UNIT-III

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

No. A → Differential (Because in option)
B → shunt (Because constant flux)
C → Cumulative

09/07/14

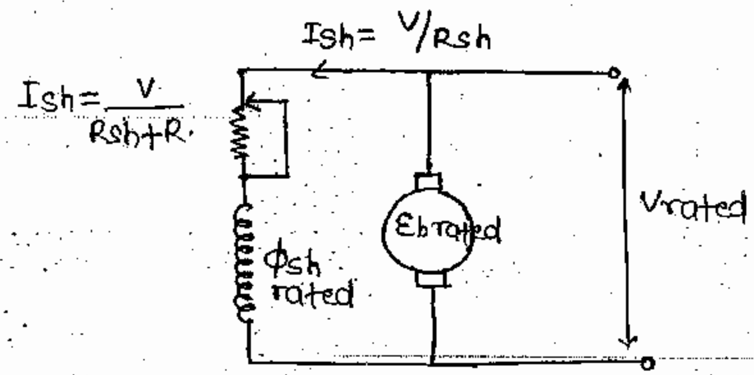
*** SPEED CONTROL →**

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

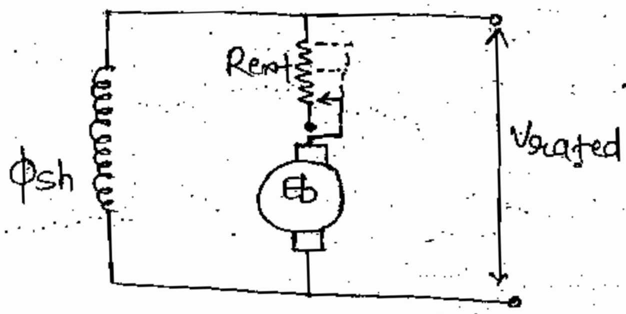
* Loss associated with external resistance in the field ckt is small

* No need of large rheostat

* No need of additional cooling.

* Requires 4-Point starter specialy to control speed over wide range.
* Additional arm. reaction as the main flux is reduced. Therefore it requires interpoles, compensating wdg etc.
* Also called as variable torge 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 →



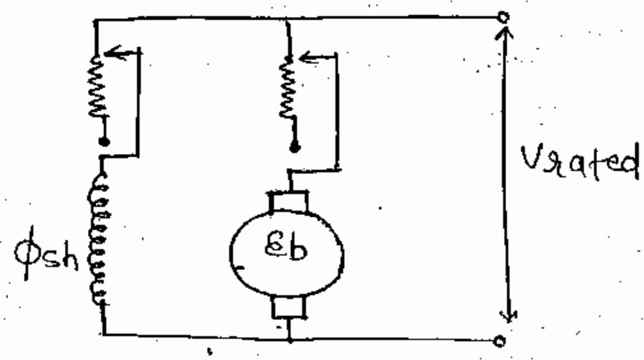
$$\downarrow E_b = [V - I_a(R_a + R_{ext}\uparrow)] \downarrow$$

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

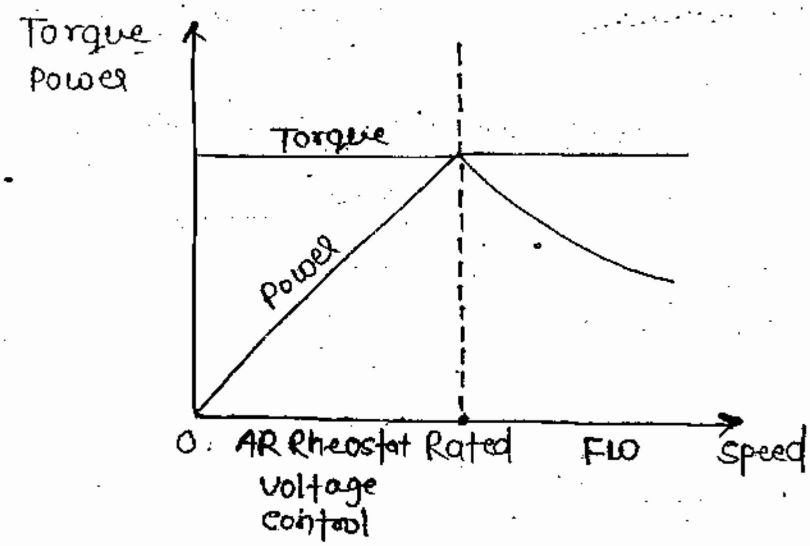
* By connecting an external resistance in series with arm. the voltage across the motor arm. is varies concequently the speed is vary.
* It is basicaly the vol. control without varying supply vol.
* It includes resistance & produce more cu loss. Therefore less efficient method.
* It is to control speeds 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 maxm 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→

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

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

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

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

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

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

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

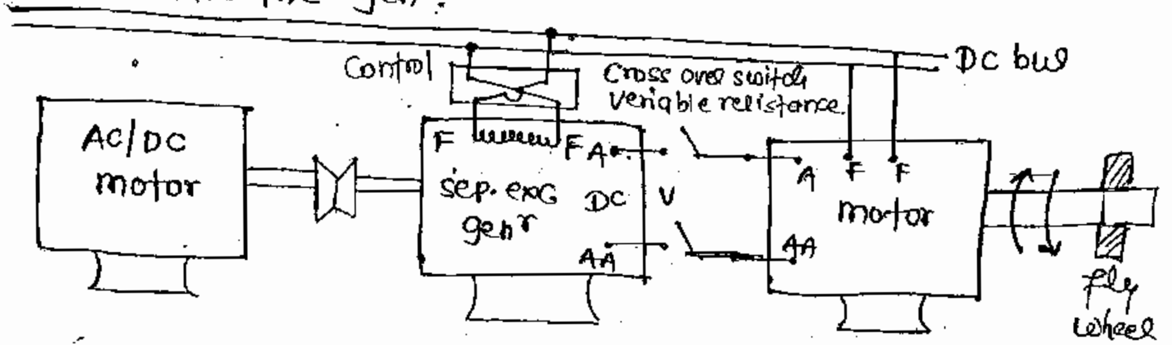
$$\frac{N_2}{N_1} = 1$$

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

Case② If the flux is constant

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

* 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.

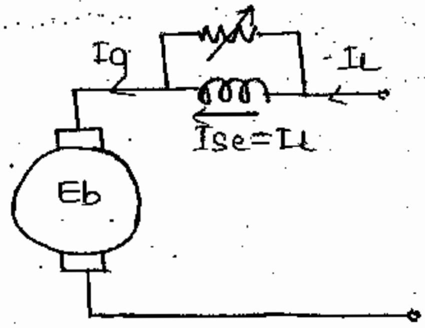


* This is exclusively use to control the speed from rated to below rated efficiently without inserting the resistance in series with arm. & to control speed in both dirⁿ.
* The control is through a cross over switch which varies the excitation of seprately excited genʳ.
* As it requires two additional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

* Speed control of series motors →

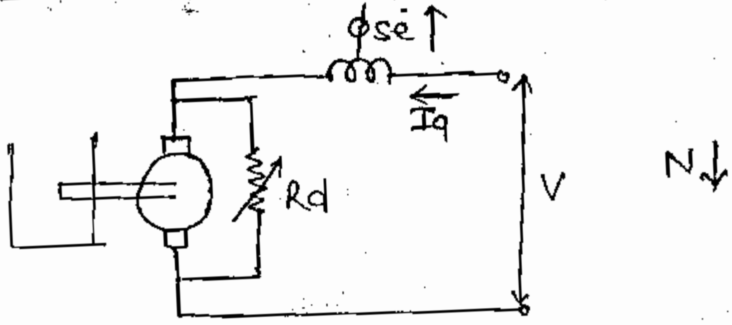
(1.) Field diverter
(2.) Armature diverter
(3.) Tapped field
(4.) Paralleling field coils
(5.) Armature Resistance
(6.) multiple voltage.

(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.

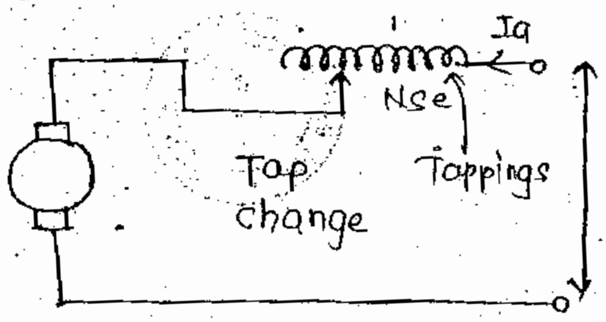
② Armature diverter →



$T \propto \phi I_a$

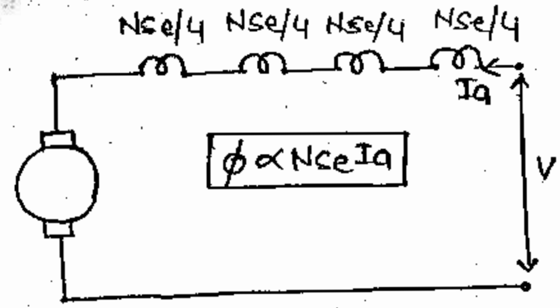
* By connecting diverter across arm., arm. current gets diverted due to which the torque is reduced.
* In order to maintain the torque the motor draws more current from supply which comes through the field wdg flux ↑ speed ↓.

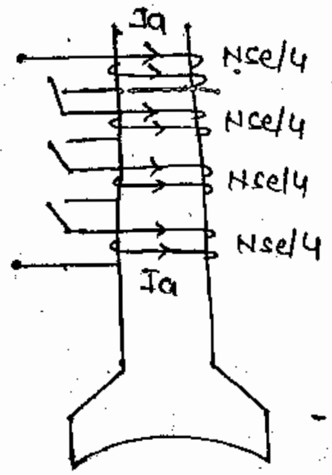
③ Tapped Field →

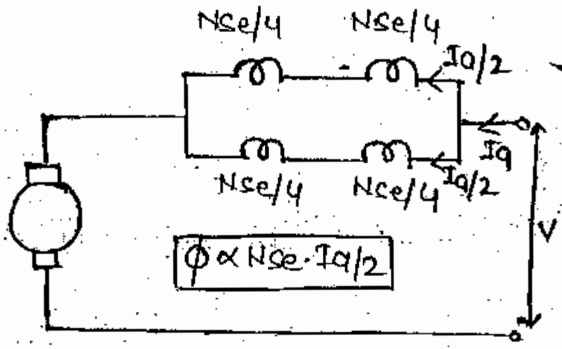


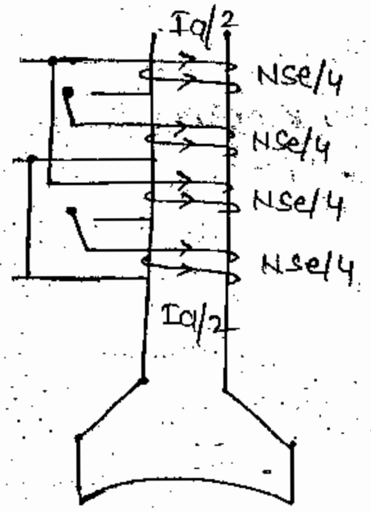
* If the tappings are more, then turns are more & Hence by increasing the value of turns the value of flux increases & the speed may decreases.

(4) Paralleling Field Coils →



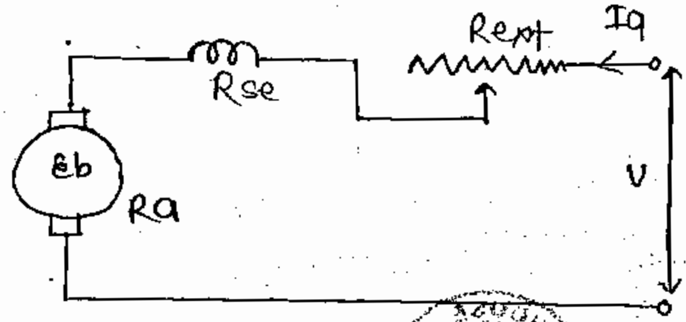






* The field wdg is arranged in the form of coils which can be externaly switch in series & parallel.
* In order to gets speeds b/w the steps a diverter may be connected

(5) Armature Resistance Control →

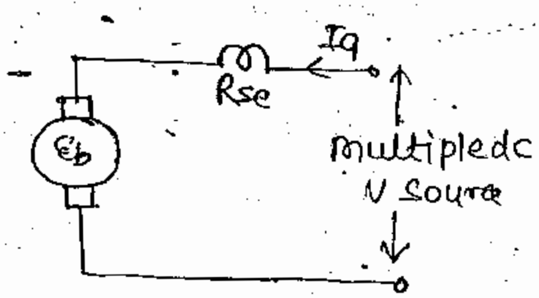


$$\downarrow E_b = [V - I_a (R_{se} + R_{ext} \uparrow + R_a)] \downarrow$$

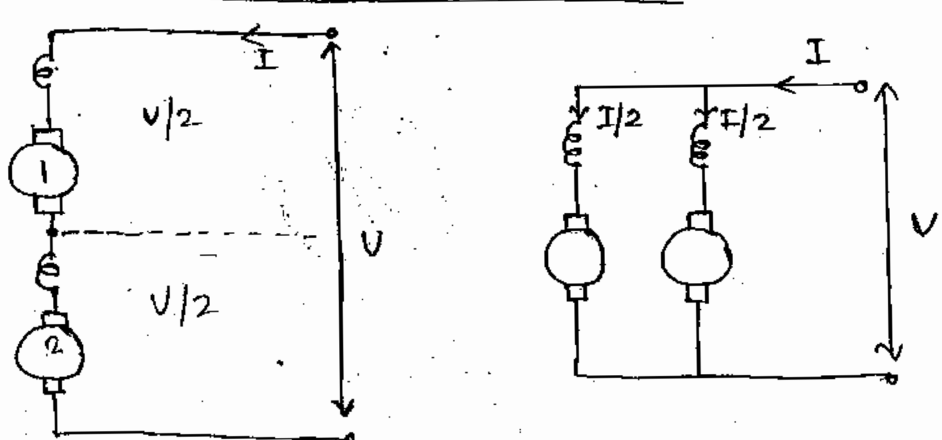
$$N \downarrow$$

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

(6) Multiple vol. Control →



* Traction motors in series & parallel →



$N \propto \frac{E_b}{\phi}$ $\quad\quad$ $N \propto \frac{E_b}{\phi}$ $\quad\quad$ $E_b \propto V$, $\phi \propto I$

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

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

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

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

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

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

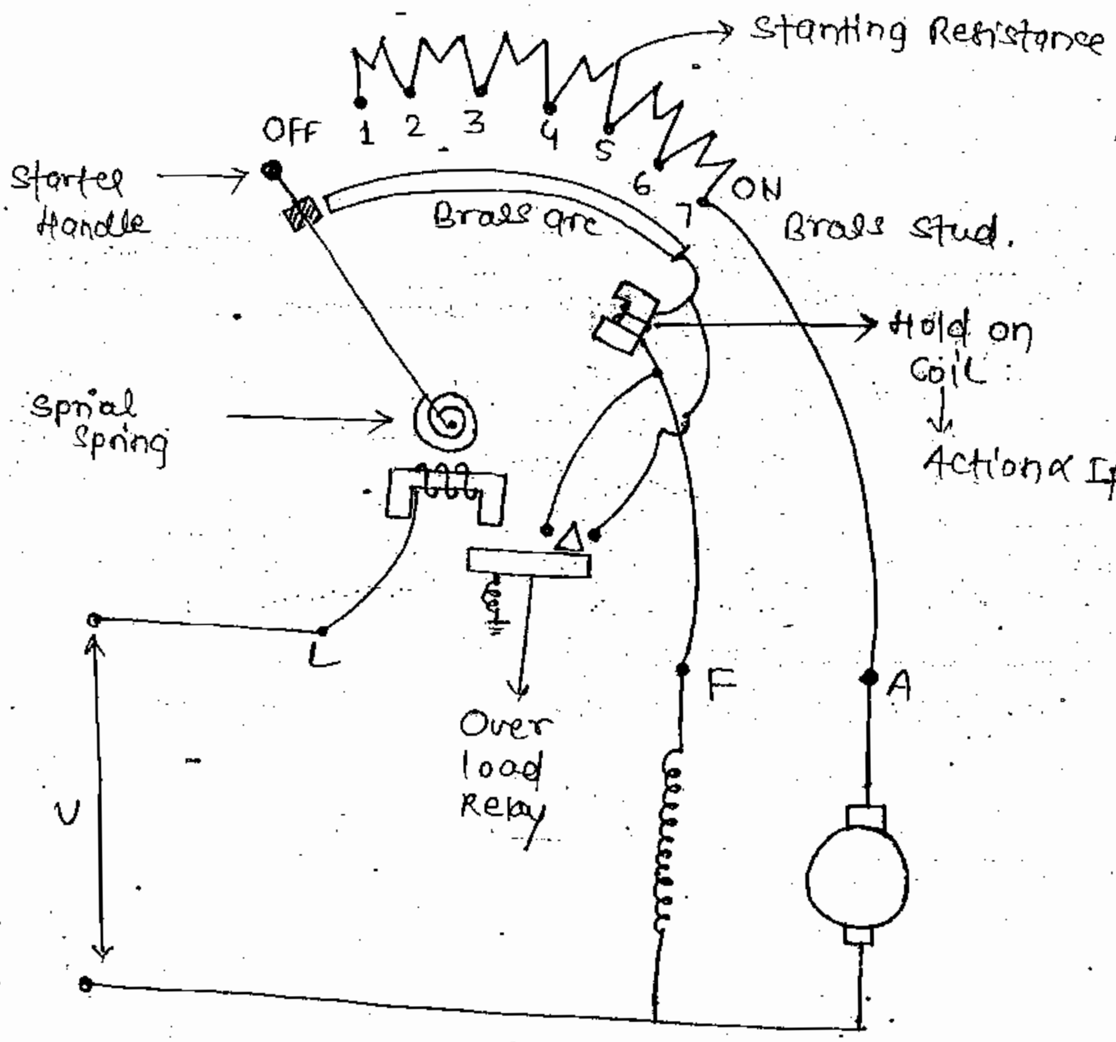
*** $T_{sh} = \frac{T_{se}}{4}$

* 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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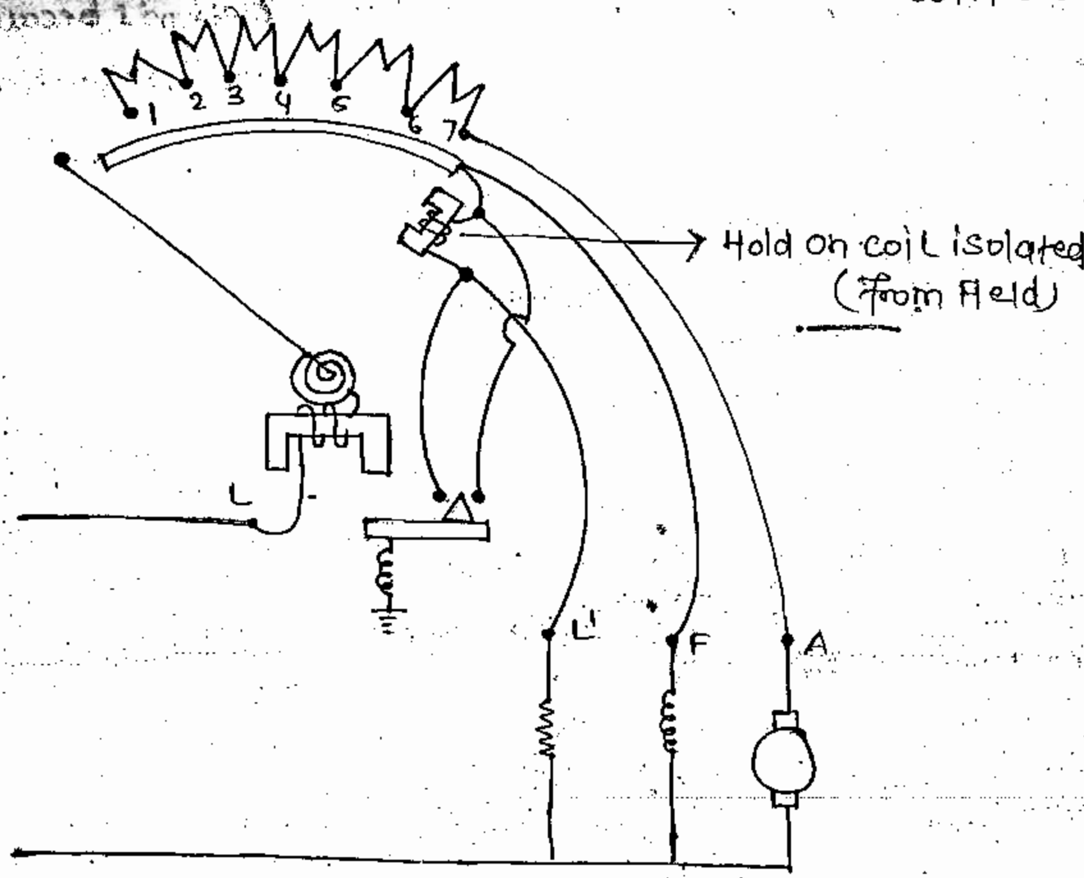
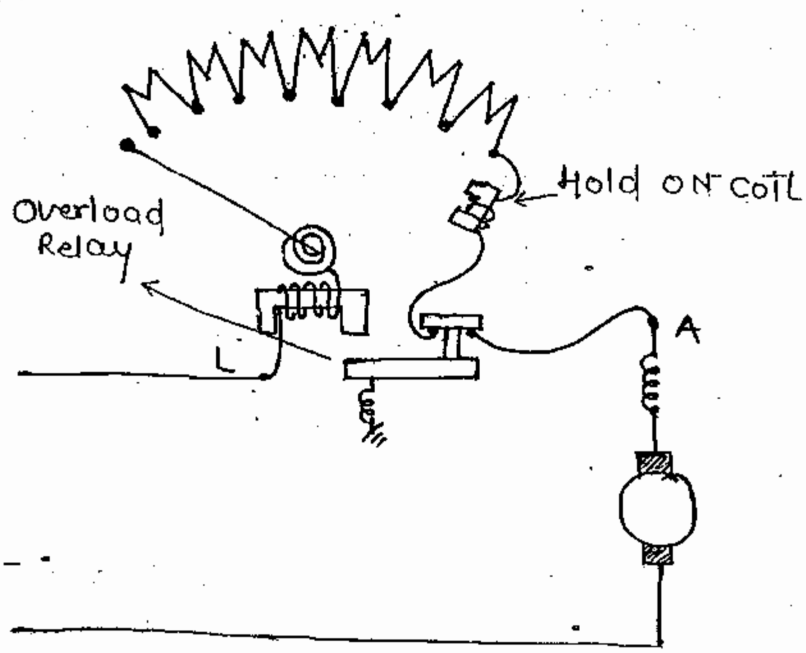
* 3 Point Starter →

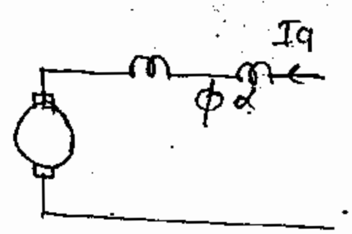


* 2 point Starter →



* 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.

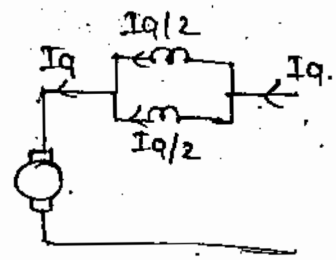
* For such appl^n 4-point startar should be used.
* Its Hold on coil is isolated from field wdg even though field current decreased. it won't effect Hold on coil action but there is no field faliure prevention.
* 2 point starters are specialy used for series motor only which contains all the 4-schemes.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



$T \propto \phi . I_a$

$T \propto I_a . I_a$

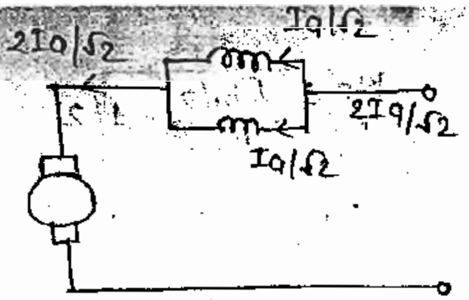
$T \propto I_a^2$



$T \propto \phi I_a$

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

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



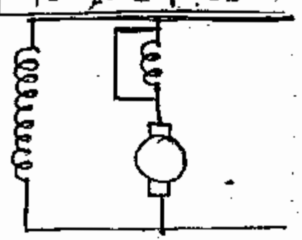
$T \propto \phi I_a$

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

$T \propto I_a^2$

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} $\phi \downarrow$

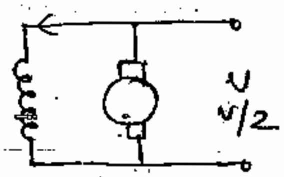
$\uparrow N \propto \frac{E_b}{\phi \downarrow}$

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

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

(34/7) Rated power →

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



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

$\phi \rightarrow \phi/2$

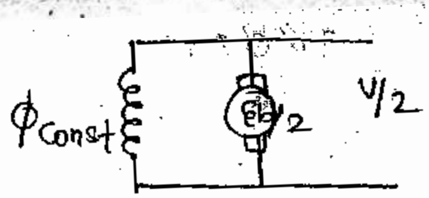
$\frac{N_2}{N_1} = \frac{E_{b1}/2}{E_{b1}} \times \frac{\phi_1}{\phi_1/2}$

$N_2 = N_1$ speed 1 PU

$P = E_b I_a$

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

(38/8)



$$\frac{N_2}{N_1} = \frac{E_{b1}/2}{E_{b1}} = 1/2$$

$$N_2 = 0.5N \text{ PU}$$

$$P = E_b I_a \qquad I_a = 2 \text{ PU}$$

DATE - 10/07/14

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

* There are 2 basic brakings

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

(ii) **Ele. braking →** Isolating the motor from supply is basic electric braking but the motor doesn't stop. In order to stop the motor at the required instant quickly additional braking methods are used.

(a) Dynamic/ Rheostatic braking

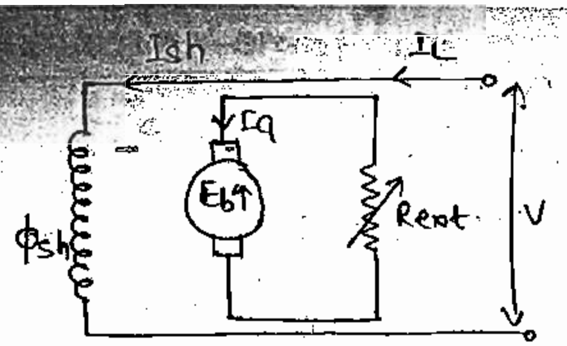
(b) Plugging

(c) Regenerative braking.

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

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

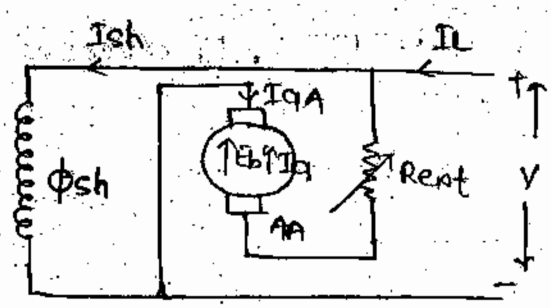
* At the instant of braking the induced back emf will circulate a current in the opposite dirn to reverses the torque & motor stops quickly.



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

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

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



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

(93/9)

$E_b = V - I_a R_a$

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

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

$I_a = I_L - I_{sh}$

$I_a = 12A$

$E_b = V - I_a R_a$

$= 240 - 12(0.5)$

$= 234$

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

44/9

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

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

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

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

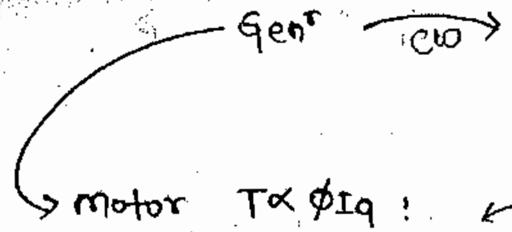
* ~~It occurs naturaly~~ due to the inherent property of motor when it is subjected to over hauling load condn like a train moving down a gradient a crane lowering its load etc.
* Due to increased speed if $E_b > V$, I_a reverses & the torque reverses & the speed is reduced.
* Concequently the motor regains its original mode ($E_b < V$)
* During braking it is acting as genr simultaneously.
* In series motor in order to acheive this braking its field wdg need to be separately excited.

For series motor

$$T = (-\phi)(-I_a)$$
↓
+ve

* So in series motor we brake the arm. & a series field.
* This are so advantage in the mountain Railway.

★ Genr across busbar operating as motor →



$T \propto \phi I_a$: ← ACW

$T \propto -\phi I_a$ → CW

$T \propto \phi(-I_a)$ → CW

$T \propto (-\phi)(-I_a)$ ← ACW

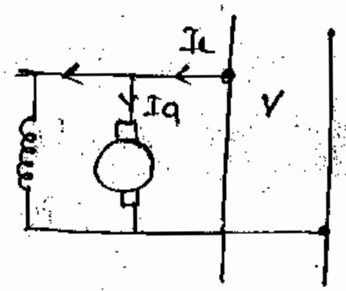
⊛ A shunt genr supplying power across bus bar when the prime mover fails it will act as

(a.) shunt motor running at same dirn.

(b.) Shunt motor running in opposite dirn.

(c) It will stop.

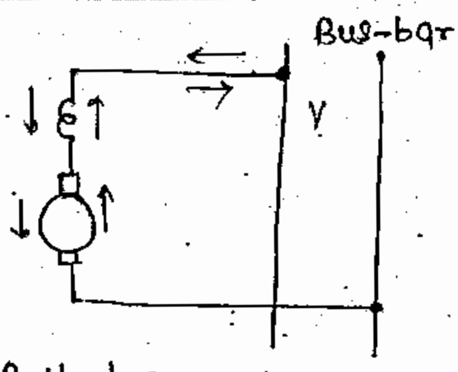
Ans (a.) (Only I_a dirn change)



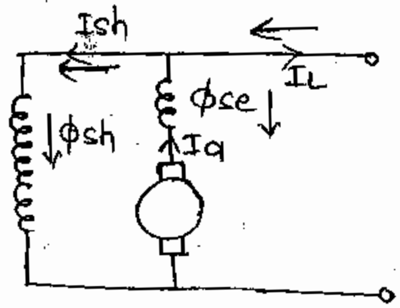
⊛ Series genr supplying power to a bus bar, when its prime move fails it will act as

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

(21/5)

$\phi_1 \to \phi_1$, $\phi_2 \to 1.1\phi_1$

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

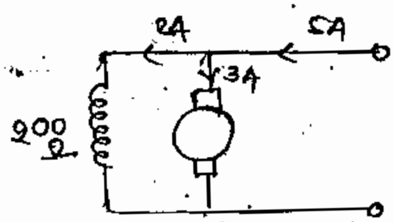
$E_{b2} = 0.95 E_{b1}$

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

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

$N_2 = 863$ rpm

(54/10)



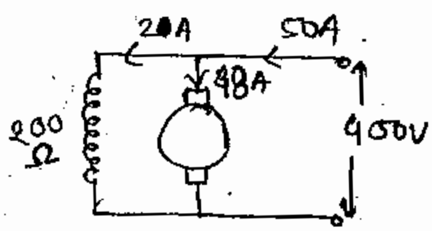
$N \propto \frac{E_b}{\phi}$

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

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

E_b at FL $= 400 - 48(0.5)$

$= 376V$



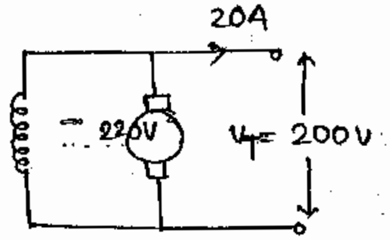
$$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}}$$

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

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

(69/13)

(46/9)



$\phi_2 = 1.1\phi_1$

$E_g = V + I_a R_a$

$= 200 + 20(0.2)$

$E_g = 204V$

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

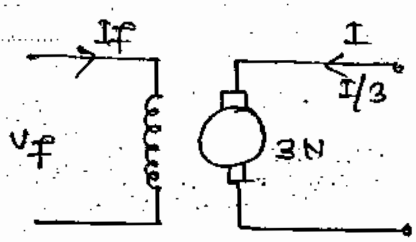
$E_b = V - I_a R_a$

$= 200 - 20(0.2)$

$= 196V$

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

(40/8)



$P = 3E_b \cdot I_a/3$

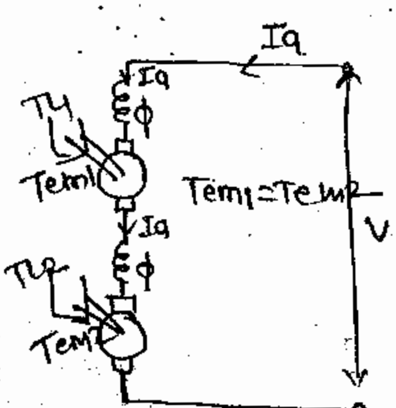
Constant power

$T \propto I_a \phi$

(1/1)

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

(11/4)



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

$P \propto NT$

Because same T

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

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

$\boxed{1:1}$

Tem – Electromagnet torque

TL = load torque

If in quen 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.) Hystenisis.

Cycles per rotation = P/2

Rotation per seconds = N/60

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

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

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

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

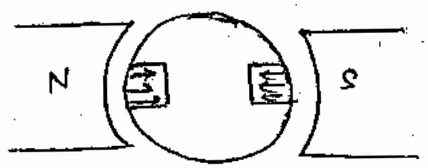
B_m = flux density

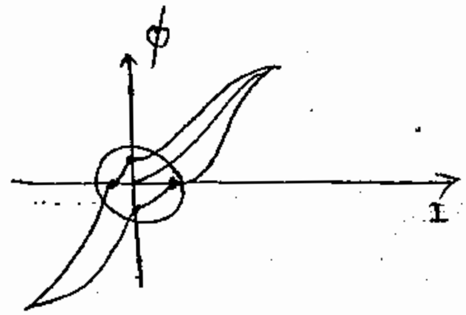
t = thickness

V = volume

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

* Hysteresis loss →





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

$$W_h = K_h B_m^x f V$$

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

② Cu loss / ohmic (I^2R) →

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

  $I_a^2 R_{se}$ (series m/c (or) long sh.)

  $I_L^2 R_{se}$ (short sh.)

  (4) cpw cu loss, IPW cu loss, cu loss due to brush resistance.

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

5) Mechanical loss →

(1) Friction loss ⟶ Due to brush, Bearings

(2) Windage loss ⟶ Air friction.

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

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

Total losses = Constant loss + Variable loss

I, F (or) W ... cu loss.

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

Condition for max^m η →

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

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

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

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

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

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

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

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

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

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

$$I_a^2 R_a = W_c$$

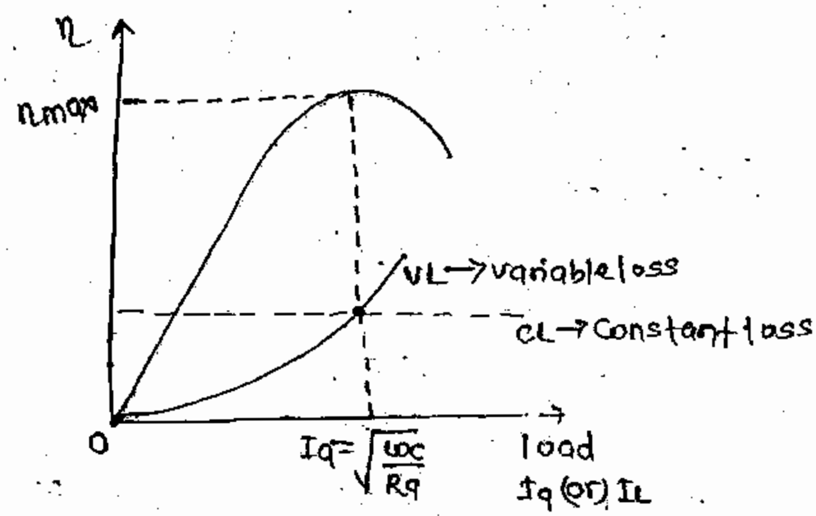
variable loss = constant loss

$$I_a^2 R_a = W_c$$

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

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

* 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 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.

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

* 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.

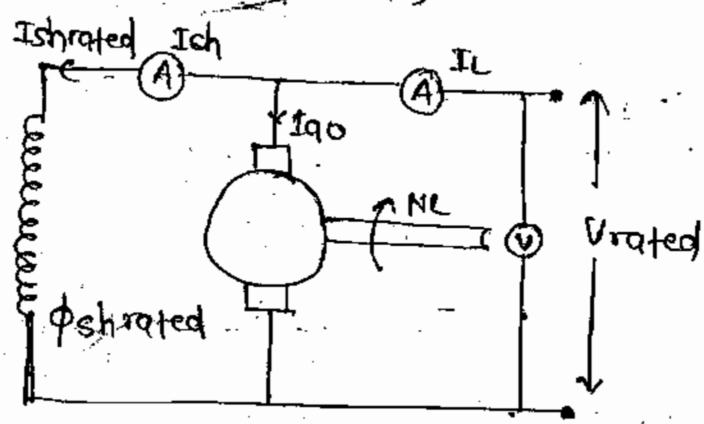
) Indirect → * The m/c is not loaded directly but the η is free determined by determining losses.

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

* 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	Ish	I_a	Constant loss	variable loss	Total loss	I/p	$\eta = \frac{I/p - loss}{I/p}$
FL	220	11	1	104	45	$10^2 \times 1 = 100$	1450	220 x11	$= \frac{220 \times 11 - 145}{220 \times 11}$
½L	220	6	1	54	45	$5^2 \times 1 = 25$	70	220 x6	$= \frac{220 \times 6 - 70}{220 \times 6}$

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

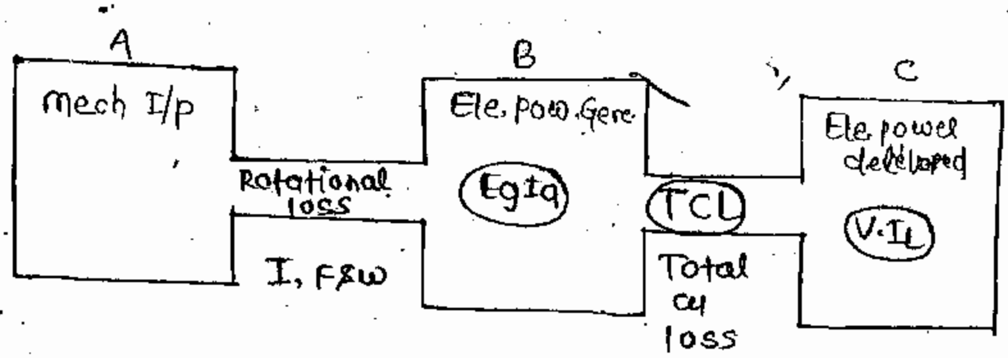
	V	I_L	Ish	I_a	Constant loss	variable loss	Total loss	o/p	$\eta = \frac{o/p}{o/p + loss}$
FL	220	9	1	10	45	$10^2 \times 1 = 100$	145	220 x9	$\frac{220 \times 9}{220 \times 9 + 145}$

Genr $I_a = I_L + I_{sh}$

~~* Power stages of Genr →~~

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.

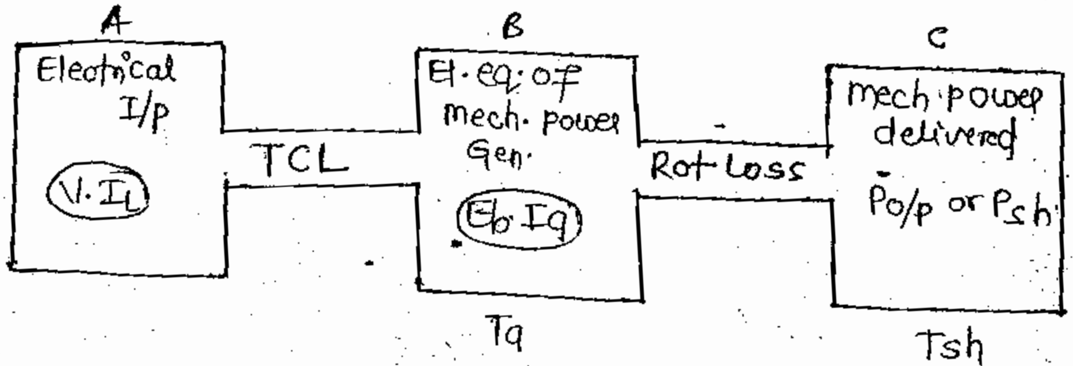
Power stages of genr →



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

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

Power stages of motor →



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

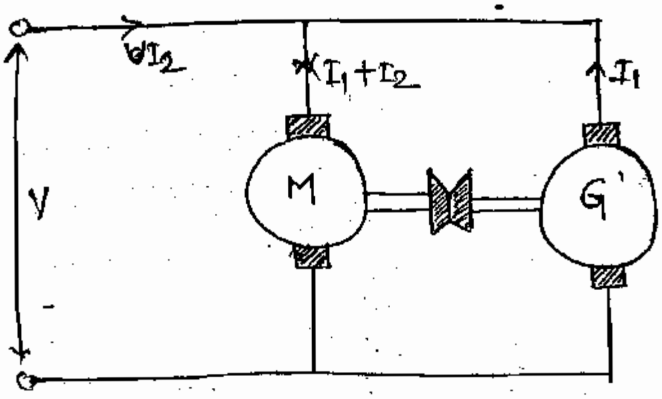
$$\eta_{mech} = \frac{C}{B} = \frac{\text{Mech O/p } (P_{sh})}{E_b \cdot I_a}$$

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

$$T = \frac{60}{2\pi N} \cdot P \qquad T_a = \frac{60}{2\pi N} (E_b \cdot I_a)$$

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

* 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 & Gen^r.

Approximate η →

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

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

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

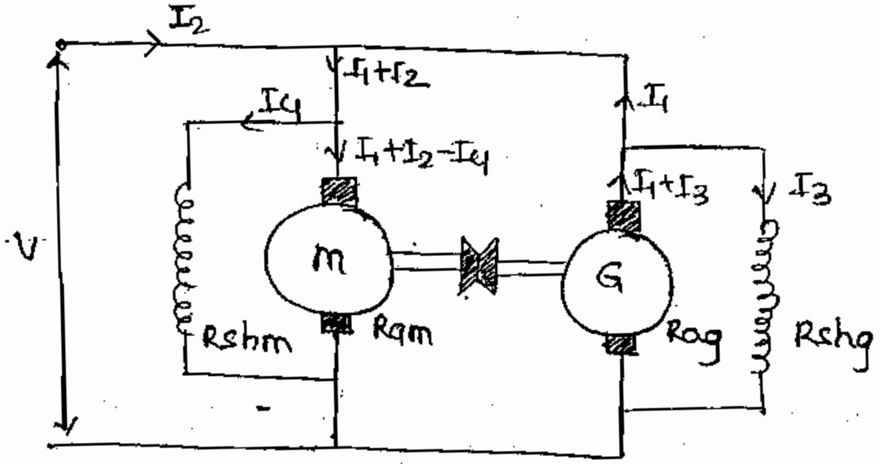
$$\eta_{mot} = \frac{O/P \text{ of motor}}{I/P \text{ of motor}} \Rightarrow {*}O/P \text{ of motor} = \eta_{mot} \times I/P \text{ of } (m)$$

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

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

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

Accurate →



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

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

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

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

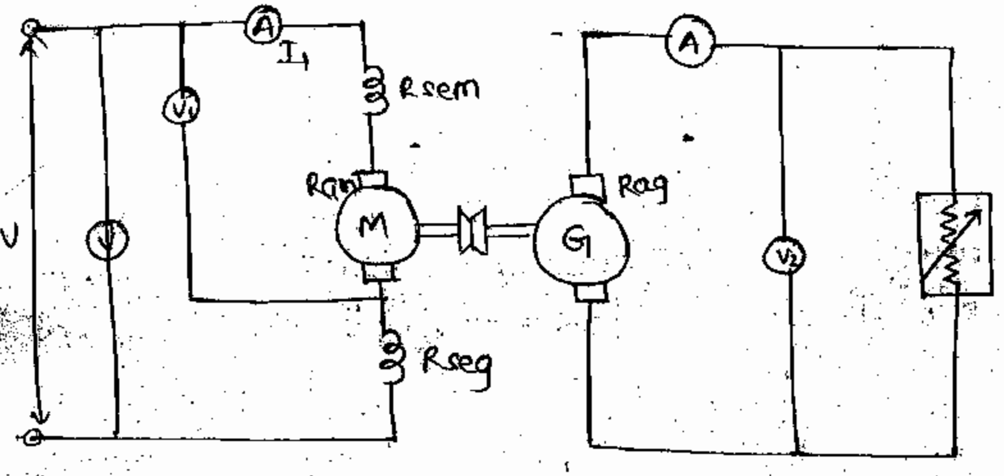
$$\eta_g = \frac{VI_1}{VI_1 + \left[P_R/2 + (I_1+I_3)^2 R_{ag} + I_3^2 R_{shg}\right]}$$

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

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

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.



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

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

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

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

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

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

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

* 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.

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

J = Moment of inertia

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

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

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

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

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

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 →

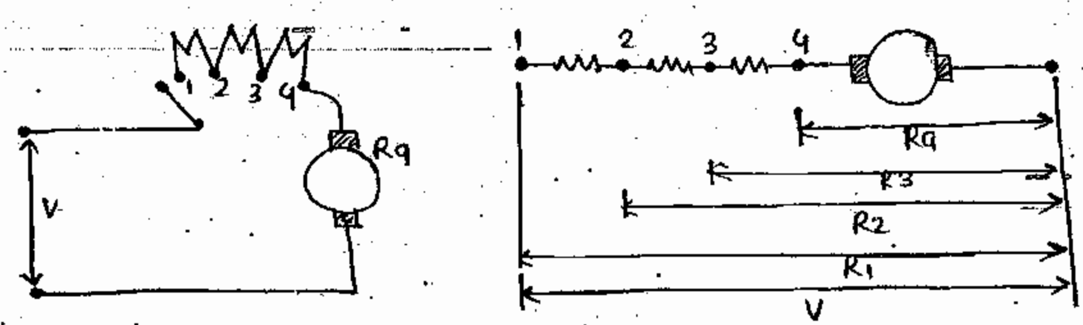
$$\text{Rot. loss} = \left(\frac{2\pi}{60}\right)^2 \times 75 \times 1000 \times \left(\frac{60}{15}\right)$$

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

* 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

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

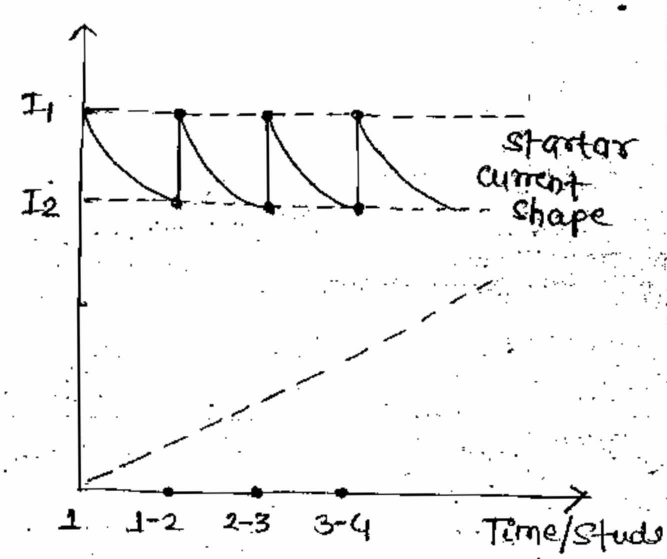
②—③ $I_1 = \frac{V - E_{b2}}{R_3}$

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

At ③ After some instant

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

③—④ $I_1 = \frac{V - E_{b3}}{R_a}$



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

$R_3 = K R_a$

$R_2 = K R_3 = K^2 R_a$

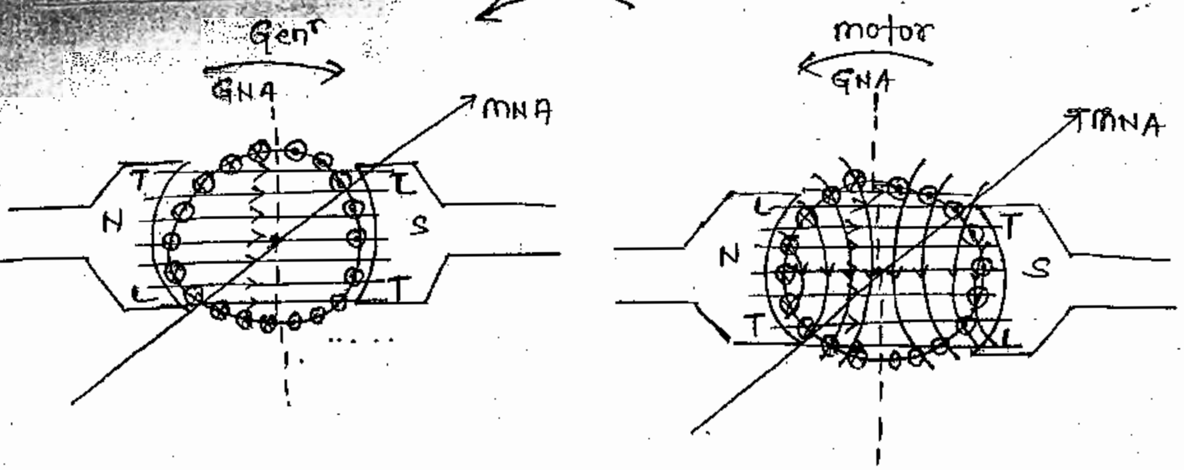
$R_1 = K R_2 = K^3 R_a$

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

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

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

Armature Reaction in dc motors →



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

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

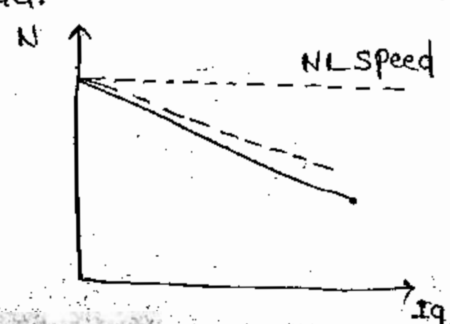
(2) The flux density will increase under the leading pole tips.

(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–III

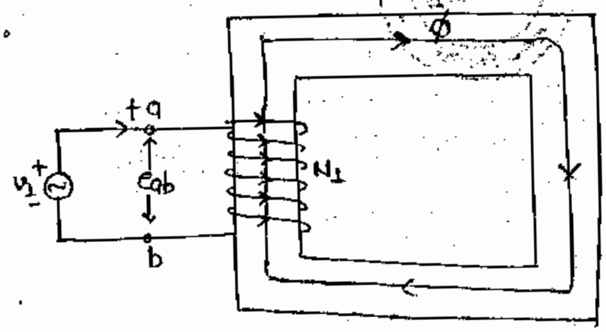
SINGLE-PHASE TRANSFORMERS

DATE 03/11/14

Transformers

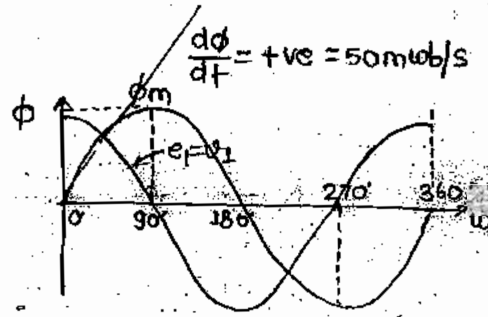
Sagar sen
887145353 6

* TF is not an ele. m/c



* Core provides → low reluctance path
  → mech. support

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



(timing dia)

Flux linkage (λ) = NI

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

V_{ab} – vol. of a wrt b

i_{ab}
a o→—[ ]——o b
i_{ab}

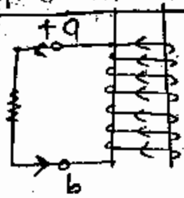
$$e_{ab} = \pm \frac{d\lambda}{dt}$$

* **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 curent so produced would have an effect that opposes the cause.

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

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

Testing of Lenz law →

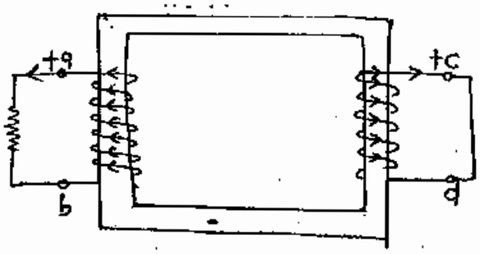


$$e_{ab} = +\frac{d\lambda_1}{dt}$$

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

$$= 100 \times (50 \times 10^{-3}) \text{ volts}$$

$$= 5 \text{ volts}$$

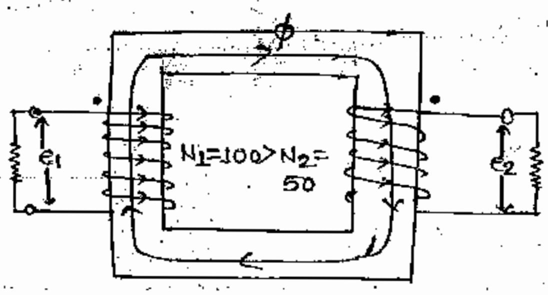


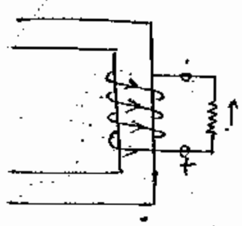
$$e_{cd} = \pm\frac{d\lambda_2}{dt}$$

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

$$= +50 \times (50 \times 10^{-3})$$

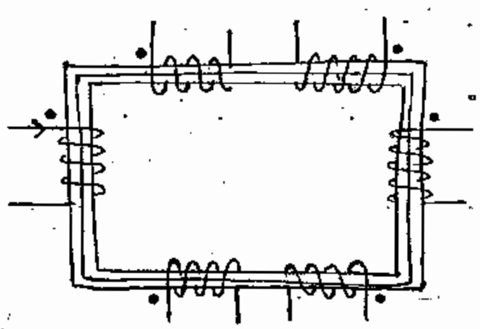
$$= +2.5 \text{ volts}$$





Dot conve→ If the curents enter (or) leave through the dots simultaneouly 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 satiesfy the lenz law.

In other words the dots have the same instantaneous polarity.

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

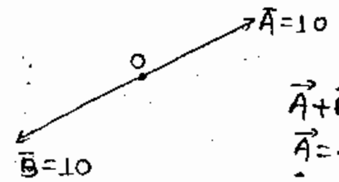
$$e_1 = N_1 \frac{d\phi}{dt}$$

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

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

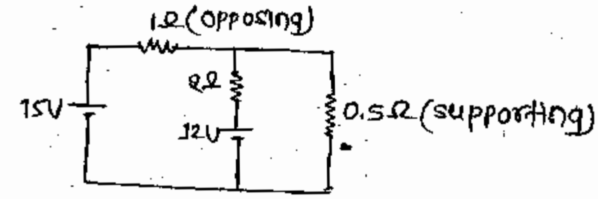
$$\Downarrow$$

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

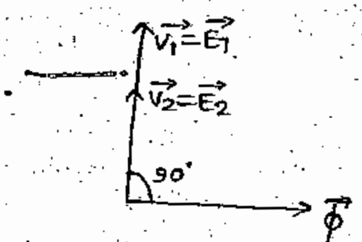


$$\vec{A} + \vec{B} = 0$$

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



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



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

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

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

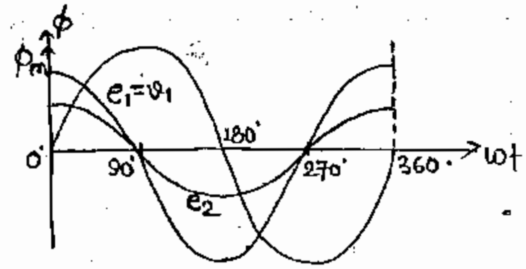
$$= N_2 \frac{d}{dt}(\phi_m \sin\omega t)$$

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

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

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

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



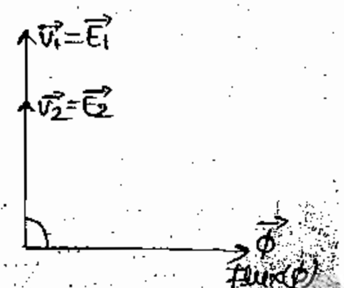
* **Ideal transformer →** (No losses, $\mu = \infty$)
↓
*(Flux will establish without any exciting current)

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

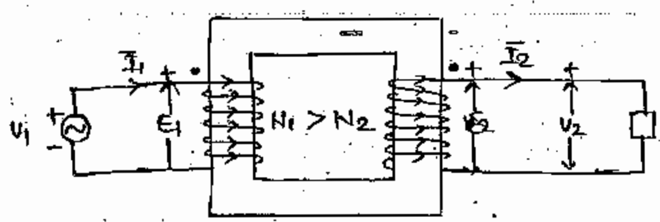
$$\phi = \frac{NI_0}{l/\mu A}$$

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

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



Phasor dia. of ideal Xmer on NL



mmf Balance on load of ideal transformer

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

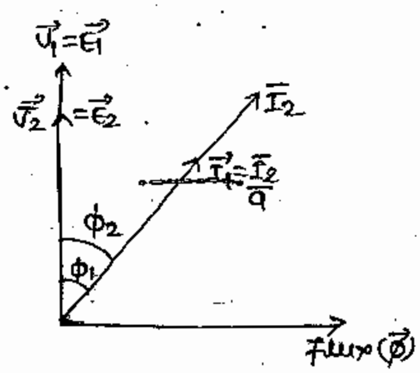
$$N_1\vec{I_1} = N_2\vec{I_2}$$

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

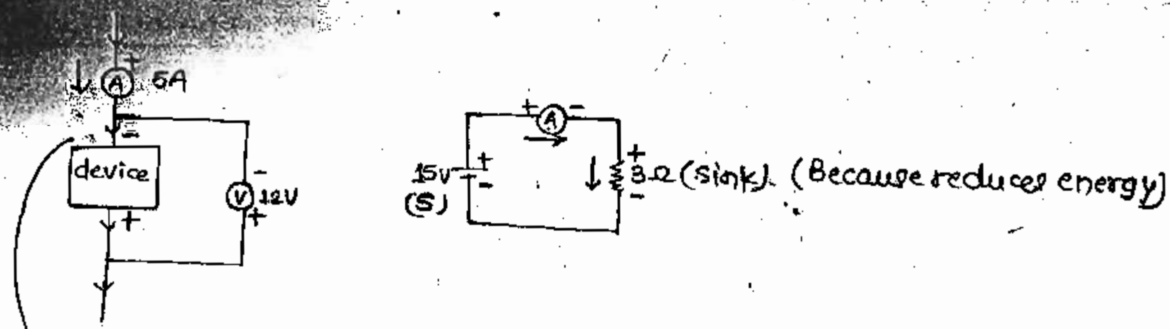
$$\boxed{I_1 = \frac{I_2}{a}} \quad \boxed{I_1 = I_2'}$$

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

I_2' = 2° current refered to 1°



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



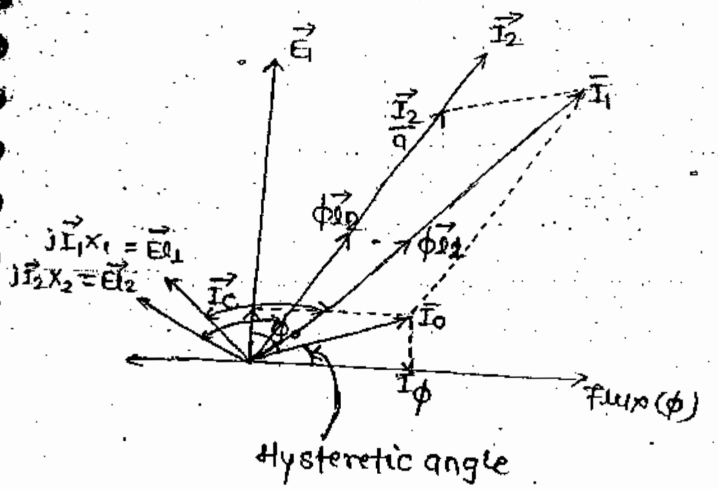
Current enter at lower potential & exit from higher potential. Then the device is <u>Source.</u>

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

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

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

* **Hysteretic angle →** It is the angle b/n sinusoidal flux & sinusoidal current



I_c = Core loss component of exciting current (I_0)

I_ϕ = Magnetising current of exciting current

$$I_c = I_0 \cos\phi_0$$
$$I_\phi = I_0 \sin\phi_0$$

($\phi_0 = 80°$)

E_{l_1} = 1° leakage flux voltage

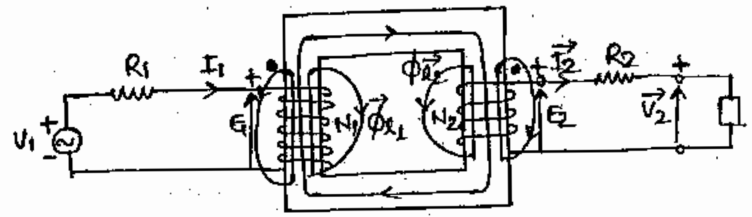
E_{l_2} = 2° leakage flux voltage

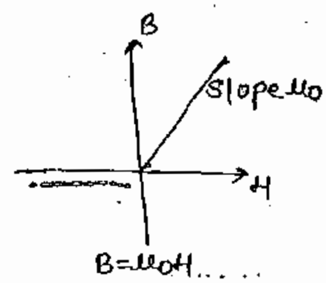
$X_2 = \frac{E_{l_2}}{I_2}$, $X_1 = \frac{E_{l_1}}{I_1}$

MMF balance of practical TF →

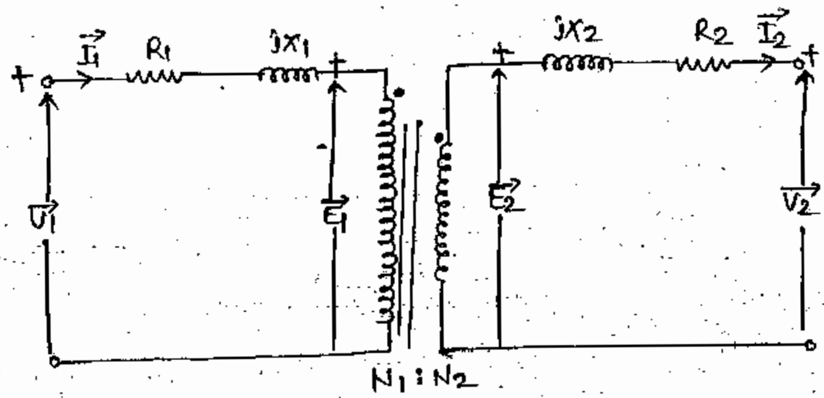
$$N_1 \vec{I_1} - N_2 \vec{I_2} = N_1 \vec{I_0}$$

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





ϕ_l = leakage Flux.

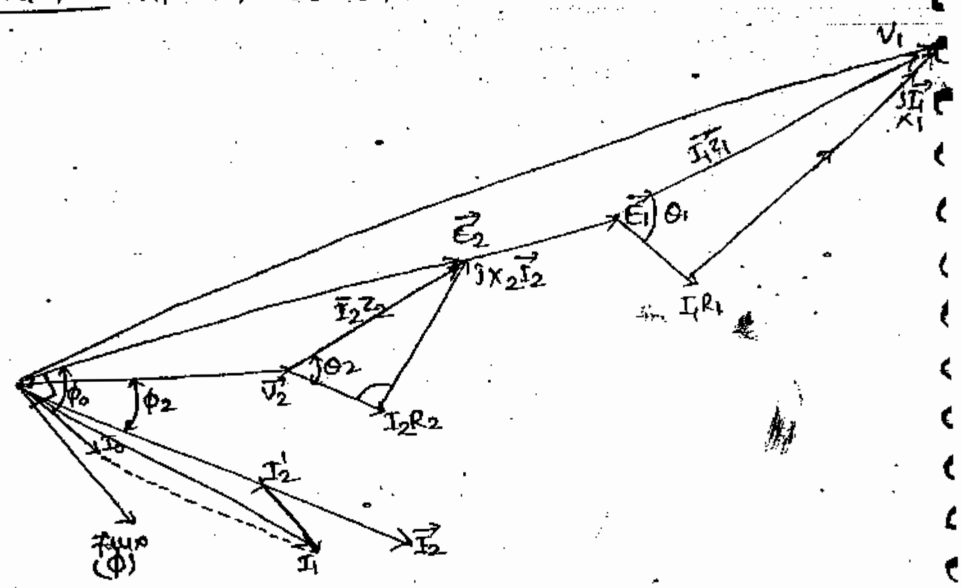


Representation of a practical 2wdg TF

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

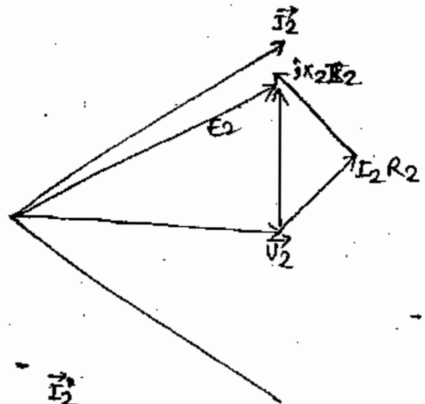
$\vec{E_1} = a\vec{E_2}$ $\quad\quad = \vec{I_2'} + \vec{I_0}$

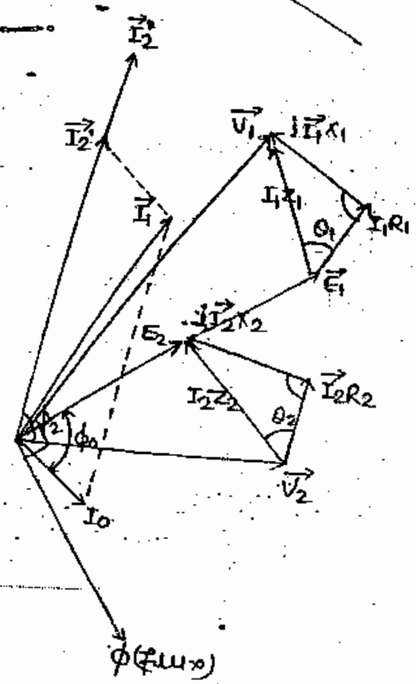
Complete phaser diagram → $N_1 > N_2$, Lagging PF operation.



Tight coupling by iron core.

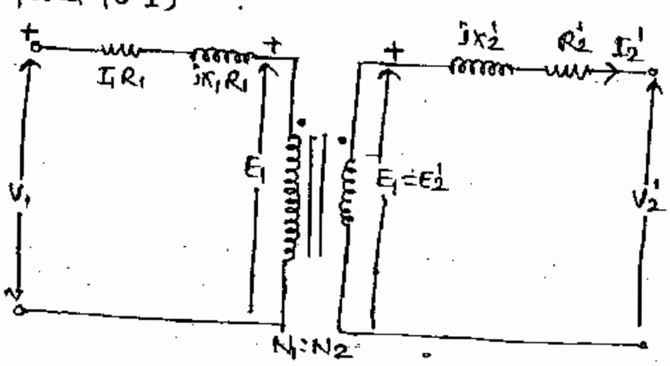
$N_1 > N_2$, Lagging PF operation→





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

DATE-04/11/14 (Refered to 1°)



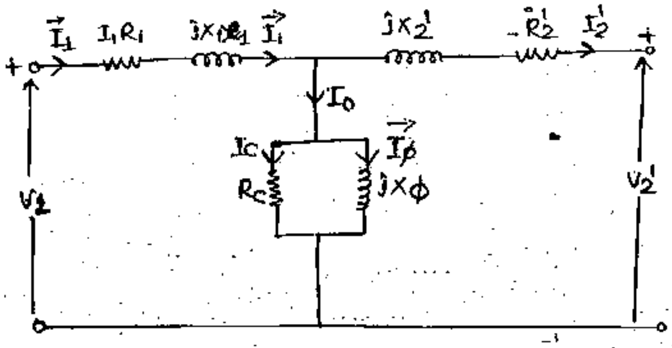
$$\vec{E_2} = \vec{V_2} + \vec{I_2}R_2 + jX_2\vec{I_2}$$

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

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

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

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



R_c = Core loss eq. resistance.

fig → Exact equivalent ckt
"T" Equivalent

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

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

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

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

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

Rated voltage - Rated Flux.

1000W, 200V
↓
180V

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

taking V_2 as ref.

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

$= 625\angle -36.87° A$

$V_2' = aV_2 = 10 \times 240\angle 0^\circ$ $\qquad a = \frac{2400}{240} = 10$

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

$I_2' = \frac{I_2}{a} = \frac{625\angle -36.86^\circ A}{10}$ $\qquad Z_2' = a^2 Z_2$

$= 62.5\angle -36.86^\circ A$ $\qquad = (10)^2[(2+4.5j)\times 10^{-3}]$

$= (0.2+0.45j)\Omega$

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

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

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

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

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

$I_0 = I_c + I_\phi$

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

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

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

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

$I_1 = I_2' + I_0$

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

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

$V_1 = E_1 + I_1 Z_1$

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

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

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 $\qquad \boxed{PF = 0.7821 (lag)}$

* FIRST approximate equivalent circuit →

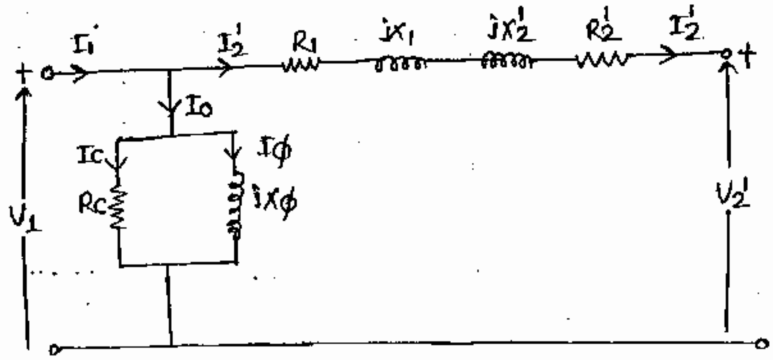
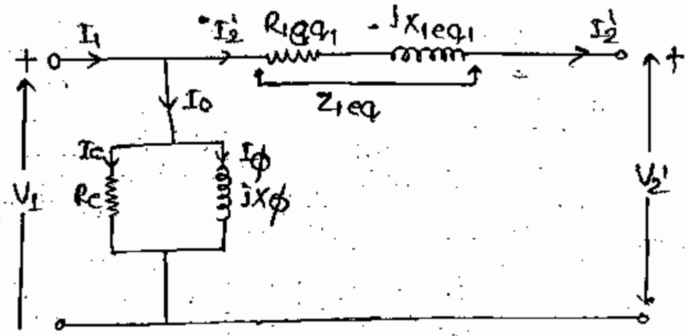


Fig- Cantilever eq:



For η cal^{n} 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 →