Unit 1

Electromechanical Energy Conversion Principles

Introduction:

Electrical energy is seldom available naturally and is rarely directly utilized. There are two conversion takes place-------

a. One form to electrical form
b. Electrical form to original form or any other desired form

The device through which we convert one form to electrical form & back to original form or any other desired form is studied in EMEC.

Like—Transformers, D.C. Machines, A. C. Machines (Induction and Synchronous)

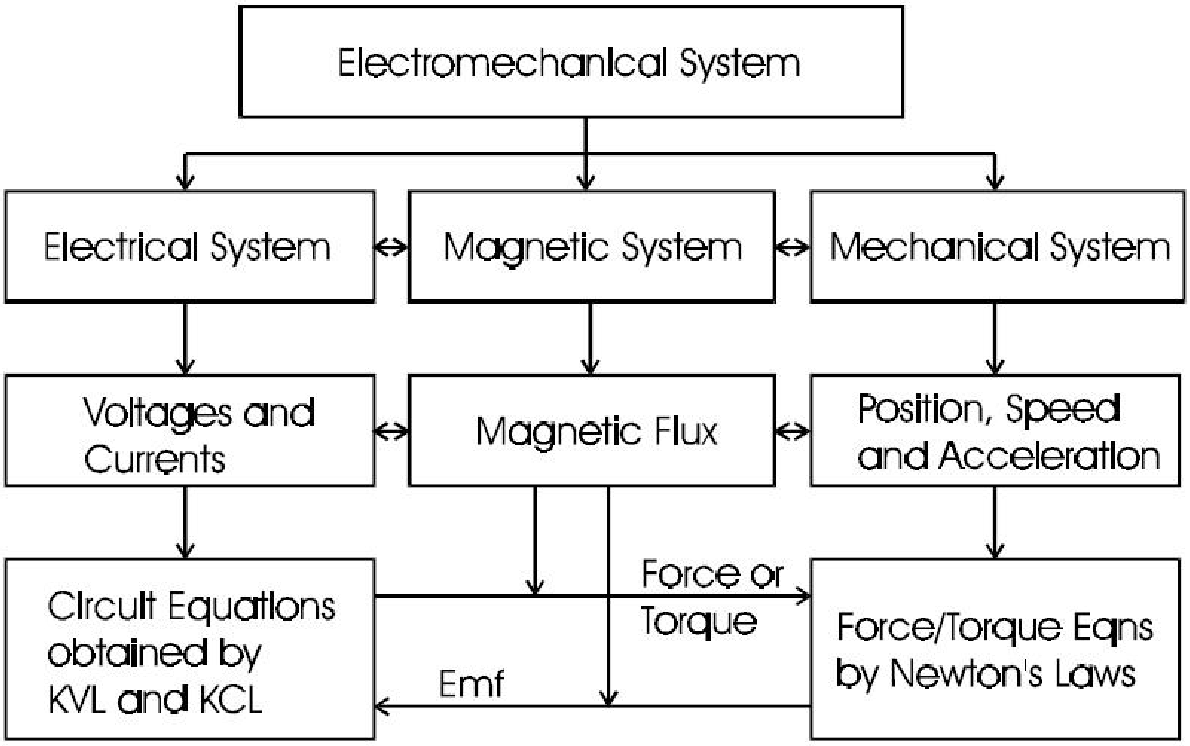
These devices can be transducers for low energy conversion processing and transporting. A second category of such devices is meant for production of force or torque with limited mechanical motion like electromagnets, relays, actuators etc.

A third category is the continuous energy conversion devices like motors or generators which are used for bulk energy conversion and utilization.

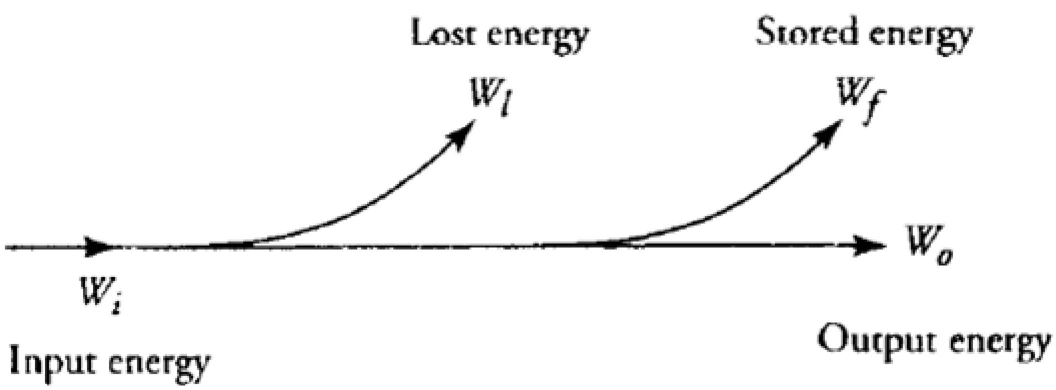
EMEC-----------via----------Medium of magnetic or electric field. For practical devices magnetic medium is most suitable.

When we speak of electromechanical energy conversion, however, we mean either the conversion of electric energy into mechanical energy or vice versa.

Electromechanical energy conversion is a reversible process except for the losses in the system. The term "reversible" implies that the energy can be transferred back and forth between the electrical and the mechanical systems.



Concept map of electromechanical system modeling



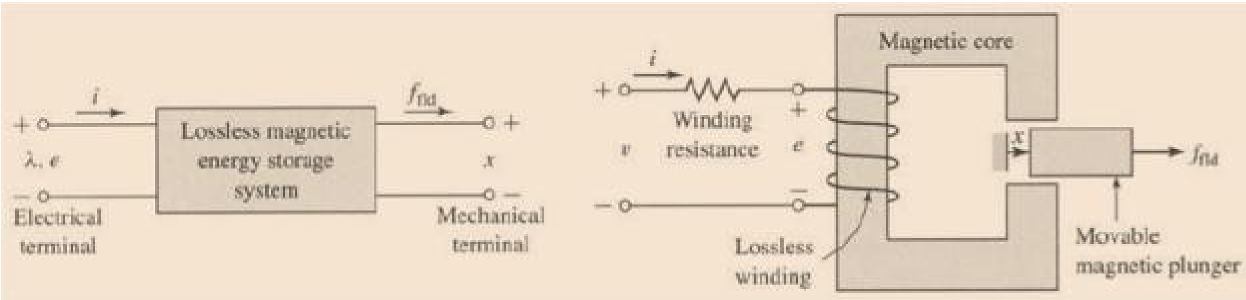
Energy Flow Diagram

From energy diagram we can see that principle of energy conservation is accurately followed. i.e Input Energy=Losses + Stored Energy + Output Energy.

Singly Excited System:

Consider a singly excited linear actuator as shown below. The winding resistance is R. At a certain time instant *t*, we record that the terminal voltage applied to the excitation winding is *v*, the excitation winding current i, the position of the movable plunger x, and the force acting on the plunger $\mathbf{F}$ with the reference direction chosen in the positive direction of the x axis, as shown in the diagram. After a time interval dt, we notice that the plunger has moved for a distance dx under the action of the force $\mathbf{F}$. The mechanical done by the force acting on the plunger during this time interval is thus

$$dw_m = Fdx$$



Singly Excited system energy conversion

The amount of electrical energy that has been transferred into the magnetic field and converted into the mechanical work during this time interval can be calculated by subtracting the power loss dissipated in the winding resistance from the total power fed into the excitation winding as

$$dw_e = dw_f + dw_m = vidt - Ri^2 dt$$

Since,

$$e = \frac{d\lambda}{dt} = v - Ri$$

So,

$$dw_f = dw_e - dw_m = eidt - Fdx = id\lambda - Fdx$$

we can also write,

$$e = \frac{d\lambda}{dt} = v - Ri$$

$$dw_f(\lambda, x) = \frac{dw_f(\lambda, x)}{d\lambda} d\lambda + \frac{dw_f(\lambda, x)}{dx} dx$$

the energy stored in a magnetic field can be expressed as

$$w_f(\lambda, x) = \int_0^{\lambda} i((\lambda, x)d\lambda$$

For a magnetically linear (with a constant permeability or a straight line magnetization curve such that the inductance of the coil is independent of the excitation current) system, the above expression becomes

$$W_f(\lambda, x) = \frac{1}{2}\frac{\lambda^2}{L(x)}$$

and the force acting on the plunger is then

$$F = -\frac{\partial W_f(\lambda, x)}{\partial x} = \frac{1}{2}\left[\frac{\lambda}{L(x)}\right]^2 \frac{dL(x)}{dx} = \frac{1}{2} i^2 \frac{dL(x)}{dx}$$

In the diagram below, it is shown that the magnetic energy is equivalent to the area above the magnetization or λ-i curve. Mathematically, if we define the area underneath the magnetization curve as the ***coenergy*** (which does not exist physically), i.e.

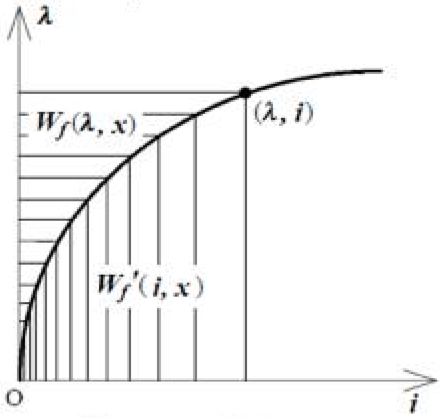
$$W_f'(i,x) = i\lambda - W_f(\lambda, x)$$

we can obtain

$$dW_f'(i,x) = \lambda di + id\lambda - dW_f(\lambda, x)$$

$$= \lambda di + F dx$$

$$= \frac{\partial W_f'(i,x)}{\partial i} di + \frac{\partial W_f'(i,x)}{\partial x} dx$$



Energy and coenergy

Therefore,

$$\lambda = \frac{\partial W_f'(i,x)}{\partial i}$$

and $$F = \frac{\partial W_f'(i,x)}{\partial x}$$

From the above diagram, the coenergy or the area underneath the magnetization curve can be calculated by

$$W_f'(i,x) = \int_0^i \lambda(i,x) di$$

For a magnetically linear system, the above expression becomes

$$W_f'(i,x) = \frac{1}{2} i^2 L(x)$$

and the force acting on the plunger is then

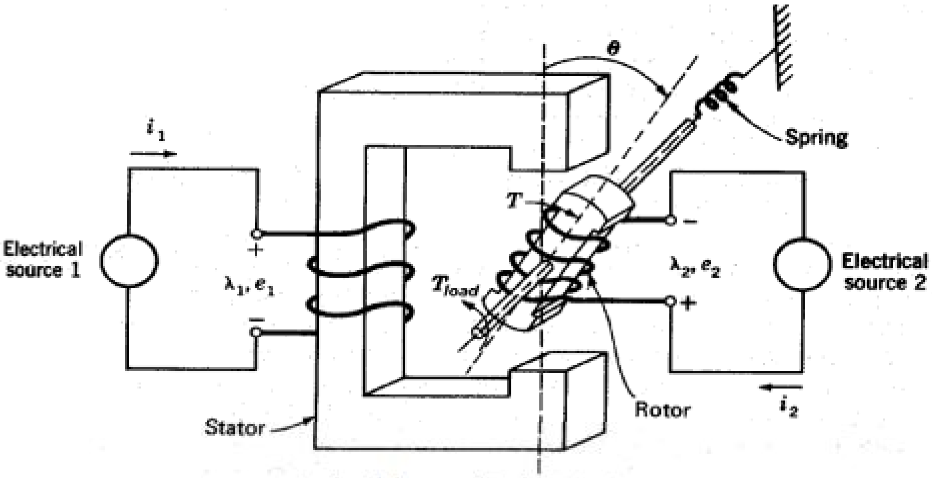
$$F = \frac{\partial W_f'(i,x)}{\partial x} = \frac{1}{2} i^2 \frac{dL(x)}{dx}$$

Doubly Excited Rotating Actuator

The general principle for force and torque calculation discussed above is equally applicable to multi-excited systems. Consider a doubly excited rotating actuator shown schematically in the diagram below as an example. The differential energy and coenergy functions can be derived as following:

$$dW_f = dW_e - dW_m$$

where $$dW_e = e_1 i_1 dt + e_2 i_2 dt$$



A doubly excited actuator

$$e_1 = \frac{d\lambda_1}{dt}, \qquad e_2 = \frac{d\lambda_2}{dt}$$

and $$dW_m = Td\theta$$

Hence,

$$dW_f(\lambda_1, \lambda_2, \theta) = i_1 d\lambda_1 + i_2 d\lambda_2 - Td\theta$$

$$= \frac{\partial W_f(\lambda_1,\lambda_2,\theta)}{\partial \lambda_1} d\lambda_1 + \frac{\partial W_f(\lambda_1,\lambda_2,\theta)}{\partial \lambda_2} d\lambda_2 + \frac{\partial W_f(\lambda_1,\lambda_2,\theta)}{\partial \theta} d\theta$$

and

$$dW_f'(i_1,i_2,\theta) = d\left[i_1\lambda_1 + i_2\lambda_2 - W_f(\lambda_1,\lambda_2,\theta)\right]$$
$$= \lambda_1 di_1 + \lambda_2 di_2 + T d\theta$$
$$= \frac{\partial W_f'(i_1,i_2,\theta)}{\partial i_1} di_1 + \frac{\partial W_f'(i_1,i_2,\theta)}{\partial i_2} di_2 + \frac{\partial W_f'(i_1,i_2,\theta)}{\partial \theta} d\theta$$

Therefore, comparing the corresponding differential terms, we obtain

$$T = -\frac{\partial W_f(\lambda_1,\lambda_2,\theta)}{\partial \theta}$$
$$T = \frac{\partial W_f'(i_1,i_2,\theta)}{\partial \theta}$$

07/14

DC MACHINES

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

① DC gen^r → * A m/c which is designed to take the advantage of electromegnatic ind^n. in order to convert mech. movement into electricity (dc vol.)

* Faraday's law of electromegnatic ind^n → * whenever a cond^r cuts megnatic flux a dynamically induced emf is produced in the cond^r. 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 & cond^r or cond^r & flux.

* It depends 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 & cond^r for the flux linkage.
* If the flux is time varying it automaticaly links with stationary cond^r.
* According to Faraday there are 3 modes of flux linkages

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

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

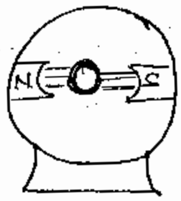
$$e = N\frac{d\phi}{dt} \times \frac{di}{di}\ \text{Volts}$$

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

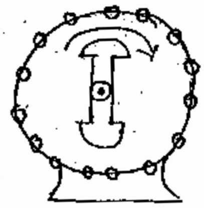
$$\boxed{e = L\frac{di}{dt}}$$

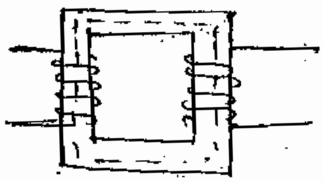
3 modes →

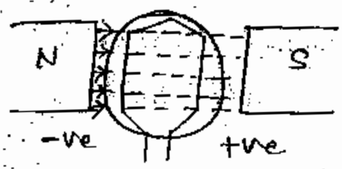
(1) Conductors (Rotating) Flux (stationary) }
(2) Conductors (stationary) flux (rotating) } (Time invarying)
(3) Conductors (stationary) flux (stationary)



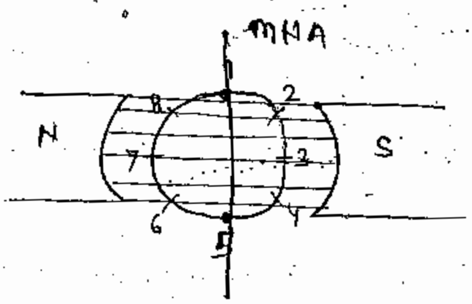
Dc m/c
mode(1)

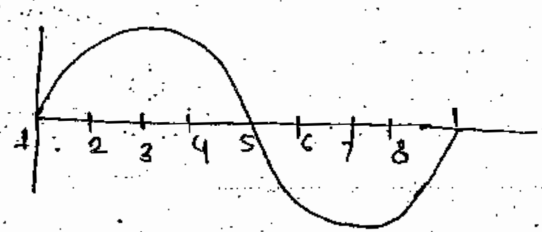

syn. m/c
mode(2)


T/F
mode(3)



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





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

$e = B l v \sin\theta$ volts

FRR
Fore - Dir^n of flux
Thumb - Dir^n of rot/motion
Middle - Dir^n of emf/current

θ = Angle b/w cond^r rotation & flux line

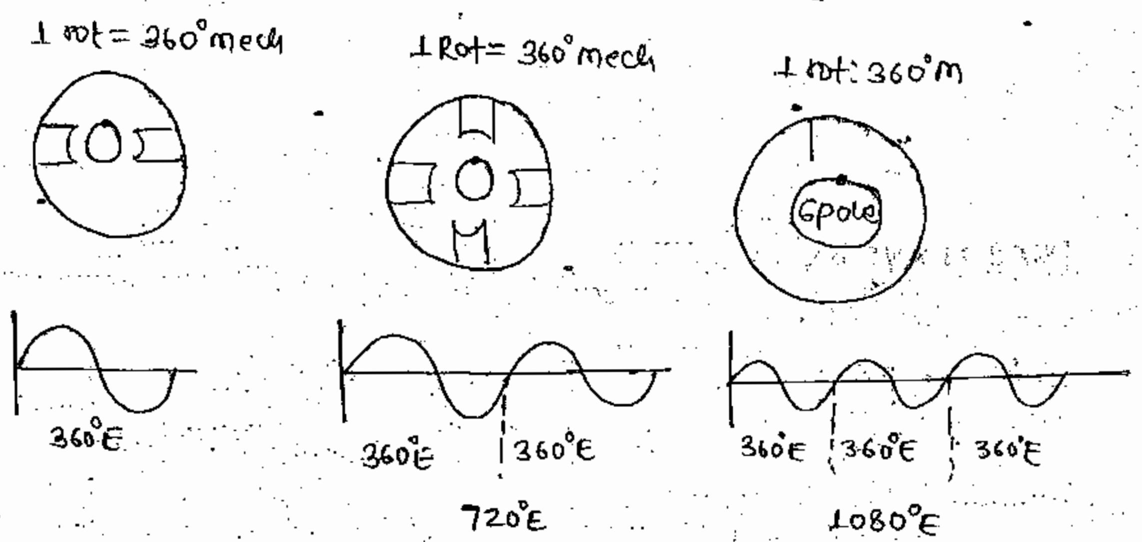
* Consider a simple coil rotating clockwise between 2 poles N & S. In one complete rotation it will produce 1 +ve half cycle & -ve half cycle which is periodic in nature known as alternating vol. or current.
* In positions 1 & 5 the cond^r movement is exactly parallel to the flux lines (θ=0)

* 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 <u>Magnetic Neutral axis.</u>

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

* Consequently max^m induced emf.

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



* <u>Under a pole there are always</u> 180 ele. degree.

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

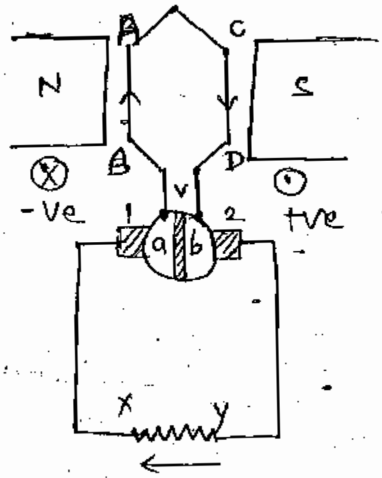
* In AC or DC gen^r there will be alternating vol. induced in the cond^r (AC)

* 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→5, 0→180°

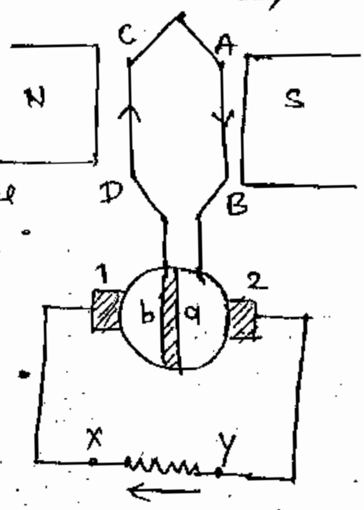
BA CDb2VX 1aB



5→1, 180→360°

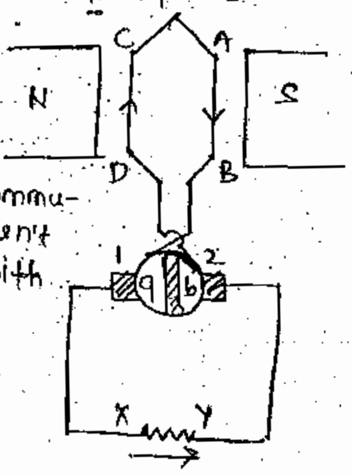
DCABa2YX1bD

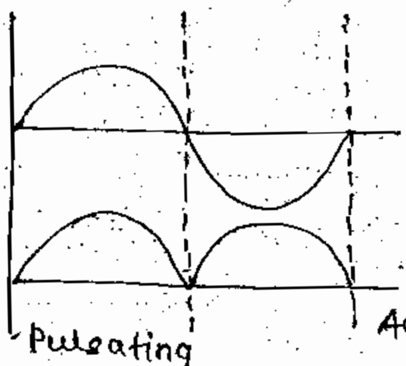
Commutator is rotating with coil



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 →

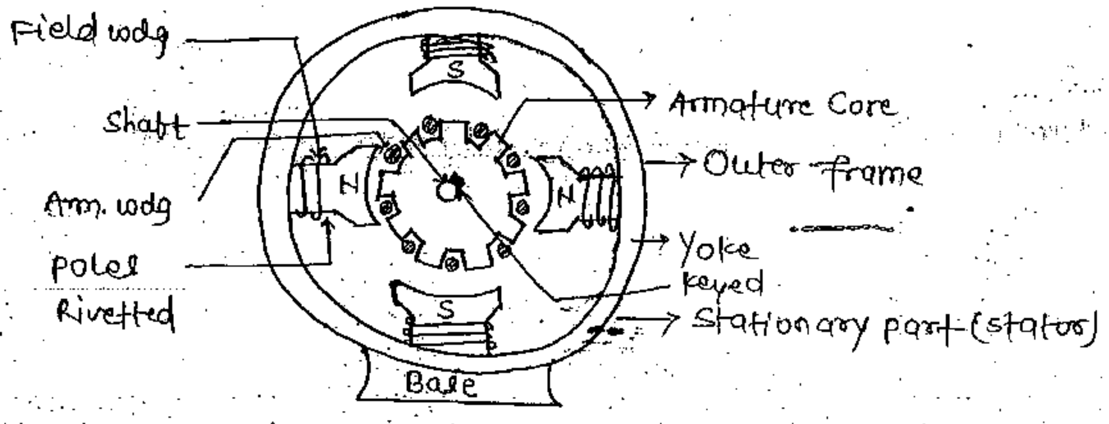
(1) Common features for all rotating ele m/c →

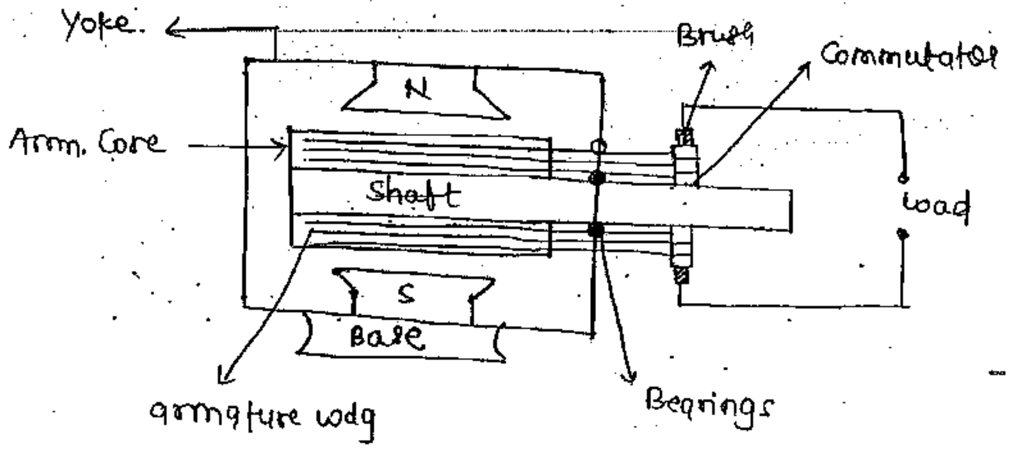
(i) The poles contains Hetropolar st (alternate North & South poles of even no.)

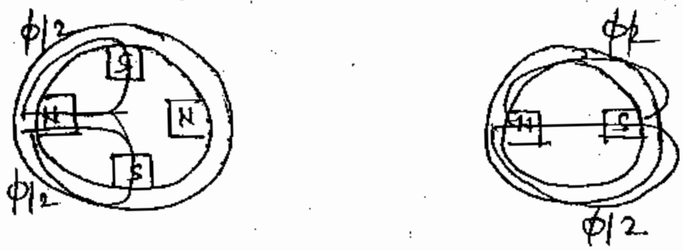
(ii) Excitation should be essentialy in dc.

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

Air gap → 0.5–2mm







Yoke → * It acts as protective covering to the entire m/c.

* It supports the poles as the poles are directly rivetted to it.

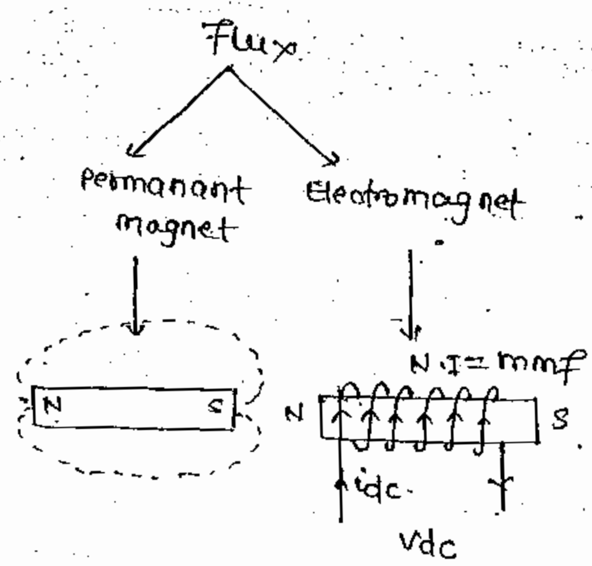
* It offers flux path complition of $\phi/2$ (if ϕ is flux/pole flux passing through yoke is $\phi/2$) Therfore yoke should be good megnatic material.

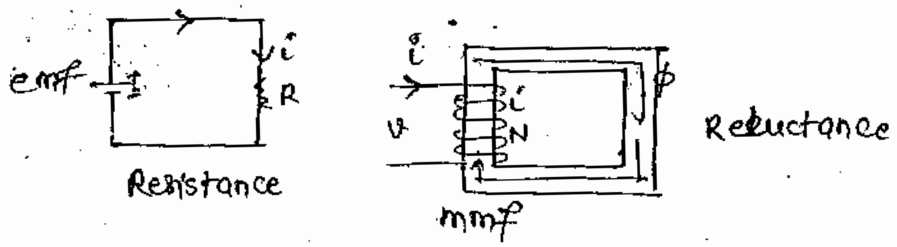
* For small m/c cast iron is used, large m/c - Fabricated ~~rolle~~ steel.

* If the dc-m/c are operating across power electronic converters laminated yokes are preferred. (to reduce eddy current loss)

Pole → * It has to produces working flux in the m/c.

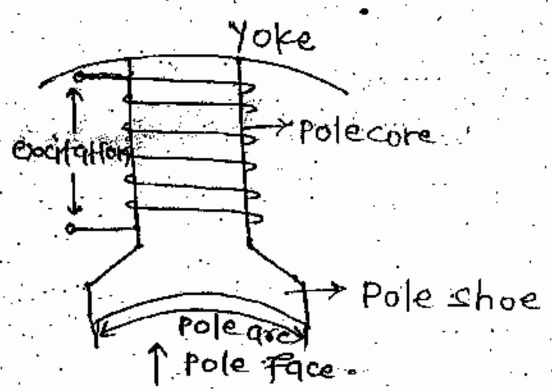
* The basic s



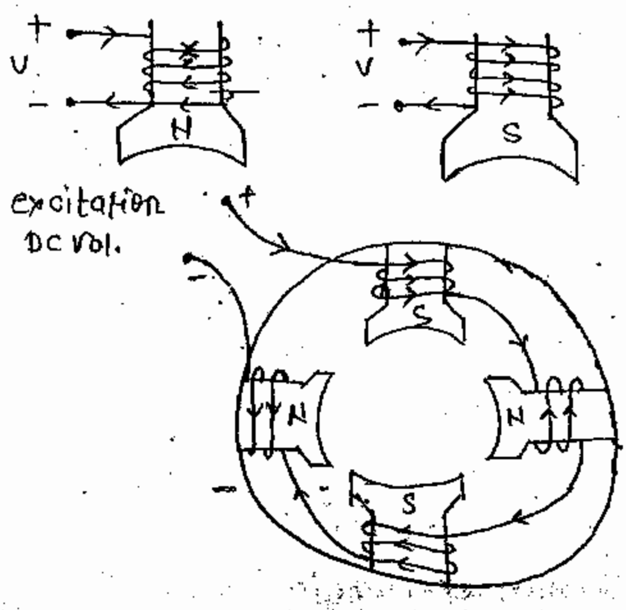


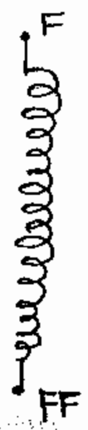
Permeability → Permit to flow the flux.

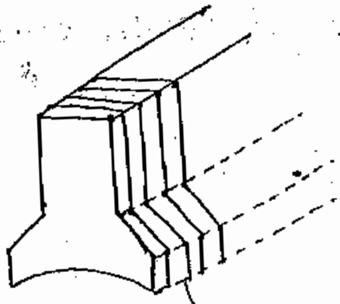
* Excitation should be always dc for the field wdg.
* The funⁿ of the pole is to produce the working flux in the m/c.
* The basic source of flux is permanent magnet which is uncontrolable.
* In order to control the m/c flux need to be controllable. Therefore electromagnets are prefered which requires wdg & a dc vot. 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. cond^{r}



* The polarity of a pole depends 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.

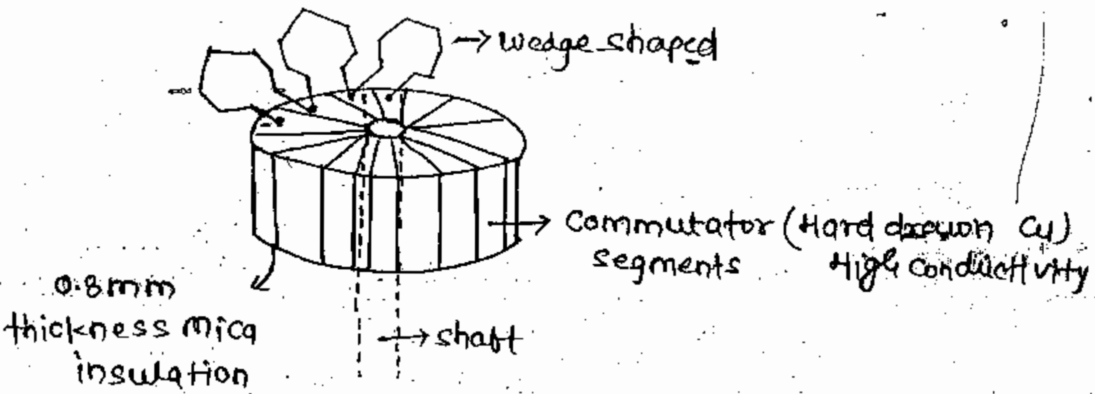
3) Armature Core → * Arm. core is a cylindrical drum like st punched into slot on the peripheral.

* The arm. wdg is placed in this slot with the suitable insulation.
* It is mounted & keyed to the shaft. It should be superior 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.

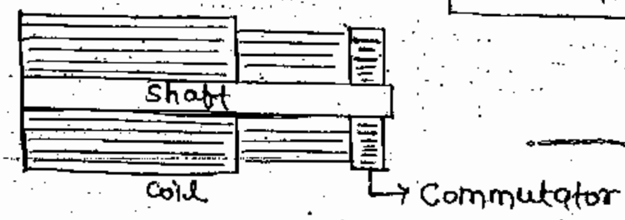
Si + steel
↓
– low hysteris coefficient
Reduce the conductivity of steel
$x = 1.5 - 2.5$
Reduce eddy current & hysteris loss
Also called ~~electrostat~~ technic

* 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 destroying its megnatic property as well as it has low hysteeis cofficient as 1.6 to reduce it Hysteris loss.
* If more Si is added it will destroy mech. property of steel.

* Commutatore →



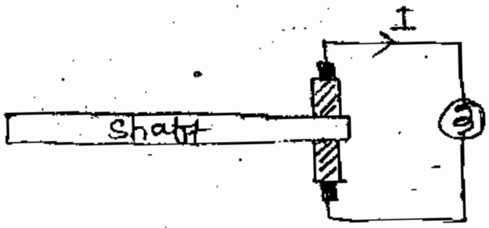
Commutator segments = No. of coils



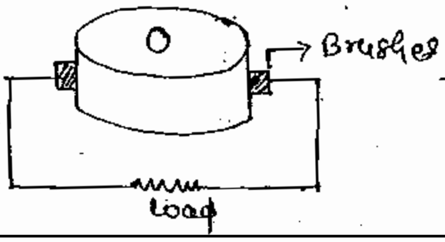
* Commutator is split ring which is segmented through 0.8mm thickness mica insulation.
* The segments are made up of hard drawn Cu.
* It converts by directional emf or current inside the coil into unidirectional.
* It is the ~~ar~~ image of arm. wdg inside.
* The no of commutator segments are equal to 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 & electrographite.
* 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.

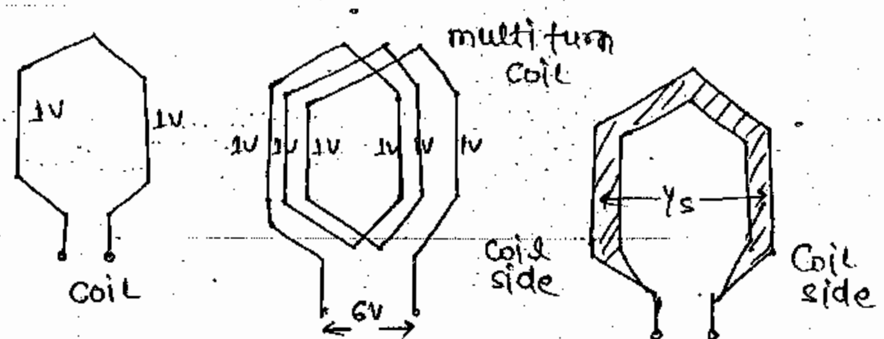
For large m/c → Rolar bearing
Small → Ball bearing

***

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.

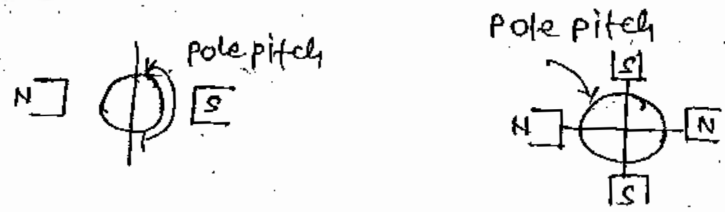


* If a coil consist of 1 turn it is known as 1 turn coil.
* If if there are two are more turns then it will be multiturn coil.
* Practicaly multiturn coil are used, as the provide more voltage
* A multiturn coil consist of two coil sides which are placed in the slots with a coil span.

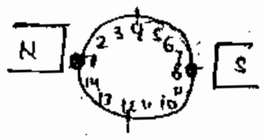
Coil span → (Y_s) Distance b/w 2 coil sides of a coil

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

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

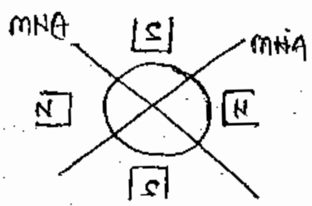


$\boxed{1 \text{ Pole pitch} = 180° \text{ ele degree}}$



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

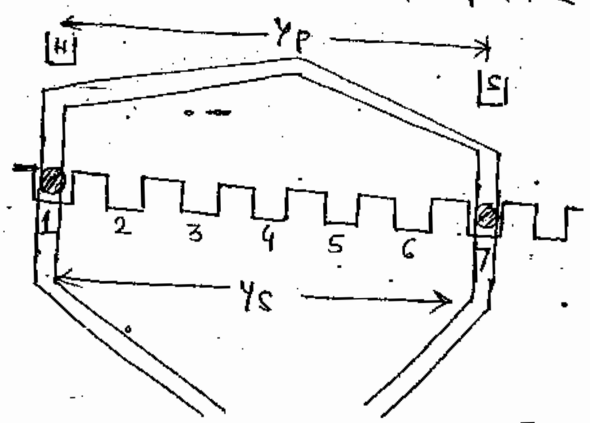
$$\text{slots/pole} = \frac{14}{2} = 7$$ (Hence put a 8) (maintain 7 slots gap)



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.
* Do m/c arm. wdg are full pitch wdg only
* In order to get max^m induced emf

Coil span < pole pitch

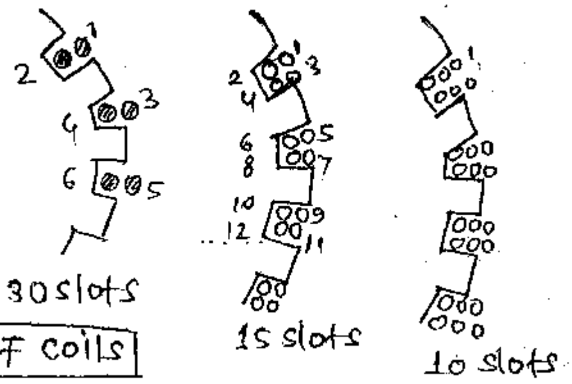


Single layer wdg → One coil side placed in one slot.

60 coil side
30 coil
60 slots

(Small m/c)

Double layer → Two coil side placed on one slot.
or
Two layer large m/c

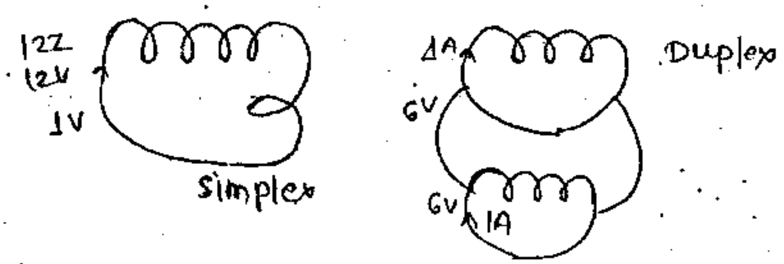


$\boxed{\text{No. of slots = No. of coils}}$

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

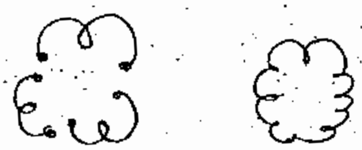
Front pitch → The no. of cond^r spanned by one coil at the
(Y_f) front end of arm. (Front end is commutator end)

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

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

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

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



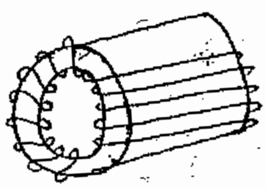
open wdg

close wdg

Closed
- → Gramme Ring
- → Drum
  - → Lap
  - → wave
  - → Frog 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.

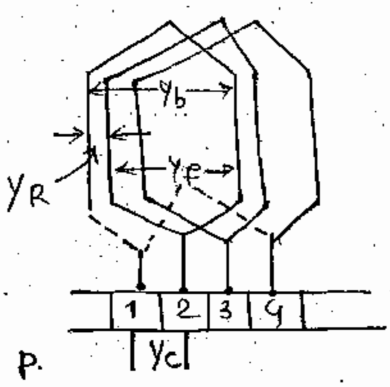
(2) Insulating maintanance, repairs & design is costly.

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 $Y_b \cdot Y_f$.

(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^n 4 Poles.

soln →

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

$$Y_b + Y_f = 12,$$

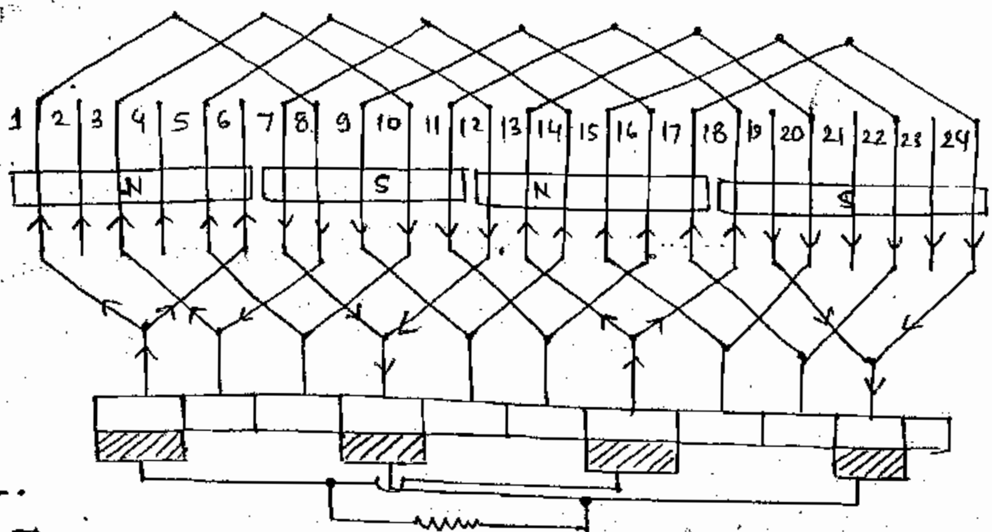
$$Y_b - Y_f = 2$$

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

wdg table →

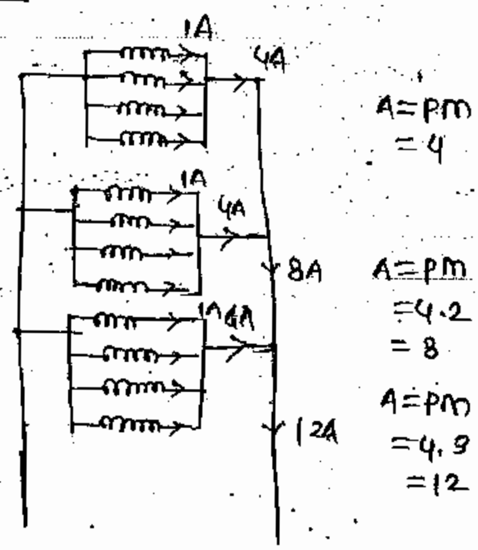
$Y_b = 7$	$Y_f = 5$
1+7=8	8-5=3
3+7=10	10-5=5
5+7=12	12-5=7
7+7=14	14-5=9
9+7=16	16-5=11
11+7=18	18-6=13
13+7=20	20-5=16
15+7=22	22-5=17

wdg. diagram →



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

Therefore $\boxed{A = Pm}$



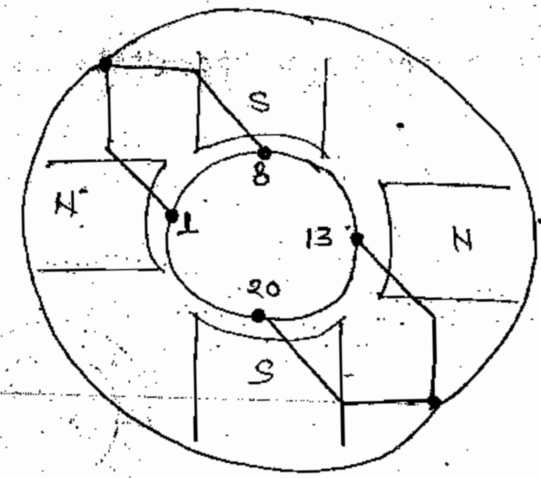
* It is also known as parallel wdg as there are more parallel path in it.
* Consequently no. of condr in series per parallel path is less.

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

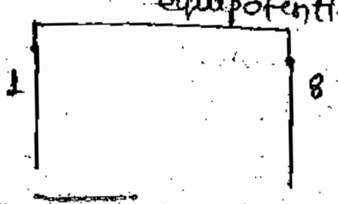
Equilizer rings → This are thick cu cond^r located at the back end of arm. which has low resistance.

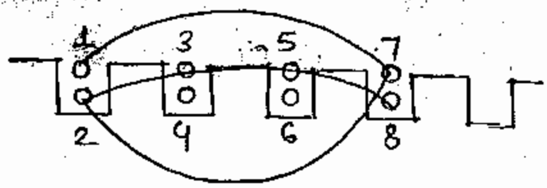
* Equipotential coils are tapped individualy to respective equilizer rings.
* Any circulating current will be bypassed & circulates within the equilizer rings at the back end & doesn't enter into the commutator at front end.

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



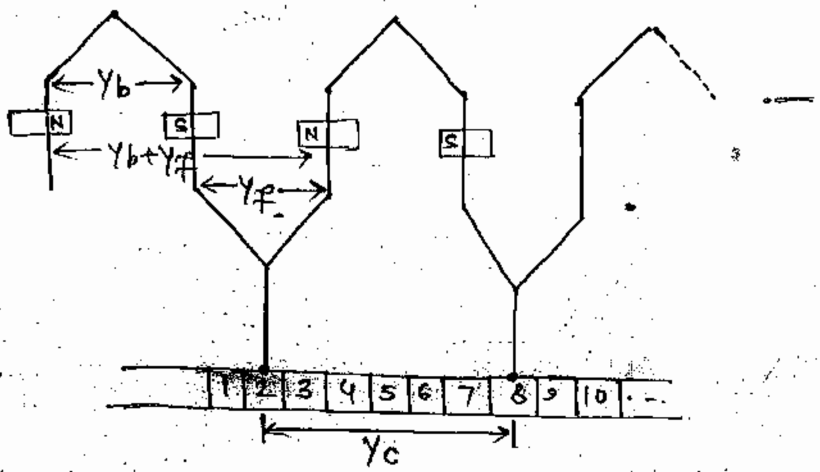
* Any unbalance in the induced emfs in the parallel paths will create a circulating current which interface with commutation when it flow through the bus.
* Therefore any circulating current will be bypass through the equlizer ring at the back end & doesn't enter into the commutator at front end.





→ 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

$$\boxed{Y_b = Y_f}$$

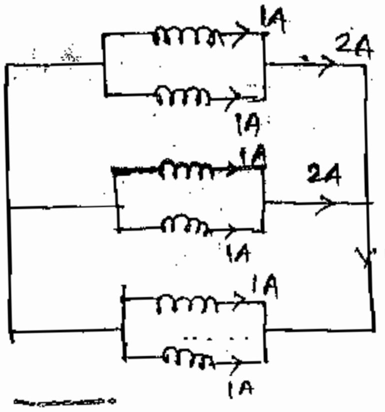
(OR)

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

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

* The no. of parallel paths are independant 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 cond^r 15 slots 4 pole simplex.

Sol^n →

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

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

$$14 \times 4 = 56$$

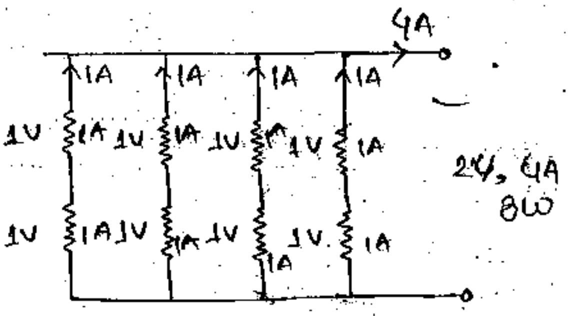
But in 15^{th} slot = ?

* For some set of data Y_A will not be integer in order to make is integer value the nearest possible cond^r will be considred.
* Due to which some cond^r 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.

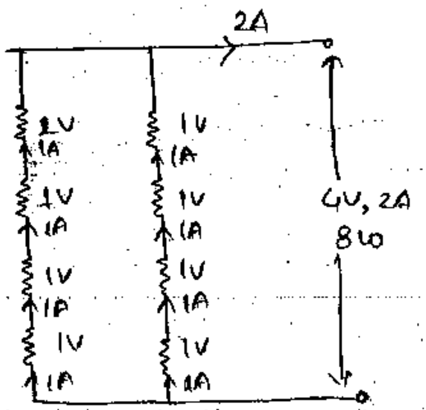
* It is not connected to the rest of the wdg.
* As there are only 2 parallel path any unbalance will become a balanced condn.
* Therefore no need of equilizer rings.

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.

$$\boxed{\begin{array}{l} I \propto A \rightarrow \dfrac{I_L}{I_W} = \dfrac{A_L}{A_W} \\ V \propto \dfrac{1}{A} \rightarrow \dfrac{V_L}{V_W} = \dfrac{A_W}{A_L} \end{array}}$$

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

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

Soln →

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

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

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

$$E_g \propto \phi N$$

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

(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

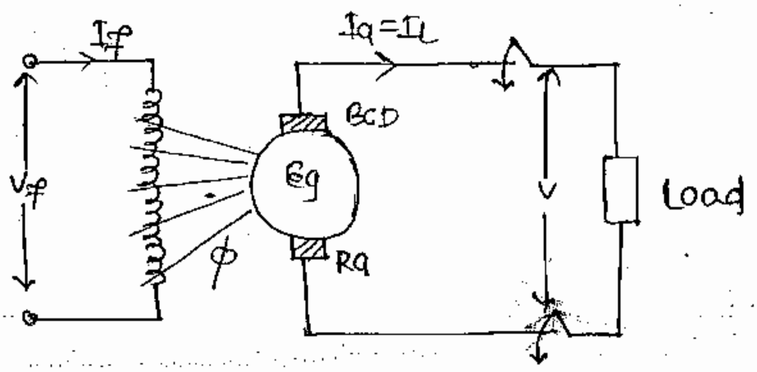
$$\frac{E_{g2}}{E_{g1}} = \frac{N_2}{N_1}$$

* Classification of dc genr → * In order to control the m/c electromagnets are prefered as poles which requires a dc vol. excitation across it

* The classification of genr is according to method of excitation:-

Excitation → Seprate Excitation
Excitation → Self excitation → Shunt Excitation
→ Series Excitation
→ Compound Excitation

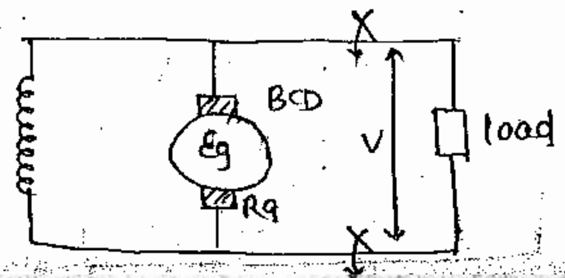
* Seprate Excitation →



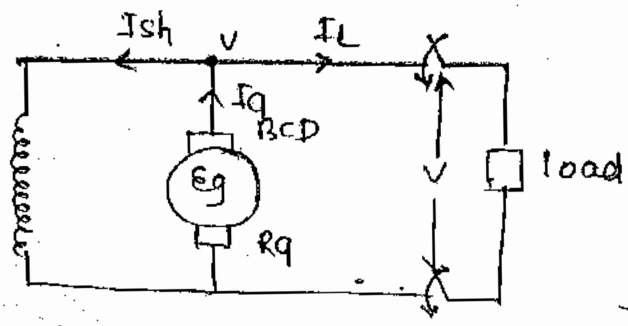
* It requires a seprate dc source for its excitation.
* Its field & arm. wdg are isolated electricaly.
* The terminal voltage (V) across the load doesn't affect its excitation.
* Due to additional voltage source requirement It is rarely used genr around 95% dc genr used are self excited only.

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 →



$E_g = I_a R_a - BCD = V$

$I_a = I_L + I_{sh}$

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

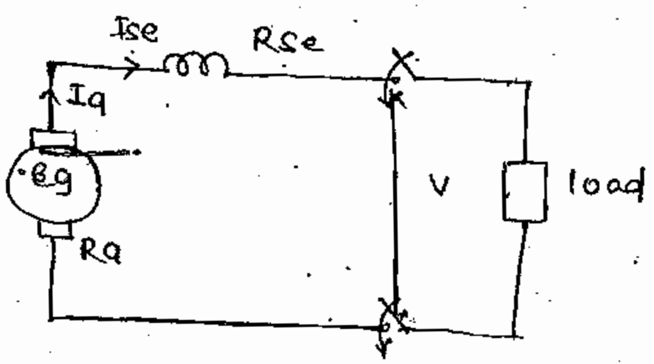
* The field wdg is connected in parallel with arm. through brushes.
* The terminal vol. itself act as excitation.
* Shunt field turns are very large in no. due to its resistance is high with thin condr.

Range 50–250Ω

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

* 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 →

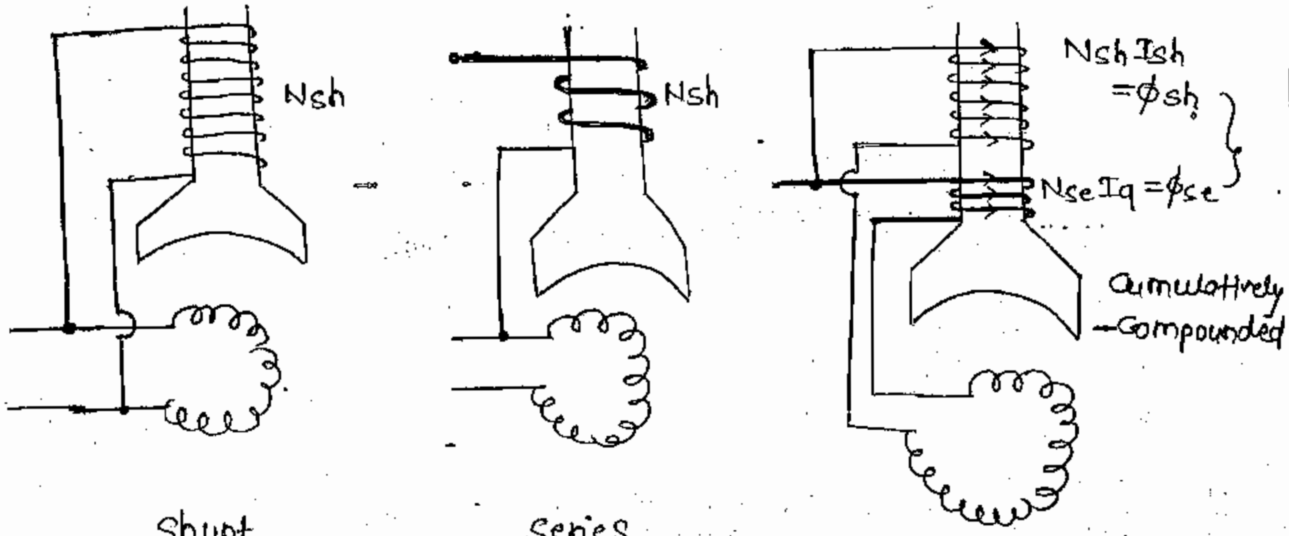


* In this mode it is known as series genr & current operated field.

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

$I_a = I_L = I_{sh}$

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

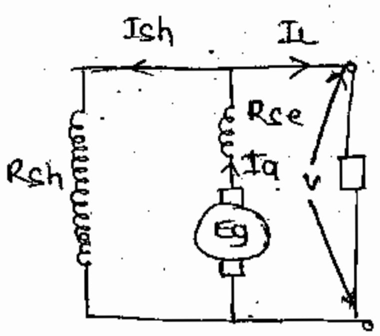


Shunt Series Compound

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

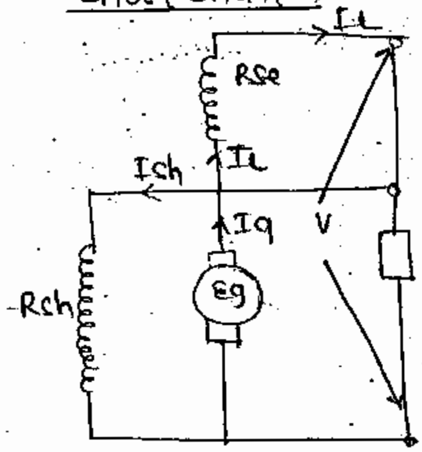
DATE - 04/07/14

Long shunt →



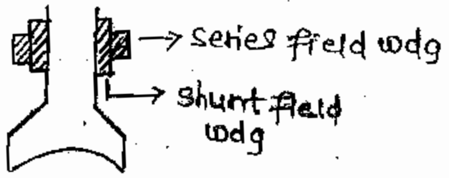
$$E_g - I_a(R_a + R_{se}) - BCD = V$$
$$I_a = I_L + I_{sh}$$
$$I_{sh} = V/R_{sh}$$

Short shunt →

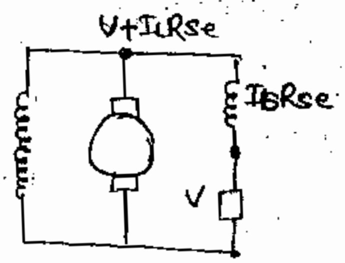


$$E_g - I_a R_a - I_L R_{se} - BCD = V$$
$$I_a = I_{sh} + I_L$$
$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$$

~~* There is no~~



Short shunt



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

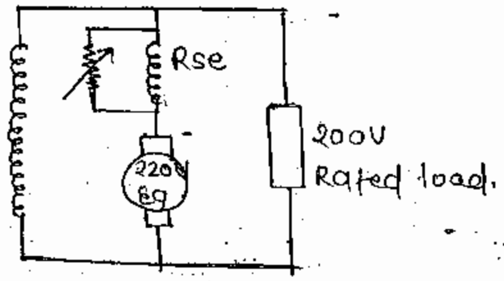
Cumulative: currents in both field wdg same dirn on the pole core. Therefore both fluxes add each other and the net flux increases with load.

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 gen^r by varying its series field ampere turns by connecting a diverter across its series field wdg.

* Depanding on the degree of compounding a cumulative compound gen^r can act as under, flat, over compound gen^r.
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 max^m value a cumulative compound gen^r 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 gen^r as its series flux opposes shunt flux.

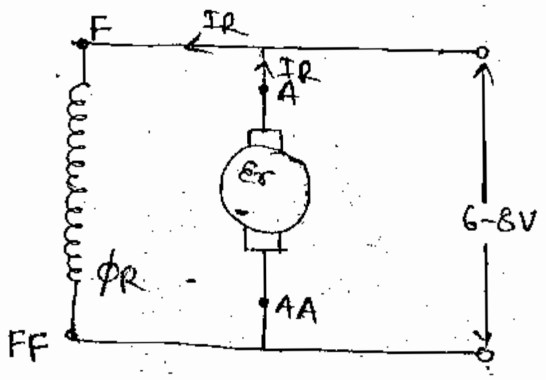
* NL induced emf of flat compound gen^r is exactly equal to rated voltage at rated load.
Since series flux is adjusted to compensate all the drops at rated load.

Voltage build up → [In self excited gen^r]

* In a separately excited gen^r there is a seprate source to exite the field & produce flux.

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

Shunt gen^r →



1.* Consider a shunt gen^r 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 gen^r is on NL, all the initial current will flow into field wdg. to produce initial mmF with field wdg turns.

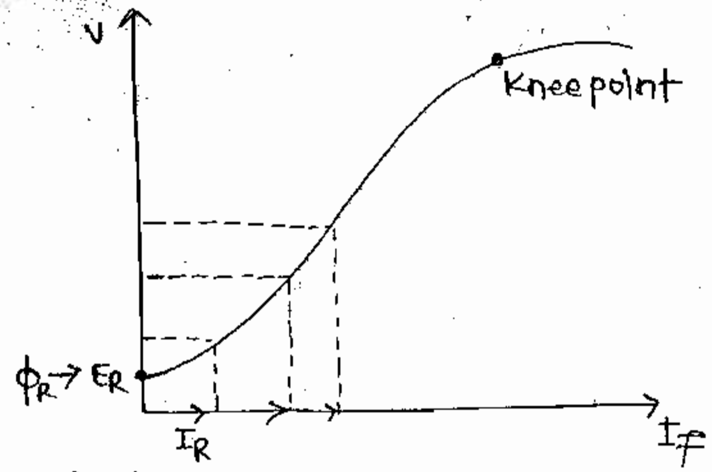
2.* The field should be properly connected to the arm in order to make initial mmf at the residual flux.

* 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

$\phi_R \rightarrow E_R \rightarrow I_R$

$I_R N_{sh} \rightarrow \phi_1 + \phi_2 \rightarrow E_1 + E_R \rightarrow I_1 + I_{R}$

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



(3.) The operating speed of the gen^r should be greater than critical speed.

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

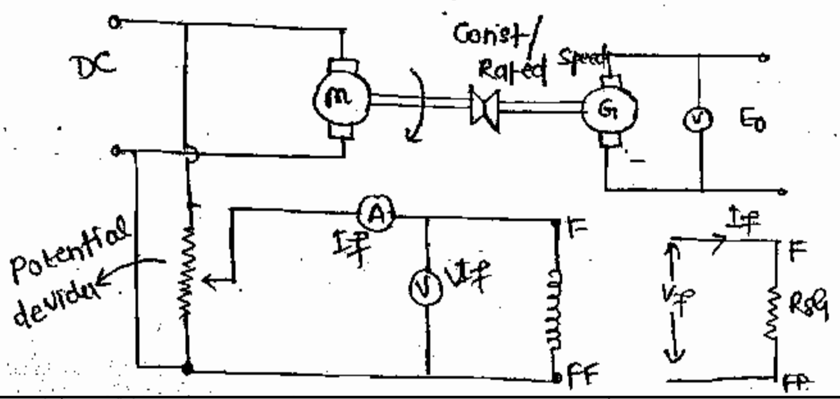
(5.) The best cond^n for a shunt gen^r to build up voltage successfully is it should be on NL.

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

Determination of critical resistance & critical speed →

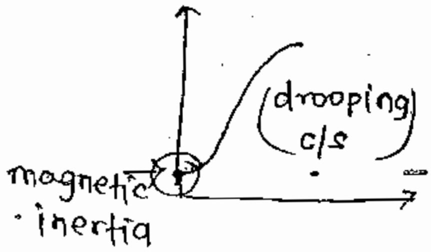
OCC (open circuit c/s)
NLS (No load saturation)
magnetisation c/s
} Eo Vs If

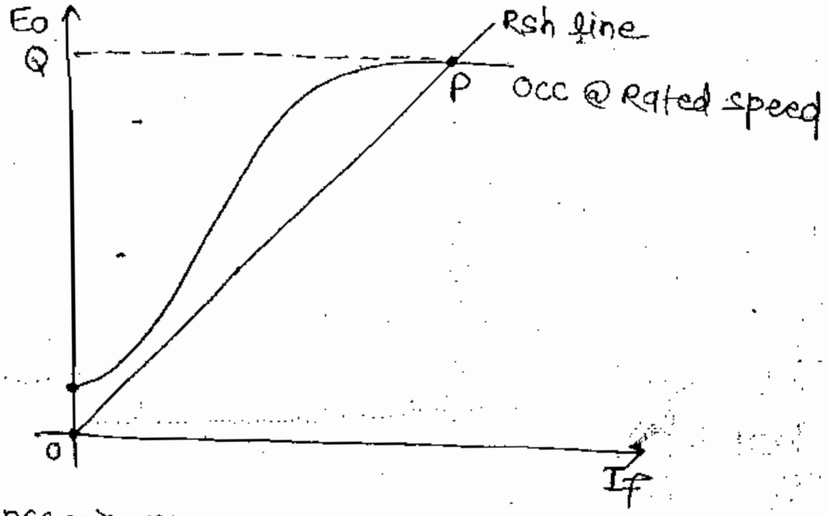
* In order to plot occ to determine Rc & Nc of a self exc. shunt gen^r it requires to be seprately excited.



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



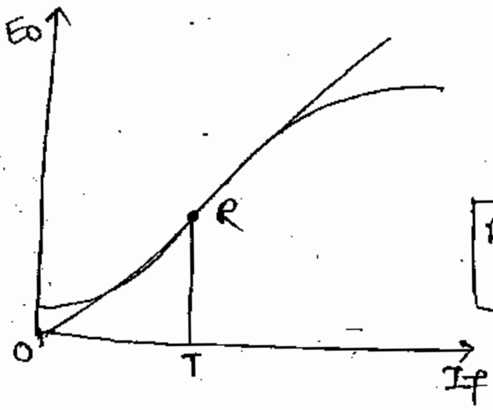


Critical Resistance → The resistance of the field wdg about which the genʳ doesn't build up voltage ~~this is~~

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

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.



$$R_c = \frac{RT_V}{OT_A}$$

Sagar Sen
887145356

Steps:- (1) Draw the occ line.

(2) Plot a tangent through occ.

Critical speed ~~Determination~~ →

Steps → (1) Draw original shunt field line.

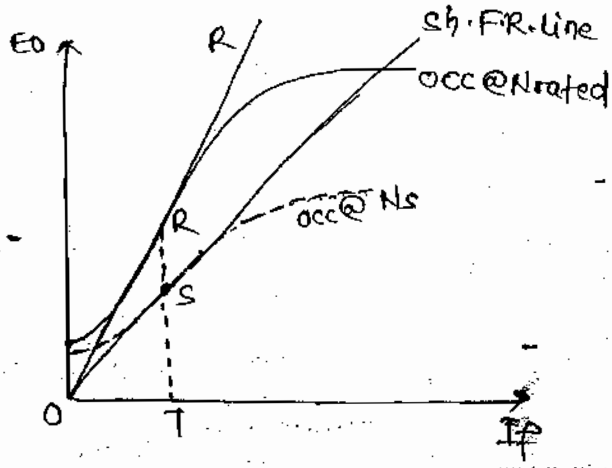
Resistance

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 genr depends on the operating speed. from critical speed & above.
* It varies proportionaly with speed.
* When the m/c is running at critical speed its field resistance value itself is critical resistance.

Eg.→ A shunt genr 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. Dirn of rotation of genr is reversed. options same.

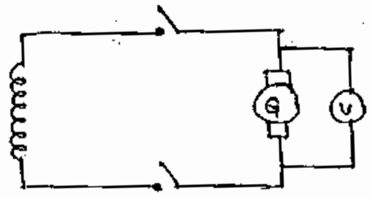
Ans. → (c) $-E_g \propto \phi(-N)$

e.g.→ If both dirn of rotation as well as field wdg is reversed.

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

ans. (a)

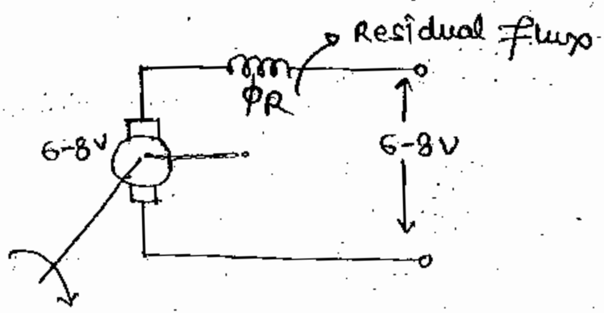
2/1



	switch open	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 genr →

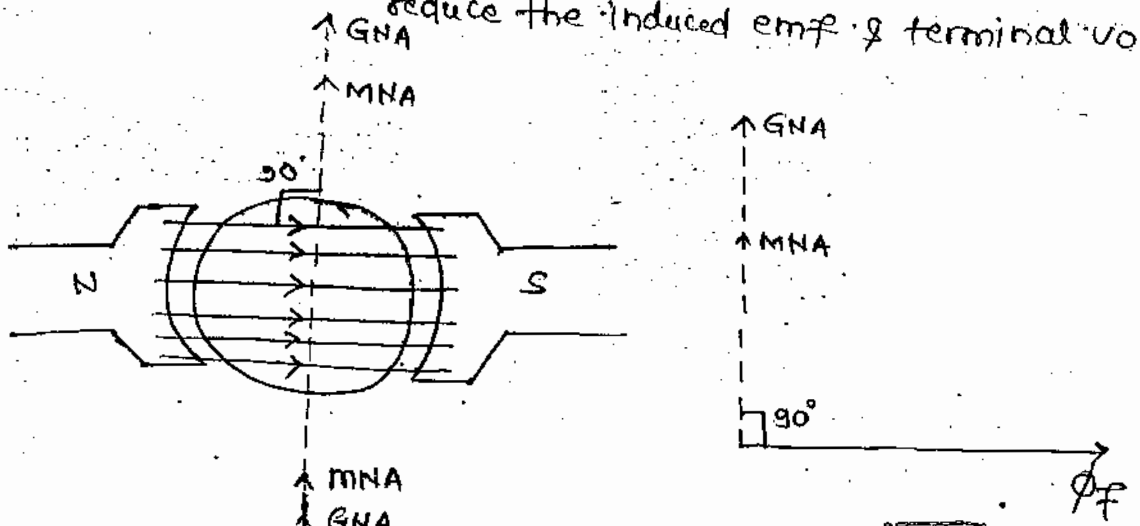
* A compound genr is eq. to a shunt genr on NL. Therefore its vol. build up is eq. to shunt genr.

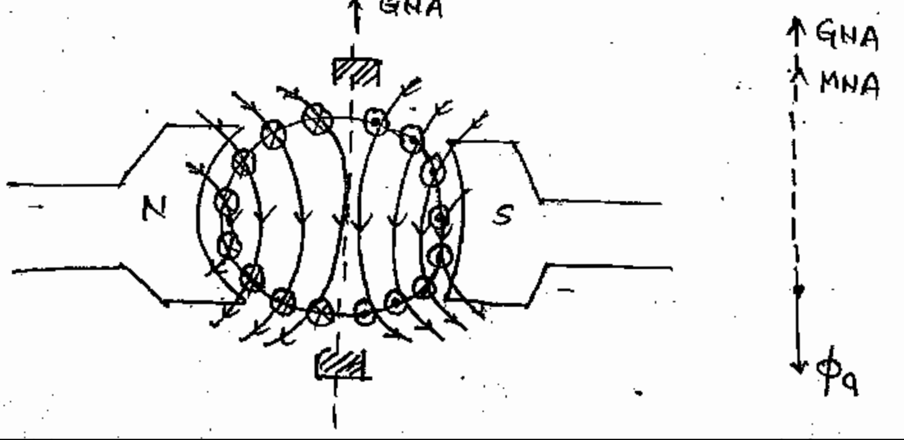
Armature Reaction ⟹

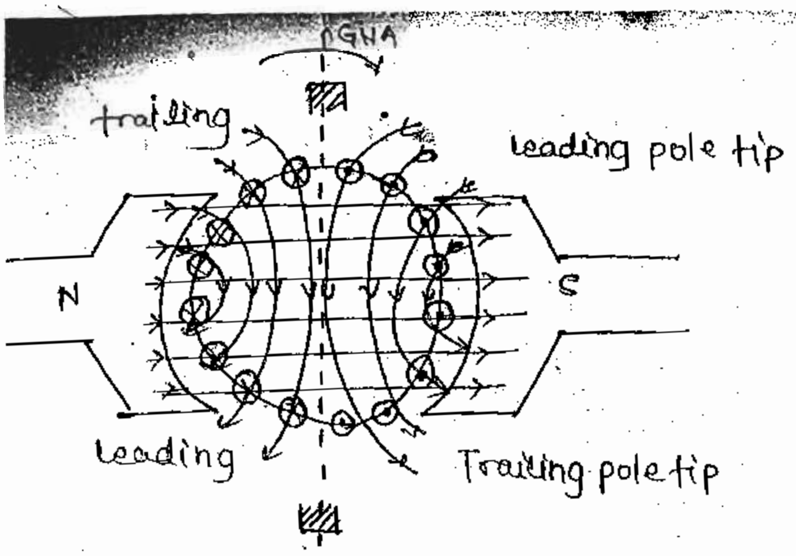
* On NL the arm. current is negligible. Concequently there is only main flux in the air gap distributed uniformly in flat topped nature.
* As the arm. is loaded load current flows in the arm. condr or turns which produce arm. mmF & arm. flux which is also distributed uniformly throughout the arm. peripheral 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.

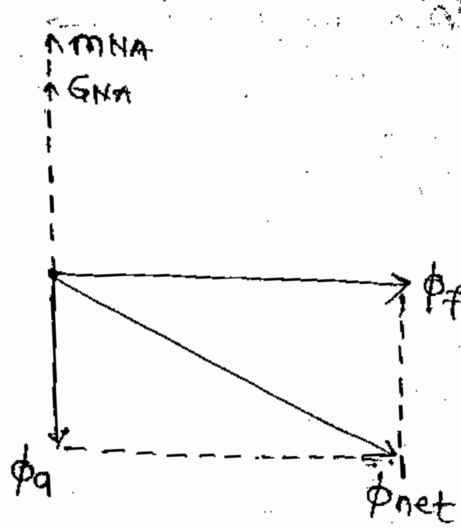
Cross magnetisation → It is distortion of main flux due to which MNA is shifted. & the commutation will not be successful due to sparking.

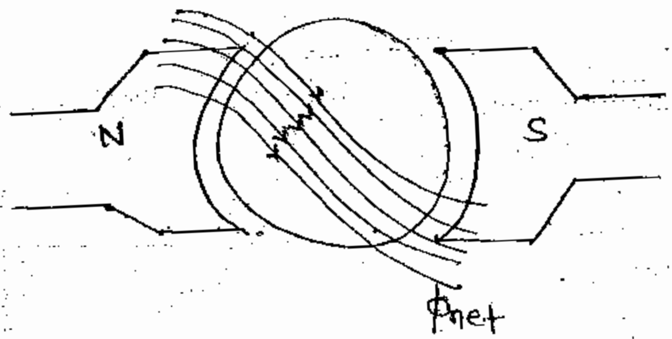
Demagnetisation → It is Reduction in the main flux which reduce the induced emf & terminal voltage.

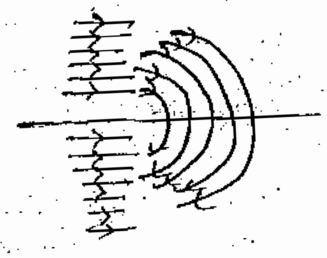




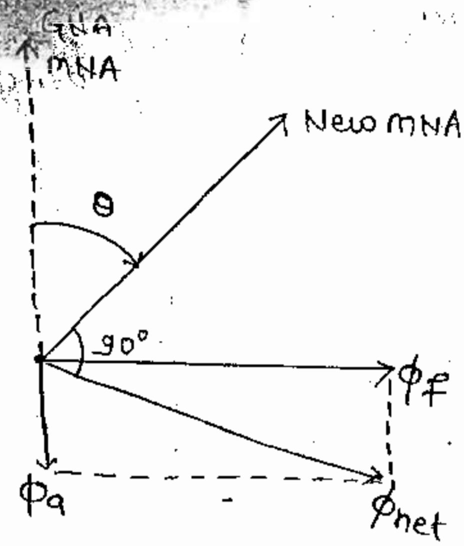






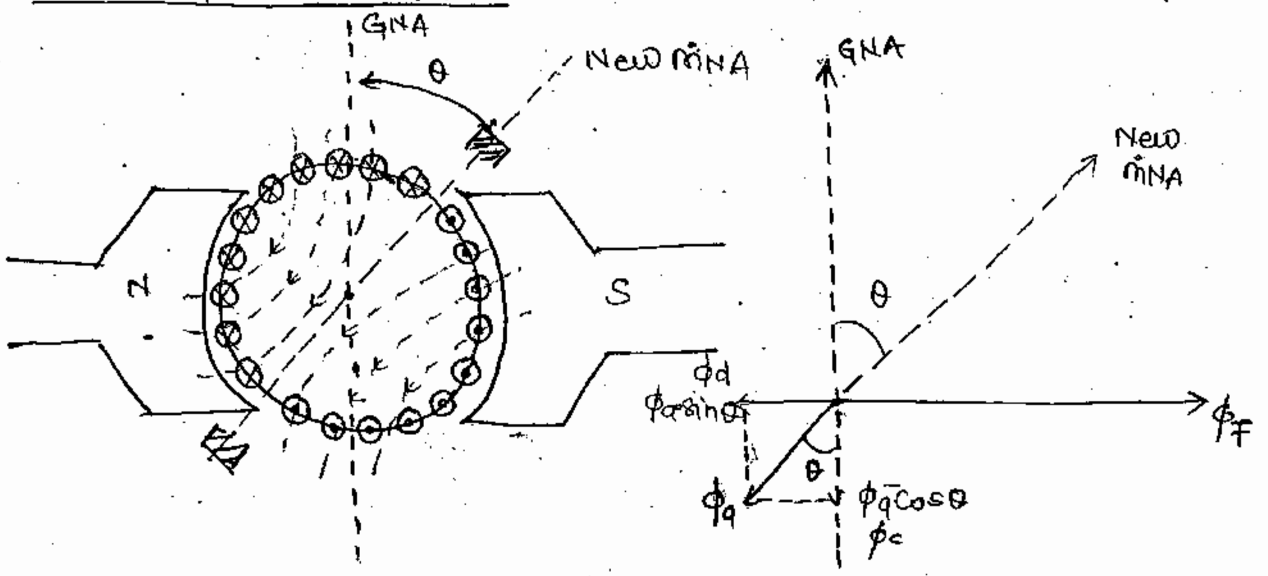


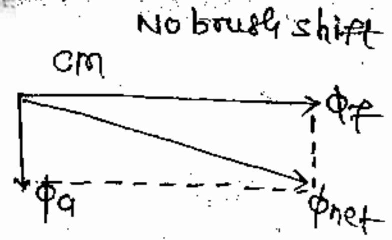
* Depanding on the dirn of rotation the pole tips are named as leading & trailing.
* The arm. flux under the trailing pole tips of genr will increase the flux density as it is in the same dirn with the main flux.
* The arm. flux under the leading pole tips will demagnetise the main flux as it is in the 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 magnetically saturated & conceqently the increase in flux density under trailing pole tips is comparitively less than that of decrease in the flux under leading pole tips.

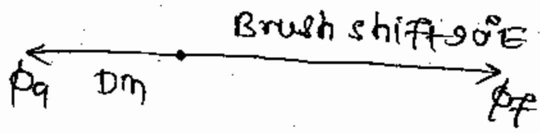


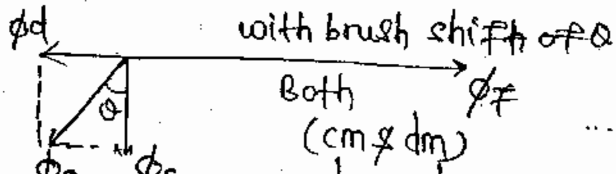
* Due to arm. flux which is also called as cross flux the main flux is distorted. known as cross magnetised due to which MNA is shifted in the dirn of rotation of genr.
* In order to improve commutation the brushes also need to be shifted in the dirn of rotation of genr.
* Due to the affect of brush 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 →









Both (cm & dm)

↓ Arm. flux ↓ $\phi_a \cos\theta$

→ arm. flux → $\phi_a \sin\theta$

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

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

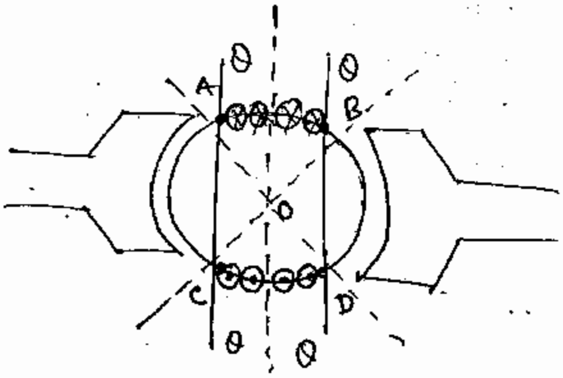
when $\theta = 0$

$\phi_d = 0$, $\phi_c = \phi_a$ (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 ATd/p →



$$\frac{2\theta°}{180°}$$

OAB, OCD } Dm

OAC, OBD } cm

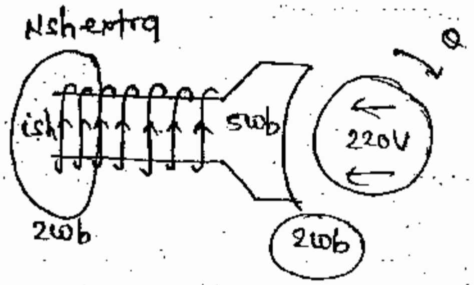
$$\boxed{\frac{2\theta°}{180°} \times \frac{I_a}{A} \times \frac{Z}{2P}}$$

Cross-magnetising Amp-turns/pole →

$$\boxed{AT_c/p = \frac{180-2\theta}{180^\circ} \times \frac{I_a}{A} \times \frac{Z}{2p}}$$

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

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



$$\boxed{N_{sh\,extra} \times I_{sh} = AT_d/p}$$

$$\boxed{N_{sh\,extra} = \frac{AT_d/p}{I_{sh}}}$$

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

* The no. of extra turns to be added on each pole of shunt gen^r in order to compensate additional demagnetisation produced by the brush shift is equal to $AT_d/p / I_{sh}$.
* Similarly in a series gen^r $\boxed{N_{se\,extra} = \frac{AT_d/p}{I_a (\text{or}) I_{se}}}$

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* Upper 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 →

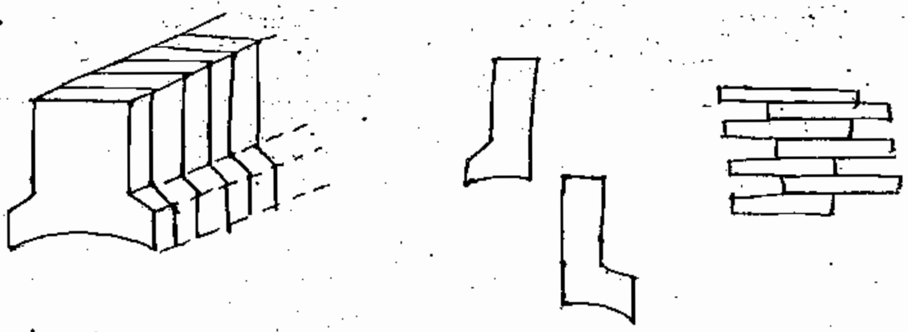
Due to CM Commutation is not successful & there will be unacceptable sparking which damage the brush surface.

(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 →



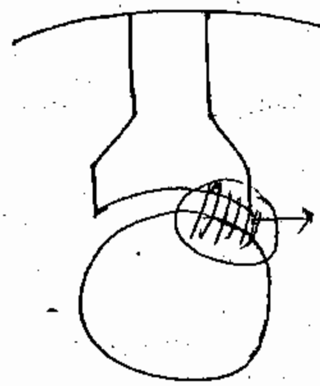
* The pole laminations are alternately stacked to introduced air gap under the pole tips.

* 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 →

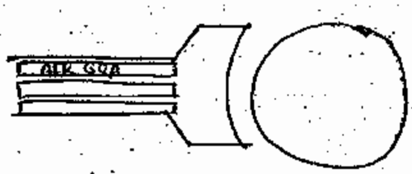
minm reluctance at the center & increased reluctance towards the pole tips.
Concept is same as pole stacking.



(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.

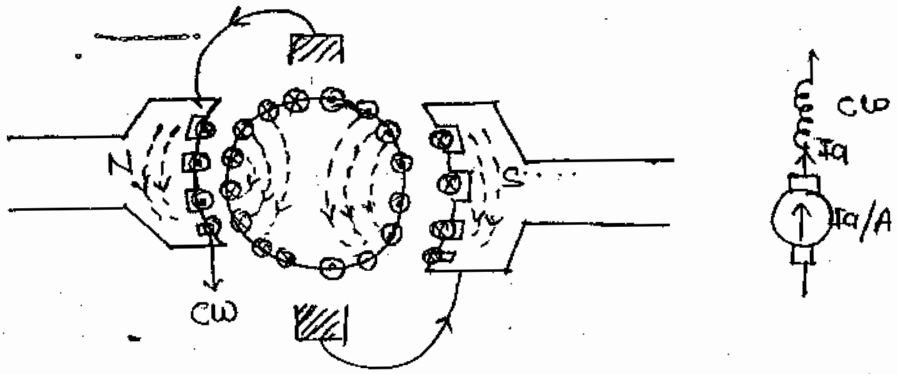
$$\boxed{\text{Flux} = \frac{\text{mmf}}{\text{Reluctance}}}$$



*** (4.) Compensating winding →

* In large rating dc m/c operating at variying load condn running at high speeds compensating 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 statically 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

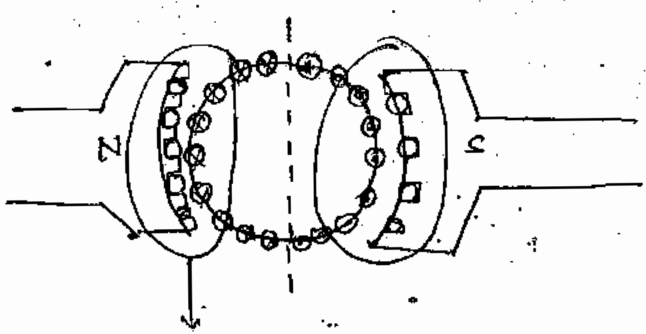
Let z_c be cw condr, z be AW condr

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

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

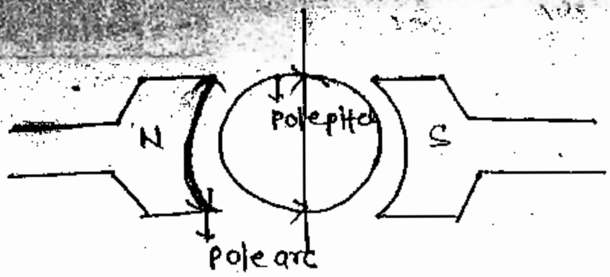
No. of compensating wdg under each pole

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

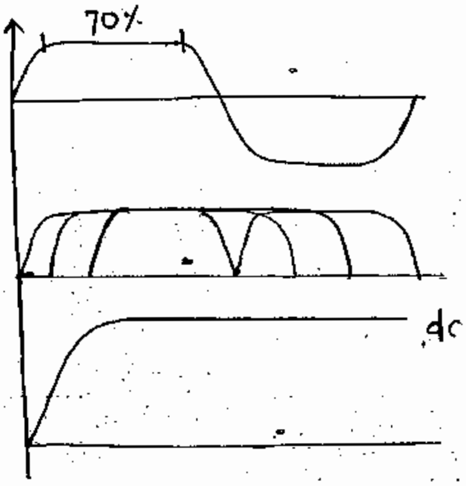


cw area.

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



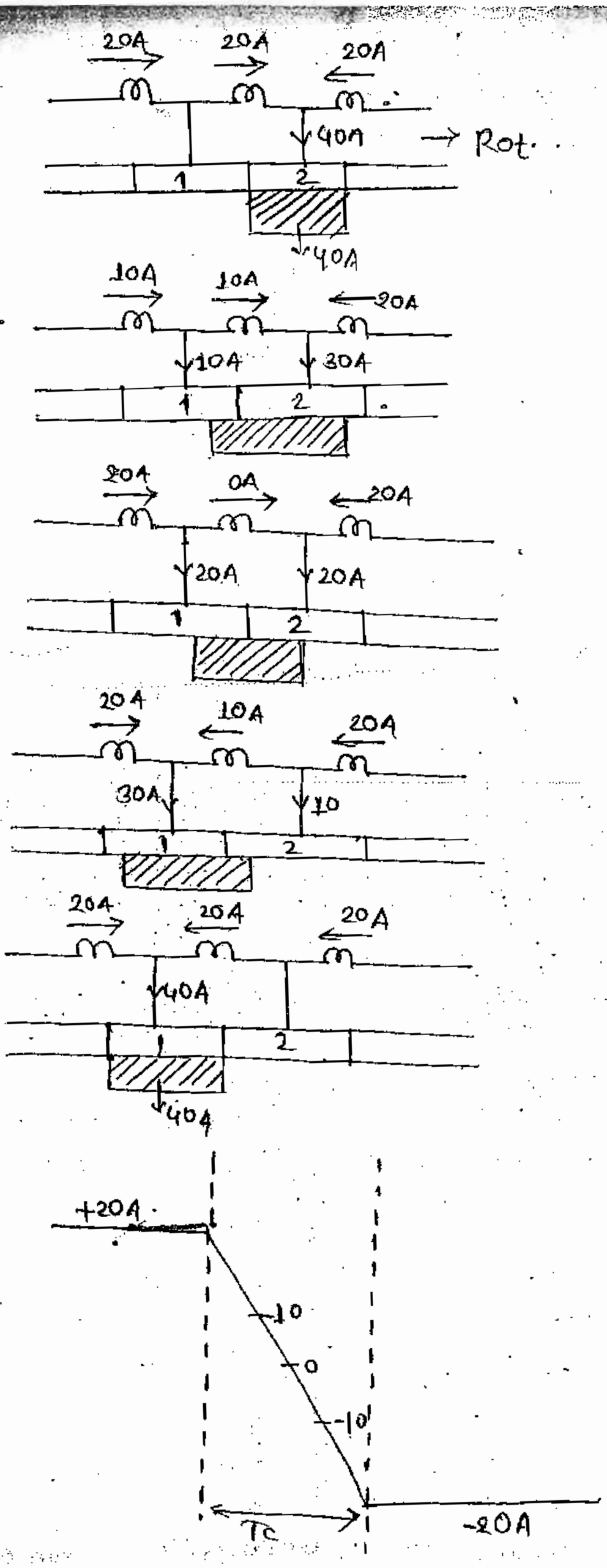
* Flux distribution under the pole in dc m/c is flat topped nature.



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

Because Z_c is placed on pole arc region that's why multiplying with Pole arc / Pole pitch.

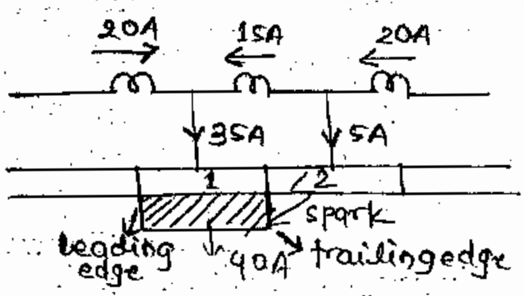
* COMMUTATION → The process of current reversal in the coil when it passes through a brush is known as commutation.
* The time taken for the brush to span from 1 segment to the other is known as commutating time.
* If the current reverses completely within the commutation time in the coil undergoing 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
1
2
40A
+20A
10
0
-10
Tc
-20A

Reactance voltage →

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

* 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. Therefore 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.

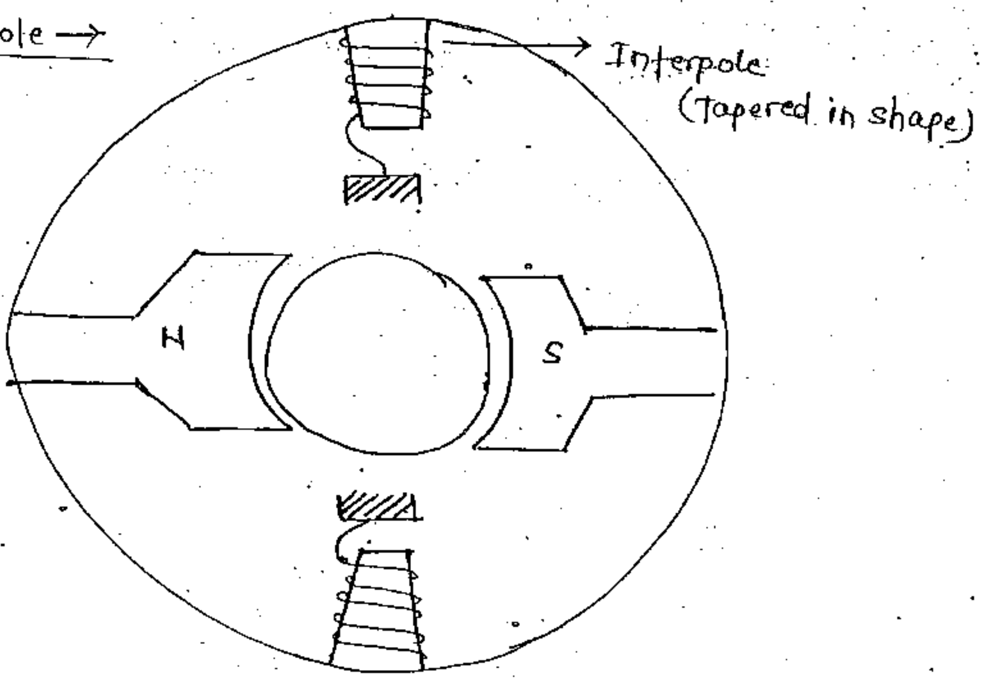
* C brushes have high resistance compare to Cu.
* Due to its high resistance C brush doesn't incourage sparking at trailing edge & improve commutation.

* 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 ~~turn~~ done after the invention of interpole.

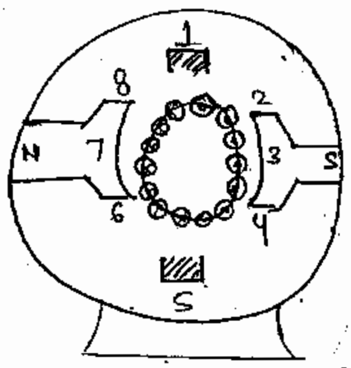
* Interpole →



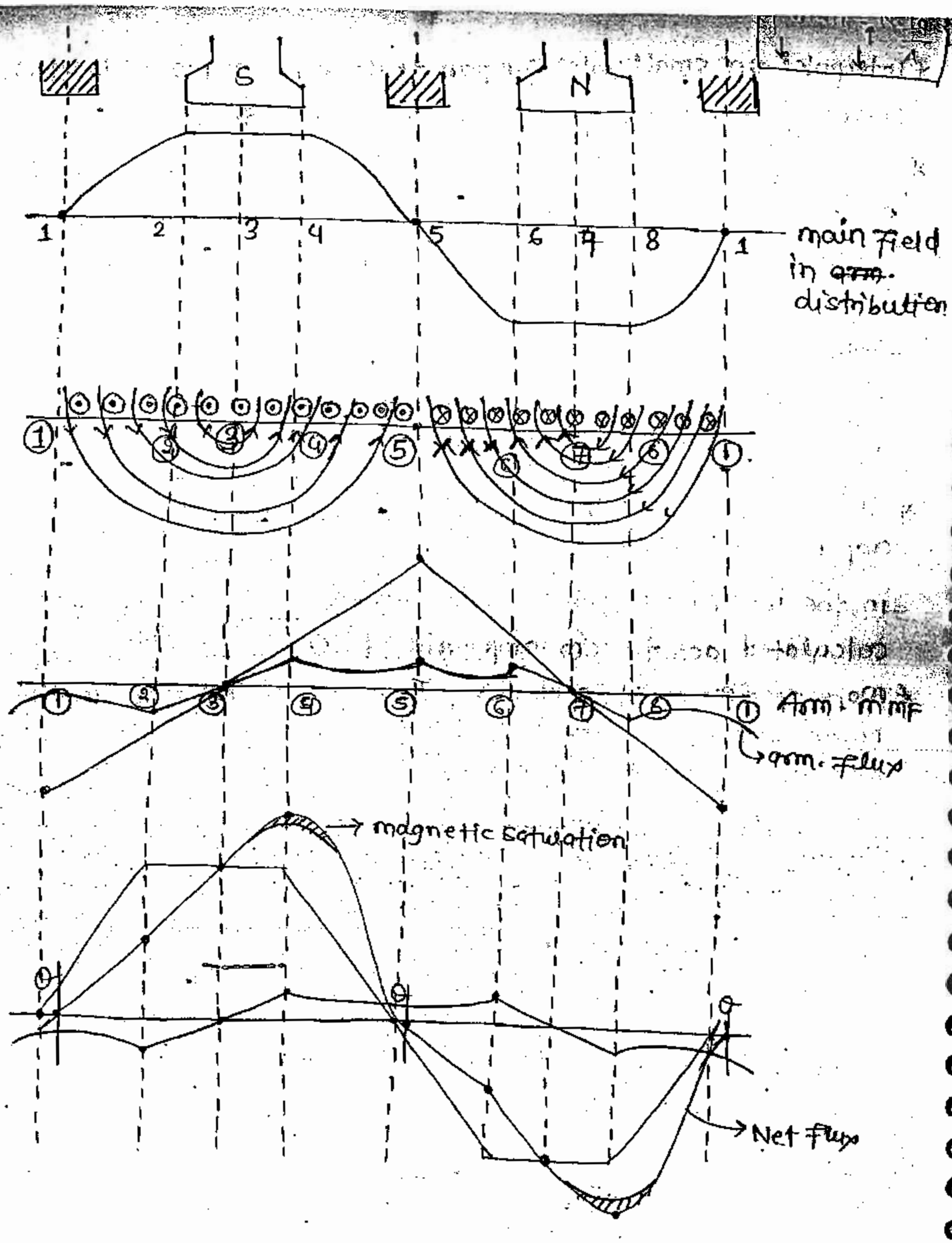
* Interpoles are small poles compare to main ploes placed in the inter polar region between the main poles on the yoke.
* These are also electromagnets with interpole wdg which is connected in series with arm. wdg throught brushes in order to have automatic neutralisation of arm. flux in the interpolar region.
* It performs 2 fun^n:-
  (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 ~~the~~ 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
3-5	↑	+ve
5-7	↓	+ve
7-1	↑	-ve
3-1	↑	-ve


S
N
1
2
3
4
5
6
7
8
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 shape 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/motor~~

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

* The arm. flux stationary wrt poles.

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$$\frac{I_a}{A} = \frac{50}{6} \times \cancel{\frac{720}{2\times 6}}$$

AT/P

$$T = \frac{720}{2}$$

$$P = 6$$

$$AT/P = \frac{50}{6} \times \frac{720}{2\times 6} = 600\,AT$$

* 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 →

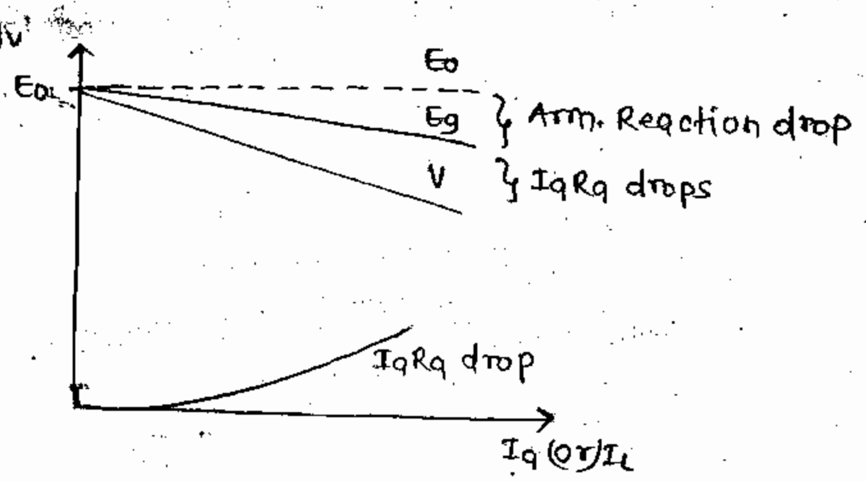
* This are the graphical representation of the key parameters which are plotted to know the suitability of appln.

→ No load → E_0 Vs I_f

→ load → Internal (E_g Vs I_a)

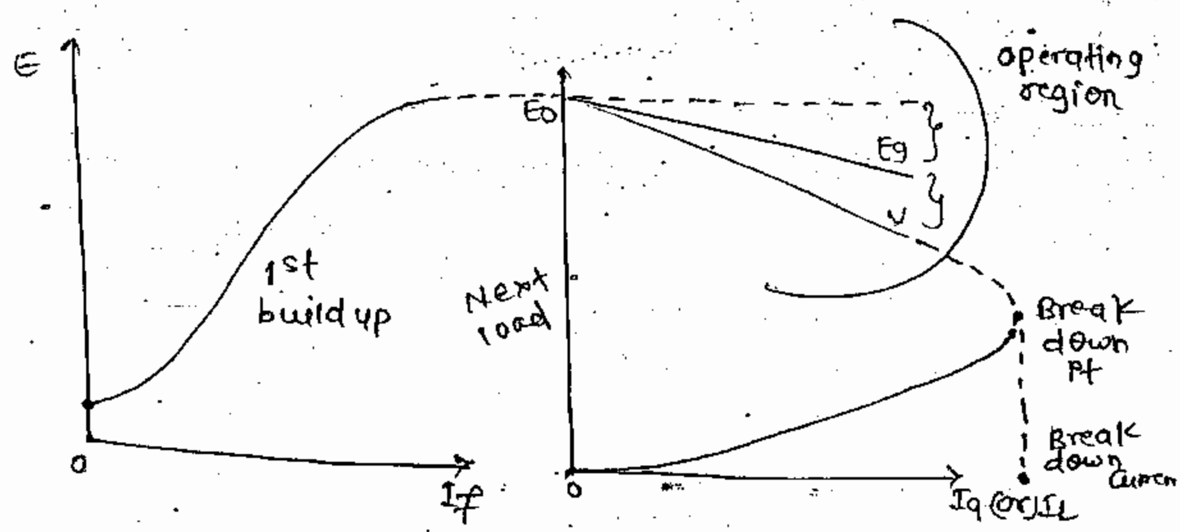
→ External (V Vs I_L)

* 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 →

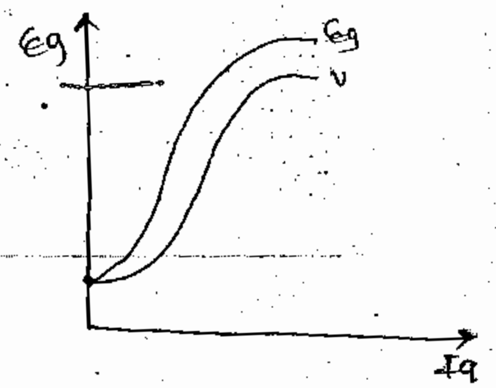


* In its operating region its flux remains approx. same, but beyond breakdown value a cumulative reduction of vol. happen reduce the terminal vol. to 0 drastically.

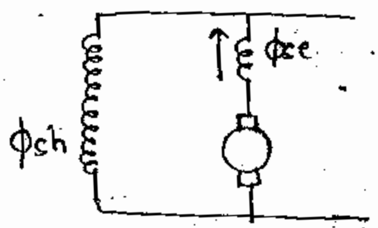
* Generally the operating region will be around 125% of rated load.
* It is used as small dc power supply & exclusively used for battery charging.
* It was also used in excitation sys. of power plant genr. along with seprately excited genr.

* Series Genr →

* As the field wdg is in series with arm. & load as the load increases flux increases to in turn 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.

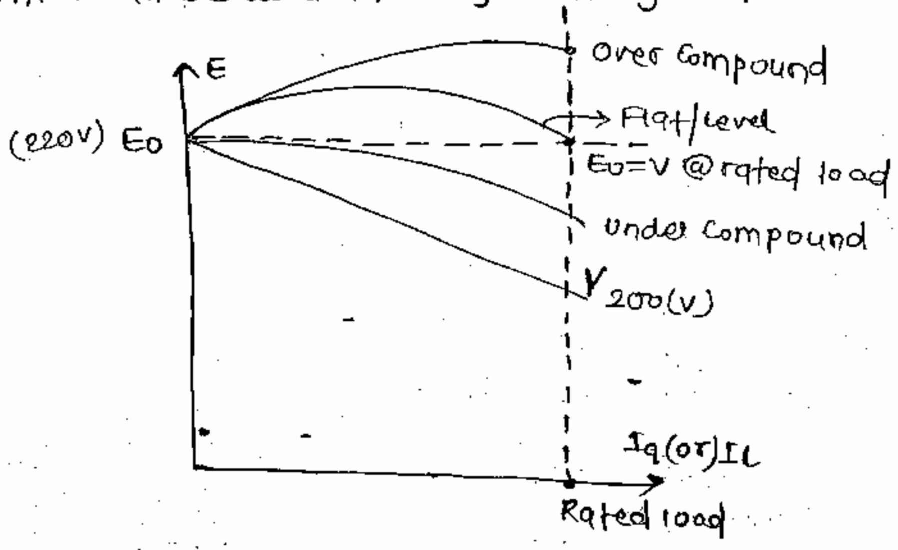


Cumulative →

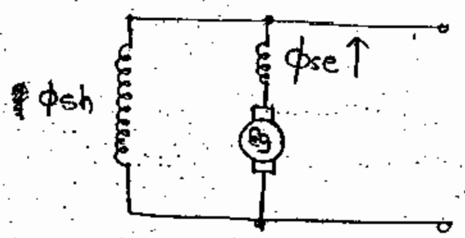


* As the series flux add its shunt flux the net flux increases with load. Conceqeuently it has better vol. c/s. then seprately & shunt genr.

* 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.

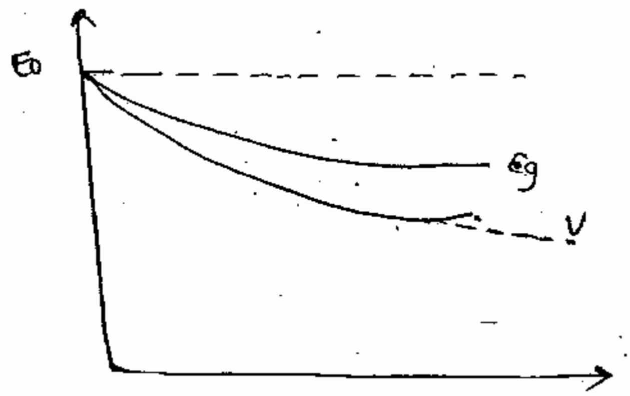


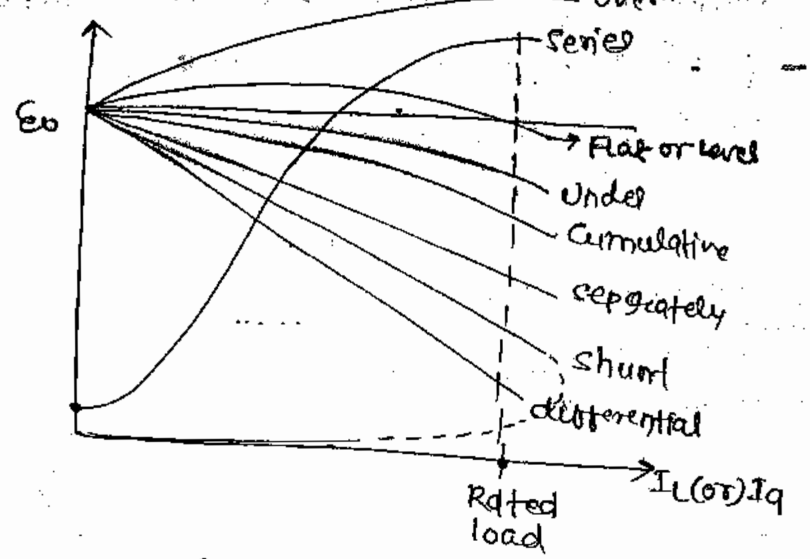
Differentialy → -



* 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 min^m as possible, best/ideal value is 0. which happens for only Flat/level compound gen^r.
* For series & over Compound VR becomes -ve. not suitable for ordinary load purpose.

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* 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.)

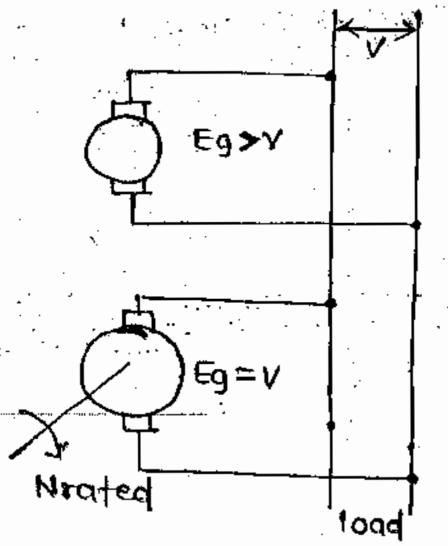
(2.) High reliability.

(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.



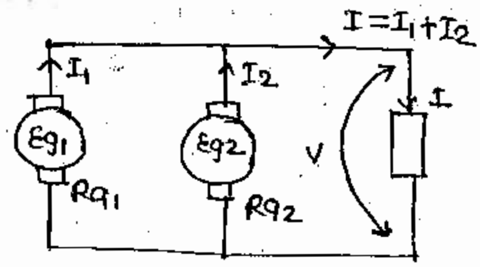
Eg > V	Generating mode
Eg = V	Floating mode
Eg < V	motoring mode

* 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.



$Eg_1 - I_1 Ra_1 = V$

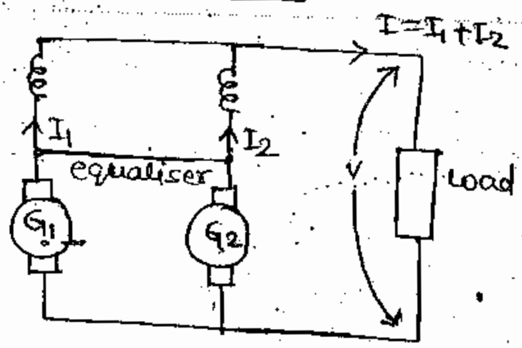
$Eg_2 - I_2 Ra_2 = V$

$$\boxed{I_1 = \frac{Eg_1 - V}{Ra_1}} \quad \boxed{I_2 = \frac{Eg_2 - V}{Ra_2}}$$

*** 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.

* Series genr in parallel →



$I_2 \uparrow \; \phi_{se_2} \uparrow \; Eg_2 \uparrow$ (gain load sharing capability)

$I_1 \downarrow \; Eg_1 \downarrow$ (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.

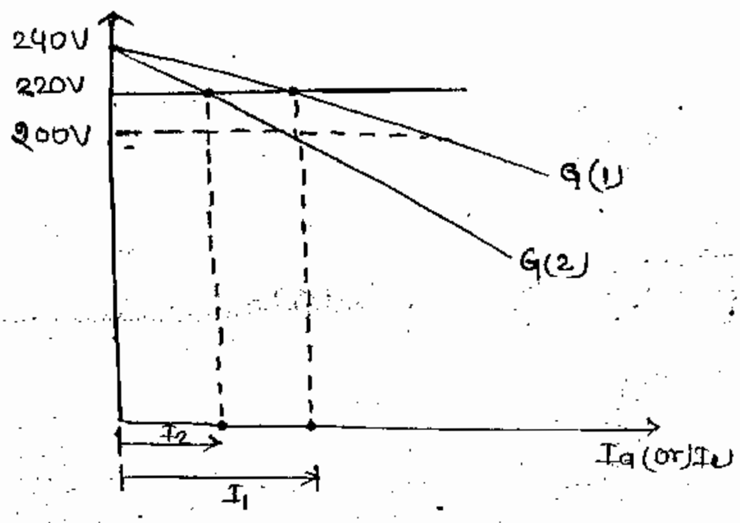
* This is due to the rising c/s of series genr.

* 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)

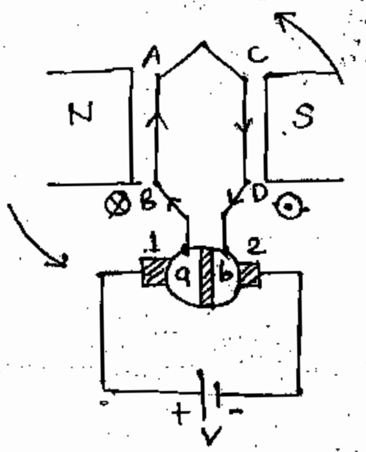
* By adjusting the c/s the genr can be loaded according to there ratings.

UNIT-II

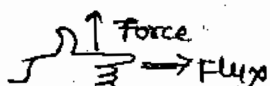
PERFORMANCE OF D.C. MACHINES

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.

$T \propto \phi I_a$

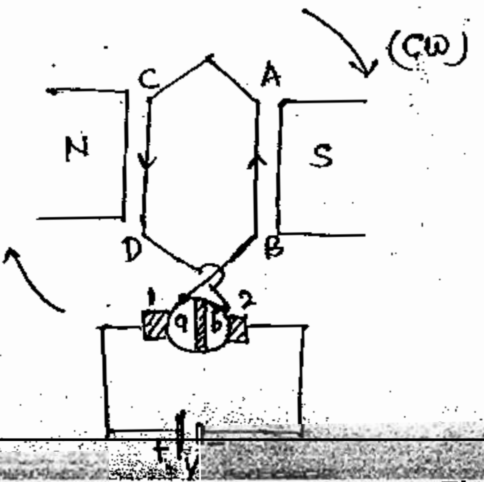
Principle →

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

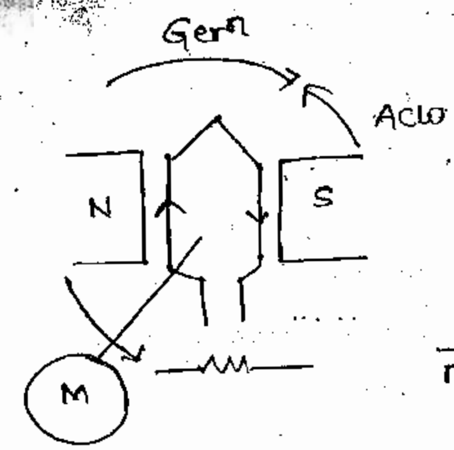
$$F = Bil \text{ Netw.}$$

& 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.

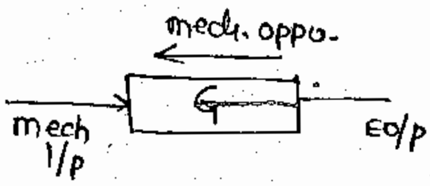
* The funn of commutator is to produce unidirectional torque.



Motor Action in a Genr →

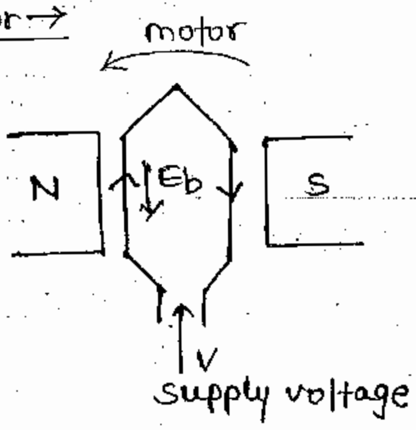


Genr → CW
Motor → ACW



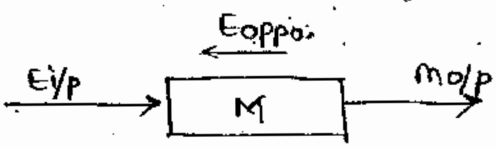
* Energy conversion from one form to other occurs through an opposition acc. to basic fundamental laws of nature.
* In a genr mech. to ele. energy happens through mech. opposition known as motor action in genr.
* The prime mover which is rotating the genr should be capable of rotating the genr against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

Genr Action in motor →



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

E_b = Back / counter emf



* In the motor arm. condr 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.

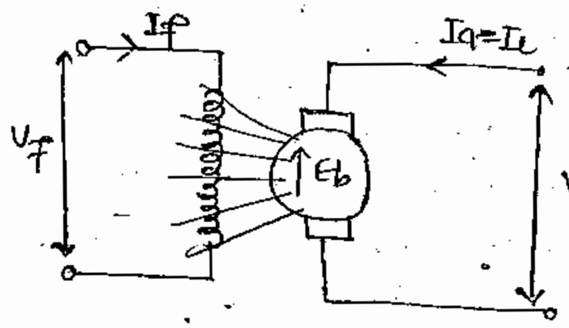
$$\boxed{E_b = \frac{\phi Z N P}{60 A}}$$

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

* 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 →

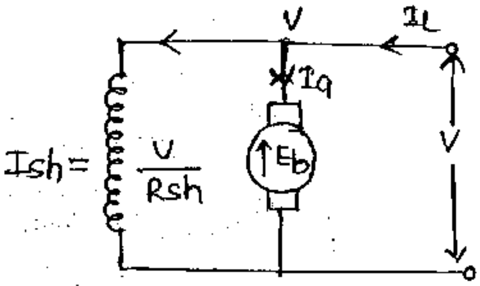


$$\boxed{V = E_b + I_a R_a + BCD}$$

$$\boxed{I_a = I_L}$$

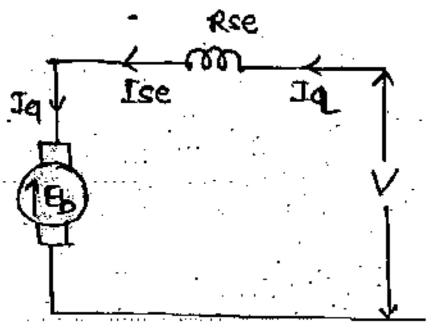
* It basically used in servo motor.

② Shunt motor →



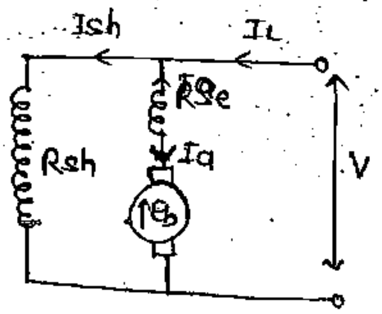
$$\boxed{\begin{aligned} V &= E_b + I_a R_a + BCD \\ I_L &= I_a + I_{sh} \end{aligned}}$$

③ Series Motor →



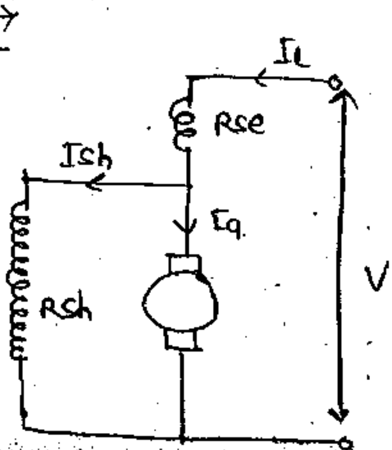
$$\boxed{\begin{aligned} V &= E_b + I_a(R_a + R_{se}) + BCD \\ I_a &= I_{se} = I_L \end{aligned}}$$

④ Long shunt →



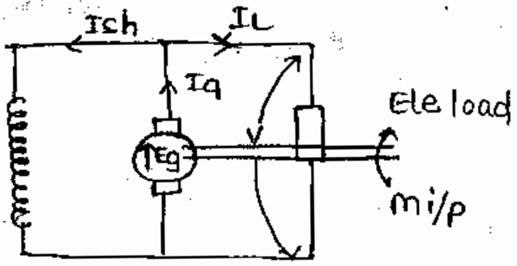
$$\boxed{\begin{aligned} V &= E_b + I_a(R_{se} + R_a) + BCD \\ I_L &= I_a + I_{sh} \\ I_{sh} &= V/R_{sh} \end{aligned}}$$

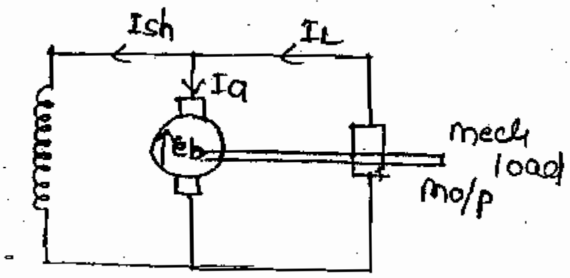
⑤ Short shunt →



$$\boxed{\begin{aligned} V &= E_b + I_L R_{se} + I_a R_a + BCD \\ I_L &= I_{sh} + I_a \\ I_{sh} &= \frac{V - I_L R_{se}}{R_{sh}} \end{aligned}}$$

Shunt Gen^r | Shunt motor





(1.) Gen^r delivers $I_a = I_L + I_{sh}$ | (1.) Motor draws $I_L = I_a + I_{sh}$

(2.) $E_g > V$ | (2.) $E_b < V$

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

(4.) $V \rightarrow$ Terminal vol. | (4.) V : supply vol.

(5.) $E_g I_a \rightarrow$ Ele. power generated in arm. | (5.) $E_b I_a$:- Ele. eq. of mech. power developed in arm.

(6.) $V I_L \rightarrow$ Power delivered to the load. | (6.) $V . I_L \rightarrow$ Ele. power I/p

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

(8.) Electrical loading | (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 (m) P_m max then (m)

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

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

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 ($I_a \uparrow$).

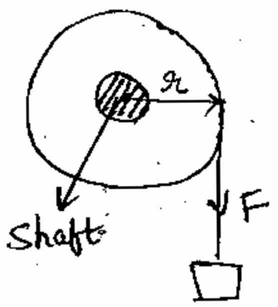
* The mech. power developed will be max^m if the back emf is half the supply vol.
* Under such cond^n the η of the motor is only 50%. Therefore dc motors are not designed for such cond^n but they are designed to give max^m η near rated load cond^n.

(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.

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



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

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

$$P = \frac{2\pi N (F \cdot r)}{60}$$

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

Power developed in the arm.

$$P = E_b \cdot I_a$$

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

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

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

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

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

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

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

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:-

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

Rotational losses ↓ IRON & mech.

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

Characterstics →

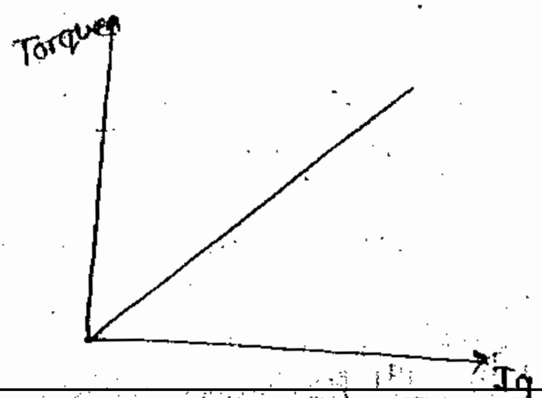
(1.) Torque vs I_a
(2.) Speed vs I_a
(3.) Speed vs T

} same (for (2.) and (3.))

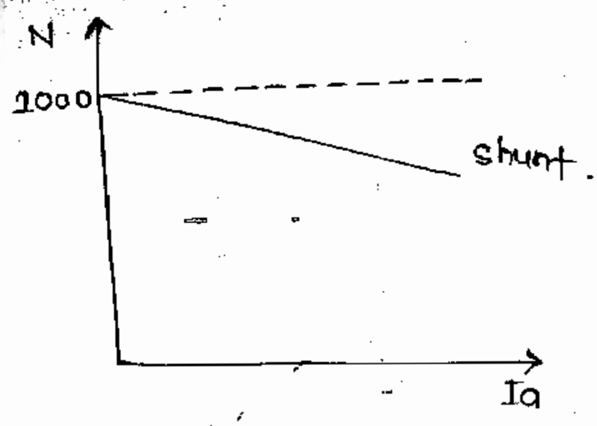
① shunt motor →

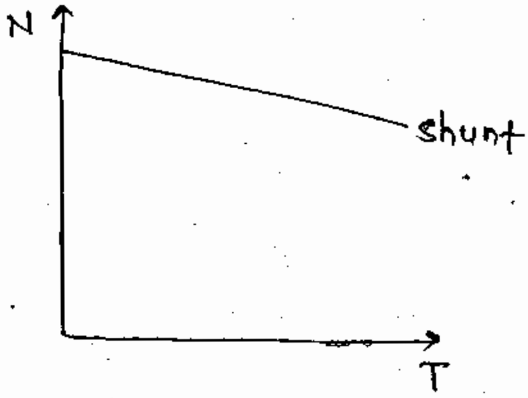
① Torque vs I_a

$T \propto I_a$



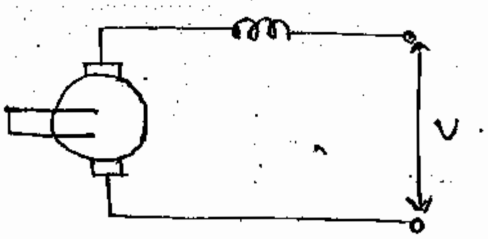
$N \propto V - I_a R_a$





* 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 ind^n motors. but shunt motors are prefered for there superior speed control.

(2) Series Motors →



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

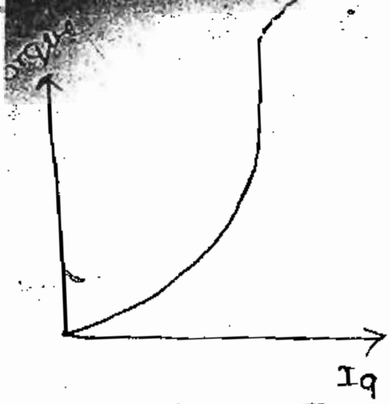
at NL the I_{ao} ↓ then ϕ_{se} ↓ & speed ↑.

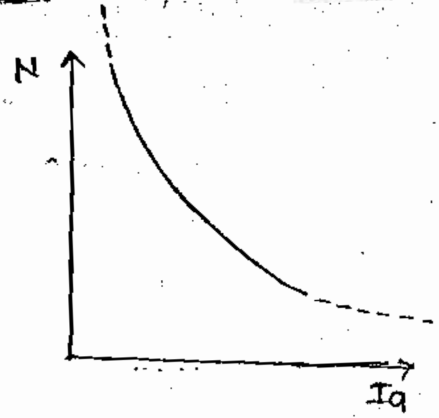
$$I_a = \frac{V - E_b}{R_a}$$

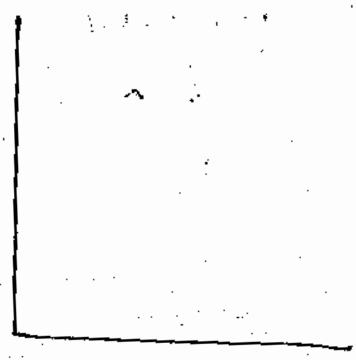
I_a ↓ E_b will max^m

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

Never start series motor at NL because speed becomes dangerous.







$T \propto \phi_{se} I_a$

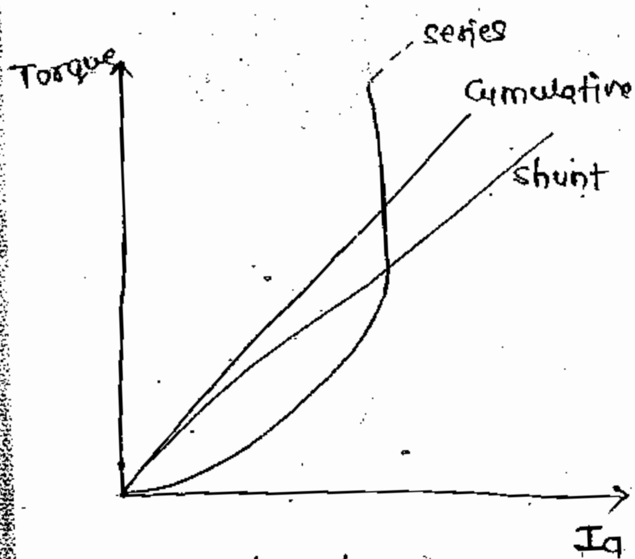
$T \propto I_a^2$ Before Satu.

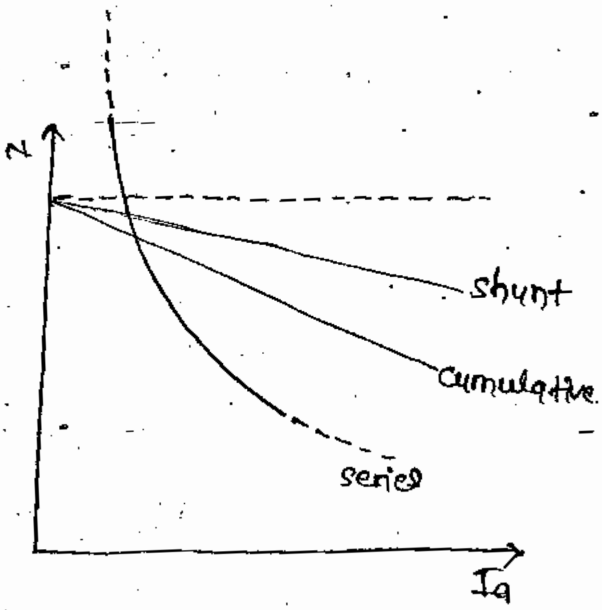
$T \propto I_a$ After saturation.

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

* 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 →





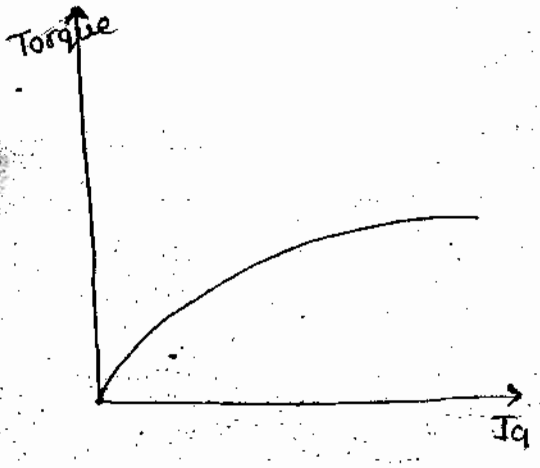
$T \propto (\phi_{sh} + \phi_{se}) I_a$

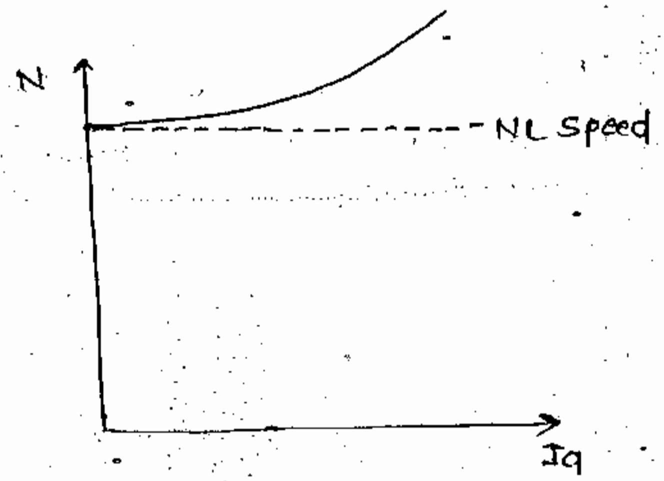
* It is best suitable for high torque intermittent load cond^n like shears & punches, presses, compressors.
* They have definate NL speed.
* The shunt flux regulates the speed on NL cond^n & the series flux increases the torque with load cond^n

(4) Differentially 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 torques & speed o/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.
* Differential 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)

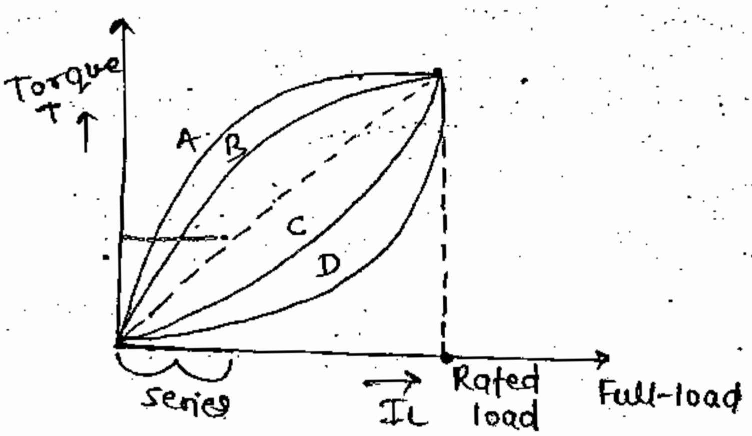
$T \propto (\phi_{sh}+\phi_{se}) I_a$ (cumu.)

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

UNIT-III

STARTING, SPEED CONTROL AND TESTING OF D.C. MACHINES

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

09/07/14

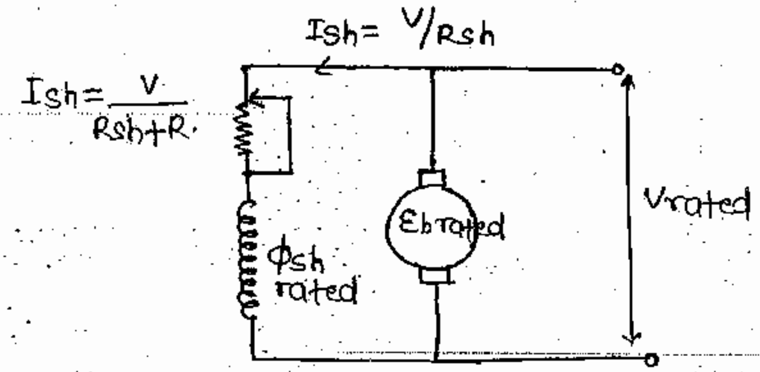
* SPEED CONTROL →

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

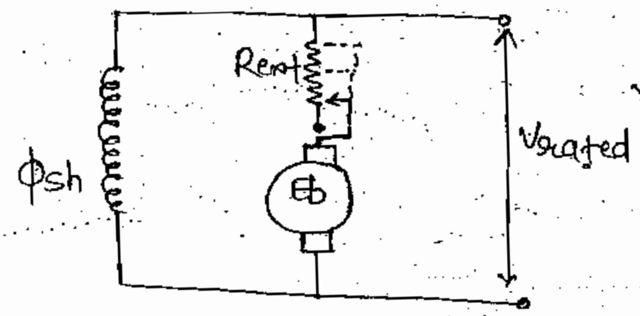


R↑ Ish↓ φsh↓ N↑

* 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 specially 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 →



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

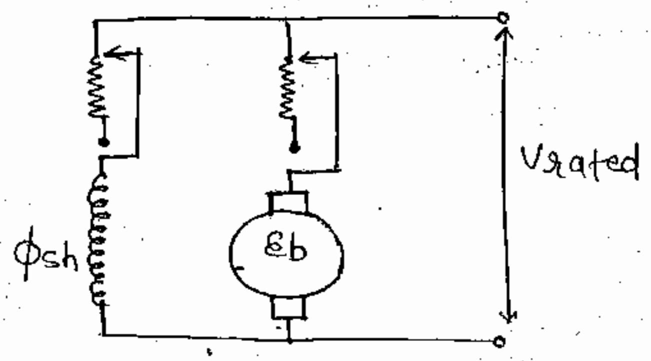
$\downarrow \frac{E_b}{\phi} \propto N \downarrow$

* 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.

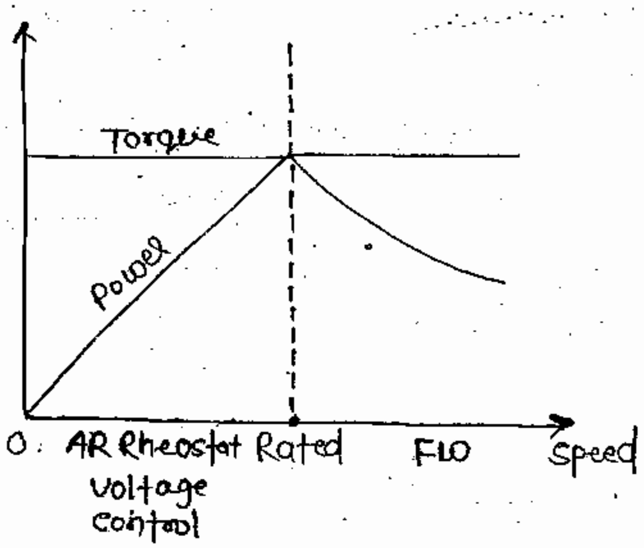
* Also called as constant torque variable power.

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

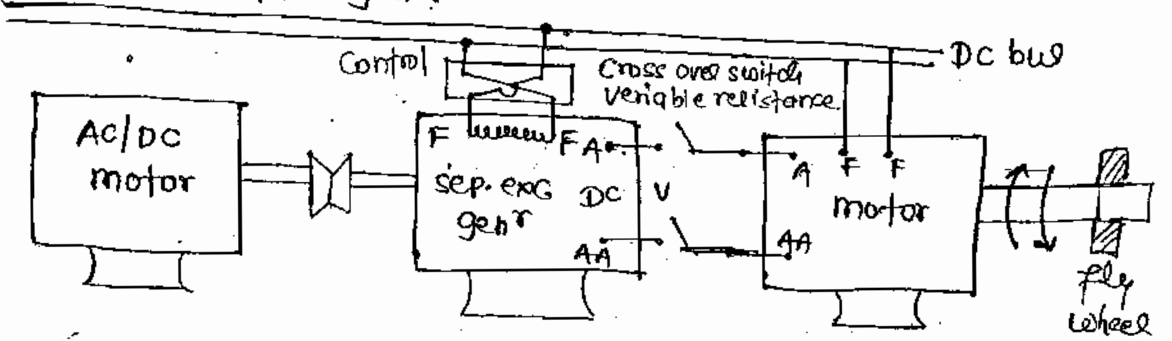
then $\phi = \phi_{sh}/2$

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.

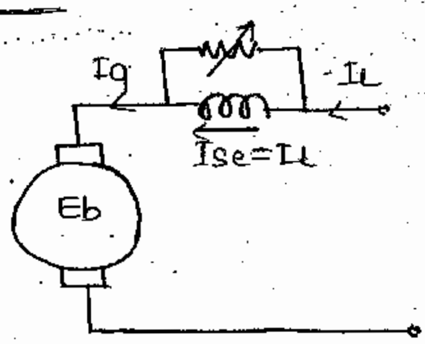


* This is exclusively use to control the speed from rated to below rated efficiently without inserting the resistance in series with arm. & to control speed in both dirn.
* The control is through a cross over switch which varies the excitation of seprately excited genr.
* As it requires two additional 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 ~~freq~~ efficiency known as ward Leonard Ilgner method.

* Speed control of series motors →

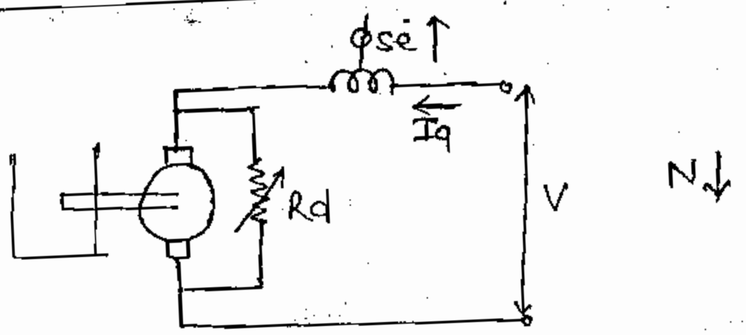
(1.) Field diverter
(2.) Armature diverter
(3.) Tapped field
(4.) Paralleling field coils
(5.) Armature Resistance
(6.) multiple voltage.

(1.) Field diverter →



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

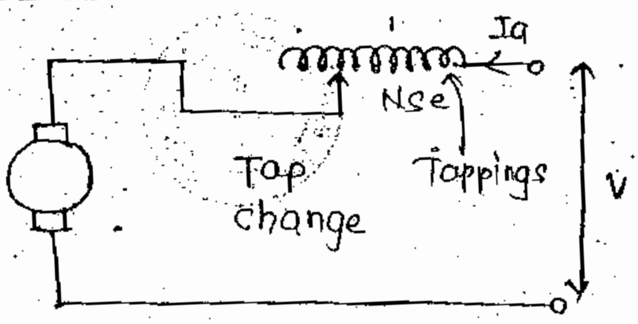
② Armature diverter →



$T \propto \phi I_a$

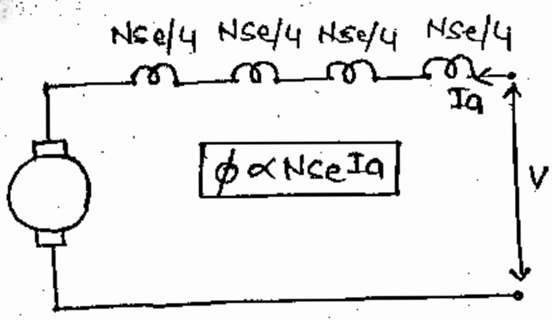
* By connecting diverter across arm., arm. current gets diverted due to which the torque is reduced.
* In order to maintain the torque the motor draws more current from supply which comes through the field wdg flux ↑ speed ↓.

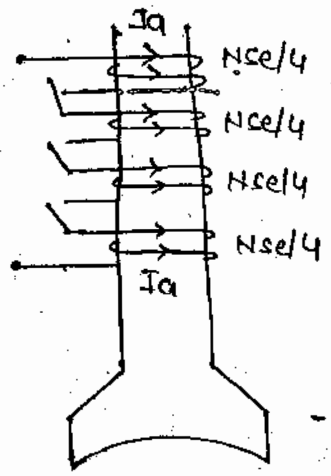
③ Tapped Field →

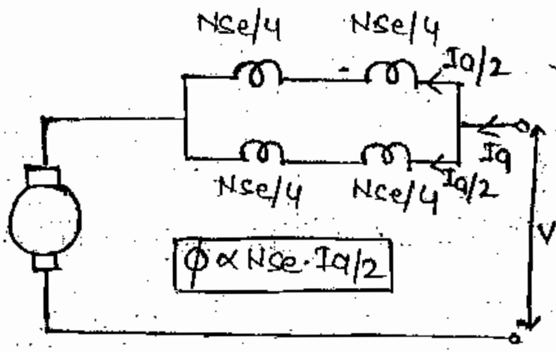


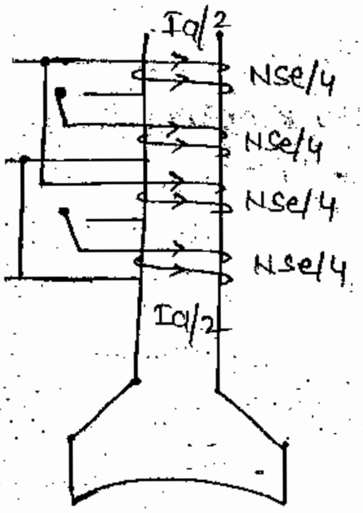
* If the tappings are more, then turns are more & hence by increasing the value of turns the value of flux increases & the speed may decrease.

(4) Paralleling Field Coils →



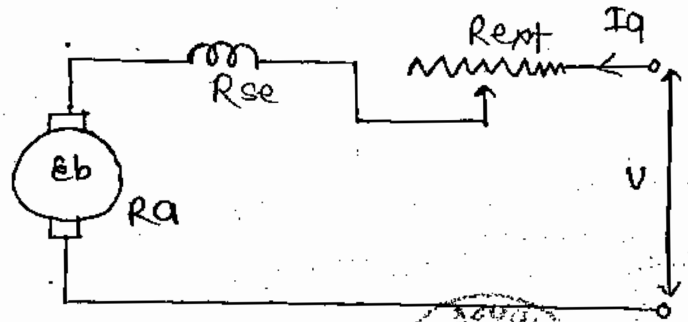






* The field wdg is arranged in the form of coils which can be externaly switch in series & parallel.
* In order to gets speeds b/w the steps a diverter may be connected

(5) Armature Resistance Control →

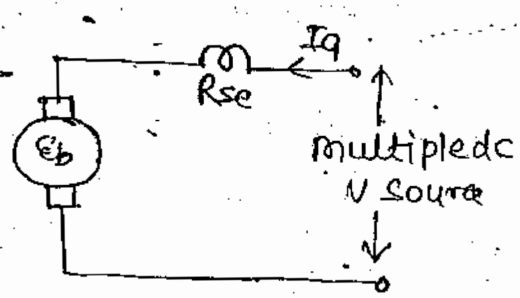


$\downarrow E_b = [V - I_a (R_{se} + R_{ext} + R_a)] \downarrow$

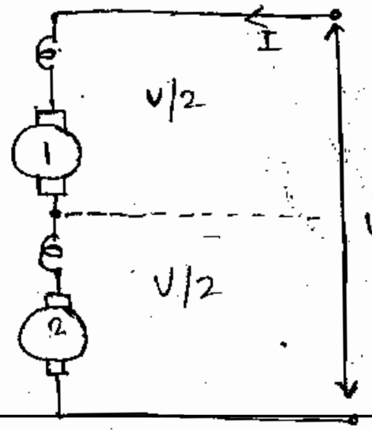
$N \downarrow$

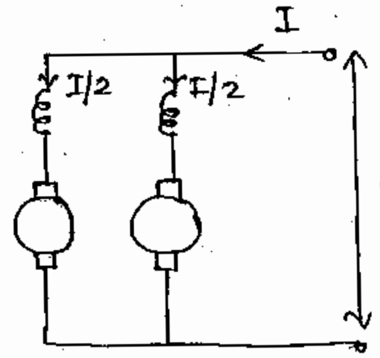
* By adjusting the resistance, vol. across the arm. is vary to vary the speed. which involves huge power loss.
* It also requires a multiple vol. source. Therefore these are rarely used.

(6) Multiple vol. Control →



* Traction motors in series & parallel →





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

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

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

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

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

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

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

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

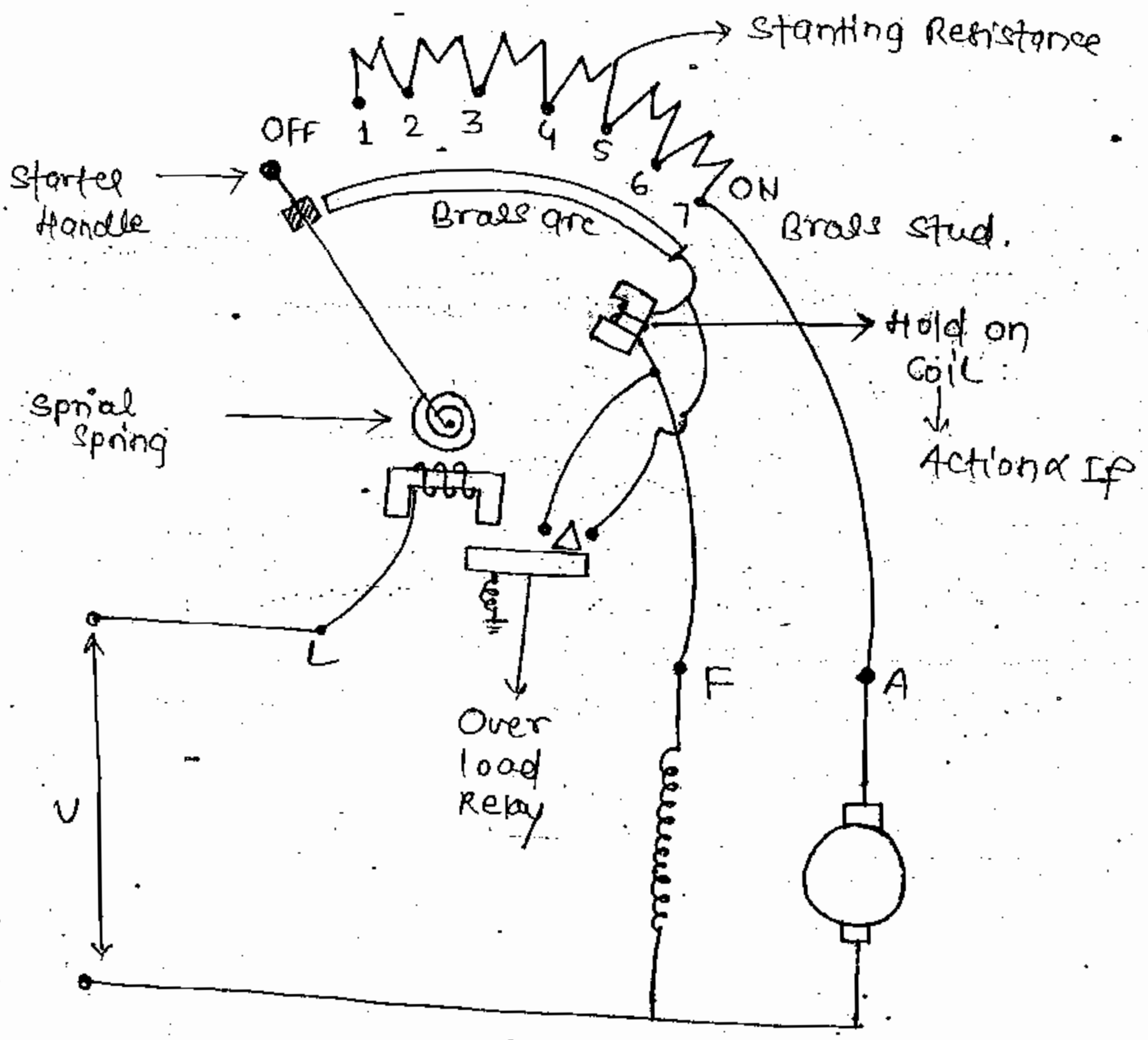
* STARTERS →

* 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 failure prevention

* There are 3 types of starter:-

- 3 point starter } shunt + compound
- 4 point starter }
- 2 point starter → Series

* 3 Point Starter →



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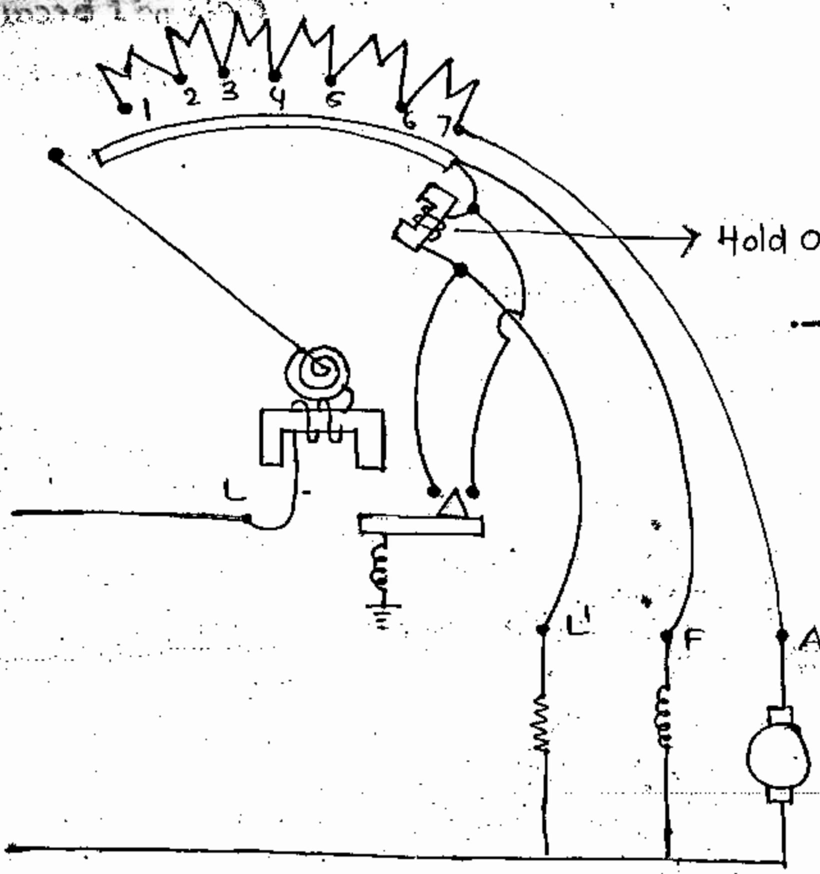
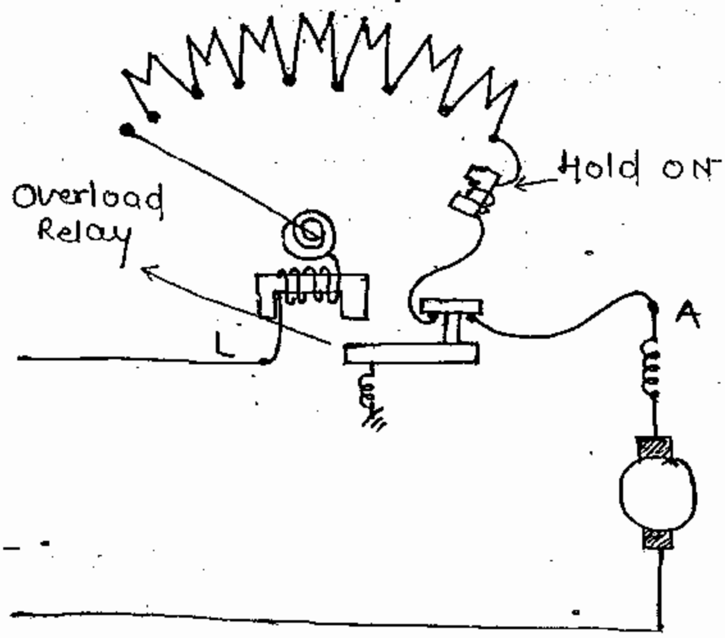
★ 3 Point Starter →



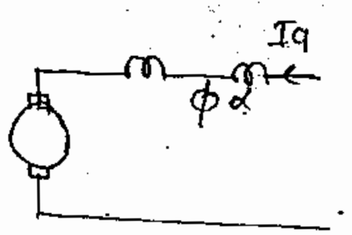
★ 2 Point Starter →



- 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 directly proportional to its field current.

* For such appl^n 4-point starter 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 failure 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.

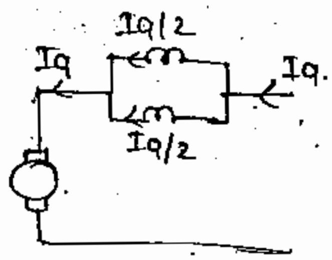
Q4/C



$T \propto \phi . I_a$

$T \propto I_a . I_a$

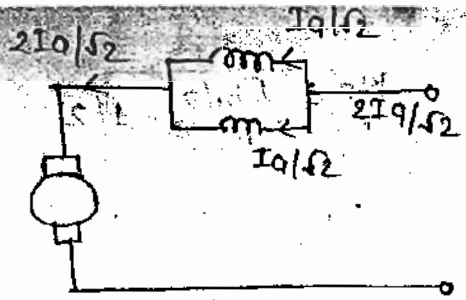
$T \propto I_a^2$



$T \propto \phi I_a$

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

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



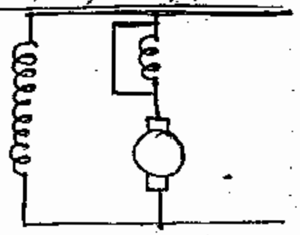
$T \propto \phi I_a$

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

$T \propto I_a^2$

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

9/1 Rated torque prob →



For cumulatively

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

series gets SC

ϕ_{sh} $\phi \downarrow$

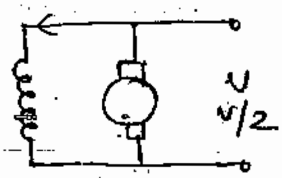
$\uparrow N \propto \frac{E_b}{\phi \downarrow}$

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

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

34/7 Rated power →

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



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

$\phi \rightarrow \phi/2$

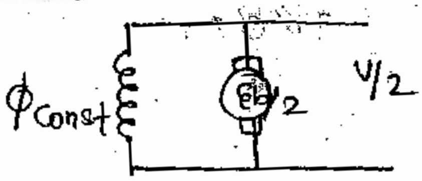
$\frac{N_2}{N_1} = \frac{E_{b1}/2}{E_{b1}} \times \frac{\phi_1}{\phi_1/2}$

$N_2 = N_1$ speed 1 PU

$P = E_b I_a$

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

88/8



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

$$N_2 = 0.5\,N \ \ PU$$

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

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

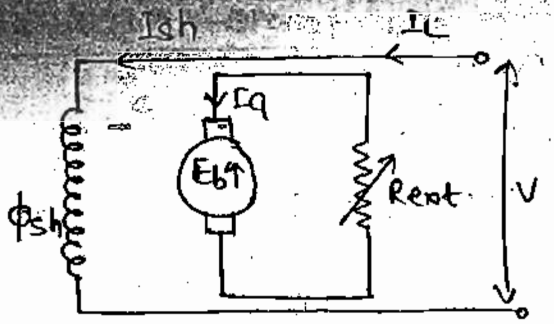
(b) Plugging

(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,

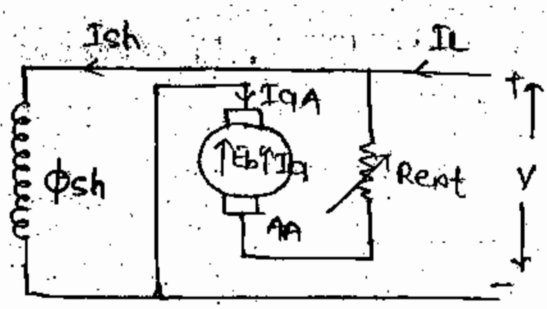
* At the instant of braking the induced back emf will circulate a current in the opposite dirn to reverses the torque & motor stops quickly.



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

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



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

93/9

$E_b = V - I_a R_a$

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

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

$I_a = I_L - I_{sh}$

$I_a = 12A$

$E_b = V - I_a R_a$

$= 240 - 12(0.5)$

$= 234$

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

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

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

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

(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.

* Consequently 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

$$T = (-\phi)(-I_a)$$
$\downarrow$
+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

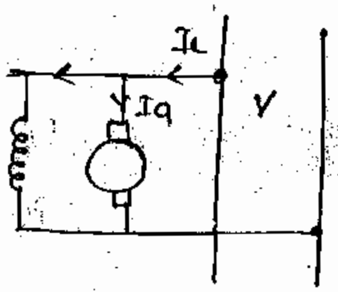
$T \propto (-\phi)(-I_a)$ ← ACW

* 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.

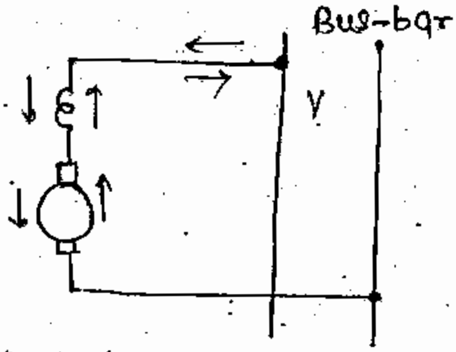


Ans-(a.) (Only I_a dirⁿ change)

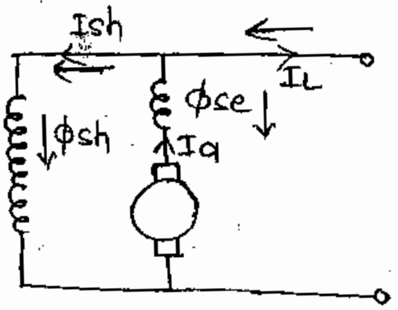
* Series genʳ supplying power to a bus bar, when its prime move fails it will act as

(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 reversal of Ia & cumulatively compound becomes diff compound because ~~of the same dirn in the~~ change in dirn.

21/5

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

$$E_{b_1} = V - (I_a R_a) \text{ (drop)}$$

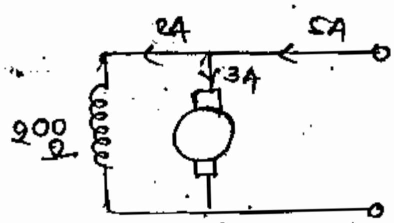
$$E_{b2} = 0.95 E_{b1}$$

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

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

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

54/10



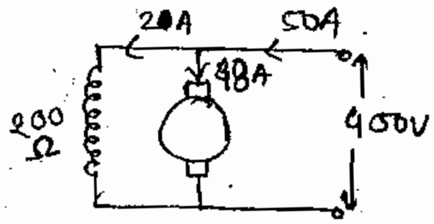
$$N \propto \frac{E_b}{\phi}$$

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

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

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

$$= 376\text{V}$$



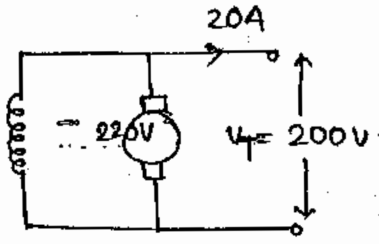
$$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}}$$

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

66/13 const: $E_b \propto \phi N \uparrow$ $\downarrow T \propto \phi I_a$

69/13

46/9



$\phi_2 = 1.1\phi_1$

$E_g = V + I_a R_a$

$= 200 + 20(0.2)$

$E_g = 204V$

$E_b = V - I_a R_a$

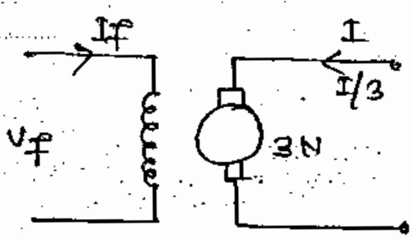
$= 200 - 20(0.2)$

$= 196V$

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

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

40/8



$P = 3E_b \cdot I_a/3$

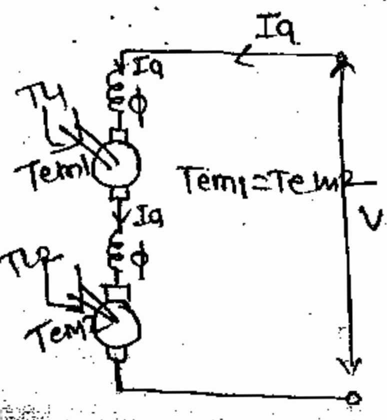
Constant power

$T \propto I_a \phi$

1/1

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

11/4



$P = \frac{2\pi NT}{60}$

$P \propto NT$

Because same T

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

$T_{L1} = T_{L2}$, $Tem_1 = Tem_2$

$\boxed{1:1}$

Tem – Electromagnetic torque

T_L = load torque

If in question 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 operatings constrains of m/c.

① Iron / Core loss →

(1.) Eddy current.

(2.) Hysterisis.

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

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

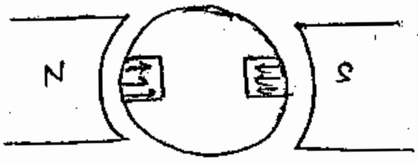
B_m = flux density

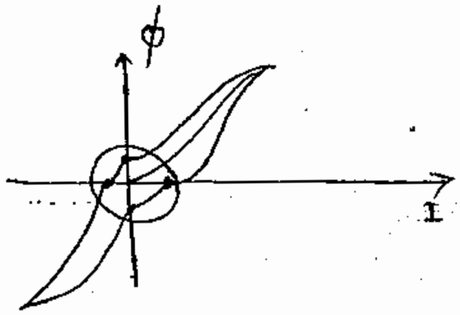
t = thickness

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 cond^n which produce Hysteris loss.
* It is also proportional 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 cond^r 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) $V \cdot I_{sh}$

(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

$I, F(\sigma)\, \omega$ cu loss.
$I_{sh}^2 R_{sh}$

Condition for max^m η →

$$I/p = o/p + \text{loss}$$

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

$$\eta = \frac{o/p}{o/p + \text{constant loss} + \text{Variable loss}}$$

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

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

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

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

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

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

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

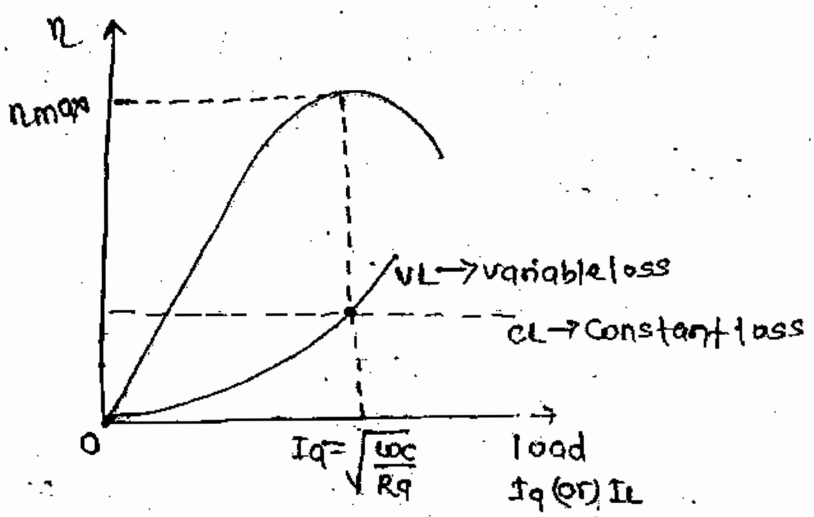
$$\boxed{\begin{array}{c} I_a^2 R_a = W_c \\ \text{variable loss} = \text{constant loss} \end{array}}$$

$$I_a^2 R_a = W_c$$

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

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

* 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.

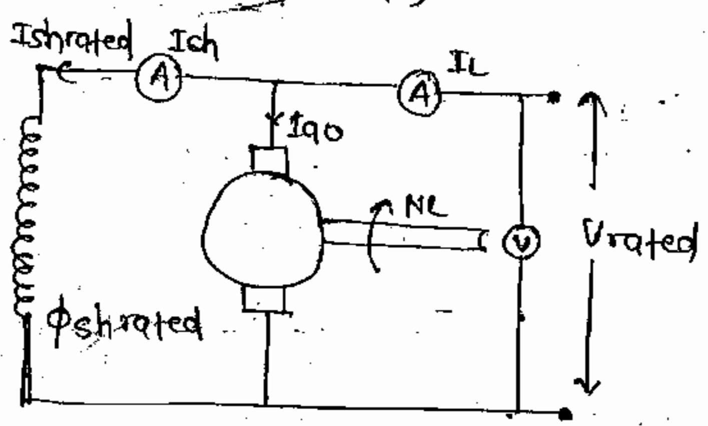
(2.) Indirect → * The m/c is not loaded directly but the η is free determined by determining losses.

$$\boxed{\eta_g = \frac{O/P}{O/P + loss}} \quad , \quad \boxed{\eta_m = \frac{I/P - loss}{I/P}}$$

* 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, in order 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	10A	45	$10^2 \times 1 = 100$	145	220×11	$= \frac{220 \times 11 - 145}{220 \times 11}$
½L	220	6	1	5A	45	$5^2 \times 1 = 25$	70	220×6	$= \frac{220 \times 6 - 70}{220 \times 6}$

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

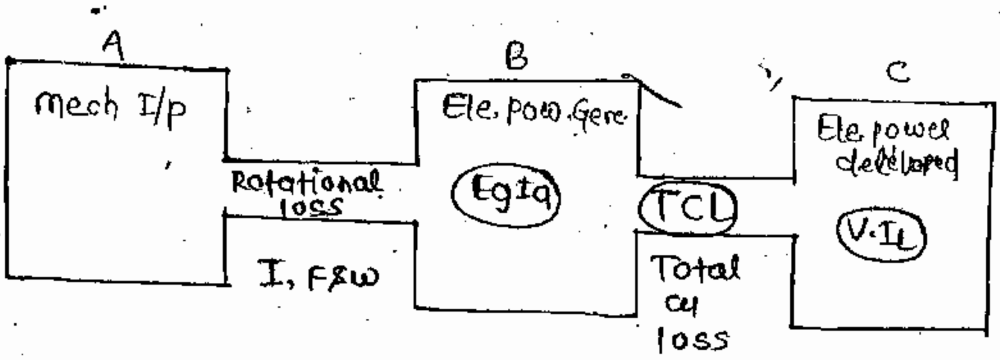
	V	I_L	I_{sh}	I_a	Constant loss	Variable loss	Total loss	o/p	$\eta = \frac{o/p}{o/p + loss}$
FL	220	9	1	10	45	$10^2 \times 1 = 100$	145	220×9	$\frac{220 \times 9}{220 \times 9 + 145}$

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

~~* 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.

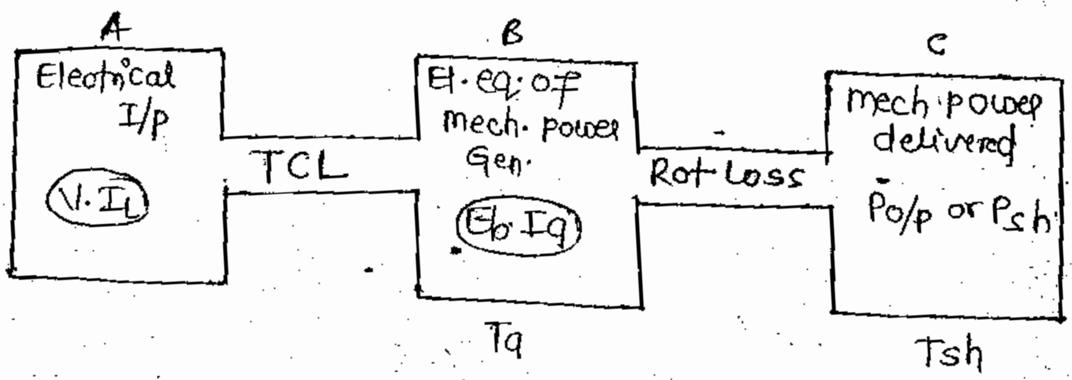
Power stages of gen^r →



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

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

Power stages of motor →



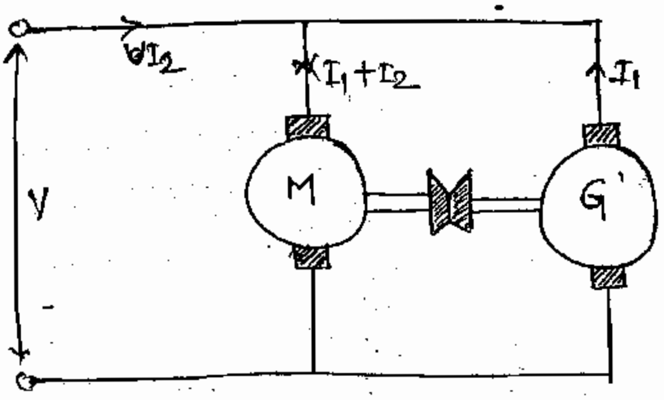
$$\eta_{ele} = \frac{B}{A} = \frac{E_b I_a}{\text{Ele. I/p } (V \cdot I_L)}$$

$$\eta_{mech} = \frac{C}{B} = \frac{\text{mech O/p } (P_{sh})}{E_b \cdot I_a}$$

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

$$\boxed{\begin{gathered} T = \frac{60}{2\pi N} \cdot P \qquad T_a = \frac{60}{2\pi N} (E_b \cdot I_a) \\ T_{sh} = \frac{60}{2\pi N} (E_b I_a - \text{Rotational loss}) \end{gathered}}$$

* 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 →

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

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

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

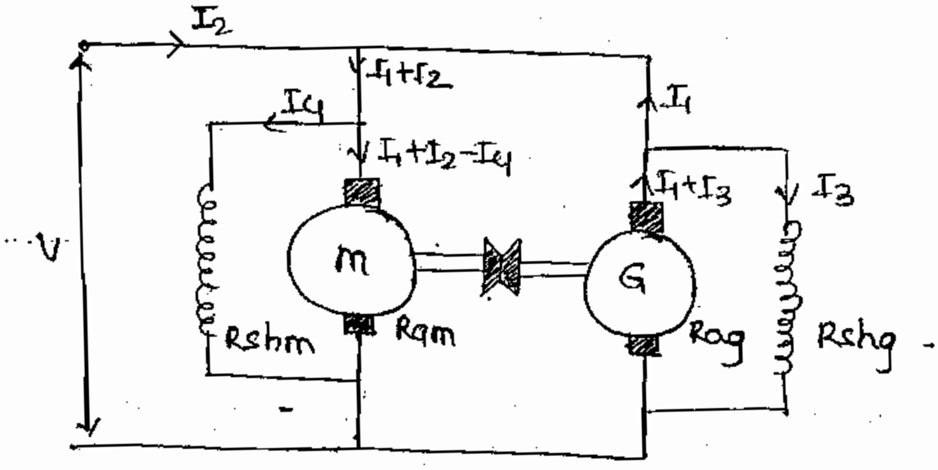
$$\eta_{mot} = \frac{\text{o/p of motor}}{\text{I/p of motor}} \Rightarrow \text{o/p of motor} = \eta_{mot} \times \text{Ip of m}$$

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

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

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

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.

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

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

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

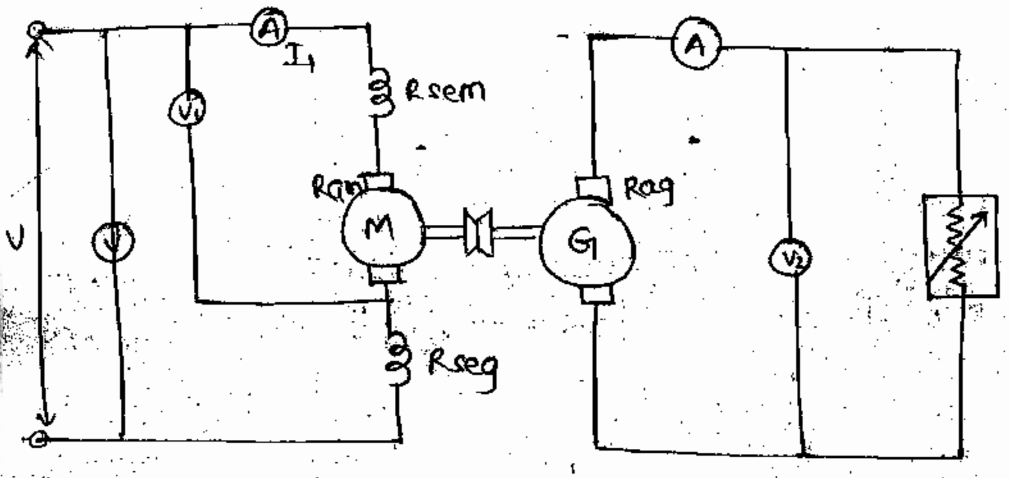
$$\boxed{\eta_g = \frac{VI_1}{VI_1 + \left[P_R/2 + (I_1+I_3)^2 R_{ag} + I_3^2 R_{shg}\right]}}$$

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

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

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.



$$I/p \; M\text{-}G \; set = VI_1$$

$$O/p \; M\text{-}G \; set = V_2 I_2$$

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

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

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

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

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

* 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.

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

J = Moment of inertia

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

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

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

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

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

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.

Soln →

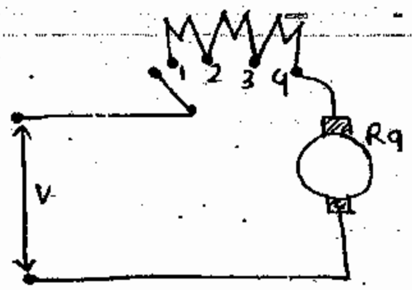
$$\text{Rot. loss} = \left(\frac{2\pi}{60}\right)^2 \times 75 \times 1000 \times \left(\frac{60}{15}\right)$$

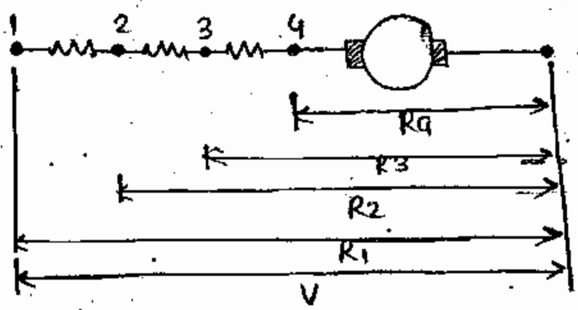
$$\text{Rot. loss} = 3289.868\,W \qquad \text{Ans}$$

* 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.





1−2, 2−3, 3−4 } 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 $I_1 = \frac{V - E_{b1}}{R_2}$

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

At ② after some instant

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

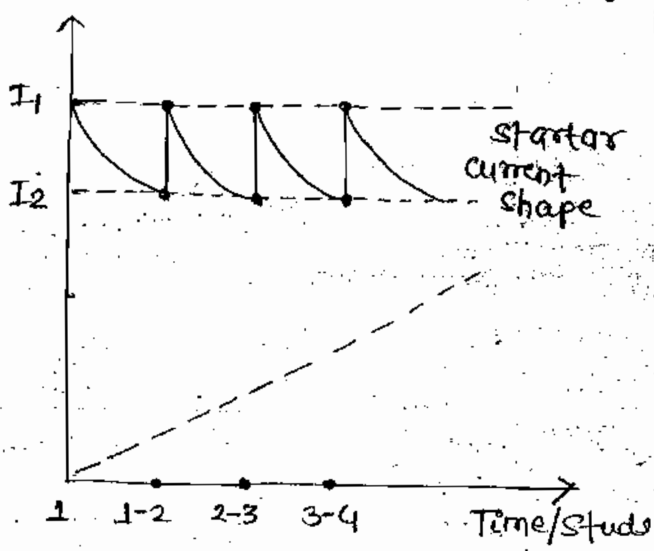
②—③ $I_1 = \frac{V - E_{b2}}{R_3}$

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

At ③ After some instant

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

③—④ $I_1 = \frac{V - E_{b3}}{R_4}$



$$\frac{I_1}{I_2} = \frac{R_1}{R_2} = \frac{R_2}{R_3} = \frac{R_3}{R_4} = K$$

$R_3 = KR_4$

$R_2 = KR_3 = K^2 R_4$

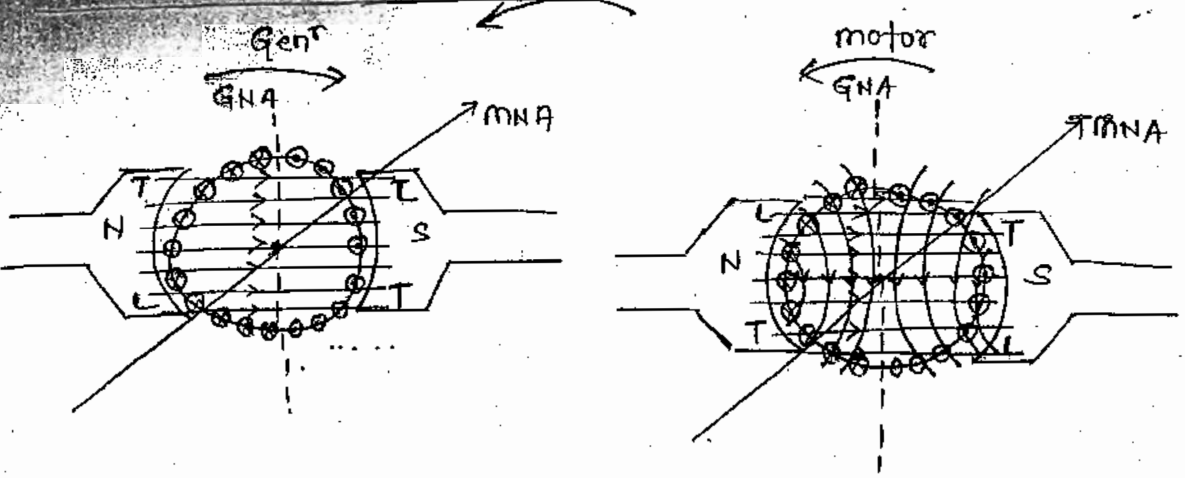
$R_1 = KR_2 = K^3 R_4$

$$\boxed{\frac{R_1}{R_4} = K^3}$$

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

$$\boxed{\frac{R_1}{R_4} = K^{n-1}}$$

Armature Reaction in dc motors →



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

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

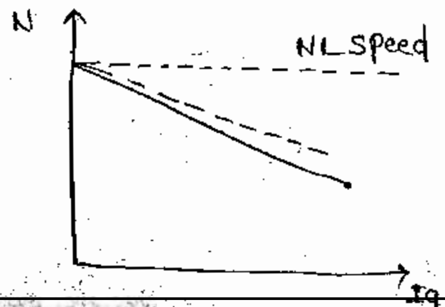
(2.) The flux density will increase under the leading pole tips.

(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.



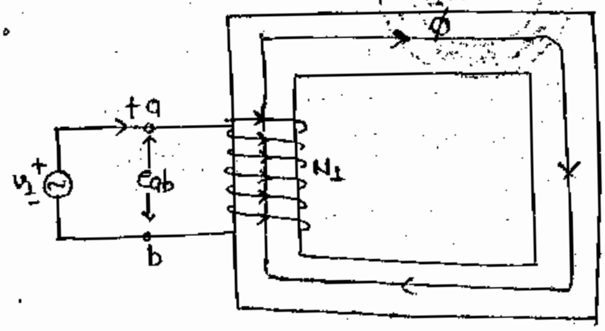
UNIT–IV

SINGLE-PHASE TRANSFORMERS

Transformers

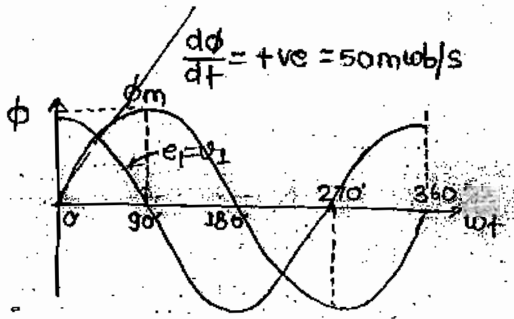
Sagar Sen
887145 3536

* TF is not an ele. m/c



* Core provides → low reluctance path
  → mech. support

$\boxed{\phi = \phi_m \sin\omega t}$
(time exp^n)

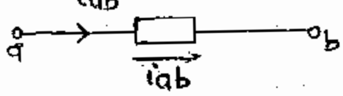


(timing dia)

Flux linkage (λ) = NI

* Whenever there is a flux linkage there is a flux.

V_{ab} – vol. of a wrt b



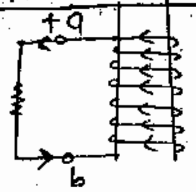
$e_{ab} = \pm \frac{d\lambda}{dt}$

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.

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

Where the sign depends on lenz law & which terminal is taken as +ve.

Testing of lenz law→

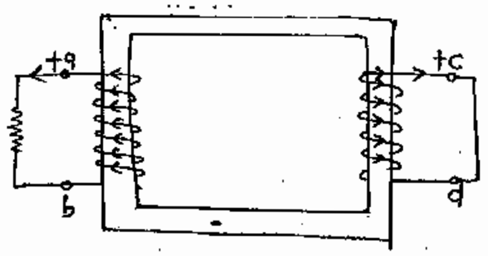


$$e_{ab} = +\frac{d\lambda_1}{dt}$$

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

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

$$= 5 \text{ volts}$$

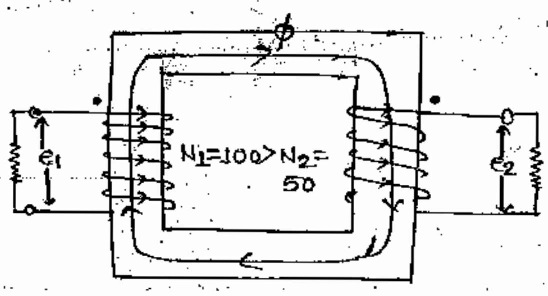


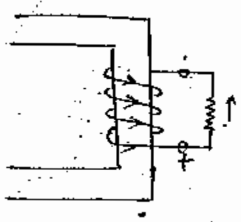
$$e_{cd} = \pm\frac{d\lambda_2}{dt}$$

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

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

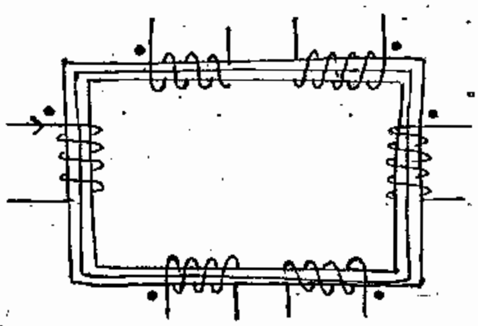
$$= +2.5 \text{ volts}$$





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 automaticaly depanding 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.

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

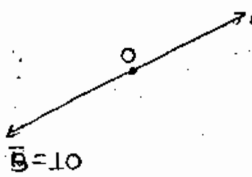
$$e_1 = N_1 \frac{d\phi}{dt}$$

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

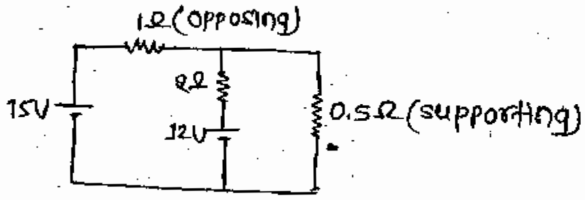
$$= N_1 \phi_m \omega \cos\omega t$$

$$\Downarrow$$

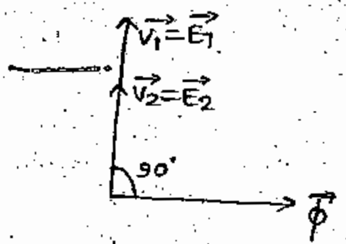
$$\sin(\omega t + 90^\circ)$$



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



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



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

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

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

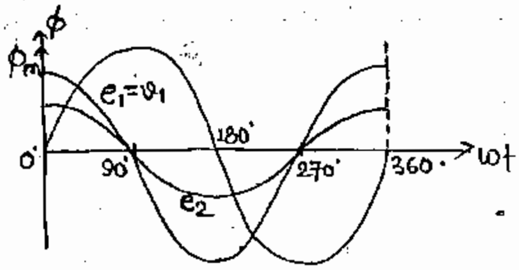
$$= N_2 \frac{d}{dt}(\phi_m \sin\omega t)$$

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

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

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

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



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

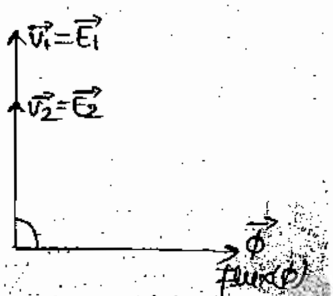
*(Flux will establish without any exciting current)

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

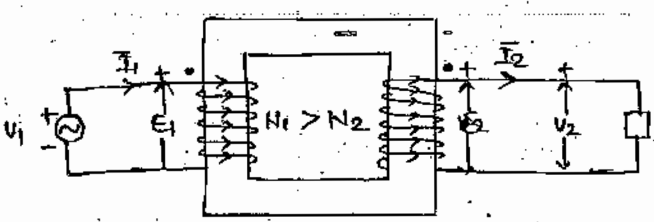
$$\phi = \frac{NI_0}{l/\mu A}$$

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

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



Phasor dia. of ideal Xmer on NL



mmF Balance on load of ideal transformer

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

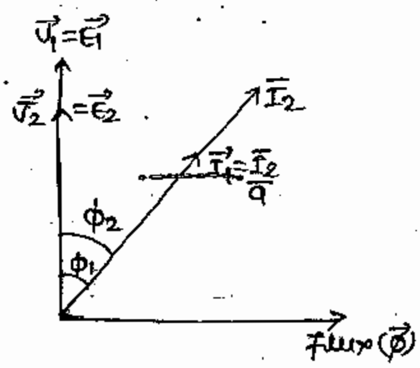
$$N_1\vec{I_1} = N_2\vec{I_2}$$

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

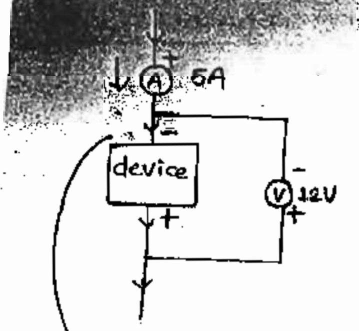
$$\boxed{I_1 = \frac{I_2}{a}} \qquad \boxed{I_1 = I_2'}$$

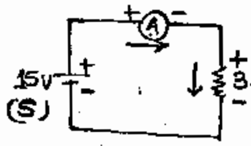
$$\boxed{\frac{V_1}{V_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = a} \rightarrow \text{Turn Ratio}$$

I_2' = 2° current refered to 1°.



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





(Because reduces energy)

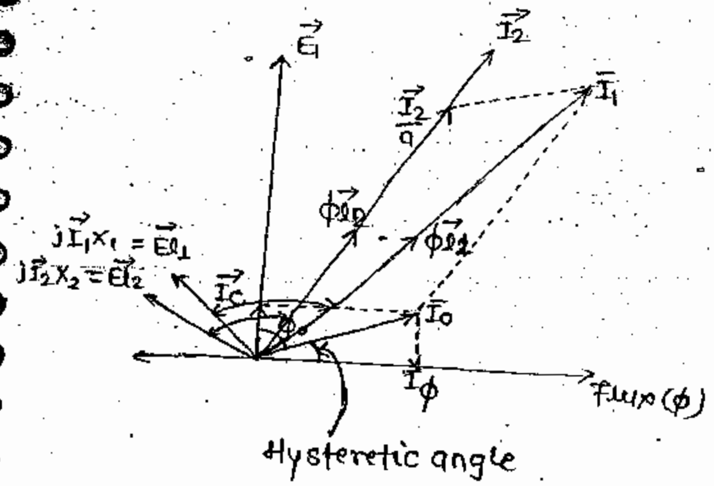
Current enter at lower potential & exit from higher potential. Then the device is <u>source.</u>

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

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

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

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



I_c = Core loss component of exciting current (I_o)

I_ϕ = Magnetising current of exciting current

$$\boxed{\begin{aligned} I_c &= I_o \cos\phi_o \\ I_\phi &= I_o \sin\phi_o \end{aligned}}$$

$(\phi_o = 80^\circ)$

E_{l_1} = 1° leakage flux voltage

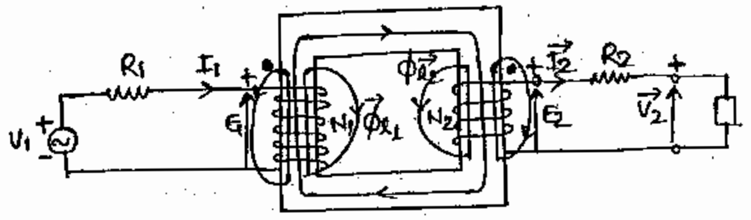
E_{l_2} = 2° leakage flux voltage

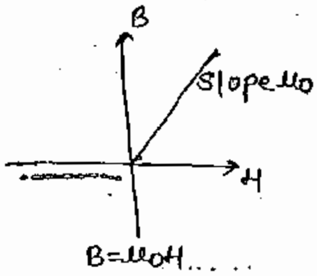
$X_2 = \frac{E_{l_2}}{I_2}, \quad X_1 = \frac{E_{l_1}}{I_1}$

<u>MMF balance of practical TF →</u>

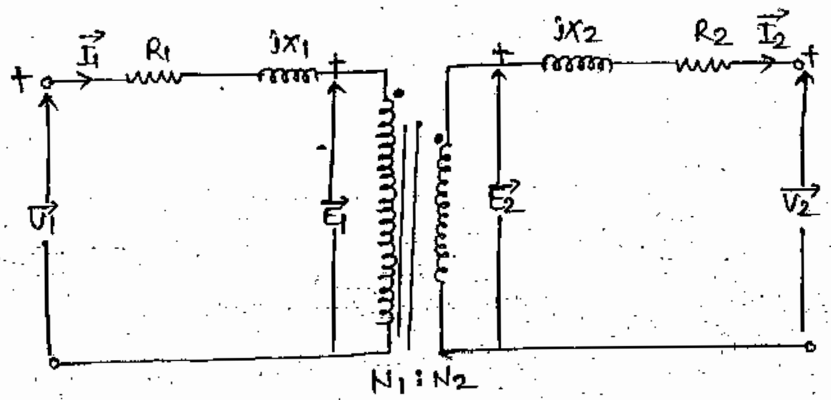
$$N_1 \vec{I_1} - N_2 \vec{I_2} = N_1 \vec{I_o}$$

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





ϕ_ℓ = leakage Flux.

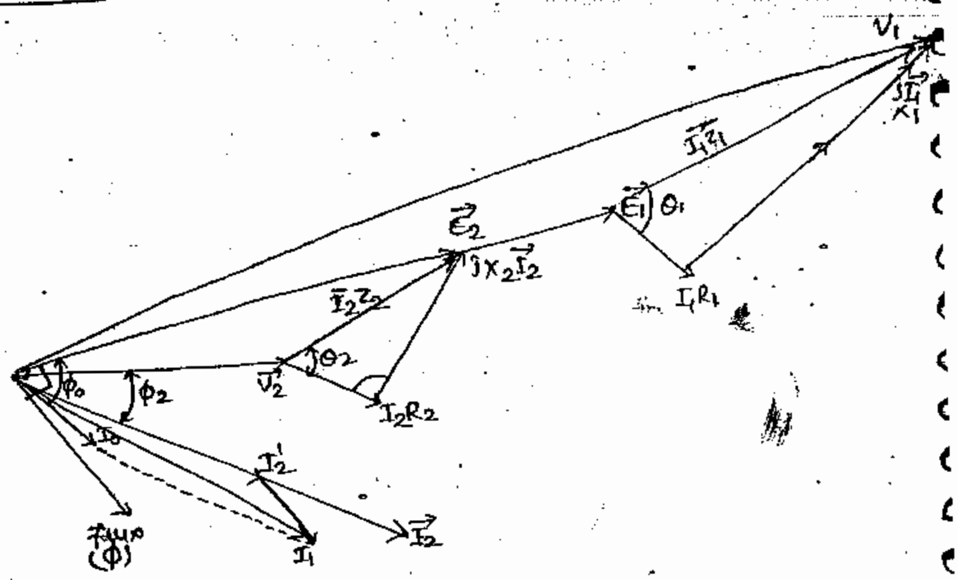


Representation of a practical 2wdg TF

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

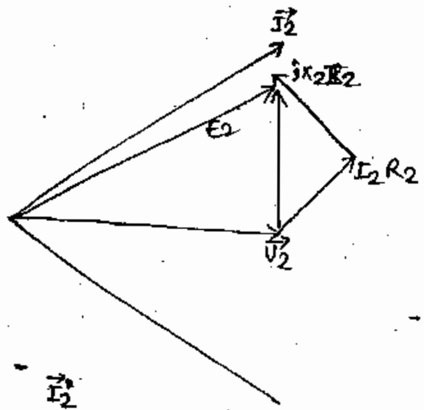
$\vec{E_1} = a\vec{E_2}$ $= \vec{I_2'} + \vec{I_0}$

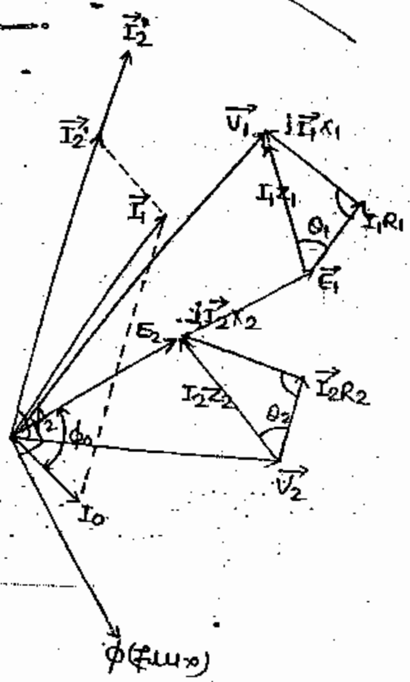
Complete phaser diagram → $N_1 > N_2$, lagging PF operation.



Tight coupling by iron core.

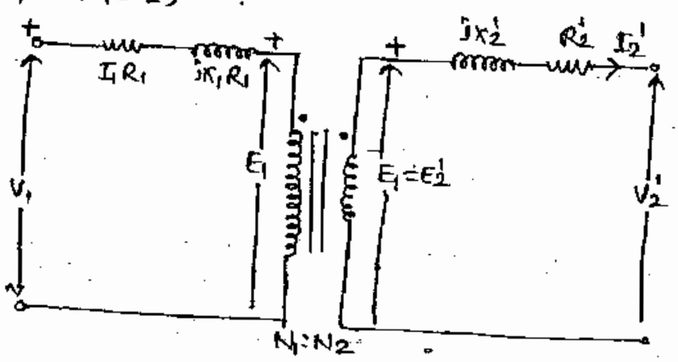
$N_1 > N_2$, Leading pf operation →





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.

DATE-04/11/14 (Refered to 1°)



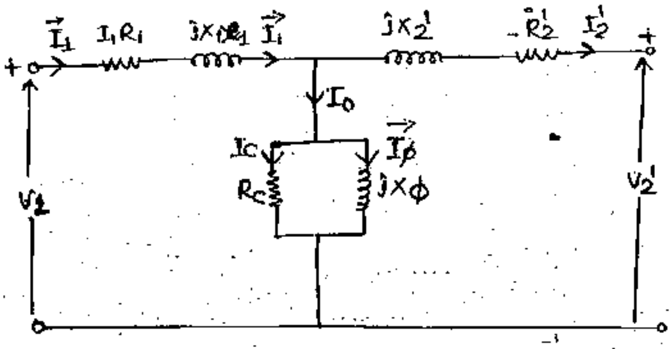
$$\vec{E_2} = \vec{V_2} + \vec{I_2}R_2 + jX_2\vec{I_2}$$

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

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

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

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



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.

Sol→ 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.

$V_2 = 240\angle 0°$; $I_2 = \frac{150\times10^3}{240}\angle -\cos^{-1}(0.8)$
$= 625\angle -36.87° A$

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

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

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

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

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

$Z_2' = a^2 Z_2$

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

$= (0.2+0.45j)\Omega$

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

$E_1 = 2400\angle 0^\circ + 62.5\angle -36.66 \times (0.2+0.45j)$

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

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

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

$I_0 = I_c + I_\phi$

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

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

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 →

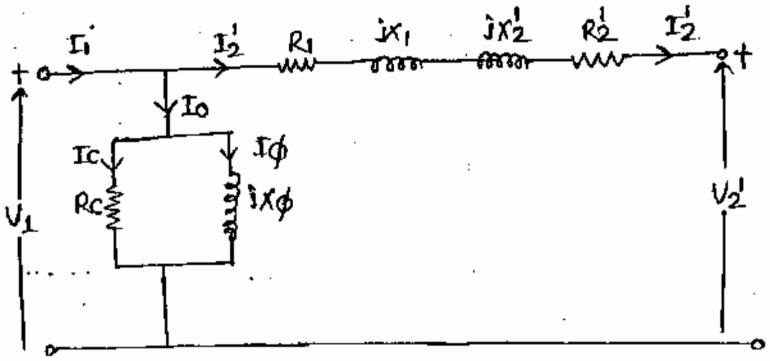
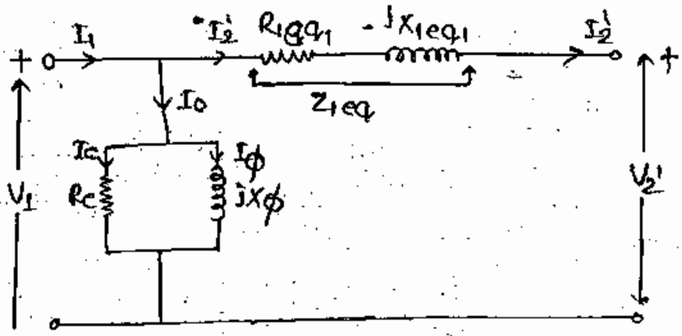


Fig- Cantilever eq:



For η calⁿ it is best suitable

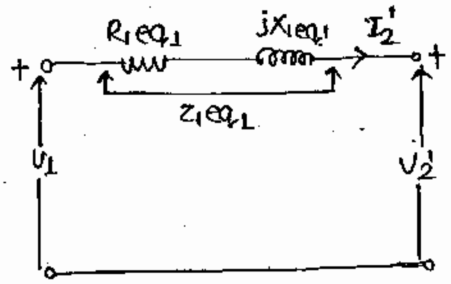
$$V_1 = 2400\angle 0^\circ + 62.5\angle -36.87^\circ \times (0.4 + 0.9j)$$

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

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

$$\boxed{V_1 = 2453.66\angle 0.69^\circ V}$$

* 2nd & Final approx eq. ckt →



UNIT-V

SINGLE-PHASE TRANSFORMERS TESTING

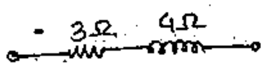
* Since the NL current is limited to 5% of FL value, the 1° Cu loss during OC test is ignored.
Also the 1° impedance vol. drop at such low current is neglected.

* Since the NL PF is very low it is recommended that a low PF wattmeter is used in this test.

Que.→ With the instruments connected on LV side OC readings are 10 kVA 450/120 V, 50 Hz, 1-ϕ Xmer are 120V, 4.2A, 80W

Find the resistance & reactance of parallel eq. exciting ckt referred to HV side.

Soln→



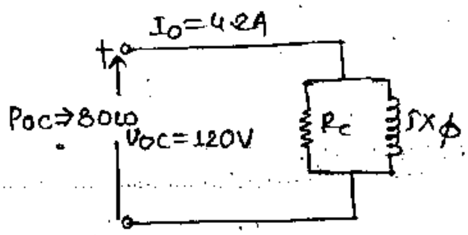
$$Y = \frac{1}{Z} = \frac{1}{3+4j} = \frac{1}{5\angle 53.13°}$$

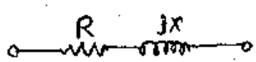
$$= 0.2\angle -53.13° \text{ semeins}$$

$$= 0.2(0.6 - 0.8j)$$

$$G - jB = 0.12 - 0.16j$$

$$G = 0.12, \quad B = 0.16$$





$$\phi = \tan^{-1}\left(\frac{X}{R}\right)$$

$$\phi = \tan^{-1}\left(\frac{R}{X}\right)$$

$$\frac{1}{Z} = Y = \frac{1}{R} + \frac{1}{jX} = \frac{1}{R} - \frac{j}{X}$$

$$\tan\phi = \left(\frac{\frac{1}{X}}{1/R}\right)$$

$$\tan\phi = \frac{R}{X}$$

$$P_{oc} = \frac{V_{oc}^2}{R_c}$$

$$R_c = \frac{(120)^2}{80} = 180\Omega$$

$$P_{oc} = V_{oc} I_0 \cos\phi_0$$

$$= 120 \times 4.2 \cos\phi_0$$

$$\phi_0 = 80.87°$$

$$\tan\phi_0 = \frac{R_c}{X_\phi}$$

$$\tan(80.87) = \frac{R_c}{X_\phi}$$

$$X_\phi = \frac{R_c}{\tan(80.87)}$$

$$\boxed{X_\phi = 28.93\Omega}$$

Ohmic value must be high on HV side & low on LV side.

Sagar Sen
8871453536

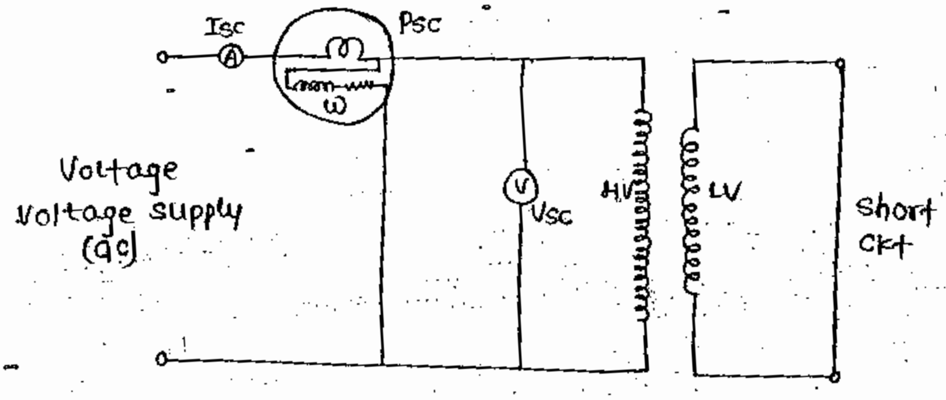
HV side ⇒ [illegible]

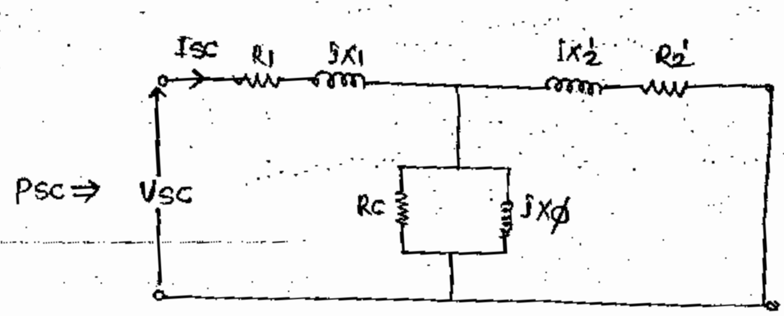
$$a = \frac{450}{120} = 3.75$$

$$R_{C(HV)} = (3.75)^2 \times 180$$
$$= 2.531\ k\Omega$$

$$X_\phi = (3.75)^2 \times 28.93$$
$$X_\phi = 406.83\Omega$$

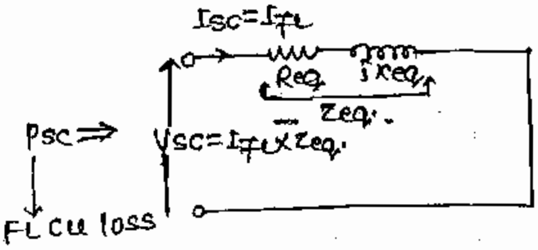
Short circuit Test →





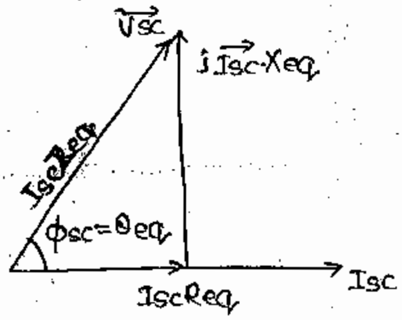
* This test is carried out by rated current to determine FL cu loss.
* Since the resistance of the wdg in Xmers is not affected much by the variation in power freq. band, this test need not be carried out strictly at rated ~~freq.~~
  Although it would be recommended to conduct the test at rated freq.
* 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 2400V/240V TF are 48V, 20.8A & 617W. Find the ~~leagal ime~~ leakage impedance, effective resistance & leakage reactance refered to LV side.

Sol^n→

$$\phi=\cos^{-1}\frac{P_{sc}}{V_{sc}I_{sc}}$$

$$=\cos^{-1}\frac{617}{48\times 20.8}=51.83$$

$$Z_{eq}=2.30\angle 51.83$$

$$Z_{eq}=1.421+1.808j \approx 1.426+j1.814$$

$$\boxed{Z_{eq}=2.31\angle 51.83^\circ\,\Omega}$$

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 components 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.

Soln → (a) $I_0 = 0.6A$, $I_{c_1} = ?$, $I_\phi = ?$

$$P_{oc} = \frac{V_{oc}^2}{R_c} \qquad P_{oc} = V_{oc} I_0 \cos\phi_0$$

$$361 = 2200 \times 0.6 \cos\phi_0$$

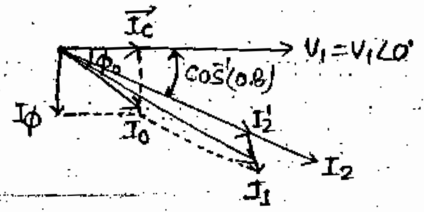
$$\phi_0 = 74.13°$$

$$I_0 = I_c + I_\phi \qquad I_c = I_0 \cos\phi_0 = 0.164$$

$$I_0 = \frac{V_{oc}}{R_c} + \frac{V_{oc}}{X_\phi}$$

Because always lag

$$I_0 = 0.6 \angle -\cos^{-1}\frac{361}{2200 \times 0.6}$$



$$I_0 = (0.1641 - j0.577)A$$
$$\downarrow \qquad \downarrow$$
$$I_c \qquad I_\phi$$

$$I_1 = I_2' + I_0$$

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

$$= 6\angle -\cos^{-1}(0.8) + (0.1641 - 0.577j)$$

$$= 6.488 \angle -40.08° A$$

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.

$$Z_{pu} = \frac{Z_{eq}(\Omega)}{Z_{base}}$$

$$= \frac{Z_{eq}(\Omega)}{V_{rated}/I_{rated}}$$

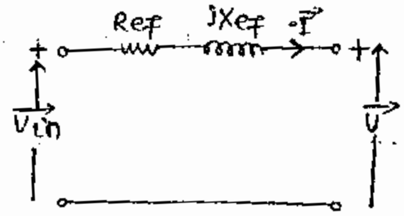
$$= \frac{I_{rated} \cdot Z_{eq}(\Omega)}{V_{rated}}$$ = Full load impedance drop in %

$$= \frac{(I_{rated})^2 \cdot Z_{eq}(\Omega)}{V_{rated}}$$ = 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.



$$\boxed{VR^n = \frac{V_{in} - V}{V} \text{ pu}}$$

Note:- Use magnitude only

where; $V = V_{rated}$

$$\vec{V_{in}} = \vec{V} + \vec{I}\,\vec{Z_{eq}}$$

$$VR^n = \left(\frac{V_{in}}{V} - 1\right) \text{pu} = (V_{in})_{pu} - 1 \text{ pu}$$

Que→ The TF has pu imp. of 0.10 pu & pu resistance of 0.01. Calc. the phase diff. bet^n 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 cond^n.

Sol^n→

$$Z_{eq} = 0.10 \angle \cos^{-1}\frac{0.01}{0.10}$$

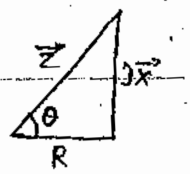
$$Z_{eq} = 0.01 + 0.0994j$$

$$= 0.1 \angle 84.26° \text{ pu}$$

$\cos\theta = \frac{R}{Z}$

$\sin\theta = \frac{X}{Z}$

$\tan\theta = \frac{X}{R}$



(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) $V_{in} = 1\angle 0° + 1.0 \angle \cos^{-1}0.8 \times 0.1 \angle 84.26$

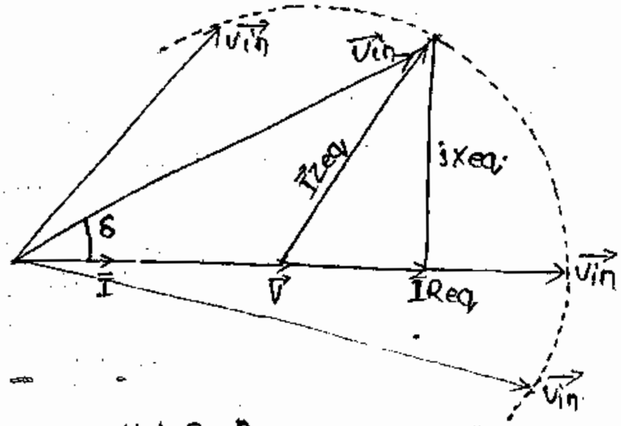
$= 0.9522 \angle 5.157$

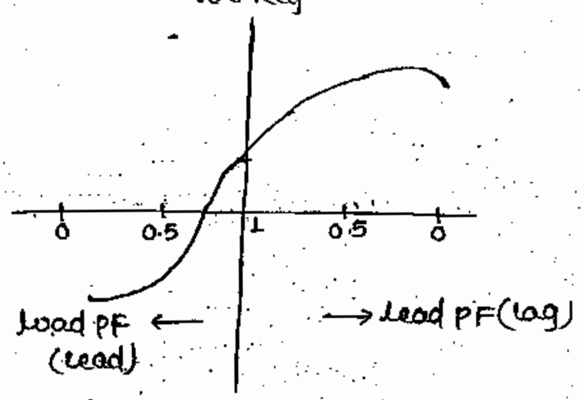
$VR^n = 0.9522 - 1$

$VR^n = -0.0478$

$\boxed{\%VR^n = -4.78\%}$ (LESS)

Locus of Vin at diff PF





0.8 PF Reg^n = Vin = $1.0702\angle 3.94$

$V_{in}\cos\delta = 1.0702\cos(3.94)$

$= 1.0675$

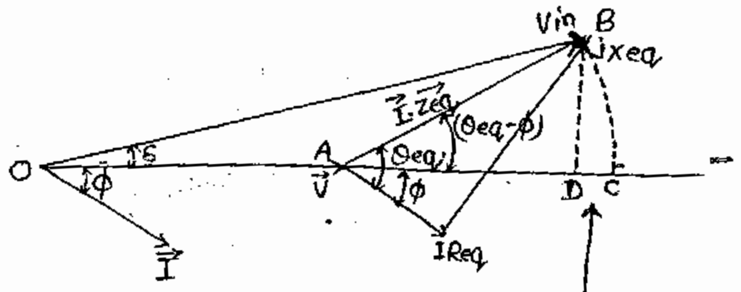
$VR^n = 1.0675 - 1$

$\% VR = 6.75\%$ → Previous value (0.8 PF lag)

$\%\ \text{error} = \frac{7.02 - 6.75}{7.02}$

$= 3.44\ \%$

* Approximate Regulation → (Graphical approach)



Neglected for calculation of approx. regn

$$\text{Actual } VR^n = \frac{OB - OA}{OA}$$

$$= \frac{OC - OA}{OA}$$

Since δ is very small; $V_{in}\cos\delta \approx V_{in}$

i.e. $OD \approx OC$

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 →

$$V_{in}\angle\delta = V\angle 0 + I\angle{-\phi} \times Z_{eq}\angle\theta_{eq}$$

$$= V + IZ_{eq}\cdot(\theta_{eq} - \phi)$$

$$V_{in}\cos\delta + jV_{in}\sin\delta = V + [IZ_{eq}\cdot\cos(\theta_{eq} - \phi)] + j[IZ_{eq}\sin(\theta_{eq} - \phi)]$$

equating Real parts

$$V_{in}\cos\delta = V + IZ_{eq}\cos(\theta_{eq} - \phi)$$

Since δ is very small

$V_{in}\cos\delta \approx V_{in}$ for caln of approx Regn

Then; $V_{in} = V + IZ_{eq}\cos(\theta_{eq} - \phi)$

$V_{in} - V = IZ_{eq}\cos(\theta_{eq} - \phi)$

approxi $Reg^n = \dfrac{V_{in} - V}{V}$

$= \dfrac{IZ_{eq}\cos(\theta_{eq} - \phi)}{V}$ ....

i.e. approx $Reg^n = Z_{pu}\cos(\theta_{eq} - \phi)$ (where ϕ is +ve for lagging PF)

*** Maximum Regulation →**

where $\theta_{eq} - \phi = 0$

$\phi = \theta_{eq}$

& $max^m\ reg^n = Z_{pu}$

& Corresponding $PF = \cos\phi$

$= \cos\theta_{eq}$ (lagging)

$= \dfrac{R_{ef}}{Z_{ef}}$ (lagging)

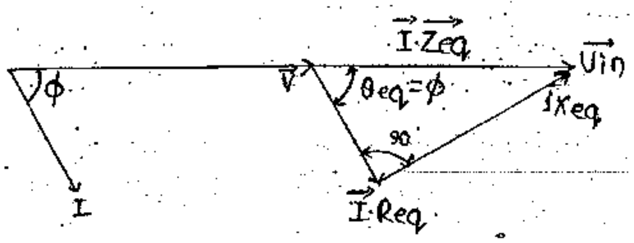


Fig:- Phasor dia. at max^m Regulation

$\boxed{\text{(No approximation is involved} \because \delta = 0)}$

*** Zero Reg^n (approxi $cond^n$) →**

when $\theta_{eq} - \phi = 90°$

$\phi = (\theta_{eq} - 90°)$ lagging

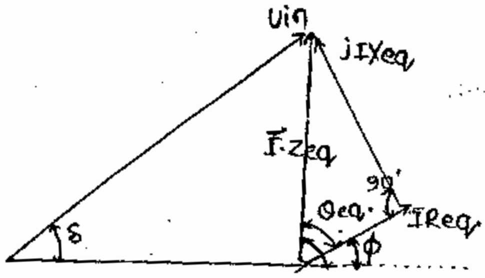
$= -(90 - \theta_{eq})$ lagging

$= (90 - \theta_{eq})$ 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) $\rightarrow$

Approximate cond^n $= Z_{pu}\cos(\theta_{eq} - \phi)$

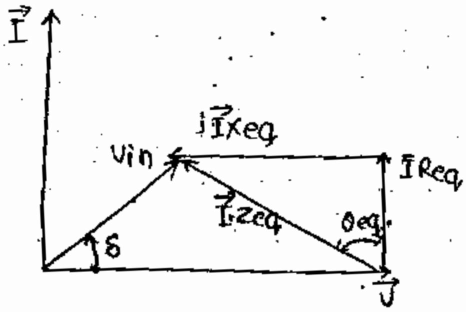
min Reg^n at $\phi = 90^\circ$ leading i.e. at zero PF leading

$$\text{min}^n\ \text{Reg}^n = Z_{pu}\cdot\cos[\theta_{eq} - (-90^\circ)]$$

$$= Z_{pu}\cdot\cos(\theta_{eq} + 90^\circ)$$

$$= -Z_{pu}\sin\theta_{eq}$$

$$= -X_{pu}$$



$*$ VR is a figure of merit of a TF & its low value is desired.

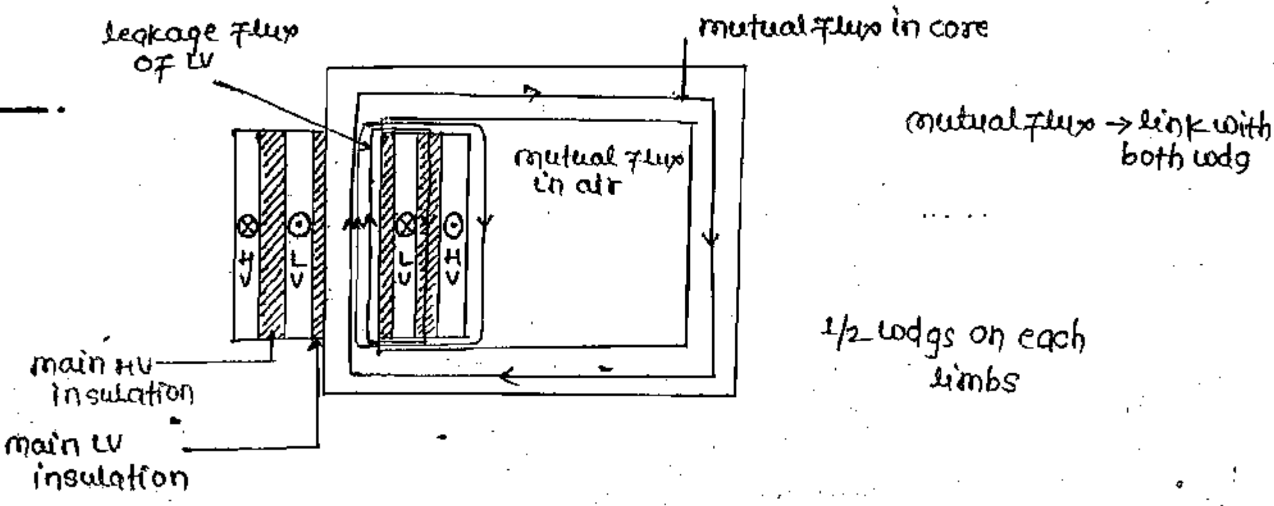
$*$ VR may be reduced by reducing the pu impedance of TF.

$*$ 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.

* Xpu can be reduced by reducing the leakage flux.



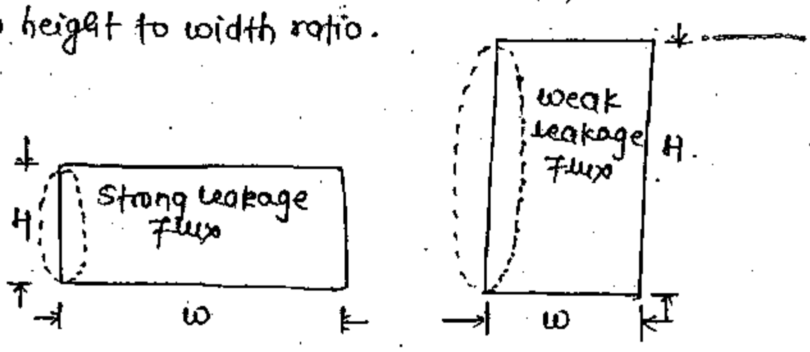
* Leakage flux can be reduced by keeping the wdgs physicaly close together.

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 $\eta = 50\%$

$$\eta = \frac{o/p}{o/p + \cancel{0.5}\underset{(1)}{}\,o/p}$$

$$\eta = \frac{o/p}{2\cancel{1.5}\,o/p}$$

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

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) $(I^2 R_{eq})$
  - 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)

$$\boxed{\eta = \frac{VI\cos\phi}{VI\cos\phi + I^2 R_{eq} + P_i}}$$

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 $S_{\eta_{max}} \rightarrow$

$$P_{cu} \propto S^2$$

$$\frac{P_{cu(\eta_{max})}}{P_{cu(j)}} = \left(\frac{S_{\eta_{max}}}{S_j}\right)^2$$

$$\sqrt{\frac{P_i}{P_{cu(j)}}} = \frac{S_{\eta_{max}}}{S_j}$$

$$\boxed{S_{\eta_{max}} = S_j \sqrt{\frac{P_i}{P_{cu(j)}}}}$$

$$\boxed{\eta_{max} = \frac{S_{\eta_{max}} \cos\phi}{S_{\eta_{max}} \cos\phi + 2P_i}}$$

DATE-06/11/14

All Day efficiency (OR) Energy efficiency

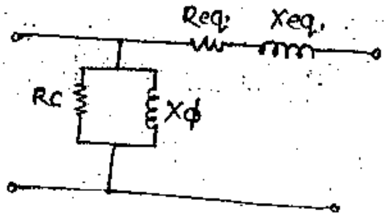
$$\eta_{all\text{-}day} \triangleq \frac{\text{o/p kwh in 24 hrs}}{\text{I/p kwh in 24 hrs.}}$$

$$= \frac{\text{o/p kwh in 24 hrs.}}{\text{o/p kwh in 24 hrs.} + P_{cu}(\text{kwh}) \text{ in 24 hrs.} + P_i(\text{kwh}) \text{ in 24 hrs.}}$$

(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 regn at a lagging PF of 0.8 is 5%.

Soln→

$$0.97 = \frac{VI}{VI + P_c + P_i} \qquad 0.97 = \frac{(0.6)^2 VI}{(0.6)VI + \frac{P_c}{(0.6)} + P_i}$$

$$0.05 = \frac{V_{in} - V}{V}$$

$$\frac{0.97}{200k} = \frac{1}{200k + P_c + P_i} \qquad \frac{0.97}{0.6 \times 200 \times 10^3} = \frac{1}{0.6 \times 200 + 0.36 P_c + P_i}$$

$$P_c + P_i = 6.186 \times 10^3 \qquad 0.36 P_c + P_i = 3.711 \times 10^3$$

$$P_c = 3865.625 \text{ w}$$

$$P_i = 2319.375 \text{ w}$$

$$0.97 = \frac{1 \times 1.0}{1 \times 1.0 + P_{c(FL)} + P_i} \qquad P_{c(FL)} + P_i = 0.0309 \text{ PU} \text{ ---(i)}$$

$$0.97 = \frac{0.6 \times 1.0}{0.6 \times 1.0 + (0.6)^2 P_{c(FL)} + P_i} \qquad 0.36 P_{c(FL)} + P_i = 0.0186 \text{ PU} \text{ ---(ii)}$$

Solving eq^n (i) & (2)

$$P_i = 0.0117\,PU \qquad P_{c(FL)} = 0.0192\,PU$$

$$P_{c(FL)} = R_{PU} = 0.0192\,PU \qquad \boxed{R_{PU} = 0.0192\,PU}$$

$$VR^n = 0.05\,PU = R_{PU}\cos\phi + X_{PU}\sin\phi$$

$$0.05 = 0.0192 \times 0.8 + X_{PU}\,0.6$$

$$X_{PU} = 0.0577\ PU \qquad \boxed{X_{PU} = 0.577\,PU}$$

$$P_i = \frac{V^2}{R_{C(PU)}}$$

$$R_{C(PU)} = \frac{V^2}{P_i}$$

$$0.0117 = \frac{1^2}{R_{C(PU)}} \qquad \boxed{R_{C(PU)} = 85.47\,PU}$$

Given; $\cos\phi_o = 0.25$

$$\phi_o = 75.5224^\circ$$

$$X_{\phi(PU)} = \frac{R_{C(PU)}}{\tan\phi_o} \qquad \because \tan\phi = \frac{R}{X}$$

$$X_{\phi(PU)} = \frac{65.47}{\tan(75.52)^\circ} = 22.07\,PU \qquad \boxed{X_{\phi(PU)} = 22.07\,PU}$$

$$Z_{Base(LV)} = \frac{(400)^2}{200 \times 10^3} = 5\Omega$$

Actual Ω = PU value × Base impedance

$$X_{\phi}(act) = 22.07 \times 5 = 110.35\Omega$$

$$R_C(act) = 85.47 \times 5 = 427.15\Omega$$

$$X_{eq}(act) = 0.0577 \times 5 = 0.2885\Omega$$

$$R_{eq}(act) = 0.0192 \times 5 = 0.096\Omega$$

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 regn at 0.8 PF lagging.

Soln→

$$\cancel{0.97} = \cancel{0.75} = 0.97 = \frac{0.75\times 1}{0.75\times 1 + 2\times P_c}$$

$$P_i = P_c = 0.0115\,PU = P_{c(75\%)}$$

$$I_{\eta max} = \sqrt{\frac{P_i}{R_{eq}}}$$

$$\cancel{S_{\eta max} = 0.01}$$

$$P_{cu(FL)} = \frac{P_{cu(75\%)}}{(0.75)^2}$$

$$= \frac{0.0116}{(0.75)^2}$$

$$= 0.0206\,PU$$

$$Z_{PU} = 0.1 \angle \cos^{-1}\frac{0.0206}{0.1}$$

$$Z_{PU} = 0.10\angle 78.11°\,PU$$

$$Reg^n = Z_{PU}\cos(\theta_{eq} - \phi)$$

$$= 0.10\cos\left[78.11 - \cos^{-1}(0.8)\right]$$

$$Reg^n = 0.0752\,PU$$

$$= 7.52\%$$

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, 0.6 PF lead

(3.) 5hrs: No load

(4.) 9hrs: 225 kVA · UPF

Cal. the all day η of TF.

Sol^n →

$$0.986 = \frac{350 \times 1.0}{350 \times 1.0 + 2P_i}$$

$P_i = 2.4848$ kW $= P_{cu}(350)$

6hrs:-

O/p kWh $= (300 \times 0.8) \times 6$hrs $= 1440$ kWh

$$P_{cu}(\text{kWh}) = \left[2.4848 \times \left(\frac{300}{350}\right)^2\right] \times 6$$

$= 10.953$ kWh

4hrs:-

O/p kWh $= 240 \times 4 = 960$ kWh.

$$P_{cu}(\text{kWh}) = 2.4848 \times \left[\frac{(240/0.6)}{350}\right]^2 \times 4$$

$= 12.982$ kWh

5hrs:-

O/p kWh $= 0$; $P_{cu}(\text{kWh}) = 0$

9hrs:-

O/p kWh $= (225 \times 1.0) \times 9 = 2025$ kWh.

$$P_{cu}(\text{kWh}) = \left[2.4848 \times \left(\frac{225}{350}\right)^2\right] \times 9$$

$= 9.242$ kWh.

Total during the day (24 hrs.)

O/p kWh $= 442.5$ kWh

$P_{cu}(\text{kWh}) = 33.177$ kWh

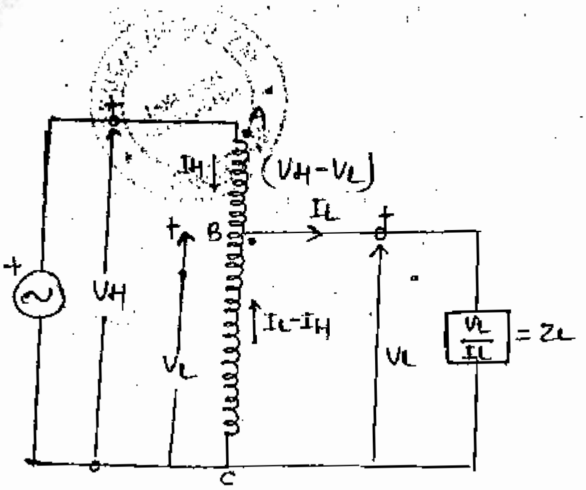
$P_i(\text{kWh}) = 2.4848 \times 24 = 59.6352$ kWh

$$\eta_{\text{all-day}} = \frac{442.5}{442.5 + 33.177 + 59.6352}$$

$= 0.9795$ 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

$\downarrow \qquad\qquad \downarrow$

$\propto I \qquad\qquad \propto N$

$\propto NI$

$\propto$ mmF

$$\therefore \frac{Cu(auto)}{Cu(2wdg)} = \frac{(N_H - N_L)I_H + N_L(I_L - I_H)}{N_H I_H + N_L I_L}$$

$$= \frac{N_H I_H - N_L I_H + N_L I_L - N_L I_H}{2 N_H I_H}$$

$$= \frac{2N_H I_H - 2N_L I_H}{2N_H I_H}$$

$$= \frac{N_H - N_L}{N_H}$$

$$= 1 - \frac{N_L}{N_H}$$

$$\boxed{\frac{Cu(auto)}{Cu(2wdg)} = \left[1 - \frac{1}{a(auto)}\right]}$$

$$Cu\text{-}saving = \frac{Cu(2wdg) - Cu(auto)}{Cu(2wdg)}$$

$$= 1 - \frac{Cu(auto)}{Cu(2wdg)}$$

$$= 1 - \left[1 - \frac{1}{a(auto)}\right]$$

$$\boxed{\% Cu\ saving = \frac{1}{a(auto)} \times 100\%}$$

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

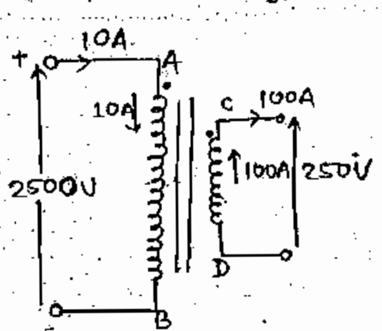
$$S_{BC} = V_L(I_L - I_H)$$
$$= V_L I_L - V_L I_H$$
$$= V_H I_H - V_L I_H$$
$$= (V_H - V_L) I_H$$
$$S_{BC} = S_{AB}$$

Ratio →

$$\frac{S(\text{cond})}{S(\text{Total})} = \frac{V_L I_H}{V_L I_L} = \frac{I_H}{I_L} = \frac{1}{a(\text{auto})} = Cu(\text{saving})$$

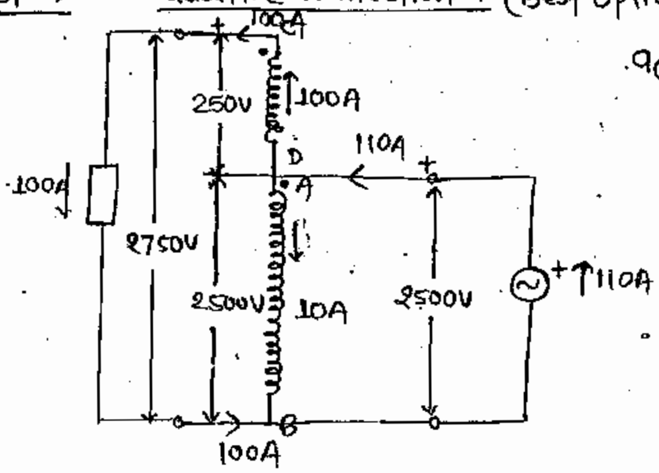
$$\frac{S(\text{ind})}{S(\text{Total})} = 1 - \frac{1}{a(\text{auto})}$$

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)



$$a(\text{auto}) = \frac{2750}{2500} = 1.1$$

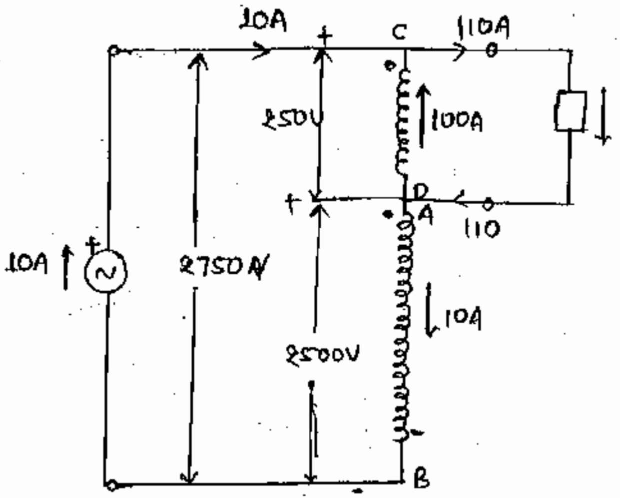
$S_{auto} = 2750 \times 100$ (OR) 2500×110

$= 275$ KVA

Given → 25 KVA → Inductive tra

$\frac{250}{275}$ KVA → ~~Capacitive~~ Conductive

(Bad option)

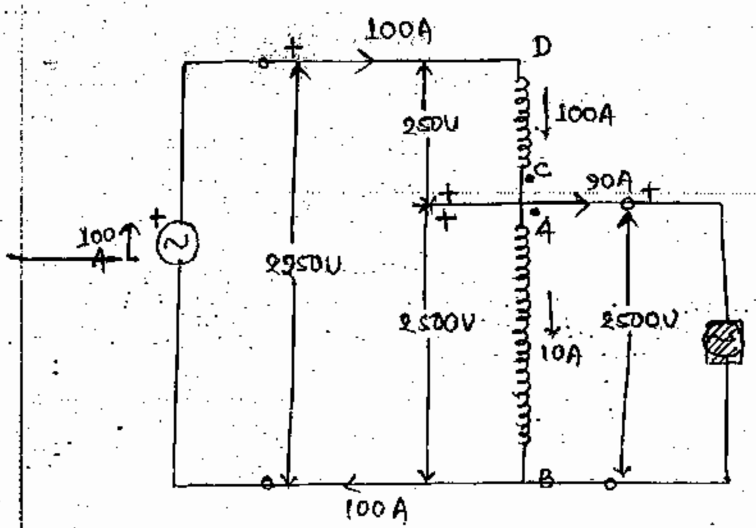


$a_{(auto)} = \frac{2750}{250} = 11$

$S_{(auto)} = 2750 \times 10$ (OR) 250×110

$= 27.5\,kVA$

Subtractive connection → (Good option)



$a_{(auto)} = \frac{2500}{2250} = 1.111$

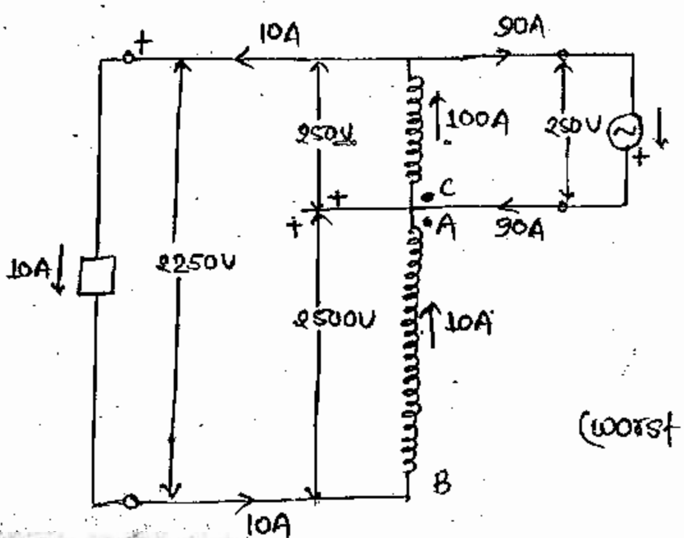
$S_{auto} = 2500 \times 90$ & 2250×100

$= 225\,kVA$

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)

$$a_{(auto)} \simeq 1 \rightarrow S_{(auto)} = [a_{(2wdg)} \pm 1] \times S_{(2wdg)}$$

$$a_{(auto)} > 1 \rightarrow S_{(auto)} = \left[1 \pm \frac{1}{a_{(auto)}}\right] \times S_{(2wdg)}$$

- 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 2 ckts.
  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 →

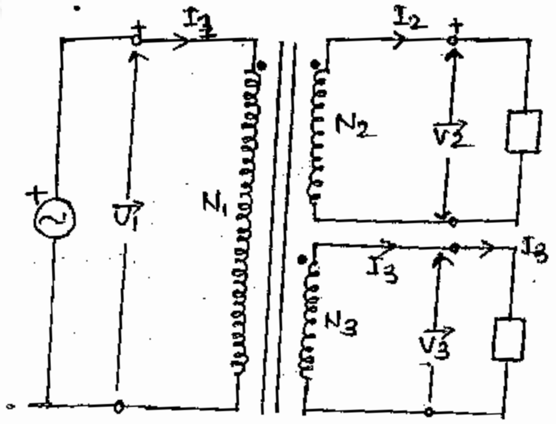
(1) To connect 2 power sys. of diff vol. levels where the vol. ratio is close to 1 & usualy limited to 2.
eg:- 765kv/400kv, 400/220kv & 220kv/132kv etc.

(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. appliccations (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 →

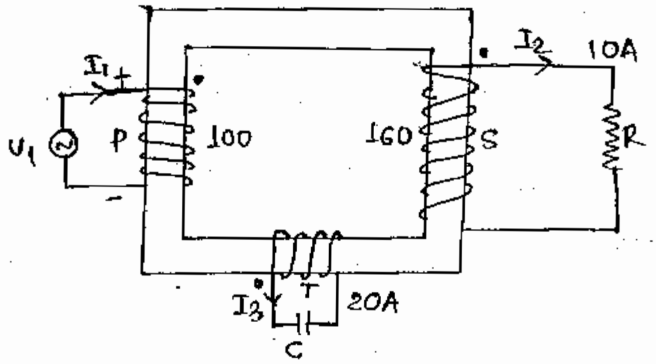
$$\vec{I_1} = \frac{N_2}{N_1}\vec{I_2} + \frac{N_3}{N_2}\times\vec{I_3}$$

$$= \frac{2}{10}\times 45\angle\cos^{-1}0.8 + \frac{1}{10}\times 50\angle\cos^{-1}(0.71)$$

$$= 13.97\angle -39.69°A$$

$$1° \; PF = \cos(39.69) = 0.7695 \text{ (lagging)}$$

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.

Sol^n→ 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 - 08/01/14

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.

UNIT-VI

3-PHASE TRANSFORMERS

3-ϕ transformers

$v = V_m \sin\omega t$; $i = I_m \sin(\omega t - \phi)$

$P = \frac{dw}{dt}$ $\quad w = qv$

$= v\frac{dq}{dt}$

$= vi$

$P_{(1-\phi)} = v.i$

$= V_m \sin\omega t . I_m \sin(\omega t - \phi)$

$= \frac{V_m I_m}{2} . 2\sin\omega t . \sin(\omega t - \phi)$

$= \frac{V_m}{\sqrt{2}} . \frac{I_m}{\sqrt{2}} \left[\cos(\cancel{\omega t} - \cancel{\omega t} + \phi) - \cos(\omega t + \omega t - \phi) \right]$

$= V.I \left[\cos\phi - \cos(2\omega t - \phi) \right]$

$$\boxed{P_{(1-\phi)} = V.I\cos\phi - VI.\cos(2\omega t - \phi)}$$

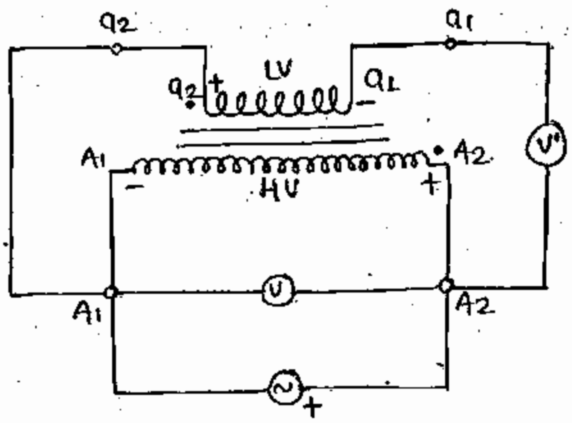
So; a 1-ϕ power suffers from double freq. component.

3000 kVA

option 1: 1 x 3000 kVA, 3-ϕ unit

option 2: 3 x 1000 kVA, 1-ϕ TF connected in 3-ϕ bank

POLARITY TEST



V' > V

Fig:- additive polarity

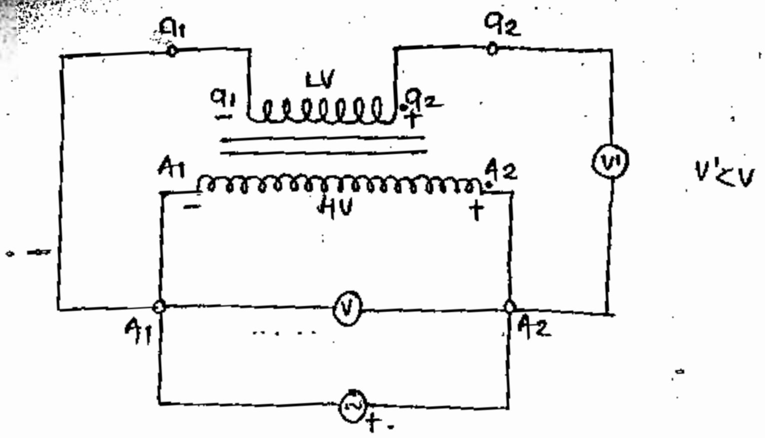


Fig :- Subtractive polarity.

* Phasor Groups →

Group (1) :- 0° → Yy0, Dd0, Dz0

Group (2) :- 180° → Yy6, Dd6, Dz6

Group (3) :- 30° (lag) → Yd1, Dy1, Yz1

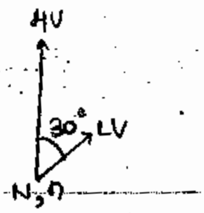
Group (4) :- 30° (lead) → Yd11, Dy11, Yz11

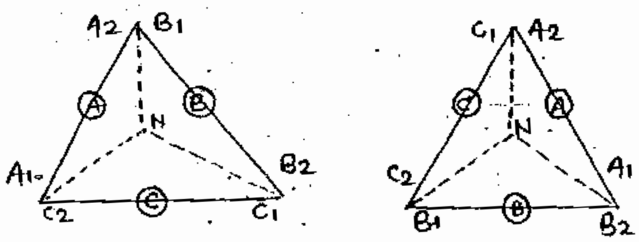
Y d 1

Y → HV is star

d → LV is delta

1 → Face of the clock





* British Practise for phasor groups →

(1.) Phasor seq. in ABC.

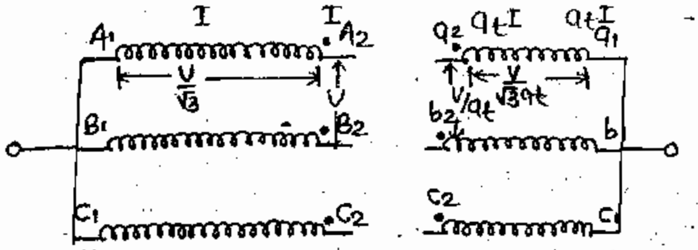
(2.) HV line (A-N) phasor always at 0 o'clock.

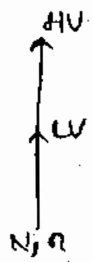
(3.) HV line 'A' terminal to be taken from A_2

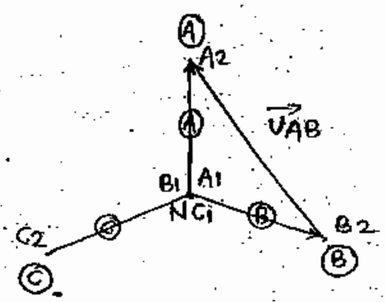
(4.) $\vec{V}_{a_2a_1}$ is in phase with $\vec{V}_{A_2A_1}$.

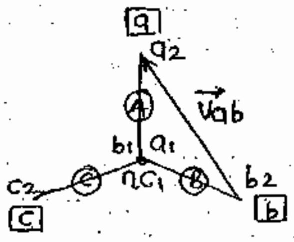
Yy0 →

$a_t = \frac{N_{HV}}{N_{LV}}$









$V_{AB} = V_{AN} - V_{BN}$

$V_{AN} = V_{AB} + V_{BN}$

Phase vol. transformation Ratio $= \frac{V}{\sqrt{3}} : \frac{V}{\sqrt{3}a_t} = a_t : 1$

line vol. transformation Ratio $= V : \frac{V}{a_t} = a_t : 1$

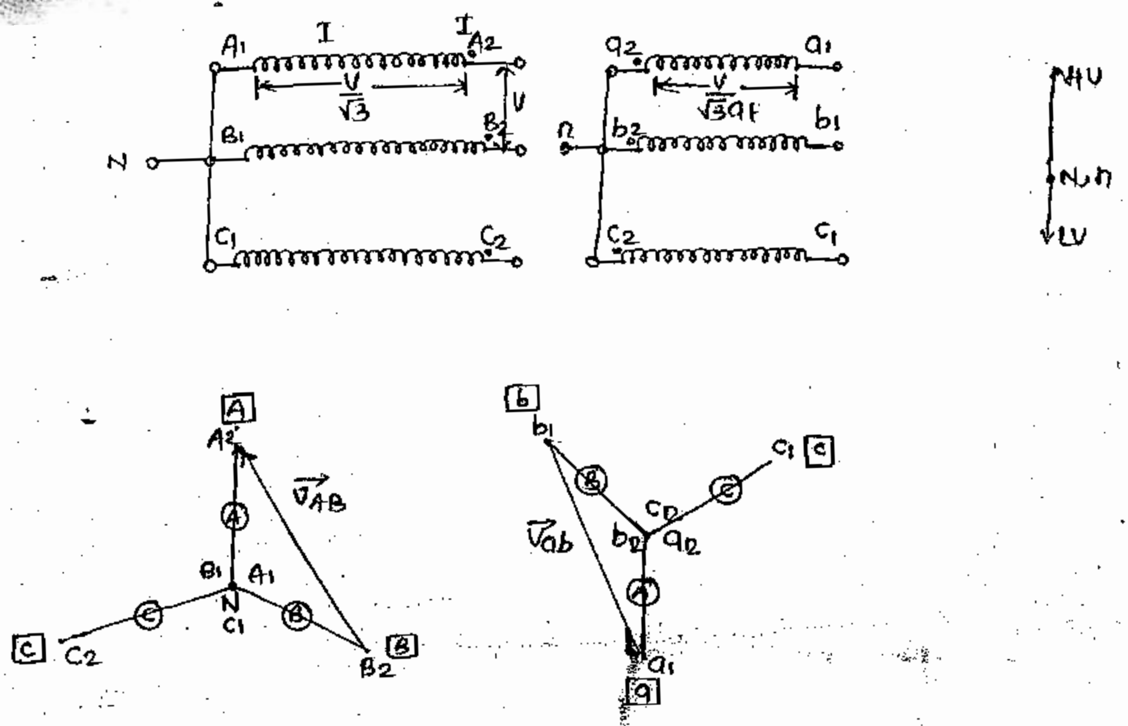
$S_{HV} = \sqrt{3} V I$ $\qquad S_{LV} = \sqrt{3}\left(\frac{V}{a_t}\right)(a_t I)$

$= \sqrt{3} V I$

$= S_{HV}$

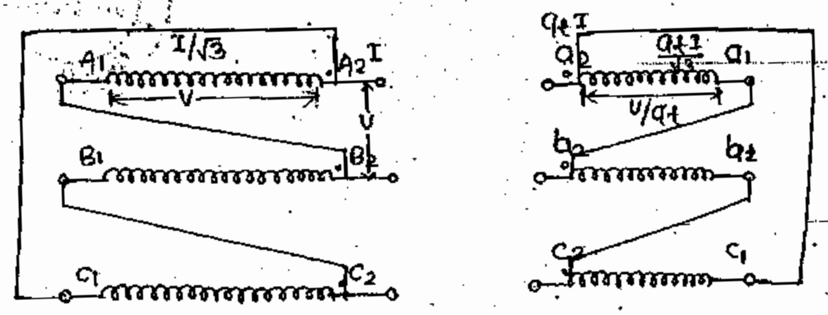
$\boxed{S_{LV} = S_{HV}}$

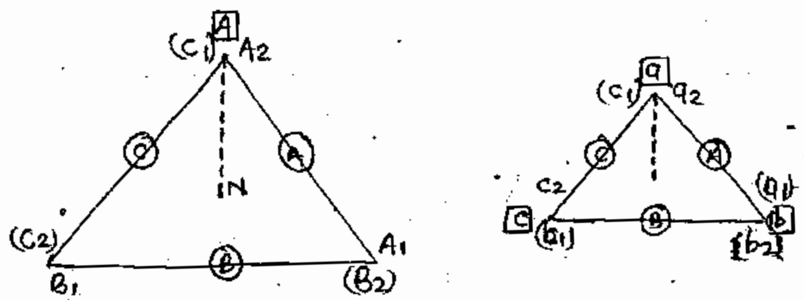
Yy6 →



Dd0 →

* The British convention 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 $= V : \frac{V}{at} = at : 1$

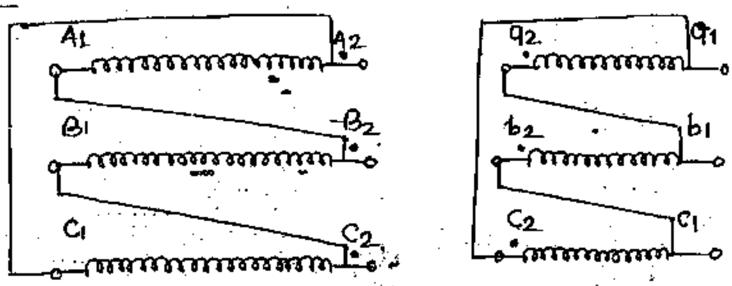
line vol. Xmation ratio $= V : \frac{V}{at} = at : 1$

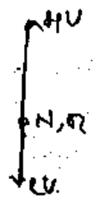
$S_{HV} = \sqrt{3} VI$ $\qquad S_{LV} = \sqrt{3}\left(\frac{V}{at}\right)(aI)$

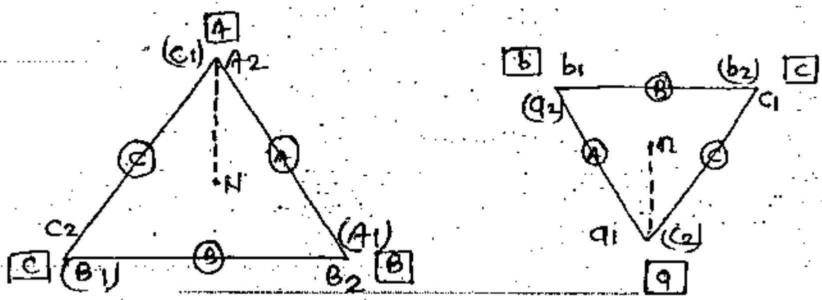
$= \sqrt{3} VI$

$\boxed{S_{LV} = S_{HV}}$

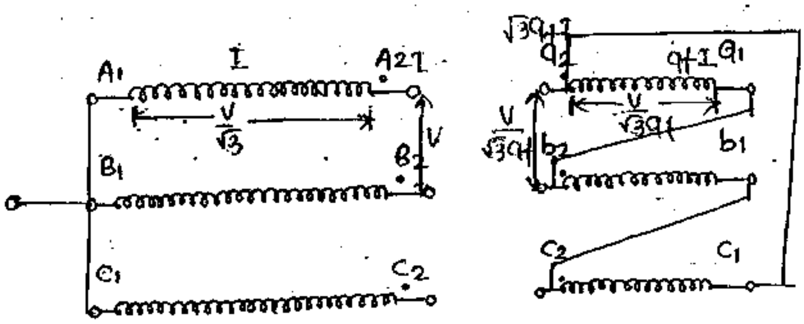
Dd6 →







Yd1 →



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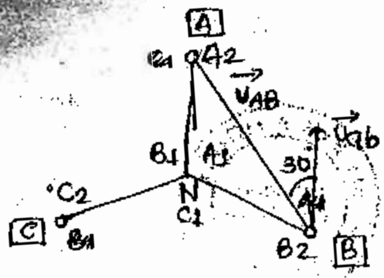
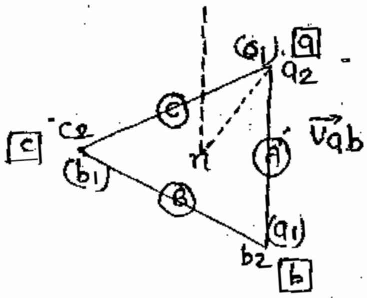




Phase vol. Xmation Ratio $= \frac{V}{\sqrt{3}} : \frac{V}{\sqrt{3}a_t} = a_t : 1$

line vol. Xmation Ratio $= V : \frac{V}{\sqrt{3}a_t} = \sqrt{3}a_t : 1$

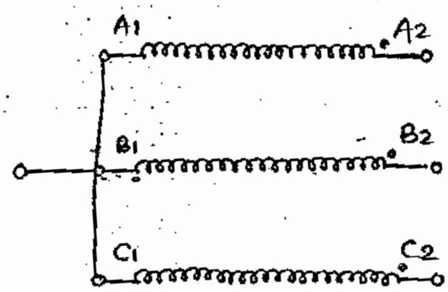
$S_{HV} = \sqrt{3}\,VI$

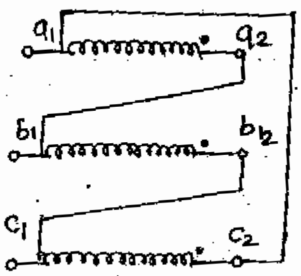
$S_{LV} = \sqrt{3}\left(\frac{V}{\sqrt{3}a_t}\right)\cdot(\sqrt{3}a_t I)$

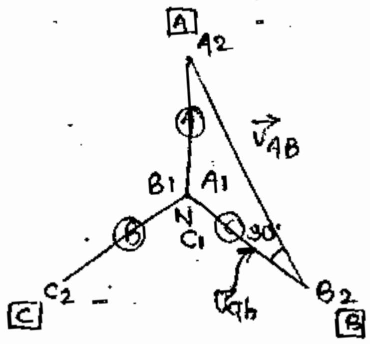
$= \sqrt{3}\,VI$

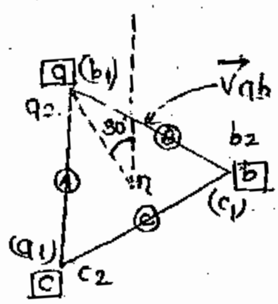
$S_{LV} = S_{HV}$

Yd11 →

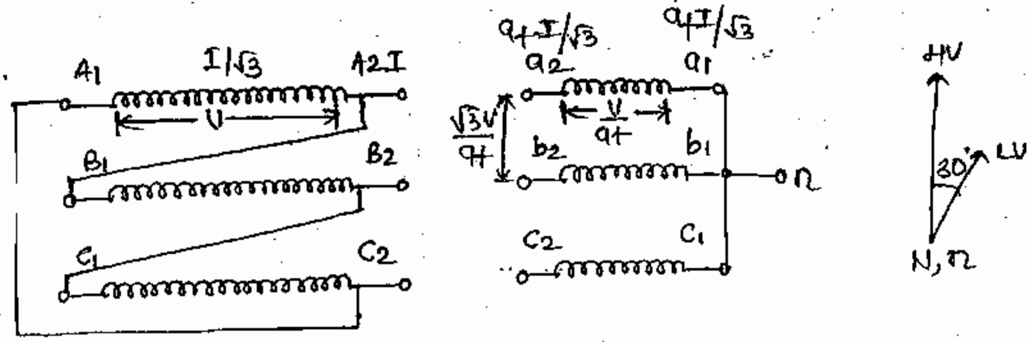


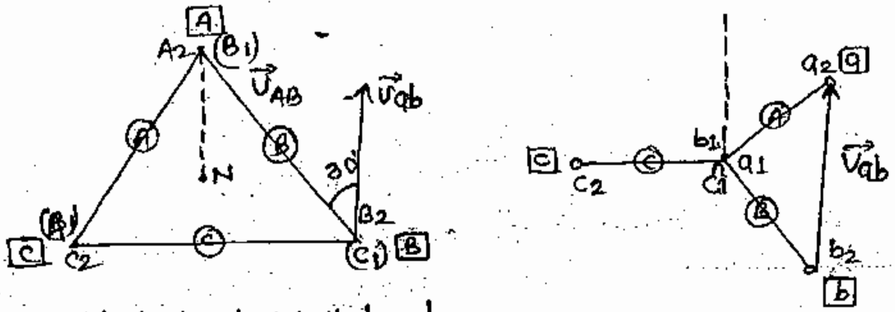






Dy1 →





Hint → Δ limb is decided by λ

Phase vol. Xmation Ration $= V : \frac{V}{a_t} = a_t : 1$

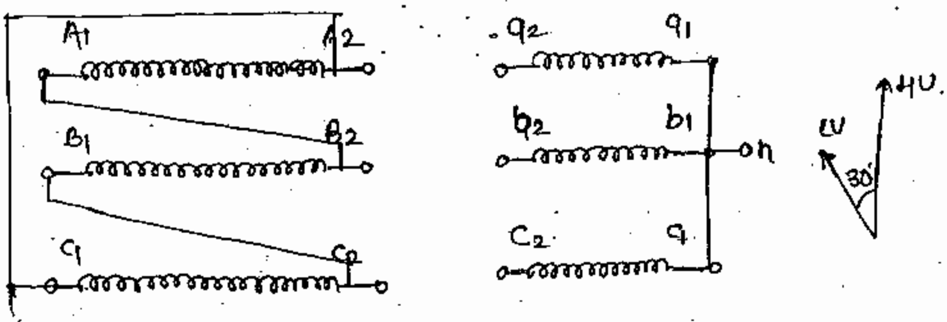
line vol. Xmation Ratio $= V : \frac{\sqrt{3}V}{a_t} = \frac{a_t}{\sqrt{3}} : 1$

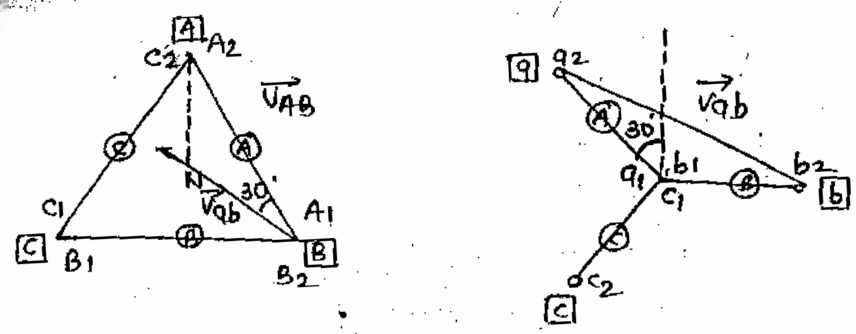
$S_{HV} = \sqrt{3}VI$ $\quad S_{LV} = \sqrt{3}\left(\frac{\sqrt{3}V}{a_t}\right)\left(\frac{a_t I}{\sqrt{3}}\right)$

$= \sqrt{3}VI$

$S_{LV} = S_{HV}$

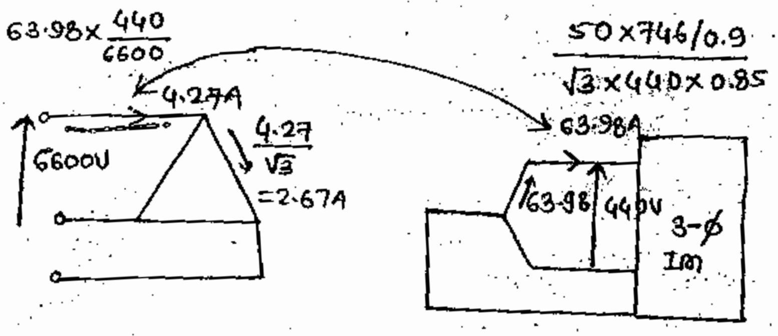
Dy11 →





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 windgings 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→

$$I_1 N_1 = I_2 N_2 - I_3 N_3 - I_0 N_1$$

$$I_1 = I_2 \frac{N_2}{N_1} - I_3 \frac{N_3}{N_1} - I_0$$

$$\vec{S}_1 = \sqrt{3} \times 11 \times I_1 \angle \cos^{-1}(0.82) \text{ kVA}$$

$$\vec{S}_2 = 600 \angle \cos^{-1}(0.8) \text{ kVA} = 600 \angle 36.87 \text{ kVA}$$

$$S_3 = \frac{150}{\cos\phi_3} \angle \phi_3 \text{ kVA} \quad \text{(assuming lag. PF } 3^\circ \text{load)}$$

$$S_0 = \sqrt{3} \times 11 \times 3 \angle 90^\circ \text{ kVA}$$
$$= 57.158 \angle 90^\circ \text{ kVA}$$

$$S_3 = \frac{150}{\cos\phi_3} \angle \phi_3$$

$$= \frac{150(\cos\phi_3 + j\sin\phi_3)}{\cos\phi_3}$$

$$S_3 = 150(1 + j\tan\phi_3)$$

$$S_1 = S_2 + S_2 + S_0$$

$$\sqrt{3}\, 11 \times I_1 \angle \cos^{-1}(0.89) = 600 \angle \cos^{-1}(0.8) + (150 + j150\tan\phi_3) + \sqrt{3} \times 11 \times 3 \angle 90^\circ$$

$$15.623 I_1 + j10.905 I_1 = 630 + j\left[360 + 150\tan\phi_3 + 33\sqrt{3}\right]$$

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 recommondation 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.

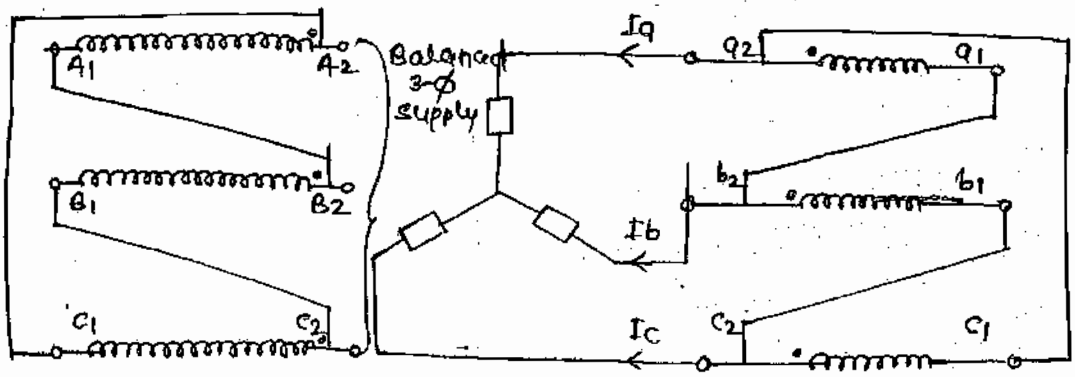
  Therefore a Δ-λ connection is used in the step down mode in 2° distribution TF.

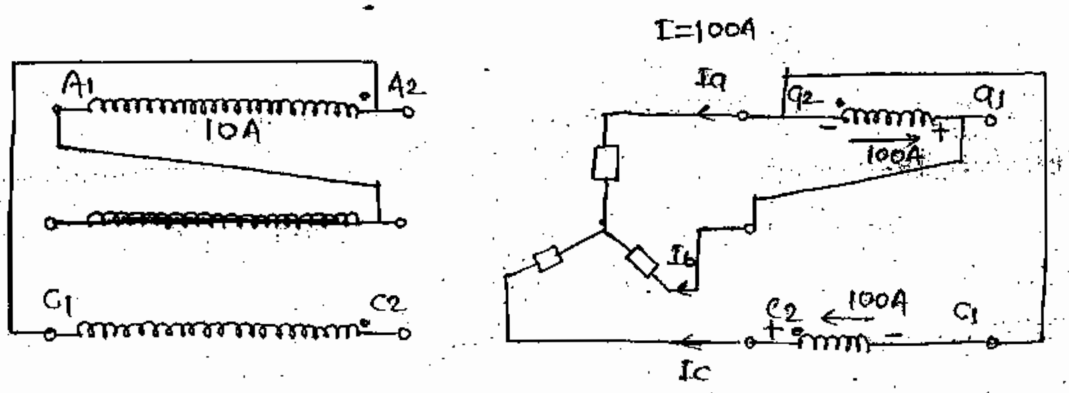
* A Δ-Δ connection is quite suitable to feed 3-ϕ loads of high capacity at LV levels.

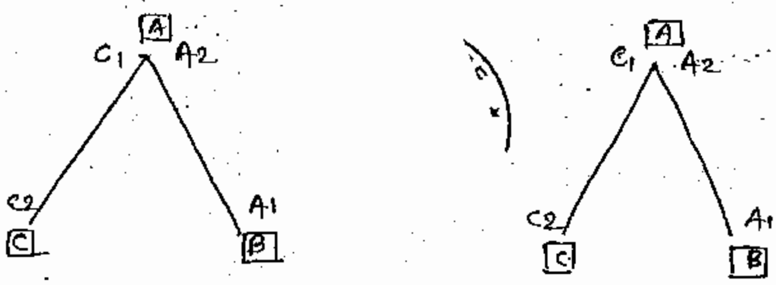
  If a 3-ϕ bank of 1-ϕ TF is used in Δ-Δ & if one TF has to be removed then the remaining 2 TF may still be used in open Δ (or V) connection to continue to supply 3-ϕ loads although at a reduced capacity of 57.7%.

* 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







$$S_{\Delta\text{-}\Delta} = \sqrt{3}\, V \cdot I$$

$$S_L = \sqrt{3}\, VI \angle\phi$$

$$S_{Vee} = \sqrt{3} \cdot V \left(\frac{I}{\sqrt{3}}\right)$$

$$= VI$$

$$\frac{S_{Vee}}{S_{\Delta\Delta}} = \frac{VI}{\sqrt{3}\, VI}$$

$$= \frac{1}{\sqrt{3}} = 0.577$$

$$\boxed{\frac{S_{Vee}}{S_{\Delta\Delta}} = 57.7\%}$$

$\vec{S_C} = VI\angle\phi+30^\circ = \frac{S_L}{\sqrt{3}}\angle\phi+30^\circ$

$\vec{S_A} = VI\angle-(30-\phi)$

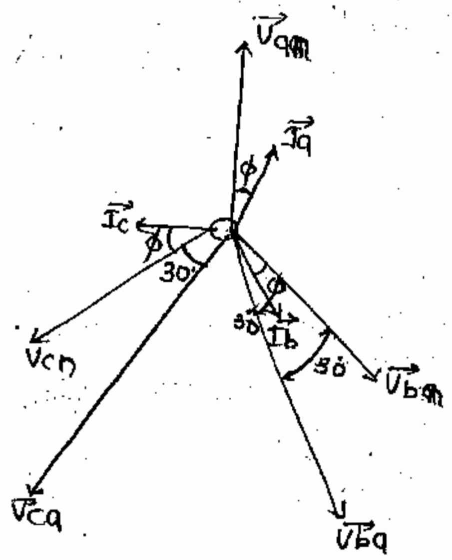
$\vec{S_A} = VI\angle\phi-30^\circ = \frac{S_L}{\sqrt{3}}\angle\phi-30^\circ$

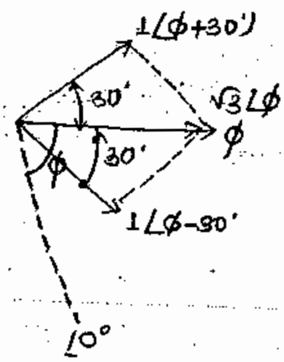
$\vec{S_C}+\vec{S_A} = VI[1\angle\phi+30^\circ + 1\angle\phi-30^\circ]$

$= VI[\sqrt{3}\angle\phi]$

$= \sqrt{3}VI\angle\phi$

$\boxed{S_C + S_A = \vec{S}_{load}}$





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.

Soln→

$\phi = \cos^{-1}(0.866)$

$= 30^\circ$ lag

$\vec{S_C} = \frac{1000}{\sqrt{3}}\angle 30+30^\circ$

$= 0.577\angle 60^\circ$ kVA

at PF 0.5 lag.

$\vec{S_A} = \frac{1000}{\sqrt{3}}\angle 30-30$

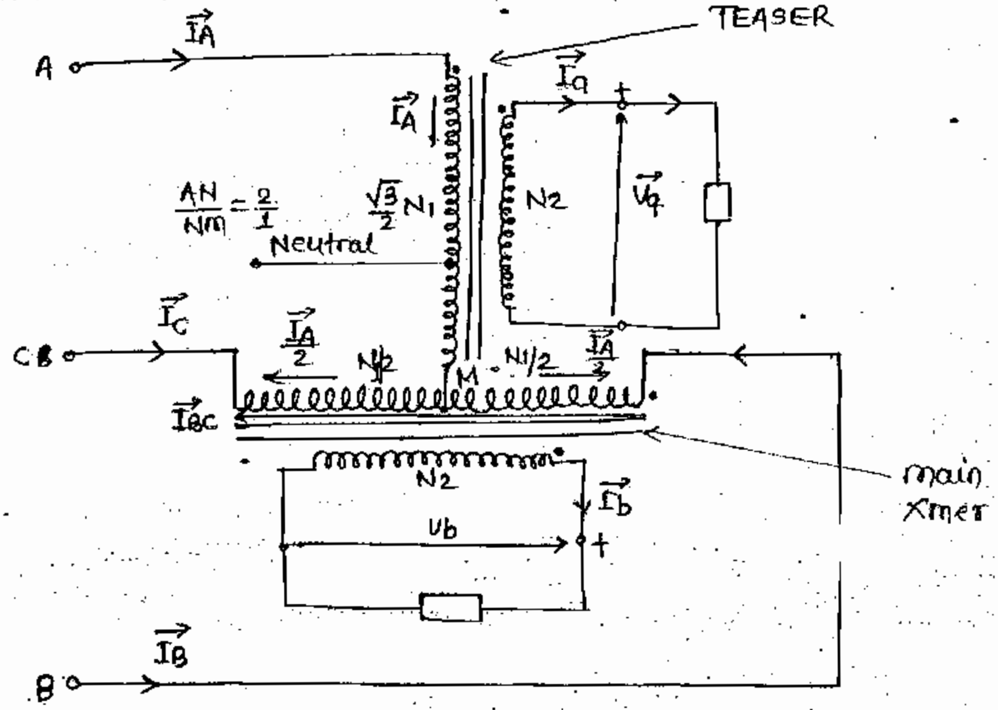
$= 0.577\angle 0^\circ$

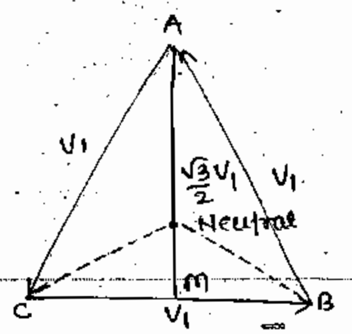
at PF = 0

DATE: 29/11/14

SCOTT CONNECTION

* Scott connection for 3-ϕ to 2-ϕ conversion.





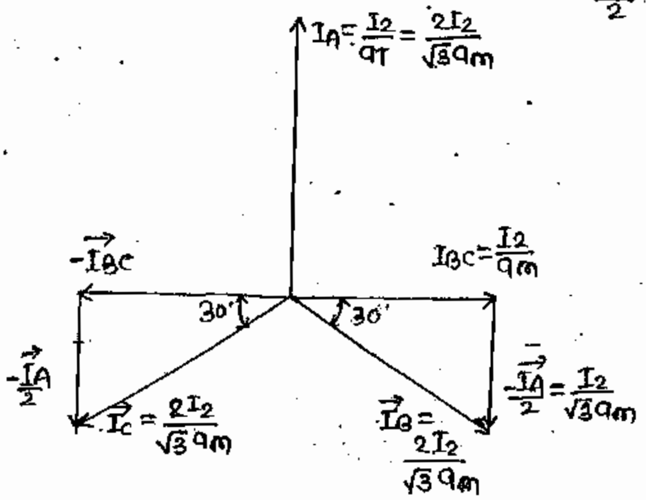
$$a_m = \frac{N_1}{N_2}$$

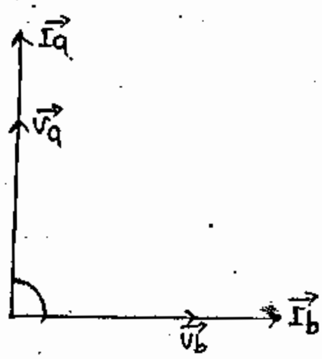
$$a_T = \frac{\sqrt{3}N_1/2}{N_2} = \frac{\sqrt{3}}{2}a_m$$

$$V_b = \frac{V_1}{a_m} \; ; \; V_a = \frac{\sqrt{3}V_1/2}{a_T} = \frac{\sqrt{3}V_1/2}{\sqrt{3}a_m/2}$$

$$V_a = \frac{V_1}{a_m} = V_b$$

$$\vec{I_B} = \vec{I_{BC}} - \frac{\vec{I_A}}{2} \; ; \; I_C = -I_{BC} - \frac{\vec{I_A}}{2}$$





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) $$a_m = \frac{N_1}{N_2} = \frac{6600}{80}$$

$$a_m = 82.5 \qquad a_T = \frac{\sqrt{3}}{2} a_m = \frac{\sqrt{3}}{2} \times 82.5 = 71.45$$

$$a_m = 82.5, \; a_T = 71.45$$

$$I_b = \frac{800 \times 10^3}{80 \times 0.8} \angle -\cos^{-1}(0.8) = 12500\angle -36.87^\circ A.$$

$$I_a = \frac{800 \times 10^3}{80 \times 0.8} \angle 90 - \cos^{-1}(0.8)$$

$$I_a = 12500\angle 53.13^\circ A$$

$$\vec{I}_{BC} = \frac{\vec{I}_b}{a_m} = 151\angle -36.87 A, \quad \vec{I}_A = \frac{I_a}{a_T} = 174.95\angle 53.13^\circ A$$

$$\vec{I}_B = \vec{I}_{BC} - \frac{\vec{I}_A}{2} \qquad I_C = -I_{BC} - \frac{I_A}{2}$$

$$= 174.96\angle -66.87^\circ A \qquad = 174.96\angle 173.13^\circ A$$

$$\boxed{I_A = 174.95\angle 53.13^\circ A, \; I_B = 174.96\angle -66.87^\circ A \quad I_C = 174.96\angle 173.13^\circ A}$$

(b) $\vec{I_b} = \dfrac{800\times10^3}{80\times0.707} \angle -\cos^{-1}(0.707)$ $\qquad$ $\vec{I_q} = \dfrac{500\times10^3}{80\times1.0} \angle 90^\circ$

$= 14144.27\angle -45^\circ A$ $\qquad$ $= 6250\angle 90^\circ A$

$$\vec{I_{BC}} = \frac{\vec{I_{b}}}{9m} = 171.45\angle -45^\circ A$$

$$\vec{I_A} = \frac{\vec{I_a}}{9T} = 87.47\angle 90^\circ A$$

$$\vec{I_B} = \vec{I_{BC}} - \frac{\vec{I_A}}{2} = 204.72\angle -53.69^\circ A$$

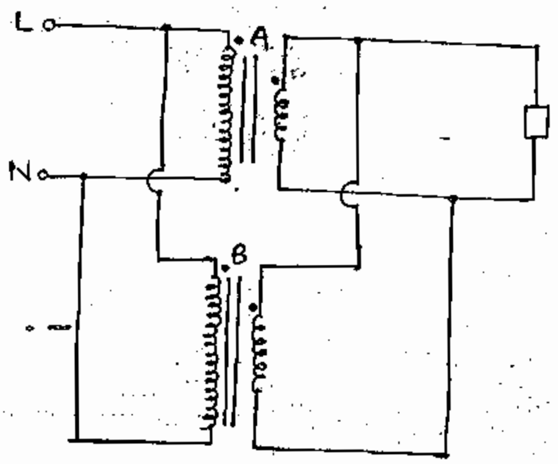
$$\vec{I_C} = -\vec{I_{BC}} - \frac{\vec{I_A}}{2} = 143.89\angle 147.47^\circ A$$

Parallel Operation OF Transformer

Cond^n to be satisfied for parallel operation of Xmer →

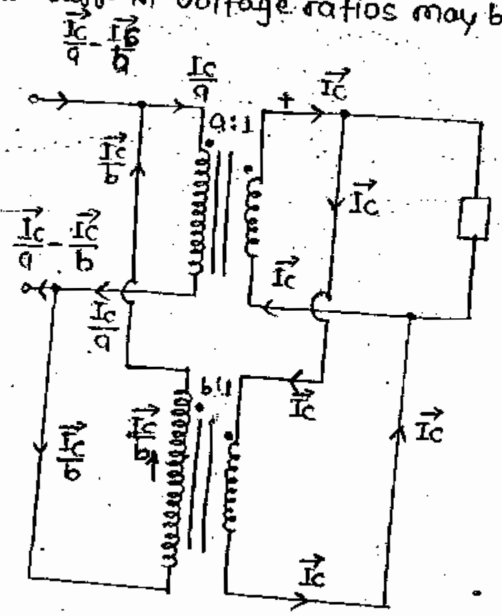
(A.) For 1-φ TF & 3-φ TF →

(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)

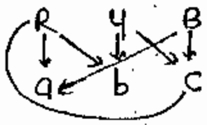
↓

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 corresponding line voltage.

This means that TF belonging to same phasor group may alone be parallel. (MUST)

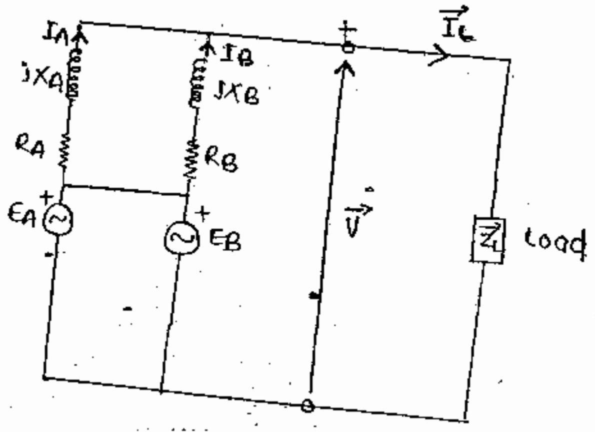
Dy11 (a) Yy0 (b) Dd0 (c) Yy6 (d) Yd1

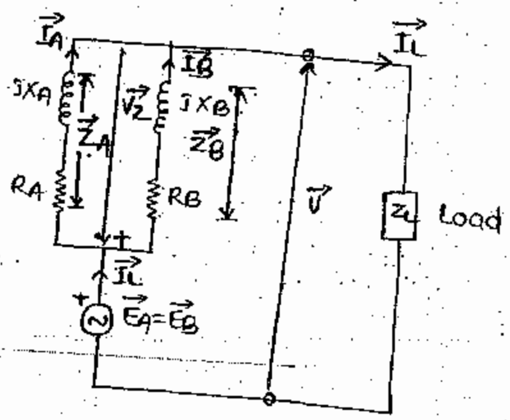
Because if we change the seq. of 1° then get 30° lead/ lag.

LOAD SHARING

Equal voltage Ratios

$E_A = E_B$





Two Xmer;

$$\vec{V_Z} = \vec{I_A}\vec{Z_A} = \vec{I_B}\vec{Z_B} = \vec{I_L} \times \vec{Z_{PJ}}$$

$$= I_L \times \frac{\vec{Z_A}\vec{Z_B}}{\vec{Z_A}+\vec{Z_B}}$$

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 →

$$\vec{V_z} = \vec{I_A}\vec{z_A} \pm \vec{I_B}\cdot\vec{z_B} = \vec{I_C}\vec{z_C} \text{ ------ } = \vec{I_n}\vec{z_n} = \vec{I_L}\times\vec{z_p}$$

$$\Rightarrow \vec{I_A}\vec{Z_A} = \vec{I_L}\times\vec{z_p}.$$

$$\Rightarrow \vec{I_L} = \cancel{\vec{I_A}}/\cancel{\frac{\vec{Z_B}}{Z_A}} = \frac{\vec{I_A}.\vec{Z_A}}{z_p}$$

$$\Rightarrow \cancel{\frac{\vec{I_A}\vec{Z_A}}{\left(\frac{1}{Z_A}+\frac{1}{Z_B}+\frac{1}{Z_C}+\cdots\frac{1}{Z_n}\right)}} \cancel{= \vec{I_L}}$$

$$\vec{I_A}\vec{Z_A} = \frac{\vec{I_L}}{\left(\frac{1}{Z_A}+\frac{1}{Z_B}+\cdots\frac{1}{Z_n}\right)}$$

$$\vec{I_A} = \frac{\vec{I_L}}{Z_A\left(\frac{1}{Z_A}+\frac{1}{Z_B}+\cdots\frac{1}{Z_n}\right)}$$

$$\boxed{\vec{I_A} = \frac{\vec{I_L}}{\left(\frac{\vec{Z_A}}{Z_A}+\frac{\vec{Z_A}}{Z_B}+\cdots\frac{\vec{Z_A}}{Z_n}\right)}}$$

$$S_A = P_A + jQ_A = V_A I_A^*$$

$$S_A^* = P_A - jQ_A = V^* I_A$$

$$= V^* \frac{Z_B}{Z_A+Z_B}\times\vec{I_L}$$

$$\boxed{\vec{S_A^*} = \frac{\vec{Z_B}}{\vec{Z_A}+\vec{Z_B}}\times S_L^*}$$

Similarly;

$$\vec{S_B} = \vec{V}.\vec{I_B^*}$$

$$S_B^* = V^*\vec{I_B}$$

$$\boxed{S_B^* = \frac{Z_A}{Z_A+Z_B}\times S_L^*}$$

Per unit loading →

$$\vec{I}_j \vec{z}_{j(\Omega)} = \text{constant}$$

$$\vec{I}_j \propto \frac{1}{\vec{z}_{j(\Omega)}}$$

$$V^* \cdot \vec{I}_j \propto \frac{1}{\vec{z}_{j(\Omega)}}$$

$$S_j^* \propto \frac{1}{\vec{z}_{j(\Omega)}}$$

$$S_j^* \propto \frac{1}{\vec{z}_{j(pu)} \times \vec{z}_{j(base)}}$$

$$S_j^* \propto \frac{1}{z_{j(pu)} \times \left[\frac{V_{rated}^2}{S_{j(rated)}}\right]}$$

$$S_j^* \propto \frac{S_{j(rated)}}{z_{j(pu)}}$$

$$\frac{S_j^*}{S_{j(rated)}} \propto \frac{1}{z_{j(pu)}}$$

$$S_j^*(pu) \propto \frac{1}{z_{j(pu)}}$$

* 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 & 500KVA 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 1000kVA as common Base ; 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

$$\vec{S}_A^* = \frac{(Z_B)_{new}}{Z_A + (Z_B)_{new}} S_L^*$$

$$= \frac{0.182\angle 60^\circ}{0.0728\angle 74.05^\circ + 0.182\angle 60^\circ} \times 360\angle -25.84^\circ$$

$$= 258.78\angle -29.84^\circ \text{ KVA}$$

i.e. 224.42kW at 0.8674 PF lagging.

For 2TF only, $S_B = \vec{S}_L - \vec{S}_A$

& for n TF $S_B^* = \frac{Z_A}{Z_A + Z_{B(new)}} \times S_L^*$

$\vec{S_B} = 103.49 \angle 15.8^\circ$ kVA

i.e. 99.58 kW at 0.9622 PF lag.

(iii) $S_L = \frac{500}{10} \angle 0^\circ$ kVA

$$S_A^* = \frac{Z_{B(new)}}{\vec{Z_A} + Z_{B(new)}} \times 500 \angle 0^\circ$$

$= 359.34 \angle -4^\circ$ 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 $\Rightarrow$ $S_B^* = \frac{\vec{Z_A}}{\vec{Z_A} + \vec{Z}_{B(new)}} \times S_L^*$

$\vec{S_B} = 143.74 \angle -10.04^\circ$ 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 $S_j^* \propto \frac{1}{Z_{j(\Omega)}}$

$$\frac{S_B^*}{S_A^*} = \frac{Z_{A(\Omega)}}{Z_{B(\Omega)}} \quad \text{OR} \quad \frac{S_B^*}{S_A^*} = \frac{\vec{Z_A}}{\vec{Z}_{B(new)}}$$

$$S_B^* = S_A^* \frac{Z_A}{Z_{B(new)}}$$

$$S_L^* = S_A^* + S_B^*$$

$$= S_A^* + S_A^* \times \frac{\vec{Z_A}}{\vec{Z}_{B(new)}}$$

$$= S_A^* \left[1 + \frac{\vec{Z_A}}{\vec{Z}_{B(new)}} \right]$$

$S_L^* = S_A^* [1.3914 \angle 4^\circ]$

$= 1000 \angle -\phi_A * 1.3914 \angle 4^\circ$

$S_L \angle -36.87^\circ = 1391.4 \angle 4^\circ - \phi_A$ KVA

$max^m S_L = 1391.4$ KVA

Equating angles ⇒ $-36.87^\circ = 4^\circ - \phi_A$

$\phi_A = 40.87^\circ$

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 $S_B^* = S_A^* \times \frac{\vec{Z_A}}{Z_{B(new)}}$

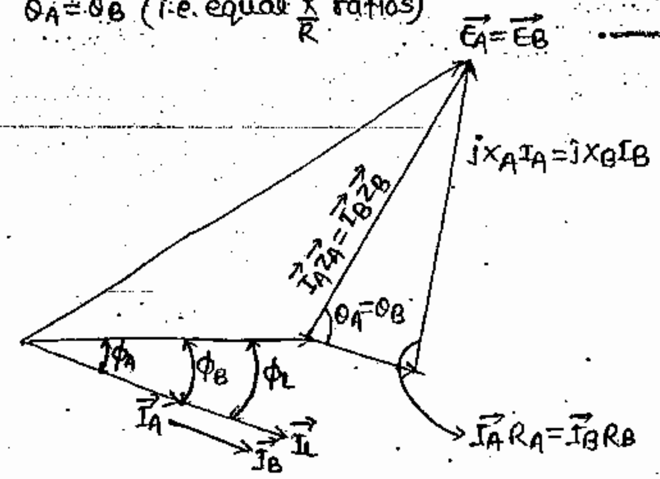
$\vec{S_B} = 399.97 \angle 26.83^\circ$ KVA

i.e. 356.92 kW at 0.8923 PF lag.

Phasor diagram →

$E_A = E_B$

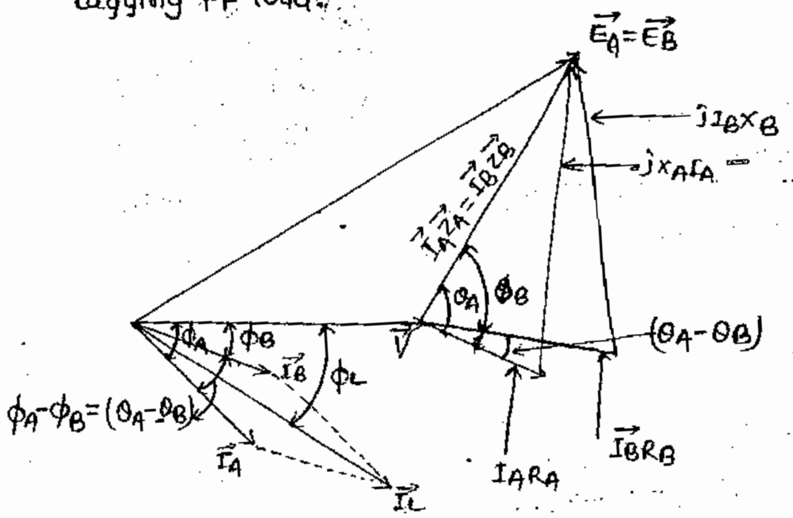
$\theta_A = \theta_B$ (i.e. equal $\frac{X}{R}$ ratios)



$E_A = E_B$

$\theta_A > \theta_B$ (a unequal $\frac{X}{R}$ ratio)

lagging PF load.



<u>Unequal Voltage Ratios →</u>

$E_A > E_B$

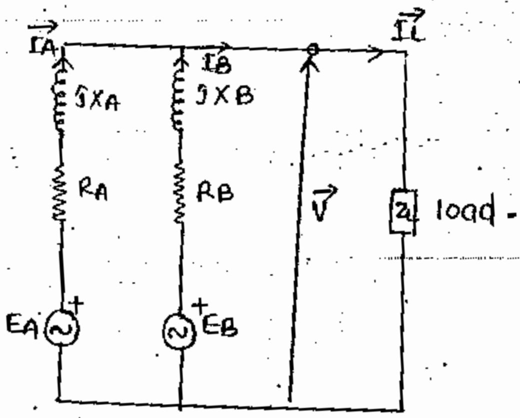
$E_A = \vec{V} + \vec{I_A}\vec{Z_A}$

$= (\vec{I_L}\cdot\vec{Z_L}) + \vec{I_A}\vec{Z_A}$

$\vec{E_A} = (\vec{I_A} + \vec{I_B})\vec{Z_L} + \vec{I_A}\cdot\vec{Z_A}$

$(\vec{Z_A} + \vec{Z_B})\cdot\vec{I_A} + \vec{I_B}\vec{Z_L} = \vec{E_A}$ ——— (i)

$Z_L\vec{I_A} + (Z_B + Z_L) I_B = E_B$ ——— (ii)



<u>Steps →</u>

(i) Calculate $\vec{I_A}$ & $\vec{I_B}$

(ii) $\vec{I_L} = \vec{I_A} + \vec{I_B}$

(iii) $\vec{V} = \vec{I_L}\vec{Z_L}$

(iv) $\vec{S_A} = \vec{V}\cdot I_A^*$; $\vec{S_B} = \vec{V}\cdot I_B^*$

<u>Use of Millman's theorem (OR) parallel generator theorem →</u>

<u>Steps →</u>

(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

$S_L = S_A + S_B$

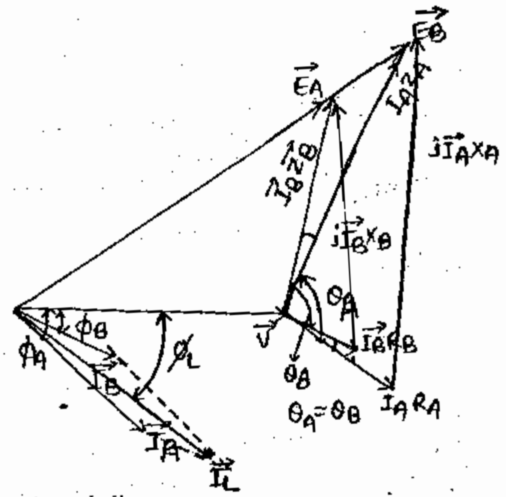
$= 14.332\angle 36.828°$

$I_A = \dfrac{E_A - \vec{V}}{Z_A} + \cancel{\dfrac{E_B - \vec{V}}{Z_B}} = 42.21\angle -38.81\,A$

$I_B = \dfrac{E_B - \vec{V}}{Z_B} = 33.57\angle -42.87°\,A$

Phasor diagram →

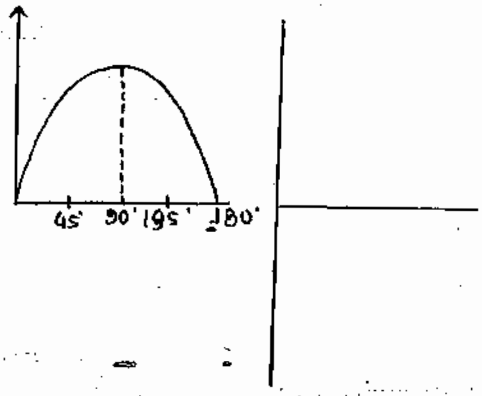
$E_A > E_B$, $\theta_A = \theta_B$, Lagging PF load.



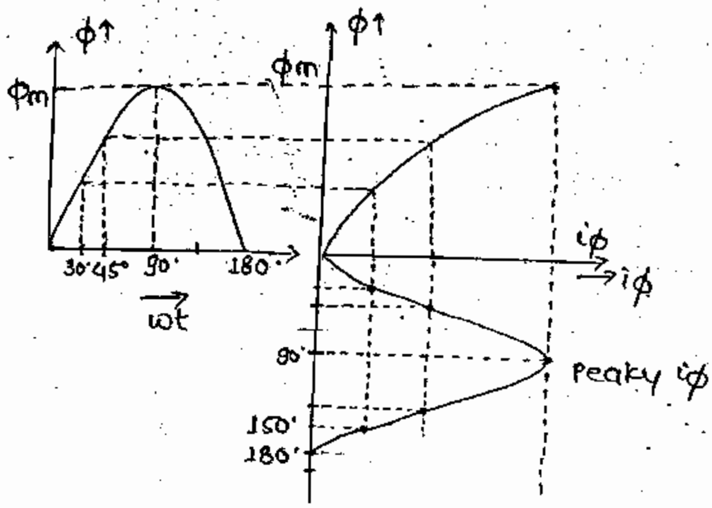
*Magnetisation Current phenomenon in the TF →

* 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.

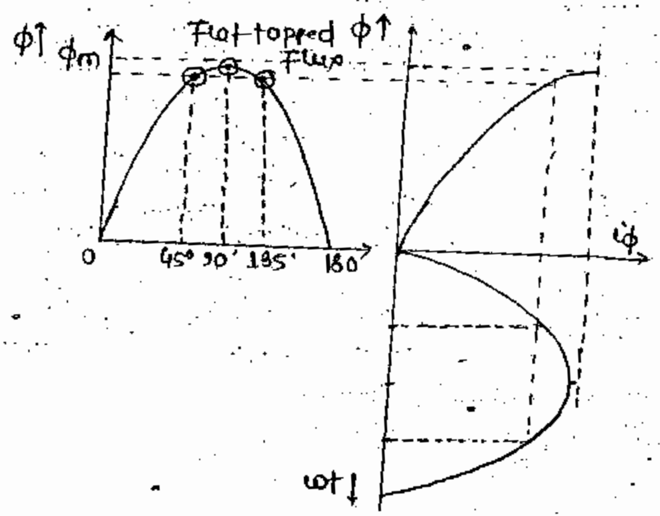


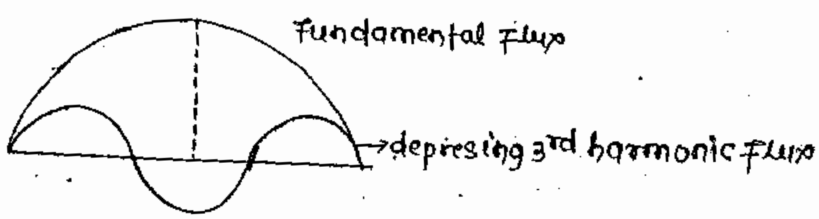
* With such a non-linear magnetisation c/s a sinusoidal flux may only be obtained with a peaky magnetising current containing dominant a 3rd harmonic component.

5. 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 component of flux may get easily establish only is magnetic ckt permits.
Hence the 3rd harmonic flux components 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 magnetically 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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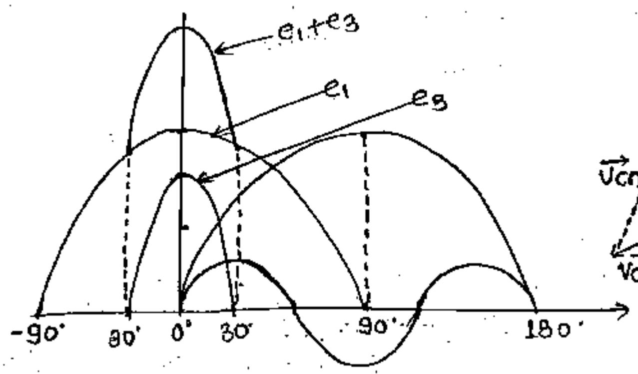
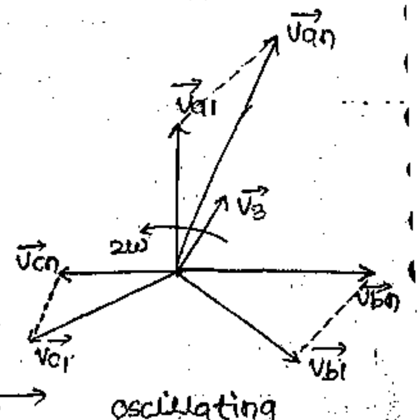
$\vec{J}_{q3} = \vec{V}_{b3} = \vec{V}_{c3} = \vec{V}_3$



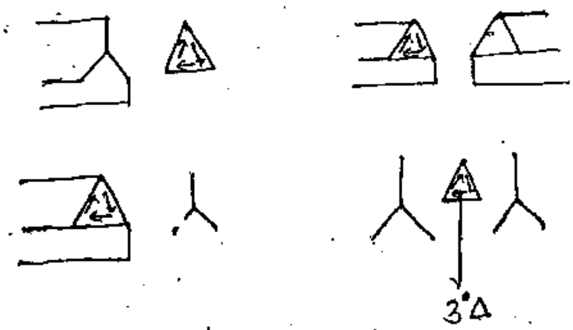


oscillating neutral

* 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 components 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 facilitatedes 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 independent 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 there by 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.