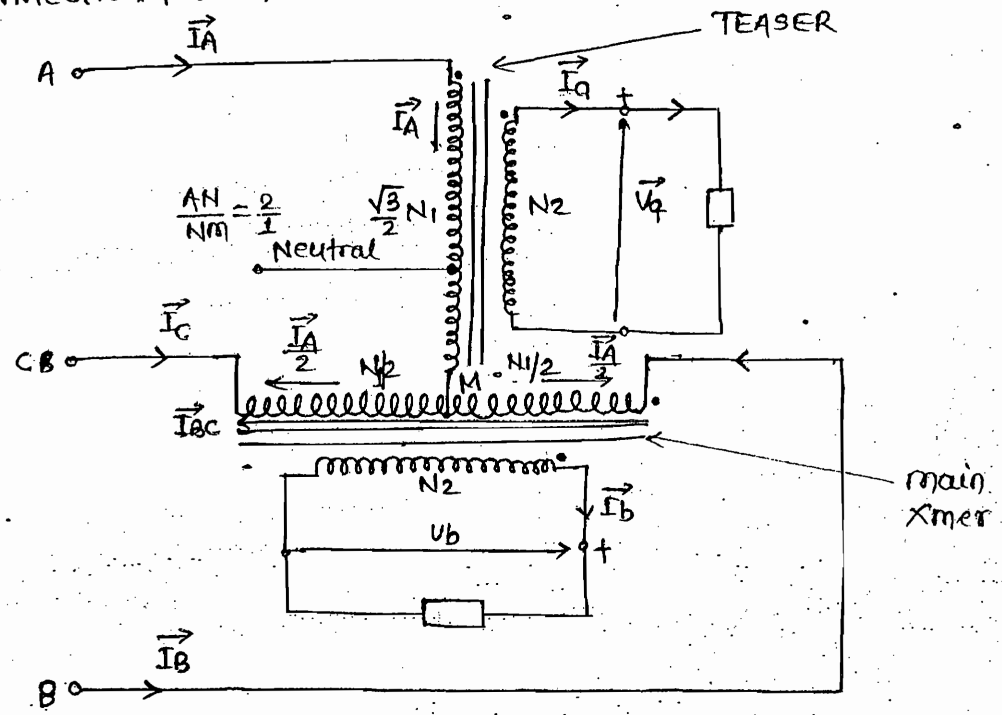
$$= 0.577\angle 0^\circ$$

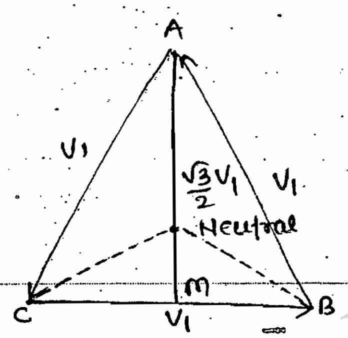
at PF = 0°

DATE 09/11/14

SCOTT CONNECTION

* Scott connection for 3-ϕ to 2-ϕ conversion.





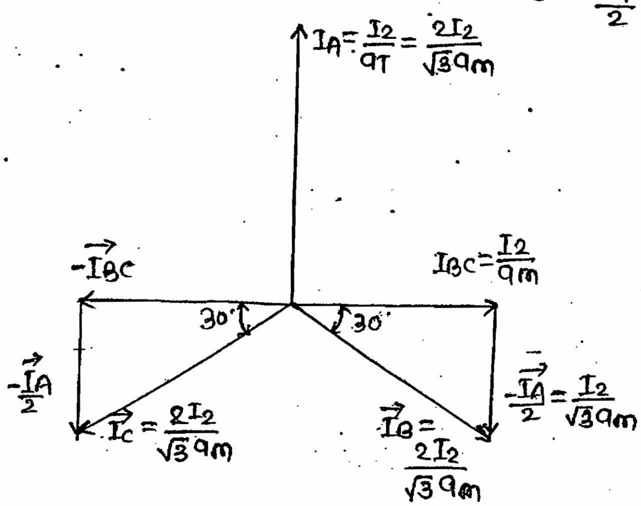
$$a_m = \frac{N_1}{N_2}$$

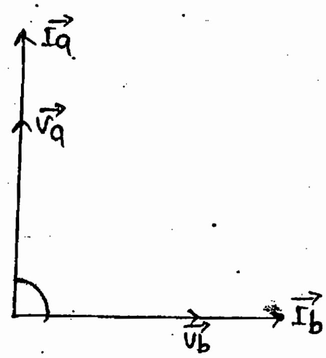
$$a_T = \frac{\sqrt{3}N_1/2}{N_2} = \frac{\sqrt{3}}{2}a_m$$

$$V_b = \frac{V_1}{a_m} \; ; \; V_a = \frac{\sqrt{3}V_1/2}{a_T} = \frac{\sqrt{3}V_1/2}{\sqrt{3}a_m/2}$$

$$V_a = \frac{V_1}{a_m} = V_b$$

$$\vec{I_B} = \vec{I_{BC}} - \frac{\vec{I_A}}{2} \; ; \; I_C = -I_{BC} - \frac{\vec{I_A}}{2}$$





unity pF load. ($I_a = I_b = I_2$)

$$S_{main} = V_1 I_1 \qquad S_{teaser} = \frac{\sqrt{3}}{2} V_1 \times I_1$$

$$\frac{S_{main}}{S_{teaser}} = \frac{2}{\sqrt{3}} = 1.15$$

$$\boxed{\frac{S_m}{S_T} = 1.15}$$

Que.→ 2-1φ Furnaces A & B are supplied at 80V by means of Scott connected Xmer combination for a 3-φ 6600V system. The vol. of Furnace A is leading. Cal. the line currents on the 3-φ side when

(a) The furnaces take 800kW each at 0.8 PF lag.

(b) Furnace A takes 500kW at UPF & B take 800kW at 0.707 PF lag.

Soln→ Let; $V_B = 80\angle 0^\circ$, $V_A = 80\angle 90^\circ$

(a) $a_m = \frac{N_1}{N_2} = \frac{6600}{80}$

$a_m = 82.5 \qquad a_T = \frac{\sqrt{3}}{2} a_m = \frac{\sqrt{3}}{2} \times 82.5 = 71.45$

$a_m = 82.5, \; a_T = 71.45$

$I_b = \frac{800\times10^3}{80\times0.8} \angle -\cos^{-1}(0.8) = 12500\angle -36.87^\circ A$

$I_a = \frac{800\times10^3}{80\times0.8} \angle 90-\cos^{-1}(0.8)$

$I_a = 12500\angle 53.13^\circ A$

$\vec{I}_{BC} = \frac{\vec{I}_b}{a_m} = 151\angle -36.87 A, \quad \vec{I}_A = \frac{I_a}{a_T} = 174.95\angle 53.13^\circ A$

$\vec{I}_B = \vec{I}_{BC} - \frac{\vec{I}_A}{2} \qquad I_c = -I_{BC} - \frac{I_A}{2}$

$= 174.96\angle -66.87^\circ A \qquad = 174.96\angle 173.13^\circ A$

$$\boxed{I_A = 174.95\angle 53.13^\circ A, \; I_B = 174.96\angle -66.87^\circ A \\ I_C = 174.96\angle 173.13^\circ A}$$

(b.) $\vec{I_b} = \frac{800\times10^3}{80\times0.707}\angle-\cos^{-1}(0.707)$ $\qquad$ $\vec{I_a} = \frac{500\times10^3}{80\times1.0}\angle 90^\circ$

$= 14144.27\angle-45^\circ A$ $\qquad$ $= 6250\angle 90^\circ A$

$$\vec{I_{BC}} = \frac{\vec{I_b}}{a_m} = 171.45\angle-45^\circ A$$

$$\vec{I_A} = \frac{\vec{I_a}}{a_T} = 87.47\angle 90^\circ A$$

$$\vec{I_B} = \vec{I_{BC}} - \frac{\vec{I_A}}{2} = 204.72\angle-53.69^\circ A$$

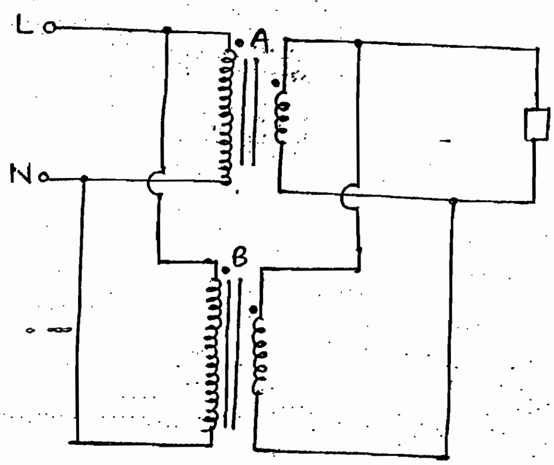
$$\vec{I_C} = -\vec{I_{BC}} - \frac{\vec{I_A}}{2} = 143.89\angle 147.47^\circ A$$

Parallel Operation Of Transformer

Condⁿ to be satisfied for parallel operation of Xmer →

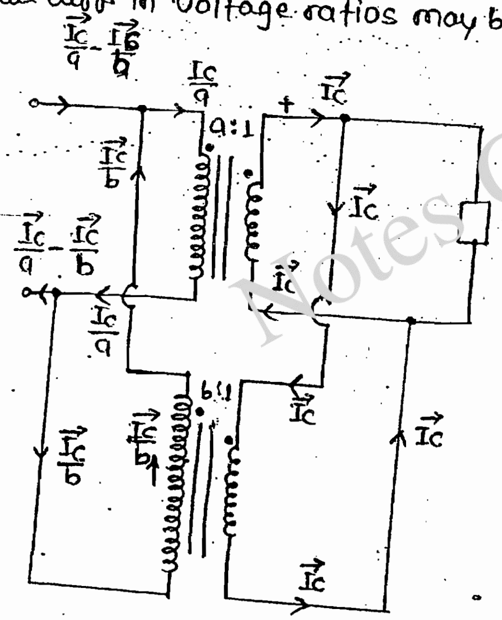
(A.) For 1-ϕ TF & 3-ϕ TF →

(a.) Same polarity. i.e. the dots must be connected to dots. (MUST)



(b.) Equal vol. Ratios (same vol. Rating) (MUST)

Note → A small diff. in voltage ratios may be permitted if unavoidable.



$E_A > E_B$

$\frac{V_1}{a} > \frac{V_1}{b}$

$b > a$

$I_c b > I_c a$

$\frac{I_c}{a} > \frac{I_c}{b}$

(c.) Same pu impedance for proportional load sharing. (desirable)

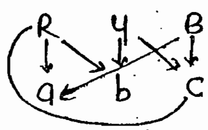
↓

Name plate Zpu

(d.) same $\frac{X}{R}$ ratios. (i.e. same impedance angle) For same PF operation, as that of the load PF (desirable).

(B.) For 3-ϕ TF only →

(e.) same phase sequence (MUST)



(f.) Zero phase diff between the corrosponding line voltage.

This means that TF belonging to same phasor group may alone be parallel. (MUST)

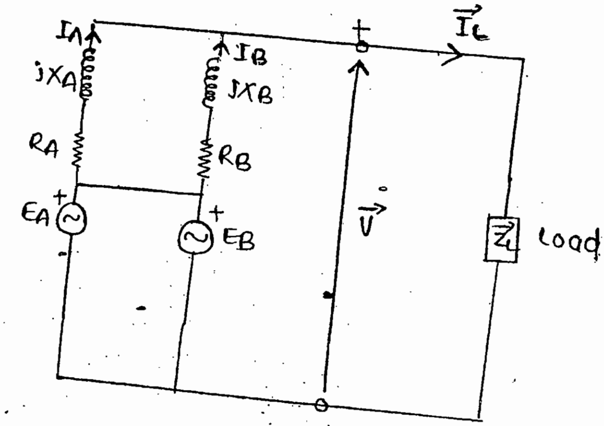
DY11 (a) Yy0 (b) Dd0 (c) Yy6 ~~(d)~~ YD1

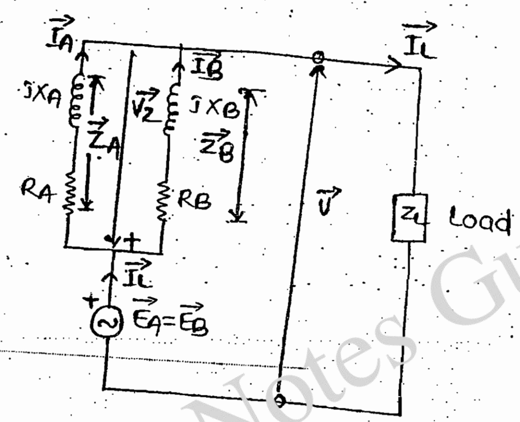
Because if we change the seq. of 1° then get 30° lead/lag.

LOAD SHARING

Equal voltage Ratios

$$E_A = E_B$$





Two Xmer;

$$\vec{V_Z} = \vec{I_A}\vec{Z_A} = \vec{I_B}\vec{Z_B} = \vec{I_L} \times (\vec{Z_P})$$

$$= I_L \times \frac{\vec{Z_A}\vec{Z_B}}{\vec{Z_A}+\vec{Z_B}}$$

where; Z_A & Z_B are in actual volts.

$$\vec{I_A} = \frac{Z_B}{Z_A+Z_B} \times \vec{I_L} \quad \& \quad \vec{I_B} = \frac{\vec{Z_A}}{Z_A+Z_B} \times \vec{I_L}$$

However if the impedance are expressed in pu then there pu values should be converted on a common base to insure that the ohmic ratio remain unchanged.

for 'n'-Xmers →

$$\vec{V_z} = \vec{I_A}\vec{Z_A} \pm \vec{I_B}\cdot\vec{Z_B} = \vec{I_C}\vec{Z_C} \text{ ------ } = \vec{I_n}\vec{Z_n} = \vec{I_L}\times\vec{Z_p}$$

$$\Rightarrow \vec{I_A}\vec{Z_A} = \vec{I_L}\times\vec{Z_p}$$

$$\Rightarrow \vec{I_L} = \cancel{\vec{I_A}}\cancel{\vec{Z_A}} = \frac{\vec{I_A}.\vec{Z_A}}{Z_p}$$

$$\Rightarrow \frac{\cancel{\vec{I_A}\times\vec{Z_A}}}{\cancel{\left(\frac{1}{Z_A}+\frac{1}{Z_B}+\frac{1}{Z_C}+\cdots\frac{1}{Z_n}\right)}} = \cancel{\vec{I_L}}$$

$$\vec{I_A}\vec{Z_A} = \frac{\vec{I_L}}{\left(\frac{1}{Z_A}+\frac{1}{Z_B}+\cdots\frac{1}{Z_n}\right)}$$

$$\vec{I_A} = \frac{\vec{I_L}}{Z_A\left(\frac{1}{Z_A}+\frac{1}{Z_B}+\cdots\frac{1}{Z_n}\right)}$$

$$\boxed{\vec{I_A} = \frac{\vec{I_L}}{\left(\frac{\vec{Z_A}}{Z_A}+\frac{\vec{Z_A}}{Z_B}+\cdots\frac{\vec{Z_A}}{Z_n}\right)}}$$

$$S_A = P_A + jQ_A = V_A I_A^*$$

$$S_A^* = P_A - jQ_A = V^* I_A$$

$$= V^* \frac{Z_B}{Z_A+Z_B}\times\vec{I_L}$$

$$\boxed{\vec{S_A^*} = \frac{\vec{Z_B}}{\vec{Z_A}+\vec{Z_B}}\times S_L^*}$$

Similarly;

$$\vec{S_B} = \vec{V}\cdot I_B^*$$

$$S_B^* = V^*\vec{I_B}$$

$$\boxed{S_B^* = \frac{Z_A}{Z_A+Z_B}\times S_L^*}$$

Per unit loading →

$$\vec{I_j}\,\vec{z}_{j(\Omega)} = \text{constant}$$

$$\vec{I_j} \propto \frac{1}{\vec{z}_{j(\Omega)}}$$

$$V^* \vec{I_j} \propto \frac{1}{\vec{z}_{j(\Omega)}}$$

$$S_j^* \propto \frac{1}{\vec{z}_{j(\Omega)}}$$

$$S_j^* \propto \frac{1}{\vec{z}_{j(PU)} \times z_{j(Base)}}$$

$$S_j^* \propto \frac{1}{z_{j(PU)} \times \left[\frac{V^2_{rated}}{S_{j(rated)}}\right]}$$

$$S_j^* \propto \frac{S_{j(rated)}}{z_{j(PU)}}$$

$$\frac{S_j^*}{S_{j(rated)}} \propto \frac{1}{z_{j(PU)}}$$

$$S_{j(PU)}^* \propto \frac{1}{z_{j(PU)}}$$

* This means that the TF with lowest PU impedance on its own base (i.e. name plate z_{pu}) would have max^m PU loading & therefore would be the 1st to reach its FL.

For proportional load sharing

$$S_j \propto S_{j(rated)}$$

$$\frac{S_j}{S_{j(rated)}} = \text{constant}$$

$$S_{j(PU)} = \text{constant}$$

Since $S_{j(PU)} \propto \dfrac{1}{z_{j(PU)}}$

∴ For proportional load sharing

$$z_{j(PU)} = \text{constant}$$

Que.→ 2-1φ Xmers rated 1000 KVA & 500 KVA respectively are connected in parallel on both HV & LV sides. They have equal voltage ratings of 11kV/400V & there pu impedances are $0.02+j0.07$ & $0.0455+j0.0788$ PU respectively.

(A) How will the following loads will share

360 KVA at 0.9 PF lagging.

500 kW at UPF.

(B) What is the largest value of 0.8 PF lagging load that can be delivered by the parallel combination at the rated vol.

Determine the load shared & operating PF of the 2 TF under these condn.

Soln→ $Z_A = 0.0728\angle 74.05^\circ$ PU ; $Z_B = 0.091\angle 60^\circ$ PU

Because the value of the Z_A is less, then it will go for FL 1st.

Selecting 1000 kVA as common Sbase ; Z_A will same

$$(Z_B)_{new} = 0.091\angle 60^\circ \times \frac{1000}{500}$$

$$(Z_B)_{new} = 0.182\angle 60^\circ \text{ PU}$$

$$S_L = 360 \text{ KVA}$$

Part (A)

(i) $S_L = 360\angle 25.84^\circ$ ~~PU~~ KVA

$$\vec{S_A}^* = \frac{(Z_B)_{new}}{Z_A + (Z_B)_{new}} S_L^*$$

$$= \frac{0.182\angle 60^\circ}{0.0728\angle 74.05^\circ + 0.182\angle 60^\circ} \times 360\angle -25.84^\circ$$

$$= 258.73\angle -29.84^\circ \text{ KVA}$$

i.e. 224.42 kW at 0.8674 PF lagging.

For 2 TF only, $S_B = \vec{S_L} - \vec{S_A}$

& for n TF $S_B^* = \frac{Z_A}{Z_A + Z_{B(new)}} \times S_L^*$

$$\vec{S_B} = 103.49\angle 15.8^\circ \text{ kVA}$$

i.e. 99.58 kW at 0.9622 PF lag.

(ii) $S_L = \frac{500}{10}\angle 0^\circ$ kVA

$$S_A^* = \frac{Z_{B(new)}}{\vec{Z_A} + Z_{B(new)}} \times 500\angle 0^\circ$$

$$= 359.34\angle -4^\circ \text{ kVA}$$

i.e. 358.47 kW at 0.9976 PF lag.

For 2 Xmer only; $\vec{S_B} = \vec{S_L} - \vec{S_A}$

n TF use common formula $S_B^* = \frac{\vec{Z_A}}{\vec{Z_A} + \vec{Z_{B(new)}}} \times S_L^*$

$$\vec{S_B} = 143.74\angle -10.04^\circ \text{ kVA}$$

i.e. 141.54 kW at 0.9847 PF lead.

(B) Since $S_{pu} \propto \frac{1}{Z_{pu}}$; TF A would reach FL; 1st

$$S_{pu} \propto \frac{1}{Z_{pu}}$$

$$Z_A < Z_B$$

Then $\vec{S_A} = 1000\angle\phi_A$ kVA

Since $S_j^* \propto \frac{1}{Z_j(\Omega)}$

$$\frac{S_B^*}{S_A^*} = \frac{Z_A(\Omega)}{Z_B(\Omega)} \quad \text{OR} \quad \frac{S_B^*}{S_A^*} = \frac{\vec{Z_A}}{\vec{Z_{B(new)}}}$$

$$S_B^* = S_A^* \frac{Z_A}{Z_{A(new)}}$$

$$S_L^* = S_A^* + S_B^*$$

$$= S_A^* + S_A^* \times \frac{\vec{Z_A}}{\vec{Z_{B(new)}}}$$

$$= S_A^* \left[1 + \frac{\vec{Z_A}}{\vec{Z_{B(new)}}}\right]$$

$$S_L^* = S_A^* \left[1.3914 \angle 4^\circ\right]$$

$$= 1000 \angle -\phi_A * 1.3914 \angle 4^\circ$$

$$S_L \angle -36.87^\circ = 1391.4 \angle 4^\circ - \phi_A \text{ KVA}$$

$$\max^m S_L = 1391.4 \text{ KVA}$$

Equating angles $\Rightarrow -36.87^\circ = 4^\circ - \phi_A$

$$\phi_A = 40.87^\circ$$

i.e. $\vec{S_A} = 1000 \angle 40.87^\circ$ KVA

~~7/2~~ 756.2 KW at 0.7562 PF lag.

New $\vec{S_B} = S_L - S_A$ for 2 TF

Also in general $S_B^* = S_A^* \times \dfrac{\vec{Z_A}}{Z_{B(new)}}$

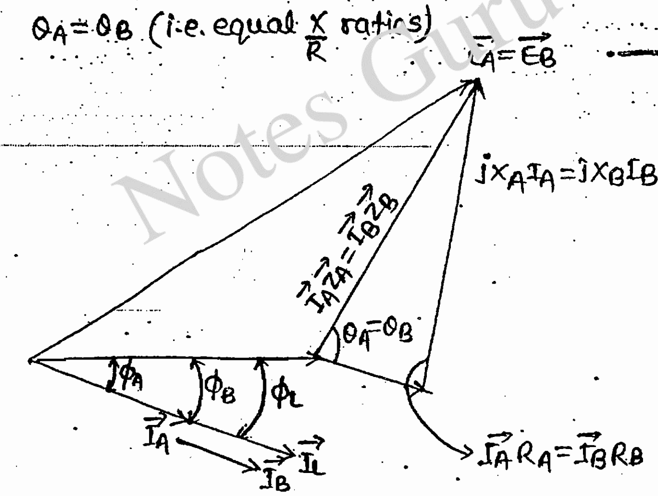
$$\vec{S_B} = 399.97 \angle 26.83^\circ \text{ KVA}$$

i.e. 356.92 KW at 0.8923 PF lag.

Phasor diagram $\rightarrow$

$E_A = E_B$

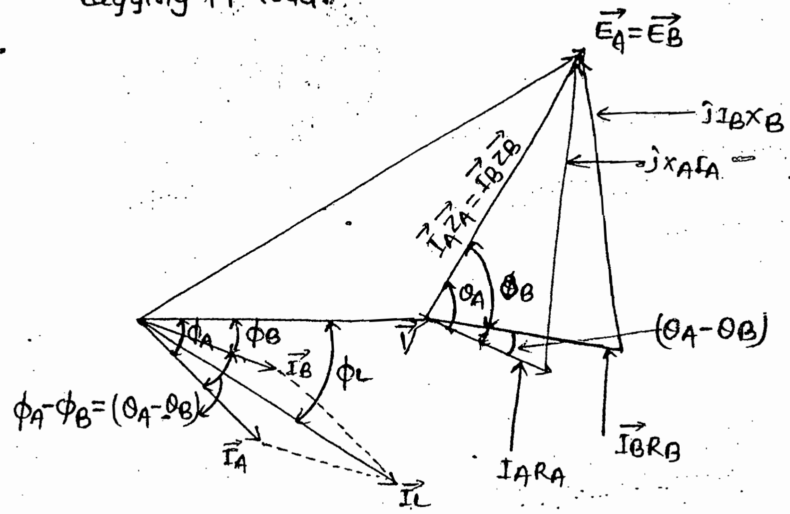
$\theta_A = \theta_B$ (i.e. equal $\frac{X}{R}$ ratios)



$E_A = E_B$

$\theta_A > \theta_B$ (a unequal $\frac{X}{R}$ ratio)

lagging PF load.



Unequal Voltage Ratios →

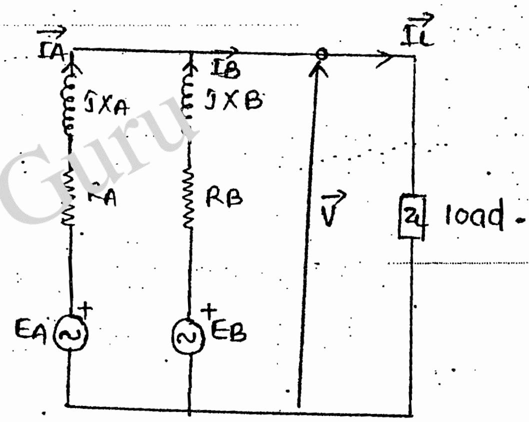
$E_A > E_B$

$E_A = \vec{V} + \vec{I_A}\vec{Z_A}$

$= (\vec{I_L}\cdot\vec{Z_L}) + \vec{I_A}\vec{Z_A}$

$\vec{E_A} = (\vec{I_A} + \vec{I_B})\vec{Z_L} + \vec{I_A}\cdot\vec{Z_A}$

$(\vec{Z_A} + \vec{Z_B})\cdot\vec{I_A} + \vec{I_B}\vec{Z_L} = \vec{E_A}$ ——(i)



Steps→ $Z_L\vec{I_A} + (Z_B + Z_L)\,I_B = E_B$ ——(ii)

(i) calculate $\vec{I_A}$ & $\vec{I_B}$

(ii) $\vec{I_L} = \vec{I_A} + \vec{I_B}$

(iii) $\vec{V} = \vec{I_L}\cdot\vec{Z_L}$

(iv) $\vec{S_A} = \vec{V}\cdot I_A^*$; $\vec{S_B} = \vec{V}\cdot I_B^*$

Use of Millman's theorem (OR) parallel generator theorem →

Steps→

(i) $\vec{V} = \vec{I_{sc}}\,\vec{Z_p}$

where $\vec{I_{sc}} = \sum_{j=1}^{n} \frac{E_j}{Z_j}$

& $\frac{1}{\vec{Z_p}} = \frac{1}{\vec{Z_L}} + \sum_{h=1}^{n} \frac{1}{Z_j}$

(2.) $\vec{I_j} = \dfrac{\vec{E_j} - \vec{V}}{\vec{Z_j}}$ where; $j = 1, 2, \ldots, n$.

(3.) $\vec{S_j} = \vec{V} \cdot \vec{I_j}^*$ where; $j = 1, 2 \ldots n$

$\vec{S_L} = \sum_{j=1}^{n} \vec{S_j}$

Calculation check

Also; $\vec{S_L} = \dfrac{(V)^2}{Z_L^*}$

$S_L = V \cdot I_L^*$

$= V \cdot \left(\dfrac{V}{Z_L}\right)^*$

$= \dfrac{V \cdot V^*}{Z_L^*}$

$= \dfrac{V^2}{Z_L^*}$

Que.→ 2 TF A & B are connected in parallel to a common load $2 + j1.5\,\Omega$. There impedances in 2° terms are $Z_A = (0.15 + 0.5j)\,\Omega$ & $Z_B = (0.1 + 0.6j)\,\Omega$. There NL terminal voltages are $E_A = 207\angle 0°$ & $E_B = 205\angle 0°$. Find the power o/p & PF of each TF.

Solⁿ→

$\vec{I_{sc}} = \dfrac{\vec{E_A}}{Z_A} + \dfrac{\vec{E_B}}{Z_B}$

$= \dfrac{207\angle 0°}{(0.15 + 0.5j)} + \dfrac{205\angle 0°}{0.1 + 0.6j}$

$= 732.105\angle -76.625°$

$\dfrac{1}{Z_p} = \dfrac{1}{Z_L} + \dfrac{1}{Z_A} + \dfrac{1}{Z_B}$

$(Z_p)^{-1} = (Z_L)^{-1} + (Z_A)^{-1} + (Z_B)^{-1}$

$Z_p = 0.258\angle 72.85°$

$\vec{V} = \vec{I_{sc}} \cdot \vec{Z_p}$

$= 189.25\angle -3.78°\,V$.

$S_A = V \cdot I_A^*$

$= 7.988\angle 35.03°\,kVA$

i.e. 6.541 kW at cos 35.03° lag

i.e. 0.8189 PF lag

$S_B = V \cdot I_B^*$

$= 6.353\angle 39.09°\,kVA$

i.e. 4.931 kW at cos 39.09 PF lag

i.e. 0.7762 PF lag

$S_L = S_A + S_B$

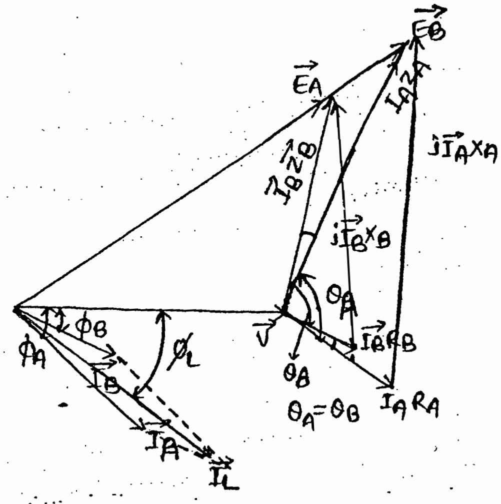
$= 14.332\angle 36.828°$

$I_A = \dfrac{E_A - \vec{V}}{Z_A} + \cancel{\dfrac{E_B - \vec{V}}{Z_B}} = 42.21\angle -38.81\,A$

$I_B = \dfrac{E_B - \vec{V}}{Z_B} = 33.57\angle -42.87°\,A$

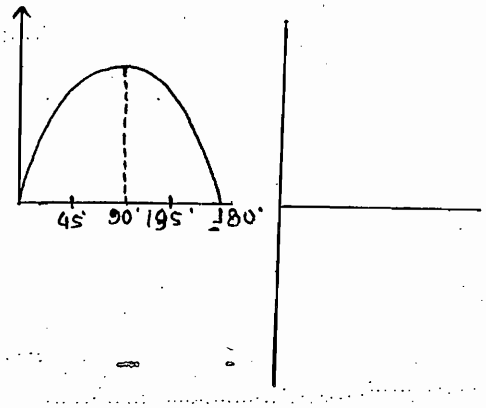
Phasor diagram →

$E_A > E_B$, $\theta_A = \theta_B$, lagging PF load.

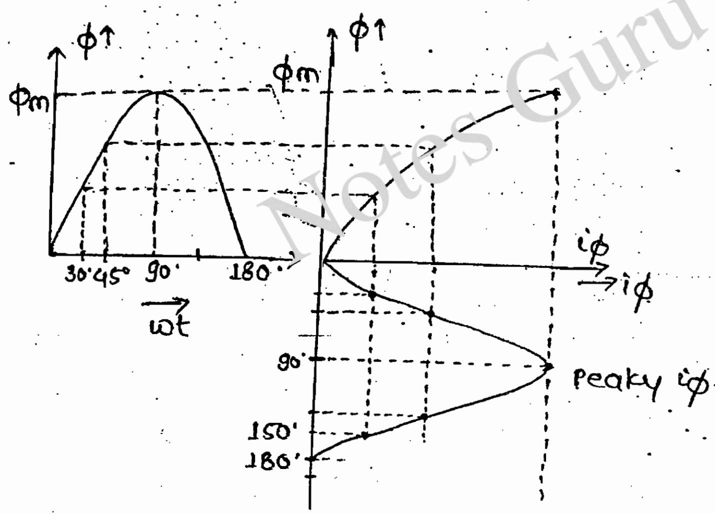


* Magnetisation Current phenomenon in the TF →

* If the applied vol. to the TF is sinusoidal then the core flux should also be sinusoidal.
* ~~If~~. the magnetisation curve of core material would have been linear then the magnetising current would also have been sinusoidal.



* Model TF are operated with high flux density in the core due to economic reason & this drives the core into deep saturation. Obeously the magnetisation curve becomes highly non-linear.

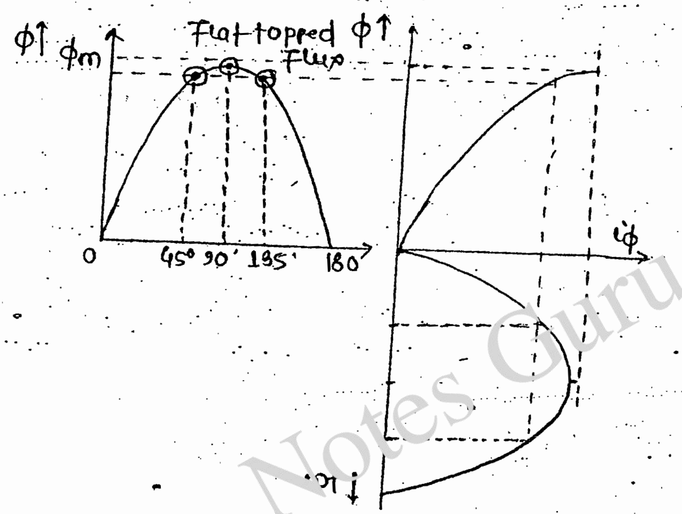


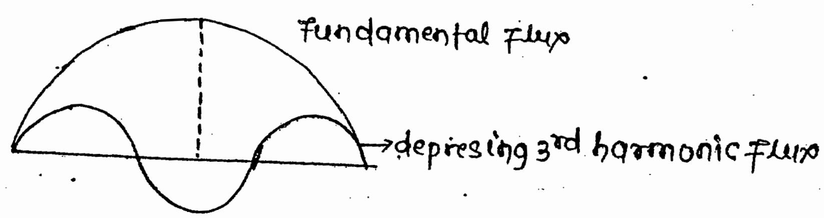
* With such a non-linear magnetisation c/s a sinusoidal flux may only be obtained with a peaky magnetising current containing dominant a 3rd harmonic componant.

* The 3rd harmonic component of the magnetising current may flow only if the electric circuit permits.
Thus it can easily flow in 1-ϕ TF of 1-ϕ circuit. However in 3-ϕ TF the 3rd harmonic current of 3 phasors are all in phase; thereby constituting 0 seq. current.
Hence they can flow only in the 1° star neutral of the TF is connected to the source neutral (or) it can flow in closed Δ.

* In a λ-λ TF there is no path for flow of 3rd harmonic components of magnetising current & therefore the magnetising current remains sinusoidal if higher non-triplant odd harmonics are neglected.

* With a sinusoidal magnetising current the core flux becomes flat toped containing dominant depresing 3rd harmonic flux component.





* The 3rd harmonic componant of flux may get easily establish only is magnetic ckt permits.
Hence the 3rd harmonic flux componants may get established easily in those TF that have independant magnetic ckts such as in 3-ϕ bank of 1-ϕ TF, 3ϕ shell type TF & 5 limbed (OR 4 limbed) core type TF.

* Concequently in magneticaly independant TF the 3rd harmonics flux gets strongly established resulting into a peaky ~~induced~~ emf in both wdgs; that in creates high insulation stress in both wdgs in addition to producing a highly objecnable phenomenon called oscillating neutral.

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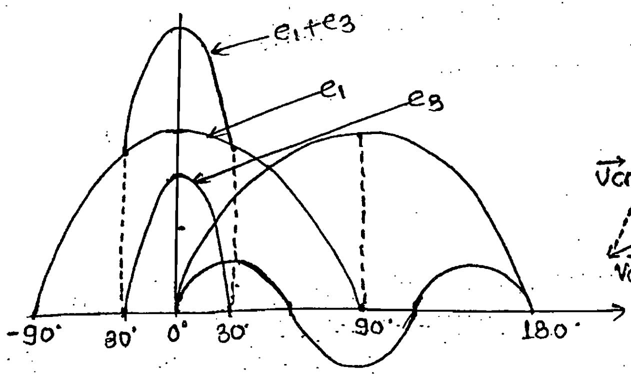
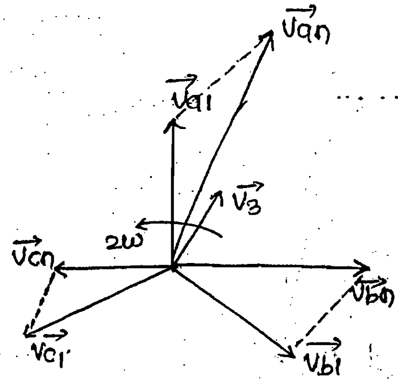
$\vec{V}_{a3}=\vec{V}_{b3}=\vec{V}_{c3}=\vec{V}_3$



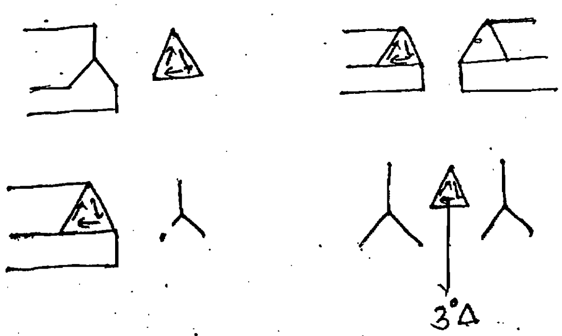


oscillating neutral

* The soln to the above prob. is to provide a 3°Δ wdg in a λ-λ TF so that the electric ckts permits flow of 3rd harmonic componants in the closed 3°Δ, that eventualy would restore harmonic variation to the core flux.

* The presence of a Δ-wdg provides a low reluctance path for 0-seq. currents & therefore restores harmonic variation (sinusoidal) to the core flux & also facilitates 1-φ loads besides reducing the effect of floating (or) shifting neutral.

It also prevents current choking in λ-λ TF. The presence of Δ also helps in detection of unsymmetrical faults; perticularly those involving ~~drum~~ ground.



* The problems discussed above relate to those TF that have magnetically independant ckts.
However a 3-limb core type TF has magnetically interlinked ckt & therefore the 3rd harmonic flux forming 0 seq. finds a very high reluctance path through air & tank valves.
Consequently the magnitude of 3rd harmonic flux remains extreamly low although it ultimately results in tank valve heating.
Therefore large 3 limb core TF are provided with a cu ring that surrounds the core thereby providing a cu screen for the 3rd harmonic flux & minimizes tank valve heating.
Hence a 3-limbed core type TF may be connected in λ-λ without a 3°Δ.
However if the unbalance is expected to exceed then it is recommended to use a 3°Δ wdg.

* A 3 limbed core type TF does not permit easy excess to 3rd harmonic flux & this results into increased 5th & 7th harmonic componants in the magnetising current.
These componant can't be suppressed by any electric connection. Hence if these harmonics are objectionable then a 4-limbed (or) 5 limbed st. should be provided.

Note:- The 1° λ neutral in a λ-λ connection is not connected to the genr neutral to provide a path for 3rd harmonic componant of magnetising current.
This is because the genr ϕ vol. itself contain 3rd harmonic vol. & this would appear across the 1° ϕ of TF.
Obeously then the 2° λ ϕ would now contain 3rd harmonic vol. componant in all its 3-ϕ.
Since the 2° λ neutral would be grounded, 3rd harmonics currents would flow in the xn line resulting into objecnable communication interferance. Thus the other alternative of providing a 3°Δ wdg is adopted to allow flow of 3rd harmonics of magnetising current.

Mislaneous →

Phantom loading → Rated current flowing but not rated load.

* Shell type → High current low voltage (Cu surrounded iron)
* Core type → High vol. low current.
  Iron surrounded Cu.
* Yoke – 20% higher then core (cross sectional area)
* $\circ \xrightarrow[I]{} \circ$ area ↑
* Core type – circule wdg (round coil) so max^m area ~~fore~~
* Stepped core is used in big TF.
* two stepped – crusiform (max^m area)(min^m perimeter)
* Stepping – provides circular shaped (for max^m mechanical strength)
* linear dimentions → k times
  KVA Rating – k^4 times
  losses – k^3 times
  surface area – k^2 times

If k=3, KVA – 81 & loss – 27 times, area – 9 times
so heat dessipation problem.
so linear dimention ↑ then improve cooling for this

REM → moment of inertia – k^5 times
for small TF – cooling (Air natural) (AN)
Big TF – cooling (air forced / air blast)
Oil. (oil natural air natural) (ONAN)
oil (oil forced – through pump air natural) (OFAN) Radiator size ↑
oil forced air forced (OFAF)

* Tap changer → ON load (costly) cooling must be good
→ off load (cheap)

Tap changer → HV side
(100:1)

If one turn change in LV then 100V in HV.

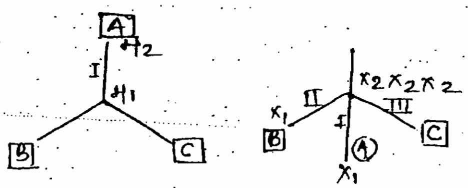
Taps are used in center because of axial force are balanced.in

* Core type - circular coil
Shell type - Rectangular/
→ Helical wdg (HV)
→ disc (HV) invariably large TF

Spiral wdg - ~~2000~~ 100A↑

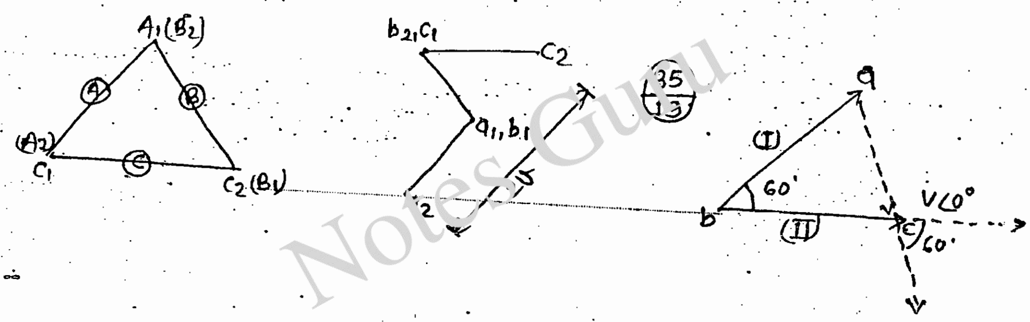
cross over coil - 20A (max^m) low capacity HV coil

22/17



23/17 ϕ is +ve for lagging PF.

24/17 32/19



SYNCHRONOUS MACHINE

– Sagar Sen
8871453536

$$f = \frac{PN}{120} \text{ Hz}$$

$$50 = \frac{PN}{120}$$

$$PN = 6000$$

armature wdg → stator (OR) Rotor means both. because of generation of AC
armature wdg → Rotor (dc m/c) (RDAR)

Field (or) cond^r both can rotate.

247 MVA, 0.85 PF lag, 3-ϕ Gen^r, 50Hz, 3000 rpm

<u>armature wdg :-</u> 3-ϕ AC, 15.75 kV, 9050A, double star → on stator.

(Parallel line)

insulation, High current, cooling are difficult in above.

<u>Field wdg :-</u> 2600A dc, 310V dc → on rotor.

5Hz → Gives lamps flicker effect.
100Hz → Gives x^n problem.
50Hz → Reliable. (std.)

(freq.↑ size↓)

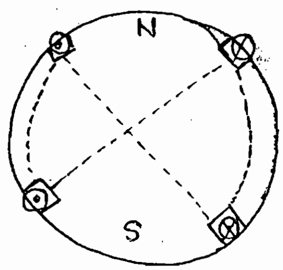
* cylindrical rotor/ Round Rotor/ Non-salient

* turbogenerator – Ni cd (3000 RPM) No lamination
Rotor

Relative velocity 0.

– 115cm diameter (periphery)↓ area for poles↓.

Cylindrical Rotor/Non-salient.

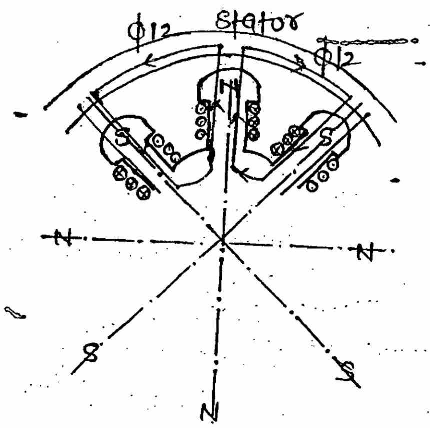


Poles: $\frac{1}{3}$rd

field wdg = $\frac{2}{3}$rd

$P \not> 4$

Salient pole rotor (salient - projected)



* ~~leakage flux~~ doesn't take place in the power transfer. like electric choke.
* mutual flux is responsible for power transfer.

Sinusoidal waveform → ~~*~~This only producing the ~~REF~~ RMF

* This can be expressed in complex (phasors).

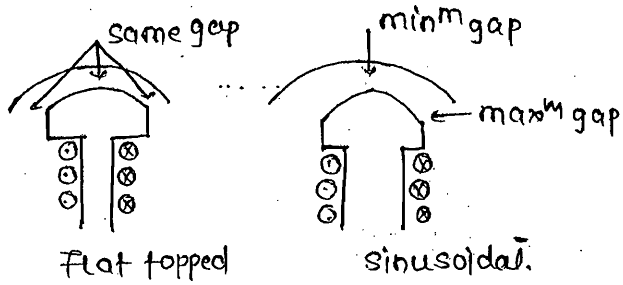
BLV
↳ Not sinusoidal.
→ must be sinusoidal.

flux per pole – Total no. of ~~flux pole~~ flux line that an observer were find in total N-space. (1-pole pitch)

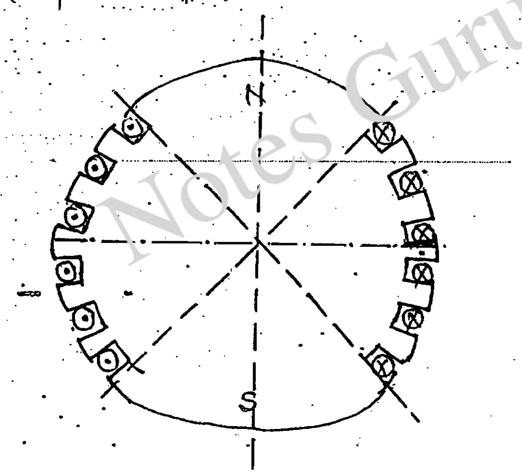
Sinusoidal flux density distribution in the air gap:-

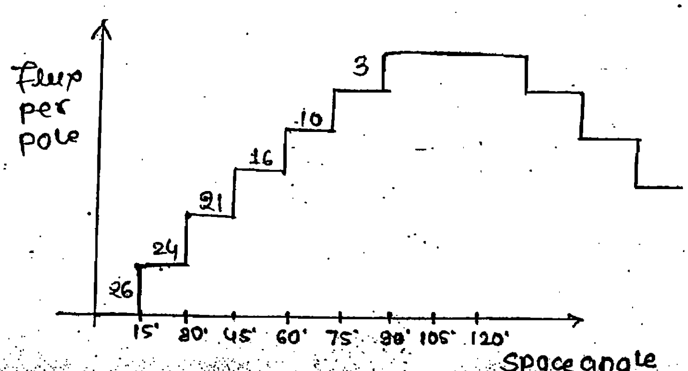
(1) The req. waveform of generated vol. is sinusoidal.

(2) A sinusoidal vol. may only be generated if the radial flux density in the air gap is sinusoidal.



(3) In a salient pole rotor the field wdg is concentric but concentrated & therefore the field mmf in the air gap of the pole arc is constant. Hence a sinusoidal flux density distribution may be obtained by shaping the pole such that the air gap at the center of pole kept minm & goes on increasing as one moves away from the center of the pole. Offcource the variation in the airgap should be compatible with the desired sinusoid. (Ref above fig)





In a cylindrical rotor the field wdg is concentric but distributed in space in no. of slots. The air gap however is uniform & therefore the reluctance of airgap is constant.

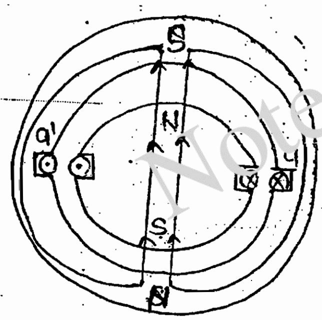
Therefore a sinusoidal flux density may only be obtain with a sinusoidal field mmf wave.

This may be obtained by providing max^m no. of turns in the slots adjecent to the interpolar axis & the no. of turns in the subsequent slots goes on decreasing as one approaches the pole. Such that the min^m no. of turns is provided in the slots adjecent to the pole.

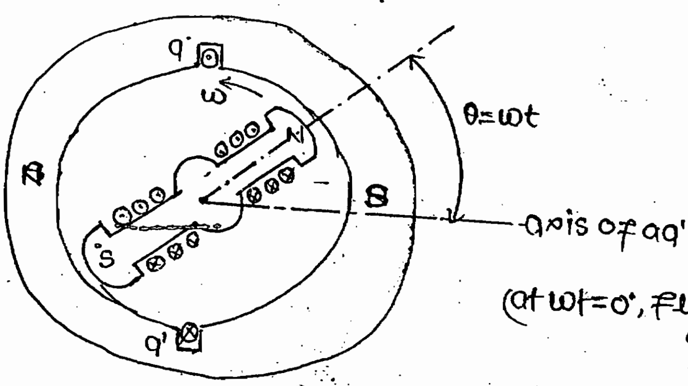
Offcourse the variation in the no. of turns the diff. slots should be compatible with the desired flux density distribution.

Such a provision results into a stepped field mmf wave that approximate a sinusoid.

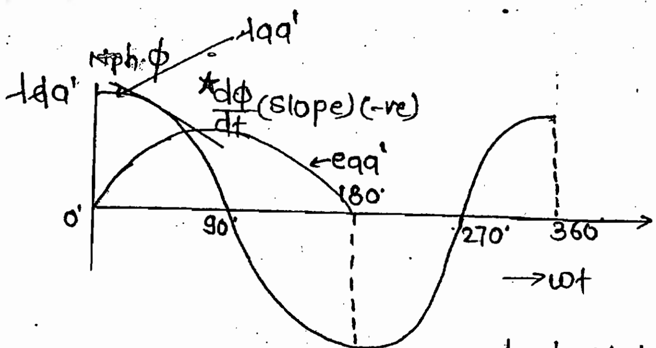
A perfact sinusoidal mmf may only be obtained if the no. of field slots is infinite.



Induced EMF →



(at ωt=0°, flux will max^m) at a & a'



$\lambda aa' = N_{ph}\cdot\phi\cos\omega t.$

P = No. of pole, N = speed in rpm.

$$f = \frac{PN}{1000}\ Hz$$

ϕ = flux/pole ;= Bavg × Area/pole

$$= \left(\frac{2}{\pi}B_m\right) \times \frac{\pi DL}{P} \quad wb/pole$$

N_{ph} = No. of turns/phase.

$$e_{aa'} = \pm\frac{d}{dt}(\lambda aa')$$

$$e_{aa'} = -\frac{d}{dt}(\lambda aa')$$

$$e_{aa'} = -\frac{d}{dt}(N_{ph}\cdot\phi\cdot\cos\omega t) \quad = -\left[N_{ph}\,\phi\,\frac{d}{dt}(\cos\omega t) + N_{ph}\cos\omega t\,\frac{d\phi}{dt}\right]$$

$$\cancel{= N_{ph}\,\phi\,(-\sin\omega t)\,\omega t} \quad = -\left[N_{ph}\cdot\phi\,\omega(-\sin\omega t) + N_{ph}\cos\omega t\,\frac{d\phi}{dt}\right]$$

$$\cancel{= N_{ph}\,\phi\,\omega\,\sin\omega t} \quad = \left[N_{ph}\cdot\phi\,\omega\sin\omega t - N_{ph}\cos\omega t\,\frac{d\phi}{dt}\right]$$

$$\cancel{= N_{ph}\cdot\phi\,\omega t\cdot\sin\omega t}$$

~~$e_{aa'}$ = speed voltage~~

$$\boxed{e_{aa'} = \underbrace{N_{ph}\cdot\phi\,\omega\sin\omega t}_{\text{speed voltage}} - \underbrace{N_{ph}\cos\omega t\,\frac{d\phi}{dt}}_{\text{Xmer voltage}}}$$

Since all synchronous m/c have there field excited by dc, $\frac{d\phi}{dt} = 0$

$$e_{aa'} = N_{ph}\cdot\phi\,\omega\sin\omega t = \underbrace{N_{ph}\cdot\phi\,\omega}_{\text{max}^m\text{ value}}\cos(\omega t - 90^\circ)$$

Therefore Rms $E_{ph} = \dfrac{N_{ph} \cdot \phi \omega}{\sqrt{2}}$

$$= \frac{N_{ph} \cdot \phi (2\pi f)}{\sqrt{2}}$$

$$E_{ph} = \sqrt{2}\pi f \phi N_{ph}$$

$$\boxed{E_{ph} = \sqrt{2}\pi f \phi \cdot N_{ph}} \text{ volts/ph.}$$

Valid for full pitched concentrated winding

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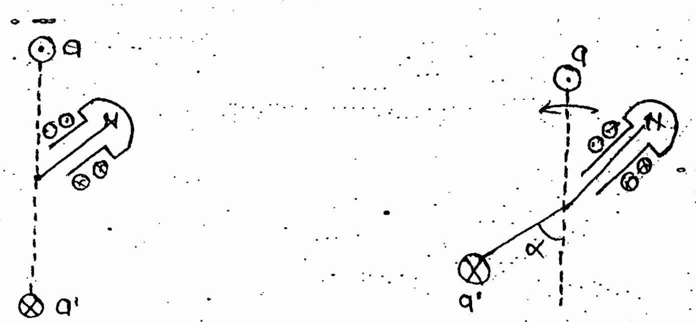
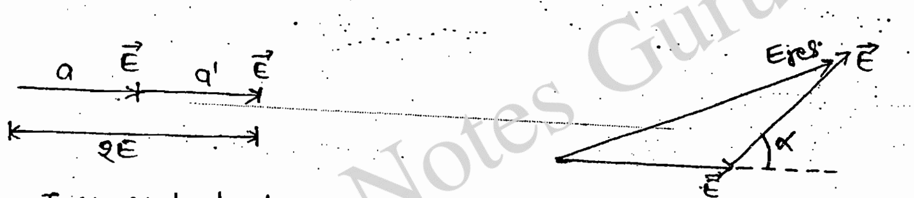
Chorded winding →





Full pitched wdg

$E_{res} = 2E\cos\frac{\alpha}{2}$ CHORDED wdg.

chording factor/coil span factor/pitch factor

$$\boxed{k_c = \cos\frac{\alpha}{2}} \text{ for fundamental}$$

For nth harmonic voltage

replace($\alpha = n\alpha$)

Then $\boxed{k_{c(n)} = \cos\frac{n\alpha}{2}}$

To eliminate nth harmonic $\frac{n\alpha}{2} = 90°$

$$\boxed{\alpha = \frac{180°}{n}}$$

However practical value of $\boxed{\alpha \text{ is } 30^\circ \text{ elect. } (\alpha = 30^\circ)}$ ***

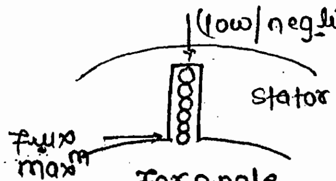
If m-phase sys. the $2m \pm 1$ (Belt harmonics)

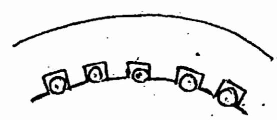
$m = 3$ (3-ϕ sys) 5th & 7th harmonics are belt harmonics

* chording reduces the harmonics
* If $\alpha = 60^\circ$, more cu will be needed, so cost increases here.

$$\boxed{E_{ph} = K_c \sqrt{2}\pi f \cdot \phi N_{ph}} \text{ volt}/\phi$$

(valid for chorded but concentrated wdg.)

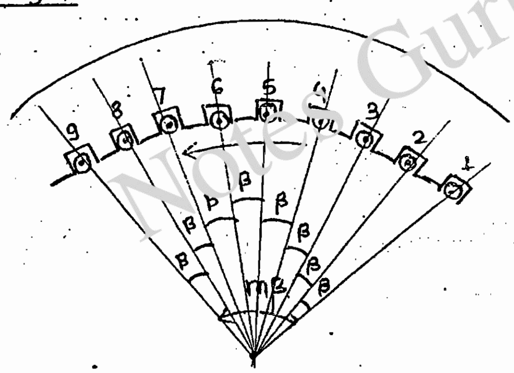


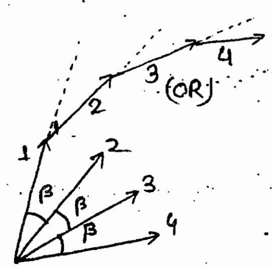


* Iron increases because of depth increasing.
* ~~So~~ Needed more iron

* Iron reduces & flux is same for all the cond^r.
(Good design)
* Iron needed reduces.

* Distributed winding →





β = angle between adjacent slots.

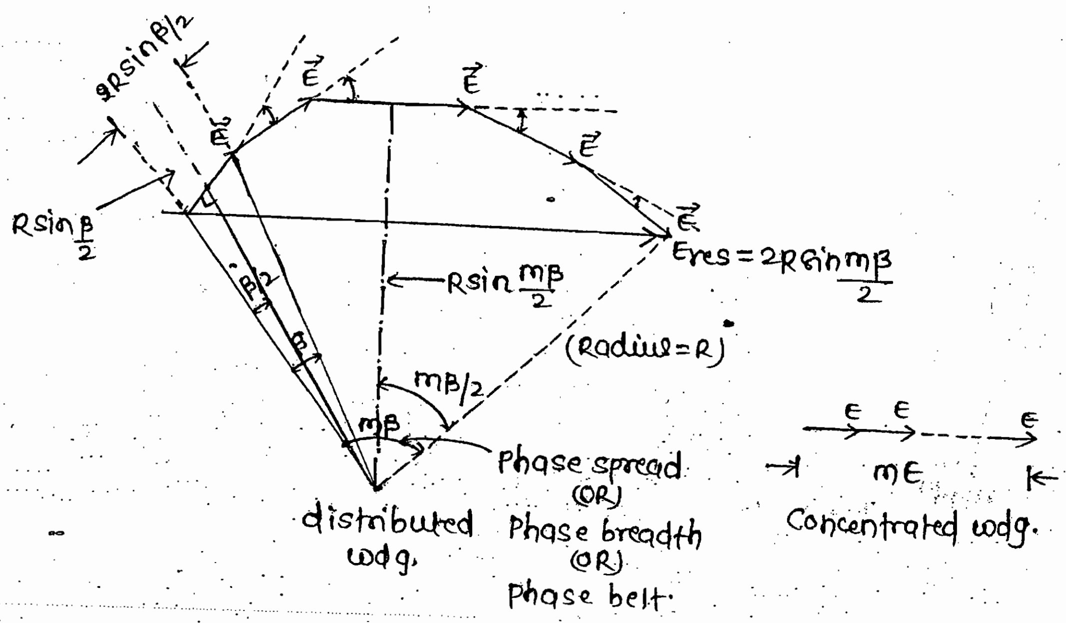
$$= \frac{360^\circ}{\text{No. of slots}} \text{ mech.}$$

$$= \frac{P}{2} \times \frac{360^\circ}{\text{No. of slots}} \text{ mech. ele}$$

$$= \frac{180^\circ}{\text{No. of slots per pole}} \text{ elec.}$$

m = (No. of slots per pole) per phase = No. of slots per pole phase

= (no. of slots / pole) / phase



distribution factor; $k_d = \dfrac{2R\sin\frac{m\beta}{2}}{mE}$

$= \dfrac{2R\sin\frac{m\beta}{2}}{m \times 2R\sin\frac{\beta}{2}}$

$$\boxed{k_d = \dfrac{\sin\frac{m\beta}{2}}{m\sin\beta/2}}$$ For Fundamental.

* For nth harmonics;

Replace β by nβ

$$\boxed{k_{d(n)} = \dfrac{\sin\frac{m(n\beta)}{2}}{m\sin\left(\frac{n\beta}{2}\right)}}$$

*** distributed & chorded wdg is used mainly for reduction of harmonics.

approx kd for fundamental vol.

since $\frac{\beta}{2}$ is very small

$$\sin\frac{\beta}{2} \simeq \frac{\beta}{2}$$

then $$kd = \frac{\sin\frac{m\beta}{2}}{\frac{m\beta}{2}}$$

$$\text{approx } kd = \frac{\sin\frac{\text{Phase spread}}{2}}{\frac{\text{Phase spread}}{2}}$$

$$\boxed{\begin{aligned} E_{ph} &= k_c k_d \times \sqrt{2}\pi f \phi N_{ph} \text{ volts}/\phi \\ &= k_w \sqrt{2}\pi f \phi N_{ph} \ V/\phi \end{aligned}}$$

valid for chorded & distributed wdg.

where $k_w = k_c k_d$ = winding factor.

Que → A 3ϕ 2P 3000 Rpm λ connected cylindrical rotor turbogenerator has the following data

No. of slots = 60, max^m flux density in air gap = 1.32T

mean air gap dia = 1.12m, effective axial length = 3m,

No. of turns/ϕ = 10

Cal. the line to line vol. on N.L if the coil span is $150°$.

Sol^n →

$\alpha = 180° - 150°$
$= 30°$ ele.

$K_c = \cos\frac{30}{2} = 0.9659$

$\beta = \frac{~~180~~\ 360°}{60}$ mech.

$= \frac{P}{2} \times 6$ ele. $= \frac{2}{2} \times 6$ ele.

$\beta = 6°$ ele.

$m = \frac{60/2}{3} = 10$

$$kd = \frac{\sin\frac{10\times 6}{2}}{10\sin\frac{6}{2}}$$

$= 0.9554$

$$\phi = \left(\frac{2}{\pi} \times 1.32\right) \times \left(\frac{\pi \times 1.12 \times 3}{2}\right)$$

$\phi = 4.4352$ wb/pole

$E_{ph} = k_c k_d \times \sqrt{2}\pi f \phi N_{ph}$

$= 0.965 \times 0.9554 \times \sqrt{2} \times \pi \times 50 \times 4.4352 \times 10$

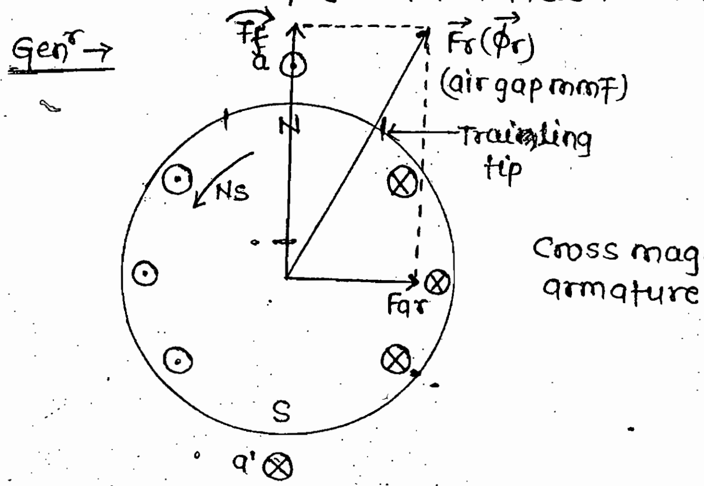
$= 9092.13$ volts per star phase (line to neu.)

$E_{(L-L)} = \sqrt{3}\, E_{ph} \approx 15.75$ KV

Armature Reaction →

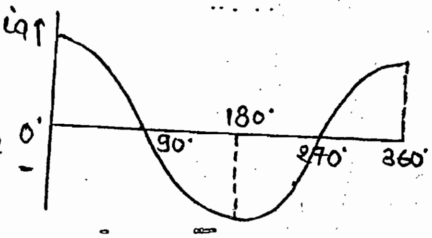
* The effect of arm. mmf on the main field is ~~called arm. reaction~~.
* Behind the every genʳ action there is motoring action.

Genʳ →

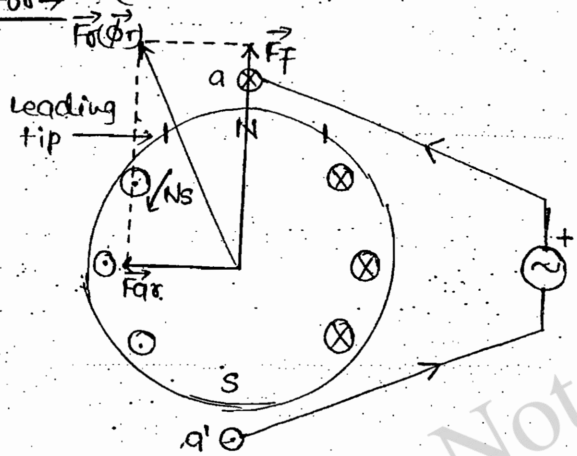


(Internal) unity PF

Cross magnetising armature Reaction



motor →

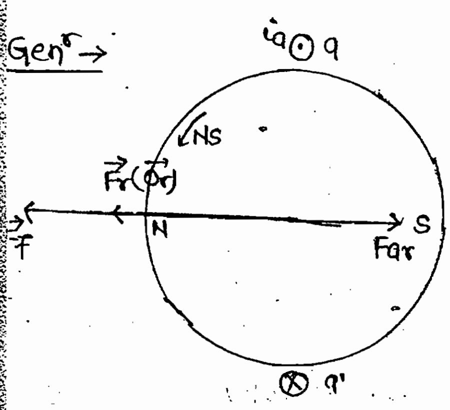


(Internal) unity PF

Cross magnetising armature Reaction

* Concentration of the flux is in the trailing tip at genʳ action & in the motor the concentration is in the leading tip.

Genʳ →

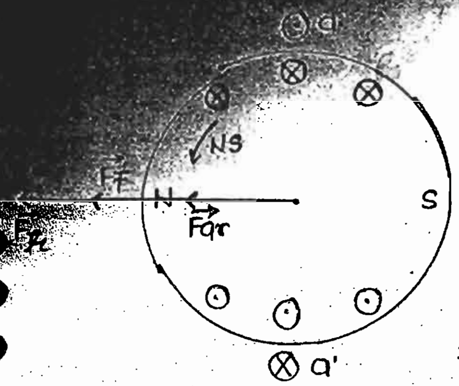


(Zero) PF lag

directly demagnetising armature Reaction

$\boxed{\text{since } F_f > F_r}$

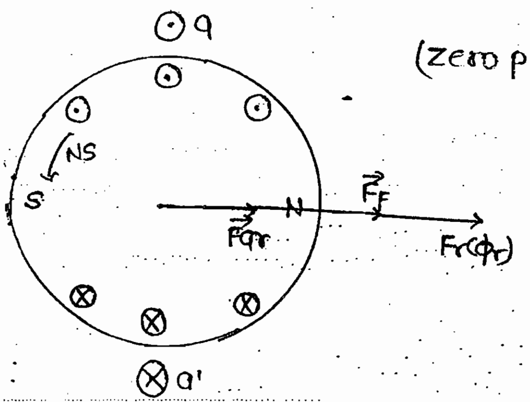
Overexcited genʳ



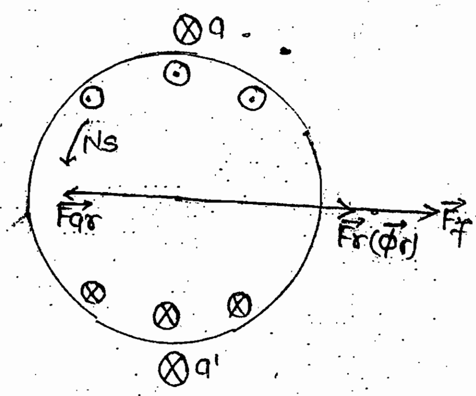
(zero)PF lag.

directly magnetising
armature Reaction.
$\boxed{F_F<F_r}$
∴ Under excited motor

(zero PF lead)



directly magnetising
armature reaction
$\boxed{\text{Since } F_f<F_r}$
Underexcited genr

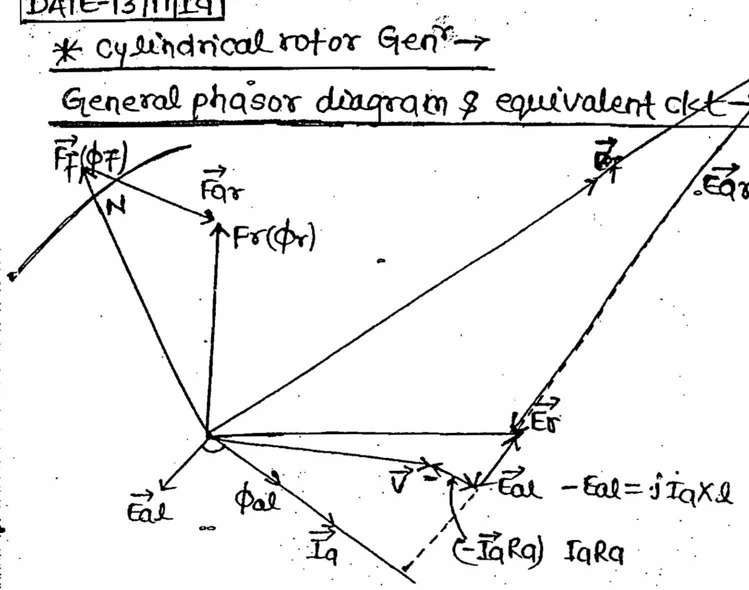


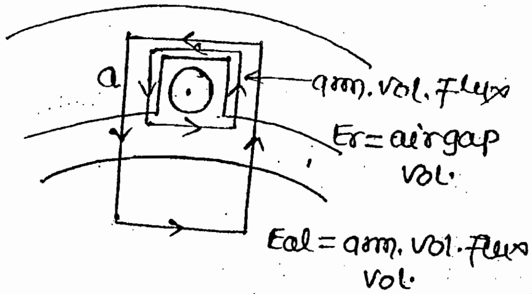
directly demagnetising
armature reaction
$\boxed{\text{Since } F_f>F_r}$
Overexciated motor

DATE-13/11/14

* Cylindrical rotor Genʳ →

General phasor diagram & equivalent ckt →





E_f = Excitation vol.
(OR)
Internal vol.
(OR)
OC voltage

E_{ar} = armature reactin vol.

X_l = Armature leakage reactance

X_{ar} = armature Reation reactance
(OR)
magnetising Reactance of synchronous Re m/c

X_s = synchronous Reactance $(X_l + X_{ar})$

$$\vec{V} = \vec{E_r} + \vec{E_{al}} - \vec{I_a}R_a$$

$$\vec{V} = (\vec{E_f} + \vec{E_{ar}}) + E_{al} - I_aR_a$$

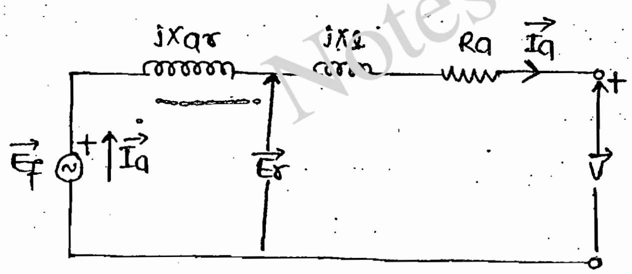
$$* \ \vec{E_f} = \vec{V} + I_aR_a - E_{al} - E_{ar} \quad \text{------} (i)$$

$$= \vec{V} + \vec{I_a}R_a + jI_aX_l + jI_aX_{ar}$$

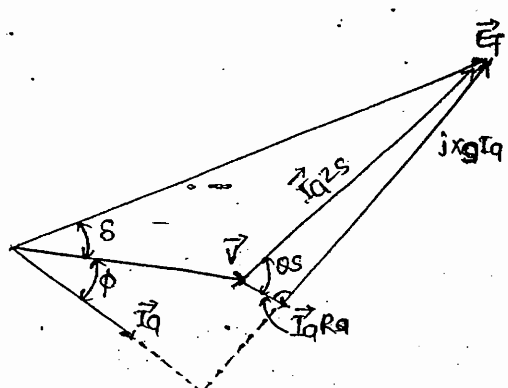
$$= V + I_aR_a + jI_a(X_l + X_{ar})$$

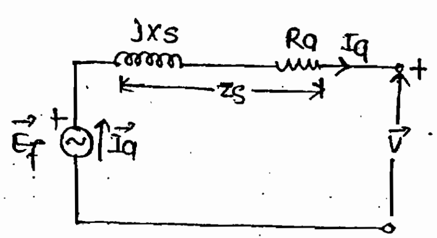
$$= \vec{V} + I_aR_a + j\vec{I_a}X_s \quad \text{-----} (ii)$$

* Equivalent ckt →



eqⁿ (i) ckt diagram





eqⁿ (ii) eq. ckt

Angle between F_f & ϕ_r = torque angle

angle betwen $\vec{E_f}$ & $\vec{V}$ = power angle/ Rotor angle.

** air gap in 200MW syn. m/c is 70mm
500MW - 130mm

$\boxed{\text{Open circuit Test \& Short circuit Test}}$

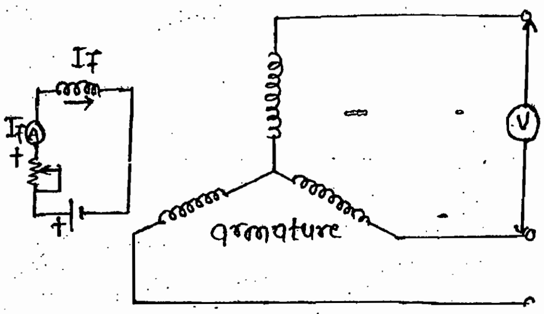
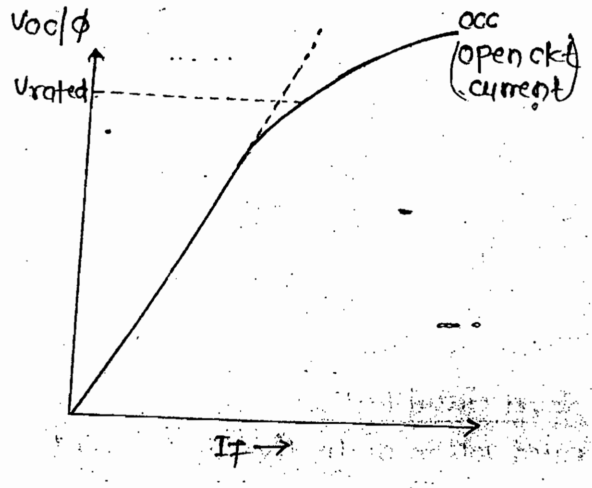


Fig-oc test



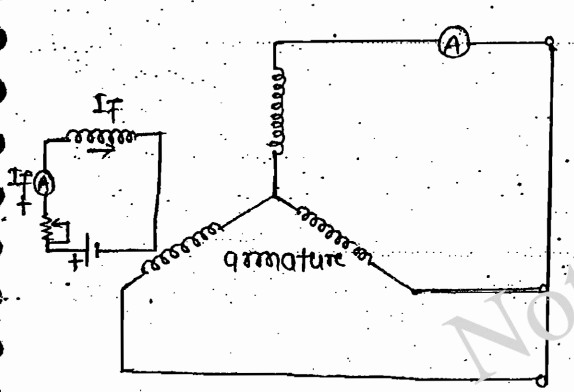
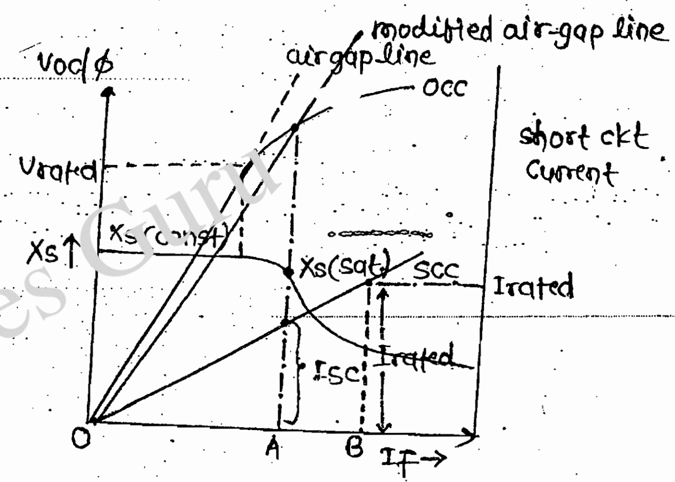


Fig-sc test



* allow 1.2–2 times of FL current.

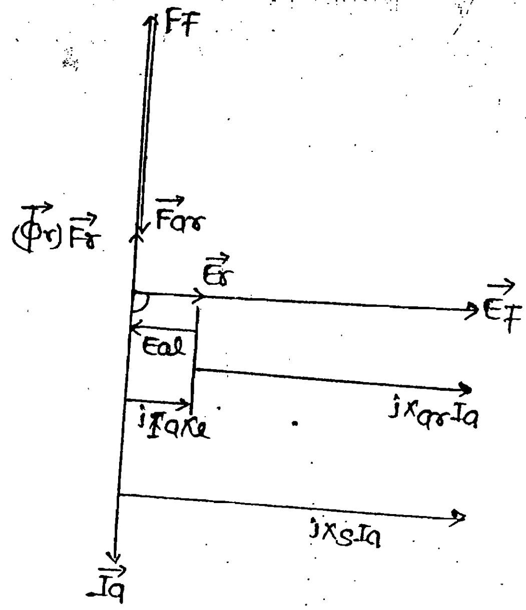
(Xs constant at 1st then variable)

* modified air gap line is the occ of an eq. unsaturated m/c that gives rated vol. at the same field current as the actual m/c.

Isc by defination is that value of sc arm. current which is obtained at a field current that gives rated vol. on oc.

$$\boxed{X_{s(sat.)} \triangleq \frac{V_{rated}}{I_{sc}}}$$

$X_{s(sat)}$ = staturated synchronous Reactance (OR) Adjusted syn. reactance



* Short circuit Ratio is defined as the ratio of the field current req. to give rated vol. on oc to the field current req to give rated arm. current on sc.

Short circuit Ratio, $SCR \triangleq \frac{OA}{OB}$

$$\boxed{SCR = \frac{I_{sc}}{I_{rated}}}$$

I_{Rated} = Base value, I_{sc} = actual value.

$$\boxed{\frac{I_{sc}}{I_{rated}} = I(pu) = SCR}$$

$$= \frac{V_{rated}/X_{s(sat)}}{I_{rated}} \qquad \because X_{s(sat)} = \frac{V_{rated}}{I_{sc}}$$

$$= \frac{V_{rated}/I_{rated}}{X_{s(sat)}}$$

$$= \frac{Z_{Base}}{X_{s(sat)}}$$

$$SCR = \frac{1}{X_{s(sat)}/Z_{Base}}$$

$$\boxed{SCR = \frac{1}{X_{s(sat)}\,pu}}$$

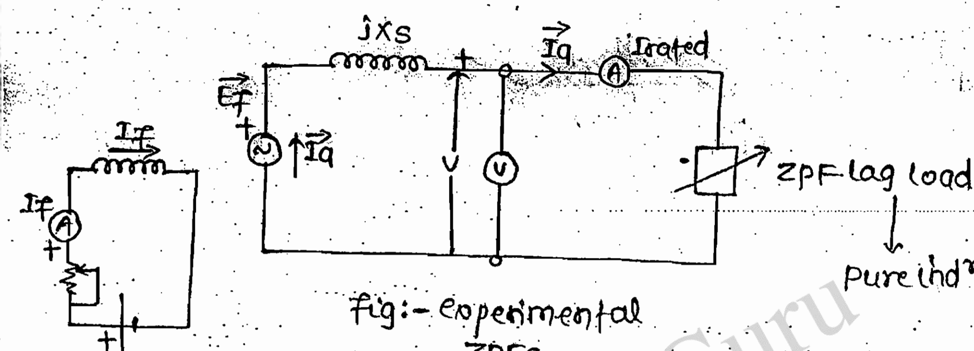
$X_s \uparrow$ SCR $\downarrow$ ⇒
(i) VR% will be also increases because high value of vol. drop.
(ii) Stability decreases.

* For turbogen^r 0.58 but not less than 0.35 (By IEEE For (SCR)
* Salient pole gen^r the client needs (or) ~~0.8~~ not less than 0.8.

Zero Power Factor
ZPF c/s (OR) Potier c/s

* ZPF c/s, also called Potier c/s shows the variation of terminal vol. against field current when arm. current is maintained at its rated value & ZPF lag.

$V \sim I_f$
when $I_a = I_{rated}$ at ZPF lag.



Pure ind^r (OR) Unloaded & underexcited syn. motor.

fig:- experimental ZPFC

* Since the variation in field current (or) the variation in load effects the arm. current as well as the terminal vol., it is recommended that the field current be increased for terminal vol. & subsequently the load may be adjusted for rated arm. current.

I_f	V	I_a
3.2A	225V	200A
3.5A	246V	218A
3.5A	257V	200A

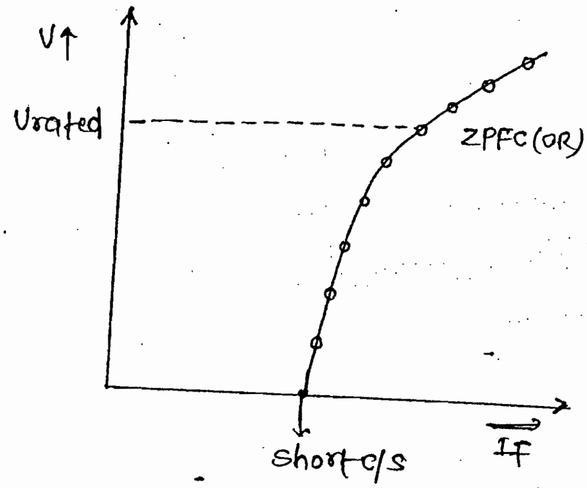
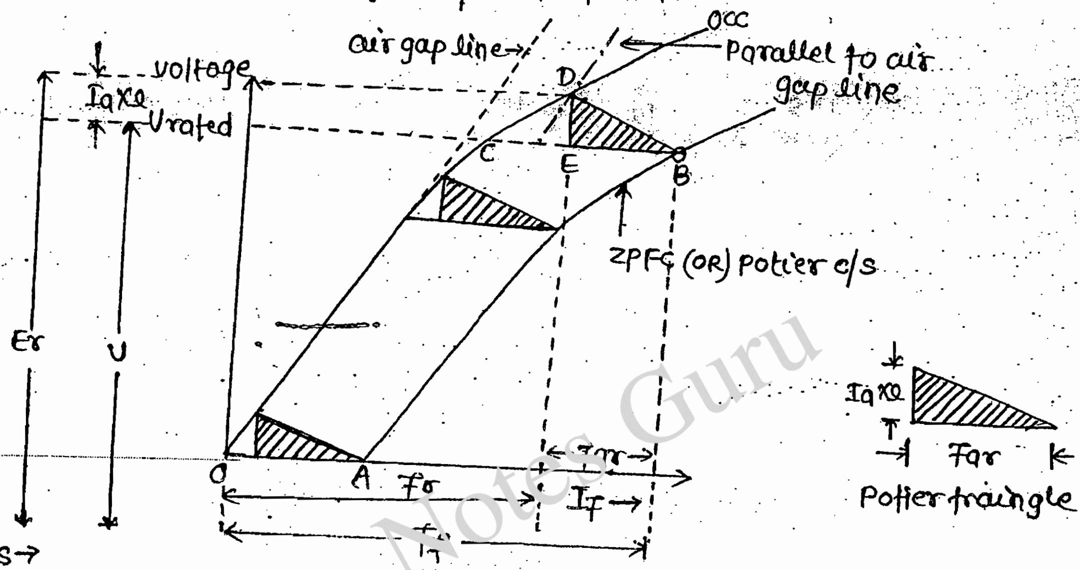


Fig:- Experimental ZPFC



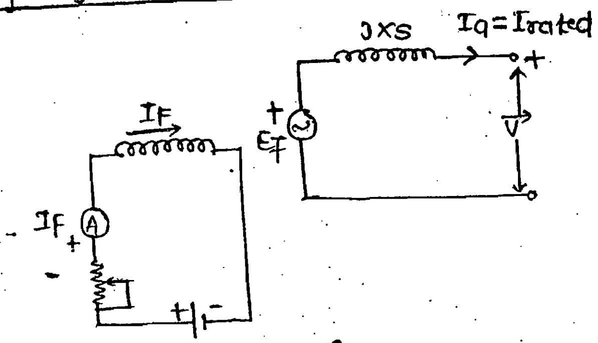
Steps→

* Draw the OCC & Locate the 2 experimental points A & B. point A represents the field current req. to give rated arm. current on SC. point B represents
* point the field current req. to give rated terminal vol. when the arm. current equals Rated value at ZPF lag.
* Take BC = OA as shown in fig.
* From point C, draw a line parallel to the air gap line intersecting the OCC at point D.
* From point D, draw a perpandicular DE on BC. The Δ, DEB is the potier Δ. In the potier Δ BE represents the effect of Far in the air gap. DE represents the arm. leakage reactance drop on FL. & its called potier drop.

* move the potier Δ parallel to itself while always keeping its vertex D on the occ. The locus of point B is the ZPFC also called potier c/s.

DATE- 15/11/14

* Voltage Regulation →



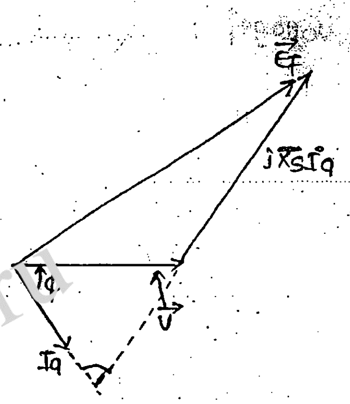
$$\text{Voltage Reg}^n = \frac{E_f - V}{V}\ PU$$

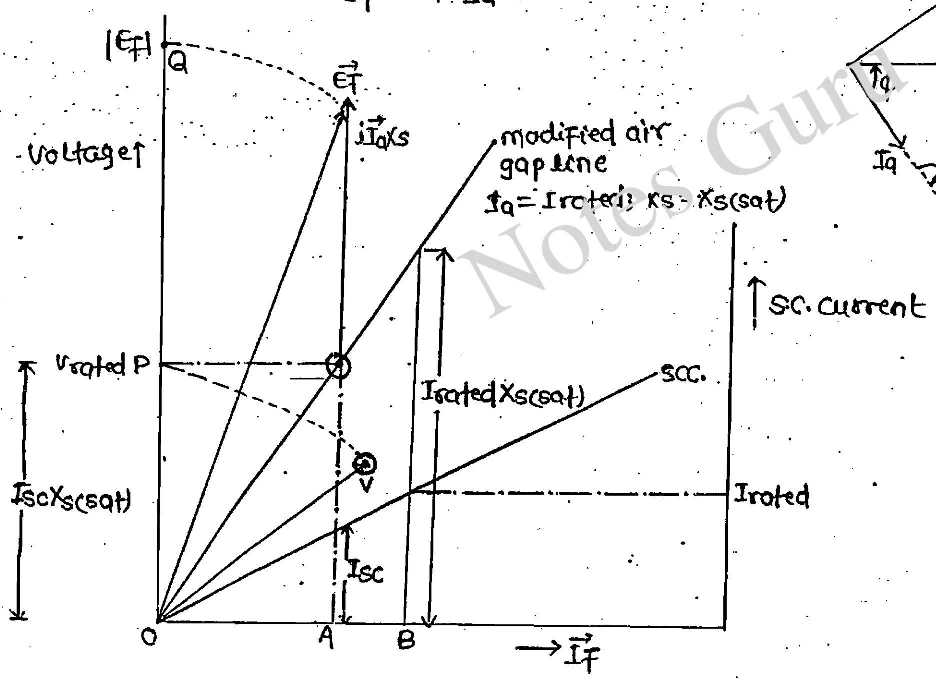
where $V = V_{rated}$.

* VR^n of an alternator is defined as the rise in o/p terminal vol. expressed as a fraction of FL rated vol. when FL at a specified pF is thrown off keeping the excitation constant.

VR^n by EMF method →

$$\vec{E_f} = \vec{V} + j\vec{I_a}X_s$$

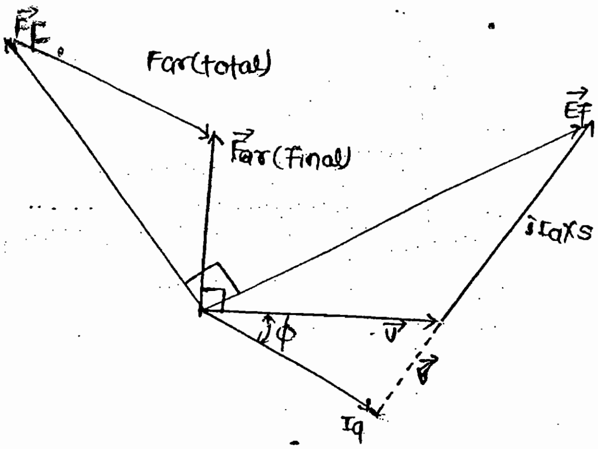


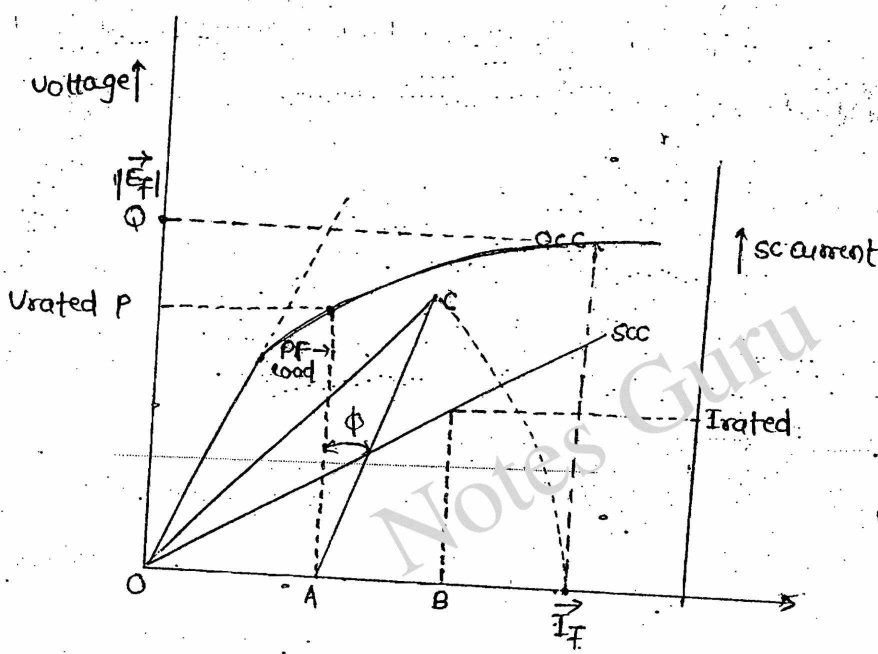


$$VR^n = \frac{OQ - OP}{OP}\ PU$$

* The value of VR^n obtained by EMF method is higher than actual & therefore this method is called pessimistic.

* VR^n by mmF method → (OR) amp-turn method.





$OA \equiv F_r(\text{Final})$

$OB \equiv F_{ar}(\text{total})$

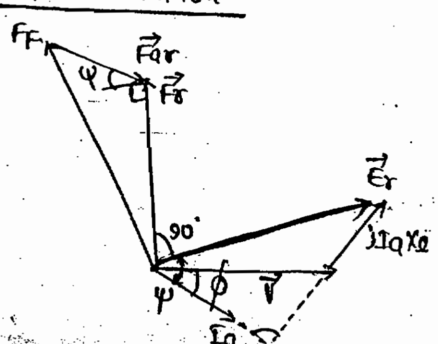
$AC = OB$

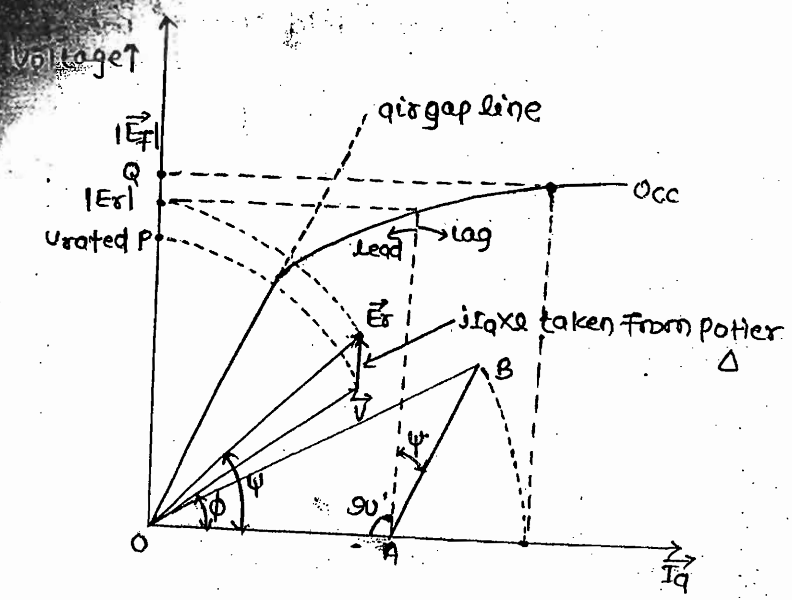
$\therefore OC \equiv F_f$

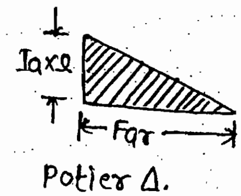
$$VR^n = \frac{OQ - OP}{OP}$$

* The value of the VR^n obtain by mmF method is less than actual & therefore this method is called optimistic method.

VR^n by ZPF method (OR) potier method →







* The VR^n obtained by EMF method was found to be pessimistic while the mmf method produced the optimistic.

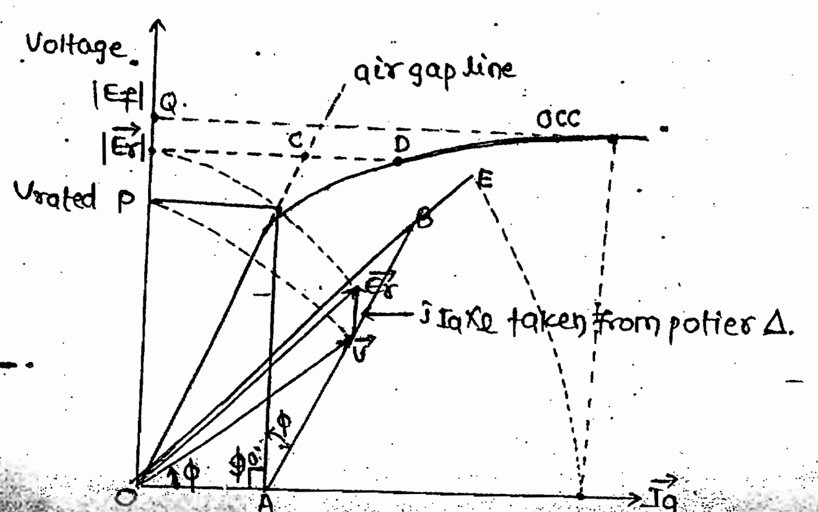
The Potier method also called ZPF method treats the quantity as they actualy exist in a m/c on load.

The VR^n obtained by ZPF method therefore more realistic then the earlier 2 methods.

Thus the potier method was long used for the determination of VR^n of syn. gen^r untill American astd. association (ASA) proposed there modification of mmf method.

This method is now popularly knows as ASA method.

*VR^n by ASA method →



* 1PU field current in a syn. m/c is that value of field current which gives rated voltage on the air gap line.

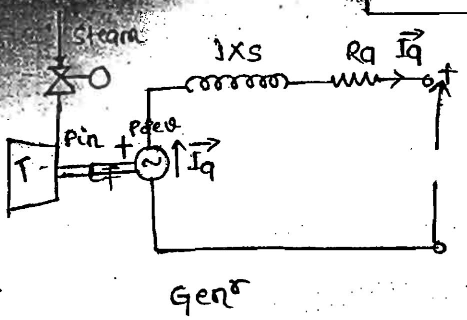
* The ASA modified the mmf method by determining Fr final from the air gap line instead of from the OCC. It was then combined with Far total taken from SC data to determine the Ff of unsaturated m/c.

* Since the degree of saturation depends on the air gap mmf, the additional field mmf req. to overcome saturation was determine as a horizontal intersect b/n the air gap line and occ at Er level.

* This additional field mmf was added to the Ff of unsaturated m/c to finaly determine the Ff of actual m/c under actual operating condn.

* The ASA method has been found to give satisfactory method for cylindrical rotor & as well as the salient pole m/c & it is latest recommondation for determination of VR of syn. genr.

POWER ANGLE RELATIONS



$$\vec{E_f} = \vec{V} + \vec{I_a} Z_s$$

$$\vec{I_a} = \frac{\vec{E_f} - \vec{V}}{Z_s} = \frac{E_f\angle\delta - V\angle 0^\circ}{Z_s\angle\theta_s}$$

$$\boxed{\vec{I_a} = \frac{E_f}{Z_s}\angle\delta-\theta_s - \frac{V}{Z_s}\angle-\theta_s}$$

$$S_{out} = \vec{P}_{out} + \vec{Q}_{out}j$$

$$= V I_a^*$$

$$= V\angle 0\left[\frac{E_f}{Z_s}\angle\theta_s-\delta - \frac{V}{Z_s}\angle\theta_s\right]$$

$$S_{out} = \frac{VE_f}{Z_f}\angle\theta_s-\delta - \frac{V^2}{Z_s}\angle\theta_s \quad \text{———— (i)}$$

$$\therefore P_{out} = \frac{VE_f}{Z_s}\cos(\theta_s-\delta) - \frac{V^2}{Z_s}\cos\theta_s$$

P_{out} is max^m when $\delta = \theta_s$ (variable = constant)

then $\boxed{P_{out(max)} = \frac{VE_f}{Z_s} - \frac{V^2}{Z_s}\cos\theta_s}$

$$\vec{S}_{dev} = P_{dev} + jQ_{dev} = \vec{E_f} I_a^*$$

$$= E_f\angle\delta\left[\frac{E_f}{Z_s}\angle\theta_s-\delta - \frac{V}{Z_s}\angle\theta_s\right]$$

$$\vec{S}_{dev} = \frac{E_f^2}{Z_s}\angle\theta_s - \frac{VE_f}{Z_s}\angle\theta_s+\delta \quad \text{———— (ii)}$$

$$P_{dev} = \frac{E_f^2}{Z_s}\cos\theta_s - \frac{V.E_f}{Z_s}\cos(\theta_s+\delta)$$

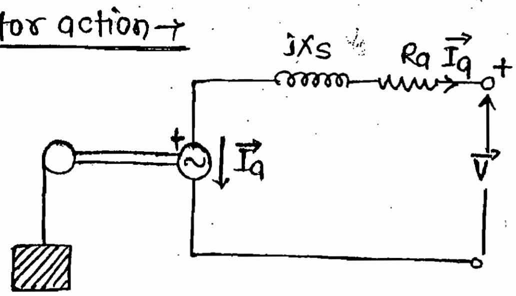
P_{dev} is max^m when -

$$\theta_s + \delta = 180^\circ$$

$$\boxed{\delta = (180 - \theta_s)}$$

And this decides steady state stability limit.

motor action →



$$E_f = V - \vec{I_a} Z_s$$

$$\vec{I_a} = \frac{V - E_f}{Z_s}$$

$$\vec{I_a} = \frac{V\angle 0° - E_f\angle -\delta}{Z_s\angle\theta_s}$$

$$\boxed{\vec{I_a} = \frac{V}{Z_s}\angle -\theta_s - \frac{E_f}{Z_s}\angle -(\theta_s+\delta)}$$

$$S_{dev} = P_{dev} + jQ_{dev}$$

$$= E_f I_a^*$$

$$= E_f\angle -\delta\left[\frac{V}{Z_s}\angle\theta_s - \frac{E_f}{Z_s}\angle\theta_s+\delta\right]$$

$$\boxed{S_{dev} = \frac{VE_f}{Z_s}\angle\theta_s-\delta - \frac{E_f^2}{Z_s}\angle\theta_s} \quad \text{------(3.)}$$

Now; $P_{dev} = \frac{VE_f}{Z_s}\cos(\theta_s-\delta) - \frac{E_f^2}{Z_s}\cos\theta_s$

P_{dev} is max^m when $\boxed{\theta_s = \delta}$ & this decides steady state stability limit of the motor.

& $\boxed{P_{dev(max)} = \frac{VE_f}{Z_s} - \frac{E_f^2}{Z_s}\cdot\cos\theta_s}$

$$S_{in} = P_{in} + jQ_{in}$$

$$= E\cdot\vec{V}\cdot\vec{I_a}^*$$

$$= V\left[\frac{V}{Z_s}\angle\theta_s - \frac{E_f}{Z_s}\angle\theta_s+\delta\right]$$

$$\boxed{S_{in} = \frac{V^2}{Z_s}\angle\theta_s - \frac{VE_f}{Z_s}\angle\theta_s+\delta} \quad \text{------(4.)}$$

$$P_{in} = \frac{V^2}{Z_s}\cdot\cos\theta_s - \frac{V\cdot E_f}{Z_s}\cdot\cos(\theta_s+\delta)$$

Neglecting $R_a \rightarrow$

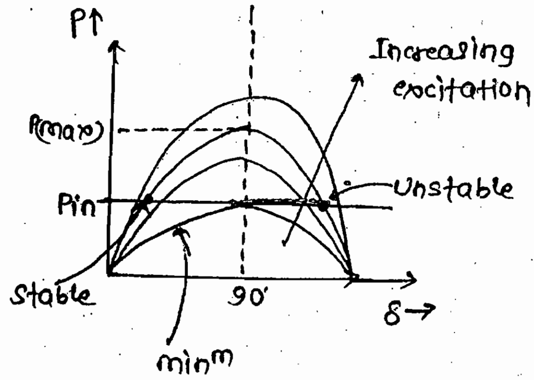
$R_a = 0$; then $Z_s = X_s$, $\theta_s = 90°$

Gen$^r \rightarrow$ $P_{out} = P_{dev} = P = \frac{V \cdot E_f}{X_s} \cdot \sin\delta$

motor $\rightarrow$ $P_{dev} = P_{in} = P = \frac{V \cdot E_f}{X_s} \cdot \sin\delta$

& $P_{max} = \frac{E_f V}{X_s}$ at $\delta = 90°$

$$\boxed{P = P_{max} \sin\delta}$$



* Reactive Power $\rightarrow$

Gen$^r \rightarrow$

$Q_{out} = \frac{V}{X_s}(E_f \cos\delta - V)$

motor $\rightarrow$

$Q_{in} = \frac{V}{X_s}(V - E_f \cos\delta)$

Gen$^r \rightarrow$

Case(i) $\rightarrow$

when $E_f \cos\delta = V$ i.e. normaly excited gen^r then $Q_{out} = 0$.

And therefore operating at UPF.

case(ii) $\rightarrow$

when $E_f \cos\delta$ is more then V i.e over excited gen^r then Q_{out} = +ve

i.e. supplying lagging VARs. And therefore operating at lagging PF.

case(iii) $\rightarrow$

when $E_f \cos\delta$ is less then V i.e. underexcited gen^r, then Q_{out} = −ve

i.e supplying leading VARs & therefore operating at leading PF.

motor $\rightarrow$

case(i) $\rightarrow$

when $E_f \cos\delta = V$; i.e. normaly excited gen^r then $Q_{out} = 0$

& therefore operating at UPF.

Case(ii) $\rightarrow$

when $E_f \cos\delta > V$; i.e. Q_{out} = −ve i.e. taking leading VARS & ∴ operating at leading VARS.

Case(3) →

when $E_f \cos\delta < V$; i.e. underexcited motor then $Q_{in} = +ve$ i.e. absorbing lagging VAR & ∴ operating at lagging PF.

*** Effect of change in excitation at constant(kW) o/p →**

$P = V I_a \cos\phi$

$\propto I_a \cos\phi$

constant

$P = \frac{V E_f}{X_s} \sin\delta$

$= E_f \sin\delta$

(constant)

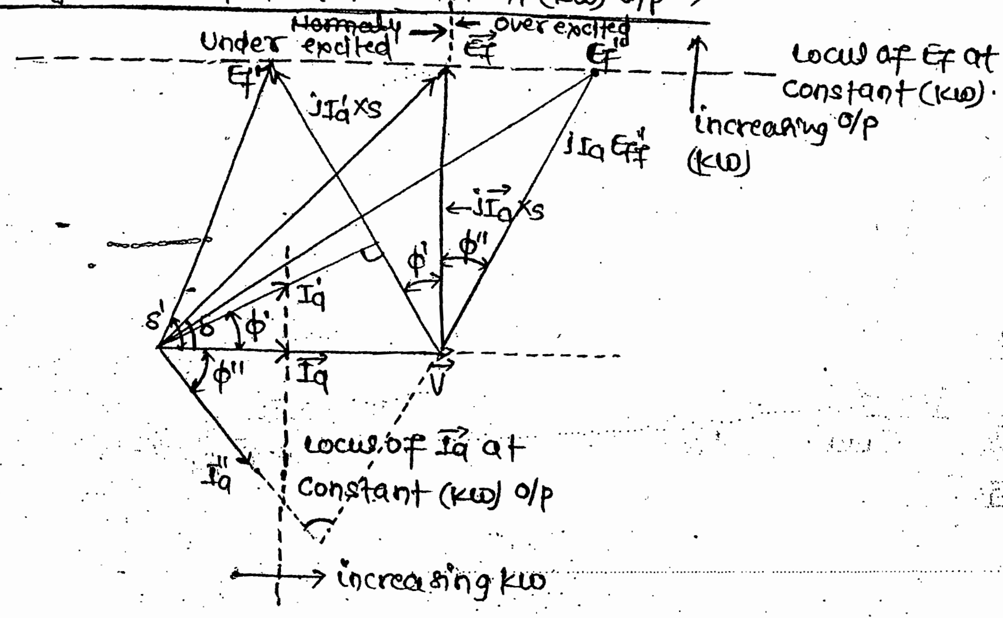


Fig → Genr

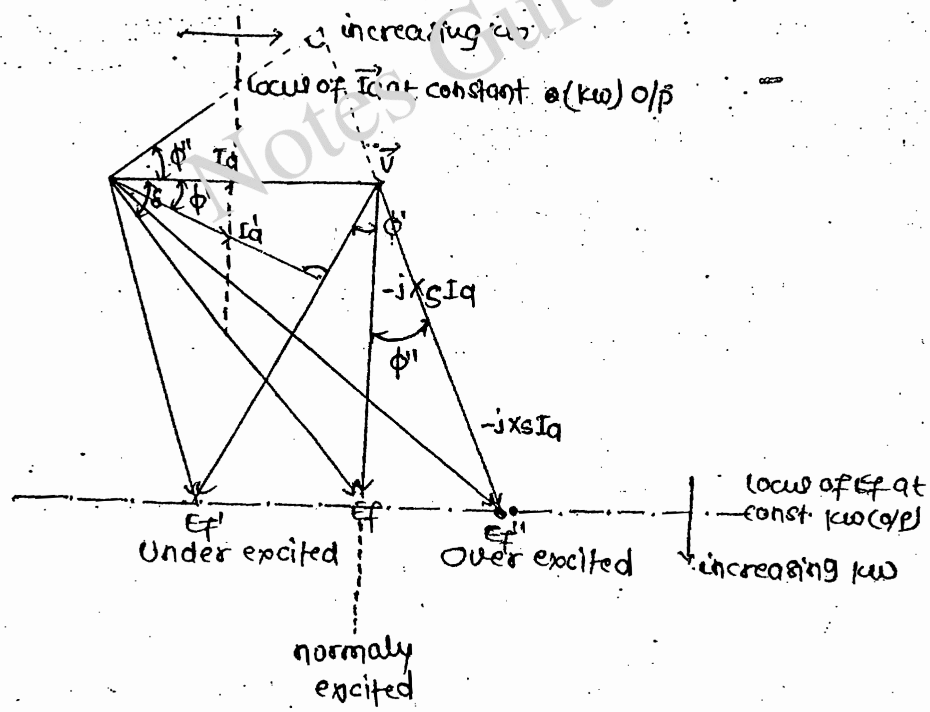


Fig. → motor

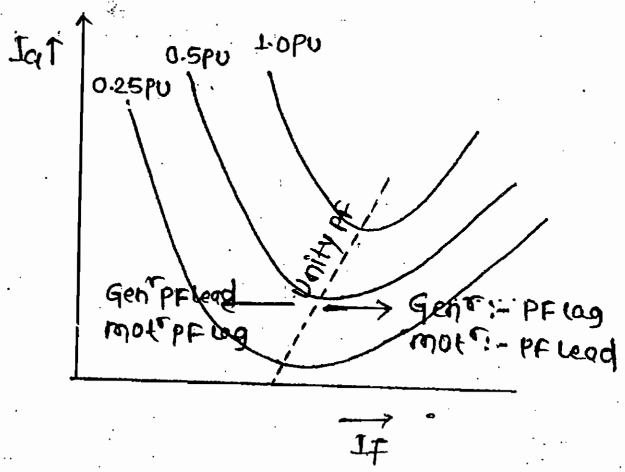


Fig:- Syn. m/c 'V' curves

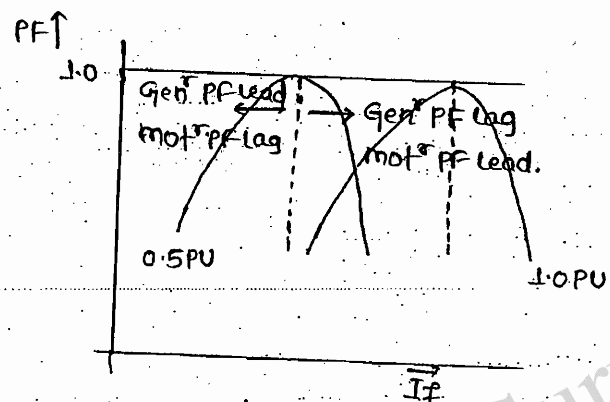
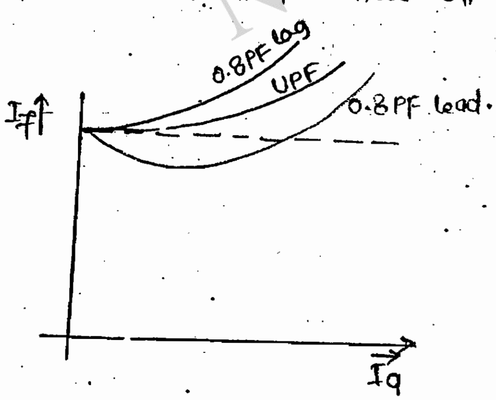


Fig:- Syn. m/c inverted 'V' curves.

* Compounding curve of a gen^r shows the variation of the field current req. to maintain constant terminal vol. when a const. PF load is varied.



Gen^r compounding curves.

Que.→ A cylindrical rotor syn. gen^r with syn. reactance of 1.6 PU & neglegible arm. reactance is connected to an ∞ bus at rated vol.

(a.) Determine the excitation emf & power angle when it delivers full load current at 0.8 PF lag.

Hence cal. VR^n of the gen^r.

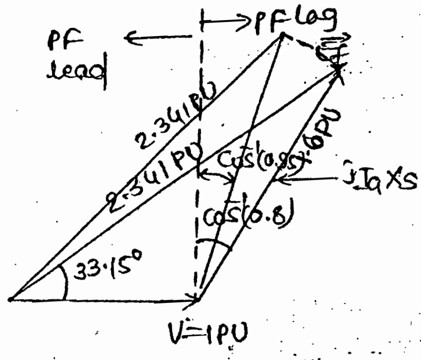
Sol^n→

$X_s = 1.6 PU$

$E_f = V + j\vec{I_a}X_s$

$= 1\angle 0° + j1\angle -\cos^{-1}(0.8) \times 1.6$

$\boxed{E_f = 2.341 PU \angle 33.15°}$



$\therefore VR^n = E_f(PU) - 1$

$= 2.341 - 1$

$VR^n = 1.341 PU = 134.1\%$

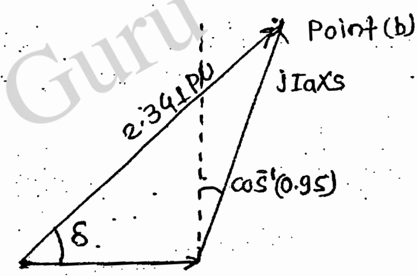
(b.) With the excitation at pt (a) the gen^r is made to operate at 0.95 PF lag. Calculate the corresponding arm. current & power angle?

Sol^n→

$E_f = V + jI_aX_s$

$2.341\angle \cancel{33.15°}^{\delta} = 1\angle 0° + jI_a(1.6)\ I_a\angle -\cos^{-1}(0.95)$

$2.341\angle \cancel{33.15}^{\delta} = 1 + 1.6 I_a \angle 71.81$



$= [1 + 1.6 I_a \cos(71.81)] + j1.6 I_a \sin(71.81)$

Squaring & equating magnitudes

$(2.341)^2 = 1^2 + 2 \times 1 \times 1.6 I_a \cos(71.81) + (1.6 I_a)^2$

$(1.6)^2 I_a^2 + 2 \times 1.6 I_a \cos 71.81 + (1 - 2.341^2) = 0$

By solving eq^n

$I_a = 1.142 PU$

from (1.) $\delta = \angle[1 + 1.6 \times 1.1421 \angle 71.81]$

$\delta = 47.87°$

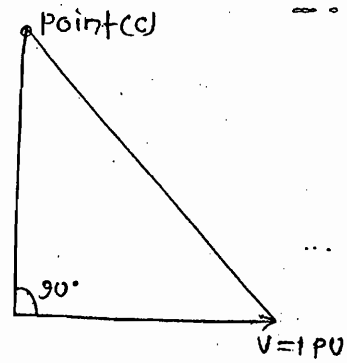
(c) With the excitation as part (a), determine the max^m power o/p & the corresponding arm. current & PF.

Sol^n →

$$P_{max} = \frac{V \cdot E_f}{X_s} \quad (at\ \delta = 90°)$$

$$= \frac{1.0 \times 2.341}{1.6}\ PU$$

$$= 1.4631\ PU$$



$$I_a = \frac{E_f - V}{jX_s}$$

$$= \frac{2.341\angle 90° - 1}{1.6j}$$

$$I_a = 1.591\angle 23.130$$

PF = cos(23.130) leading

$$\boxed{PF = 0.9196}$$

Cal^n check

$V I \cos\phi = P_{max}$

$1\angle 0° I_a \times 0.9196 = 1.4631$

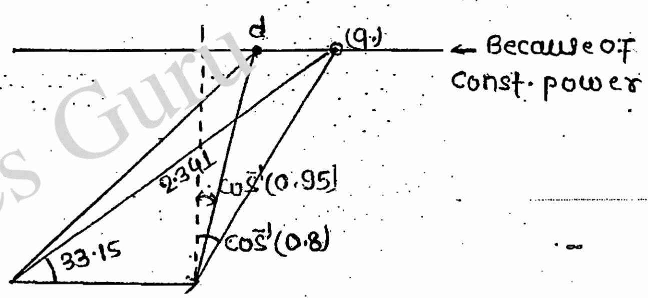
(d.) If the steam i/p of part (a) remains unchanged cal. the excitation emf & power angle at which PF becomes 0.95 lagging.

Sol^n →

$P = V I_a \cos\phi$

$\propto I_a \cos\phi$

constant



$I_{a_2}\cos\phi_2 = I_{a_1} \cdot \cos\phi_1$

$I_{a_2} \cdot (0.95) = (1.0) \times 0.8$

$I_{a_2} = 0.8421$ PU

$\vec{E}_{f2} = 1\angle 0° + j\,0.842\angle -\cos^{-1}(0.95) \times 1.6$

$$\boxed{E_{f2} = 1.9123\angle 42.02°\ PU}$$

(e) If the steam i/p of part (a) remains unchanged cal. the excitation emf & PF at which PF becomes 0.85 leading.

Sol^n →

$I_{a_2} \cdot \cos\phi_2 = I_{a_1}\cos\phi_1$

$I_{a_2}(0.85) = 1.0 \times 0.8$

$I_{a_2} = 0.9411$

$E_{f2} = 1\angle 0° + j\,0.9411\angle \cos^{-1}(0.85) \times 1.6$

$$\boxed{E_{f2} = 1.297\angle 80.822}$$

(f) Cal. the min^m excitation emf for the same steam i/p as in part (a) & determine corresponding arm. current & PF?

Sol^n →

$P = VI\cos\phi$

$\propto I\cos\phi$

Alternative (1) → when Pin is given

$P = 1\times1\times0.8$

$P = 0.8$ pu

$0.8 = \dfrac{V\times E_{f(min)}}{X_s}$

$E_{f(min)} = \dfrac{1.6\times0.8}{1}$

$\boxed{E_{f(min)} = 1.28 \text{ PU}}$

alternative (2) → when pin is not given

$P = \dfrac{V.E_f}{X_s}.\sin\delta$

$\propto E_f \sin\delta = \text{constant}$

$E_{f_2}\sin\delta_2 = E_{f_1}.\sin\delta_1$

$E_{f(min)}\sin 90^\circ = 2.341\times\sin(33.15^\circ)$

$\boxed{E_{f(min)} \approx 1.28 \text{ PU}}$

$I_{a_2} = \dfrac{1.28\angle 90^\circ - 1\angle 0^\circ}{1.6j} = 1.0152\angle 38^\circ$ PU

$PF = \cos 38^\circ$ (leading)

$\boxed{PF = 0.788 \text{ (leading)}}$

(g.) If the steam i/p of (a) unchanged but the excitation is increased by 30% cal. the new arm. current & PF

Sol^n → alternative (1.) → when p is given

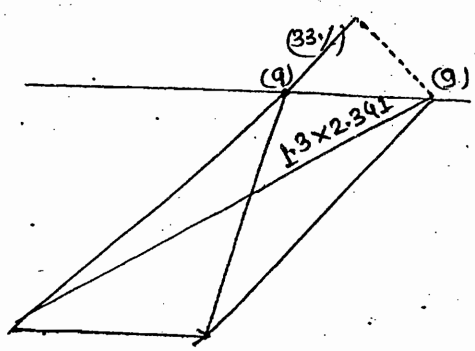
$P = VI\cos\phi = 1\times1\times0.8$

$P = 0.8$ PU

$P_{max} = \dfrac{V.E_f}{X_s}\sin\delta$

$0.8 = \dfrac{1\angle0^\circ\times1.3\times2.341}{1.6}\sin\delta_2$

$\boxed{\delta_2 = 24.87^\circ}$



Alternative(2) → when p is not given

$$P = \frac{E_f \cdot V}{X_s} \sin\delta$$

$\propto E_f \sin\delta$

constant

$$E_{f_2} \sin\delta_2 = E_{f_1} \sin\delta_1$$

$$(1.3 E_{f_1}) \sin\delta_2 = E_{f_1} \sin(33.15^\circ)$$

$$\delta_2 = 24.87^\circ$$

$$I_{a_2} = \frac{1.\cancel{3}2.341\angle 24.87^\circ - 1\angle 0^\circ}{1.6j}$$

$= 1.3607\angle -53.99^\circ$ PU

$\therefore$ PF $= \cos(53.99)^\circ$ (lagging)

$= 0.5839$ (lagging)

(H.) For a power angle of 20' cal. the 2 possible values of excitation emf. if the gen^r delivers 30% of FL current. Determine corresponding PF & power o/p.

Soln → $(\delta = 20^\circ)$

$$\cancel{I_a = \frac{E_{f_1} - V}{X_s}}$$

$$\cancel{I_a = \frac{E_{f_1} - 1}{1.6}}$$

$$\cancel{1.6 I_a = E_{f_1} - 1}$$

$$\cancel{-1.6 I_a + E_{f_1} = 1}$$

$$\cancel{0.3 I_a = \frac{E_{f_2} - 1}{1.6}}$$

$$\cancel{0.3 \times 1.6 I_a = E_{f_2} - 1}$$

$$\cancel{E_{f_2} = 0.48 I_a = 1}$$

$$\cancel{P = \frac{V \cdot E_{f_1}}{X_s} \sin\delta}$$

$$\cancel{P = \frac{1 \times E_{f_1}}{1.6} \sin(20^\circ)}$$

$$\cancel{P = 0.213 E_{f_1}}$$

**

$$E_f\angle 20^\circ = 1\angle 0^\circ + j0.3\angle\phi + 1.6$$

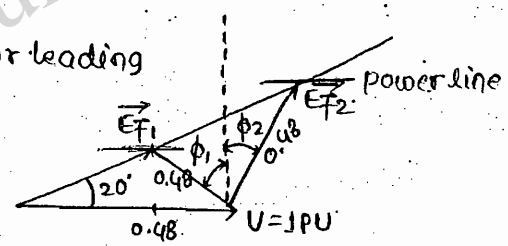
(ϕ is +ve for leading PF)

$$E_f\angle 20^\circ = 1 + 0.48\angle(90+\phi)$$

$$0.48\angle(90+\phi) = E_f\angle 20^\circ - 1$$

$$= E_f \cos 20^\circ + jE_f \sin 20^\circ - 1$$

$$0.48\angle(90+\phi) = (E_f \cos 20^\circ - 1) + jE_f \sin 20^\circ \text{ ------ (i)}$$



squaring & equating.

$$(0.48)^2 = E_f^2 - 2E_f \cos 20^\circ + 1.$$

$$E_f^2 - 2E_f \cos 20^\circ + (1 - 0.48^2) = 0$$

$$E_f = 1.278, 0.6029$$

$$\boxed{E_f = 0.6029, 1.28 \text{PU}}$$

Low excitation →

$$90^\circ + \phi = \angle[0.6029\angle 20^\circ - 1]$$

$$= 154.26^\circ$$

$$\phi = 64.56^\circ$$

$$PF = 0.4296 \text{ (leading)}$$

$$P = 1 \times 0.30 \times 0.4296$$

$$\boxed{P = 0.1289 \text{ PU}}$$

High excitation →

$$90^\circ + \phi = \angle[1.2765\angle 20^\circ - 1]$$

$$= 65.44^\circ$$

$$\phi = -24.56^\circ \text{ leading}$$

$$= 24.56^\circ \text{ lagging}$$

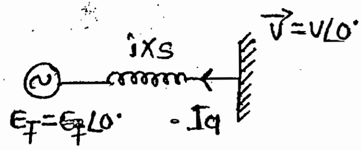
$$PF = \cos 24.56 \text{ lagging}$$

$$= 0.9095 \text{ (lag)}$$

$$P = 1 \times 0.30 \times 0.9095$$

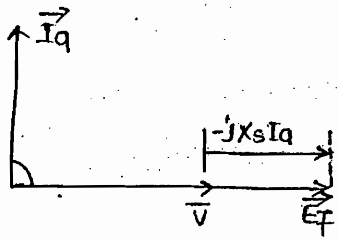
$$\boxed{P = 0.2729 \text{ PU}}$$

* Synchronous condenser → (synchronous phase advancing, syn. capacitor)

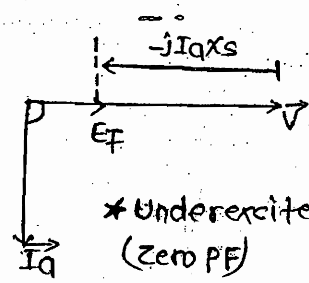


$$\boxed{Q_{in} = \frac{V}{X_s}(V - E_f)}$$

(Indetermined PF Because $I_q = 0$)
* Normaly excited -



* Overexcited (zero PF lead)



* Underexcited (zero PF)

* Underexcited – absorbing lagging VARs.
* syn. compensator (actual name)
* syn. phase modifier

Note:- (1) If big m/c is operating without prime mover & shaft → syn. com.
(2) The dia. of shaft is kept small because of operating on NL.
(3) It is used 200 MVARs (upto)
(4) It gives clean Reactive powers (like w/o harmonics)

Genʳ → $Q_{out} = \frac{V}{X_s}(E_f\cos\delta - V)$

If $E_f = 0$, ~~cos~~ $\delta = 90°$

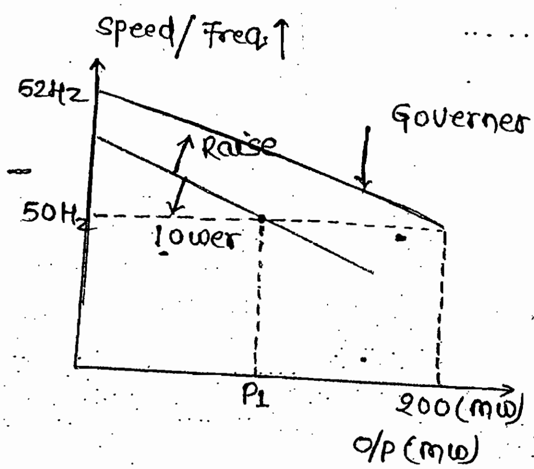
$Q_{out} = \frac{-V^2}{X_s}$

$\boxed{Q_{out} = -V^2 \times SCR}$
↓
(line charging capacity)

* Turbogenʳ are situated at load center so req. less xⁿ line & the SCR is low but hydrogenʳ is situated at different area so req. more xⁿ line & SCR is high for those.

* Parallel operation of gen^r →

* The ele. aspects of parallel operation of syn. gen^r would be handled by Millmens theorem exactly similar as in parallel operation of TF with unequal voltage Ratio.



* $\text{Governer Reg}^n = \dfrac{52Hz - 50Hz}{50Hz} = \dfrac{2Hz}{50Hz} = 0.04\,pu \,/\, 4\%$

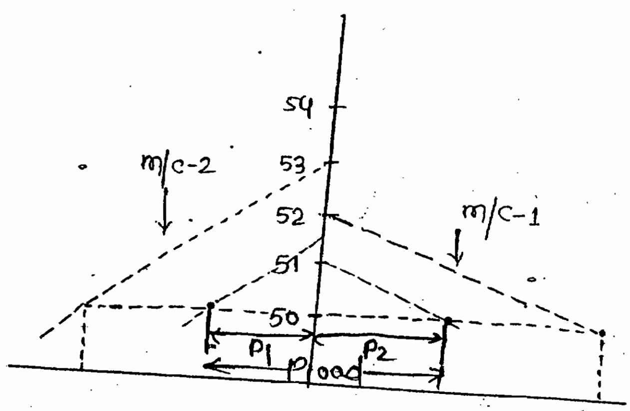
(OR)

$$\text{Droop} = \frac{52Hz - 50Hz}{200MW} = 0.01\ Hz/MW$$

when once droop is decided then it is not changed.

* Contol gear also known as speeder gear / speed changer is a device that simply shifts the governer c/s ∥ral to itself on being given a raise (OR) lower command. (above dia.)

$$\text{In pu (droop)} = \frac{1.04 - 1.00}{1.00} = 4\%$$



Que.→ 2 identical 2000kW, 50Hz alternator operate in parallel. The governor of the 1st m/c is such that the Freq. rises uniformaly from 50Hz on FL to 52 Hz on NL. The corrosponding uniform Freq. rise of 2nd m/c is 50Hz to 52.5 Hz.

(a.) If each m/c is fully loaded at rated Freq. what would be load in each m/c when total load is reduced 2560 kW.

(b.) Cal. the max^m load at which one of the m/c would become unloaded?

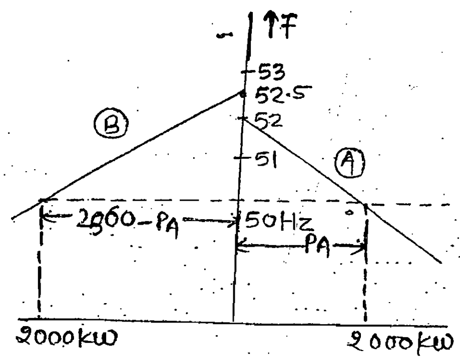
Sol^n→ (a)→

m/c A

$$\frac{P_A}{2000} = \frac{52-F}{52-50} \quad \text{------} (A)$$

m/c B

$$\frac{2560-P_A}{2000} = \frac{52.5-F}{52.5-50} \quad \text{------} (B)$$



Solving eq^n (A) & (B)

$P_A = 1200\text{kW}$, $P_B = 2560-1200$

$= 1360\text{kW}$

$$\boxed{F = 50.8\text{Hz}}$$

(b.)→

$$\frac{P_L}{2000} = \frac{52.5-52}{52.5-50}$$

$$\boxed{P_L = 4000\text{kW}}$$

Que.→ 2 identical 2000kW alternators operate in parallel. The governor of the 1st m/c is such that the freq. drop uniformaly from 50Hz on NL to 48Hz on FL. The corrosponding uniform Freq. drop of 2nd m/c is 50Hz to 47.5Hz.

(a) How will the 2-m/c share the load of 2880kWs.

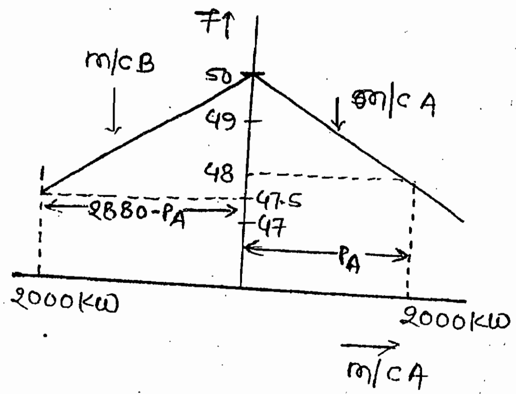
(b) what is the max^m load that can be delivered w/o overloading either m/c.

Sol^n→

(a) →

m/c A $\quad \frac{P_A}{2000} = \frac{50-f}{50-48}$ ------ (A)

m/c B $\quad \frac{2880-P_A}{2000} = \frac{50-f}{50-47.5}$ ------ (B)



Solving eqn (A) & (B)

$P_A = 1600\ kW,\ f = 48.4\ Hz$

Then, $P_B = 2880 - 1600$

$= 1280\ kW$

(b.) →

$$\frac{P_B}{2000} = \frac{50-48}{50-47.5}$$

$$P_B = \frac{2000 \times 2}{2.5} = 1600\ kW$$

$$P_{load}(max) = 2000 + 1600 = 3600\ kW$$

$$\boxed{P_{load}(max) = 3600\ kW}$$

* Synchronization →

Condition to be satisfied →

(1.) Equal Freq.

(2.) Equal voltage

(3.) Same polarity in 1-ϕ genr & same phase seq. in 3-ϕ genr.

(4.) Zero phase differance at instant of synchronization.

(5.) Same waveforms.

Synchronization by synchoscope →

(1.) match the freq. of the incoming m/c with that of the running m/c. It is recommanded that the incoming freq. be kept slightly higher.

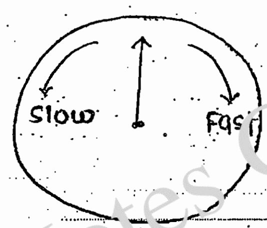
*(2.) match the incoming vol. with the running vol. It is again recommended that the incoming vol. be kept slightly higher

*(3.) switch ON the synchroscope & also the check synchronization relay if such relay is available. Switch off anti motoring protection if provided. (Reverse power protection)

*(4.) Fine control the incoming Freq. such that the synchroscope pointer moves very slowly in the fast dirn. when the pointer reaches 11 o'clock position, give a command to the CB switch to close the breaker.
It is expected that the breaker contacts would actualy close at 12 o'clock position, a position that reprents zero phase diff.

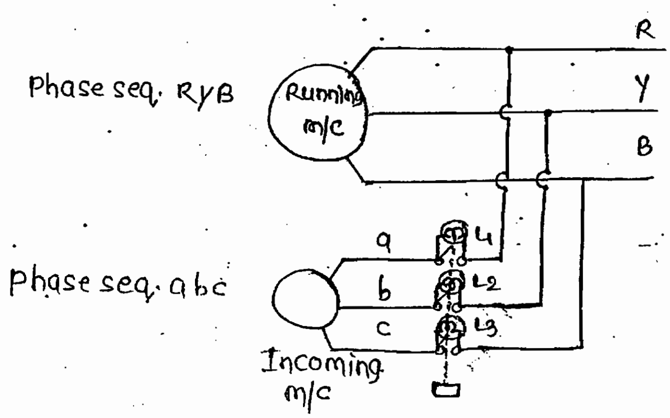
*(5.) Switch-off the synchroscope & also check synchronization relay. Take min^m recommended load on the unit & adjust excitation for desired PF of operation.

*(6.) After taking sufficient load on the unit switch on the antimotoring protection switch.

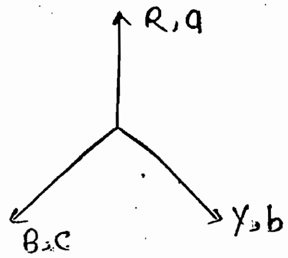


Synchroscope.

* Dark Lamp method → (Kothari/Ashphaq)

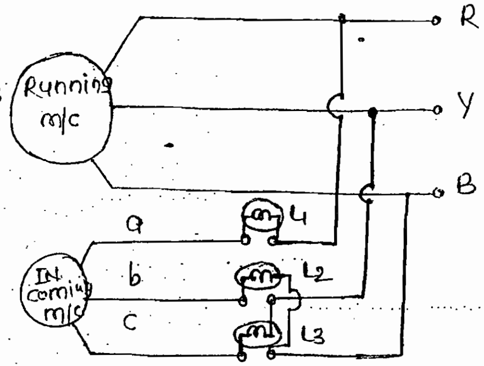


a − R → L1
b − Y → L2
c − B → L3

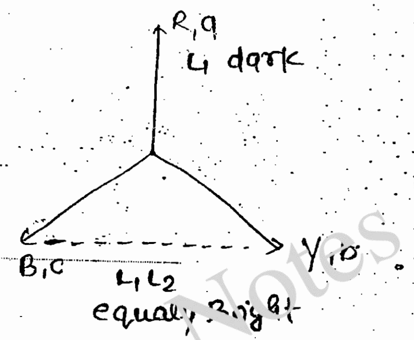


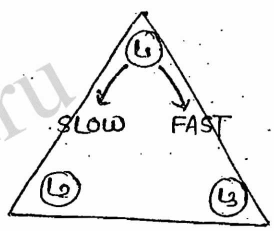
L_1, L_2, L_3 dark then synchronise.

*** Rotating lamp method →** (Dark & bright method) (Siemens & HALSKE method)



a − R → L_1
b − B → L_2
c − Y → L_3





Sequence →

$L_1 - L_3 - L_2$; Incoming m/c is Fast.

$L_1 - L_2 - L_3$; Incoming m/c is slow.

5.11/600

Que → A syn. m/c is synchronised with an ∞ bus at rated vol. Now the steam i/p to prime mover is increased. the syn. m/c starts operating at Rated KVA. The m/c has syn. imp. $Z_s = 0.02 + j0.8$ pu. Determine the operating pf of alternator & its load angle.

Analytical approach →

Soln →

$Z_s = 0.02 + 0.8j$ PU , PF = ? , δ = ?

$= 0.80025\angle 88.57^\circ$ $\cos\phi = ?$, $\delta = ?$

$E_f = V + I_a Z_s$; $\cancel{\cos\phi = \frac{KVA}{VI}}$

$E_f = 1\angle\delta$, $V = 1\angle 0^\circ$, $I_a = 1\angle\phi$

$1\angle\delta = 1\angle 0^\circ + 1\angle\phi\,(0.80025\angle 88.57)$ .....

$1\angle\delta = 1 + 0.80025\,\angle(88.57+\phi)$

$0.80025\angle 88.57^\circ + \phi = 1\angle\delta - 1$ ——— (i)

$0.80025\,\angle(88.57^\circ+\phi) = (\cos\delta - 1) + j\sin\delta$

squaring & equate eqn

$(0.80025)^2 = 1 - 2\cos\delta + 1$

$\boxed{\delta = 44.17^\circ}$

putting in eqn (i)

$(88.57^\circ + \phi) = \angle[1\angle 47.17^\circ - 1] = 113.59^\circ$

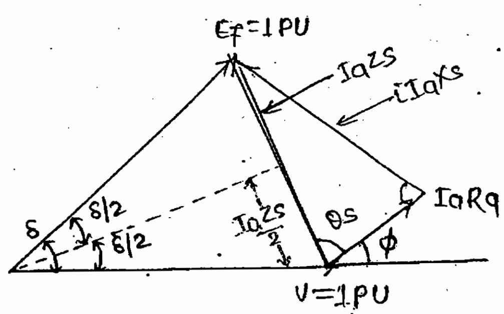
$\cancel{113.59^\circ}$

$\phi = 25.02^\circ$

PF = cos(25.02) leading

$\boxed{PF = 0.9062}$ leading

Graphical Approach →



$\theta_s + \phi = 90^\circ + \frac{\delta}{2}$

$\phi = (90 - \theta_s) + \frac{\delta}{2}$ (leading)

$\sin\frac{\delta}{2} = \frac{I_a Z_s/2}{V}$

$\frac{\delta}{2} = \sin^{-1}\left[\frac{1.0 \times 0.80025}{2 \times 1.0}\right]$

$= 23.586^\circ$

$\delta = 47.17^\circ$

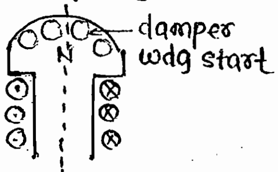
$\phi = (90^\circ - 88.57) + 23.586^\circ$

$\boxed{\phi = 25.02^\circ}$

DATE-17/11/14

Synchronous motor starting

- ON-LOAD START
  - Variable Freq. Start ($\frac{V}{f}$ = constant)
  - Damper wdg Start



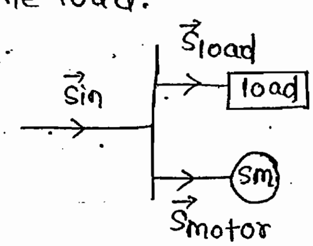
    - * Synduction motor
    - * Hunting phenomenon
- No Load Start
  - Auxillary (PONY) moto start
    - Induction motor
      - P = No. of SM Poles
      - If SM poles are large in No. then P = SM−2
    - dc motor
      - Speed control available (synchronise as gen^r later remove PONY motor)
      - Speed control not available Do as with IM.

Que.→ A 3-ϕ-λ connected load takes 50A as current at 0.707 lagging PF with 220V b/n the lines. A 3ϕ λ connected round rotor syn. motor having a syn. reactance of 1.27Ω/ϕ is connected in parallel with the load. The power developed by motor is 33kW at a power angle of 30°. Calculate the overall pF of the motor & the load.

Soln→

$$\vec{S}_{load} = \sqrt{3} \times 220 \times 50 \angle \cos^{-1}(0.707) \text{ VA}$$

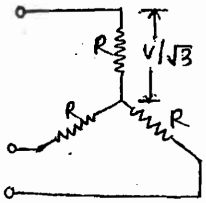
$$= 19.053 \angle 45^\circ \text{ KVA}$$



$$P = \frac{V \times E_f}{X_s} \sin\delta$$

$$330 \times 10^3 = \frac{220 \times E_f}{1.27} \sin 30^\circ$$

$$\boxed{E_f = 381 \text{ volts (L-L)}}$$

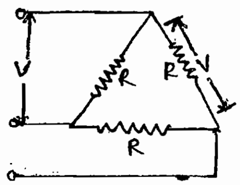


$$P_{1-\phi} = \frac{(V/\sqrt{3})^2}{R} = \frac{V^2}{3R}$$

$$P_{3-\phi} = 3 \times P_{1-\phi} = 3 \times \frac{V^2}{3R}$$

$$P_{3-\phi} = \frac{V^2}{R}$$

$$\boxed{P_{1-\phi} = \frac{V^2}{3R} \qquad P_{3-\phi} = \frac{V^2}{R}}$$



$$P_{1-\phi} = \frac{V^2}{R}$$

$$P_{3-\phi} = 3 \times P_{1-\phi}$$

$$P_{3-\phi} = \frac{3V^2}{R}$$

$$\boxed{P_{1-\phi} = \frac{V^2}{R} \qquad P_{3-\phi} = \frac{3V^2}{R}}$$

$$Q_{motor} = \frac{-V}{X_S}(V - E_f \cos\delta)$$

$$= \frac{220}{1.27}(220 - 381\cos 30^\circ)$$

$$= -19.047 \text{ KVAR (leading VARs)}$$

$$\vec{S}_{motor} = (33 - j\,19.047)$$

$$\vec{S}_{in} = \vec{S}_{load} + \vec{S}_{motor}$$

$$= 46.806\angle{-6.84^\circ}\text{ kVA}$$

Overall PF $= \cos(6.84)$ (leading)

$= 0.9929$ (leading)

$\boxed{PF = 0.9929}$

(5.5 / 590) A 230V, 4P 50Hz λ connected syn. motor has $R_a + jX_s = (0.6 + j3)\,\Omega/\phi$. Its field current is so adjusted that the motor draws 10 A at UPF from rated vol. source. Now with field current unchanged load on the motor increase till it draws 40A from supply. Find the torque dev. & New PF.

Soln: At UPF $\quad E_{f1} = \frac{230\angle 0^\circ}{\sqrt{3}} - 10\angle 0^\circ \times (0.6 + 3j)$

$$= 130.29\angle{-13.31^\circ} \text{ voltz (L-N)}$$

When load is increased →

$$130.29\angle{-\delta_2} = \frac{230}{\sqrt{3}}\angle 0^\circ - 40\angle{-\phi_2} \times 3.06\angle 78.89^\circ$$

$$130.29\angle{-\delta_2} = 132.79 - 122.4\angle 78.69^\circ - \phi_2$$

$$= [132.79 - 122.4\cos(78.69^\circ - \phi_2)] - j[122.4\sin(78.69^\circ - \phi_2)]$$

squaring & equating magnitudes ..

$$\cos(78.69^\circ - \phi_2) = 0.4811$$

$$\phi_2 = 17.45^\circ \text{ lagging}$$

New PF = $\cos(17.45^\circ)$ lagging

$$\boxed{\text{New PF} = 0.954 \text{ lagging}}$$

$$P_{dev} = P_{in} - \text{Total arm. cu loss}$$

$$= \sqrt{3} \times 230 \times 40 \times 0.954 - 3 \times 40^2 \times (R_a = 0.6)$$

$$\boxed{P_{dev} = 12321.86 \text{ Watts}}$$

$$T_{dev} = \frac{P_{dev}}{\omega_{sm}}$$

$$= \frac{12321.86}{\frac{2}{(P=4)} \times 2\pi f}$$

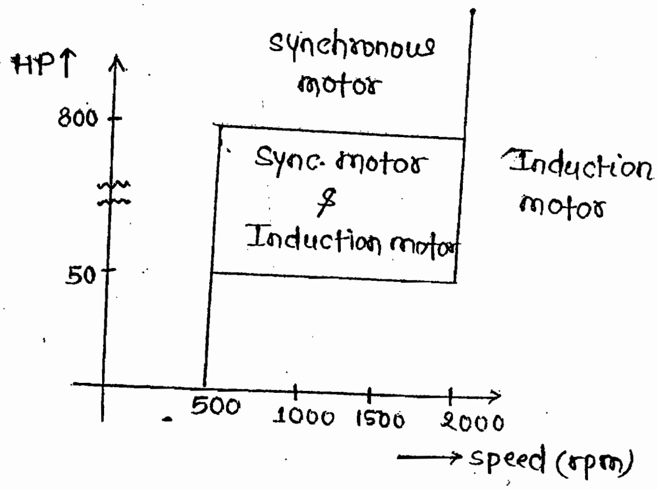
$$\because \omega_{sm} = \frac{2\pi N_s}{60} = \frac{2\pi}{\cancel{60}} \times \frac{\cancel{120}^{2} f}{P}$$

$$\omega_{sm} = \frac{2}{P} \times 2\pi f$$

$$= \frac{12321.86}{(1/2) \times 2\pi \times 50}$$

$$\boxed{T_{dev} = 78.44 \text{ N-m}}$$

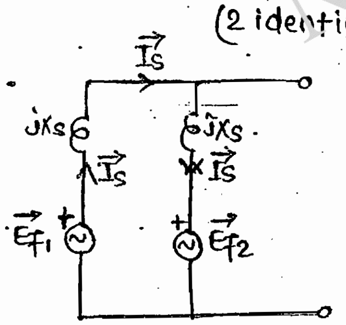
MOTOR APPLICATION GUIDE



* Below 500 rpm indⁿ motor not is use (12P) & above 2000 rpm syn. motor is not in use.
* Below 50 HP use Indⁿ motor & above HP 800 only syn. motor.
* (50HP-800HP) & (500-2000) Rpm both is available.
* Squarral cage SM is popular because of
* SM speed is not effected by voltage where as IM highly affected by vol. variation.

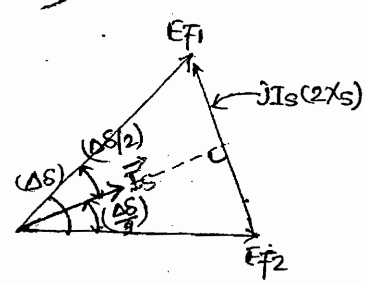
SYNCHRONISING POWER

(2 identical m/c on No-load)



$E_{f1} = E_{f2} = E_f$

Before disturbance



$$\sin\frac{\Delta\delta}{2} = \frac{I_s X_s}{E_f}$$

$$I_s = \frac{E_f}{X_s}\sin\frac{\Delta\delta}{2}$$

* Due to incoming disturbance in the m/c there will be an excitation occurs & then E_{f2} will be excited by $(\Delta\delta)$ with E_{f1}.

* m/c-1 (work as genʳ & source) will deaccelerate this increase in the excitation & the m/c-2 (work as motor & sink) will accelerate.

* The amount of power which is going away from genʳ & coming into motor is equals in amount is known as synchronising power. i.e. the power used for synchronising the excitation. is &

$$\text{Synchronising power } P_s = \Delta P = E_f \cdot I_s \cdot \cos\frac{\Delta\delta}{2}$$

$$= E_f\left[\frac{E_f}{X_s} \cdot \sin\left(\frac{\Delta\delta}{2}\right)\right]\cos\left(\frac{\Delta\delta}{2}\right)$$

$$P_s = \Delta P = \frac{E_f^2}{2X_s}\sin(\Delta\delta) \text{ watts}$$

Since; $\Delta\delta$ is very small,

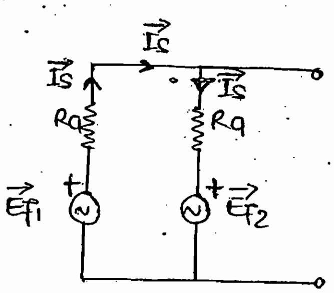
$$\sin(\Delta\delta) = \Delta\delta \text{ elect rad}$$

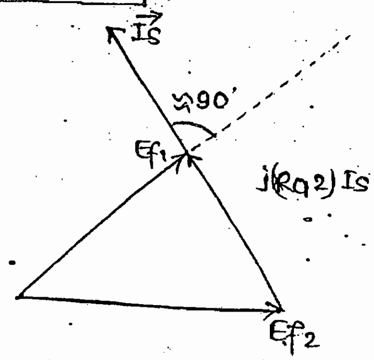
$$P_s = \Delta P = \frac{E_f^2}{2X_s} \times (\Delta\delta) \text{ watts}$$

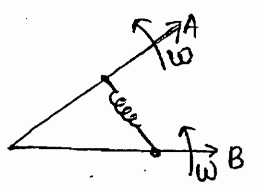
$$\text{Synchronising power coff. } S_p \triangleq \frac{P_s}{\Delta\delta} = \frac{\Delta P}{\Delta\delta} \text{ watts/elect rad.}$$

(OR)

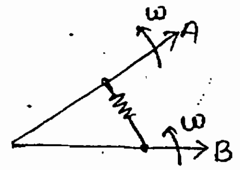
$$\text{Stiffness coff } \boxed{S_p = \frac{E_f^2}{2X_s}} \text{ watts/elect rad.}$$





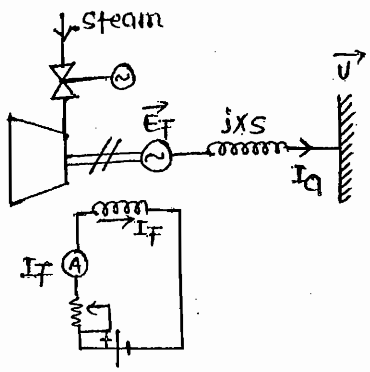


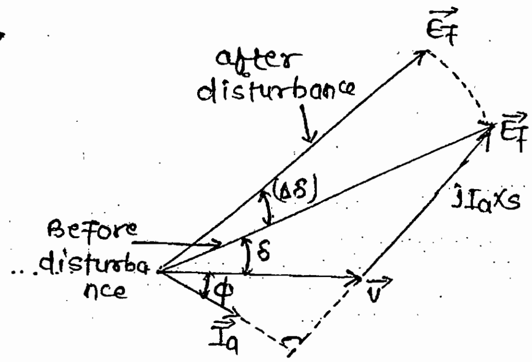
Restoring capability



No restoring capability.

* Synchronising Power → (Large m/c connected to ∞ bus)





Before disturbance; $P = \frac{VE_f}{X_s}\sin\delta$

After disturbance; $P + \Delta P = \frac{VE_f}{X_s}\sin(\delta + \Delta\delta)$

∴ synchronising power; $P_s = \Delta P = \frac{VE_f}{X_s}\left[\sin(\delta+\Delta\delta) - \sin\delta\right]$ watts

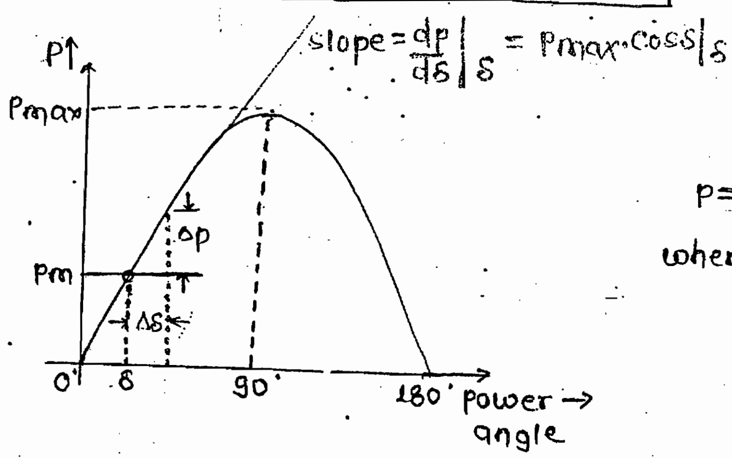
$$= \frac{VE_f}{X_s}\left[\sin\delta\times\cos\Delta\delta + \cos\delta\cdot\sin(\Delta\delta) - \sin\delta\right]$$

$$= \frac{VE_f}{X_s}\left[\cos\delta\cdot\sin(\Delta\delta) - \sin\delta(1-\cos\Delta\delta)\right]$$

$$= \frac{VE_f}{X_s}\left[\cos\delta\cdot\sin\Delta\delta - \sin\delta\times 2\sin^2\left(\frac{\Delta\delta}{2}\right)\right]$$

~~since $\frac{\Delta\delta}{2}$ is very small; $\sin^2\frac{\Delta\delta}{2} \simeq 0$~~

$$\boxed{P_s = \Delta P = \frac{VE_f}{X_s}\cdot\cos\delta\times\sin(\Delta\delta)} \text{ watts}$$



$P = P_{max}\sin\delta$

where $P_{max} = \frac{VE_f}{X_s}$ at $\delta = 90°$

Since $\Delta\delta$ is small; $\sin(\Delta\delta) = (\Delta\delta)$ elect·rad

$$P_s = \Delta P = \frac{VE_f}{X_s}\cdot\cos\delta \times (\Delta\delta) \text{ watts}$$

Hence $S_P = \frac{P_s}{\Delta\delta} = \frac{\Delta P}{\Delta\delta}$ watts/elect·Rad.

$$S_P = \frac{VE_f}{X_s}\cdot\sin\delta$$

$$= P_{max}\sin\delta$$

$$= \frac{dP}{d\delta}\Big|_{\delta = \text{initial operating angle}}$$

$S_P = P_{max}$ at $\delta = 0$ (i.e. on NL)

* This is the reason that it is recommended that the gen^r is synchronise on No Load.

* Captive power plant is a prisoner for own industries. i.e. generation of power for only own industries.

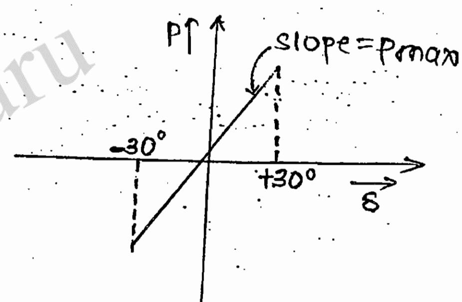
*** Linearised Analysis →**

$$P = (P_{max})\cdot\sin\delta$$

In the range $-30° \leq \delta \leq +30°$

$\sin\delta \approx \delta$ elect rad.

Thus; $P = (P_{max}) \times \delta$ watts



* This is the reason that it is recommanded that the syn. m/c be operated with power angle limited to 30°.

Que.→ Cal. the synchroning cofficient in kW & N-m/mech° at FL for a 50 Hz 1000 KVA 0.8 PF lag, 6.6 KV 3P λ connected syn. gen^r of negligible resistance & syn. reactance of 0.8 PU.

Sol^n →

$$\vec{E_f} = 1\angle 0° + j(1.0)\angle -\cos^{-1}(0.8) \times 0.8$$

$$= 1.60\angle 23.38° \text{ PU} \approx 1.6125\angle 23.39° \text{ PU}$$

$$S_P = \frac{E_f V}{X_s}\cdot\cos\delta\Big|_{\delta = 23.38} = \frac{1.60 \times 1}{0.8}\cos(23.38)$$

$$= 1.836 \text{ PU}$$

≈ 1.85 PU per elect rad.

$S_p = 1.85 \times 1000$ kw/elect rad.

$= 1850$ kw/elect rad.

$= 1850 \times \frac{\pi}{180^\circ}$ kw/elect°

$= 32.289$ kw/elet°

$= 129.156$ kw/mech°

Rad $\frac{\pi}{180}$ degree

Synchronising torque coff. $= \dfrac{129.156 \times 10^3}{\frac{2}{8} \times 2\pi \times 50}$

$= 1644.465$ Nm/mech°

$F_{ar} = F_{ar(d)} + F_{ar(q)}$

$N_{ph} I_a = F_{ar(d)} + F_{ar(q)}$

$I_a = \dfrac{F_{ar(d)}}{N_{ph}} + \dfrac{F_{ar(q)}}{N_{ph}}$

$\vec{I_a} = \vec{I_d} + \vec{I_q}$

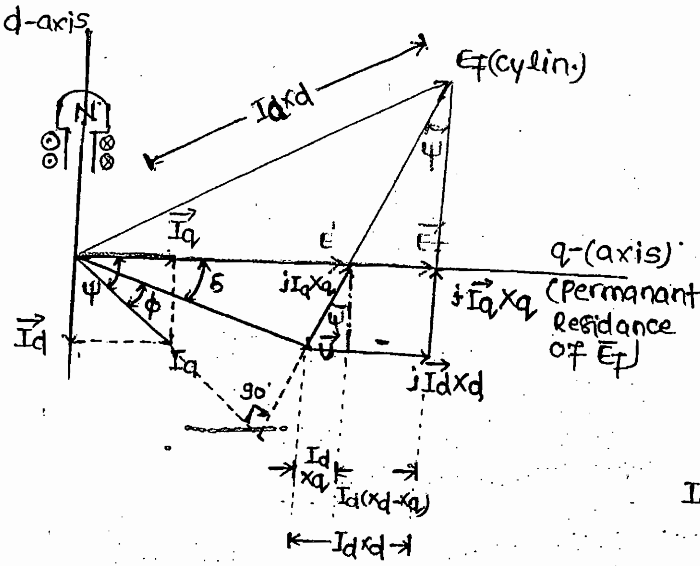
$X_q = 0.6 X_d$ to $0.7 X_d$

Salient Pole m/c

* Blondel's 2 reaction theory →

$I_q = I_a \cdot \cos\psi$

$I_d = I_a \sin\psi$



Over excited gen^r (PF lag)

The initial challange

Locating the q-axis

$E' = V + jI_a X_q$

$\therefore E_f = E' + I_d(X_d - X_q)$

(OR)

$E_f = V\cos\delta + I_d X_d$

$I_q X_q = (I_a \times ?) \cos\psi$

$= (I_a \cos\psi) \cdot ?$

$= I_q \times ?$

$? = X_q$

$P = VI_a \cdot \cos\phi$

$= VI_a \cos(\psi - \phi)$

$= VI_a[\cos\psi \cdot \cos\delta + \sin\psi \cdot \sin\delta]$

$= V\cos\delta(I_a\cos\psi) + V\sin\delta(I_a \sin\psi)$

$= V\cos\delta \cdot I_q + V\sin\delta\, I_d$

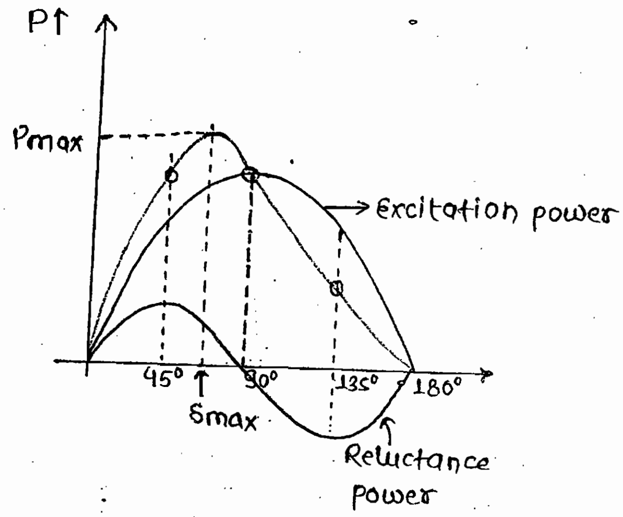
$= \frac{V\cos\delta}{X_q} \cdot I_q X_q + \frac{V\sin\delta}{X_d} \cdot I_d X_d$

$= \frac{V\cos\delta}{X_q} V\sin\delta + \frac{V\sin\delta}{X_d}(E_f - V\cos\delta)$

$= \frac{VE_f}{X_d} \cdot \sin\delta + V^2 \sin\delta\cos\delta\left(\frac{1}{X_q} - \frac{1}{X_d}\right)$

$= \frac{V \cdot E_f}{X_d} \sin\delta + \frac{V^2}{2}\sin 2\delta\left(\frac{1}{X_q} - \frac{1}{X_d}\right)$

$$\boxed{P = \underbrace{\frac{V \cdot E_f}{X_d} \cdot \sin\delta}_{\text{Excitation Power}} + \underbrace{\frac{V^2}{2}\sin 2\delta\left(\frac{1}{X_q} - \frac{1}{X_d}\right)}_{\text{Power due to Saliency (OR) Reluctance power}}}$$


P
Pmax
Excitation power
45°
90°
135°
180°
δmax
Reluctance power

Induction Machine

by

murali Sir

By Murli sir

DATE-04/12/14

Induction m/c

* These are the most commonly used motors because of there basic ad. like simple design, less cost, mech. strong, excellent running c/s, good speed regn no arm. reactions, commutation, sparkings & operates on AC (No need of any dc supply).

* RMF → It also operates as genr but not prefered conventional pwr generation these are more popular in motor segment.

* They operate on the basis of Rotating magnetic Field.

* RMF → * when a 3ϕ supply is applied to a 3ϕ wdg which is distributed with the space dispalacement 120° a net flux is produced which rotates at a constant speed ($N_S = 120f/P$) with a const. magnitude ($1.5\phi_m$) and with a perticular dirn depanding on ϕ seq.

$$\phi_A = \phi_m \sin\omega t$$

$$\phi_B = \phi_m \sin(\omega t - 120)$$

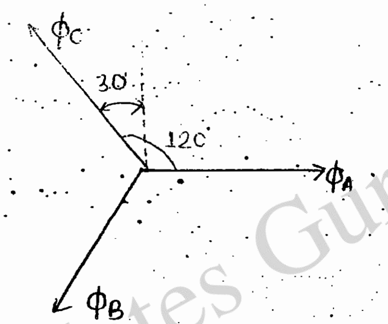
$$\phi_C = \phi_c \sin(\omega t - 240)$$

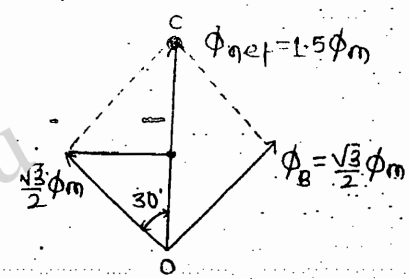
at $\omega t = 0$

$\phi_A = 0$

$\phi_B = -\frac{\sqrt{3}}{2}\phi_m$

$\phi_C = \frac{\sqrt{3}}{2}\phi_m$





From Δ OAB

$$\cos 30° = \frac{OA}{OB}$$

$$OA = OB\cos 30° = \frac{\sqrt{3}}{2}\phi_m \cdot \frac{\sqrt{3}}{2} = \frac{3}{4}\phi_m$$

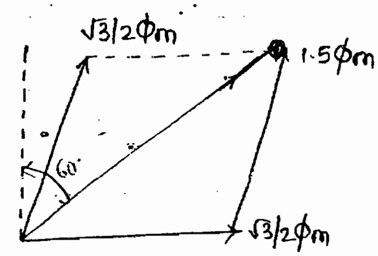
$$OC = \frac{3}{2}\phi_m = 1.5\phi_m$$

at $\omega t = 60°$

$\phi_A = \sqrt{3}/2\,\phi_m$

$\phi_B = -\sqrt{3}/2\,\phi_m$

$\phi_C = 0$

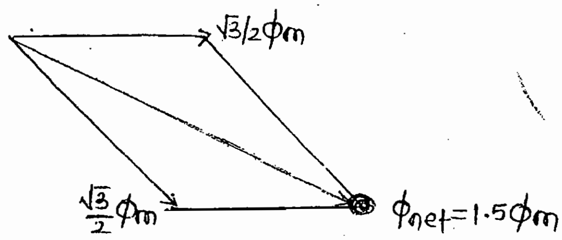


at $\omega t = 120°$

$\phi_A = \sqrt{3}/2\, \phi_m$

$\phi_B = 0$

$\phi_C = -\frac{\sqrt{3}}{2} \phi_m$

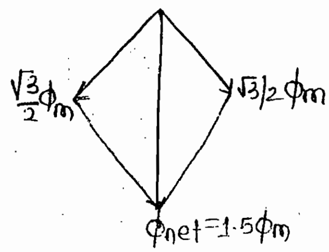


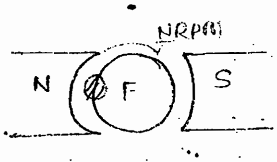
at $\omega t = 180°$

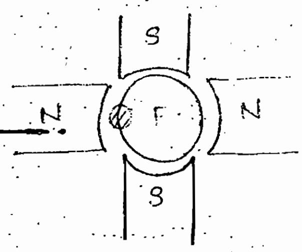
$\phi_A = 0$

$\phi_B = \sqrt{3}/2\, \phi_m$

$\phi_C = -\sqrt{3}/2\, \phi_m$







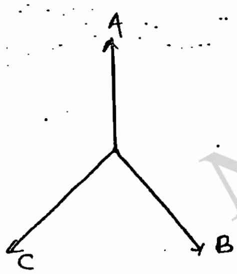
$N/60$ RPS

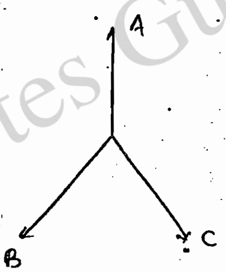
cycles/rotation $= P/2$

rot/sec x cycles/rot $= \frac{PN}{120}$

Cycles/sec $\Rightarrow f = \frac{PN}{120}$

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





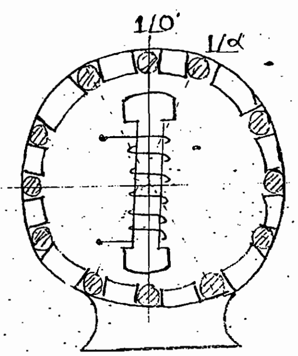
*Construction →

* Like all rotating ele. m/c it also consists of stationary part stator & the rotating part rotor mounted on the shaft & supported by suitable bearings.
* There will be least possible air gap. b/n stator & rotor.

* stator →

* It contains slots at the inner peripheral made up of si-steel laminations.
* 3ϕ wdg either λ (or) Δ (depending on starting method) will be placed in the slots which offer good mech. sequrity for the wdg.

* Design of 3ϕ wdg →



slots angle $\alpha°$

phase displacement contributed by 1 slot in ele°

$$\alpha = \frac{180°}{\text{No. of slots/pole}}$$

Slots = 12, $\alpha = 30°$

Slots = 120, $\alpha = 3$

Phase Group/Band/Belt : n (adjacent)

Phase spread : $n\alpha$

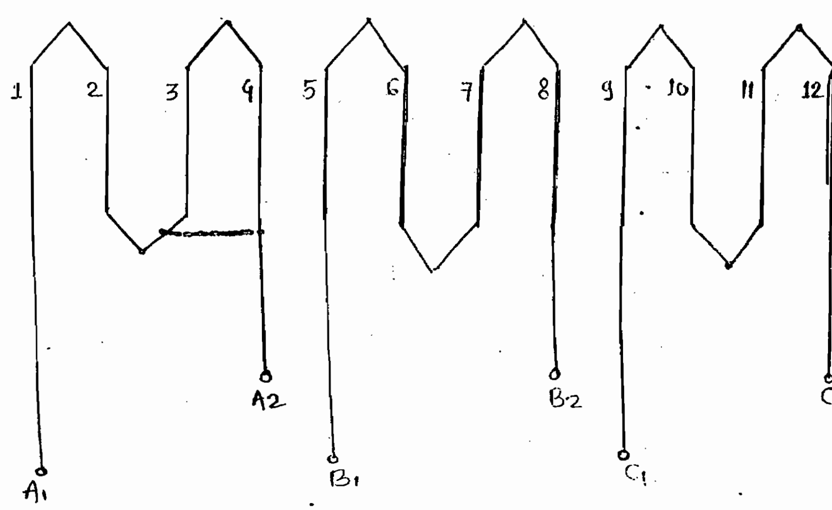
Phase group → The no. of adjacent slots (or) condr belonging to a same phase.

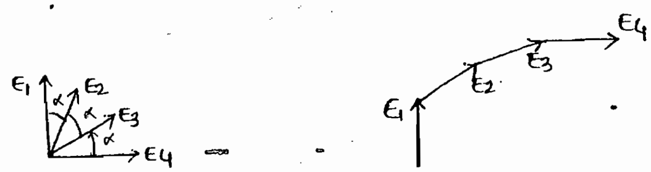
Phase spread → The angle subtended by one phase group is phase spread.

3ϕ wdgs can be designed for 120° ph. spread (or) 60° phase spread.

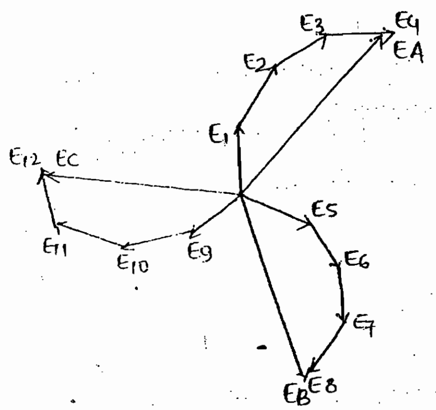
120 phase spread → $n\alpha = 120°$, $\alpha = 30°$, $n = 4$

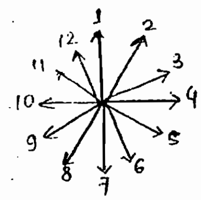
n → slots/pole/phase (SPP)





* Distribution of wdg is done only for getting improving the shape of wave forms.



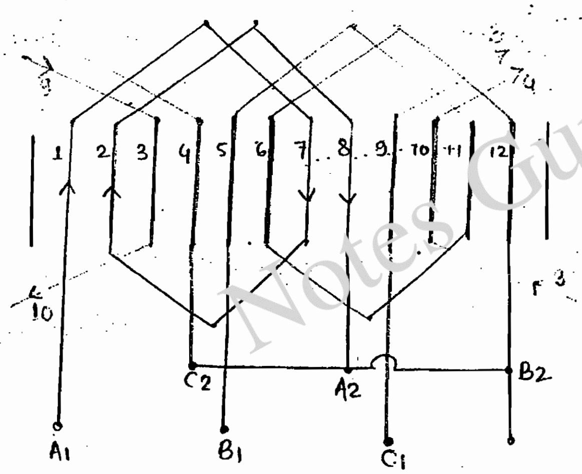


* 60° phase spread → $n\alpha = 60^\circ$; $\alpha = 30^\circ$; $n = 2 \rightarrow 6$ phases

↓

Combined to be 3 phase

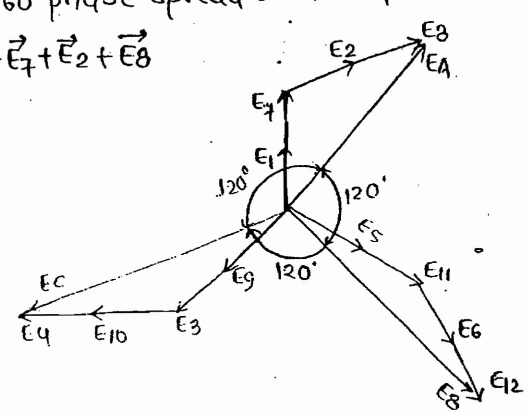
Bunch of 2 phases.



Note:-

To maintain 60 phase spread 1 should be connected to 7.

$$E_A = \vec{E_1} + \vec{E_7} + \vec{E_2} + \vec{E_8}$$



Sagar Sen
8871453536

$\boxed{E_{120^\circ} < E_{60^\circ} \quad \text{Phase spreads}}$

distribution factor $k_d = \dfrac{\text{emf DW}}{\text{emf CW}}$

$$k_d = \frac{\sin \frac{n\alpha}{2}}{n \sin \frac{\alpha}{2}}$$

since; $\sin\frac{\alpha}{2} \approx \frac{\alpha}{2}$

$$k_d = \frac{\sin \frac{n\alpha}{2}}{\frac{n\alpha}{2}}$$

$$k_{d60} = \frac{\sin \frac{60}{2}}{60/2} \quad ; \quad k_{d120} = \frac{\sin \frac{120}{2}}{120/2}$$

$$\frac{k_{d60}}{k_{d120}} = 1.15$$

$$\boxed{k_{d60} = 1.15\, k_{d120}}$$

* Pitch Factor →

$k_p = \cos \beta/2$

3rd → $k_p = 0.866$

5th → $k_p = 0.95$

7th → $k_p = 0.97$

$k_{p_3} = \cos 3\beta/2$

$k_{p\gamma} = \cos \gamma\beta/2$

***

$$\boxed{\begin{array}{l} \frac{\gamma\beta}{2} = 90^\circ \\ \beta = \frac{180}{\gamma} \end{array}}$$

$$k_{d\gamma} = \frac{\sin \frac{n\gamma\alpha}{2}}{n \sin \frac{\gamma\alpha}{2}}$$

$\sin \frac{n\gamma\alpha}{2} = 180^\circ$

$$\boxed{n\alpha = \frac{360^\circ}{\gamma}}$$

* Practicaly 60° phase spread is prefered as it gives better vol. & power ratings.
120° pha. spread will eliminate 3rd harmonic content in line.
However the wdgs are prefered to be λ. Therefore the 3rd harmonic content in line is 0 even though it exist in each phase.

* Harmonics can be eliminated by short pitching the coils by introducing pitch factor eliminating higher order harmonics like 5th & 7th is more advantageous.

* For high vol. λ connected stator wdg is preferred as it reduces insulation requirements as well as no. of turns in each phase.

* The 3ϕ wdg is also classifies acc. to 2 types :-
(1.) Integral slot wdg (2.) Fractional slot wdg

(1.) Integral slot wdg ↓ n = spp (integer)
Eg:- 12/2/3 , 18/2/3

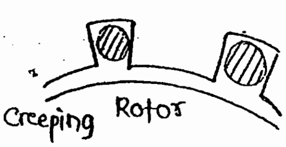
(2.) Fractional slot wdg ↓ n = non integer (fraction)
Eg:- 18/4/3

* Fractional slot wdgs practicaly offer short pitched wdg specialy more suitable in double layer wdg cases.

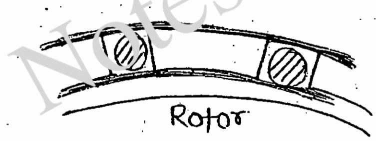
Fractionaly ⟶ Automaticaly short pitched

***Type of slots →**

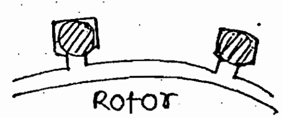
Open



Closed



Semi-open/closed



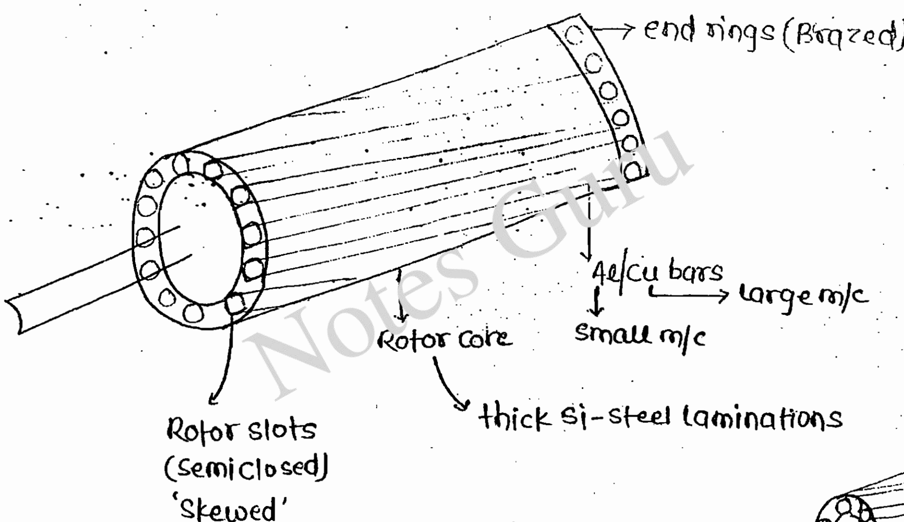
Open	Closed	Semi-open/closed
* wdg design, routine maintainance, repairs is easy less expensive.	Difficult	quite difficult.
* Offer high reluctance to leakage flux, less leakage reactance.	High leakage flux ; high leakage reactance	moderate.
* Net air gap is more which requirs more magnetising current to maintain flux & the operating PF will be low wrt ct.	Net air gap is less, so magnetising current less PF more.	mode~~rate~~.

* wrt. leakage reactance its Operating PF is better Comparitively.	wrt leakage reactance Operating PF is low	moderate.
* Non uniform air gap will produce space harmonics by distorting flux wave-form. also called as slot/tooth harmonics.	No slot/tooth harmonics	moderate

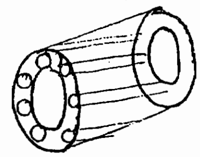
* Generaly prefered slots in IM in stator (OR) rotor are semiclosed type.
* Large rating m/c eg. power plant genr (OR) Large rating IM prefered open type because they produce less leakage reactance & also offers easy, maintaince repair works.

* Rotor →

(1) Squirral cage (OR) cage rotors.
(2) Wound/Slip Ring rotors.



Less depth rotor slots.



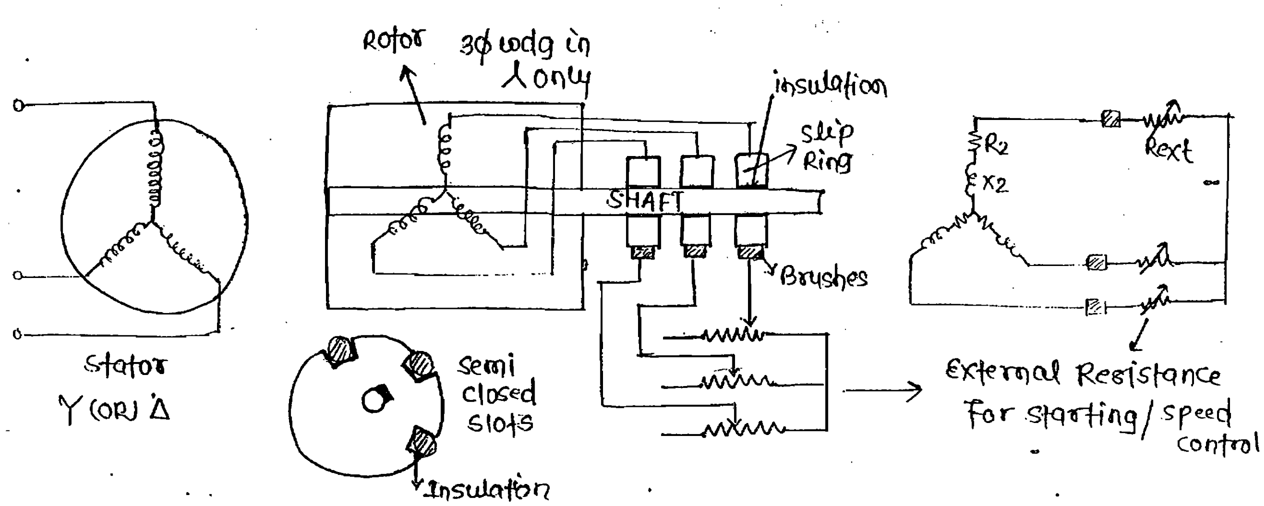
* It has most simple construction doesn't contain any wdg.
* Rotor is made up of thick Si-steel laminations punched into slots of less depth preferabely semiclosed.
* AL (OR) cu bars are directly placed in this slots w/o any insulation (as the current flows only ~~through~~ least resistance)

* This bars are solidaly closed (or) sc with 2 end rings (Brazed)
* Rotor slots are skeyed (twisted or inclined) wrt shaft axis or stator slots to avoid locking tendancy during starting.
* Under the running condⁿ rotor Freq. is negligible & the rotor core losses are very low.
Therefore no need of thin laminations.
* It requires least maintaince repairs, mech. strong, simple design, less cost & excellent running c/s.
* The drawback is due to its low starting torque.
* As the rotor is permanantly closed its resistance can't be varied for starting (or) controlling purpose.

"Poles are automaticaly formed on the rotor equal to the no. of poles on stator."
* Due to mutual indⁿ the poles are induced in the rotor.
Therefore it reacts to any no. of poles on the stator.

DATE-05/12/14

(2.) Slip Ring/wound → * The rotor is a cylindrical drum shaped st. punched into slots (semiclosed) on the outer peripheral which contain a 3ϕ wdg similar to stator wdg but essentialy star connected.
* Rotor is designed for the same no. of poles as on the stator. but preferabely the no. of slots should not be same & should not have a common factor to avoid any chance of magnetic locking during starting.
* The 3 terminals of λ connected wdg will be brought out & connected to 3 slip rings mounted on the same shaft with suitable insulation.



* The starting torque is $\propto$ to rotor resistance but the rotors are naturaly designed for least possible resistance. In order to have high starting torque an external resistance is inserted in each phase equaly through slip ring & brushes.

* Under running condn the resistance is disconnected using a METAL COLLAR arrangement the brushes are slight down & 3 slip rings are SC to form a closed rotor.

* This is only used for high starting torque appn. Around 90% of motors are squarral cage type only.

* Slip motors are expensive, complecated design, high maintaince repairs, running c/s are not good comparitevely.

* Principle:-(How rotor run)?

* When a 3ϕ supply is given to stator RMF is produced at Ns. As the flux sweeps past the rotor cuts it & cuts it & induces EMF due to relative speed Ns. & the rotor freq. at stand still is supply freq.

* As the rotor is essentialy closed it produces current & the current carrying condr placed in the magnetic field will experienced a force which is torque & the rotor rotates.

* According to Lenz law it rotates in the dirn of magnetic field to oppose the cause i.e. relative speed.

* Actualy the rotor want to catch the rotating magnetic field but it could not catch it due to losses in the rotor. and rotates at a speed N slightly less than Ns.

* The rotor slips back RMF by a speed N_s-N known as ~~steep~~ slip speed.

* The principle of operation is mutual indn acc. to Faraday & it is equivalent to a rotating Xmer with SC 2°.

* It is a singly excited m/c.

* Vol. is applied only to stator & the vol. are induced in the rotor through electromagnetic indn.
  Therefore called as Indn motor.

* As it can't run at synchronous speed it is also called as asynchronous motor.

* slip →

* It is the diff of syn. speed & actual speed of the rotor expressed in % of syn. speed.

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

$$\%S = \frac{N_s - N}{N_s} \times 100$$

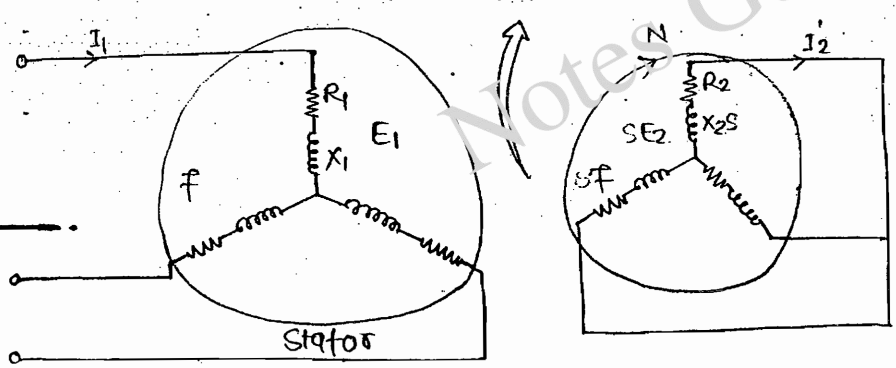
$$N_s - N = SN_s$$

$$\boxed{N = N_s(1-S)}$$

* During starting at N=0, S=1·0
* A well designed ind^n motor runs near to syn. speed with low value of slip on NL & slip is near to 0 (but not 0)
* If the rotor runs at Ns, then no relative speed, no E_2, $I_2=0$, $T=0$.
* The operating region of ind^n motors will be around 1-5% slips from NL to rated load.
* For small motor it may be around 8% at rated load.
* slip plays major role in the operation & performance & behaviour of IM.

* Affect of slip →

Representation →



$$E_2 \propto N_s - 0$$

$$E_2' \propto N_s - N$$

$$\frac{E_2'}{E_2} = \frac{N_s - N}{N_s}$$

$$E_2' = SE_2$$

Relative Speed
Ns-N

* If the rotor resistance is adjusted to a suitable value i.e. exactly equal to rotor leakage reactance at standstill then the motor starts with its max^m torque.
* Under such cond^n the rotor PF will be 0.707 lagging

* Running torque → Consider a motor running at rated load will slips & speed Ns

$$T_f \propto E_2' I_2' \cos\phi_2'$$

$$T_f \propto [K_1\phi]\, I_2' \cos\phi_2' \qquad (E_2 \propto \phi)$$

$$T_f \propto (K_1\phi) \times \frac{SE_2}{\sqrt{R_2^2+(SX_2)^2}} \cdot \frac{R_2}{\sqrt{R_2^2+(SX_2)^2}}$$

$$T \propto \frac{(K_1\phi)\, SE_2 R_2}{[R_2^2+(SX_2)^2]}$$

$$T = K \cdot \boxed{\frac{SE_2^2 R_2}{R_2^2+(SX_2)^2}} \qquad \left(K = \frac{3\times 60}{2\pi N_S}\right)$$

* For a given (or) const. supply vol. $T_f \propto \frac{SR_2}{R_2^2+(SX_2)^2}$

* Under normal running cond^n at low values of slip;

$$S\downarrow;\ (SX_2)^2 << R_2$$

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

$$\boxed{T_f \propto \frac{S}{R_2}}$$

& at the high values of slip

$$S\uparrow \quad (SX_2)^2 >> R_2$$

$$T_f \propto \frac{SR_2}{(SX_2)^2} \propto \frac{R_2}{SX_2^2}$$

$$\boxed{T_f \propto \frac{R_2}{SX_2^2}}$$

* For a given R_2, X_2 values of rotor the torque developed is directly proportional to slip in the low slip region & torque is inversely proportional to slip in the high slip region.

* The running torques are also sensitive to supply vol. variations.

* Condⁿ for maxᵐ running torque →

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

$$\text{let} \downarrow y = \frac{1}{T_F \uparrow}$$

$$\frac{dy}{ds} = 0$$

$$y = \frac{1}{T_F} = \frac{R_2^2+(SX_2)^2}{SR_2}$$

$$\frac{dy}{ds} = \frac{-R_2}{S^2} + \frac{X_2^2}{R_2} = 0$$

$$\frac{R_2}{S^2} = \frac{X_2^2}{R_2}$$

$$R_2^2 = X_2^2 S^2$$

$$\boxed{R_2 = SX_2}$$

* If the rotor resistance = slip times the rotor reactance at stand still then the rotor develops maxᵐ running torque.

maxᵐ starting torque $\boxed{R_2 = X_2}$

maxᵐ running torque $\boxed{R_2 = SX_2}$

Starting	Running torque
$T_{st\,max} \propto \frac{R_2}{R_2^2+X_2^2}$	$T_{F(running)} \propto \frac{SR_2}{R_2^2+(SX_2)^2}$
$T_{st\,max} \propto \frac{1}{2X_2}$	$T_{F(max)} \propto \frac{1}{2X_2}$

$$\boxed{T_{max} \propto \frac{1}{2X_2}}$$

$$K_1 = \frac{3 \times 60 E_2^2}{2\pi N_S}$$ (Refer $\frac{V}{F}$ speed control)

$$\boxed{S_m = \frac{R_2}{X_2}}$$ (Also a condⁿ for maxᵐ value)

* The motor rotates at any slip b/n 0 & 1 but it delivers its max^m torque only at a particular slip $S_m = R_2/X_2$.

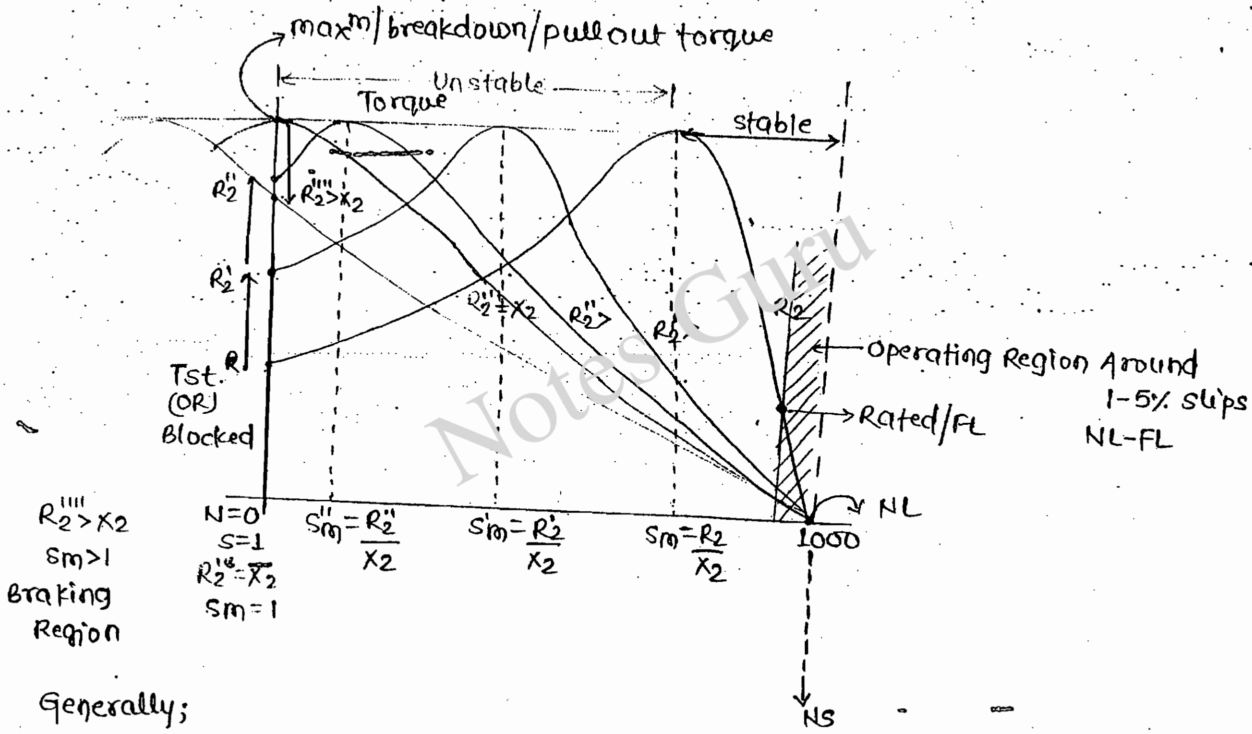
* Generaly rotor resistance is a least possible value compared to its leakage reactance at stand still.

* If an external resistance is added into the rotor to make $R_2 + R_{ext} = X_2$ then $S_m = 1$ which means the motor starts with its max^m torque because slip at which max^m torque occurs $S_m = 1$

* max^m torque magnitude is independant of rotor resistance but the slip at which it occurs depends on R_2.

* max^m torque is inversaly proportional to leakage reactance of rotor at stand still.
Therefore it will be designed as min^m as possible with less depth slots.

* Torque-slip c/s →



Generally;

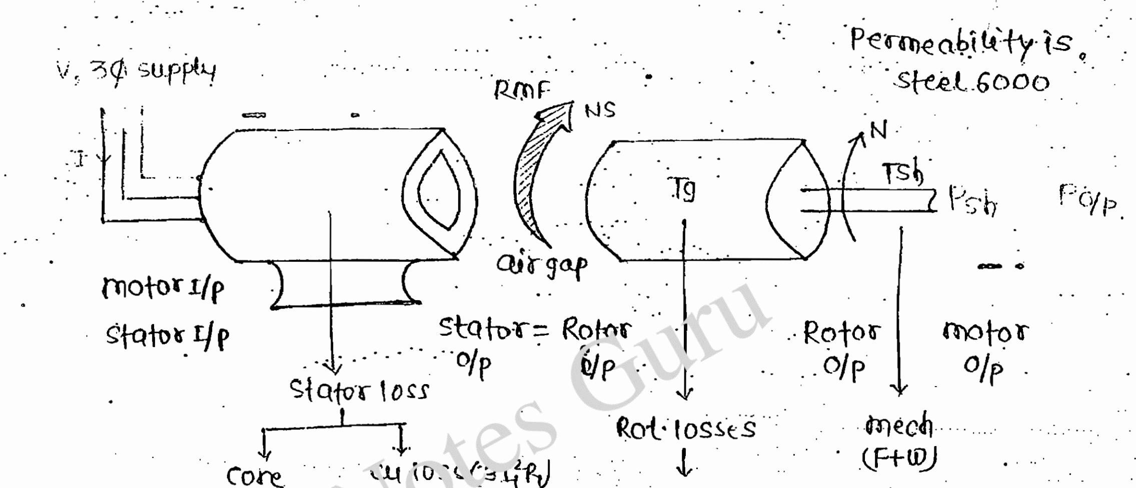
$T_{max} >> T_F$

$(T_{max} \simeq 2\text{-}3\, T_F)$

& $(T_{st} \simeq 1.5\, T_F)$

* T-S c/s are essentialy straight line in the operating region (Low slip). Every motor will have its max^m capacity (or) capability to develop torque which occurs only at slip s_m if the load increases beyond it it can't deliver torque & its stops which is unstable region.
* Im have excellent overload capability but not desirable to operate at over-Loading but can be done for short duration if req.
* All the stable region is not operating region; it should be operated at Low slip only due to η consideration.
* The max^m torque is independant of rotor resistance but the slip & speed where it occurs depands on rotor resistance.
* If $R_2 >> X_2$ max^m torque occurs in the braking region.

* Power stages →



Stator losses → core loss
→ cu loss

Rotor losses → only cu losses

mech. losses → Frictional
→ windage

* There are no losses in the air gap.

Stator I/p − Stator loss = Stator o/p = $\boxed{\text{Rotor I/p} = \text{Air gap power}}$

Rotor I/p − Rotor Cu loss = Rot. o/p

Rot. o/p − Rot loss = shaft (or) motor o/p

$$\eta = \frac{\text{motor o/p } (P_{sh})}{\text{motor I/p } (\sqrt{3} V_L \cdot I_L \cos\phi)}$$

$$P = \frac{2\pi N T_g}{60}$$

Rotor Pi/p = $\frac{2\pi N_s T_g}{60}$ watts | Rot Po/p = $\frac{2\pi N T_g}{60}$ watts

Rotor Pi/p − Rotor Po/p = Rot cu loss = $\frac{2\pi T_g}{60}(N_s - N) = \frac{2\pi T_g}{60} \cdot \frac{S}{N_s} = \underbrace{\frac{2\pi T_g N_s}{60} \cdot S}_{R i/p \times S}$

Rotor cu loss = S. Rot. Pi/p

Rotor Pi/p − Rotor Po/p = S Rot. I/p ⇒ Rotor = (1−S) Rotor Pi/p

$$\frac{\text{Rotor Po/p}}{\text{Rotor Pi/p}} = (1-S) = \eta_{rotor} = \frac{N}{N_s}$$ (Approx η of IM.)
(Negl. mech. & stat)

∗ Core loss (iron) + mech (F+W) = constant loss.

∗ If IM is running at 950 RPM then its approx. η will be 90% because Ns taken as 1000 RPM in Indian condn like (f = 50Hz etc). (Neglecting const. losses)

∗ T developed →

$$T_g = \frac{60}{2\pi N_S} \times \text{Rotor power I/p}$$
(OR)
~~Rot rotor~~ Air gap power.

$$T_g = \frac{60}{2\pi N_S} \cdot \frac{\text{Rot. cu loss} \longrightarrow 3I_2'^2 R_2}{\text{slip}}$$

$$= \frac{60}{2\pi N_S} \cdot \frac{3 I_2'^2 R_2}{S}$$

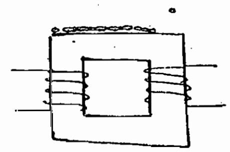
$$= \frac{60}{2\pi N_s} \cdot 3 \times \left[\frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}\right]^2 \times \frac{R_2}{S} \qquad \because I_2' = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

$$= \frac{60}{2\pi N_s} \times \frac{3 \cdot S E_2^2}{R_2^2 + (SX_2)^2} \cdot R_2$$

$$\boxed{T_g = \frac{3\times 60}{2\pi N_S} \cdot \frac{S E_2^2 R_2}{R_2^2 + (S X_2)^2}} \quad N\text{-}m$$

$$T_g = \frac{3\times 60}{2\pi N_S} \times \frac{S(KE_1)^2 \cdot R_2}{R_2^2 + (S X_2)^2} \quad N\text{-}m$$

$$K = \frac{\text{Rotor turns/phase}}{\text{stator turns/ph.}} = \frac{E_2}{E_1} \text{ (stand still)}$$



$E_1 = N_1 \frac{d\phi}{dt}$ $\quad E_2 = N_2 \frac{d\phi}{dt}$

$K = \frac{E_2}{E_1}$

* Torque Ration in terms of 'sm' →

$$T_{st} \propto \frac{R_2}{R_2^2 + X_2^2}$$

$$T_f \propto \frac{S R_2}{R_2^2 + (S X_2)^2}$$

$$T_m \propto \frac{1}{2 X_2}$$

Now;
$$\frac{T_{st}}{T_{max}} = \frac{R_2}{R_2^2 + X_2^2} \times \frac{2X_2}{1}$$

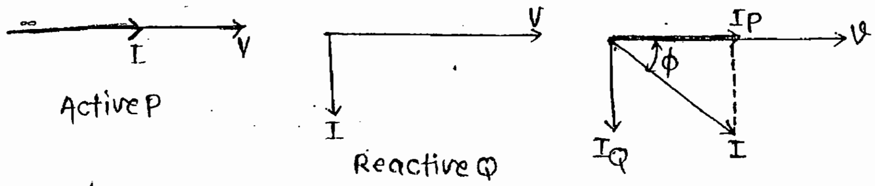
$$= \frac{2 R_2 \cdot X_2 / X_2^2}{\frac{R_2^2}{X_2^2} + \frac{X_2^2}{X_2^2}} = \frac{\frac{2R_2}{X_2}}{\frac{R_2^2}{X_2^2} + 1}$$

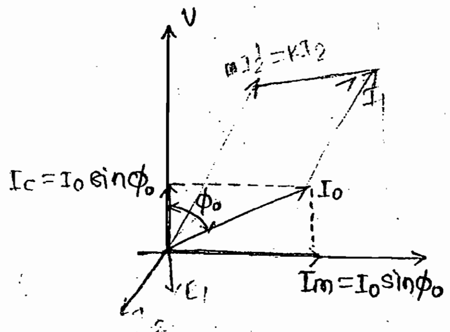
$$\boxed{\frac{T_{st}}{T_{max}} = \frac{2 s_m}{s_m^2 + 1}}$$

$$\frac{T_f}{T_{max}} = \frac{S R_2}{R_2^2 + S^2 X_2^2} \times \frac{2X_2}{1}$$

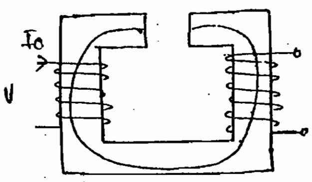
$$= \frac{2 S R_2 X_2 / X_2^2}{\frac{R_2^2}{X_2^2} + \frac{S^2 X_2^2}{X_2^2}}$$

$$\boxed{\frac{T_f}{T_{max}} = \frac{2 \cdot S \cdot s_m}{s_m^2 + S^2}}$$





No Load

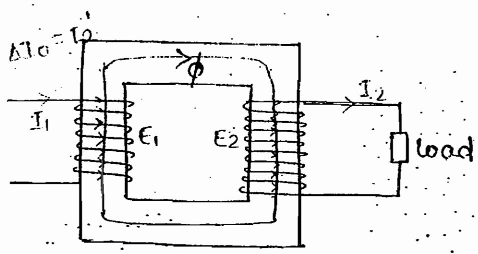


* draw more current to flowing flux in air gap because of high reluctance in the air

2-6% I_{rated}

Highly lagging

* Active power → supply some losses
* Reac~~tive power~~ power → To maitain flux



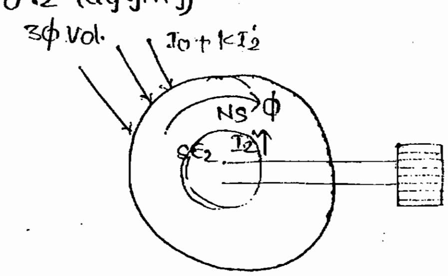
$I_2' = kI_2$

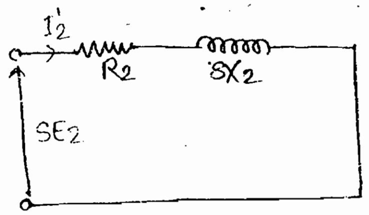
$I_2' \propto I_2$

$I_2' = \frac{N_2}{N_1} I_2$

$\phi_2' = \phi_2$

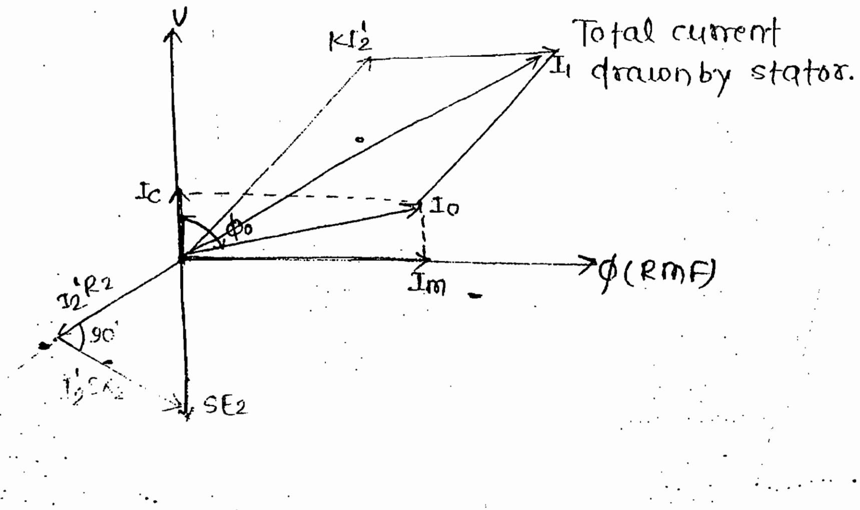
* IM on NL → * It draws a large magnetising current around 30% of rated to establish flux (RMF) in the air gap of high reluctance.
* Only ZPF Lagging current will supply flux (magnetising current).
* Im draws reactive power to establish flux in the air gap.
* It draws active power for supplying its losses & load torque if loaded.
* On NL as the magnetising current is very high it operates at low lagging PF (less than 0.2 lagging)



Rotor ⇒ 

$$SE_2 - I_2'(R_2 + jX_2) = 0 \quad (V)$$

$$I_2' = \frac{SE_2}{R_2 + jsX_2}$$

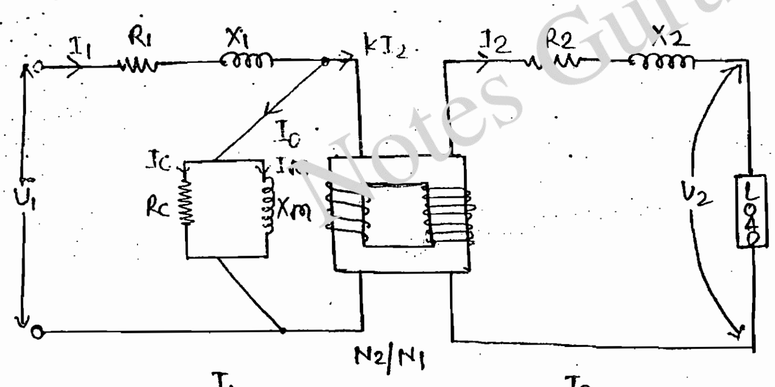


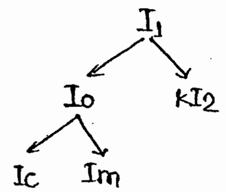
* On load rotor current increase proportionaly to produce its own flux in the air gap which is stationary wrt stator RMF but opposes it acc to Lenz law & reduce it.
* Therefore stator draws more current proportionaly to maintain the flux const in the air gap.
* whenever rotor is loaded it will immediately call current from stator. (KI_2')
- with load PF improves but operate at low PF comparitive to an eq Xmer.

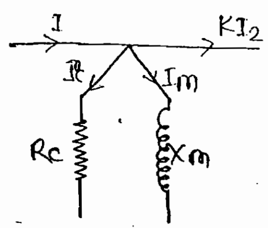
Transformer	Induction motor
(1.) Ele. to ele. energy conversion through magnetic medium in high permeabilitity core	Ele to mech. energy conversion. through magnetic medium in the air gap of high reluctance.
(2.) Require less magnetising current	Requires large magnetising current.
(3.) NL current 2-6% of rated	Around 30-40% of rated.
(4.) Low lagging PF on NL	Very much low lagging PF.
(5.) PF improves with load.	PF improves with load. but compare low.
(6.) Concentrated wdg.	Distributed wdg produce RMF.

(7.) Contain Core loss & Cu loss only	Stator core loss, no loss in air gap & rotor core loss negligible & includes mech. loss. with cu losses of stator & rotor.
(8.) Induced emfs depands on turns ratio.	Induced emfs depands on turns ratio only at standstill but vary with slip under running.
(9.) Freq. of 1°, 2° same	freq. of stator, rotor same. only at stand still but vary with slip.
(10.) 2° is never SC	But rotor should be essentialy SC.
(11) Ele. loading across 2° terminals	mech. loading across rotor shaft.
(12.) Leakage flux less & leakage reactances	Leakage flux high & leakage reactance.
(13.) Constant flux device	Constant flux m/c.
(14.) mutual ind^n	mutual ind^n.

* T/F eq. ckt Representation →







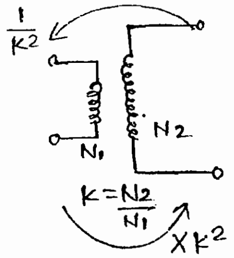
$R_c = \frac{V_1}{I_c} \gg X_m = \frac{V_1}{I_m}$ [Ficticious/Imag. value]

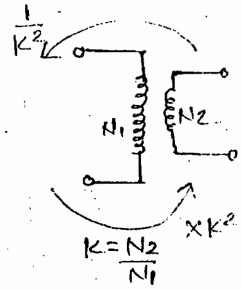
$I_c < I_m$

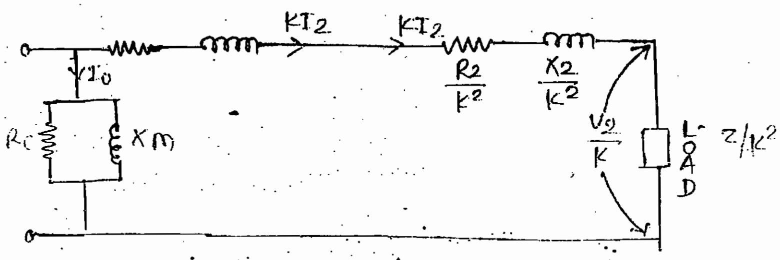
Rc, Xm ~~depends~~ on Ic & Im.

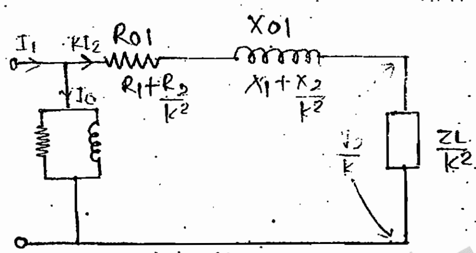
$$I_1^2 R_2' \Longrightarrow I_2^2 R_2$$

$$R_2' \Rightarrow \left(\frac{I_2}{I_1}\right)^2 R_2$$



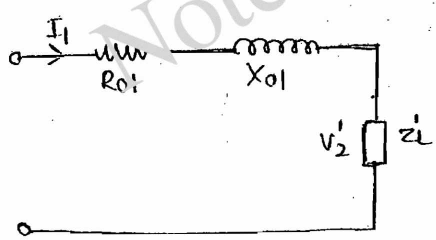






approx. eq. ckt Neglecting shunt branch

Ref to 1°

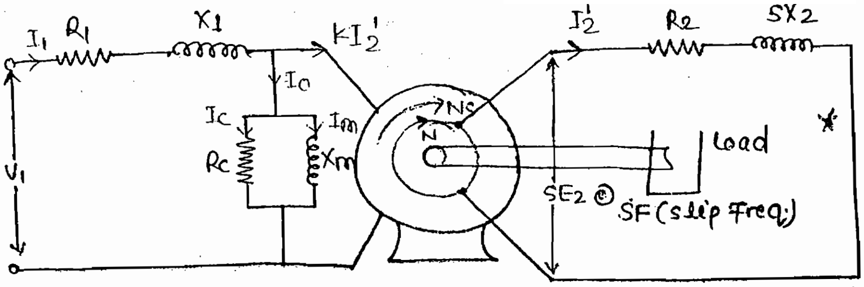


Note→ As the principle of operation behaviour is identical to both TF & IM which is also called as rotating TF. The TF eq. ckt is used for representing IM. For analysis purpose.

* However there are 2 major diff which need to be resolved:-

(i) Freq. of rotor is slip freq.

(ii) Loading is mech. across the shaft.



Stator Rotor

S_{RMF} wrt stator @ N_s

R_{RMF} ~~wrt stator~~ @ $SN_s + N$

∵ Rotor itself rotate @ N in the same dirn of mag. field

$N_s - N + N$
$= N_s$

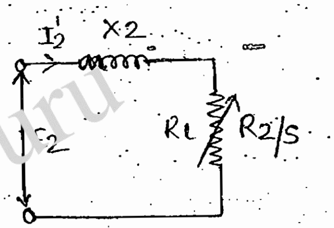
Note:- Both stator RMF & rotor RMF runs at syn. speed in the air gap & make the rotor to rotate at any speed N.

* The absolute flux in space will always rotate at syn. speed wrt a stationary point in space of stator but wrt rotor it is at SN_s.

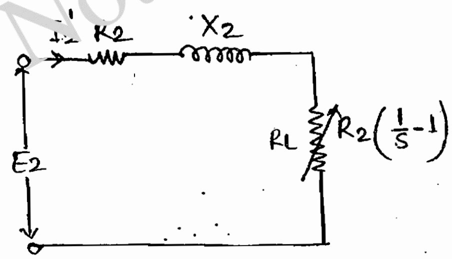
*

$$I_2' = \frac{SE_2}{R_2 + jX_2 S}$$

$$I_2' = \frac{E_2}{\frac{R_2}{S} + j\frac{X_2 \cancel{S}}{\cancel{S}}} \Rightarrow$$

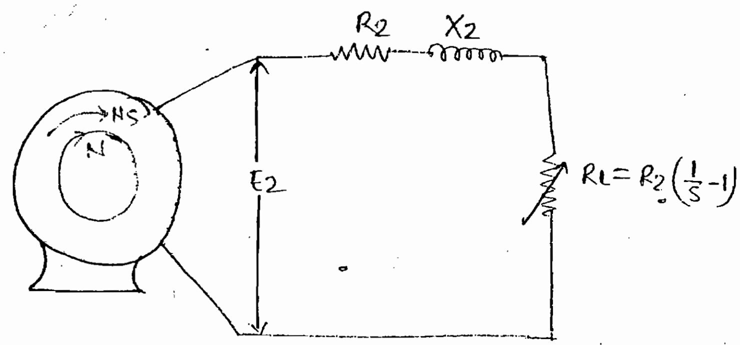


(at rotor freq.)

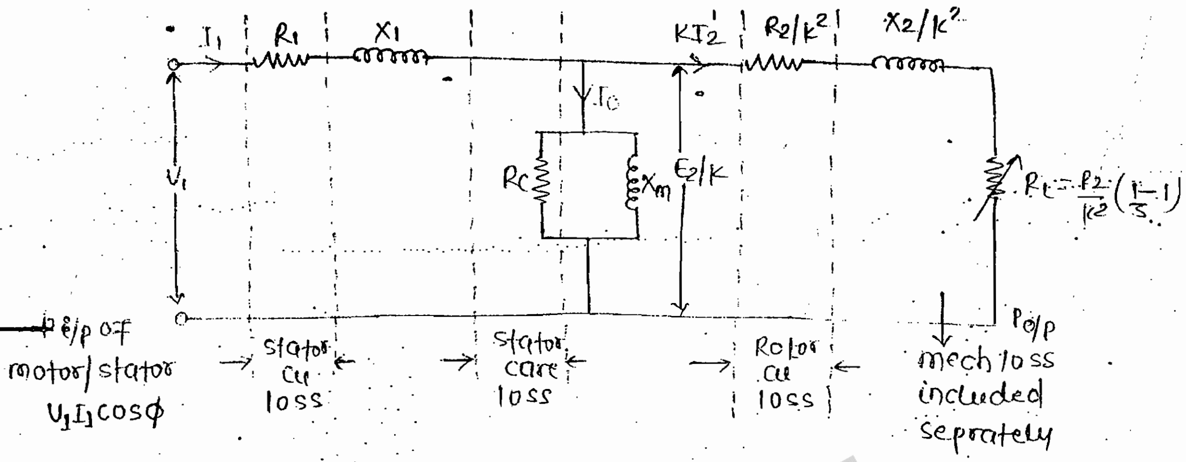


* If Im → open (NL)
$S \to 0$
$R_L \to \infty$ (OC) like TF

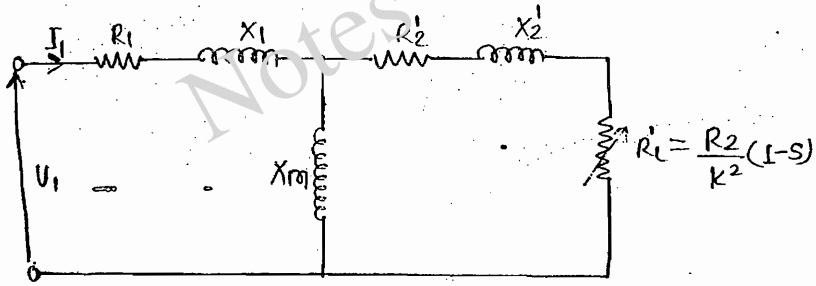
* Im → Rated load
$S \to 1$
$R_L \to 0$ (SC)



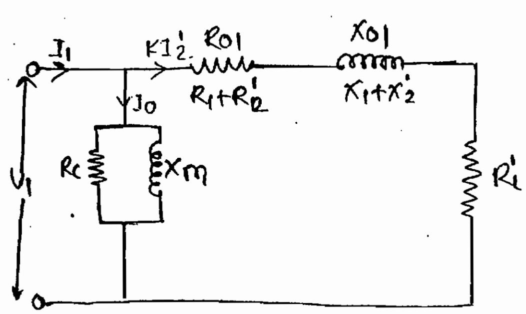
$$K = \frac{\text{Rotor turns/phase}}{\text{Stator turns/phase}} = \frac{E_2 \text{ @ stand still}}{E_1}$$



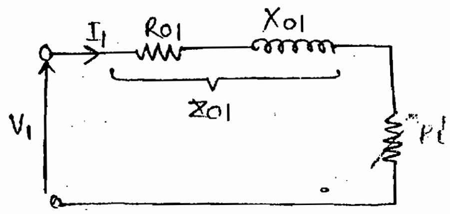
*** IEEE standard ckt representation →** Shunt branch resistance is eliminated in the std ckt but core losses & mech. losses should be included in net power calⁿ. This will be accurate analysis.



*** Approx Eq. ckt →**



Neglecting shunt branch →



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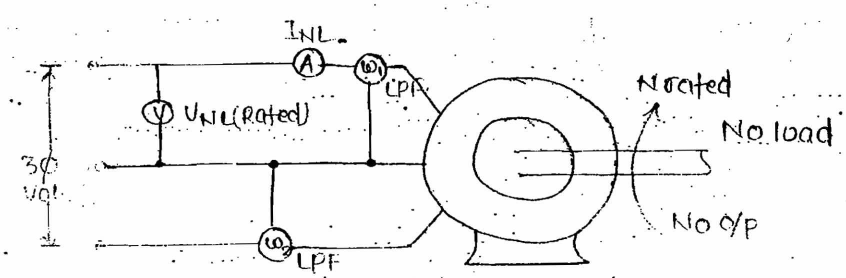
* Determination of eq. ckt parameters → It requires 3 tests to be performed:-

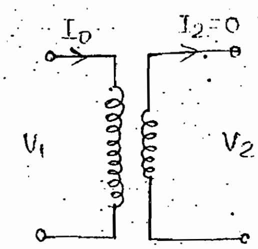
(1.) No Load

(2.) Blocked rotor test

(3.) DC test (OR) voltmeter-Ammeter method.

(1.) No Load test →





$W_{NL} = W_1 + W_2$ (algebric sum)
↓
(P i/p drawn)

No Load
No o/p
I/p = o/p + Total Loss

* Apply rated vol. across the stator & ~~along~~ allow it to run freely on NL.

* Connect necessary meters & essentialy LPF wattmeters are req.

* The 3φ power is measured using 2 wattmeter method & the total power is algebric sum of both meter.

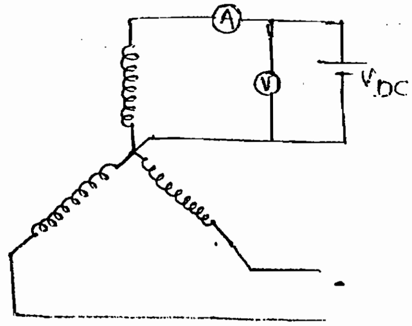
* On the NL as o/p is 0 the i/p power drawn is to supply all the losses at NL. Therefore the wattmeter reading is concerned as loss.

Total loss = Stator coreloss ✓
Stator cu loss ✓
Rotor core loss → Neglected due to slip freq. less
Rotor cu loss → Neglected
mechanical loss ✓

* on NL the NL power drawn is considered to supply stator core.

* In order to cal. rotational or constant losses stator resistance need to be calculated to eliminate stator Cu loss.

3.) DC test (OR) V-m, A-m method →



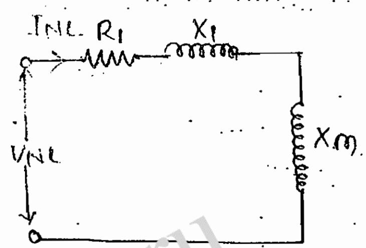
V/A Ratio R_{1DC}/phase

$R_{1AC}/ph = \underbrace{1.2-1.6}_{\text{skin effect \& Hot resistance}} R_{1DC}/ph$

$$W_{NL} - 3I_{NL}^2 R_1 = \text{Constant Loss/Rotational loss.}$$

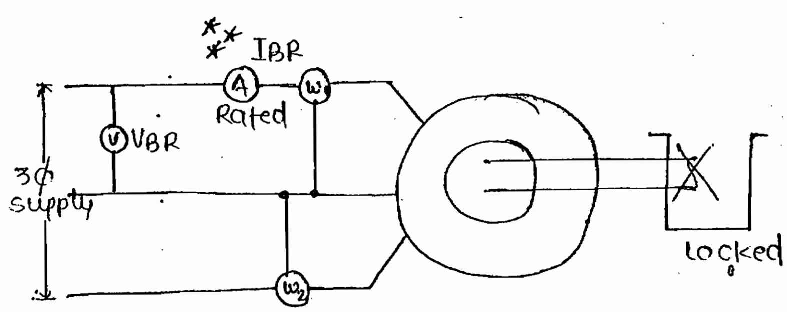
$Z_{NL} = V_{NL}/I_{NL}$

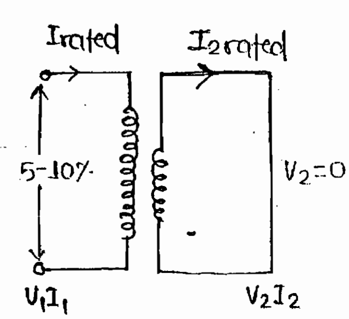
$Z_{NL} = R_1 + j(X_m + X_1)$



From the meter reading Z_{NL} is calculated. From blocked rotor test X_1 is cal. & the magnetising reactance X_m is determined using the above eq^n.

2.) Blocked Rotor test → The rotor is blocked initialy to ensure no rotation. Vol. is applied across the stator carefully using the suitable auto Xmer to ensure rated current.





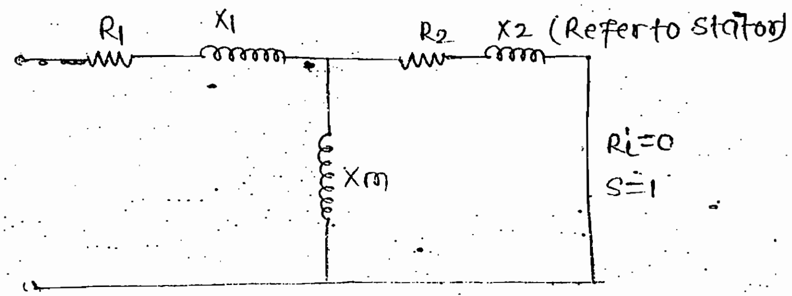
$W_{BR} = W_1 + W_2$ (algebric sum)

$$P = \frac{2\pi NT}{60} \qquad (N=0)$$

$P=0$ [so we have right to take W-M reading as loss]

So W-M readings are $\longrightarrow$ Total losses

- $\rightarrow$ Stator core loss X (vol. is low)
- $\rightarrow$ St. Cu loss ✓ (Rated current)
- $\rightarrow$ Rotor core loss X ($\phi\downarrow$, $V\downarrow$)
- $\rightarrow$ Rotor Cu loss ✓
- $\rightarrow$ mech. loss = 0 (Not running of motor)



Eq. ckt on blocked rotor condⁿ

* This tests gives the information of Cu loss at rated current condⁿ

$$\frac{V_{BR}}{I_{BR}} = Z_{BR} = R_{BR} + jX_{BR}$$

$$Z_{BR} = [R_1 + jX_1] + jX_m \,||\, (R_2 + jX_2)$$

$$Z_{BR} = (R_1 + jX_1) + \frac{jX_m(R_2 + jX_2)}{j(X_m + X_2) + R_2} \times \frac{[R_2 - j(X_m + X_2)]}{[R_2 - j(X_m + X_2)]}$$

$$= (R_1 + jX_1) + \frac{jX_m[R_2^2 - jR_2(X_2 + X_m) + jR_2X_2 + X_2(X_2 + X_m)]}{R_2^2 + (X_2 + X_m)^2}$$

$$= (R_1 + jX_1) + \frac{jX_m[R_2^2 - jR_2X_m + X_2(X_2 + X_m)]}{R_2^2 + (X_2 + X_m)^2}$$

Equating imaginary terms

$$X_{BR} = X_1 + \frac{X_m[R_2^2 + X_2(X_2 + X_m)]}{R_2^2 + (X_2 + X_m)^2}$$

$\because X_m$ is practicaly high compared R_2^2

(X_2+X_m) is also high ...... let it be (X_{2m})

$$X_{BR} = X_1 + \frac{X_m[R_2^2 + X_2 \cdot X_{2m}]}{R_2^2 + X_{2m}^2}$$

$$= X_1 + \frac{X_m[R_2^2/X_{2m} + X_2]}{[R_2^2/X_{2m} + X_{2m}]}$$

* $\frac{R_2^2}{X_{2m}}$ is practicaly very low

$$X_{BR} = X_1 + \frac{X_m X_2}{X_{2m}} = X_1 + \frac{X_m X_2}{X_2 + X_m}$$

$$X_{BR} = X_1 + \frac{\frac{X_m X_2}{X_m}}{\frac{X_2}{X_m} + \frac{X_m}{X_m}}$$

$$= X_1 + \frac{X_2}{\left[\frac{X_2}{X_m} + 1\right]}$$

→ Practicaly low, negligible

$$\boxed{X_{BR} = X_1 + X_2'}$$

$X_2 \to X_2'$ (Because of refer to stator)

* There is no practical method to seprate or measure X_1, X_2'.

Therefore it is approximated as

$$\boxed{X_1 \simeq X_2' \simeq \frac{X_{BR}}{2}}$$

Equating the real parts of eq^n

$$R_{BR} = R_1 + \frac{R_2 X_m^2}{R_2^2 + X_{2m}^2}$$

$$= R_1 + \frac{R_2}{\frac{R_2^2}{X_m^2} + \frac{X_{2m}^2}{X_m^2}}$$

→ low

$$R_{BR} = R_1 + \frac{R_2}{(X_{2m}/X_m)^2}$$

$$R_2 = (R_{BR} - R_1)\left(\frac{X_{m2}}{X_{2m}}\right)^2$$

$$\boxed{R_2' = (R_{BR} - R_1)\left(\frac{X_{2m}}{X_m}\right)^2}$$

from Blocked rotor test X_1, X_2', R_2' & Cu losses are calculated.

from both the tests all the eq. ckt parameters are evaluated including η

$$\eta = \frac{o/p}{o/p + \underset{\text{loss}}{\text{const}} + \underset{\text{loss}}{\text{variable}}}$$

const loss → Iron, Fric., windage

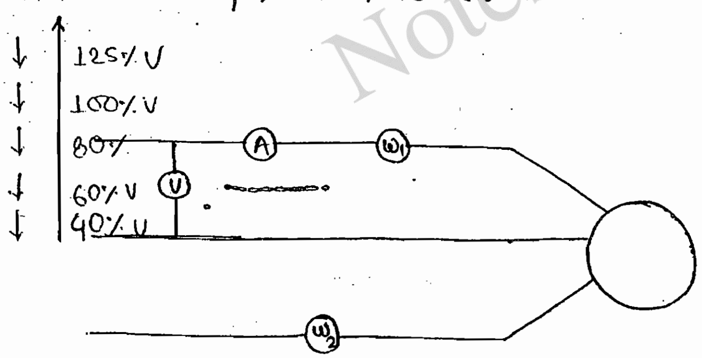
variable loss → Cu

* <u>sepration of rotational losses</u> → * A NL test is performed to seprate iron & mech. losses. using a suitable auto Xmer apply different vol. across the stator. from 125% rated to around 40% rated.

* As the motor is running on NL the torque requirement is very low & the variation of slip with variation is V is low upto a breakdown point. Therefore in the testing condn the speed of motor is approx. same (variation is less)

$$T \propto sV^2 \qquad (\because E \propto V)$$

* Iron losses $\propto \phi$, mech. losses $\propto N$



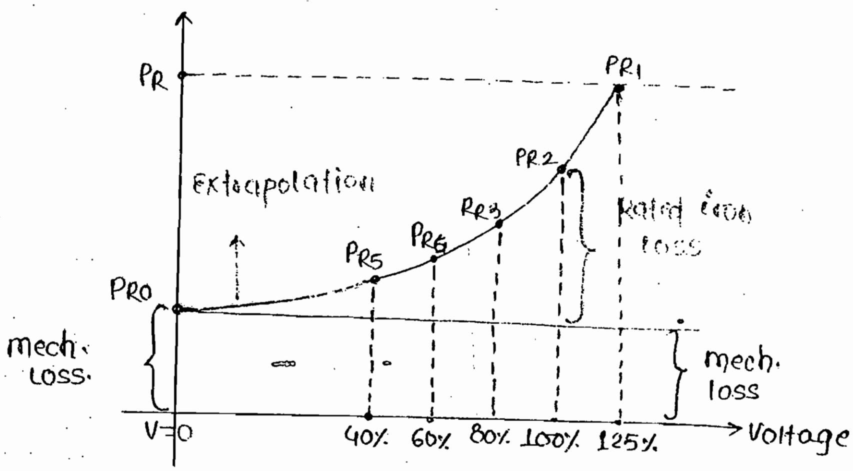
(1.) V_{NL1} I_{NL1} $W_{NL1} \longrightarrow W_{NL1} - 3I_{NL1}^2 R_1 = PR_1$

(2.) V_{NL2} I_{NL2} $W_{NL2} \longrightarrow W_{NL2} - 3I_{NL2}^2 R_1 = PR_2$

(3.) 80% $\qquad W_{NL3} - 3I_{NL3}^2 R_1 = PR_3$

(4.) 60% $\qquad W_{NL4} - 3I_{NL4}^2 R_1 = PR_4$

(5.) 40% $\qquad W_{NL5} - 3I_{NL5}^2 R_1 = PR_5$



(Curve is parabolic along with V^2)

* Circle diagram →

* It is the graphical representation of approximate eq. ckt.

* Once a circle dia. is plotted any analysis parameter can be simply & rapidly determined (approximately) w/o approaching the motor.

* ~~w~~ The locus of current in a series RL ckt will make a circle with a dia. V/X.

* If a chord in a circle is bisected it passes through its center.

* In order to plot it is requires data from NL test, blocked rotor test & the dc test.

* Circle dia. is plotted on a vertical vol. as ref. axis.
Therefore blocked rotor test value need to be adjusted to rated vol. base. for plotting circle dia.

No Load test → V_{rated}

V_{NL} $\quad I_{NL}$ $\quad W_{NL} = \sqrt{3}\, V_{NL} I_{NL} \cdot \cos\phi_{NL}$

*$V_{rated} \leftarrow I_{NL}$ $\quad \phi_{NL} = \cos^{-1}\left[\dfrac{W_{NL}}{\sqrt{3}\, V_{NL} I_{NL}}\right]$

Blocked Rotor → (5–10% V_{rated}) → V_{BR}

$\left.\begin{matrix} I_{BR} \\ W_{BR} \end{matrix}\right\}$ (values adjust to V_{rated})

V_{BR} $\quad I_{BR}$ $\quad W_{BR} = \sqrt{3}\, V_{BR} I_{BR} \cdot \cos\phi_{BR}$

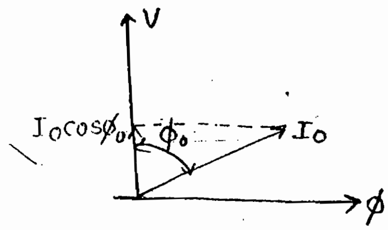
If V_{rated} $\quad$?(I_{SN}) let $\quad \phi_{BR} = \cos^{-1}\left[\dfrac{W_{BR}}{\sqrt{3}\, V_{BR} I_{BR}}\right]$

$$\boxed{I_{SN} = \frac{V_{rated}}{V_{BR}} \times I_{BR}}$$

I_{BR}^2 W_{BR}

I_{SN}^2 ? W_{SN}

$$\boxed{W_{SN} = \left(\frac{I_{SN}}{I_{BR}}\right)^2 \cdot W_{BR}}$$



* As the circle dia. is plotted on vertical V-axis as a ref., all the vertical distances on the circle dia. represents active power in watts.

Steps→

(1) Draw NL current wrt its PF angle with suitable scale

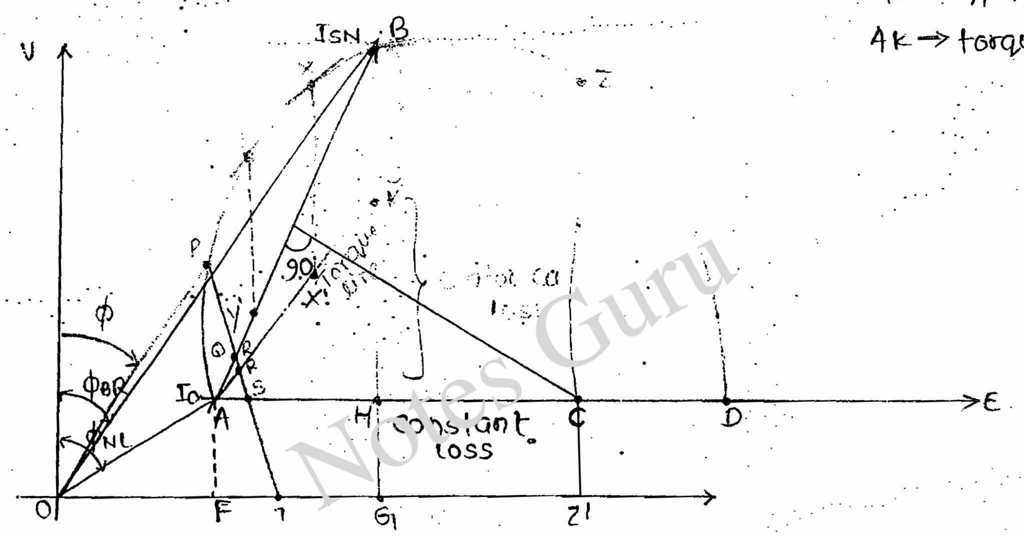
(2) Draw I_{SN} wrt its PF angle ϕ_{BR}

(3) Bisect the o/p line to meet at point C on the horizontal line AE. C as center & length of AC as radius.

A circle is plotted to meet ABD.

AB → o/p line.

AK → torque line



* The vertical distance length of BG represents total losses for a current I_{SN}. As it is blocked rotor mode mech. losses are zero. but it gives sufficiently accurate value because rotor core losses are neglected under such condⁿ.
* length of BH represents variable losses i.e. stator cu loss & rotor cu loss for I_{SN}.
* From dc test stator cu losses are cal. For a current I_{SN} value & using power scale a ~~poto~~ point K is located where length of HK represents stator cu loss.
* Consequently the other length BK represents rotor cu loss.

Power scale:- watts/cm.

$$l(BG)_{cms} = W_{SN}\,(\text{watts})$$

$$1\,cm = \frac{W_{SN}(\text{watts})}{l(BG)\,cms}$$

Join AK, which is called as torque line

Data obtained from circle dia:-

(1) Max^m torque :- Draw a tagent on circle parallel to torque line to meet at point X. Drop a vertical on to the torque line to meet at X'.

$$l(XX') \times \text{power scale} = T_{max} \text{ in watts}$$

$\downarrow$

Synchronous watts

$$T = \frac{60}{2\pi N_s} \times RP\,i/p$$

Constant

$$T \propto P$$

(2) max^m o/p → Draw a tangent parallel to o/p line to meet at point on the circle dia. Drop a vertical on to vertical line to meet at Y'.

$$l(YY') \times \text{power scale} = \text{max o/p in watts}$$

(3) Starting torque → ~~start~~

$$T = \frac{60}{2\pi N_s} \times RP\,i/p$$

$$= 60N_s \times \frac{\text{Rotor cu loss}}{S}$$

$$T = \text{const} \times \frac{\text{Rotor cu loss}}{1}$$

$$\boxed{T_{st} \propto \text{Rotor cu loss}} \qquad (S=1)$$

$$T_{st} \propto \text{length of } (BK) \text{ in watts}$$

$$T_{st} = \frac{60}{2\pi N_s}\, l(BK)\ \cancel{N\text{-}m} \times \text{power scale}\ (N\text{-}m)$$

(4) I/P →

$$I/p = O/p + \text{Total losses}$$

Extent point c on to the circle dia. to meet at z & the bottom axis to meet at z'.

$$= l(zz') \times \text{power scale}$$

Eg:- From the test data given plot circle dia. & cal. all its performance parameter when the motor operates at full load.

*Calculate the rated current of motor & locate a point p on the circle dia. so that length of op represents Irated.

Draw a vertical line parallel to vol. axis to meet at point Q, R, S, T

$$l(ST) \times \text{power scale} = \text{const. loss}$$

$$l(RS) \times \text{power scale} = \text{stator cu loss}$$

$$l(RQ) \times \text{Power scale} = \text{Rotor cu loss}$$

$$I/p = O/p + \text{total losses}$$

$$\boxed{PT = PQ + TQ}$$

$$l(PQ) \times \text{power scale} = O/p$$

$$l(PT) \times \text{power scale} = I/p$$

$$l(TQ) \times \text{power scale} = \text{total loss}$$

$$\eta = \frac{O/P}{I/P} = \frac{PQ}{PT}$$

slip = ? , rotor cu loss = s. Rotor power I/P

$$l(RQ) = s \cdot l(PR)$$

$$s = \frac{RQ}{RP}$$

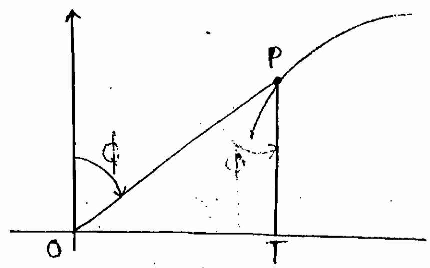
$$N = N_S(1-S)$$

known

$$T_g = \frac{60}{2\pi N_S} \cdot l(RP) \times \text{power scale} \quad N\text{-m}$$

$$T_{sh} = \frac{60}{2\pi N} \cdot l(PQ) \times \text{power scale} \cdot N\text{-}m$$

Power Factor →



From Δ OPT

$$\cos\phi = \frac{PT}{OP}$$

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* starting methods → when rated vol. is applied across the stator of IM during starting N=0, s=1 it is eq. to applying rated vol. across Xmer 1° when its 2° is sc.
* The rotor will have huge current which comes through stator.
Therefore the motor draws extremely large current from supply which is not acceptable because it produce vol. dip in supply lines.
* It may not damage the motor as they are rugged in construction & accelerate quickly & the starting current is inrush.

(1.) Direct online starting (DOL)
(2.) Stator resistance/ Reactance starting
(3.) Auto Xmers.
(4.) Star-delta
(5.) Rotor resistance

(2.)–(4.) } Reduced vol. starting

(1.) Direct online starting →

* popular for 1ϕ & upto 5kW for 3ϕ because of cost is less.
* Push ON/ push OFF

Overload ⟶ Bimetallic
Underload ⟶ when power is not present

* It is not reduced vol. starting.
* It has a push ON/ push OFF switch where the stator is directly connected to

supply.

* starting current is very high but it is inrush.
  As the motor starts quickly.
* It is only suitable to small rating.
  most popular under 2kW segment (1ϕ) as it is low cost.
* There are 2 protection:-

(1) Overload protection using thermal elements like bimetallic.

(2) Undervol protection to prevent the motor from unintentional start after a power failure.

(2.) Stator resistance/reactors starting →

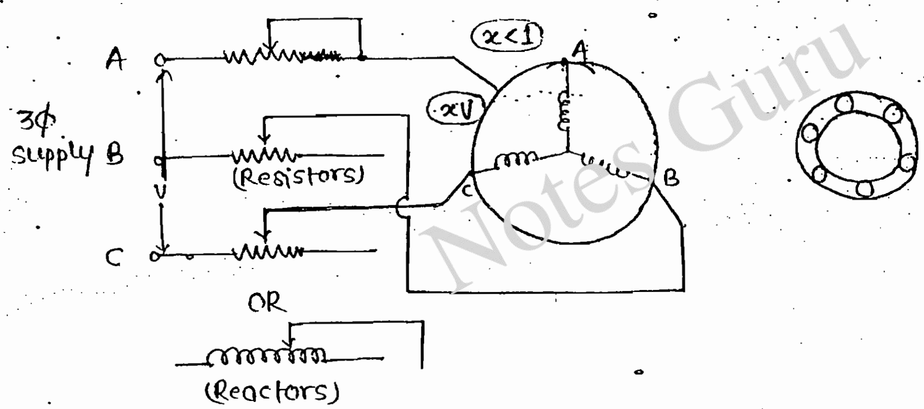
when we supply the stator excessive amt. of current flows in the rotor.

so;

$$I_2 = \frac{E_2}{\underbrace{(R_2 + jX_2)}_{\text{Fixed}}}$$

$$E_2 \downarrow , \quad I_2 \downarrow$$

$$\text{so; } E_2 \downarrow \longrightarrow \phi \downarrow \longrightarrow V_1 \downarrow$$



$$T_g = \frac{60}{2\pi N_s} \cdot \frac{\text{Rot. cu loss}}{s}$$

$$T_g = \frac{60}{2\pi N_s} \cdot \frac{3(I_2'^2 R_2)}{s}$$

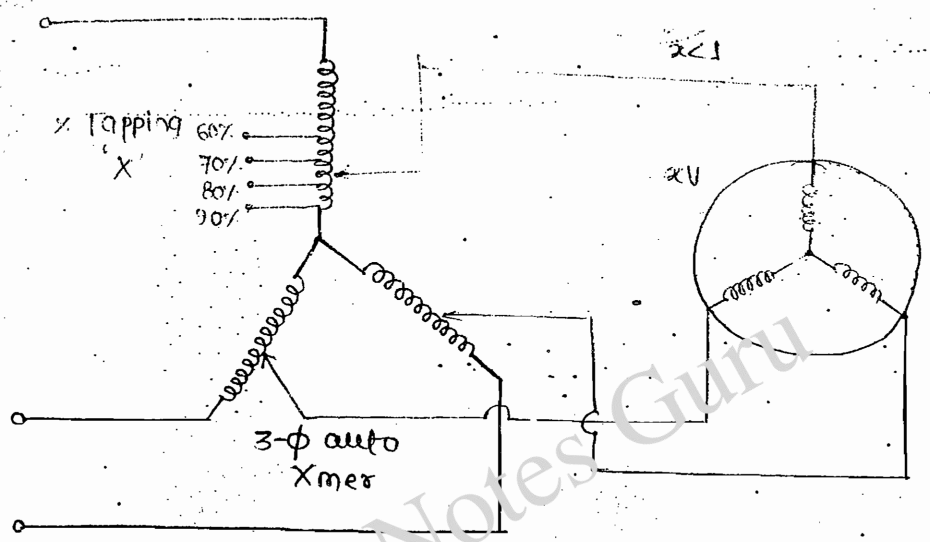
$$T_{st} \propto \frac{I_{st}^2}{S_{st}} \quad \Bigg| \quad T_F \propto \frac{I_F^2}{S_F} \qquad (S_{st} = 1)$$

$$\boxed{\frac{T_{st}}{T_F} = \left(\frac{I_{st}}{I_F}\right)^2 \cdot S_F}$$

$$\frac{T_{st}}{T_f} = x^2\left(\frac{I_{st}}{I_f}\right)^2 \cdot s_f$$

* By adding some external resistance in series with stator some vol. gets dropped & reduced vol. will appear across stator which corrospondingly control the starting current.
* Reactors also can used where η is not greatly effected but pf of the motor will be low lagging & starting torque also less.
* The effect of starting torque is expressed in above relation.

(3.) Auto Xmer starting →

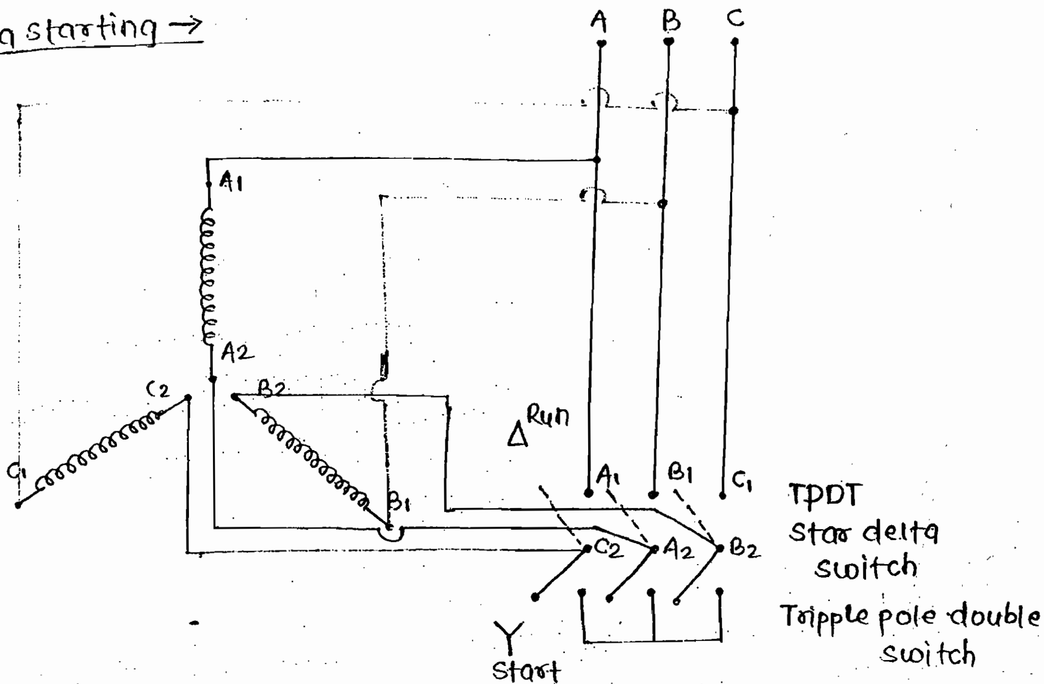


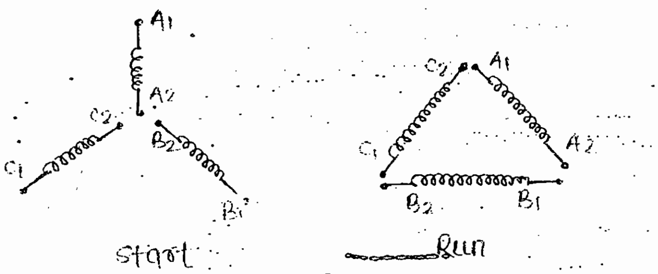
* This is generaly prefered for starting large rating IMs due to its flexibility & high η but expensive method.
* It requiree a suitable rating 3φ auto Xmers.
* Depanding on % tapping (x<1)

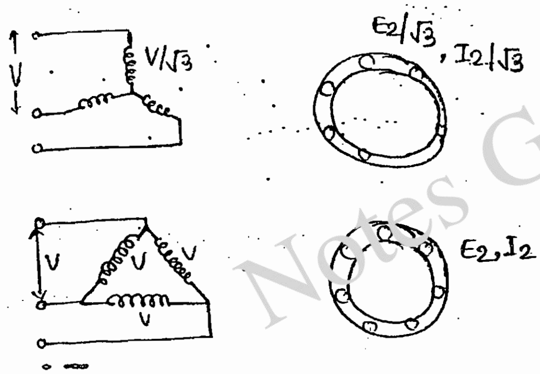
Depanding on tapping starting current control & effect of starting torque expressed

$$\frac{T_{st}}{T_f} = x^2\left(\frac{I_{st}}{I_f}\right)^2 \cdot s_f$$

(4.) Star-delta starting →







* It gives one step control on the starting current.

It is most simple & economic starter with a TPDT switch only.

The stator 3ϕ wdg is connected as shown.

It is suitable for motors which are designed for Δ under running condⁿ

1st the stator is connected the ⅄ which results in reduced vol. & current in rotor about 57.7% only ($V_{ph} = V_L/\sqrt{3}$).

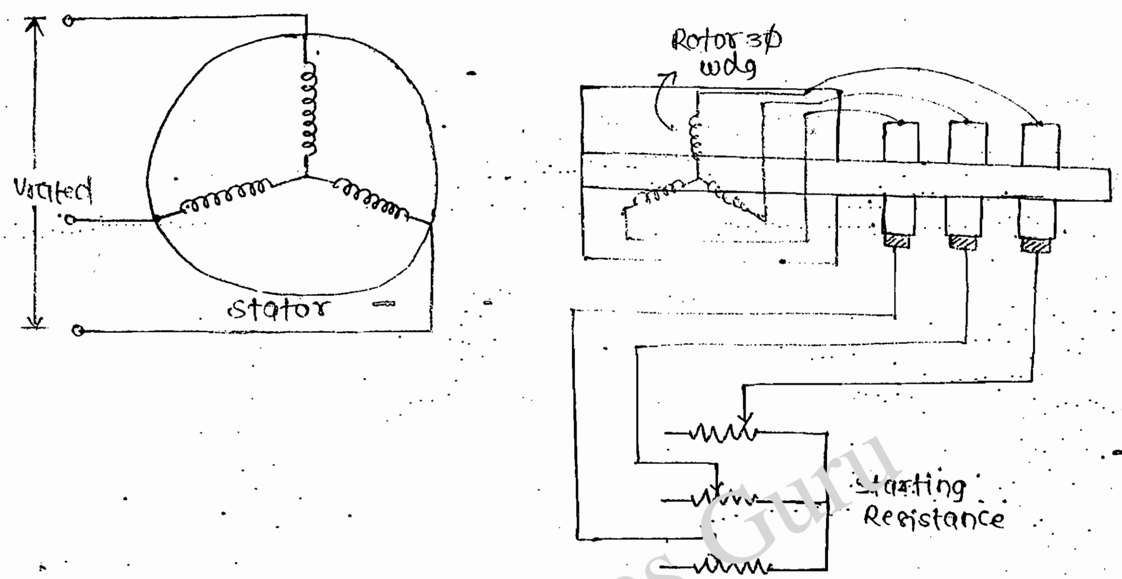
Under running the switch should be thrown out to Δ atleast the motor reach 90% of rated speed for normal rated operating condⁿ ($V_L = V_{ph}$)

* Not suitable for extra high vol. rating greater than 3.3kV because those motors stators are preferabley designed for λ.

$$\boxed{\frac{T_{st}}{T_f} = \frac{1}{3}\left(\frac{I_{st}}{I_f}\right)^2 \cdot S_f}$$

* The ratio of starting to FL torque is expressed above.

~~(5.) Rotor~~ resistance starting →



$T \propto E_2 I_2 \cos\phi_2$ ↑very (Because of resistance)
Rated

* This is technacaly best way to start IM.
* It is fundamental method of starting slip ring motors by inserting some resistances into rotor of suitable value through slip rings & brushes.
* This resistance will control the rotor current & motor current during starting. While reducing the starting current to a required value starting torque is increased because the improved PF will dominate.
* However rated vol. is applied across the stator.

This are prefered for high starting torque appln like electric traction

52/32 (c)

$$\frac{T_{st}}{T_f} = x^2\left(\frac{I_{st}}{I_f}\right)^7 s_f$$

$$1.5 = x^2(7)^2(0.05)$$

$$x = 78.25\%$$

53/32 (b.)

$$\frac{T_{st}}{T_f} = \frac{1}{3}\left(\frac{I_{st}}{I_f}\right)^2 s_f$$

$$= \frac{1}{3}(7)^2(0.05)$$

$$= 0.816$$

54/32 (c) Because of no given any starting method, we basic formula.

$$\left(\frac{T_{st}}{T_f}\right) = \left(\frac{I_{st}}{I_f}\right)^2 s_f$$

$$0.5 = \left(\frac{I_{st}}{I_f}\right)^2 \times 0.05$$

$$\left(\frac{I_{st}}{I_f}\right) = 3.16$$

60/33 (d.)

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 s_f$$

$$1 = \left(\frac{I_{st}}{I_f}\right)^2 (0.04)$$

$$\left(\frac{I_{st}}{I_f}\right) = 5$$

64/33 (d.)

$$(0.3)^2 \longrightarrow 80 \text{ N-m}$$

$$(0.6)^2 \longrightarrow ?$$

* Speed control →

* These are not popular like dc shunt motors when compared to effective speed control. even though the T-S c/s are identical, shunt motors are prefered because of there effective speed control.

* Speed control can be done from stator side & rotor side (slip ring)

* Stator side →

(1.) supply voltage control

(2.) Freq. (V/F)

(3.) pole changing

(4.) Stator Resistance.

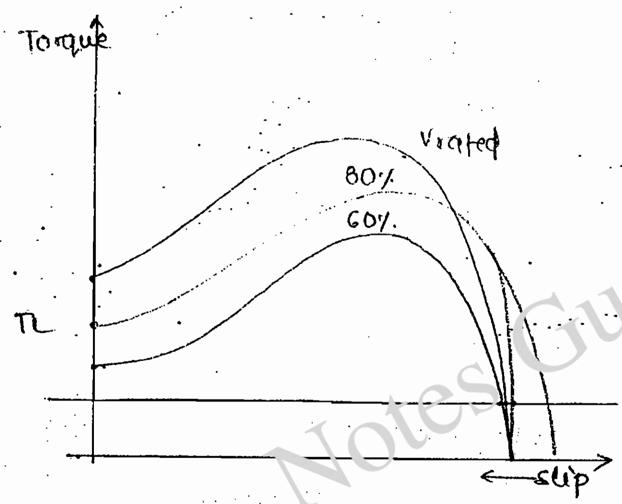
* Rotor side →

(1.) Rotor Resistance control

(2.) slip power recovery

(3.) Cascading/ Tandem connection.

(1.) supply vol. control →



* It requires an auto Xmer of suitable ratings for getting variable vol. If the motor run at constant load (or) torque condn as the vol. reduces the motor will react by increasing its slip.

* Concequently speed reduces & operate at different speed. However for same load the motor will draw more current from supply & becomes inefficient.

(2) Freq. (V/F) control →

* freq. is varied by keeping V/F ratio constant in order to maintain flux density constant.
* Otherwise the stator & rotor core gets deeply saturated & motor draws large magnetising current.
* It requires expensive power electronic converter ckt for variable vol. & freq.

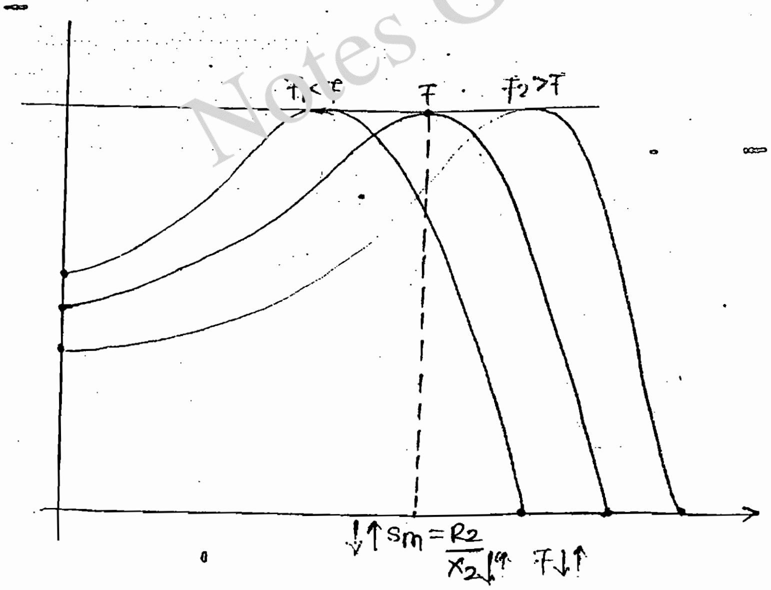
$$V_1 = E = 4.44 f N_1 B_m A$$

$$\boxed{B_m \propto \frac{V}{f}}$$

$$T_{max} \propto \frac{1}{N_s} \frac{E_2^2}{(2X_2)} = \frac{3 \times 60}{2\pi N_s}\left(\frac{E_2^2}{2X_2}\right)$$

f	N_s	f	E_2	f	X_2
f_1	$N_{s1} = \left(\frac{f_1}{f}\right) N_s$	f_1	$E_{21} = \left(\frac{f_1}{f}\right) E_2$	f_1	$X_{21} = \left(\frac{f_1}{f}\right) E_2$

$$T_{max_1} = \frac{1}{N_{s1}} \times \frac{E_{21}^2}{2X_{21}}$$



* within the control range the max^m & breakdown torque remain same.
* However it doesn't offer wide range as the voltages also correspondingly reduced.
* method is very expensive.

(3.) Pole exchanging →

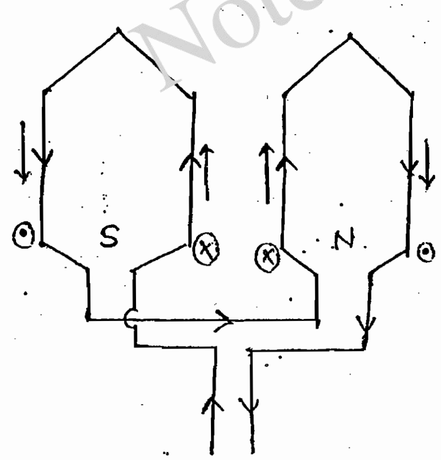
(1.) multiple wdgs.

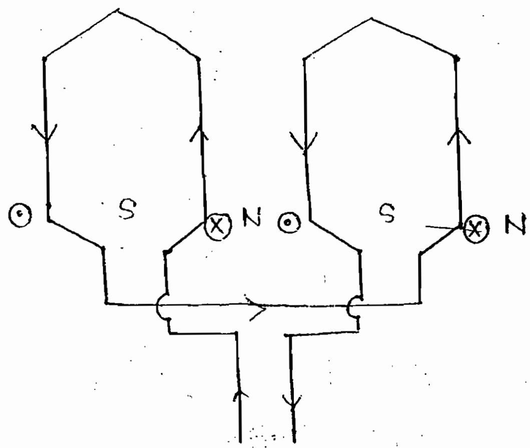
(2.) Concequent pole changing.

* The stator slot contains 2 independant sets of wdg designed for different no. of pole.

eg:- 2,4 (OR) 4,8.

* Depanding on the speed requirement either wdg can be connected to the supply & other one left disconnected.
* The wdgs are preferabely in λ. This will increase stator size & overall size of motor & motor becomes expensive & economicaly not advantages for more sets of wdgs.
* Another alternate method is through switching the wdg externaly. for a concequent pole formation in the stator.
* It supports only sq. cage rotor because the poles are formed automaticaly & the rotor responds to any no. of poles on stator.





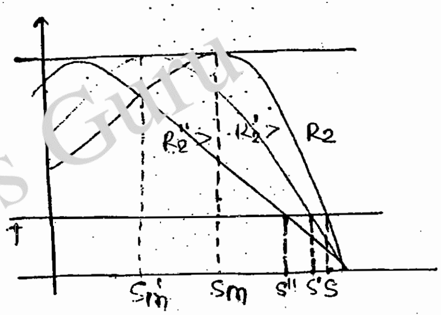
(4.) Stator resistance →

* It is the same method used start the motor.
* It is vantagenous starting than speed control because it will greatly effec. ie η but prefered because of low cost for small rating.
* Principle is identical to vol. control.
* It requires only resistances to reduce vol. across stator

* Rotor side →

(1.) Rotor resistance control →

$T \propto \frac{s\uparrow}{R_2\uparrow}$



* In slip ring motors external resistance can be added into the rotor ckt under running condⁿ
* If the motor runs at const. load (or) torque as the rotor resistance increases slip increase corrospondingly to maintain torque ~~on~~ constant.
* As the rotor resistance increased with increased current the rotor loss increases gets overheated practicaly.
- Therefore it is not suitable for wide range (or) long duration.

(2) slip power recovery →

* Injecting external vol. into the rotor through slip-rings at rotor freq. (or) slip freq. in order to obtain steady torque.
* However this control is also expensive & doesn't give a wide range. It can be done in 2 ways:-

* (1.) Injecting the vol. to add the exsisting rotor vol.

$$\uparrow T \propto \downarrow s E_2^2 \uparrow$$

speed ↑

$$T \propto \uparrow s E_2^2 \downarrow$$

speed ↓

* To maintain the torque const. slip reduce & speed increase
* (2.) Injecting the vol. to oppose the rotor vol. which reduces the vol. is rotor. & to main the torque the motor react by increasing its slip.

conceqently speed ↓

'subsynchronous'

DATE-09/12/14

(3) Cascading/Tandem connection →

Sagar Sen
8871453536

$N_1 = N_{s1}(1-S_1)$ $\quad$ $N_2 = N_{s2}(1-S_2)$

$N_1 = \left(\frac{120f}{P_1}\right)(1-S_1)$ $\quad$ $N_2 = \left(\frac{120f S_1}{P_2}\right)(1-S_2)$

$N_1 = N_2 = N$

$$\left(\frac{120f}{P_1}\right)(1-S_1) = \left(\frac{120 S_1 f}{P_2}\right)(1-S_2)$$

$$\frac{1-S_1}{P_1} = \frac{S_1 - S_1 S_2}{P_2} \qquad (\because S_1 S_2 \to 0)$$

$$\frac{1-S_1}{P_1} = \frac{S_1}{P_2}$$

$$\frac{1-S_1}{S_1} = \frac{P_1}{P_2}$$

$$\frac{1}{S_1} - 1 = \frac{P_1}{P_2}$$

$$\frac{1}{S_1} = \frac{P_1}{P_2} + 1$$

$$\frac{1}{S_1} = \frac{P_1+P_2}{P_2}$$

$$S_1 = \frac{P_2}{P_1+P_2}$$

$$N = \frac{120f}{P_1}\left(1 - \frac{P_2}{P_1+P_2}\right)$$

$$\boxed{N = \frac{120f}{P_1 \pm P_2}}$$

+ cumulative cascading.
− Differential cascading.

<u>Individual operation:-</u>

$$N_3 = \frac{120f}{P_1}, \quad N_1 = \frac{120f}{P_1+P_2}, \quad N_4 = \frac{120f}{P_2}, \quad N_2 = \frac{120f}{P_1-P_2}$$

* It requires essentially one slip ring motor.
* Both the motors are mechanically coupled as well as electrically connected to slip rings.
* This drive will offer 4 sets of speed with indepandant operation included.
* If the ϕ seq. of 2nd motor is same it is cumulatively cascaded otherwise differential.

* The poles should be different for 2 motors specialy for differential cascading.

32/29 (c.)

Que→ A 50Hz 4P IM is running at 1200 rpm. what should be the freq of vol. injected into rotor for obtaining steady torque?

Soln→

$$S = \frac{1500-1200}{1500} = \frac{1}{5}$$

$$Sf = \frac{1}{5} \times 50 = 10\,Hz$$

* Braking→

Braking is done to intentionaly to stop motor rapidaly at required instant.

This is very essential perticulary manufacturing process of drives.

It is similar to braking in dc motors.

(1.) Plugging→ Reversing the ϕ seq by interchanging any 2 ϕ terminal across stator in running motor.

The rotor want to rotate in the opposite dirn due to which it come near 0 speed where an adequete mech. braking is applied otherwise there is a danger of motor rotating in reverse dirn.

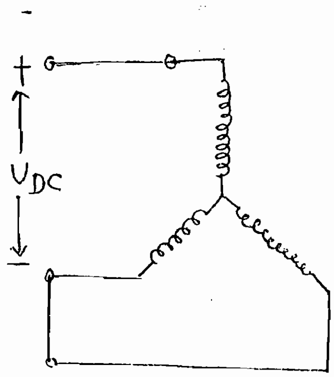
During plugging due to high relative speed ($N_s + N$) high vol. current will appear in rotor motors undergo plugging should be design to stand this condn which include high temp. rise.

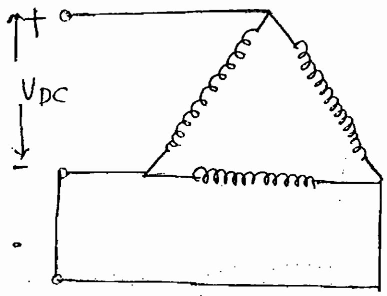
However the time of plugging is small as the motor starts it will disconnected from supply.

(2) Dynamic→ Disconnecting 3ϕ supply across stator & a suitable dc vol. will be applied across any 2 phases. it produces a constant stationary time invarying flux in air gap & make rotor to stop quickly.

As the rotor rotates due to flux emf, current & torque produce to oppose cause (relative speed)

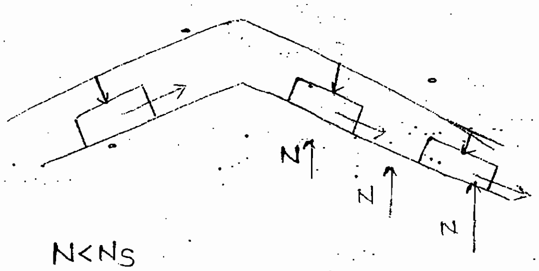
Therefore rotor stops quickly.





Note → There is no danger of speed reversal but induced currents in rotor should be control either from stator side (or) rotor side if its a slip ring.

(3.) Regenerative Braking →



$N < N_S$

$S : 1 - 0$

$N > N_S$

$-S = \frac{N_S - N}{N_S}$ $\quad -E_2 \quad -I_2 \quad -T$

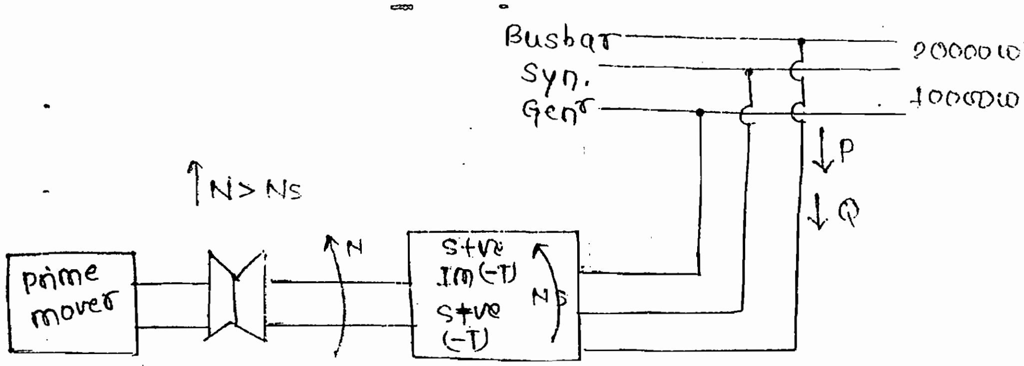
$I_1 \to I_0$, $-KI_2$

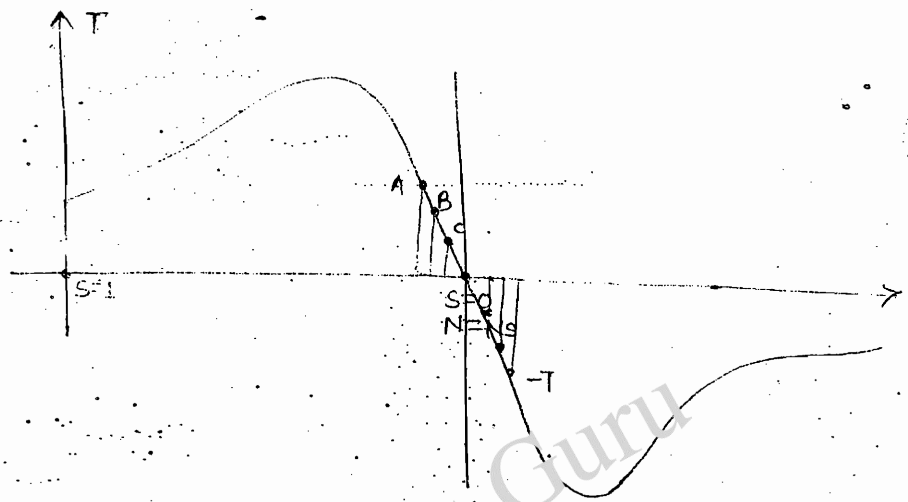
* This is not intentional braking & it won't stop the motor like above 2 b.
* But it will naturaly produced a braking torque when motor it subjected to overhauling load & release some stress for mech. braking sys.
- Therefore it is advantagenous in mountain railways where slip ring motors are prefered.
* When the motor increases its speed ($N > N_S$) slip becomes -ve to develop -ve torque which produce braking.
* The rotor induced emf & current also reverses & concequently rotor componant in stator will reverse.

Therefore during ~~this braking~~ braking period IM act as Indⁿ genʳ while supplying the rotor componant of current to supply lines instead of drawing it.

* In the period it contineous to draw magnetising current from supply.

* Induction Generator →





* If an IM is connected to suitable prime mover & rotated greater then its syn. speed it act as Indn genr by supplying active power while drawing reactive power from bus (supply lines where it is connected)

* It can't operate alone as it requires Q when it is connected to ∞ bus where syn. genr are operating across it the active power supplied to the bus freq. depands on the freq. of reactive power drawn from bus.

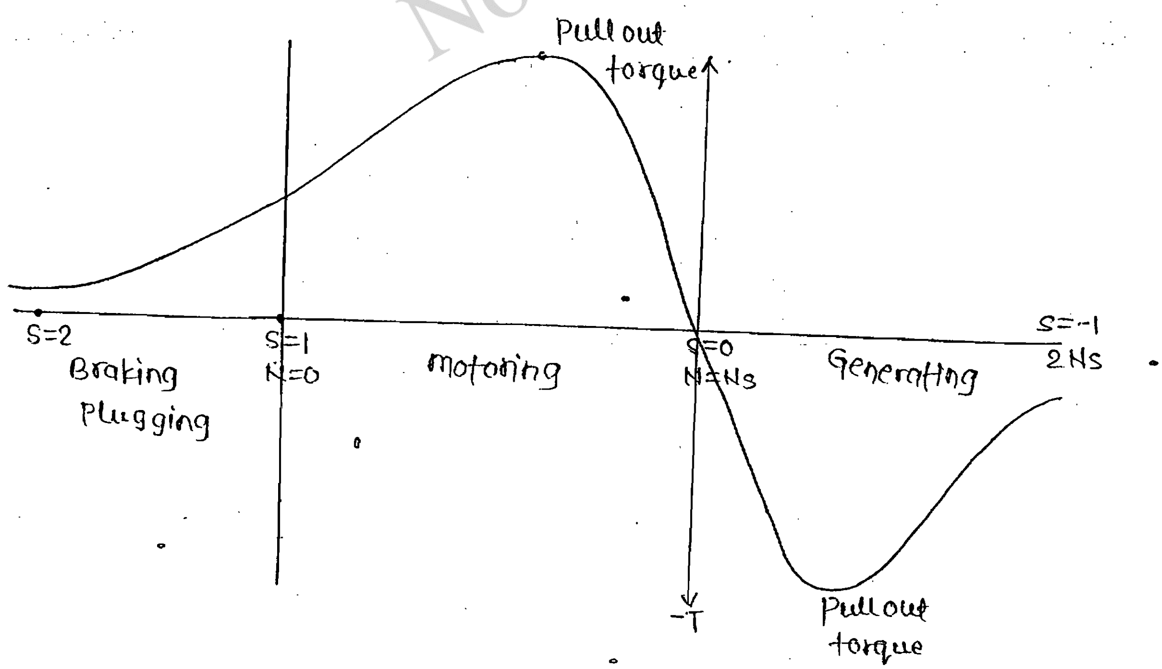
Therefore in such condn in its operating region the freq of active power supplied is independant of speed variation.

Therefore it is used for variable speed generation specialy non-conventional like wind mills, mini hydro plants etc.

* It act as reactive power burden on existing syn. genr.
Therefore not prefered generaly, but advantageous in specific power genrn as the m/c is simple in design, less cost, maintanance free operation, no hunting, stability prob. & doesn't require any dc excitations.
* In such emergancy appln it can be used a load as self excited Indn genr.

* Self excited indn genr →

The principle is as similar to vol. build up in self excited shunt genr.
It requires some residual flux in rotor which is acheived through running m/c as IM for some time.
Once the rotor is rotated residual flux induce vol. in the stator where a capacitor bank is connected across it which supplies reactive power for flux development.
There is a cumulative build up of flux in air gap upto saturation of stator & rotor cores.
This is not suitable for loads which demand high reactive power eg.- Large IM while starting.
The capa. bank should supply the reactive power demand of genr as well as load.
Effective control is required to control reactive power otherwise bus vol. will vary.



* Special Constructions →

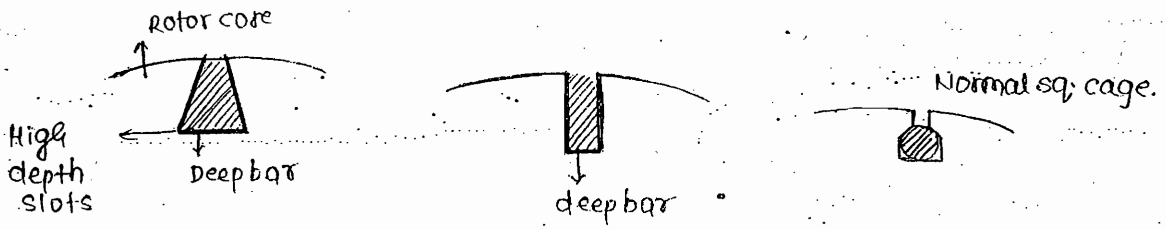
Squarral cage Im ~~Rotor~~ → Generally around 90% motors are sq. cage type because of there own ad.

* But the basic limitation is due to there low starting torque.
* In order to increase there starting torque w/o effecting there η must some special constr. are adopted.
* The principle of cons is based on skin effect.

(1.) Deep bar

(2.) Double cage

* Deep bar →



* The rotor contains high depth slots where deep bars are placed & solidaly sc with 2 end rings.
* Dring starting rotor Freq. is supply Freq. Skin effect dominates & the current want to flow only on the top region of deep bar.

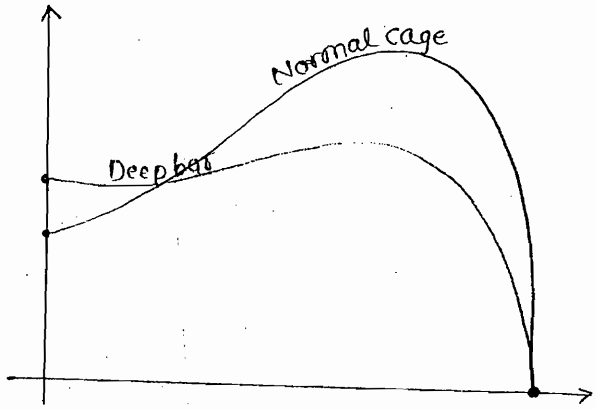
Therefore it offers high resistance to starting current which increase the starting torque while reducing starting current.

* When the motor runs the rotor freq. is slip freq. very low.

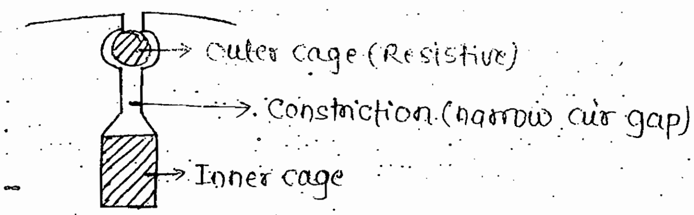
Therefore skin effect is negligible.

* Concequently the current shifts into bottom region which offer low resistance & running η are not affected.
* Due to deep slot (or) bar the leakage reactance at stand still is high.

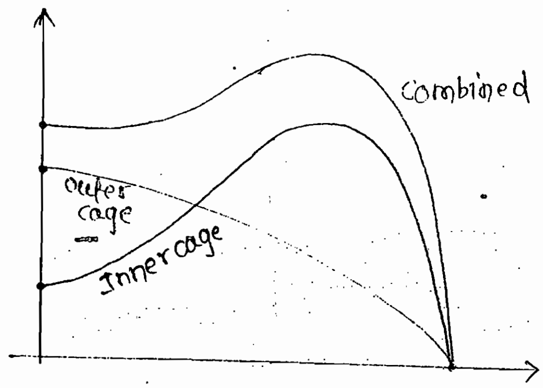
Therefore this motors have less max^m (or) breakdown torque not suitable for high rating loads (or) doesn't have good overload capability used for small rating app^n comparatively which demand high starting torque.

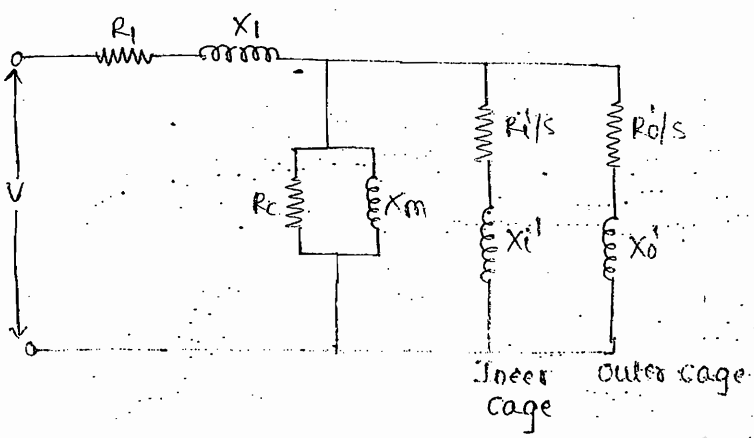


* Double cage →



* It contains 2 cages :-
  (1) Outer cage with small cross-sectional area high resistance.
  (2) Inner cage is large cross-sectional area less resistance.
* which are solidaly sc with end rings on both sides.
* During starting the freq. of rotor is supply freq. & starting current only flows in outer cage which offer high resistance to result in high starting torque while reducing starting current.
* Under running condn rotor freq. will be negligible & skin effect is quite low. Therefore the current shifts into inner cage which offer low resistance. Starting torque increased w/o effecting running η must.
* The basic diff. b/n ~~deep~~ bar & double cage lies in constriction (narrow air gap b/n 2 cages).
* It reduce leakage reactance of rotor at stand still & result in more max^m or breakdown torque compare to deep bar.





* These special constructions are rarely prefered for specific appⁿ specialy less rantings compared to sq. cage but demand high starting torque.
* For large rating high starting torque requirements slip ring motors are prefered.

DATE-10/12/14

Crawling→

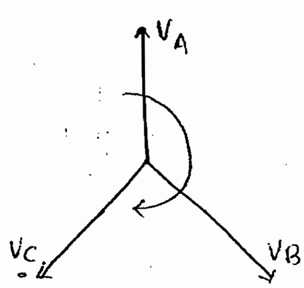
Odd → 3m 3, 9.....
Odd → 3m−1 5, 11......
Odd → 3m+1 7, 13.. ....

Fundamental (f)

$V_A = V_m \sin\omega t$

$V_B = V_m \sin(\omega t - 120)$

$V_c = V_m \sin(\omega t - 240)$



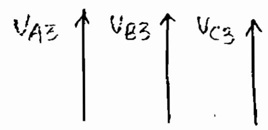
Sagar Sen
8871453536

3rd harmonics (3f)

$$V_{A3} = V_{m3} \sin 3\omega t$$

$$V_{B3} = V_{m3} \sin 3(\omega t - 120) = V_{m3} \sin 3\omega t$$

$$V_{C3} = V_{m3} \sin 3(\omega t - 240) = V_{m3} \sin 3\omega t$$



cophasal triplen

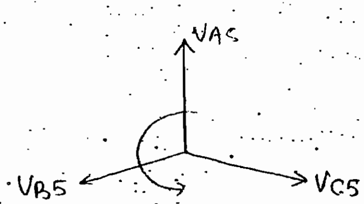
* They have no mutual ϕ displacement & called as cophasal which doesn't support 3ϕ sys. & can't exist easily.

5th harmonics →

$$V_{A5} = V_{m5} \sin 5\omega t$$

$$V_{B5} = V_{m5} \sin 5(\omega t - 120) = V_{m5} \sin(5\omega t - 240^\circ)$$

$$V_{C5} = V_{m5} \sin 5(\omega t - 240^\circ) = V_{m5} \sin(5\omega t - 120^\circ)$$



* They have mutual ϕ displacement 120° support 3ϕ nature, exist easily but they have opposite ϕ seq. to that of fundamental.

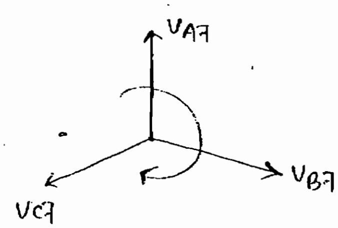
Therefore there affect will be in the braking region of I.M. (s>1)

7th harmonics →

$$V_{A7} = V_{m7} \sin 7\omega t$$

$$V_{B7} = V_{m7} \sin 7(\omega t - 120) = V_{m7} (7\omega t - 120^\circ)$$

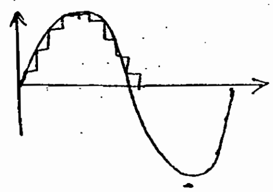
$$V_{C7} = V_{m7} \sin 7(\omega t - 240^\circ) = V_{m7} (7\omega t - 240^\circ)$$



* They are having mutual ϕ displacement of 120° Exactly 3ϕ nature, easily exist & they are as identical to fundamental with same ϕ seq.

5th → Braking
7th → Motoring

* If harmics applied in the supply they known as time harmonics.



slot harmonics

* If a fundamental is produced by p no. of poles then fictiously a 5th harmonic is produced by 5P no. of poles & 7th is produced by 7P no. of poles.

$$N_{S7} = \frac{120f}{7P} = \frac{N_S}{7}$$

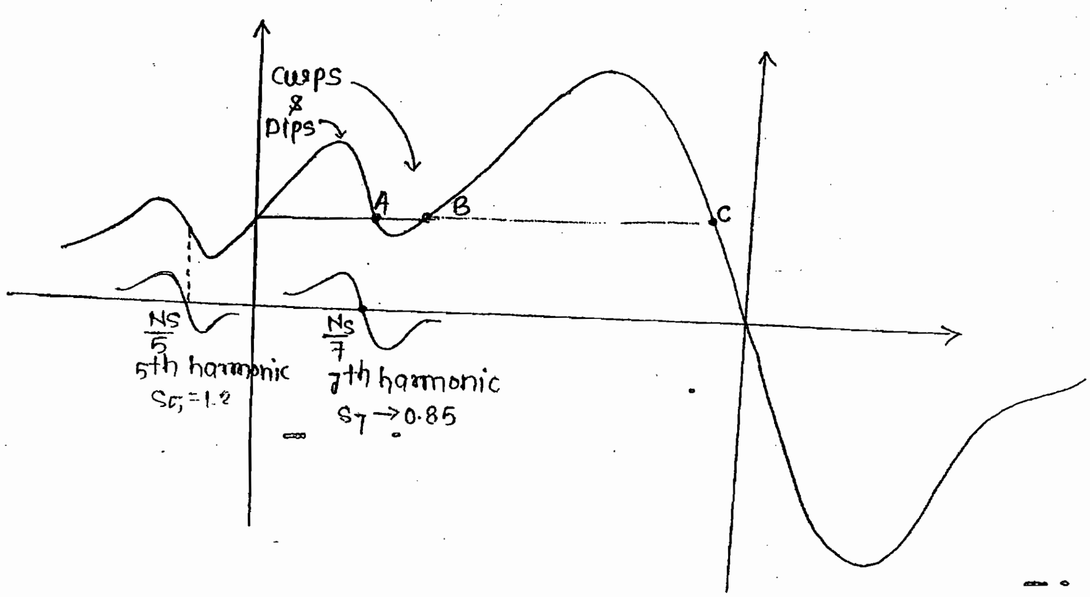
$$S_7 = \frac{N_S - \frac{N_S}{7}}{N_S} = \frac{6}{7}$$

$$N_{S5} = \frac{120f}{5P} = \frac{N_S}{5}$$

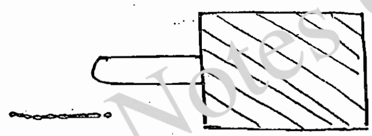
$$\therefore S_5 = \frac{N_S - \left(\frac{-N_S}{5}\right)}{N_S} = \frac{6}{5}$$

Because of Plugging

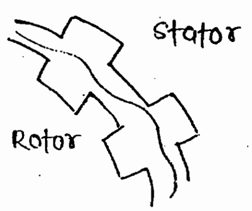
$= 1.2$



* It is a different behaviour of sq. cage IM to run at reduced speed around $N_s/7$ during starting.
* Due to time/slot harmonics the flux distribution will gets distorted & contains harmonics in it.
* The most effective harmonics is 7th in motoring region & 5th in the braking region. They distort fundamental T-S c/s in there operating regions & corresponding slips
* If the motor starts with low starting torque it may fall near $N_s/7$ & runs stabliy supplying a perticular load torque ~~even though~~ (point A) Even though it is a stable point it is not desired operating pt. due to high slip, high current, huge noise, high loss, low speed.
* If starting torque high eg. slip ring there is no effect of crawling even though it contain harmonic content inside.
* In order to eliminate crawling effect due to harmonics stator wdg is uniformaly distributed & short pitched.
* Fractional slot wdgs, semi closed slots are prefered.
* The rotor slots are also skeyed for better flux distribution & elimination of harmonic content.



* With skeying it will also produce uniform torque smooth running with reduced noise (magnetic hump).



* Cogging →

* It is a tendancy of magnetic locking b/w stator & rotor teeth due to alingment b/n them.
* If the rotor & stator slots (or) teeths are exactly equal & parallel to each other the alingment torque b/n them will dominate the accelerating torque specialy in sq. cage motors as there starting torques are low (reduced vol. starting).
* Rotor refuse to start & being stationary with locking is known as cogging.
* To eliminate this ~~stator~~ rotor slots are essentialy skeyed (inclined or twisted). skeying also increase the resistance of rotor bars & produce high starting torque comparitively.
* But the running η is comparitively low.
* skeying also increased leakage reactance & reduce max^m torque comparitively.

"while designing Im the slots of stator & rotor will made different & also doesn't contain common factor b/n them but the no. of poles should be same."

* Comparision b/n sq. cage & slip ring Im →

* Net air gap of sq. cage is comparitively low & req. less magnetising current & operate at better PF.
* Rotor resistance of solid bars in sq. cage is comparitively low & the η is comparitively more.
* The end ring doesn't contain overhang but in slip ring due to overhang & increased depth of slot leakage reactance is compritively more.
* max^m (or) breakdown torque & overload capacity is comparitively more in sq. cage.
* Construction is simple, low cost; mech. strong, less weight, maintainance free operation.

* Inverted IM (or) Rotor Fed →

SRMF wrt stator at

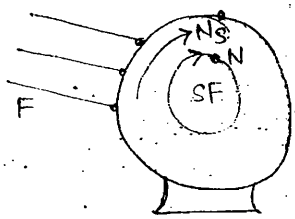
* If an IM is supplied with 3ϕ supply across its rotor by closing its stator it is called as IM rotor fed.
* It operates nomaly but rotor runs at opposite dirn.
* It can be done only in slip ring type as the rotor is accessible through slip ring & brushes but conventionaly motors are operated through stator.

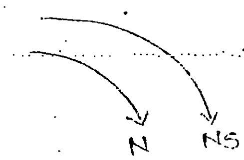
SRMF wrt. stator at Ns

RRMF wrt. stator at SNs + N = Ns

As rotor itself rotate at N in direction of mag. field

SRMF & RRMF wrt. rotor : Ns − N
= SNs

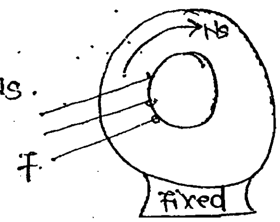




* When rotor is fed with supply with freq. f. it will produce RMF at speed Ns wrt rotor. cut the stator induces emf, current produce torque & want to make stator rotate.
* As the stator is fixed part & rotor is designed for rotation inability to make the stator rotate will result in the rotor rotating in the opposite dirn to that of magnetic field.

Rotor RMF wrt rotor at Ns

rotor RMF wrt. stator ~~at stationary point~~ at Ns − N = SNs
(or) stationary point in space



* Stator freq. is sf, therefore stator RMF wrt. stator is at SNs.

SRMF wrt. stator at SNs

SRMF & RRMF wrt. rotor at SNs − (−N) ⇒ SNs + N
Ns

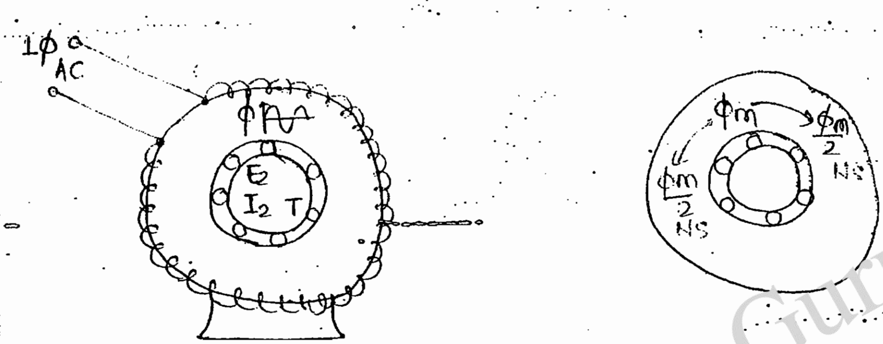
∵ rotor rotate in opposite dirn.

* when rotor fed the absolute flux in space rotates at an speed N_s wrt. rotor & runs at slip speed $(N_s - N)$ wrt. stator (or) stationary point at space.

15/11 (d) 26/28 (b.) (77) a

Single phase Ind^n motors

* If the fuse blows off in 3ϕ motors when running at light weight cond^n it won't stop but continue to run as 1ϕ motor with reduced speed & increased current.
* 1ϕ motor are popular because of there small ratings 1w to 1kw & domastic supply is 1ϕ.
* There construction is as identical to 3ϕ motors.
* stator contain 1ϕ wdg for 2, 4, 6 no. of poles generaly.
* Depanding on the starting method adopted stator wdg differs.
* Rotors are essentialy sq. cage type with skeying.
* The basic limitation of 1ϕ motors compare to 3ϕ is due to there non-self starting nature which can be analised, acc. to double field revolving theory. The complete analysis, eq. ckt representation is based on this theory.



When a 1ϕ supply is applied across stator containg one wdg a pulasting (or) alternating magnetic field is produced.
It links with rotor & results in induced emf as the rotor is essentialy closed it develops current & torque but rotor doesn't start.
If an external force applied the rotor continues to rotate in the dir^n of force & reaches its rated speed.
This behavioue is analysed acc. to double field revolving theory.
Acc. to this theory a pulsating magnetic field contains 2 magnetic fields running at synchronous speed at equal magnitude ($\phi m/2$) & in opposite dir^n.

forward :- ϕ_f $\quad \phi_m/2 \quad N_s \quad T_f \quad N \quad s_f \Rightarrow s_f = \frac{N_s - N}{N_s} = s$

Backward :- ϕ_b $\quad \phi_m/2 \quad N_s \quad T_b \quad -N \quad s_b \Rightarrow s_b = \frac{N_s + N}{N_s} = \frac{N_s + N - N_s + N_s}{N_s} = \frac{2N_s - (N_s - N)}{N_s}$

$$= 2 - s$$

* As the rotor is subjected to both fields the entire operating region of 1ϕ motor will be considered b/n 2 extreme boundary condⁿ 0 & 2.

at start $\quad s = 1$

$s_f = 1, \quad s_b = 1$

motoring region for 1ϕ IM

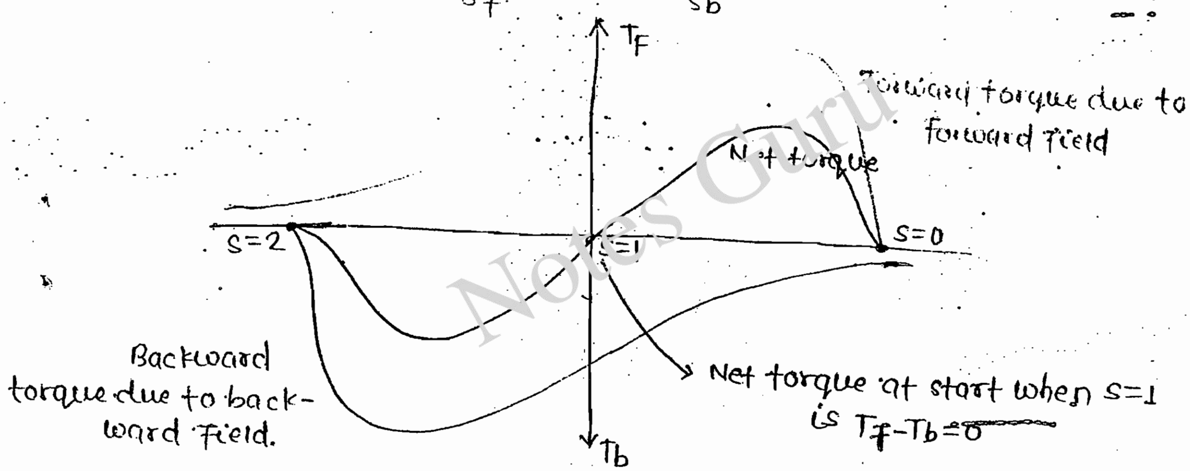
$s = (0 \quad 1, \quad 2)$

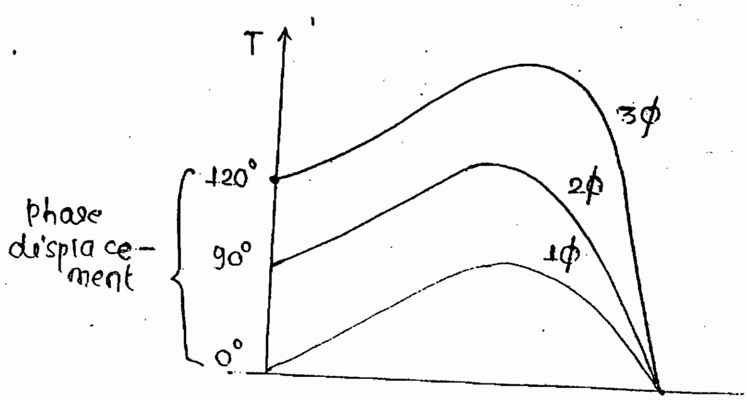
Running $\quad s = 0$

$s_f = 0, \quad s_b = 2$

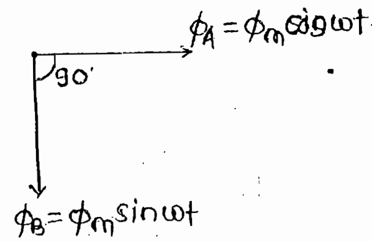
$$T_g = \frac{60}{2\pi N_s} \times \frac{RCL}{s}$$

$$T_f \propto \frac{I^2 R_2}{s_f} \quad ; \quad T_b \propto \frac{I^2 R_2}{s_b}$$

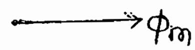




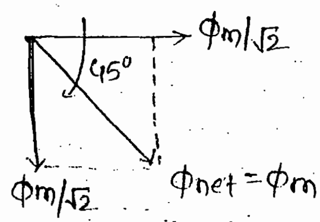
* RMF with 2-ϕ supply →

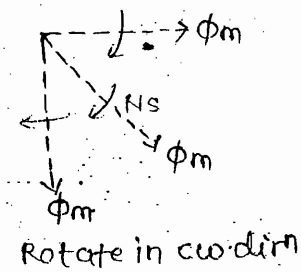


at $\omega t = 0$; $\phi_A = \phi_m$,
$\phi_B = 0$



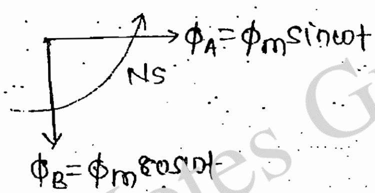
at $\omega t = 45°$; $\phi_A = \phi_m/\sqrt{2}$
$\phi_B = \phi_m/\sqrt{2}$



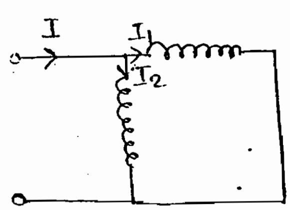


at $\omega t = 90°$ → $\phi_A = 0$
$\phi_B = \phi_m$

If we want to change the dirn of field the reverse the phase seq.

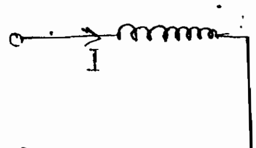


* Like a 3ϕ supply a 2ϕ supply also produce RMF which rotates at syn. speed but with reduced strength ϕ_m only.

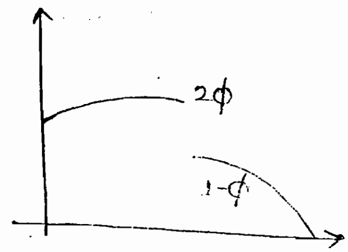


at starting

split 1ϕ into 2 parts & connect parallel.



at running

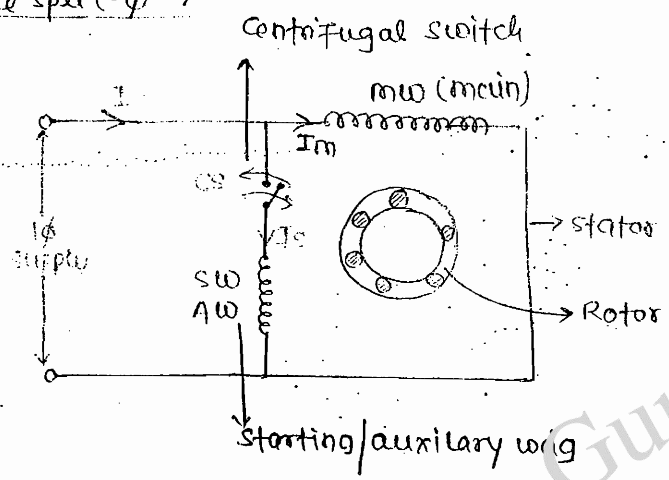


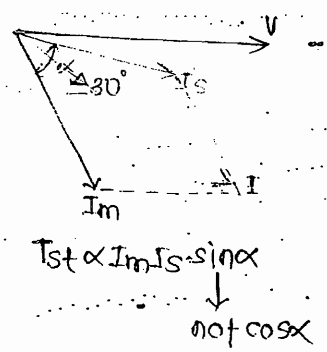
* Depanding on starting method adopted 1-ϕ motors are classified into 2 types:-

(1.) split-phase → Resistance split phase/split phase; capacitor start; capacitor start & capacitor run/capacitor run motor.

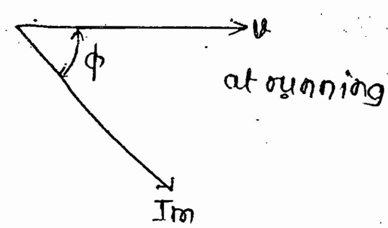
(2.) split-pole → shaded pole.

* Resistance split-ϕ →





* This is most popular for motors rating around 250w only.

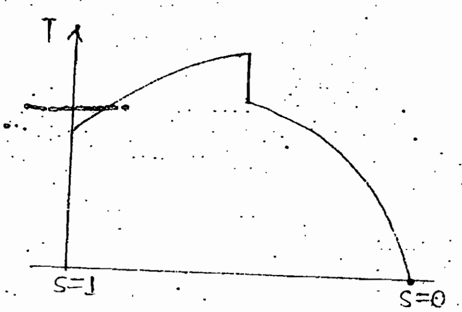


* Stator contains split ϕ wdg (2 wdgs):-
  (i) main wdg (Running wdg) which is having large no. of turns more inductive naturally
  (ii) Starting (or) auxiliary wdg which is having less no. of terms intentionaly made highly resistive with thin condr.
* This will introduce an angle of displacement b/n both current in wdgs I_m & I_s around $\alpha = 30°$.
* It is sufficient to produce starting torque for small rating motors around 250w but not suitable for high inertia loads abouts 250w ratings.

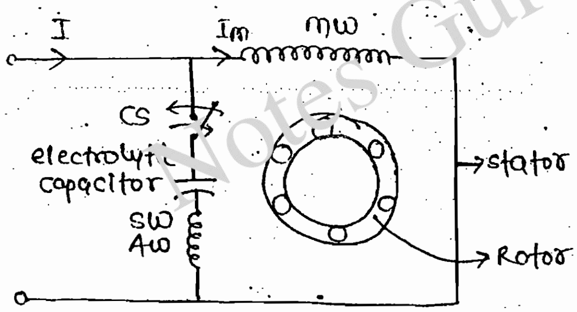
* This are not suitable for frequent starting & stopping but for contineous operation in its segments. α is low current drawn high.
  (Because of temp. rise in the resistor).

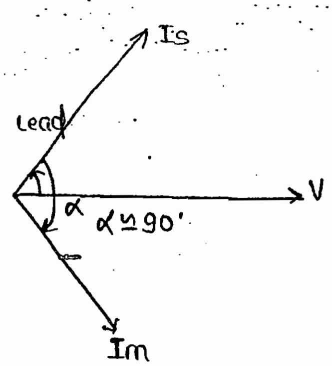
Appliⁿ →
250W
Domestic/sump motors
Centrifugal motors.
Fans/ blowers.

* Once the motor starts & reach 80% of rated speed the centrifugal switch gets opened to isolate starting wdg from supply. & motor continues to run with main wdg only.



(2) Capacitor start →





$T_{st} \propto I_m I_s \sin\alpha$

* In order to create a large φ diff b/n Im & Is (α≃90) a capacitor is included in series with starting wdg through a switch.
* As α is high the starting current drawn is comparitively low.
* It has high starting torque & used for high inertia load (hard to start) of 250-750W.
* As the motor reaches near rated value of speed the centrifugal switch will gets

Opened & ~~this~~ disconnectes both capacitor & starting wdg.

* Under running condn it is quite similar resistance split phase starting. This is prefered for frequent startings & stopping load specially.

Applications →

250–750W

Fans/ blowers

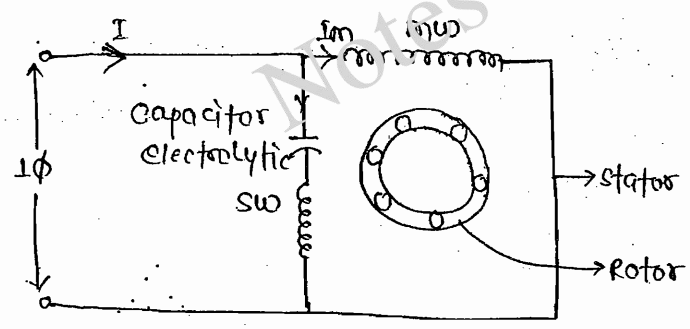
sump pumps/ centrifugal pump

refrigerator units, AC, washing m/c, grinders etc.

$\boxed{\text{Electrolytic capacitor} \longrightarrow \text{cost effective}}$

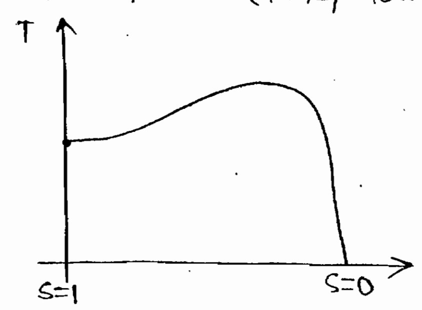
(3.) Capacitor start & capacitor Run →

* There is no centrifugal switch & the capa. is contineouly connected to supply along with starting wdg.
* The design cost is high comparitively because the starting wdg should efficient.
* It starts & run as perfect 2ϕ motor but capacitor start motor start as 2ϕ motor but run as 1ϕ motor with low PF.
* capacitor run motors are popular because of there silent operation with smooth T-S c/s & good starting as well as running torques.

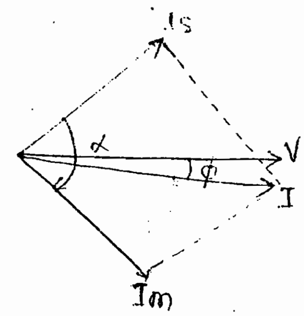


Appli^n →

All ceiling fans, AC & motors in (fans/blowers/pumps) of ratings 750–1000W



* As the capacitor is contineously connected 2 small range capacitor are used in parallel with switching option externaly, depanding starting & running torque they can be switched.

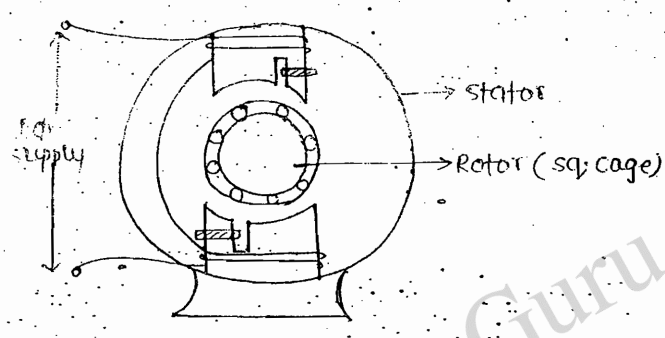


angle low
PF High

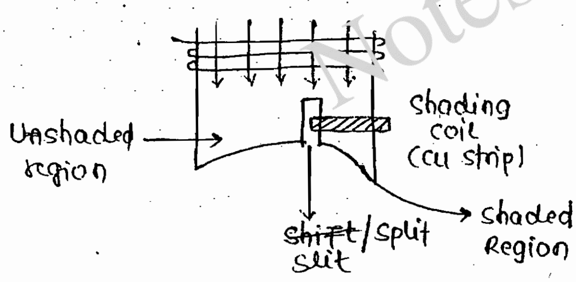
$$p = VI\cos\phi$$

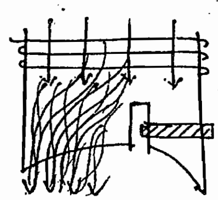
$$\uparrow \cos\phi = \frac{P}{VI}$$

* Shaded pole →

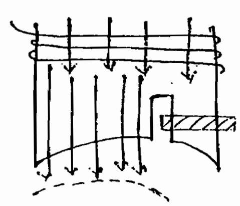


[1-50w Ranges
Toys]

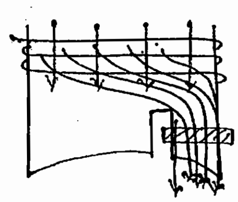




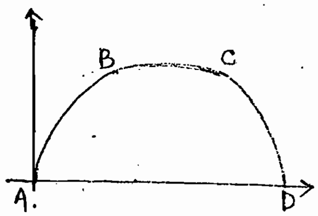
opposes
AB



BC



CD



Application →

Toys.

Small Fans/ Desk Fans

Cooling Fans in laptop

Xerox m/c

Advertisement displays.

Compact applianses like Hair drayes etc.

* It is popular for its compactness & widely used in small ranges less than 50W.
* Stator is totally different from split phase type.
* It contains projected poles with a split & Cu strip slo solidaly closed in one region of pole called as shaded region.
* At instant AB the rate of change of flux linkage is +ve, Emf induces in the shading coil produce current & its own flux to oppose the main flux coming out of the pole

  Therefore all the flux lines gets crowded in unshaded region at instant
* BC rate of change of flux linkage is very low & emf induced current & flux of shading coil negligible

  Therefore the flux distributes uniformaly through out the pole
* At instant CD Rate of change of flux linkages are in the –ve manner.

  Therefore the opposition will be in +ve manner which makes the flux lines crouded in shaded region.
* This will create a moving or RMF in air gap under all the poles.

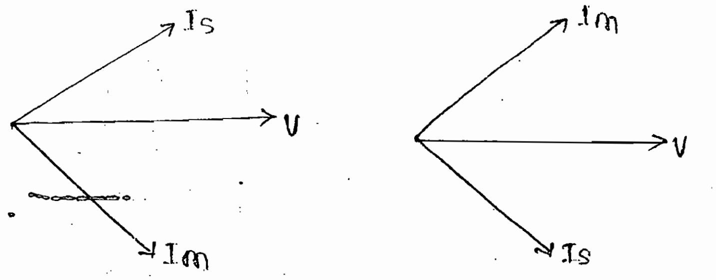
  However starting torques are very low & non-uniform magnetic field results in the non-uniform speeds & torque.

* In order to reverse the dirⁿ of rotation of splitphase motor:-

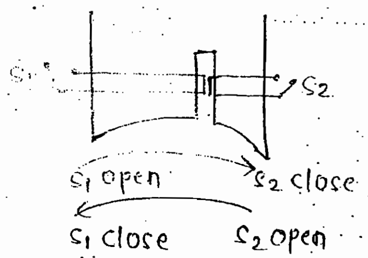
(1.) Either reversing mw terminals.

(2.) Either reversing sw terminals.

(3.) Interchanging capacitor from starting wdg to main wdg.



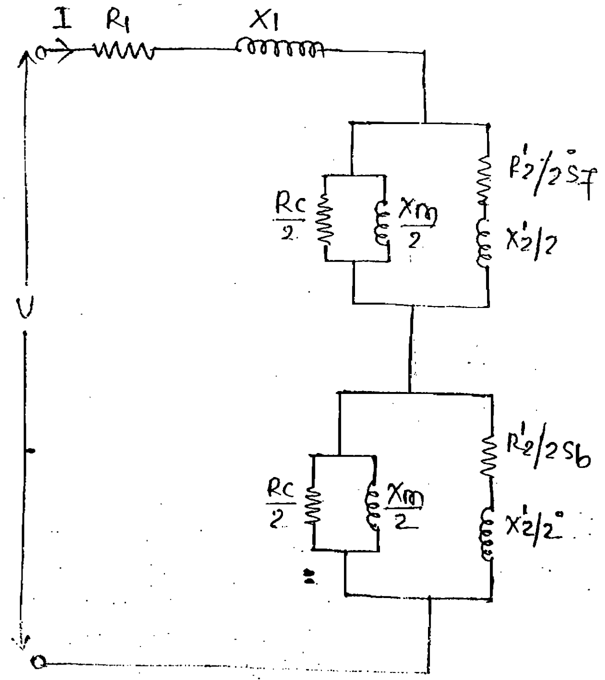
* By reversing both mw & sw (or) reversing supply terminals doesn't change the dirⁿ of rotation of motor.

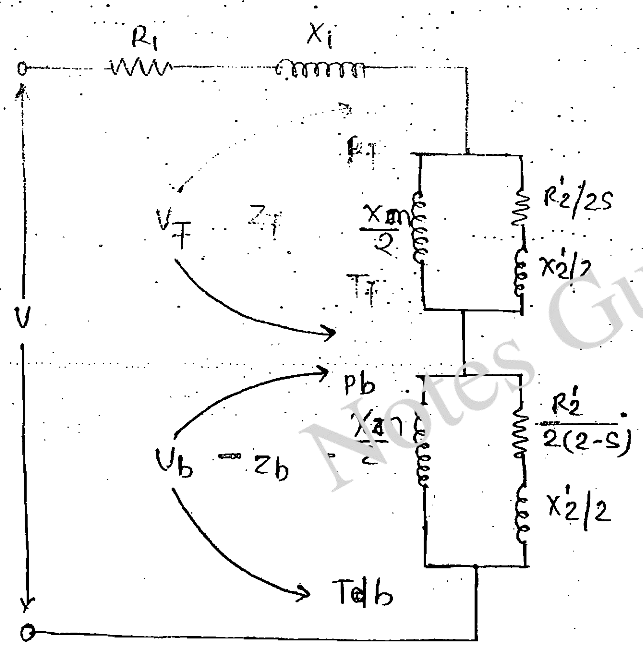


* The flux always moves from unshaded to shaded region only. Therefore it requires 2 shading coils which can be externaly switch.

* Equivalent circuit representation →

* The motor is represented on eq. ckt for further analysis.
* In 1ϕ motors the representation acc to double field revolving theory.
* Acc. to this as one rotor is reacting to both forward & backward fields it will be one stator 2 rotor representation as shown below.





* $Z_1 = R_1 + jX_1$

* $Z_f = j\frac{X_m}{2} \,\|\, \frac{R_2'}{2S} + j\frac{X_2'}{2}$

$= R_f + jX_f$

* $Z_b = j\frac{X_m}{2} \,\|\, \frac{R_2'}{2(2-S)} + j\frac{X_2'}{S}$

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$$Z_{eq} = Z_1 + Z_f + Z_b$$

$$I = \frac{V}{Z_{eq}}$$

$I\angle\phi$ $\therefore$ $PF = \cos\phi$ (lagg)

Power i/p to forward rotor $\rightarrow$ $I^2 R_f = P_f$

Power i/p to backward rotor $\rightarrow$ $I^2 R_b = P_b$

Net P/p to rotor (OR) Air gap power $= P_f - P_b$

Power o/p of rotor $= (1-s)(P_f - P_b)$

* For accuracy in the analysis from eq. circuit while calculating net power cal^n iron, friction & windage (const. or rotational losses) should be included while eliminating shunt branch resistance R_c from actual ckt

Net/shaft/motor o/p $= (1-s)[P_f - P_b]$ $-$ Rotational loss

$$\eta = \frac{\text{Shaft o/p}}{\text{E. Input}} = \frac{(1-s)[P_f - P_b] - [\text{Rotational loss}]}{VI \cdot \cos\phi}$$

Gross torque $T_g = \frac{60}{2\pi N_s}$ Rot. P/p

$$T_g = \frac{60}{2\pi N_s}(P_f - P_b)$$

Shaft torque $T_{sh} = \frac{60}{2\pi N}$ shaft o/p

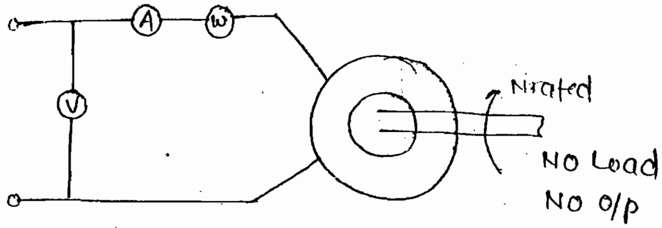
$$T_{sh} = \frac{60}{2\pi N} P_{sh}$$

Shaft o/p $= P_{sh} = (1-s)[P_f - P_b] - [\text{Rotational loss}]$

* Determination of eq. ckt parameter →

It requires determination of 3 tests to be conducted in order to find out the parameters of eq. ckt as similar to 3ϕ motors.

(1) No Load test →



* Apply rated vol. across the given 1ϕ IM & allow it to run freely on NL.

$$I_p = \cancel{o/p} + loss(total)$$

$$I_p = loss$$

→ Stator cu loss
→ Stator core loss
→ Rotor cu loss × (current is low)
→ Rotor core loss × (sf is small)
→ mech. loss

* It requires LPF wattmeter to measure NL power i/p.
* The wattmeter reading is considered to be containing stator core loss + mech. loss + small stator cu loss.

(2) DC test →

* Apply small vol. (dc) across the stator by connecting a V-m & ammeter.
* Ratio of V/I gives dc resistance.
* It is adjusted to ac value by multiplying with suitable factor around 1.5. $\boxed{R_{1AC} = 1.5 R_{DC}}$

$$W_0 - I_0^2 R_1 = \text{Rotational loss (Iron, Friction \& windage)}$$

* From stator resistance value rotational loss is calculated.

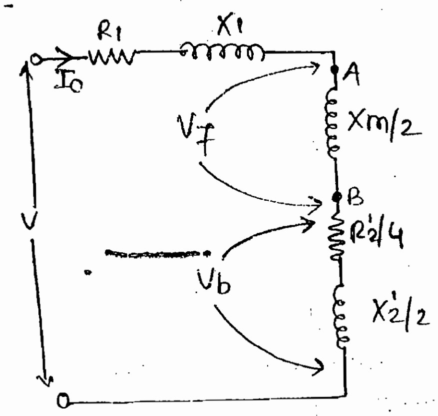


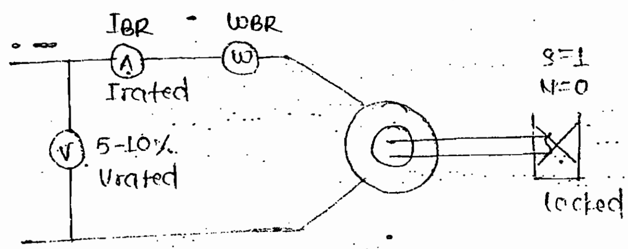
Fig:- Eq. ckt at No Load

$$V_{AB} = I_0 \times \left(\frac{X_m}{2}\right)$$

$$\therefore X_m = \frac{2V_{AB}}{I_0}$$

$s \to 0$
- $\to R_2'/2s$ (OC)
- $\to X_m/2$ (High value)

(3.) Blocked Rotor test →

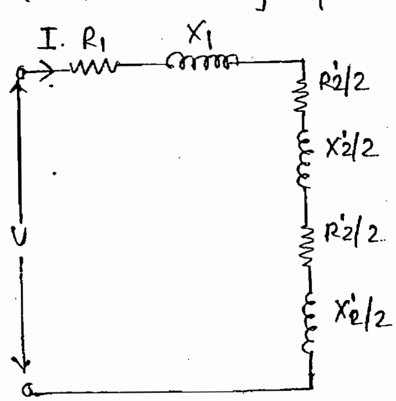


* Rotor is initialy blocked & small vol. is applied across stator through a suitable auto Xmer while insuring rated current drawn by motor.

Total loss
- → stator cu loss
- → stator core loss × (V is least)
- → rotor cu loss
- → Rotor core loss × (V is least)
- → mech. loss × (N=0)

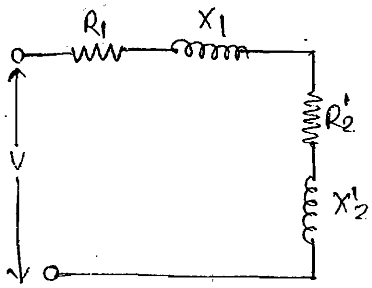
Wattmeter Reading → only cu loss

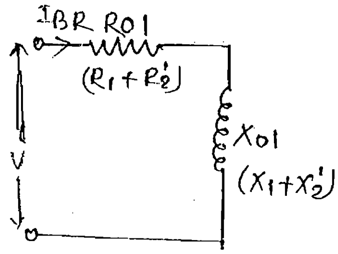
* In this test wattmeter reading represent both stator & rotor cu losses.



S=1

Fig:- Eq. ckt on blocked rotor condⁿ





$W_{BR} = $ (stator + Rotor) cu loss

$$= (I^2R_1 + I^2R_2') = I^2R_{01}$$

$$= I_{BR}^2 \cdot R_{BR}$$

$$W_{BR} = I_{BR}^2 \, R_{BR}$$

$$R_{BR} = \frac{W_{BR}}{I_{BR}^2}$$

$$Z_{BR} = \frac{V_{BR}}{I_{BR}}$$

$$X_{BR} = \sqrt{Z_{BR}^2 - R_{BR}^2}$$

$$\boxed{X_1 = X_2' \simeq \frac{X_{BR}}{2}}$$

$$X_{BR} = X_{01} = X_1 + X_2'$$

$$Z_{BR} = Z_{01}$$

$$\eta = \frac{O/p}{O/p + \text{Const loss} + \text{Cu loss}} = \frac{I/p - \left[\text{const loss} + \text{cu loss}\right]}{I/p}$$

* Comparision b/n 3ϕ & 1ϕ Im →

* 3ϕ power capacity is more than that of 1ϕ.
* For a same rating 1ϕ motors are comparitively having more size, cost, low torques & run with a noise due to backward field. Cost also comparitively more in 1ϕ because of Auxiliary wdg, switch & capacitor.

~~* Comparision b/n~~

* 3ϕ motors are more efficient than 1ϕ.

** $\boxed{T \propto \frac{SV^2}{R_2 f}}$

20/27 (b.) $\downarrow T \propto \frac{SV^2 \downarrow}{R_2 f}$ (c.) $\uparrow T \propto \frac{SV^2 \downarrow}{R_2 f \downarrow}$ (d.) $\uparrow T \propto \frac{SV^2}{\downarrow R_2 f}$

28/28 $T \propto SV^2$, $\frac{T_2}{T_1} = \left(\frac{S_2}{S_1}\right)\left(\frac{V_2}{V_1}\right)^2$

29/28 $S_m = \frac{1200-1000}{1200} = \frac{1}{6}$

$S_m = \frac{1}{6} = \frac{R_2}{X_2}$

$X_2 = 7.2$

$R_2 = X_2$ (max^m torque)

$X_2 = R_2 + R_2'$ (series add)

$R_2' = 7.2 - 1.2 = 6\Omega$

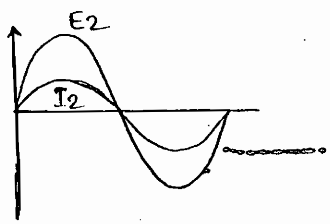
30/29 slip ring $\rightarrow$ No. of stator pole = No. of rotor pole

31/29 * Commutator converts Ac $\rightarrow$ dc, therefore in the extra load freq. is 0.

* If there are slip rings the freq. across them is slip freq.

* freq. wrt brushes on the commutator will be supply freq. (or) stator freq. only.

37/30

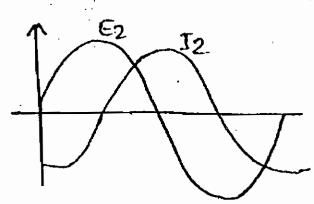


Pure Resistive

$\phi = 0$

$\cos\phi = 1$

$T \propto E_2 I_2 \cos\phi_2$

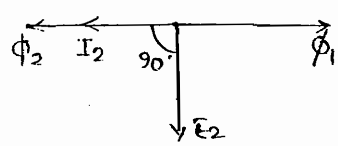


Pure inductive

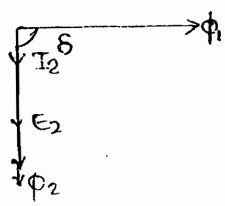
$\phi = 90'$

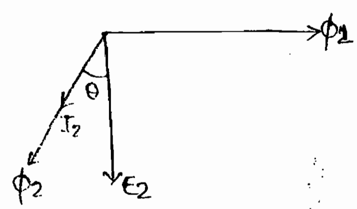
$\cos 90' = 0$

$T \propto E_2 I_2 \cos\phi_2$



$T \propto F_1 F_2 \cdot \sin\delta$





38/30

$$T \propto \frac{SV^2}{f}$$

$$\frac{N_s}{2} = \frac{120 f/2}{P}$$

$$\frac{T_2}{T_1} = \frac{S_2}{S_1}\left(\frac{V_2}{V_1}\right)^2 \cdot \left(\frac{f_1}{f_2}\right)$$

$S_2 = 2S_1$

slip speed constant

44/31

Stator core loss = 1.5K + 1200 W = 2700 W

∴ Rotor cu loss = 900 W

mech. loss = 1050 W

$P = \sqrt{3} V_L I_L \cos\phi - 2700W$

46/31

$$S = \frac{1500 - 1410}{1500}$$

2000 → total

$(1-S)2000 \longrightarrow 1880$

$P = 1880W$

$P = I^2R$

$I = \sqrt{\frac{P}{R}}$

48/31

$V_1 = 400V,\ f_1 = 50$, $N = ?$

$V_2 = 240V,\ f_2 = 30Hz$

$$\frac{V_1}{f_1} = \frac{V_2}{f_2} \quad ; V_2 = 240V$$

$$S_1 = \frac{1500 - 1440}{1500}$$

$S_1 = 0.04$

$$T \propto \frac{SV^2}{f}$$

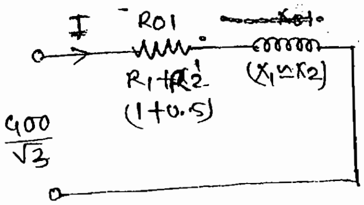
$$\frac{T_2}{T_1} = \frac{S_2}{S_1}\left(\frac{V_2}{V_1}\right)^2 \cdot \left(\frac{f_1}{f_2}\right)$$

$S_2 = 0.06$

$N = N_s(1-S)$

$$= \frac{120 \times 30}{4}(1 - 0.06) = 840$$

49/32



$$T_g = \frac{60}{2\pi N_s}\cdot\frac{RCL}{S}$$

$$= \frac{60}{2\pi N_s}\times 3I^2R$$

$$T_g = \frac{3\times 60}{2\pi N_s}\times\left\{\frac{400/\sqrt{3}}{[1.5+j2.4]}\right\}^2\times 0.5$$

50/32

$$\eta = \frac{10000}{10000+1002+1354}$$

NL	BR
15^2A	720
20^2A	?

51/32

$\frac{T_{st}}{T_f} = 1.5$ $\quad \frac{T_m}{T_f} = 3$ $\quad \frac{T_{st}}{T_m} = \frac{1}{2} = \frac{(2)s_m}{s_m^2+1}$

61/33 In NL test watt-meter reading represent iron, friction & windage but iron losses are seprated to represent as shunt branch R_c in the actual eq. ckt

62/33

$T \propto \frac{s}{R_2}$ $\qquad \frac{0.25}{0.25+0.5} = \frac{0.03}{?}$

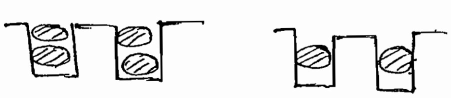
$R_2 \propto s$

63/33

50Hz → 1500
30Hz → 900

Possible speeds may be
1500 ± 900

74/34



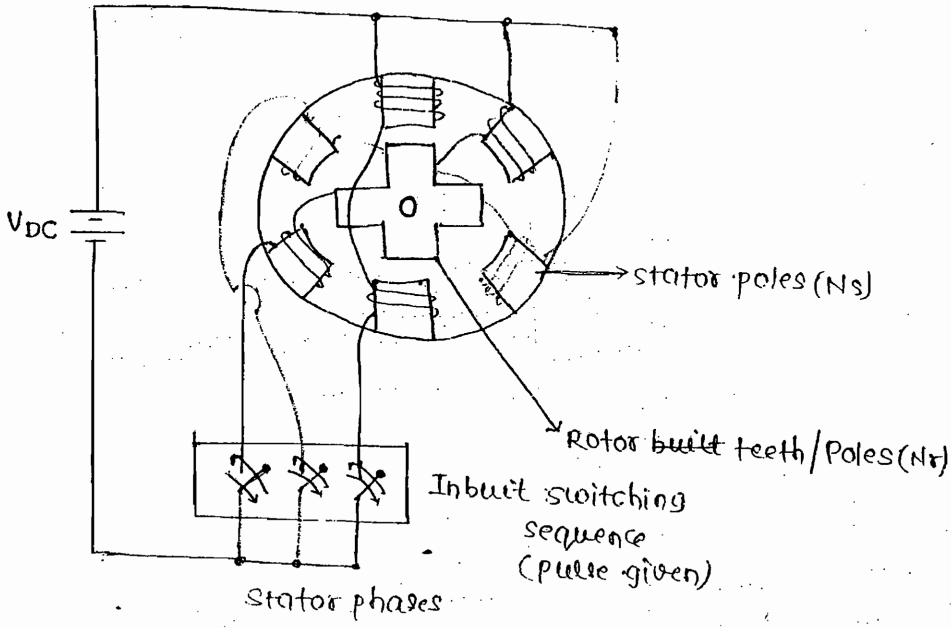
75/35

f = 48Hz

$N_s = \frac{120(48)}{6}$

N = 936

* Stepper motor →



$$\text{Step angle } \alpha = \frac{N_s - N_r}{N_s \cdot N_r} \times 360$$

(OR)

$$\alpha = \frac{360^\circ}{m \times N_r}$$

* This are not meant for continuous rotation but rotor rotates in steps by reacting to the pulses given by drive ckt acc to switching seq by a step angle α in mech. degrees.
* It can be designed depending on no. of poles & teeth in the stator & rotor.
* They can be permanent magnet (or) variable reluctance type.
* If step freq. is high (pulses are high or micro stepping) then the rotor becomes uncontrollable due to its inertia which is called as slew range.

Small Ranges → Less than 1w to few watts
Available & popular
Timing devices (clocks.)
Printers, type writer, fax
Computer controls
Robotics.

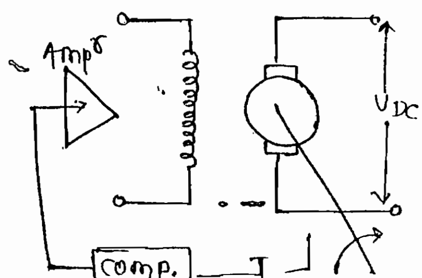
* Ac series motor/Universal →

* If 1ϕ Ac supply is applied across dc series motor it continues to run as the torque +ve in both half cycle but the torque is pulsating & not a uniform torque
* However directly dc series motors are not used but specialy designed.
  (1) stator & rotor contains high grade si- steel laminations to reduce Iron loss.
  (2) Field wdg turns will be comparitevely reduced.
  (3) Arm. reaction, perticularly commutation is not successful because of high reactance in the arm. coils.
  (4.) Sparking at the brushes will produce high maintanance repairs which need to be taken care with ~~CW~~ compensated wdg for large ratings.
* These motors are popular specialy less than 1kw ratings because of there high speed (5000-20000 rpm) & high torques within compact size.
* Due to pulsation in torque they make more noise.
* Exclusively prefered for food processing like mixers/juicers, vaccum cleaners, portable hand tools like drilling m/c, wood saw's/sewing m/c, recent automatic washing m/c.
* Ac series motors are of high rating around 500 hp are used for some traction purposes but with reduced grid frequency are 25Hz only.

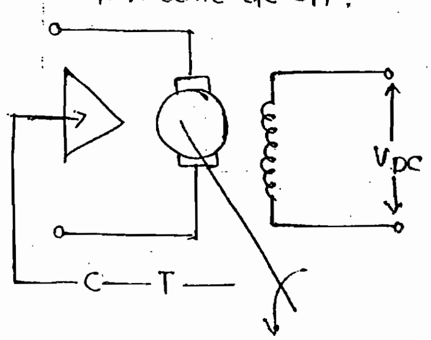
* Servo motors →

Servo mechanism → Automatic control sys.

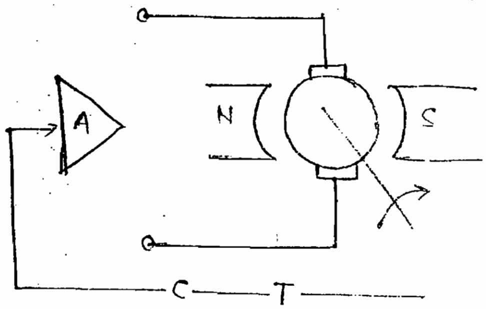
Field controlled DC SM



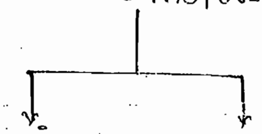
Arm cont. dc SM.



* Compared to field control arm. control servomechanism is fast acting.
* Arm. control permanant magnet is most popular dc servo motors due to its simple compact design, efficient & no requirement of field wdg & excitation.



Servo motors



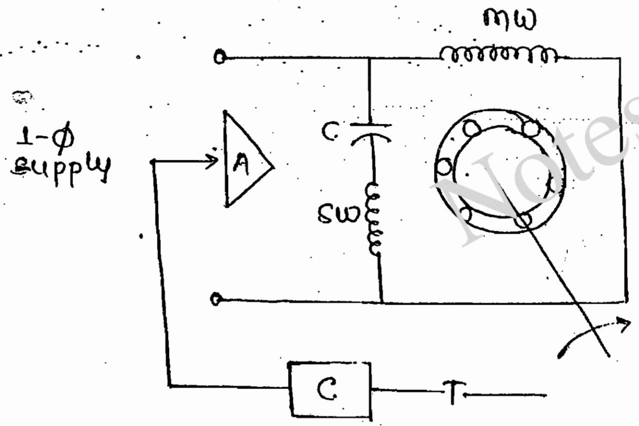
Application →

Control motor used in control sys. apps, radars, process control, Position controlling, tracking systems.

AC servo motors →

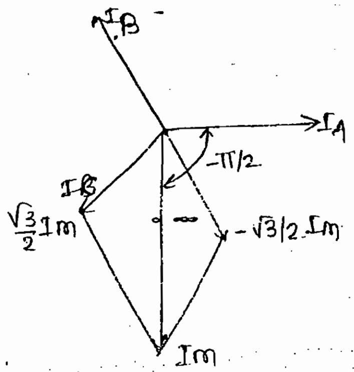
2-ϕ IM

1ϕ IM (Capacitor Run type)



* Ac servo motors are basicaly 1ϕ IM capacitor run type.
* for quick responce there rotor diameters are small & more axial length.
* Compared to conventional there X/R ratio of rotor is low. to get linear T-S c/s for effective responce.

16/49



22/51

$$\frac{R_2}{2(2-s)}$$

$$s = \frac{1500-1425}{1500}$$

$$s = 0.05$$

8