ENERGY CONVIRSION-1

LECTURE NOTE

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Atulya Mishra

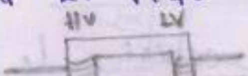
Ref. books:-

1. Electrical Machines - Nagrath & kothari
2. Electrical Machinary - P.S. Bhimbra
3. Performance & Design of AC Machines - M.G. Sen

for problems {
4. Electrical Engg. problems - Parker Smith
5. Electrical Technology vol-II - B.L. Theraja
}

Transformers

1. constant frequency device
2. constant power device
3. Electro magnetic energy conversion device [Internal conversion]
4. Overall transformer is not an energy conversion device
5. Appropriate terms:- HV and LV side but not primary and secondary



6. It is a phase shifting device. It offers 180° phase shift to its signals. (→ how?)
7. -ve f/b action is accommodated.
8. singly excited device.
9. It is a 2-port n/w [ABCD parameters]

* working principle:-

Faraday's law of Electro magnetic induction.

* Basic requirements to produce Magnetic flux or to produce emf

1. Magnetic field
2. set of conductors
3. Relative space variation b/w 1 & 2.

Method - I (Dynamically or motionally Induced emf
↓
DC generator
(The nature of emf induced in DC Gen.)

1. Magnetic field stationary
2. set of conductors being moved

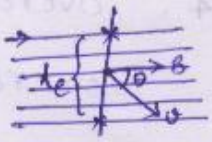
Method - II [statically induced emf]
↓
transformer

1. M.f. time varying
2. set of conductors stationary.

⟹ Dynamically induced emf :-

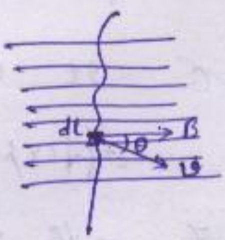
(ε_d) This is emf induced in set of conductors which are moved inside a steady or time invariant magnetic field.

flux cutting law :-



$$\varepsilon_d = B l_e v \sin\theta, \quad \theta = \angle B \,\&\, v$$

where l_e - effective length of conductor.



$$d\varepsilon_d = B v \sin\theta \, dl$$

$$\varepsilon_d = \int_{line} \bar{B}\bar{v} \sin\theta \, dl$$

$$= \int_{line} (\bar{B} \times \bar{v}) \, dl \quad (\bar{v} \times \bar{B})$$

* Direction of Dynamically induced emf is found by applying fleming's Right Hand Rule.

Thumb ~~pointing finger~~ - velocity vector (motion of conductor)
Middle finger - Direction of induced emf
~~Thumb~~ Pointing finger - Direction of flux ($\bar{B}$)

Dynamically induced emf is always perpendicular to plane containing $\bar{v}$ and $\bar{B}$ vectors.

→ **Statically Induced Emf :-**

This is the emf induced in set of stationary conductors which are placed in time varying M. Field.

The nature of emf produced in T/f is statically I. emf.

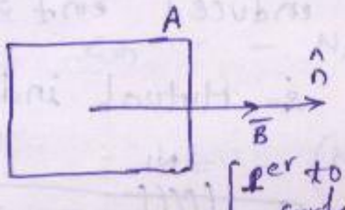
Magnitude of statically induced emf is given by → Faraday's second law :- $\varepsilon_s = N \cdot \frac{d\phi}{dt}$

ε_s is defined as the rate of change of flux linkages. ? what is faraday's first law

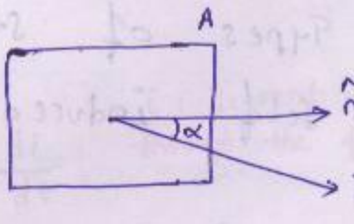
flux linkage $= N\phi$

$$\varepsilon_s = -N \cdot \frac{d\phi}{dt}$$ → -ve sign is given by lenz's.

→ Direction of ε_s is given by Lenz's law.

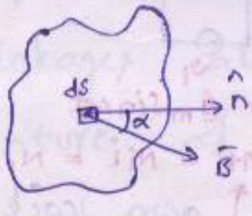


$\phi = BA$ [per to surface]



$\phi = B\cos\alpha \cdot A$

when surface is indefinite shape,



$$d\phi = B\cos\alpha \cdot ds$$

$$\phi = \iint_S B\cos\alpha \cdot ds$$

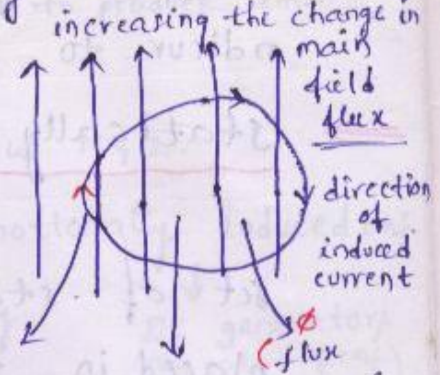
$$\varepsilon_s = -N \cdot \frac{d}{dt}\left[\iint B\cos\alpha \cdot ds\right]$$

$$= -N \cdot \iint \frac{\partial B}{\partial t}\, \bar{B}\cos\alpha \cdot \bar{ds} \qquad \bar{ds} = ds \cdot \hat{n}$$

$$= -N \iint \frac{\partial \vec{B}}{\partial t} \cdot \vec{ds}$$

* Direction of ε_s, given by Lenz's law

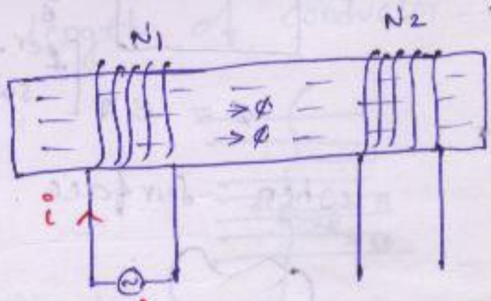
* The direction of induced current and induced voltage is same.



Acc. to Lentz' law, the dire. of ε_d is such that the current due to this emf is flowing in such a direction which intern produces some flux acc to electromagnetic theory and these flux must oppose the change in main field flux to satisfy Lenz's law, which is the cause of production of this emf as well as current.

⇒ 2 Types of statical induced emf's :-

1. self induced emf 2. Mutual induced emf.



* Self i.emf is a statical i.emf induced in a coil due to time varying nature of current flowing through its own coil.

$i = I_m \sin\omega t$

$MMF = N_1 i = N_1 I_m \sin\omega t$

↑ Time varying MMF.

$$MMF = N_1 I_m \sin\omega t$$

$$flux(\phi) = \frac{MMF}{Reluctance} = \frac{(N_1 I_m)\sin\omega t}{(R)}$$

$$\Rightarrow \phi = (\phi_m)\sin\omega t \longrightarrow \text{Time varying flux}$$

$\therefore e_{self} = -N_1 \cdot \frac{d\phi}{dt}$ ← { faraday's second law + Lenz's law }

$= -\left(N_1 \cdot \frac{d\phi}{di}\right) \cdot \frac{di}{dt}$

* Self inductance of a coil is defined as rate of change of flux linkages at a coil w.r.t. time varying nature of current flowing through its own coil.

$e_{self} = -(L_{self}) \frac{di}{dt}$

$\therefore L_{self} = \frac{d}{di}(N\phi)$

Self induced emf always opposes the changes in applied voltage source, to satisfy Lenz's law that means in a coupled ckt, e_{self} & supply voltage are 180° out of ph. with each other.

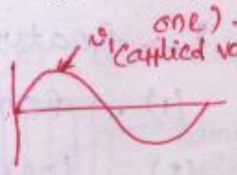
* Mutual i. emf is the statical i. emf induced in a coil due to time varying nature of i flowing through another coil which is magnetically coupled to it. (first one).

$e_m = -N_2 \cdot \frac{d\phi}{dt}$

$= -\left(N_2 \cdot \frac{d\phi}{di}\right) \frac{di}{dt}$ → i : current flowing through the first coil.

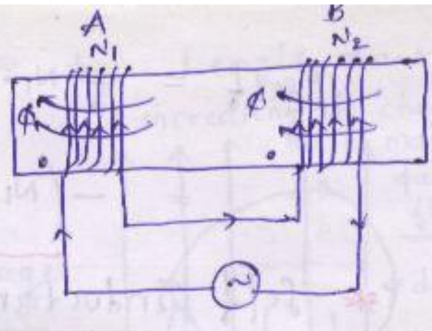
* Mutual inductance b/w two coils may be defined as rate of change of flux linkages at a coil w.r.t. time varying nature of i flowing through another coil which is magnetically coupled to it (first one).

$e_m = -M \cdot \frac{di}{dt}$

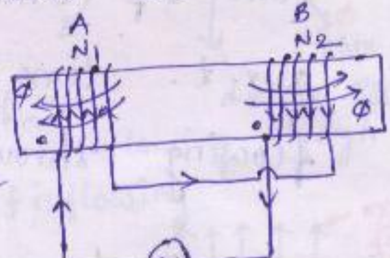


$\therefore M = N_2 \cdot \frac{d\phi}{di} = \frac{d}{di}(N_2 \phi)$

Dot Notation :-



If the flux produced by 2 coils placed on same magnetic core are aiding one another then the two coils are said to be positively coupled.



If the flux produced by 2 coils placed on same mag. core are opposing one another then the two coils are said to be negatively coupled.

If current enters [leaves] the dots at both the coils then type of coupling b/w 2 coils is +ve.

If current enters [leaves] at dot at one coil and the current leaves [enters] the dot at another coil then the type of coupling b/w 2 coils is −ve.

⟹ Construction Details of a T/f :-

1. core have low reluctance and high permiability to the flow of magnetic flux.

2. Core − Silicon steal (electrical steel)

↳ features of silicon steal :-

(1). ferro magnetic material

(2). low reluctance & high permiability

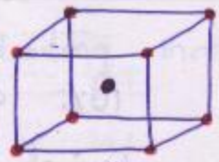
(3). low hysterisis coe. → ($x = 1.6$) so low ω_h

Hysterisis loss $= \eta B_{max}^{x} f V$ (x → hysterisis coe.)

$x = 1.6$ for Si. steal.

4. It has crystaline structure.

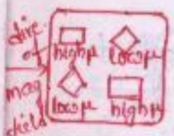
* body centred cubic structure (or) cube →



5. The silicon steal grain offers higher permiabilities along cube edges rather than along diagonals. (when compared to permiability along diagonals).

6. Cold rolling grain oriented CRG₀ steal.

⟹ Silicon steal —cold rolling grain orientation→ CRG₀ steal

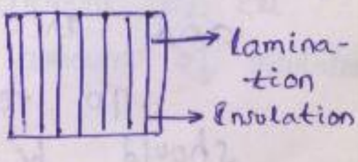


As si. steal grain offers higher permiabilities along the cube edges rather than along diagonals, if the cubes are given orientation, such that cube edges are ||el to dire. of magnetization, then permiability of si. steal can be further increased. This can be practically achieved by cold rolling grain orientation and resulting steal is called CRG₀ steal, which is used in modern T/f's.

Laminations :-

To reduce eddy current losses. In this each laminations are electrically isolated from each other.

1. China clay
2. Japan varnish
3. Impregnated paper
4. Oxide paints [Red oxide]



1. Gross cross section area (A_g) [magnetic material + insulation]
2. Net cross section area (A_n) [magnetic material]

* Stacking factor- Iron factor = $\frac{\text{Net C.S. Area}}{\text{Gross C.S. Area}}$

$k_s < 1$

10% area is occupied by insulating material so, $k_s = 0.9$

$A_n = A_g \times 0.9$

⟹ If laminations are not tightly reveted,

1. There may be possibility of thin air gap length b/w laminations which increases the reluctance of magnetic path and hence the excitation i drawn by the wdg from the source increases.

$\phi = \frac{MMF}{R}$

$\phi_{const} = \frac{N i \uparrow}{R \uparrow}$

2. Magnetostriction :- → Magnetic Hum.

This is the tendency of any magnetic material due to which changes in dimensions of magnetic material takes place whenever flux is flowing through it.

If the laminations are not properly reveted then there may be vibrations due to magnetostriction phenomina and if the frequency of vibrations falls in audible range we can listen those vibrations and the sound is called Magnetic Hum.

To reduce hum, all the laminations should be properly stragered.

⇒ Cruci form core :-

Adv. :- over square core of same cs. area

1. Reduces the amount of insulating material [diameter of circum O^{le} is less]
2. Reduces the amount of cu requirement.
3. Due to above adv. the size and weight and cost of T/f is reduced with cruci form
4. flux is uniformly distributed.

utilization factor = $\frac{\text{effective cs area}}{\text{Total cs area}}$

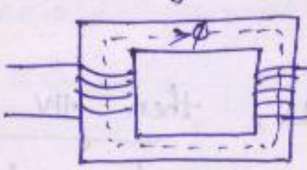
0.85 to 0.95 for cruci form

It has high u.f. than the square core.

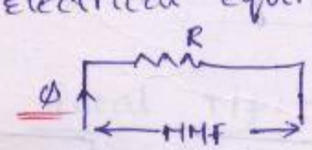
⇒ Types of Magnetic circuits :-

1. Core type

* core surrounded by wdg
* Series magnetic ckt (Acc. to flux) (flux passes through core without any division)



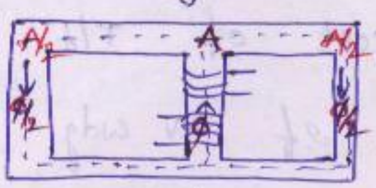
* electrical equi. ckt



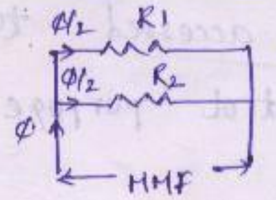
* Less amount of insulation
* Mechanically bad
* More amount of cu
* used for high voltage applications
* Interleaving wdgs preferred
* Equal cs core.
* Low current rating
* HV, small KVA rating

2. shell type of T/f core

* wdg surrounded by core
* Parallel magnetic ckt



Division of flux takes place



$R_1 = R_2$

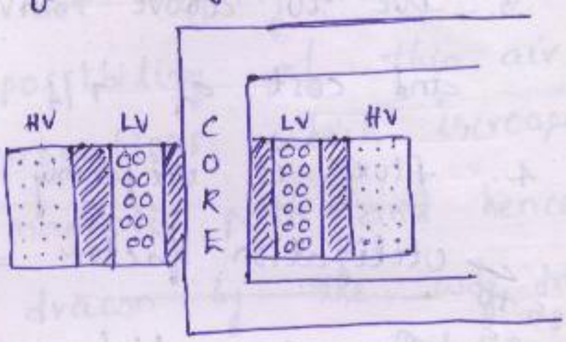
* outer cs (A/2) has 50% of middle core cs.
* LV, large KVA rating
* High current rating
* used for LV applications
* Less amount of cu
* more amount of insulation

⇒ placement of wdgs:-

1. Inter leaving of wdgs:-

purpose: To reduce magnetic leakage flux thereby increases the coe. of coupling b/w the windings.

* Advantages of placing LV wdg nearer to the core :-



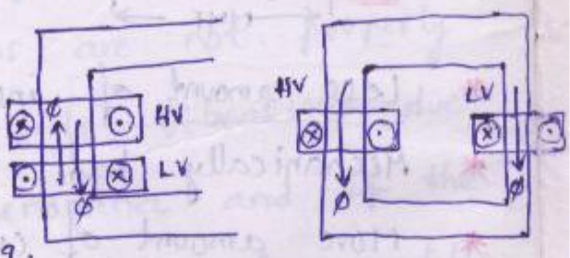
1. The amount of insulation required for T/f is reduced.

2. It also reduces the amount of cu. required for wdgs.

Due to above ~~reg~~ reasons, size, weight and cost of T/f. is reduced.

3. If HV wdg is outer to LV, then HV is is accessed to provide tappings for voltage control purpose.

→ The directions of (or) ϕ currents in HV and LV are opposing in interleaving.



* If HV & LV are placed on same limb then they should carry i in opposite dire's to satisfy lenz's law.

* If HV and LV are placed on separate limbs then they should carry i in same direction to satisfy Lenz's law.

→ In shell type T/f, core the outer LV wdg sections should have 50% turns when compare to inner LV wdg sections to get symmetry in placement of wdgs and hence to get good mechanical balance.
Sandwitching wdgs

Ideal T/f :-

Assumptions :-

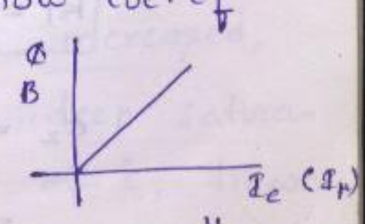
(A1). permiability of T/f is infinity.

(A2). Iron losses are in T/f core → zero

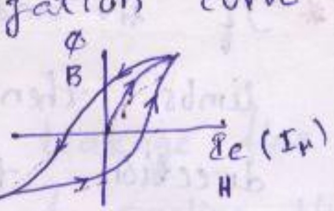
(A3). Resistance of T/f wdg → zero

(A4). No magnetic leakage flux, now coe. of coupling = 1.

(A5). Magnetization curve of T/f is linear.

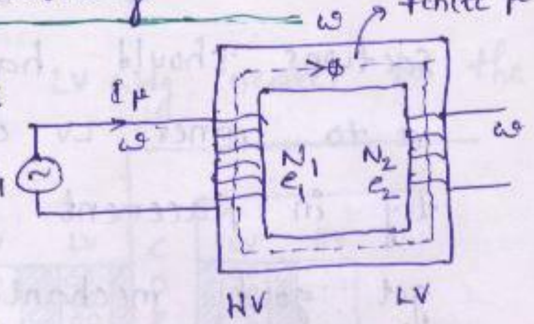


* Non-linearities in Magnetization curve are 1. Saturation NL
2. Hysterisis NL.



A1: operation

→ T/f with finite permiability core:-



I_μ - magnetising current

$i_\mu = I_m \sin\omega t$

Primary mmf $= N_1 i_\mu$

$= N_1 I_m \sin\omega t$

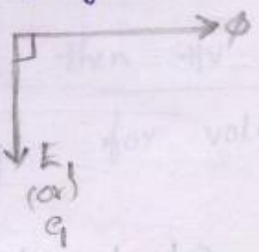
$\phi = \frac{MMF}{R} \Rightarrow \phi = \phi_m \sin\omega t, \quad \phi_m = \frac{N_1 I_m}{R}$

$e_1 = -N_1 \frac{d\phi}{dt}$ $\qquad e_1 = N_1 \phi_m \omega \sin(\omega t - \pi/2)$

$= -N_1 \frac{d}{dt}[\phi_m \sin\omega t]$

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

* emf induced in P. wdg is lagging behind the flux exactly by 90°.



At $\omega t = \pi$,

$E_{1max} = N_1 \phi_m \omega$

$E_1 = \frac{E_{1max}}{\sqrt{2}}$

$= \frac{N_1 \phi_m \omega}{\sqrt{2}} = \frac{N_1 \phi_m 2\pi f}{\sqrt{2}}$

$E_1 = 4.44 N_1 \phi_m f$

$$E_1 = 4.44 N_1 B_m A_n f$$

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

$= -N_2 \frac{d}{dt}[\phi_m \sin\omega t]$

$e_2 = N_2 \phi_m \omega \sin[\omega t - \pi/2]$

* EMF induced in S. wdg is also lagging behind the flux vector by exactly 90° and is inphase with P. induced emf.

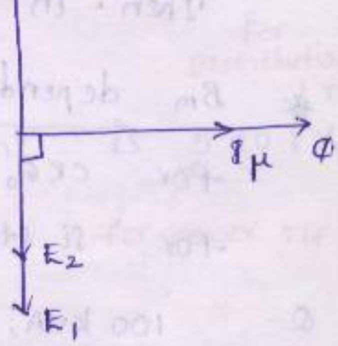
$\therefore E_{2max} = N_2 \phi_m \omega \quad (\because \omega t = \pi)$

$E_2 = 4.44 N_2 \phi_m f$

$$\boxed{E_2 = 4.44 N_2 B_m . A_n f}$$

Vector diagram :-

$v_1 = -e_1$



Observations of emf eq.s :-

1. $\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 B_m A_n f$

   ie induced emf per turn is same on both sides

2. $\frac{E_2}{E_1} = \frac{N_2}{N_1} = k \rightarrow$ Transformation ratio.

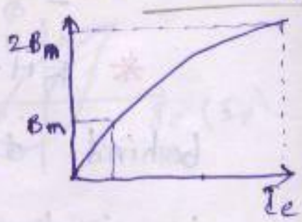
   Turns ratio $\Rightarrow N_1 : N_2$ or $E_1 : E_2$

3. $B_{max} \propto \frac{E_1}{f} \propto \frac{V_1}{f}$

   To keep B_{max} as constant., keep $\frac{V_1}{f}$ as constant $\therefore \frac{V_{11}}{f_1} = \frac{V_{12}}{f_2}$

4. By keeping V_1 (applied voltage) as constant and if the freq. of operation is reduced then the max. value of flux density in the core increased, which drives T/f core into deep saturation. $\therefore$ magnetizing component of i_0 drawn

by the p. wdg from the source is increased sharply.



* If the frequency of operation of T/f is reduced then the kVA rating of T/f reduces proportionately.

for eg, 100 kVA T/f made by US (60 Hz)

Then in India rating = 100 kVA × $\frac{50}{60}$

* B_m depends on nature of material core.

for CRG_0 - 1.2 T to 1.6 T

for Si steal - 1.0 T to 1.2 T

Q. 100 kVA, 50 Hz

100 kVA, 100 Hz

100 kVA, 200 Hz

100 kVA, 400 Hz

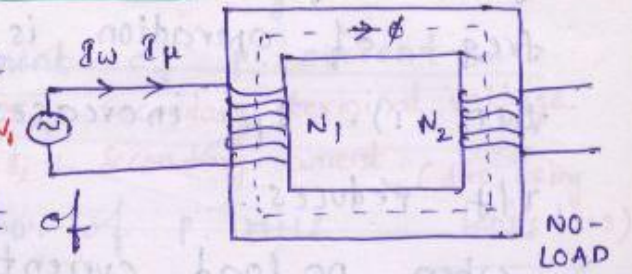
*→ for a given kVA rating and for given max. value of B of core, more the designed frequency, lesser will be the size and weight of the T/f.

*→ for a given kVA rating and for a given designed frequency superior the mag. material of core, lesser will be the size and weight of the T/f.

→ so CRG_0 core T/f has lesser size and weight than the silicon steal T/f.

A2. Operation of T/f with iron losses :-

I_μ - To create flux in the T/f core



* reactive component of current.

I_ω - To supply iron losses in the T/f core.

* active component of current.

Iron loss component of current.

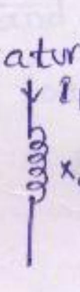
$I_\mu >> I_\omega$

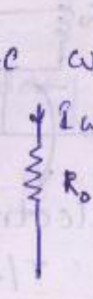
* (I_0) No-load component of current is 5 to 8% of $I_{full\ load}$.

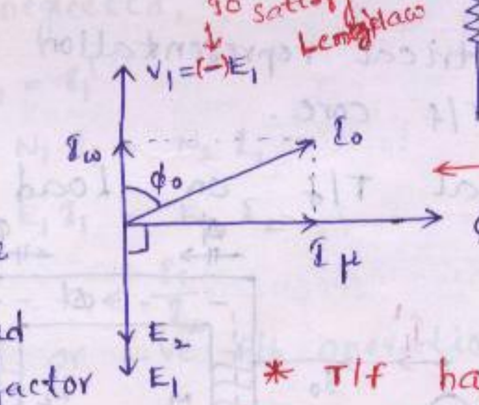
for Distribution T/f ↓ ; for power T/f ↗

$\bar{I}_0 = \bar{I}_\mu + \bar{I}_\omega$

I_μ	I_ω
* wattless component	* watt full component
* 4-6% of I_{FL}	* 1 to 2% of I_{FL}
* Quadrature with V_1	* Inphase with V_1 (Applied voltage)







← vector diagram under NL condition

ϕ_0 - No load phase angle

$\cos\phi_0$ - No load power factor

* $\phi_0 = 70$ to $75°$

* $\cos\phi_0 = 0.2$ lag,

* T/f has poor NL pf of the order of 0.2 lag b'coz its magnetising comp. of current (I_μ) is >>> I_ω.

* By keeping applied voltage constant, if the freq. of operation is reduced of a T/f then 1). I_μ increases 2). NO load PF of T/f reduces.

when no load current is $I_0 \angle \phi_0$

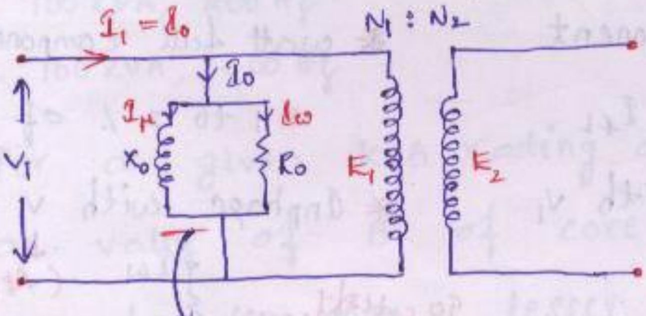
$I_\mu = I_0 \sin \phi_0$ and $I_\omega = I_0 \cos\phi_0$

NL power $= V_1 I_0 \cos\phi_0$

$= V_1 I_\omega$ = Iron losses.

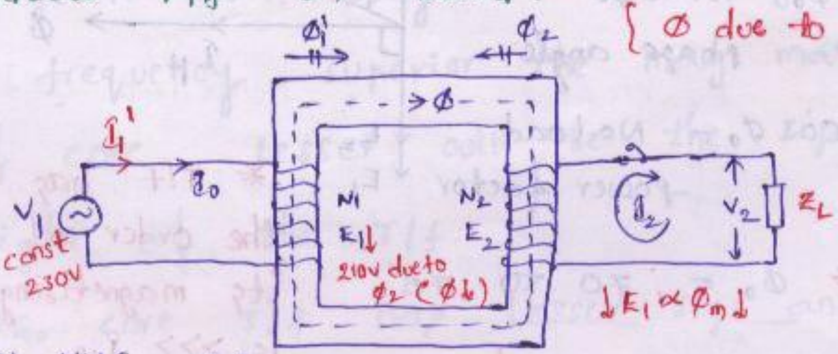
power consumed by T/f at NL, is used to supply iron losses. [if p. wdg resistance is considered small amount of NL primary cu loss also takes place].

NO LOAD condition, Equivalent circuit :-



electrical representation of T/f core.

Operation → Semi Ideal T/f on load :- [ϕ due to I_μ]



produces: primary MMF $= N_1 I_\mu$

primary flux $= \phi$ [main field flux] (or) [working flux]

Secondary flux $= \phi_2$, Secondary MMF $= N_2 I_2$

I_1' – load component of p. current.

V_2 : Secondary terminal voltage.

I_2 : Secondary current (dire. using Lenz's law)

$I_1 = I_1' + I_0$

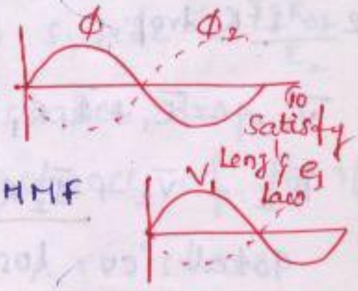
$N_1 I_1'$ – load compo. of p. MMF

ϕ_1' – " " p. flux, $\boxed{\phi_1' = \phi_2}$

* flux in the T/f core is always constant equal to NL flux irrespective of load across secondary terminals. So the T/f can be treated as constant flux device.

$$\phi_1' = \phi_2$$

$$N_1 I_1' = N_2 I_2$$



Load comp. of p. MMF = S. MMF

$$\Rightarrow \frac{N_2}{N_1} = \frac{I_1'}{I_2} = k = \frac{E_2}{E_1}$$

k ↓ Transformation Ratio

$$\Rightarrow I_1' = k I_2 \qquad k \neq \frac{I_1}{I_2}$$

and $E_1 I_1' = E_2 I_2$

load comp. of primary VA = secondary VA

If I_0 is neglected, $I_1 = I_0 + I_1'$

So T/f treated as const. power device

$$I_1 = I_1'$$

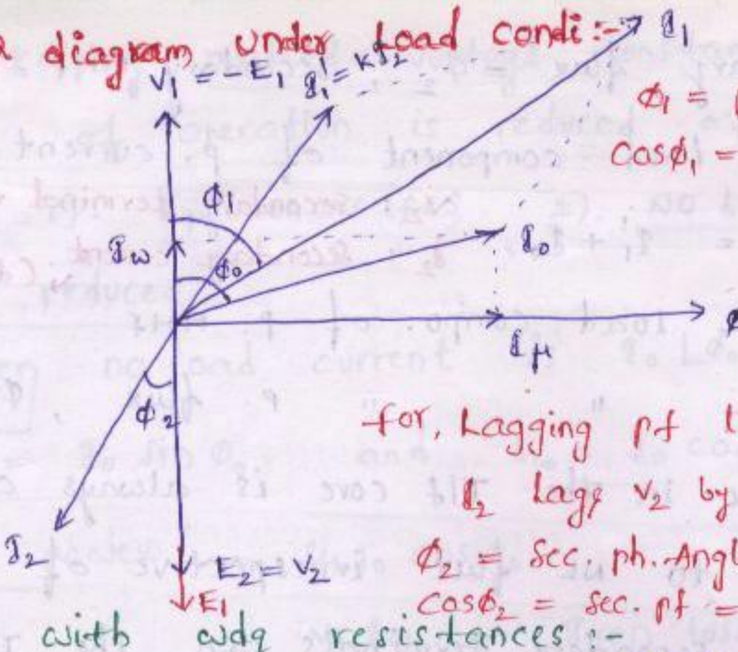
$$\longrightarrow N_1 I_1 = N_2 I_2$$

$$E_1 I_1 = E_2 I_2$$

$$k = \frac{I_1}{I_2}$$

Auto control or –ve f/b operation of a T/f :-

Vector diagram under load condi :-



ϕ_1 = pri. ph. angle

$\cos\phi_1$ = pri. pf

for, Lagging pf load,

I_2 lags V_2 by ϕ_2.

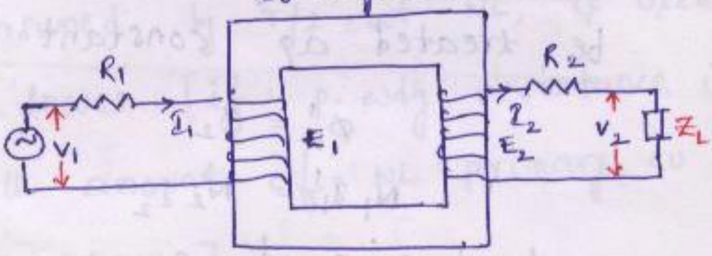
ϕ_2 = Sec. ph. Angle = load ph. angle

$\cos\phi_2$ = sec. pf = load pf.

A3. Operation of T/f with wdg resistances :-

1. IR drop
2. I^2R drop

I_0 neglected



$$\bar{V}_1 = -\bar{E}_1 + \bar{I}_1 R_1$$

$$\bar{E}_2 = \bar{V}_2 + \bar{I}_2 R_2$$

Total cu loss = $I_1^2 R_1 + I_2^2 R_2$

* → cu loss before transfer must be equal to cu loss after the transferring resistances. from one wdg to another wdg.

↓ condi. that must be satisfied while transferring resistance from one side to another side.

R_2' = equivalent of sec. resistance w.r.t. primary

$$I_2^2 R_2 = I_1^2 R_2'$$

$$\Rightarrow R_2' = R_2 \left(\frac{I_2}{I_1}\right)^2$$

$$= R_2 / k^2$$

Primary to secondary,

$$I_1^2 R_1 = I_2^2 R_1'$$

$$\Rightarrow R_1' = R_1 k^2$$

Perunit primary resistive drop :-

$$= \frac{I_1 R_1}{E_1}$$ ← Base volt. on P. side

Perunit secondary resistive drop $= \frac{I_2 R_2}{E_2}$.

R_{01} = total T/f resistance refer to P. side

$$= R_1 + R_2' = R_1 + R_2/K^2$$

R_{02} = total T/f resistance refer to S. side

$$= R_2 + R_1' = R_2 + K^2 \cdot R_1$$

Perunit resistive drop refer to P. side $= \frac{I_1 R_{01}}{E_1}$

Perunit resistive drop refer to S. side $= \frac{I_2 R_{02}}{E_2}$

In perunit system, the % resistance drop is also simply known as % resistance of the T/f.

* % resistance refer to P. side = % resistance refer to S. side.

As pu resistance on both sides of T/f is same, it is easy to transfer pu value of resistance from one side to another side when compared to ohmic values.

Total Cu loss $= I_1^2 R_1 + I_2^2 R_2$

$$= I_1^2 R_{01}$$

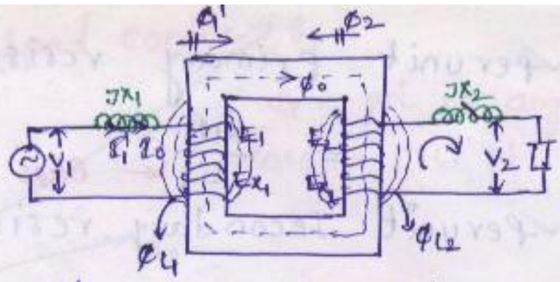
$$= I_2^2 R_{02}$$

A4. Operation of T/f with Magnetic Leakage flux :-

Primary leakage flux due to main flux ϕ and ϕ_1'.

Secondary leakage flux due to ϕ_2

Leakage flux is a flux which links either P. or S. wdgs but not both and it is not having role in transferring the power from one ckt to another ckt. So it is an undesirable flux.



* Leakage flux in the T/f are not constant but they depend on respective Load currents.

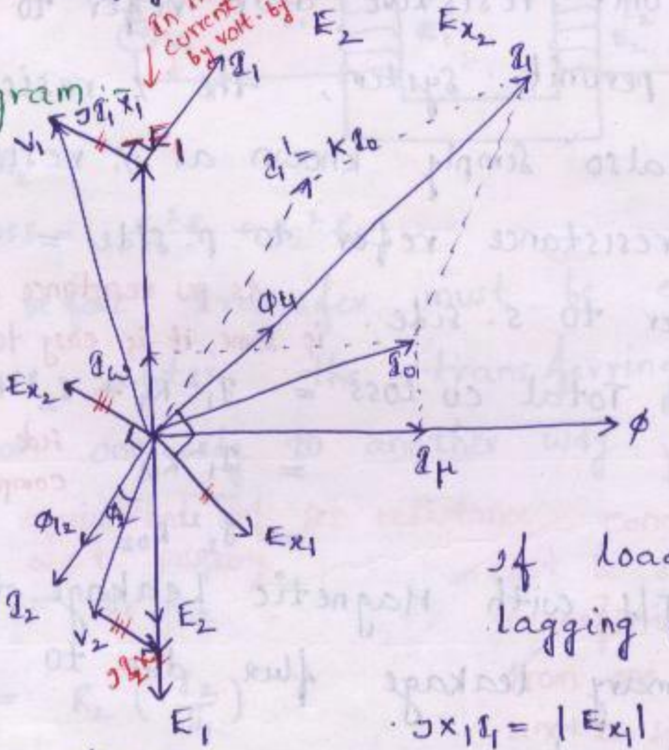
* The leakage flux at P. and S. wdg are always inphase with Load currents.

Primary		Secondary	
ϕ	ϕ_{L_1}	ϕ	ϕ_{L2}
↓	↓ (90° lagging)	↓	↓ (90° lagging)
E_1	E_{x_1}	E_2	E_{x_2}

E_1 is lagging behind ϕ by 90° ($\frac{\pi}{2}$)

In inductor current lags by volt. by 90°

Vector diagram :-



If load is lagging pf

$jx_1 I_1 = |E_{x_1}|$

→ The emf due to mag. leakage flux can be taken into account by assuming additional volt. components in the res. voltage sources such that the additional volt. compo. is used to compensate emf's due to mag. L. flux.

x_2, x_1 = leakage reactance [imaginary inductor] $= \frac{|E_{x_1}|}{I_1}$

$jx_2 I_2 = E_{x_2}$

$\Rightarrow x_2 = \frac{E_{x_2}}{I_2}$

such additional volt. comp. should lead the res. load i's by 90°. ∴ The additional volt. comp. can be taken into account by assuming imaginary reactances in series with p. and s. wdgs such that the magnitude of volt. drop across them equal to emf induced in the res. wdgs due to magnetic leakage flux.

$$\therefore \bar{V}_1 = -\bar{E}_1 + j\bar{I}_1 X_1$$ To compensate the leakage emf E_{x_1}.

$$\bar{E}_2 = \bar{V}_2 + j\bar{I}_2 X_2$$ To compensate E_{x_2}.

If resistances are considered,

$$V_1 = -E_1 + I_1 R_1 + jI_1 X_1$$

$$= -E_1 + I_1[R_1 + jX_1]$$

$$= -E_1 + I_1 Z_1$$

$$E_2 = V_2 + I_2 R_2 + jI_2 X_2$$

$$= V_2 + I_2 Z_2$$

The voltages available on Name plate are Induced EMF's. E_1 / E_2

Base voltages: E_1 on p. side & E_2 on s. side

→ * The condition that must be satisfied while transferring leakage reactance from one wdg to another wdg, the per unit reactance drop should be remain same.

per unit reactance before transferring reactance = per unit reactance after transferring.

per unit primary reactance drop = $\frac{I_1 X_1}{E_1}$ ← Base volt. on p. side

" secondary " " = $\frac{I_2 X_2}{E_2}$ ← Base volt. on s. side

Secondary to Primary :-

$$\frac{I_2 X_2}{E_2} = \frac{I_1 X_2'}{E_1} \qquad X_2' = X_2\left(\frac{I_2}{I_1}\right)\left(\frac{E_1}{E_2}\right) = X_2/K^2$$

primary to secondary :-

$$\frac{I_1 x_1}{E_1} = \frac{I_2 x_1'}{E_2} \Rightarrow x_1' = k^2 x_1$$

$$x_{01} = x_1 + x_2' = x_1 + x_2/k^2$$

$$x_{02} = x_2 + x_1' = x_2 + k^2 x_1$$

Total perunit reactance drop w.r.t. primary $= \frac{I_1 x_{01}}{E_1}$

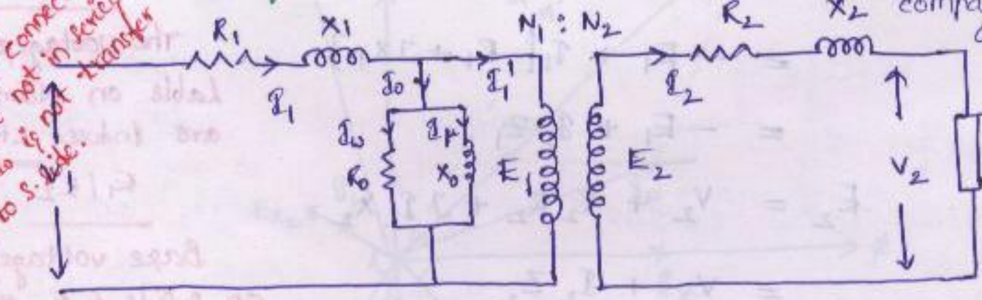
" " " " secondary $= \frac{I_2 x_{02}}{E_2}$ (both are equal)

In perunit system % reactance drop is also simply known as % reactance of the T/f.

* As, % reactance values on both sides of T/f are same, it is easy to transfer the pu values of reactance from one side to another when compared to ohmic values.

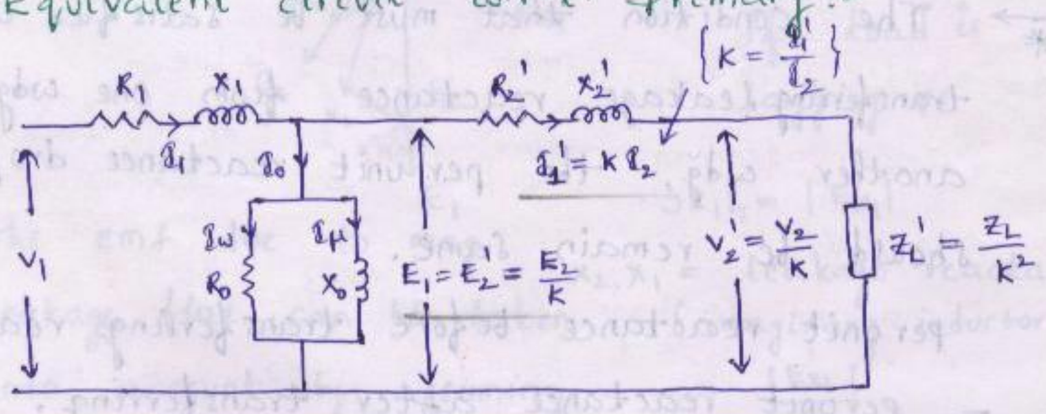
Exact Equivalent circuit :-

No load branch is connected in ||el but not in series
Reason: I_0 is not transfer from p to s. side.



Equivalent circuit w.r.t. primary :-

$\{k = \frac{I_1'}{I_2}\}$



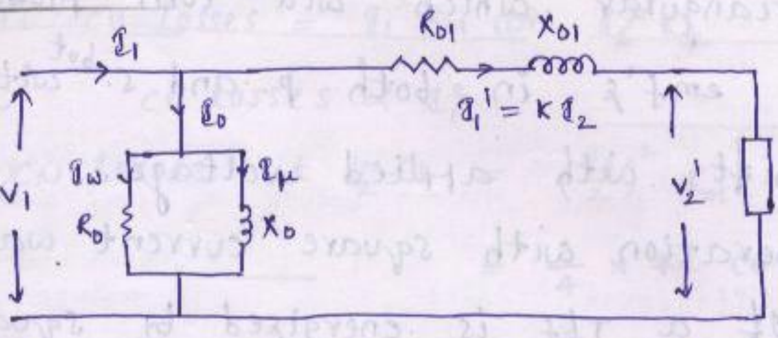
→ 1st approximation to Equivalent circuit :-

[NL branch is transferred from E_1 to V_1 location]:

1. No load p. impedance drop $I_0 Z_1$ is neglected.
2. NL p. cu loss $I_0^2 R_1$ is also neglected.
3. As $V_1 > E_1$, NL current and its components I_μ & I_w

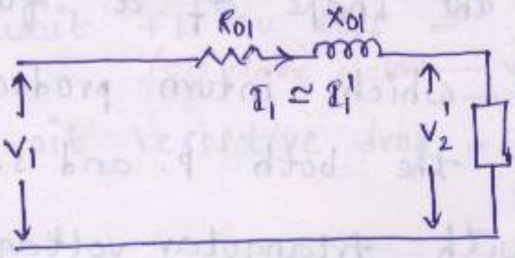
are more than the actual values.

4. As I_w value more than the actual value, the iron losses in this representation are over estimated.



both are equal

→ 2nd approximation Equivalent circuit :- [By neglecting NL branch].



Operation of a T/f with DC Source :-

If a T/f is energized by DC, the nature of production flux in the core is steady which doesn't induce any emf's in p. and s. wdgs. $E_1 = 0$ & $E_2 = 0$

↳ In the absence of self induced emf in p. it draws very high current from the source which may burn the p. wdg. That's why, never connect a T/f across a DC source even of small magnitude.

T/f operation with square wave voltage :-

$v = L\frac{di}{dt}$, $i = \frac{1}{L}\int v\,dt$

If the T/f is energised by a square then the shape of I_μ and ϕ is triangular which will turn produces square emf's in both p. and s. but with 180° ph. shift with applied voltage. ($v_1 = -e_1$)

(Triangular → Ramp ; Square → step)

T/f operation with square current wave :-

If a T/f is energised by square current wave then the shape of a flux also a square wave which inturn produces impulse emf waves in the both p. and s.

T/f operation with triangular voltage wave :-

If a T/f is energised by a triangular wave then the shapes of emf's in the T/f wdgs also triangular but 180° outoff phase with applied voltage.

{ $\int(\text{step}) = \text{Ramp}$; $\frac{d}{dt}(\text{Ramp}) = \text{step}$; $\frac{d}{dt}(\text{step}) = \text{Impulse}$ }

T/f operation with triangular current wave :-

If a T/f is energised by a triangular current wave, the shapes of emf's induced in p. and s. wdgs is a square.

May 26, 2004

Various losses in T/f :-

major {
1. Cu losses ⇒ due to T/f wdg
2. Iron losses ⇒ T/f core
}
3. Stray load losses < Cu parts / Iron parts
4. Dielectric losses → Insulating material

cu losses :- (variable loss)

Total cu losses $= I_1^2 R_1 + I_2^2 R_2$

$= I_1^2 R_{01}$

$= I_2^2 R_{02}$

FL cu losses $= I_1^2 R_{01}$ (or) $I_2^2 R_{02}$

cu losses $\propto I_1^2$

cu losses at $\frac{1}{2}$ FL $= \left(\frac{I_1}{2}\right)^2 \cdot R_{01}$

$= \frac{1}{4} \times$ FL cu loss

$\Longrightarrow$ at x FL $= x^2 \times$ FL cu loss .

per unit FL cu loss $= \frac{I_1^2 R_{01}}{\text{VA rating}} = \frac{I_1^2 R_{01}}{(E_1 I_1)}$

(on Name plate) — VA rating

per unit resistive drop = per unit resistive

$= \left(\frac{I_1 R_{01}}{E_1}\right) \times \frac{I_1}{I_1}$

= perunit FL cu loss .

* In perunit system % FL cu loss = % resistive drop in T/f , it also equal to % resistance of the T/f .

perunit cu loss $\propto I_1^2$

perunit cu loss at x of FL $= x^2 \times$ pu. cu loss

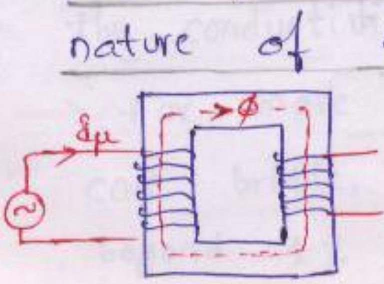
VA rating of T/f ⇒ Base VA

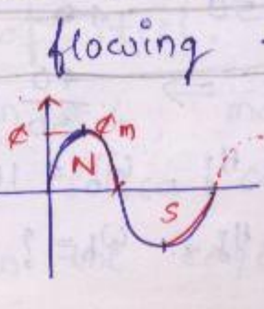
pu cu losses $\propto I_1^2$

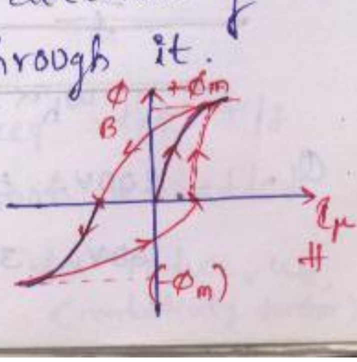
Iron losses :- → If there is no flux in the T/f core then no Iron losses .

→ (1). Hysterisis loss :-

Due to the reversal of magnetization of T/f core because alternating nature of flux flowing through it.







→ The area under hysterisis loop gives, hysterisis loss per cycle. {If freq is 50 Hz, then there are 50 no. of loops}

→ Total hysteris loss for feequency of f,

= Area of hysterisis loop per cycle × f.

⇒ Stiermatz formula,

$$* \quad \boxed{W_h = \eta B_{max}^{x} \cdot f V}$$

- x → stiermatz exponent [Hysterisis coe]
- V → Volume of core material
- f → freq. of magnetic reversal = supply freq.
- η → Stiermatz const.

{η B_{max}^{x} V} → Area under one hysterisis loop
f → no. of H-Loops

x = 1.6 for Si. steel (or) CRGO steel

$B_{max} \propto \frac{V}{f}$

Case 1: $\frac{V}{f}$ const. then B_{max} const.

$\Rightarrow W_h \propto f$ → $A = \eta B_{max}^{x} \cdot V$

$\Rightarrow W_h = Af$

Case 2 :- $\frac{V_1}{f} \neq$ const. ⇒ $B_{max} \neq$ const.

$B_{max} \propto \frac{V_1}{f} \Rightarrow W_h \propto \left(\frac{V_1}{f}\right)^{x} \cdot f$

$\Rightarrow W_h \propto V_1^{x} \cdot f^{-(x-1)}$

for $x = 1.6 \Rightarrow W_h \propto \frac{V_1^{1.6}}{f^{0.6}}$

$\Rightarrow W_h = A V_1^{x} \cdot f^{1-x}$

Q. 200V, 50 Hz, 100 W = W_h

160 V, 40 Hz, W_h = ?

Ans: $\frac{V_1}{f} = \frac{200}{50} = \frac{160}{40} \Rightarrow \frac{V_1}{f} = \text{const}, B_{max} = \text{const}$

$\therefore W_h \propto f \Rightarrow \frac{40}{50} \times 100$

Q. 200V, 50 Hz, W_h = 100 W

160V, 30 Hz, W_h = ?

Ans: $\frac{200}{50} \neq \frac{160}{30}$, $\frac{V_1}{f} \neq$ const

$\therefore \quad \omega_h = A \cdot V_1^{1.6} \cdot f^{-0.6}$

$\therefore \quad 100 = A \cdot (200)^{1.6} (50)^{-0.6} \longrightarrow ①$

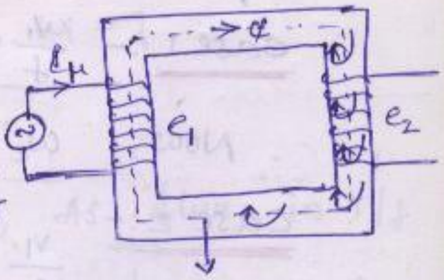
$? = A \, (160)^{1.6} (30)^{-0.6} \longrightarrow ②$

On solving $\omega_h = \left(\frac{160}{200}\right)^{1.6} \left(\frac{30}{50}\right)^{-0.6} \times 100$

* By keeping applied voltage const. and by increasing freq. ($B_{max} \neq$ const) $\Rightarrow \omega_h$ will decreases. (As per case-2)

* for frequency of operation reduction, B_{max} in the T/f is not constant, so the hysteresis loss in T/f core increased.

→ Eddy current Losses:-



Eddy current loss in T/f core $\propto$ conductivity of T/f core.

$\therefore \quad I_e \propto \sigma$

$R_{ce} \propto \frac{1}{\sigma}$

$W_e = I_e^2 R_{ce} \propto (\sigma^2) \times \left(\frac{1}{\sigma}\right) \propto \sigma \Rightarrow \boxed{\omega_e \propto \sigma}$

* Silica content in T/f core reduces the ω_e (Reduces the conductivity of the steel).

About 4% of silica is added to reduce the conductivity of steel.

→ for more than 4%, makes the T/f core brittle, the silica cannot be added beyond 4%. In the case to reduce ω_e, (conductivity further)

further core should be Laminated.

→ If the effective area of the core is reduced, the Resistance offered to the flow of eddy currents increased so ω_e decreased.

* $\omega_e = k \cdot B_{max}^2 f^2 t^2$

$f \rightarrow$ frequency of eddy current (I_e) (= Supply freq.) ($\frac{V_1}{f}$ = const)

$t \rightarrow$ thickness of lamination

$\omega_e \propto t^2$

→ So high freq operated T/f should have thinner laminations to reduce ω_e. (to maintain const)

→* More the freq. of operation of T/f, lesser will be the thickness of lamination required.

Case 1 :- $\frac{V_1}{f}$ = const., B_{max} = const

Now, $\omega_e \propto f^2 \Rightarrow \omega_e = B \cdot f^2$

Case 2 :- $\frac{V_1}{f} \neq$ const, $B_{max} \neq$ const

Now, $\omega_e \propto \left(\frac{V_1}{f}\right)^2 \cdot f^2$

$\Rightarrow \omega_e \propto V_1^2 \Rightarrow \omega_e = B \cdot V_1^2$

→* By keeping applied volt. const. if the freq. of operation of T/f reduced then B_{max} in the T/f core is not const.

∴ No change in ω_e. and ω_h increases

In this case $\omega_e \propto V_1^2$

∴ Total iron loss in the T/f core increases.

→ consequenses of reduction freq. by keeping applied voltage constant.

(i). I_μ drawn by the p. wdg from the source increases

(ii). NL pf of T/f reduces.

(iii). Iron loss in T/f core increases.

→ $\omega_h \propto B_{max}^{1.6} . B_{max}^{0.4}$

$\omega_e \propto B_{max}^2$

$\Rightarrow \omega_i \propto B_{max}^2$

$\propto (V_1/f)^2$

for maintaining f as const. $\omega_i \propto V_1^2$

for eg:- $\omega_i = 100\omega$, at 200V at 50Hz.

Then at 160V, 50Hz, $\omega_i = ?$

$\Rightarrow \omega_i \propto V_1^2$

→ * As ω_i depends on flux, As flux in T/f core const. irrespective of load across S. terminals the ω_i which depends on flux are also maintain const. irrespective of the load.

→ $$\text{pu Iron loss} = \frac{\text{Iron losses in watts}}{\text{VA rating}}$$

pu Iron loss is also const. if kVA rating of T/f taken as base kVA.

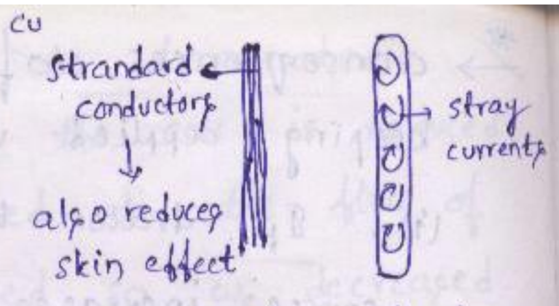
Stray Load Losses :-

(1). cu stray load losses

(2). Iron " "

→ cu stray load losses

$= I_s^2 \cdot R_{cs}$



* cu stray load losses can be reduced by using strandard conductors rather than solid conductors.

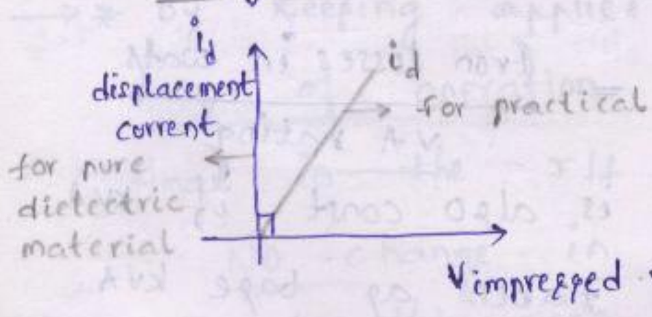
→ * Magnetic leakage flux produces some additional iron losses in T/f which are generally counted against iron stray load losses.

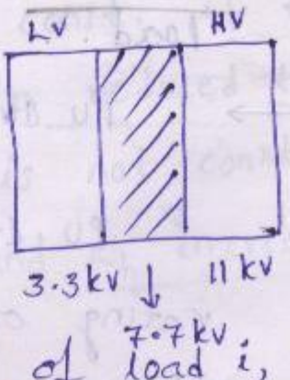
→ stray load losses in the T/f always depends on load i ∴ these are variable losses.

→ for all practical purposes ½% of total o/p can be taken as stray load losses.

Di electric losses :-

This loss normally takes place in insulating materials of T/f such as in inter wdg insulation and also T/f oil.





* As dielectric loss independent of load i, it is a constant loss. It depends on impressed voltage [applied voltage to the T/f].

For all practical purposes, 1/4 % of total o/p can be taken as dielectric losses.

May 24 Various Tests on T/f :-

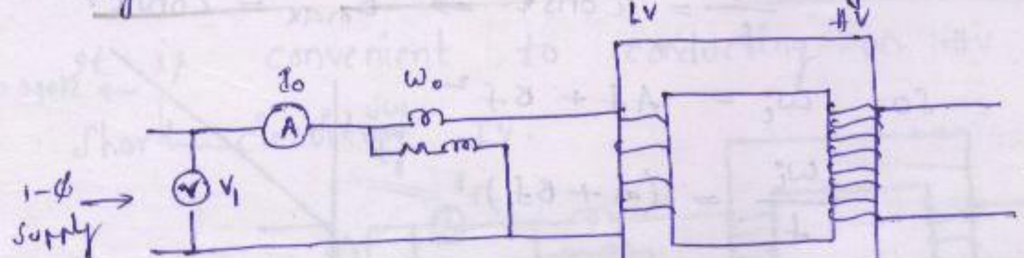
1. Open circuit test :-

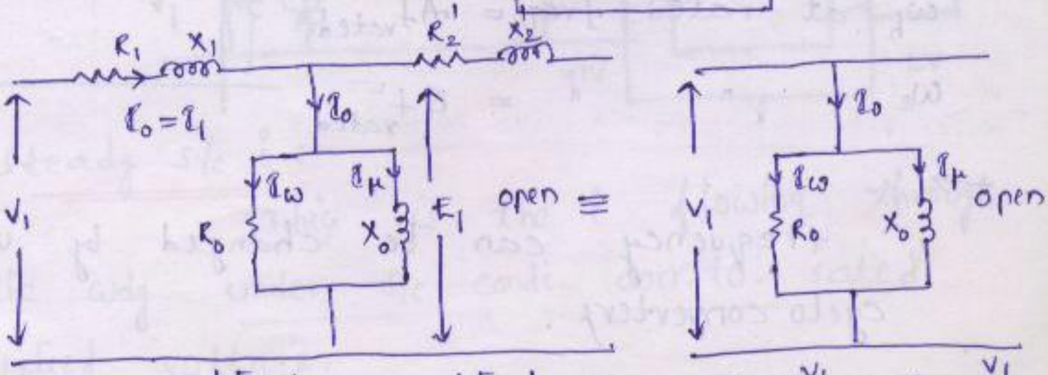
The main objectives are

1. To measure const. losses in T/f.
2. To findout parameters of NL branch. R_0 and X_0 of equivalent ckt.

→ This test is normally conducted on LV by keeping HV as open circuited. It is convenient to conduct the test on LV because, a). As this test should be conducted rated voltage condi. It is conveniently apply Low voltage on LV side.

(b). As NL i more on LV side and this high NL i can be accurately measured.





$R_0 = \left|\frac{E_1}{I_\omega}\right|$, $X_0 = \left|\frac{E_1}{I_\mu}\right|$ $R_0 \simeq \frac{V_1}{I_\omega}$, $X_0 = \frac{V_1}{I_\mu}$

① $w_0 = V_1 I_0 \cos\phi_0$ ② $I_w = I_0 \cos\phi_0$

$\Rightarrow \cos\phi_0 = \frac{w_0}{V_1 I_0}$ $I_\mu = I_0 \sin\phi_0$

③ $R_0 = \frac{V_1}{I_w}$, $X_0 = \frac{V_1}{I_\mu}$.

w_0 = losses in the T/f under O.C condi.

= Iron losses + dielectric losses

+ NL primary cu losses ($I_0^2 R_1$)

To find R_1 kelvin's bridge but not AC volt. & ammeter method ... applied ... dependent at primary

Constant losses = $w_0 - I_0^2 R_1$

Under the assumption that small amount of NL P. cu loss, dielectric losses are neglected, so w_0 directly taken as iron losses in the T/f.

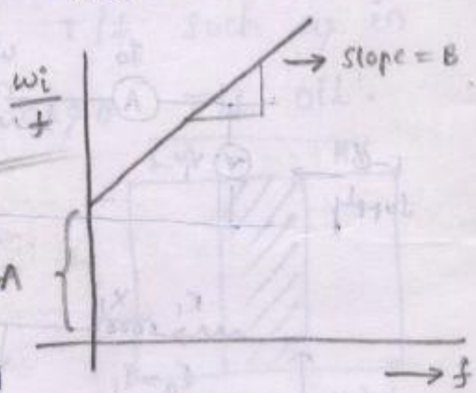
→ Seperation of Iron losses :-

To seperate iron losses into w_e & w_h, the o.c. test should be conducted at variable f and voltage such that V_1/f as constant.

$$\frac{V_1}{f} = \text{Const} \Rightarrow B_{max} = \text{Const}.$$

so $w_i = Af + Bf^2$

$\frac{w_i}{f} = (A + Bf)$



w_h at rated freq = Af_{rated}

w_e " " = Bf^2_{rated}

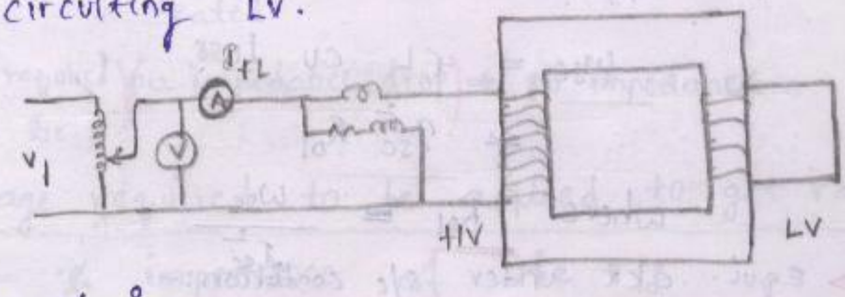
→ frequency can be changed by using cyclo converters.

→ * Consequenses in o.c. test if it is conducted at rated voltage but at less than rated frequency (i). I_μ ↑ (ii). Iron loss ↑ (iii). I_ω ↑ (iv). I_0 ↑ (v). $I_0^2 R_1$ ↑ [NL P. cu loss] (vi). ω_0 ↑ (vii). $\cos\phi_0$ ↓

⟹ Short circuit test:-

The main objectives are, (1). To find (measure) variable losses in T/f. (2). To findout total resistance and reactance of T/f refered to the wdg in which the measuring instruments are placed.

→ During this test by short circuiting one wdg terminals the applied volt. to another wdg should be increased until rated i's flow through both wdgs. As this test should be conducted at rated current condi. It is convenient to conducting on HV by short circuiting LV.



Steady s/c i :-

This is the i flowing through the wdg under s/c condi. corr. to. rated applied voltage.

* As LV is s/ced so only 8-10% of rated volt. is enough to produce rated s/c i's in both wdgs.

W_{sc} = losses in T/f under s/c condi.

= FL cu losses in both wdgs + stray load losses + small amount of iron losses corr. to V_{sc}.

Variable loss = W_{sc} − iron losses → V_{sc}

To determine iron losses corr. to V_{sc}, we use o.c test results,

$$V_{rated} \longrightarrow W_0 = W_i$$

$$V_{sc} \xrightarrow{f\ const.} ? = W_i \times \left[\frac{V_{sc}}{V_{rated}}\right]^2 \quad \because W_i \propto V_1^2$$

$$\therefore \text{Variable losses} = W_{sc} - W_i\left(\frac{V_{sc}}{V_{rated}}\right)^2$$

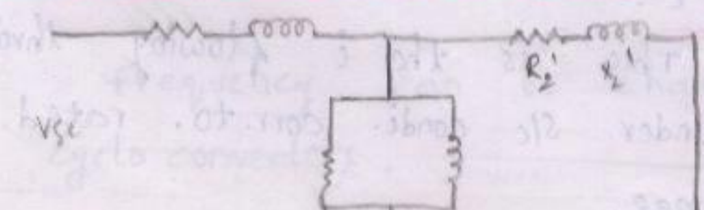
→ under the assumption that small amount of stray load loss and iron losses are neglected, wattmeter reading during s/c test can be approximately gives FL cu losses in T/f.

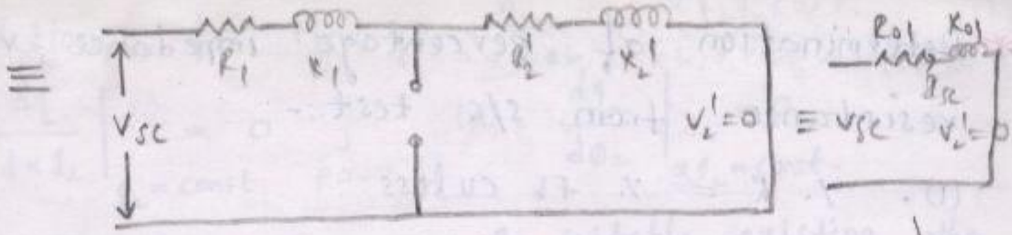
$$W_{sc} = FL\ cu\ loss$$

$$= I_{sc}^2 R_{01}$$

$$\text{where } R_{01} = \frac{W_{sc}}{I_{sc}^2}$$

⟹ Equi. ckt under s/c condition:-





$V_{sc} = I_{sc} R_{01} + j I_{sc} X_{01}$

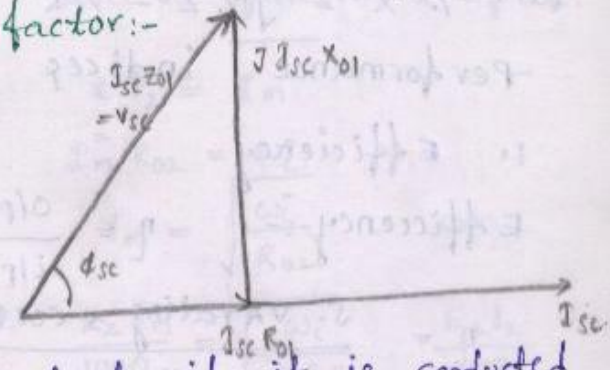
$= I_{sc} \cdot Z_{01} \Rightarrow Z_{01} = \frac{V_{sc}}{I_{sc}}$

$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

→ short circuit power factor:-

$\cos\phi_{sc}$ → s/c pf.

$= \frac{R_{01}}{Z_{01}}$



→ * Deviations in s/c test, if it is conducted with same impressed voltage but less than rated frequency (i). $X_{01} \downarrow$, $R_{01} = \text{const}$, $Z_{01} \downarrow$

$\uparrow I_{sc} = \frac{V_{sc}}{Z_{01} \downarrow}$ (ii). FL Cu loss $= \uparrow I_{sc}^2 R_{01} \Rightarrow W_{sc} \uparrow$

(iii). $\uparrow \cos\phi_{sc} = \frac{R_{01}}{Z_{01} \downarrow}$ (iv).

* $\frac{V_{sc}}{V_{rated}} = \frac{I_{sc} Z_{01}}{V_{rated}}$

(pu voltage required to produce I_{sc}) (pu impedance drop) → pu impedance

imp * % voltage required to be applied to get rated s/c i = % impedance of the T/f.

$\underset{(steady)}{I_{sc}} = \frac{V_{1rated}}{Z_{01}}$

→ $\frac{I_{sc(steady)}}{I_{1rated}} = \frac{V_{1rated}}{Z_{01} \cdot (I_{1rated})} = \frac{1}{\frac{I_{1rated} \cdot Z_{01}}{V_{1rated}}} = \frac{1}{\text{pu impedance}}$

(pu steady s/c i)

* Determination of percentage impedance, reactance, resistance from s/c test :-

(1). $\% R = \%$ FL cu loss

$$= \frac{\text{FL cu loss}}{\text{VA rating}} = \frac{W_{sc}}{\text{VA rating}} \times 100$$ → Name plate

(2). $\% Z = \frac{V_{sc}}{V_1 \text{ rated}} \times 100$

(3). $\% X = \sqrt{\% Z^2 - \% R^2}$

Performance indices of T/f :-

1. Efficiency 2. Regulation

Efficiency :- $\eta = \frac{\text{o/p power}}{\text{i/p power}} \times 100$

$$\eta = \frac{\text{S. VA rating} \times \cos\phi_2}{\text{P. VA rating} \times \cos\phi_1} = \frac{E_2 I_2 \cos\phi_2}{E_1 I_1 \cos\phi_1}$$

$$\eta = \frac{\text{o/p power}}{\text{o/p power + losses}}$$

$\bar{I}_1 = \bar{I}_0 + \bar{I}_1'$

$\bar{I}_1' = K\bar{I}_2$

$I_1 \angle \phi_1$

Rating of T/f :-

The rating of any electrical machine is limited by temp. rise of machine during its operation. The temp. rise in any machine is due to losses in that machine that means rating of any machine is indirectly determined by losses in that machine.

In case of T/f iron loss depends on voltage rating and cu loss depends on rated current

Conditions for Max. η :- $\eta_{x\ of\ FL} = \frac{x E_2 I_2 \cos\phi_2}{x E_2 I_2 \cos\phi_2 + x^2 (C I_2^2) + \omega_i}$

(i). $\left.\frac{d\eta}{dx I_2}\right|_{\phi_2 = const} = 0$ (power η)

(ii). $\left.\frac{d\eta}{d\phi_2}\right|_{xI_2 = const} = 0$.

$x^2 C I_2^2 = \omega_c$

Exact: Variable loss (includes stray) = Const. loss (includes dielectric)

$\Rightarrow$ Approximate: [cu losses = Iron loss at any x of FL]

Q. FL $\omega_{cu} = 300\omega$

$\omega_i = 400\omega$

Total losses corr. to $\eta_{max} = ?$

$(400 + 400)\omega = 2\omega_i$

$x^2 (I_2^2 R_{02}) = \omega_i$

$\Rightarrow x = \sqrt{\frac{\omega_i}{I_2^2 R_{02}}}$

* $x = \sqrt{\frac{\text{iron losses}}{\text{FL cu losses}}}$

By suitably existing the ratio b/w Iron to FL cu loss designed the max. η can be achieved at any desired fraction x of FL.

$x I_2 = I_m$

$I_m^2 R_{02} = \omega_i$

$I_m = \sqrt{\frac{\omega_i}{R_{02}}}$

$\frac{E_2 I_m}{1000} = \sqrt{\frac{\omega_i}{I_2^2 R_{02}}} \cdot \frac{E_2 I_2}{1000}$

* KVA corr. to η_{max} = (FL KVA) $\sqrt{\frac{\omega_i}{FL\ \omega_{cu}}}$

(ii). $\left.\frac{d\eta}{d\phi_2}\right|_{xI_2 = const} = 0 \Rightarrow \phi_2 = 0 \therefore \cos\phi_2 = 1$.

* By keeping load i const, if the Load pf is varied then η is max exactly at unity pf.

procedure to findout η if the losses are given in % or pu values :-

1. KVA rating of T/f choosen as Base KVA.

pu(or)% FL cu loss $= \omega_{cu}$

pu(or)% Iron loss $= \omega_i$

2. * $\eta_{FL} = \frac{1 \times \cos\phi_2}{1 \times \cos\phi_2 + \omega_{cu} + \omega_i} \times 100$

$\eta_{1/2\,FL} = \frac{0.5 \times \cos\phi_2}{0.5 \times \cos\phi_2 + \frac{1}{4}\omega_{cu} + \omega_i} \times 100$

* $\eta_{xFL} = \frac{x \cdot \cos\phi_2}{x \times \cos\phi_2 + x^2 \omega_{cu} + \omega_i} \times 100$

We know, pu FL cu losses = pu Resistance.

power T/f → power η   Distribution T/f → ?

All day η (or) Energy η (or) Operational η :-

→ Operational differences b/w power & distribution T/f :-

Power T/f	Distribution T/f
1. Used in transmission n/ω	1. Used in distribution n/ω.
2. These are not directly connected to consumers	2. Directly connected to consumers.
3. >1 MVA, Large HV T/f	3. ≤ 1MVA, Small LV T/f.
4. Load fluctuations are less.	4. Load fluctuations are more (6AM–6PM → ½ FL, 6PM–11PM → FL, 11PM–6AM → ¼ FL)
5. Windings are loaded fully throughout 24 hrs.	5. Wdgs are loaded based on load cycle of consumer T/f. (Primary is excited throughout 24 hrs)
6. Iron, Cu losses takeplace fully throughout 24 hrs	6. Cu losses depends on load cycle of consumer. Iron losses unnecessarily takeplace throughout 24 hrs. □ → ⌴ → to Iron ↓
7. $\frac{\text{Iron wt}}{\text{Cu wt}}$ is less	7. Iron losses ↓ ∝ B_{max} ↓ ; $\downarrow\phi = \downarrow B A \uparrow$ (keep const) ; $\downarrow E_1 \propto \phi_m \downarrow$ (undesirable so,) $\frac{\text{Iron weight}}{\text{Cu weight}}$ is more
8. Specific wt. is less (weight per kVA rating)	8. Specific wt. is more.
9. Avg load = FL (or) nearer to FL	9. Avg. load in Modern D-T/f = 75% FL; in Olden days = 50% of FL
10. To get max η, x = 1.	10. To get max η, x = 0.75; x = 0.5 in olden D.T/f.
11. FL Cu loss = Iron loss	11. FL Cu loss ≃ 2 × Iron losses; ≃ 4 × Iron loss in Olden D.T/f.
12. Operation of P.T/f independent of time so power basis for finding the performance of T/f.	12. Operation of D.T/f depends time, so Energy basis (power × time)

GAM–6PM, FL – 500 kVA, 12, pf
o/p in kwh = 500 × 1 × 12
Cu = 50W
→ in kwh = 50×12/1000

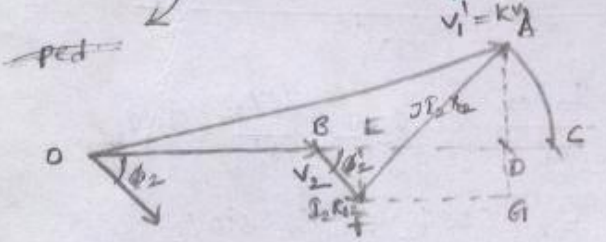
$$\eta_{\text{all day}} = \left.\frac{\text{o/p in kWH}}{\text{i/p in kWH}}\right|_{24\,hrs} = \frac{\text{o/p in kWH}}{\text{o/p in kWH} + \text{losses in kWH}}$$

depends on load cycle

* power η more than the all day η of D.T/f.

Approximate voltage drop in T/f :-

pd



$V_1' = OA = OC$

$V_2 = OB$

Exact voltage drop = BC

= OC − OB

If CD is neglected, BD is Appro. volt. drop

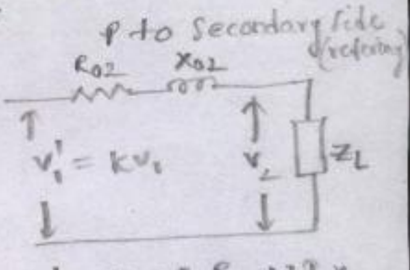
$BD = BE + ED$

$= BE + FG$

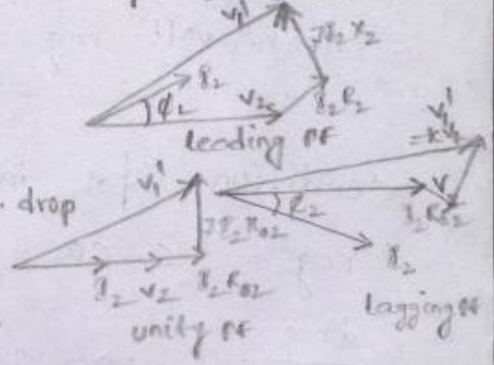
$= I_2 R_{02}\cos\phi_2 \pm I_2 X_{02}\sin\phi_2$

+ for lagging pf, − for leading pf loads.

p to Secondary side (referring)



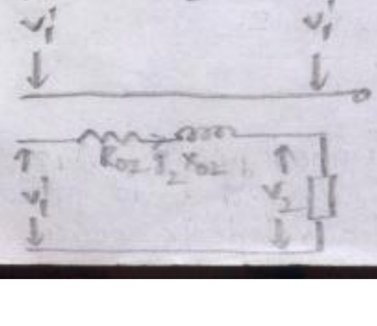
$V_1' = V_2 + I_2 R_{02} + jI_2 X_{02}$



Voltage regulation :-

The change in S. terminal volt. from NL to FL at some specific load pf and is expressed as % fraction of either NL S. terminal volt. or FL S. terminal voltage. (OR)

This is the change in S. terminal volt. when FL at some specific pf is suddenly thrown off and is expressed % fraction of either NL or FL terminal voltages. is called voltage regulation.



V_1' = NL S. terminal voltage

V_2 = FL S. terminal voltage

$$\text{volt. reg} = \frac{(V_1' - V_2)}{V_1'} \times 100$$ → reg. down (for specific pf $\cos\phi_2$)

(or) $\frac{V_1' - V_2}{V_2} \times 100$ → reg. up

* Unless otherwise specifically mentioned simply reg in sense reg. down only.

Appro. volt. reg = $\dfrac{\text{Appro. volt. drop}}{V_1'}$

pu R & pu X are findout from s/c test $= \dfrac{I_2 R_{02} \cos\phi_2 \pm I_2 X_{02} \sin\phi_2}{V_1'}$

$\epsilon_r = \dfrac{I_2 R_{02}}{V_1'} = \text{puR}$ $\quad = \dfrac{I_2 R_{02}}{V_1'} \cdot \cos\phi_2 \pm \dfrac{I_2 X_{02}}{V_1'} \cdot \sin\phi_2$

(↳ pu resistance drop; ↳ pu reactance drop)

$\epsilon_x = \dfrac{I_2 X_{02}}{V_1'} = \text{puX}$ $\quad = \epsilon_r \cdot \cos\phi_2 \pm \epsilon_x \cdot \sin\phi_2$

% (Appr. pu volt. reg) = ((puR) $\cos\phi_2$ ± (puX). $\sin\phi_2$) × 100

= (%R) $\cos\phi_2$ ± (%X) $\sin\phi_2$

condition for max. regulation :-

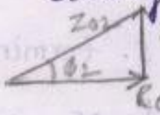
reg = $\epsilon_r \cos\phi_2 \pm \epsilon_x \sin\phi_2$

↳ take +, because max is possible in case of lagging loads

$\dfrac{d\,\text{reg}}{d\phi_2} = 0 \Rightarrow \tan\phi_2 = \dfrac{\epsilon_x}{\epsilon_r}$

$\Rightarrow \phi_2 = \tan^{-1}\left(\dfrac{\epsilon_x}{\epsilon_r}\right) = \tan^{-1}\left(\dfrac{X_{02}}{R_{02}}\right)$

* Regulation is always max. at lagging pf Loads only.



→ Impedance Δ^{le}

pf corr. to max. reg = $\cos\phi_2 = \dfrac{R_{02}}{X_{02}}$

* $\dfrac{R_{02}}{X_{02}} = \cos\phi_{sc}$

↳ If load pf = pf on s/c of T/f then volt. drop in T/f is max.

Value of Max. reg :-

reg = $\dfrac{I_2 R_{02}}{V_1'} \cos\phi_2 + \dfrac{I_2 X_{02}}{V_1'} \sin\phi_2$

At max. reg. $\cos\phi_2 = R_{02}/X_{02}$ & $\sin\phi_2 = \dfrac{X_{02}}{Z_{02}}$

$= \dfrac{I_2}{V_1' Z_{02}}\left[R_{02}^2 + X_{02}^2\right] = \dfrac{I_2 \cdot Z_{02}^2}{V_1' \cdot Z_{02}}$

$= \dfrac{I_2 \cdot Z_{02}}{V_1'} = \text{pu } Z.$ % impedance

* Max. possible reg. in T/f = % impedance of T/f which is also equal to % rated voltage required to produce % rated s/c current.

Condition for zero regulation:-

$\epsilon_r \cos\phi_2 - \epsilon_x \sin\phi_2 = 0 \Rightarrow \tan\phi_2 = \frac{\epsilon_r}{\epsilon_x}$

* zero reg. is always possible at leading pf loads only. $\phi_2 = \tan^{-1}\frac{R_{02}}{X_{02}}$ leading

$\cos\phi_2 \rightarrow$ is the pf corr. to. zero reg.

Regulation at unity pf:-

$\cos\phi_2 = 1, \quad \sin\phi_2 = 0$

$\text{Reg.} = \frac{I_2 R_{02}}{V_1'} = \text{pu } R \rightarrow (\% R)$

$= \text{pu fl cu loss.} \rightarrow (\% \text{ FL cu loss})$

ϵ_r at x of FL $= x \cdot \frac{I_2 R_{02}}{V_1'} = x \cdot \epsilon_r$

ϵ_x at x of FL $= x \cdot \epsilon_x$

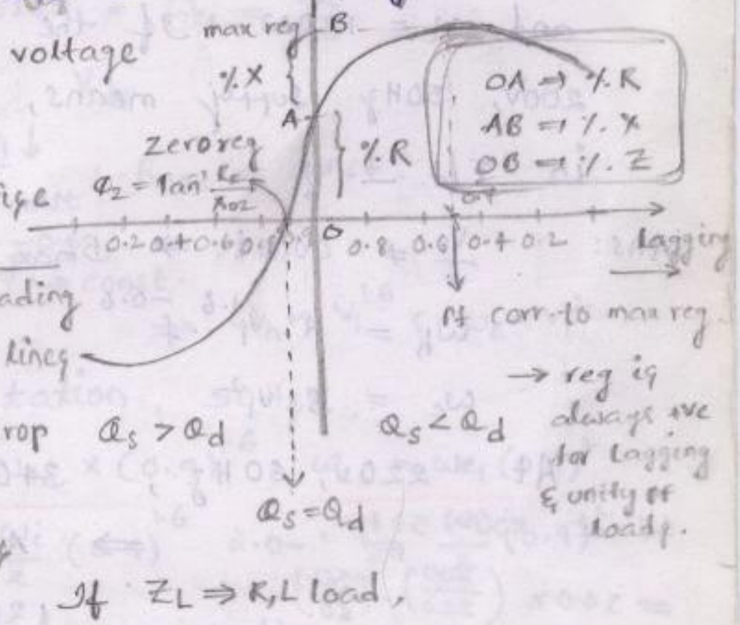
* Reg at x of FL $= x[\epsilon_r \cos\phi_2 \pm \epsilon_x \sin\phi_2]$

$= x \cdot \times$ Reg. at FL.

→ Reg. may be +ve at larger pf nearer to unity.

Reg. is always −ve at low leading pf loads.

* −ve reg. corr. to. voltage rise in the T/f.



→ $Q_s > Q_d \Rightarrow$ voltage rise

↓

R.E volt. > S.E. volt.

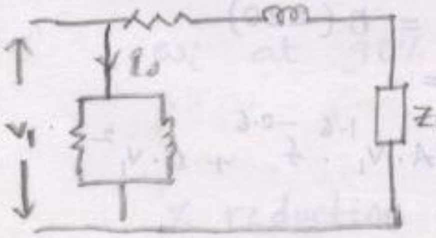
Eg:- Long transmission lines

→ $Q_s < Q_d \Rightarrow$ voltage drop

Eg:- distribution n/w

↳ Inductive loads

→ reg is always +ve for lagging & unity pf loads.



If $Z_L \Rightarrow$ R,L load,

Q.[T/f] A T/f has a $W_h = 30\,W$ at 240V, 60Hz supply. The W_h of T/f at 200V, 50Hz — ?

Ans. 25W

Ans. $\frac{V_1}{f}$ = const $\therefore W_h \propto f$.

Q. A T/f has $W_i = 90\,W$ at 60 Hz supply. and 52W at 40 Hz supply. Both losses are being measured at same peak B. Total iron loss in T/f on 50 Hz supply is — ?

Ans:- B_{max} = const.

$$W_i = Af + Bf^2$$

At 60Hz, $90 = A(60) + B(60)^2$

At 40Hz, $40 = A(40) + B(40)^2$

$\Rightarrow A = 0.9$ & $B = 0.01$

At 50 Hz, $W_i = 0.9(50) + 0.01(50)^2 = 70W$.

Q. A 220V, 1-Φ, 60Hz T/f has $W_h = 340\,W$ and $W_e = 120W$. If the T/f is operated from 200V, 50Hz supply means, the total iron loss in T/f — ?

Ans: $\frac{V_1}{f} \neq$ const $\Rightarrow B_{max} \neq$ const.

$$W_h = A \cdot V_1^{1.6} \cdot f^{-0.6}$$

$$W_e = B \cdot V_1^2$$

At 220V, 60 Hz, $340 = A(220)^{1.6}(60)^{-0.6}$

$\Rightarrow A =$

$120 = B(220)^2$

$\Rightarrow B =$

W_i at 200V, 50Hz

$= 340 \times \left(\frac{200}{220}\right)^{1.6} \cdot \left(\frac{50}{60}\right)^{-0.6} + 120 \times \left(\frac{200}{220}\right)^2$

At 200V, 50Hz, $W_i = A \cdot V_1^{1.6} \cdot f^{-0.6} + B \cdot V_1^2$

Q. The ω_h, ω_e of a 1-φ T/f when operated ~~250~~ 240 V, 60 Hz are P_H and P_e res. % decrease in losses when T/f operated from 200V, 50 Hz is —?

$\left[\begin{array}{l} P_{e_1} \propto 60^2 \\ P_{e_2} \propto 50^2 \\ V/f = const \end{array}\right]$ $\frac{240}{60}$ & $\frac{200}{50}$ $\omega_h \propto f$ $\boxed{\begin{array}{l} P_{h_1} \propto 60 \\ P_{h_2} \propto 50 \end{array}}$

Ans :-

$\omega_h \propto f, \ \omega_e \propto f^2 \Rightarrow P_h \propto f, \ P_e \propto f^2$

$\boxed{\% \text{ reduction in } \omega_h = \frac{P_{h_1} - P_{h_2}}{P_{h_1}}} = \frac{60-50}{60} \times 100$; % reduction $= \frac{P_{e_1} - P_{e_2}}{P_{e_1}} \times 100 = \frac{60^2 - 50^2}{60^2}$

Q. 50 Hz 1-Ø T/f has equal ω_h & ω_e losses at rated excitation. with the T/f operated at 50 Hz and at 90% of excitation, % reduction in ω_i when compared to rated excitation is —?

Ans:- At rated excitation, 50 Hz,

Iron losses $= \omega_i$,

Hysterisis losses $= \omega_{h_1} = \frac{\omega_i}{2}$

Eddy i losses $= \omega_{e_1} = \frac{\omega_i}{2}$

$f =$ const, $V \downarrow$

$\downarrow B_{max} \propto \frac{V_1 \downarrow}{f_{const}}$, $B_{max} \neq$ const.

$\omega_h \propto V_1^{1.6} \cdot f^{-0.6}$ → const.

$\omega_e \propto V_1^2$ $\Rightarrow \omega_h \propto V_1^{1.6}$ & $\omega_e \propto V_1^2$

At 90% excitation, 50 Hz

$\omega_{h_2} = \omega_{h_1} \times (0.9)^{1.6}$; $\omega_{e_2} = \omega_{e_1} (0.9)^2$

$= \frac{\omega_i}{2} (0.9)^{1.6}$ $= \frac{\omega_i}{2} (0.9)^2$

ω_i at 90% of excitation $= \omega_{h_2} + \omega_{e_2}$

$= 0.827\, \omega_i$

% reduction ω_i is $= 17.3\%$ ← $= \frac{\omega_i - 0.827\,\omega_i}{\omega_i} \times 100$

Q. The iron losses of 1000 ω of a given T/f are equally divided b/ω ω_h & ω_e. with certain impressed volt. & freq. If the applied volt. is ~~halved~~ halfed and freq. doubled then the ω_i will be - ?

$\omega_h = 500$, $\omega_e = 500$, $\omega_h \propto f$, $\omega_e \propto f^2$, 500, $\omega_{h2} = 500($

Ans: with certain V & f,

Total losses $\omega_i = 1000\ \omega$

$\Rightarrow \omega_{h1} = 500\ \omega$

$\omega_{e1} = 500\ \omega$

$B_{max} \propto \frac{V_1}{2f \times 2}$, $B_m \neq$ const.

$\omega_h \propto V^{1.6} \cdot f^{-0.6}$; $\omega_e \propto V_1^2$

ω_i at half rated V and doubled f,

$\omega_{h2} = \omega_{h1} (0.5)^{1.6} \cdot (2)^{-0.6}$ $\qquad \omega_{e2} = \omega_{e1} (0.5)^2$

$= 500\ (0.5)^{1.6} (2)^{-0.6}$ $\qquad = 500\ (0.5)^2$

$\therefore \omega_i = \omega h_2 + \omega e_2 =$

Q. 5 kV, 25 Hz 1-ø T/f has cu, hys. and eddy losses of 0.4 %, 0.6 %, 0.5 % of FL o/p. If T/f operated on 10 kV, 50 Hz supply system, what will be the % losses, if current in the T/f wdg remains same.

cu losses are same but % cu losses change

Ans: $\% \text{ cu losses} = \frac{\text{FL cu loss watts}}{\text{VA rating}} = \frac{\text{FL cu loss}}{E_1 I_1 \times 2}$

$V_{11} = 5\text{ kV}$ $\qquad I = \text{const.}$ $\qquad V_1 = 10\text{ kV}$

$f_1 = 25\text{ Hz}$ $\qquad f_2 = 50\text{ Hz}$

$(kVA)_1 = x$ $\qquad (kVA)_2 = 2x$

FL Cu loss in watts = const.

% Cu Loss = 0.4 becomes 0.2 %.

% W_h = 0.6 %.

$$\% \text{ H. losses} = \frac{\text{H. losses in watts} \times 2}{\text{V.A rating} \times 2}$$

FL Cu loss in watts depends on load only

$\frac{V_1}{f}$ = const., $W_h \propto f$

New % W_h = 0.6 %.

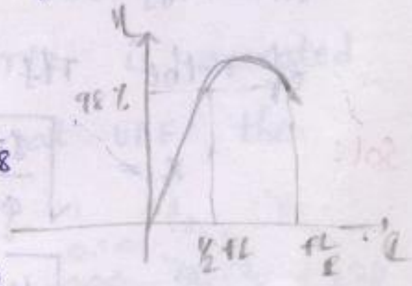
% W_e = 0.5 % $\frac{V_1}{f}$ = const. So $W_e \propto f^2$

$$\therefore \% W_e = \frac{\text{E.C losses in watts} \times 2^2}{\text{V.A rating} \times 2}$$

New % W_e = 0.5 × 2 = 1.0 %.

G'05

Q. A 20 kVA 1-φ T/f has η of 98% at FL and also at ½ FL. The PF is unity in both the cases. When the η of T/f at 3/4 FL unity PF is — ?



Ans: $$\eta_{FL} = \frac{20 \times 10^3 \times 1}{20 \times 10^3 \times 1 + W_i + W_{cu}} = 0.98$$

$\Rightarrow W_i + W_{cu} = 408 W \rightarrow ①$

$$\eta_{½FL} = \frac{10 \times 10^3 \times 1}{10 \times 10^3 \times 1 + ¼ W_{cu} + W_i} = 0.98$$

$\Rightarrow W_i + \frac{1}{4} W_{cu} = 204 W \rightarrow ②$

from ① & ② ⇒ W_{cu} = 272 W

W_i = 136 W

$$\eta_{3/4 FL} = \frac{15 \times 10^3 \times 1}{15 \times 10^3 \times 1 + (3/4)^2 . (272) + (136)}$$

= 98.1 %

Q. A. T/f has a max. η of 90% at FL pf. The η of the T/f at ½ FL at same pf is — ? (kVA not given)

Sol: FL kVA should be taken as a Base kVA.

$$\eta_{FL} = \frac{1pu \times 1}{1pu \times 1 + 2\omega_i} = 0.9$$

ω_i = pu iron loss

$$\Rightarrow \omega_i = 0.055 \, pu$$

$$\omega_{cu} = 0.055 \, pu$$

At max η: $\omega_i = \omega_{cu}$

$$\eta_{\frac{1}{2}FL, \, UPF} = \frac{0.5 \times 1}{0.5 \times 1 + \frac{1}{4}(0.055) + 0.055} = 87.88\%$$

Q. The %R & %X of a 10 kVA, 400/200 V, 1-φ T/f are 2% and 6% res. If the const. losses in T/f are 1%. The max. possible % η of the T/f — ?

↑(FL cu loss = ω_i)

Sol:

%R = 2%

%X = 6%

% const. loss = 1%

% cu loss = 2%

$$x = \sqrt{\frac{\text{Iron loss}}{\text{cu loss}}} = \sqrt{\frac{1}{2}} = 0.707$$

For const. load at unity pf η is max

$$\eta_{\text{at } 70.7\% \text{ of FL, UPF}} = \frac{0.707 \times 1}{0.707 \times 1 + 0.01 + 0.01} = 97.2\%$$

Q. A T/f has max. η of 97% at 15 kVA unity pf. The (all day η) of T/f when FL of 20 kVA at UPF for 12 hrs, and NL rest of the day on the T/f is — ?

Sol: $\eta_m = \dfrac{15\times10^3\times1}{15\times10^3\times1 + \text{total losses}} = 0.97$

$\rightarrow$ Total losses $= 463\ \omega$ FL kVA = 20 kVA

As η_{max}, $\Rightarrow 2\omega_i = 463$ $\omega_{cu} \parallel$

$\Rightarrow \omega_i = 231.5\,\omega$ $15 \longrightarrow \omega_i$

$20 \longrightarrow ?$

ω_{cu} at $3/4$ FL $= 231.5$ $\longrightarrow \left(\frac{20}{15}\right)^2 \cdot \omega_{cu}$

$\Rightarrow \left(\frac{4}{3}\right)^2 \times 231.5 =$ FL cu loss. $= \left(\frac{4}{3}\right)^2 \times 231.5$

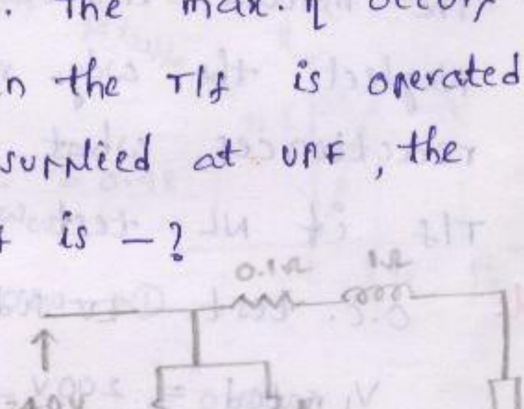
$$\eta_{all\,day} = \frac{20\times10^3\times1\times12 + 0}{(20\times10^3\times1\times12) + 231.5\times24 + 411.5\times12}$$

$= 97.8\,\%$

Q. A 25 kVA, 50 Hz 1-ϕ 2400/240 V. distribution T/f has the following parameters when refer to LV, total series impedance $0.1 + j1\,\Omega$ shunt conductance $= 0.012\,\mho$ and shunt susceptance $= 0.09\,\mho$. (1). The max. η occurs at — % of FL (2). when the T/f is operated at 240 V and is supplied at UPF, the max η of the T/f is — ?

Sol: $I_1 = \dfrac{25\times10^3}{240}$

$= 104.1\,A$



FL cu loss $= I_1^2 R_{01}$

$= (104.1)^2 \times 0.1 = 1085\,\omega$

Iron loss $= V_1 I_\omega$

$= V_1 \cdot \frac{V_1}{R_0} = V_1^2 \cdot G_0 = 240^2 \times 0.012$

$= 691.2\,\omega$

$x = \sqrt{\dfrac{\text{Iron loss}}{\text{cu loss}}} = \sqrt{\dfrac{691.2}{1085}} = 0.798$

So η is max at 79.8 % of FL.

$$\eta_{max\,(0.798FL)} = \frac{0.798 \times 1 \times 10^3 \times 25}{0.798 \times 25 \times 10^3 \times 1 + 691.2 \times 2} = 93.5\%$$

Q. A 10 kVA, 400/200 V 1-ϕ T/f with 10% impedance draws a steady s/c i of - ?

Sol: * pu steady s/c $i = \frac{1}{pu\,Z}$ — s/c → HV side

$$= \frac{1}{0.1} = 10 \text{ pu}$$

$$I_1 = \frac{10 \times 10^3}{400} = 25 A$$

steady s/c i in A = 10 pu × 25

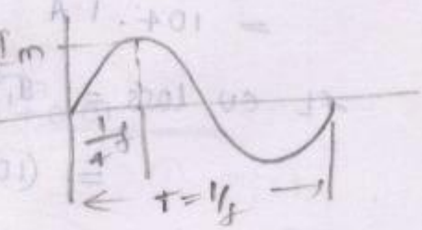
= 250 A.

Q. A 5 kVA, 50Hz 1-ϕ T/f has a ratio of 200/400 V. The data is taken on LV at rated volt shows o/c wattage as 100W. The mutual inductance b/w P & S. is 2H. Neglect the effect of wdg. resistance and leakage reactances, what will be the i taken by T/f if NL test is conducted on HV side.

Sol: o.c. test LV side

V_1 rated = 200V $\quad W_0 = 100$ W

M = 2H



NL i, I_0 on LV = $\bar{I}_\omega + \bar{I}_\mu$

$$\Rightarrow I_0 = \sqrt{I_\omega^2 + I_\mu^2}$$

Iron losses = $V_1 I_\omega = 100$ W

$$\Rightarrow I_\omega = \frac{100}{200} = 0.5 A$$

$$E_2 = M \cdot \frac{di_\mu}{dt}$$

$$= M \cdot \frac{I_m}{(1/4f)} = M \cdot I_m \cdot 4f$$

$400 = 2 \times I_m \times 4 \times 50$

$\Rightarrow I_m = 1A.$

$I_\mu = \frac{I_m}{\sqrt{2}} = 0.707\ A.$

$\therefore I_{o_{LV}} = \sqrt{0.707^2 + 0.5^2} = 0.86\ A.$

$I_o \text{ on HV} = I_o \text{ on LV} / k \quad \left(k = \frac{400}{200}\right)$

$= \frac{0.86}{2} = 0.43\ A \quad (N_2/N_1)$

Q. A 50Hz 1-φ T/f draws s/c i of 30A at 0.25 pf lagging when connected to 16V, 50Hz source. what will be it pf, if it is energized from 16 V, 75 Hz. source.

Sol: $\cos\phi_{sc} = \frac{R_{02}}{Z_{02}}$

At 16V, 50 Hz Supply

$I_{sc} = 30A$

$\cos\phi_{sc} = 0.25$ lag

$Z_{02} = \frac{V_{sc}}{I_{sc}} = \frac{16}{30} = 0.53\ \Omega$

$\cos\phi_{sc} = \frac{R_{02}}{Z_{02}}$

$\Rightarrow R_{02} = 0.25 \times 0.53 = 0.13\ \Omega$

$X_{02} = \sqrt{0.53^2 - 0.13^2} = 0.516\ \Omega$

At 16V, 75 Hz Supply

$X \propto f;\ X_{02\ new} = 0.516 \times \frac{75}{50} = 0.774\ \Omega$

$Z_{02\ new} = \sqrt{0.13^2 + 0.774^2} = 0.784\ \Omega$

$\cos\phi_{sc\ new} = \frac{R_{02}}{Z_{02\ new}}$

$= \frac{0.13}{0.784}$

$= 0.165$ lag.

Q. If 10 KVA, 400/200 V, 1-ϕ T/f with % R = 3% and % X = 6% delivering 50 amp to Resistive load. When the load side volt. of T/f is ——?

Sol:

(Resistive load UPF) (% reg = % R)

$$\% \text{ reg} = \frac{V_1' - V_2}{V_1'} = \frac{3}{100} \times 1$$

$$\frac{200 - V_2}{200} = 0.03$$

$$\Rightarrow V_2 = 194 \text{ V}$$

[I_2 rated $= \frac{10 \times 1000}{200} = 50\text{A}$]

Q. A 20 kVA 2000/200 V 1-ϕ T/f has % R of 2% % X of 6%. To maintain load side voltage at 200V at FL 0.8 pf lag, The voltage required to be applied on p. side of the T/f is —?

Sol: 2000/200 V ($E_1 : E_2$) % R = 2%, % X = 6%

$$\% \text{ reg. at 0.8 FL lag} = \% R \cos\phi_2 + \% X \sin\phi_2$$

$$= 2 \times 0.8 + 6 \times 0.6$$

$$= 5.2\%$$

[$V_2 = 200\text{V} / 0.8$ pf lag, $\Rightarrow V_1 = ?$]

voltage required to be applied on primary to maintain the terminal volt. 200 V.

= 2000 + drop w.r.t. Primary

$$V_1 = 2000 + 2000 \times \frac{5.2}{100} = 2104 \text{ V}$$

Q. A T/f has 400/200 V transformation ratio and it has a secondary pf of 0.8 when it is loaded, It requires 40 V to circulate rated s/c current and pf in case of s/c is 0.2 find the pu. reg. of T/f at FL 0.8 lag.

Sol: 400/200V , $\cos\phi_{sc} = 0.2$ $V_{sc} = 40V$

$\% reg = \% R \cos\phi_2 + \% X \sin\phi_2$

$\% Z = \frac{V_{sc}}{V_{1 rated}} = \frac{40}{400} \times 100 = 10\%$

$\cos\phi_{sc} = \frac{\% R}{\% Z} \Rightarrow 0.2 = \frac{\% R}{10} \Rightarrow \% R = 2\%$

$\% X = \sqrt{10^2 - 2^2} = 9.79\%$

% reg. at 0.8 pf lag $= \% R\cos\phi_2 + \% X\sin\phi_2 = 7.47\%$

Q. A T/f is supplied at 600V with a terminal volt. of S. side 230V at FL 0.8 pf lagging. If the equivalent R and X drops are 1% & 5% res. The turns ratio of T/f — ?

Sol: Turns ratio $= N_1 : N_2$

$= E_1 : E_2$ — induced emf / Name plate details

$V_1 = 600V$

$V_2 = 230V$ at FL 0.8 pf lag.

volt. drop is referred to P. side $= E_2 = V_2 = 230V$

$\% R = 1\%$ % voltage drop $= 1 \times 0.8 + 5 \times 0.6$

$\% X = 5\%$ $= 3.8\%$

[$E_1 = V_1$ − drop w.r.t. primary] $E_1 = 600 - 600 \times \frac{3.8}{100}$

$= 577V$

Turns ratio $= E_1 : E_2$

$= 577 : 230$ V

Q. The max. η of a 100 kVA 1-Φ T/f is 98% and it occurs at 80% FL unity pf. The leakage impedance 5% the volt. reg of T/f at FL 0.8 pf leading is — ?

Sol: $\% Reg. = \% R \cos\phi_2 - \% X \sin\phi_2$

$\% Z = 5\%$

$$\eta_{80\% \text{ of FL}} = \frac{80 \times 10^3 \times 1}{80 \times 10^3 \times 1 + \text{Total losses}} = 0.98$$

0.8 UPF (Max)

$\Rightarrow$ Total losses = 1632 W

Iron losses $= \frac{1632}{2} = 816$ W

$(0.8)^2 W_{cu} = 816$ Cu losses = 816 W at 80% of FL

$\rightarrow W_{cu\text{-}FL} = 816 \times \frac{1}{0.8^2}$

FL Cu loss $= \left(\frac{1}{0.8}\right)^2 \cdot 816 = 1275$ W

% R = % FL Cu loss

$$= \frac{\text{FL Cu loss}}{\text{VA rating}} = \frac{1275}{100 \times 10^3} \times 100 = 1.275\%$$

$\% X = \sqrt{5^2 - 1.275^2}$

% reg = 1.275 × 0.8 − 4.83

Q. A S/C test is conducted on 5 kVA, 400/100 V 1-φ T/f with 100 V shorted. I/P volt. at FL i is 40 V. Wattmeter on i/p side reads 250 W. Determine the load pf at which the S. terminal volt. is minimum.

Sol: 400/100 V, V_{SC} = 40 V

$\% Z = \frac{40}{400} \times 100 = 10\%$

W_{SC} = 250 W — FL Cu loss

(% R = % FL Cu loss)

$$\% R = \frac{W_{SC}}{\text{VA rating}} = \frac{250}{5 \times 10^3} \times 100 = 5\%$$

pf corr. to max. reg. $\cos\phi_2 = \frac{R_{02}}{Z_{02}}$

$$= \frac{\% R}{\% Z} = \frac{5}{10} = 0.2 \text{ pf}$$

Q. An iron cored T/f working at max. B of 0.8 T is replaced by Si steel core working at a max B of 1.2 T. If the total flux is to remain same. What is % reduction in volume of T/f expressed as % of original value if the frequency and volt/turn are the same?

Sol: f = const. E_1/ turn = const.

$$\frac{E_1}{N_1} = 4.44\, B_m A_n f$$

$$\Rightarrow B_{m_1} A_{n_1} = B_{m_2} A_{n_2}$$

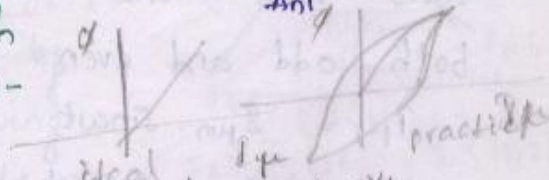
$$\Rightarrow \frac{A_{n_2}}{A_{n_1}} = \frac{0.8}{1.2} = 0.66$$

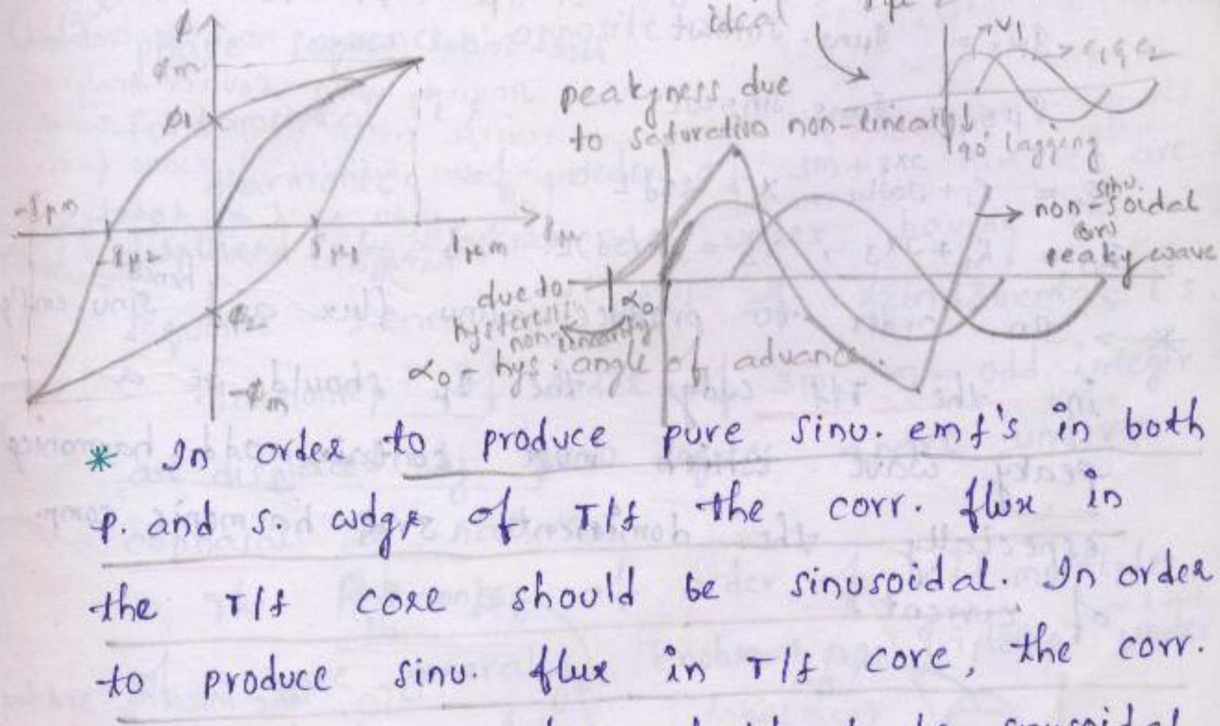
$$V \propto A \times l \Rightarrow V \propto A$$

$$\% \text{ reduction in volume} = \frac{V_1 - V_2}{V_1} = 1 - \frac{V_2}{V_1} = 1 - \frac{A_{n_2}}{A_{n_1}} = 0.33$$

JUN 2007

Operation of T/f with Non-linearity core :-





* In order to produce pure sinu. emf's in both p. and s. wdgs of T/f the corr. flux in the T/f core should be sinusoidal. In order to produce sinu. flux in T/f core, the corr. magnetising comp. of i should not be sinusoidal but it should be a non-soidal or peaky wave to satisfy saturation and hys. non-linearities of T/f core.

There are 2 deviations in the non-sinu. wave shape when it is compared with sinu.

1. current zero points an advanced from α_0 due to hys. non-linearity of T/f core.
2. There is a peakyness in I_μ wave due to saturation non-linearities of T/f core.

peakyness wave —Fourier Analysis→ Sinusoidal

If a wave form is symmetrical about x-axis [+ve half = -ve half cycle] then the fourier series of that wave form contains only odd harmonics. On the other hand if the wave form is not symmetrical about x-axis then the f.s. of that wave form contains both odd and even harmonics.

$I_{\mu 1} = I_{\mu m} \cdot \sin\omega t$

$I_{\mu 3} = I_{\mu m3} \cdot \sin 3\omega t$

$I_{\mu 5} = I_{\mu m5} \cdot \sin 5\omega t$

$\therefore I_\mu = I_{\mu 1} + I_{\mu 3} + I_{\mu 5}$

Non-soidal wave can be resolved into sinu. by using fourier Analysis → reverse process is called as wave shaping (or) synthesis of wave form.

$Z_1 = R_1 + j\omega L_1$, $X_1 = 2\pi f L$ (jX_1)

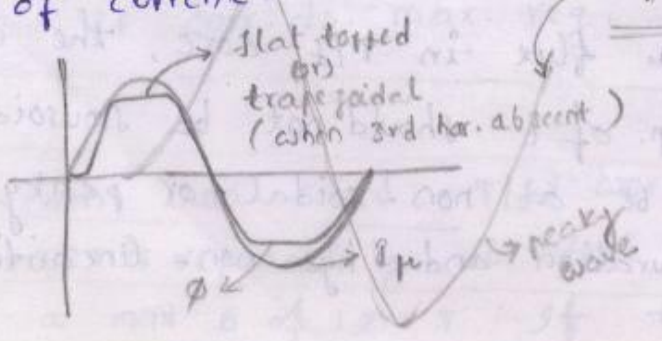
$Z_3 = R_1 + jX_3$, $X_3 = 2\pi(3f)L$.

$Z_5 = R_1 + jX_5$, $X_5 = 2\pi(5f)L$.

upto 50% of total harmonic content → 3rd har.

In order to produce sinu. flux and hence sinu. emf's in the T/f wdgs the I_μ should be a peaky wave which must contain odd harmonics especially the dominent 3rd harmonic comp. of current.

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

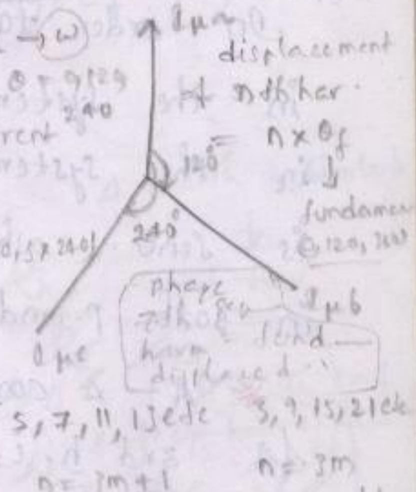


So, the missing 3rd har in I_μ will appear in ϕ & also in emf.

vibrations are due to harmonics in Machines

→ If 3rd harmonic compo. is absent in I_μ wave, then the shape of I_μ is more or less sinu. which produces a flat topped or trapezoidal flux in T/f core which contains odd harmonics especially the dominent 3rd har. comp. of flux. If flux has 3rd Har. comp., the corr. emf is not a sinu. which also contains 3rd har. emf's in addition to fundamental emf which is undesirable.

In 3-phase system :-



Harmonics of order of 3m-1, m = even (5, 11, ...) are always displaced by 0, 240, 120 under having phase sequence opposite to fundamental i's. (-ve sequence)

Harmonics of order of 3m+1, m = even (7, 13, ...) are displaced by 0, 120, 240 and are under having ph. sequence same as that of fundamental i's. (+ve sequence)

Harmonics of order of 3m, m = odd integer are displaced by zero degrees apart and are under cophasal in nature.

The harmonics of order of odd multiples of 3 are generally known as Triplans and are under cophasal in nature.

fundamental property of 3-ph. system

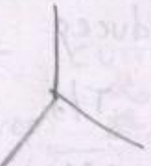
Sum of the

co-phasal ← 3, 5, 7, 9, ← co-phasal

-ve seq, +ve seq

$n \neq 3m \pm 1$ $n = 3m$

120 apart 0 apart Can present only when there was a closed path in 3-φ



$i_{a3} + i_{b3} + i_{c3} = 0$ $i_{a3} + i_{b3} + i_{c3} \neq 0$

can present in any where 3-φ system (lines & phases)

In Δ-connection system due to closed path 3rd h.c. are present, but in lines they are absent also in Y

In order to get the cophasal nature of 3rd h.c. same comp. of i in the system there must be a closed path in the system then only the shape of flux is sinu. which in turn produces sinu. emf's in both p. and s. wdgs of T/f.

* A Δ connected system provides closed path for 3rd h.c. i.s ∴ shape of emf in that case is sinu. wave.

* A Y connected system doesn't provide any closed path for 3rd h.c. of i, in that case emf is non-sinu. only when the magnetic ckt employed for the T/f provides closed path for 3rd h.c. of flux just like 5-limbed shell type T/f core. Another hand emf is non sinu. if mag. ckt employed for T/f doesn't provide any closed path for 3rd h.c. of flux just like 3-limbed core type T/f core.

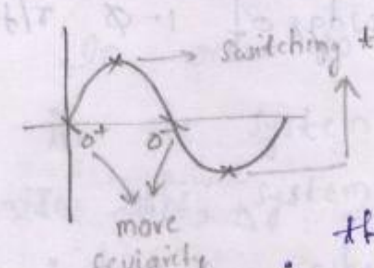
Refer My Another Notes for this
Verify this one

* purity of sinu. emf in T/f wdgs depends on the strength of 3rd har. c. of i in I_μ wave, the magnitude or strength of 3rd h.c. of i depends on magnitude of 3rd h. impedance offered by the circuit to the flow of 3rd h.c. of i.

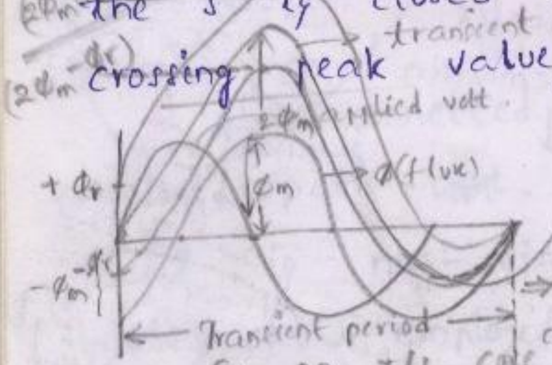
Jun. 02

Switching Transients in T/f :-

→ fast variations in V & I & ing in a shortest periods. due to disturbance



* The seviarity of switching transients always depends on the instant at which the switch is closed on the applied volt. wave 4dm. S.T. are more seviere when the s is closed at the instant when applied v. wave crossing 0 points. S.T. are less severe if the 's' is closed at when the applied v. wave crossing peak values.



Due to Magnetic inertia:- (theorem behind it) Theorem of flux linkages i.e flux linkages are cannot be changed instantaneously.

So no T/f core can produce $-\phi_m$ flux instantaneously

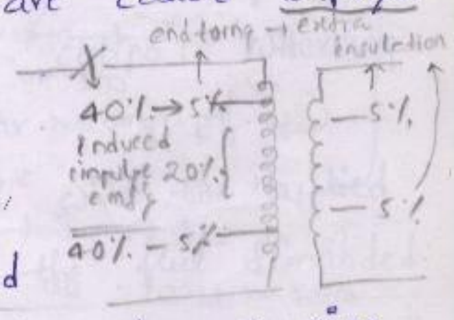
Doubling effect:- → (2-times flux wave)

* If the switch is closed when the applied voltage wave crossing zero point, flux demanded by core is $-\phi_m$ to get normal ph. relation b/w applied v and flux. But no T/f core can produce this much of flux instantaneously because of its magnetic

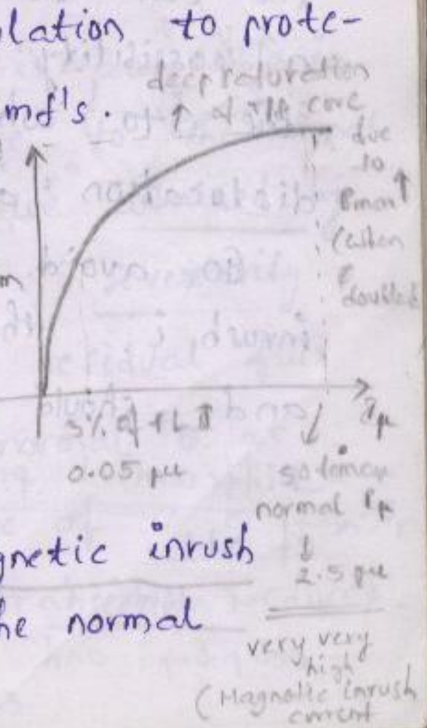
inertia [Th. of const. flux linkages]. In this case ϕ produced in T/f core doesn't trace the normal ϕ path But it traces the transient flux path and attains twice the max. value of normal flux. This effect in T/f is called doubling effect.

⇒ Undesirable consequences due to Doubling Effect:-

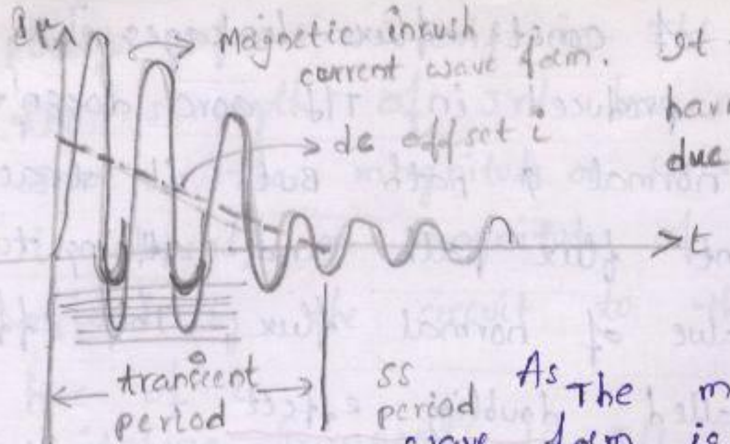
Double the amount of flux during transient period induces almost double the emf in p. and s. wdgs within a short duration of time. Thats why these emf's are called impulse emfs.



As time period very less most of the impulse voltage about 80%, 5% end turns on both sides of T/f wdgs causing lot of dielectric stress at these turns. So these turns should be provided with some extra thickness of insulation to protect them against impulse emf's.



Double the amount of flux during demands very high I_μ from source due to deep sat. of magnetic T/f core. This high I_μ generally known as Magnetic inrush current. which 50 times the normal I_μ.



It has even and odd harmonics are present due to unsymmetrical.

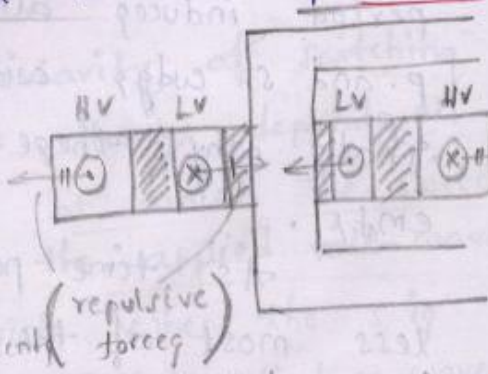
odd : 3, 5, 7 ...

even : (2) 4, 6 ... → most dominent

As The magnetic inrush i wave form is not symmetrical about x-axis. So the fourier series of that wave containg both odd & even harmonics. Among these, the most dominent harmonic is 2nd harmonic i.

No load i → only on P.

load i → transferred from one to another wdg → forces are balanced → it is less 5 % of FL i



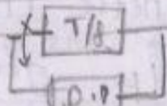
so no effect. But under transient it is only on concentrated on P so more current. so forces are not balanced. Remedy:- proper brassing of coils to avoiding dislocation of coils.

→ As mag. inrush i flowing through only P. wdg the corr. secondary comp. is absent ∴ there is a possibility of mech. unbalance b/w wdgs. due to which there is a possibility of dislocation of wdgs from T/f core.

To avoid the above consequences due to inrush i, the wdg should be properly brassed and should be given good mech. support. (shell type is best one)

→ Differential protection can protect all inner parts of T/f.

* fault i contains only sequential comp.s and free from harmonic comp.s.



extra coil ← (second harmonic restriking coil)

But inrush i → consists harmonic comp. s.

↳ whenever the T/f draws mag. inrush i, the differential protection used in conventional T/f may detect the inrush i as fault i, which may trip the T/f. Under these circumstances it is very difficult to connect the T/f across supply. To overcome above difficulty second har. restraining coils are used with D.P. to make distinguish b/w fault and mag. inrush i's. The diff. b/w fault and mag. inrush i' is the former doesn't contains any har. compo. whereas later contains strong II har. comp. of i.

* If the 'S' is closed when the applied volt. crossing peak value, the flux demanded by core at the instant of switching is zero only ∴ flux produces in core traces normal flux path and hence transients are almost absent.

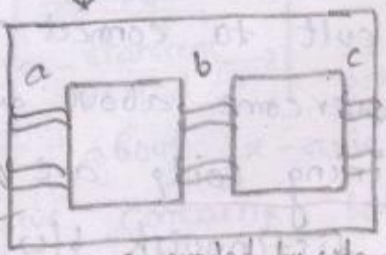
→ * with some residual flux is available in T/f core with polarity opposite to the normal flux wave then the peak value attained by transient ϕ wave is $2\phi_m + \phi_r$ ∴ severity further increases. If the residual flux having same as that of normal ϕ at switching then the peak value of ϕ is $2\phi_m - \phi_r$ ∴ severity of switching transients reduces.

3-φ Transformers :-

also used in open Δ mode.

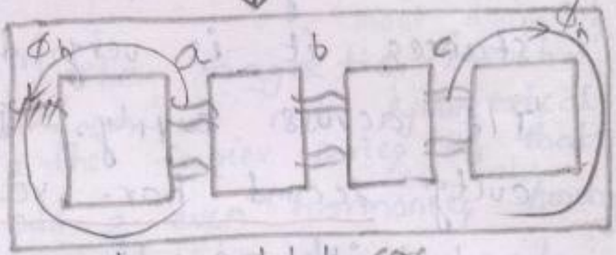
1. 3-φ bank of 3 1-φ T/f's. → reliability more
2. single unit of 3-φ T/f. → 15% less cost.
   - → 3-limbed core type
   - → 5-limbed shell type.

In 1-φ T/f's, there are core type & shell type. 2 limbed core type & 3 limbed shell type.



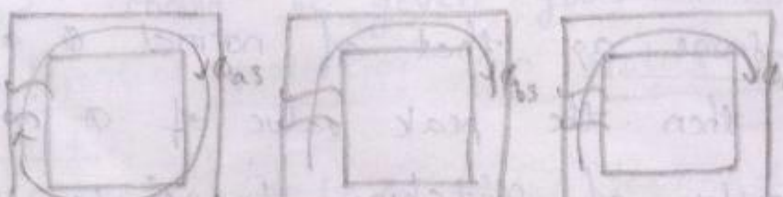
All limbs are having equal cs Area

core surrounded by wdg.



wdg surrounded by core

Core type	Shell type
1. Less mech. support	2. Good mech. support to the wdgs. (sandwitch wdg, side by side)
2. cu requirement is more (concentrate nature of wdg, HV placed over LV)	2. Less requirement of cu.
3. Insulation requirement is less	3. More
4. Economical for high volt. applications & low current rating application. (HV, low kVA rating)	4. Economical for low volt. applications & high current rating applications (LV, large kVA rating T/F)
5. 3rd harmonic flux is absent. emf is always a sinusoidal., for the connections of Δ or Y.	5. closed path for 3rd har φ, low reluctance path for 3rd har. emf is not a non-sinusoidal. for Δ → sinu. Y → non sinu. → by using grounding connections

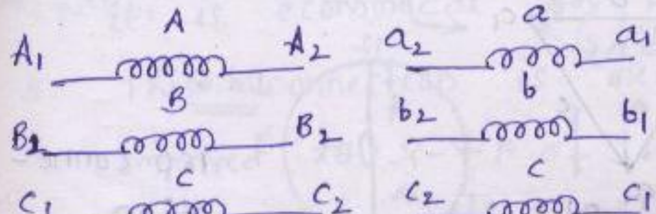


→ Same as that of shell type connections.

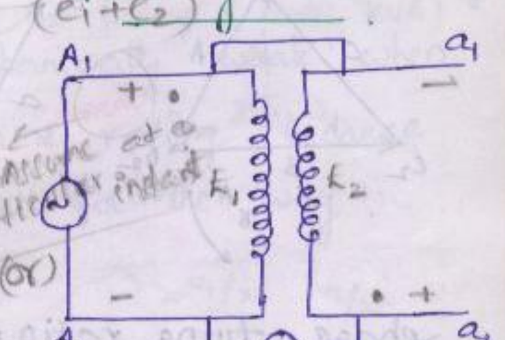
3-limed	5-limbed	3-φ Bank of 3 single T/f's
This T/f core does not provide closed path within its phases for the flow of 3rd harmonic flux. ∴ shape of emf is in T/f wdg with this core is always sinu. irrespective of whether the wdgs are connected either Y or Δ. T/f connections provides closed path for 3rd har. i's	This T/f core provides closed path within its phases for the flow of for 3rd har φ. (1) shape emf in this case is sinu. only when T/f connection is Δ. provides closed path for 3rd har. i's just like Δ connection (2) Other hand shape of emf is not sinu. If the T/f connection is Y. doesn't provide any closed path 3rd har. i. just like Y with isolated neutral.	Same as that of 5-limbed shell type  In 3-φ bank constr. also 3rd har. φ is present in individual magnetic ckt. ∴ shape of emf is sinu. only if the connection is Δ and shape of emf is non-sinu. if the connection is Y.

3-φ T/f connections:-

1. Δ-Δ T/f connections:-



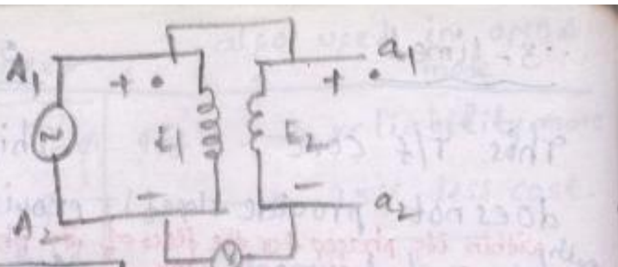
Polarity test:-

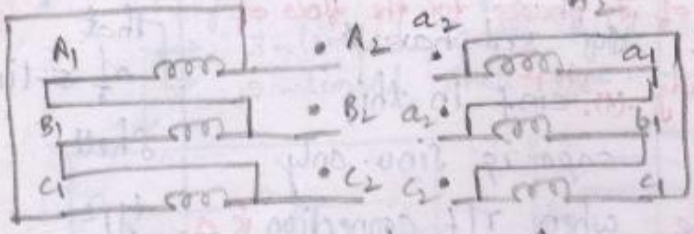


During polarity test, (voltmeter reads) when $V = E_1 + E_2$ (sum of two emf's) then the secondary side terminals should be assigned with opposite polarities as that of corr. primary side assumed terminals polarity.

ie series with aiding. (additive polarity) $(e_1 + e_2)$

when voltmeter reads, difference in two emf's $(e_1 \sim e_2)$ then the secondary side terminals should be assigned with same polarities as that of corr. primary side assumed terminals · polarities.

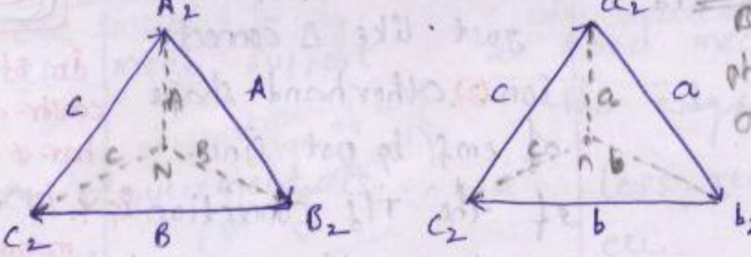




Δ Δ

In 1-Φ T/f current displaced by 180°. So there is no

phasor Identification:-

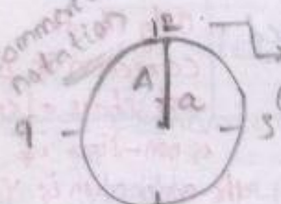


But in 3-Φ T/f, phase displacement b/w primary and secondary wdg connections. ph. displacement depends on wdg connections

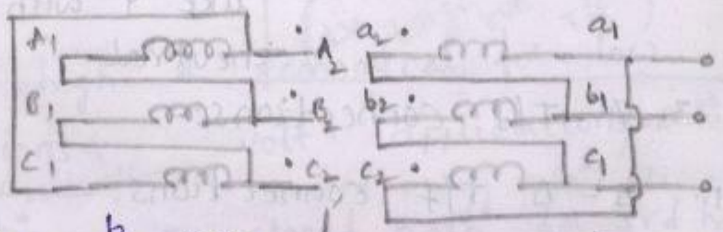
So it is called 0° connection.

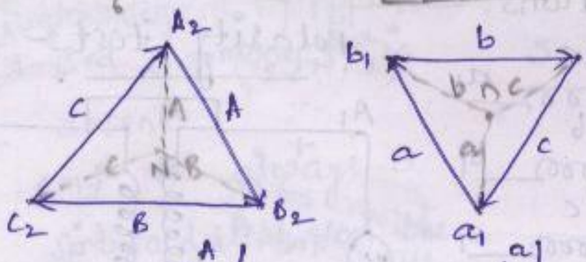
ph. sequence A B C, a b c

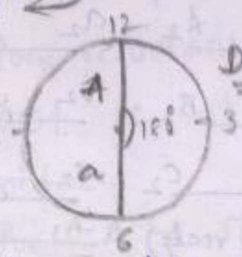
Commercial notation



→ Dd 12 (or) Dd 0







Dd 6

180° connection.

ph. sequence A B C, a b c

phase turns ratio = P. phase voltage : S. ph. voltage ($N_1/ph : N_2/ph$)

Line turns ratio = P. Line to Line voltage : S. L to L volt.

In 1-Φ T/f $E_1 = 4.44 N_1 B_m A_n \cdot f$

In 3-Φ T/f $E_1/_{ph} = 4.44 N_1/_{ph} \cdot B_m A_n f$

$E_2/_{ph} = 4.44 N_2/_{ph} \cdot B_m A_n f$

$E_1/_{ph} \propto N_1/_{ph}$

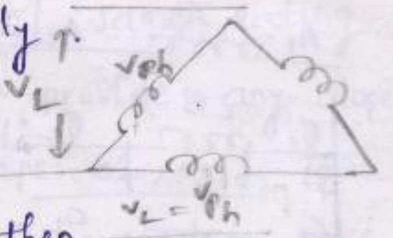
$E_2/_{ph} \propto N_2/_{ph}$

Ex. 220kV/132kV

T/f are generally specified in line-line turns ratio

05-06-07.

→ 3-ϕ T/f's are always specified with line turns ratio only.



Features of Δ-Δ :-

1. In this T/f connection, if the ph. turns ratio is x:1 then the line turns ratio is also x:1 .

Δ-Δ
$V_{ph} = V_L$
$I_{ph} = \frac{I_L}{\sqrt{3}}$

2. As ph. volt. = line volt. in Δ-Δ, it requires more no. of turns /ph and also more amount of insulation when compared to Y/Y T/f of same volt. rating.

→ Insulation requirement depends on ph. volt. rating.

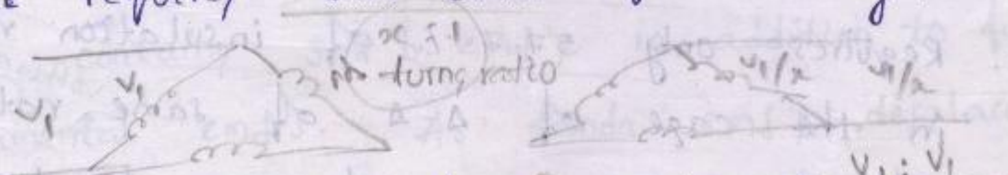
3. As ph. i = line $i/\sqrt{3}$, this Δ-Δ connection require less (57.7% of) cross sectional area of condu. when compared to Y-Y, of same i rating.

Y-Y
$V_{ph} = \frac{V_L}{\sqrt{3}}$
$I_{ph} = I_L$

4. Because of above reasons this connection is not economical for HV applications but it is economical for LV high current rating. (less volt. rating & more KVA)

(LV, large KVA)

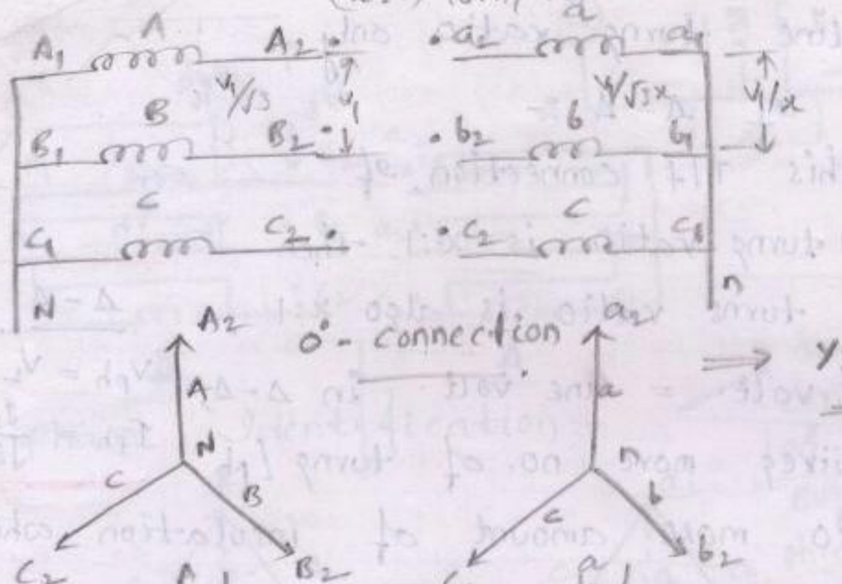
5. This connection is mechanically weak when compared to Y-Y of same current rating because it requires thin condu. for the wdg.



$V_1 : V_1/x$
x : 1 line turns ratio

6. Both sides Δ's offers closed path for 3rd h. comp. i's within its phases shape of emf induced in this T/f connection is always sinu. irrespective of shape of magnetic ckt applied for T/f.

Y-Y T/f connection :-
(x:1) turns ratio



⟹ Yy 12° or Yy 0°

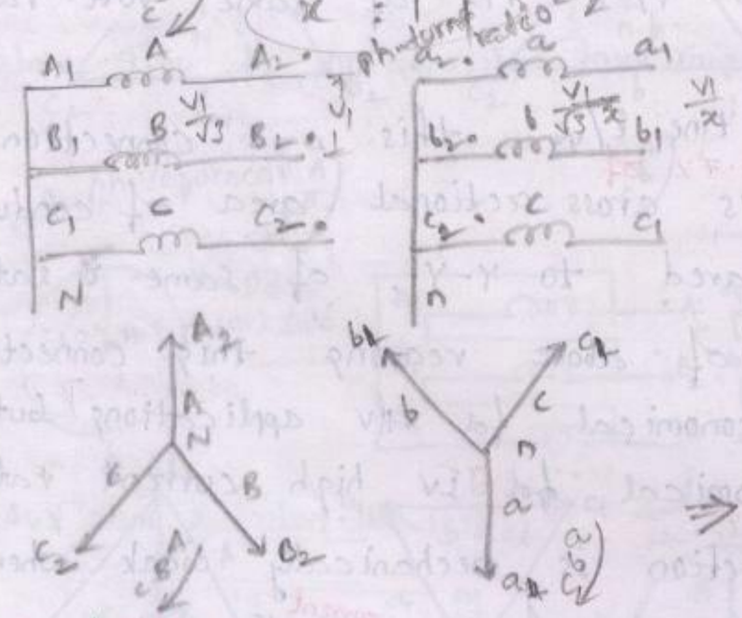
Y - Y

$V_{ph} = \frac{V_L}{\sqrt{3}}$

$I_{ph} = I_L$

$V_1 : \frac{V_1}{x} = (x:1)$ line-turns ratio

x : 1 ph. turns ratio



Yy 6° clock connection

⟹ Yy 6 or 180° - connection

features :-

1. In this Line turns ratio = ph. turns ratio of T/f.
2. Requires only 57.7 % of insulation required in the case of Δ-Δ of same voltage rating. (Insulation = 57.7 % of Δ-Δ)
3. Requires only 57.7 % of no. of turns / ph. required ... - do - . As $(V_{ph} = \frac{V_L}{\sqrt{3}})$
4. For same i rating, this connection requires more cs area of condu. when compare to Δ - Δ. (As $I_{ph} = I_L$) (ie voltage rating more, kVA less)
5. More Economical for HV rating with small i rating (HV, Small kVA)

6. This T/∆ connection is more robust when compared to ∆-∆ of same rating.

7. This connection doesn't provide any closed path of 3rd h. i within its phases. Shape of emf is sinu. only when 3-limbed core type core is employed. and non-sinu. for 5-limbed. or 3-φ bank.

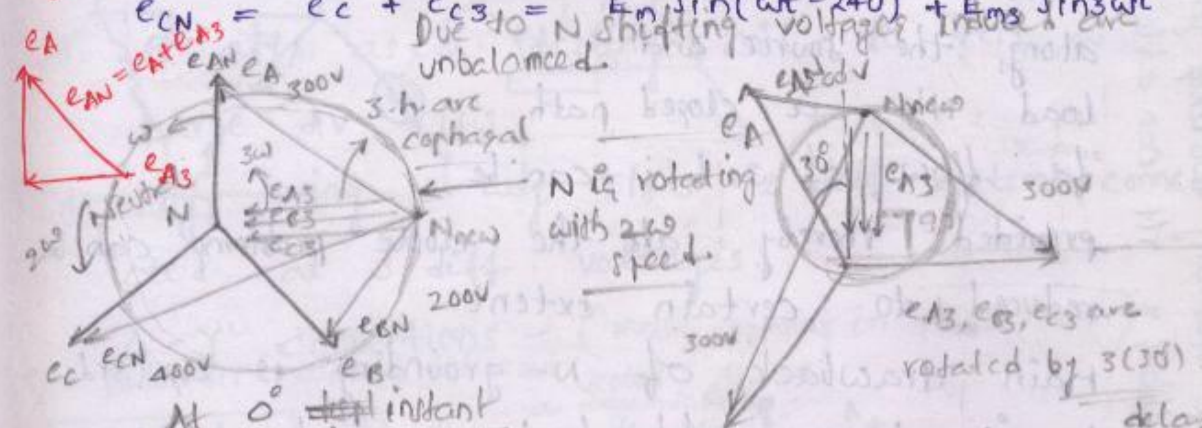
If 5-limbed shell is employed then each ph. contains

$e_{AN} = e_A + e_{A3} = E_m \sin\omega t + E_{m3} \sin 3\omega t$

$e_{BN} = e_B + e_{B3} = E_m \sin(\omega t - 120) + E_{m3} \sin 3\omega t$

$e_{CN} = e_C + e_{C3} = E_m \sin(\omega t - 240) + E_{m3} \sin 3\omega t$

Due to N shifting voltages are unbalanced.



Here relative speed : $3\omega - \omega = 2\omega$

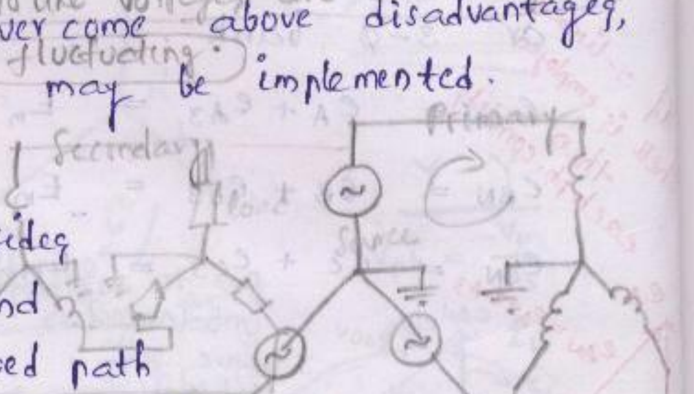
so the speed of $N_{new} = 2\omega$.

8. When Y-Y employed with 5 limbed shell type core or 3-φ bank constructions each ph. contains 3rd h. emf's in addition to fundamental emf's. As funda. emf's displaced by 120° and 3rd h. emf's are cophasal. So neutral point of Y shifted from funda. neutral loca. causing unbalanced nature of ph. voltage. unbalance system voltage. This N. point not only shifted but also rotates / oscillates at a speed of 2ω rad/sec [relative speed b/w funda & 3rd h. vectors] causing continuous fluctuations in diff. ph. voltages.

This phenomena in Y-Y is called Oscillating N or floating N.

Under this circumstances this T/f connection not suitable for load b/w any line & N. [ie 1-φ load] [As ph. voltage is fluctuating one]. This problem is called Oscillating neutral or floating neutral which is very much undesirable. (But it can supply 3-φ loads, b'coz line to line voltages are same, they are not fluctuating.) To over come above disadvantages, following methods may be implemented.

1. By grounding N points on P and S sides along the source and load N's. a closed path for flow of 3. h. i can be provided, thereby all the above problems can be reduced to certain extent.



Main drawback of N-grounding is as 3rd h. impedance offered by P. and S. ckts very high so 3rd h. i's on both sides very weak so above problem cannot be eliminated completely.

2. By using 3-wdg T/f → Tertiary wdg. on the T/f core all the above problems can be completely eliminated because Δ-connected T.W. provides very low 3rd h. impedance path to the flow of 3rd h. comp. of i's.

Functions of Δ connected Tertiary wdg (in Y-Y connection) with 5-limbed shell or 3-φ bank structure.

→ To stabilize N-point, so called stabilized wdg.

→ Improves the emf wave shape in T/f wdgs.

As resultant 3rd har. emf's b/w any two lines zero, ∴ there will not be any 3rd harm. emf comp. in line voltages that's y T/f can able to supply 3-φ loads satisfactorily.

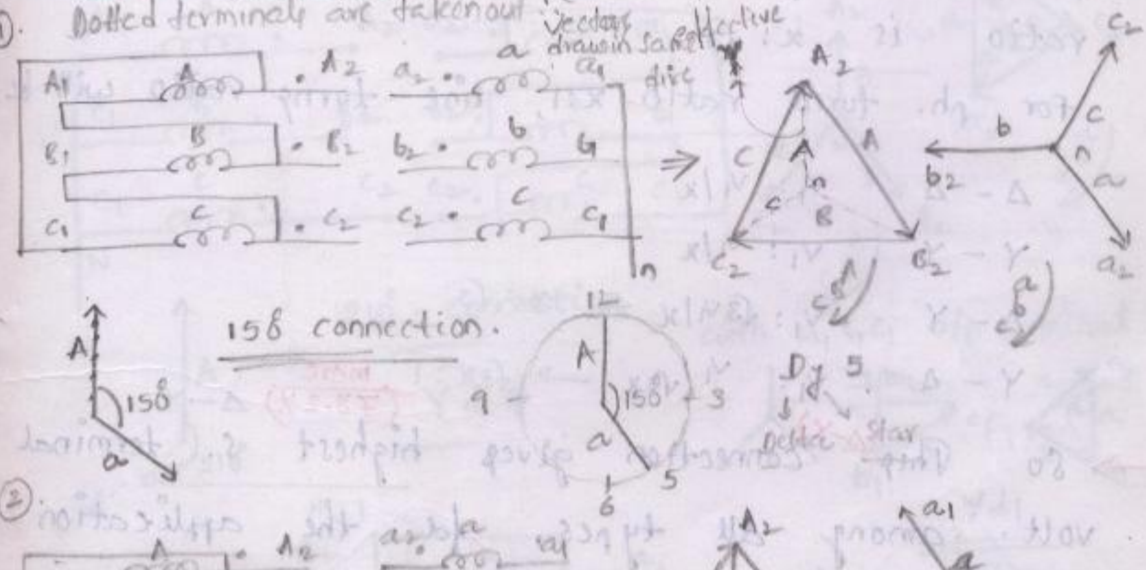
→ It makes the Y-Y T/f to supply 1-φ loads.

→ General functions of T.W. :- 220kV/132 kV/440V

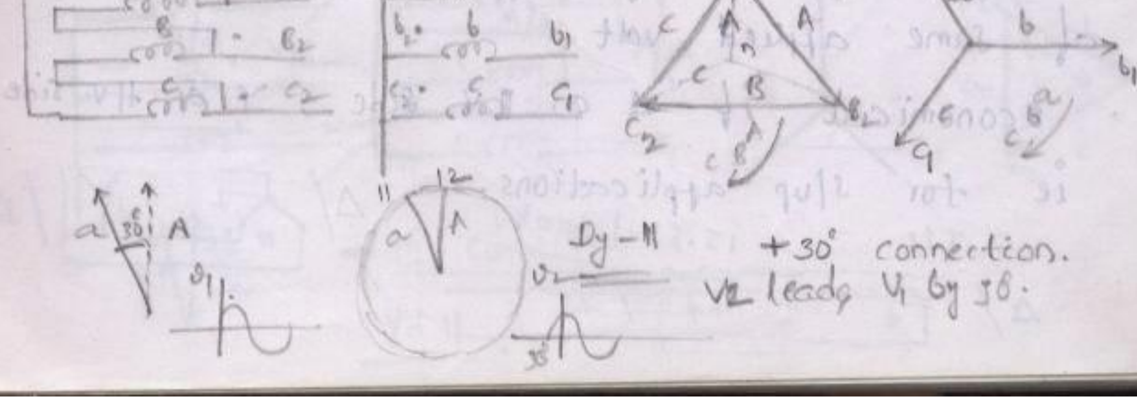
1. Used to providing power supply for power substation auxillaries such as lighting, protecting relay panals, battery chargers etc.
2. It enables the connection of capacitor banks and syn. condensers which are used to inject reactive into system to get required volt. profile.
   220kV/132kV/6.6kV (6.6kV or 3.3kV)
3. It acts as a testing coil to test a Large HV T/f's.
4. By using 3-wdg T/f's 2 diff. systems connected at 3 diff. voltages.

Δ-Y connections :- (most popular in power system)

① Dotted terminals are taken out; vectors drawn in same respective direction

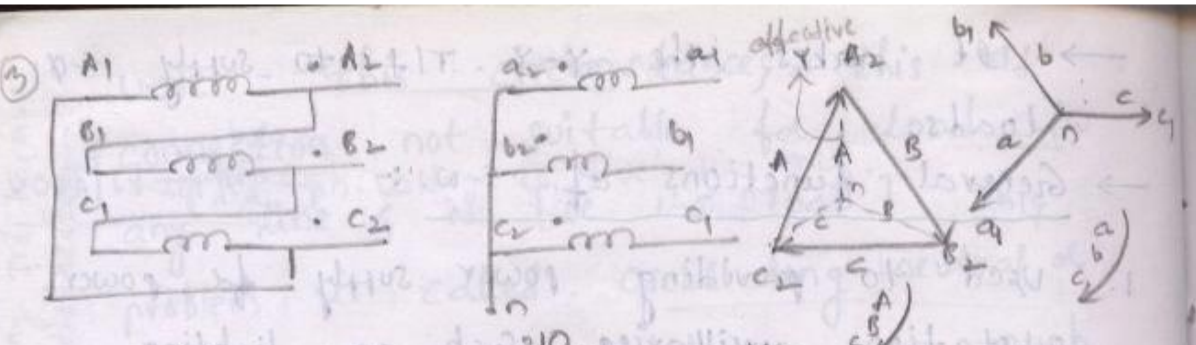


②

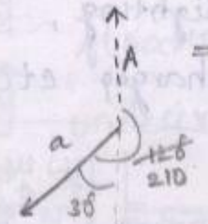


+30° connection.

V2 leads V1 by 30°.

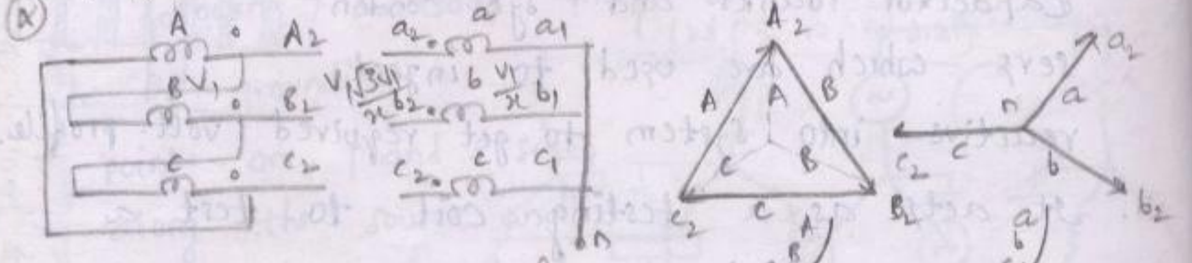


A → Dy 7 — 210° ~~120°~~ - connection



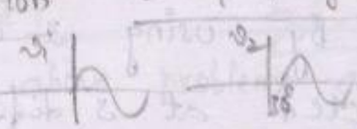
line $V_1 : \frac{\sqrt{3}V_1}{x}$, ph : $V_1 : V_1/x$

$x : 1$



$-30°$

A 30 a — Dy 1 — $-30°$ ~~+30°~~ - connection — v_2 lags v_1 by 30



features :-

1. In this if ph. turns ratio $x:1$, line turns ratio is $x : \sqrt{3}$

   for ph. turns ratio $x:1$, line turns ratio will be

   $\Delta - \Delta \quad V_1 : V_1/x$

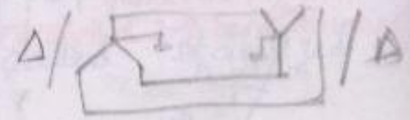
   $Y - Y \quad V_1 : V_1/x$

   $\Delta - Y \quad V_1 : \sqrt{3}V_1/x \rightarrow x : \sqrt{3}$

   $Y - \Delta \quad V_1 : V_1/\sqrt{3}x \rightarrow \sqrt{3}x : 1$ more (73.2%) $\Delta - Y$

→ So This (Δ-Y) connection gives highest s. terminal volt. among all types, for the application of same applied volt.

2. Economical if Δ on LV side, Y on HV side ie for s/up applications.



G.T/f 13.8 kV / 220 kV

3. This connection is normally employed at begining line of tr. line at a S/up T/f.

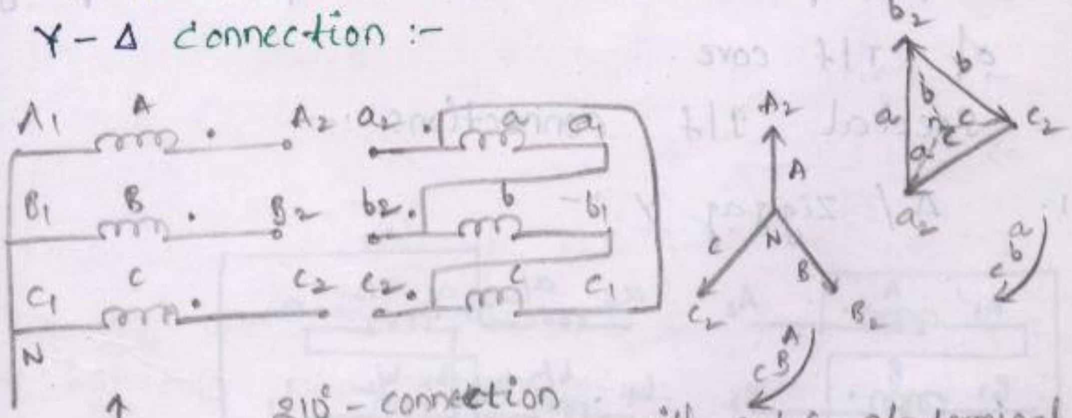
4. All the distribution T/f are connected in Δ/Y only to get 3-φ 4-wire supply system.

5. Primary Δ provides closed path for 3rd h. i. ∴

(1) Shape of emf is always sinu. irrespective of shape of magnetic ckt. (2). N point on S. side Y is exactly stable. (3). It can supply 1-φ loads satisfactorily (This is ideal choice for distr.)

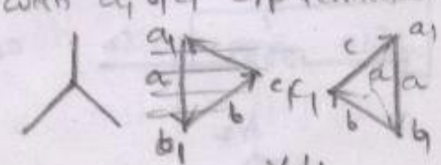
6. P. Δ stabilizes n-point on S. side because Δ provides closed path for 3rd h. i. [but in practice slight oscillation of n-point is present in S. side Y which can be stabilize by using zigzag Y instead of normal Y.

Y-Δ connection :-

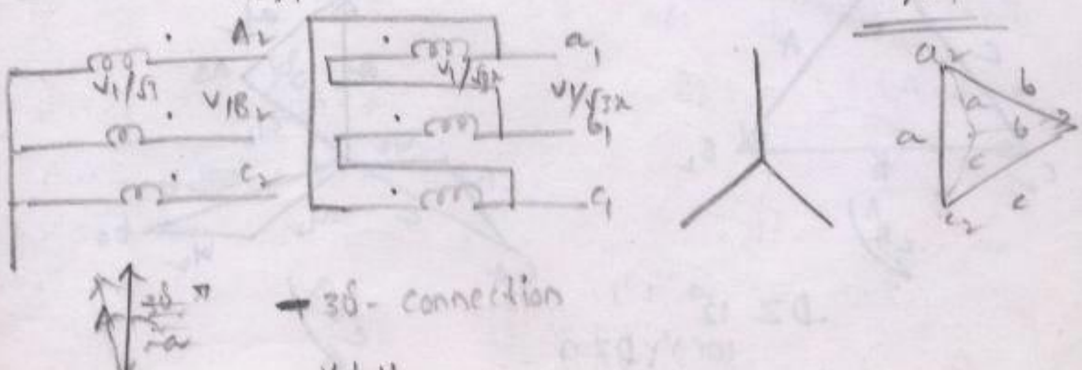


210° - connection

Yd 7



Yd1



+30 - connection

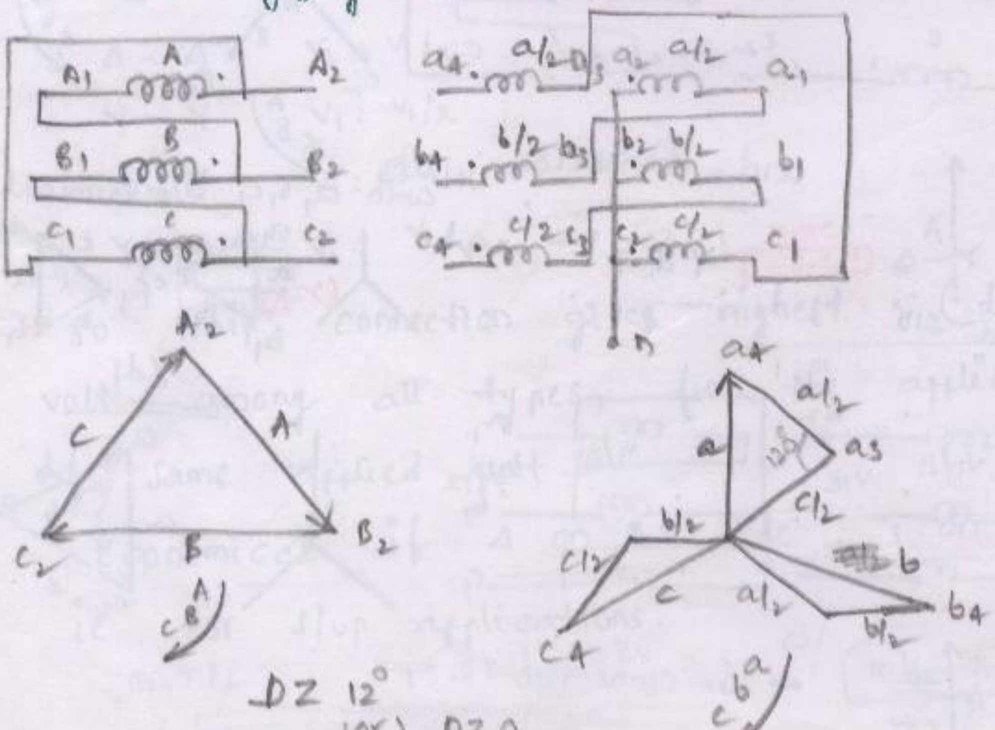
Yd 11

Features:-

1. In this if ph. turns ratio x:1, then line turns ratio is $x : 1/\sqrt{3}$.
2. This T/f connection gives least S. terminal volt. for the application same applied volt. among all the T/f connections.
3. Economical to use for S/ down applications only.
4. This is normally employed at termination end of tr. line as a S/down T/f.
5. S. Δ provides closed path 3rd h.i. so the shape of emf is sinu. irrespective of type of T/f core.

Special T/f connections :-

1. Δ / Zigzag Y :-



DZ 12°
(or) DZ0
0° - connection.

Features:-

→ This connection is 0° or 180°. So this T/f is connected ||el with either Δ-Δ or Y-Y.

→ Zigzag on S. side can nullify the 3rd h. emf's any in T/f wdg. thereby stabilizes the N-point.

→ Zig-zag connection requires about 15% more no. of turns /ph. when compare to normal Y wdg. for same V. rating.

06-06-07

Open Delta T/f connection:-

KVA of Δ-Δ bank

$(KVA)_{\Delta-\Delta} = \sqrt{3}\, V_L I_L$ (by using 2 T/f's)

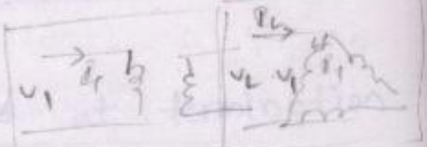
$I_L = \sqrt{3} I_1$

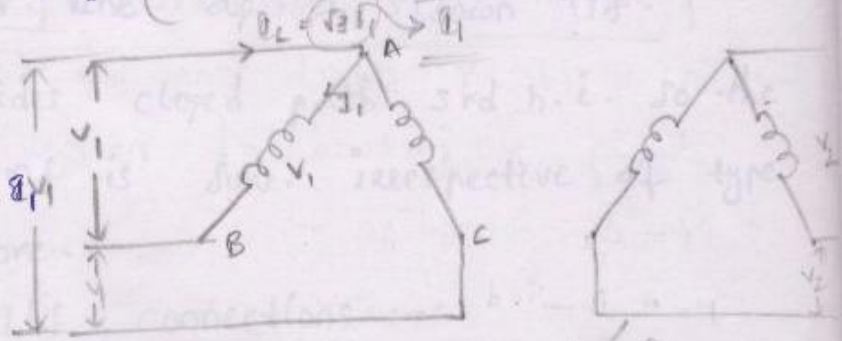
$V_L = V_1$

$\Rightarrow \sqrt{3} \cdot V_1 \cdot \sqrt{3} \cdot I_1$

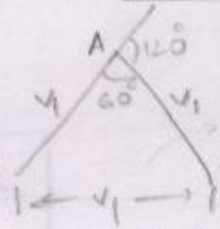
$\Rightarrow 3 V_1 I_1$

$\Rightarrow 3 [KVA]_{1-\phi}$





If any one 1-φ T/f disabled in 3-φ bank of 3 1-φ T/f's then the remaining 2 1-φ T/f's can be operated in open Δ mode. to get balanced 3-φ supply systems on both sides.



KVA rating of open Δ bank,

$(KVA)_{L-L} = \sqrt{3}\, V_L I_L$

$V_L = V_1$

$I_L = I_1$

$= \sqrt{3} V_1 I_1$

$= \sqrt{3} [KVA]_{1-\phi}$

$\therefore \dfrac{KVA_{L-L}}{KVA_{\Delta-\Delta}} = \dfrac{\sqrt{3} V_1 I_1}{3 V_1 I_1} = \dfrac{1}{\sqrt{3}}$

$= 0.577$

→ The L-L bank can handle load of 57.7% of total load that was handled by Δ-Δ bank without causing overloading of wdgs.

→ KVA supplied by each 1-φ T/f = $\frac{\sqrt{3} V_1 I_1}{2}$

→ while supplying a load of 57.7% of total load, each 1-φ T/f in L-L bank is not fully loaded but they are partially loaded upto an extent of 86.6% of its rated capacity so that % under-loading of each 1-φ T/f is 13.4%.

$= 0.866\, V_1 I_1$

$= 0.866\, [KVA]_{1-\phi}$

→ If 100% load is placed as in case of Δ-Δ bank, % over loading of each 1-φ T/f is 73.2%. (when 100% load is kept.)

(KVA supplied by each 1-φ T/f = $I_1 \cdot \sqrt{3} V_1 = \sqrt{3} V_1 I_1$)

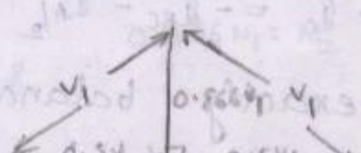
utilization factor $= \frac{(KVA)_{L-L}}{\text{Available KVA}}$

$= \frac{\sqrt{3} V_1 I_1}{2 V_1 I_1} = \frac{\sqrt{3}}{2} = 0.866$ { without causing over loading of wdg }

Scott connection :- electric arc furnace

{ 3 ph. to 2 ph. conversion T/f (supplying) } ← used 2 ph. supply
and vice versa

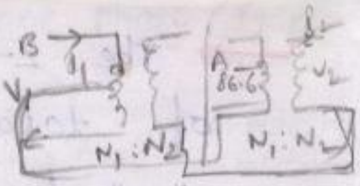
The balanced 3-φ supply system can be achieved by using only 2 vectors, 1 with 100% magnitude & another with 86.6%, and are connected such a way that 86.6% vector is joined to midpoint of 100% vector.

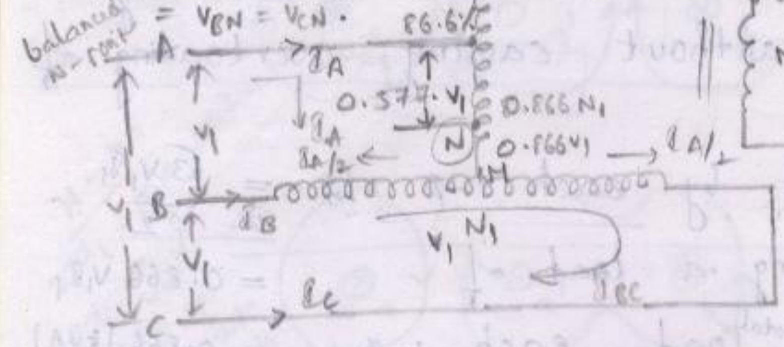


$V_{AM} = 0.866 V_1$ $\quad V_{MN} = (0.866 - 0.577)V_1 = 0.289 V_1$

$V_{AN} = 0.577 V_1$

$= V_{BN} = V_{CN}$ (balanced N-point)



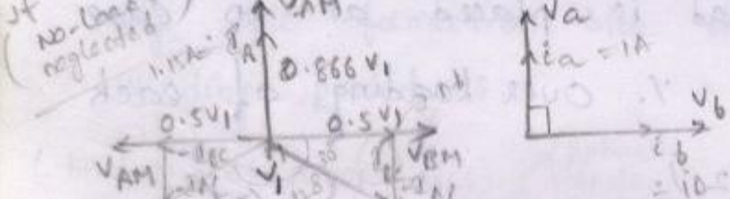


$V_{AN} = \frac{V_1}{\sqrt{3}} = 0.577 V_1$

$V_{AN} : V_{MN} = 0.577 V_1 : 0.289 V_1 \Rightarrow 2:1$

If a neutral point is located on 3-ø side such that volt. b/w any terminal to that point is $0.577\ V_1$ then such neutral point divides teaser T/f in the ratio of 2:1

(at no-load, i neglected)



$\frac{I_A}{i_a} = \frac{N_2}{0.866 N_1}$

$\Rightarrow I_A = \frac{N_2}{0.866 N_1} \times i_a$

for $N_1 : N_2 = 1:1$

$I_A = 1.15\ i_a$ (primary) (secondary)

$\frac{I_{BC}}{i_b} = \frac{N_2}{N_1} \Rightarrow I_{BC} = \frac{N_2}{N_1} i_b$

for $N_1 : N_2 = 1:1$

$\Rightarrow I_{BC} = i_b$

→ $I_A = 1.15\ i_a$

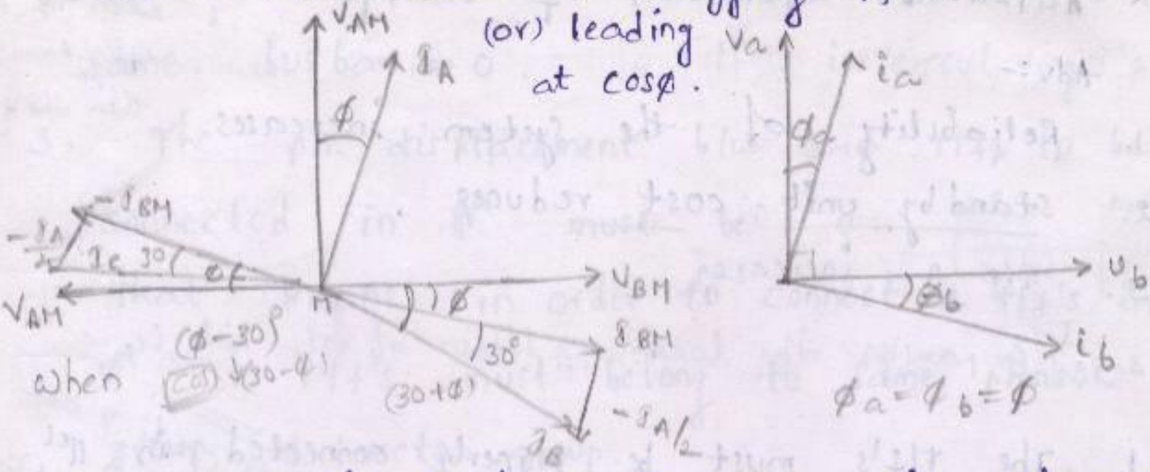
→ $\bar{I}_B = \bar{I}_{BC} - \bar{I}_{A/2}$

→ $\bar{I}_C = -\bar{I}_{BC} - \bar{I}_{A/2}$

→ whenever 2-ph. load is balanced on secondary, then the corr. 3-ø currents on primary side are also exactly balanced.

→ If load pf is unity, then the T-T/f operates at same pf as of load but the 2 halfs of m. T/f donot operate at load pf but one half T/f operates at cos 30 lagging and another half operates at pf of cos 30 leading

When the load is lagging pf. (balanced) (or) leading at $\cos\phi$.



when (or) $(30-\phi)$

→ In general if load pf is $\cos\phi$, then the T. T/f operates at same pf as that of load but one half of M. T/f operates at $\cos(30+\phi)$ another half at $\cos(30-\phi)$.

$(KVA)_{scott} = \sqrt{3}\, V_L I_L$ $\quad$ V_1 - volt. rating of 1-φ T/f

I_1 - current " " .

$$\left.\begin{array}{l} V_L = V_1 \\ I_L = I_1 \end{array}\right\} = \sqrt{3}\, V_1 I_1 = \sqrt{3}\,[KVA]_{1-\phi}$$

$$\text{Utilization factor} = \frac{[KVA]_{scott}}{\text{Available KVA}} = \frac{\sqrt{3}\, V_1 I_1}{2 V_1 I_1}$$

$$= 0.866$$

With 2, 1-φ similar T/f's the U.f. of scott is 86.6 %.

with 2, 1-φ dissimilar T/f's. $\quad N_1 : N_2$

$$U.f. = \frac{\sqrt{3}\, V_1 I_1}{V_1 I_1 + 0.866\, V_1 I_1} = 0.928 \quad 0.866 N_1 : N_2$$

U.f. of scott with two, dissimilar T/f's (1-φ) one with $N_1 : N_2$ & another with $0.866 N_1 : N_2$ is 92.8 %.

07-06-07

Parallel Operation of Transformers

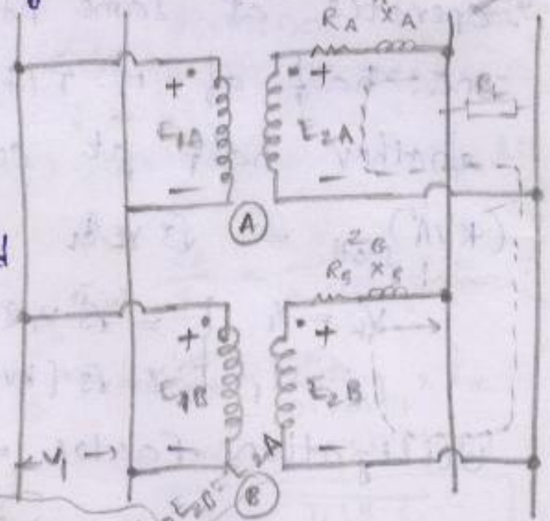
Adv:-

1. Reliability of the system increases
2. Stand by unit cost reduces.
3. T/f η increases
4. for Expansion the load, addition of t/f will be.

when t/f is fully loaded then the $\parallel$ man

1. The T/f's must be properly connected with regard to polarity. All conditions are used to avoid $\parallel^{el}$ circulating currents

The proper polarity means, dotted terminals should be connected to same bus bar and undotted should be connected to another bus bar both on p. and s. side.

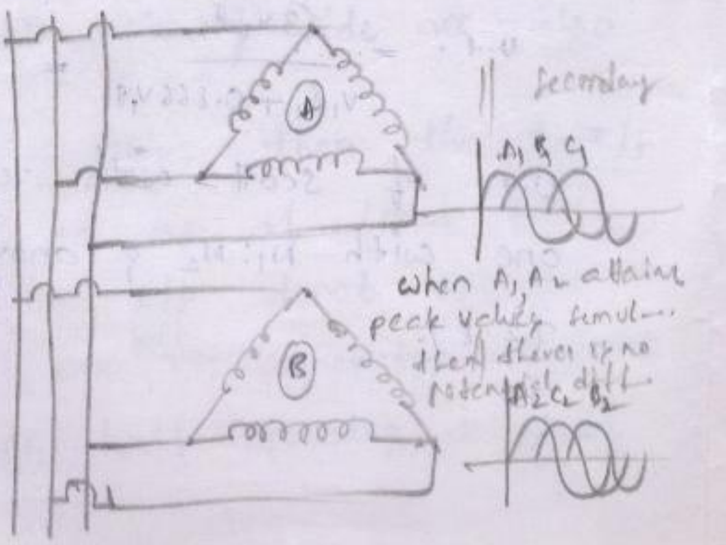


for equal voltage ratio $E_{1A} = E_{1B}$

$E_2A - E_2B = 0$ → secondary loop current = 0 ✓

2. In case of 3-ϕ T/f's the ph. sequence of 3-ϕ T/f's to be connected in $\parallel^{el}$ must be same. Order in which the different terminals attaining peak values.

Proper ph. sequence means terminals in both the transformers which attain peak values simul.. must be connected to same bus bar. so

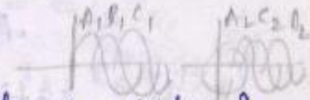


when A_1, A_2 attain peak values simul— then there is no potential diff

→ so voltmeter is used to detect same ...

that the p.D. b/w terminals connected to same bus bar = 0. → for there is circulating i's.

3. The ph. displacement b/w 3-φ T/f to be connected in ‖el must be = 0.



that means in order to connect 2 T/f's in ‖el, 2 T/f's must belong to same phasor group or vector group.

inter converted group				
0° connection	Δ/Δ	Y/Y	Δ/zig Y	} vector group-I
180	Δ/Δ	Y/Y	Δ/zig Y	
+30	Δ/Y	Y/Δ	Y/zig. Y	
-30	Δ/Y	Y/Δ	Y/zig Y	} vector group-II
150	Δ/Y	Y/Δ	Y/zig Y	
210	Δ/Y	Y/Δ	Y/zig Y	

(inter converted group)

For Δ/Δ & Y/Y are connected ‖el, but Δ/Δ & Δ/Y connection there is some ph. displacement so ‖el not possible

Desirable condi:-

1. The 2 T/f's to be connected in ‖el should have equal volt. ratio's. suppose not equal $E_{2A} \neq E_{2B}$
If the volt ratio's are (in this circulating i's is less but the problem is overheating) not same then there is a possibility of circulating i's in addition to normal load i which may overheat the T/f wdgs.

2. The ohmic values of impedances of T/f's to be connected in ‖el should be inv. proportional to respective kVA ratings of T/f or the pu. impedances of T/f's to be connected in ‖el based on the respective kVA ratings should be equal. or the pu. impedances of

the T/f's based on some common base kVA should be inv. proportional to respective kVA rating. $Z_A \propto \frac{1}{S_{A rated}}$; $Z_B \propto \frac{1}{S_{B rated}}$

Any one of the above condi. should be satisfy to get sharing of load by the T/f's proportional to their kVA ratings.

(margin note: % kVA rating or % leakage impedance)

$Z_A(\Omega) \propto \frac{1}{S_{A rated}}$ $\qquad \frac{Z_A(\Omega)}{Z_B(\Omega)} = \frac{V_2 I_{B rated}}{V_2 I_{A rated}}$

$\rightarrow Z_A^{(\Omega)} \propto \frac{1}{V_2 I_{A rated}}$ $\qquad \rightarrow \frac{I_{A rated} \cdot Z_A(\Omega)}{V_2} = \frac{I_{B rated} \cdot Z_B(\Omega)}{V_2}$

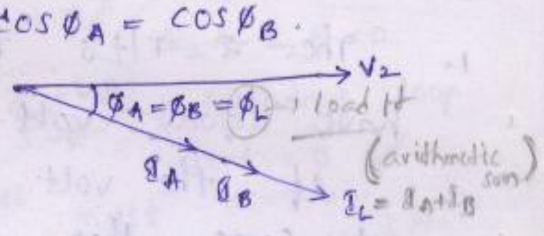
$Z_B(\Omega) \propto \frac{1}{V_2 I_{B rated}}$ $\qquad \rightarrow Z_A(pu) = Z_B(pu)$

3. The $\frac{X}{R}$ ratio's of the T/f's to be connected in $||^{el}$ should be equal to avoide the operation of T/f at different pf's.

$$\frac{X_A}{R_A} = \frac{X_B}{R_B} \Rightarrow \phi_A = \phi_B$$ [arithmetic sum > vector sum]

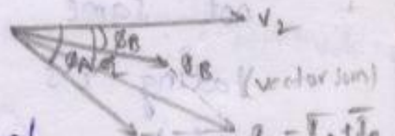
$$\phi_A = Tan^{-1}\left(\frac{X_A}{R_A}\right) \Rightarrow \cos\phi_A = \cos\phi_B.$$

$$\phi_B = Tan^{-1}\left(\frac{X_B}{R_B}\right)$$



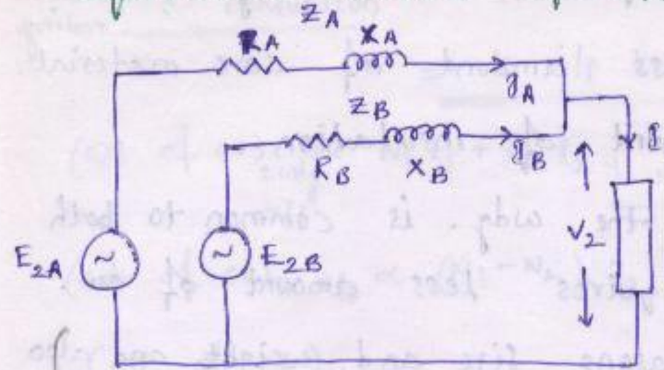
when $\frac{X_A}{R_A} > \frac{X_B}{R_B} \Rightarrow \phi_A > \phi_B$

$\rightarrow \cos\phi_A < \cos\phi_B$



If the 2 T/f's have unequal $\frac{X}{R}$ ratio's then the 2 T/f's operated at different pf and are deviated from load pf. The T/f which is having more $\frac{X}{R}$ operates at imperior pf and T/f with less $\frac{X}{R}$ operates at superior pf when compared to load pf.

Equivalent circuit of T/f's connected in ||el :-



voltage ratio's are assumed to be same.

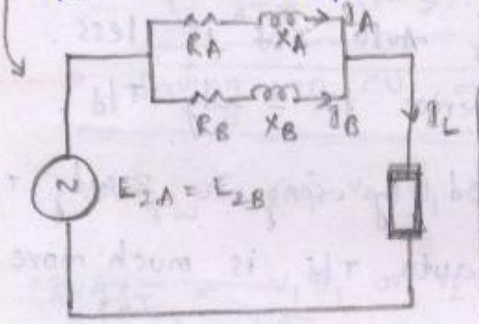
$$E_{2A} = E_{2B}$$

$$V_2 = E_{2A} - I_A(R_A + jX_A)$$
$$= E_{2A} - I_A \cdot Z_A$$

$$V_2 = E_{2B} - I_B(R_B + jX_B)$$
$$= E_{2B} - I_B \cdot Z_B$$

$$\therefore E_{2A} - I_A Z_A = E_{2B} - I_B \cdot Z_B$$
$$\Rightarrow I_A Z_A = I_B Z_B.$$

for equal V. ratio's of T/f's connected in ||el the corr. impedance drops are also equal.



$$\frac{V_2}{1000} I_A = \frac{V_2}{1000} I_L \times \frac{Z_B}{Z_A + Z_B}$$

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

$$S_A = S_L \cdot \frac{Z_B}{Z_A + Z_B}$$

$$S_B = S_L \cdot \frac{Z_A}{Z_A + Z_B}$$

NOTE 1

In the above formula's, Z_A and Z_B are ohmic values or in pu. values.

$$Z_{(pu)\,new} = Z_{(pu)\,old} \cdot \frac{(kVA)_{B.new}}{(kVA)_{B.old}} \cdot \frac{(kV)^2_{B.old}}{(kV)^2_{B.new}}$$

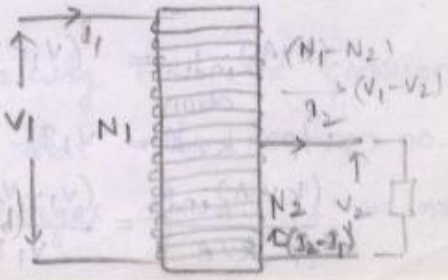
→ need to take equal kv rating for ||el operation

NOTE 2

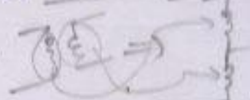
If the pu impedances are given then these pu impedances adjusted to some common base kVA before substituting in the above formulae.

Auto Transformer:-

$$K = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$ (I_0 neglected) (voltage drop neglected)



Adv. of A. T/f compared to Two wdg. T/f of same rating

1. A. T/f requires less amount of core material.
2. Requires less amount of insulation.
3. As some part of the wdg. is common to both P. and S., it requires less amount of cu.
4. Due to above reasons size and weight and also cost is less.
5. It has more η, since volume of iron and cu requirement is less so iron & cu losses less.
6. As some part of wdg is common to both p and s the leakage reactance of Auto T/f is less.
   $\therefore$ Its regulation is superior to 2 wdg T/f.
7. If an auto T/f is realised by using a 2 wdg T/f then the kVA rating of auto T/f is much more than kVA rating of 2 wdg T/f. 

The above advantages in A. T/f high if the common no. of turns in A. T/f more. ie k approached to unity.

$k > 0.33$ for $N_1 : N_2 > 3:1$ advantages of A. T/f not possible

→ So A. T/f are feasible only when turns ratio $N_1 : N_2 \leq 3:1$ & transformation ratio (k) ≥ 0.33 $(N_1 \leq 3N_2)$

→ The imp. feature of A. T/f is power is not only transfer by means of induction but also by direct conduction.

$(kVA)_{induction} = (V_1 - V_2) I_1$

$i/p \ kVA = V_1 I_1$

$$\frac{(kVA)_{indu}}{i/p \ kVA} = \frac{(V_1 - V_2) I_1}{V_1 I_1} = 1 - k$$

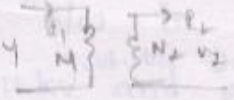
$\Rightarrow (kVA)_{indu} = (1-k) \ i/p \ kVA$

→ $(kVA)_{conduction} = i/p\ kVA - (kVA)_{indu}$

$= k \cdot i/p\ kVA$

wt. of cu ∝ volume of cu ∝ $l \times a$ ∝ NI

$(wt.\ of\ cu)_{2\,wdg\ T/f} \propto N_1 I_1 + N_2 I_2$



$(wt.\ of\ cu)_{A.T/f} \propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$

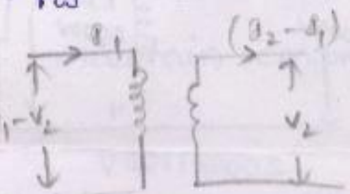
$$\frac{(wt.\ of\ cu)_{AT/f}}{(wt.\ of\ cu)_{2wdg}} = \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_2 I_2}$$

$$= \frac{2N_1 I_1 - 2N_2 I_1}{2N_1 I_1} = 1 - \frac{N_2}{N_1} = 1 - k$$

→ $(wt.\ of\ cu)_{AT} \downarrow = (1-k) \cdot (wt.\ of\ cu)_{TW}$; when $k=1$, wt. of cu $= 0$

→ Saving in cu $= k \cdot (wt.\ of\ cu)_{TW}$ means

$(kVA)_{TW} = (V_1 - V_2) I_1$ (or) $V_2 (I_2 - I_1)$



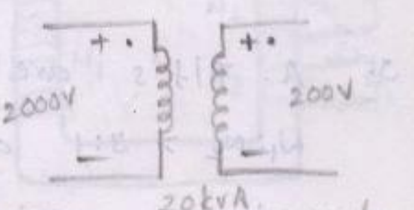
$(kVA)_{AT} = V_1 I_1$ or $V_2 I_2$

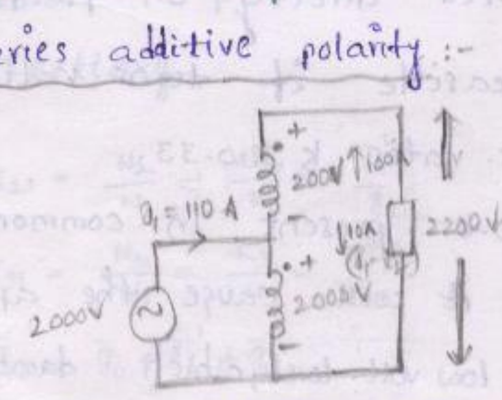
→ $$\frac{(kVA)_{AT}}{(kVA)_{TW}} = \frac{V_1 I_1}{(V_1 - V_2) I_1} = \frac{V_1}{V_1 - V_2} = \frac{1}{1-k}$$

where $k = \frac{V_2}{V_1}$ = transformation ratio of A.T/f.

Realisation of A.T/f from 2 wdg T/f :-

1. Series additive polarity :-





→ 2000/2200 V

While realising A.T/f from 2 wdg T/f the common part should be HV wdg so that the common no. of turns are more and advantages of A.T/f are more.

$I_1 = \frac{20\times10^3}{2000} = 10A$, $I_2 = \frac{20\times10^3}{200} = 100A$

$V_1 < V_2 \Rightarrow I_1 > I_2$ $(KVA)_{AT} = V_1 I_1$

$= 2000 \times 110 = 220 \, kVA$

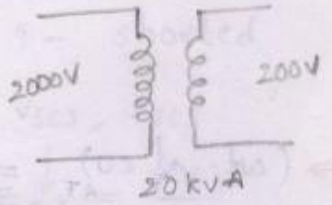
$(KVA)_{Indu} = 200 \times 100$

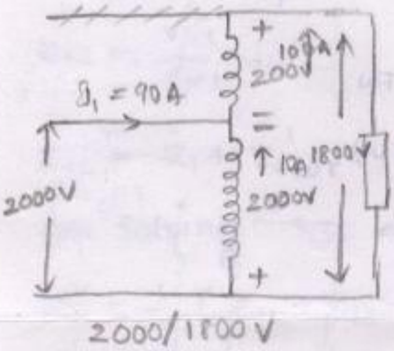
$= 20 \, kVA \rightarrow (KVA)$ of 2 wdg.

$(KVA)_{condu} = 220 - 20 = 200 \, kVA$

The reason for having more kVA rating for A.T/fs is the additional condu. KVA available in A.T/f.

2. Series subtractive polarity :-





$I_1 = 10A$

$I_2 = 100A$

$V_1 > V_2$ $(KVA)_{AT} = 2000 \times 90$

$I_1 < I_2$ $= 180 \, kVA$

$(KVA)_{indu.} = 200 \times 100 = 20 \, kVA$

In both cases KVA condu. same. $(KVA)_{condu} = 180 - 20 = 160 \, kVA$

Disadvantages of A.T/f :-

1. A.T/f is not suitable where perfect electrical isolation required b/w 2 diff. circuits.
2. whenever some fault occurs on S. side the same will be reflected directly on P. side.
3. A.T/f's are not feasible if turns ratio $N_1 : N_2 > 3:1$ or trans. ratio $K \geq 0.33$.
4. whenever accidental O.C. present in common part of the wdg. it will cause the appearance of HV across low volt. level, which damage the load and also causing severe shock hazard to the personnel working at that voltage level.

Applications of A. T/f :-

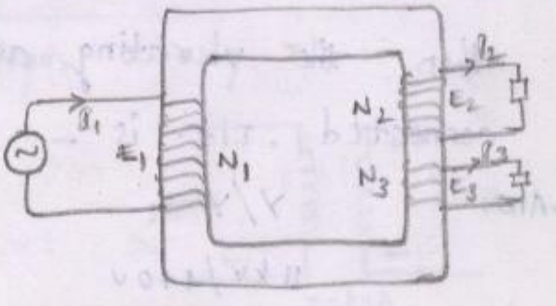
× 132 kV/220 kV
✓ 220 kV/132 kV
× 220 kV/33 kV
× 132 kV/33 kV
✓ 33 kV/11 kV
× 11 kV/440 V
✓ 400 kV/220 kV

1. A. T/f's nowadays used as power T/f's in transmission n/w in 220 kV/132 kV, 33 kV/11 kV (sub.stn) and also in 400 kV/220 kV inter connecting T/f's.
2. A. T/f's with variable tappings are generally used to get variable volt. supplies in lab.s. such as in dimmerstat or variacs.
3. A. T/f's are generally used to start 3-φ IM to reduce starting i drawn by the motor.
4. Generally used as volt. boosters, to boost of the system volt. so as to maintain consumer terminal volt. constant.
5. A. T/f's generally used as volt. balance coils to get supply for diff. loads at diff. v. levels.
6. The above application used in control panels.

3 wdg Transformers :-

General fun.s :-

1. Tertiary.



$$k_{21} = \frac{N_2}{N_1} = \frac{E_2}{E_1} = \frac{I_1'}{I_2}$$

$$k_{31} = \frac{N_3}{N_1} = \frac{E_3}{E_1} = \frac{I_1''}{I_3}$$

$(kVA)_{3w.T/f}$ = kVA rating in primary $= E_1 I_1$

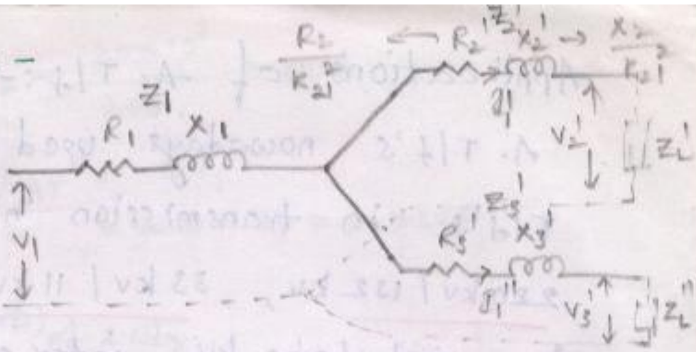
$$\bar{I}_1 = \bar{I}_0 + \bar{I}_1' + \bar{I}_1''$$

$$I_1' = -k_{21} \cdot I_2$$

$$I_1'' = -k_{31} \cdot I_3$$

but in 2w T/f $(kVA)_{second}$ of $(kVA)_{primary}$ when I_0 neglected because of diff. N's.
$(kVA)_P = (kVA)_{sc}$. supply. ((20 kVA 0.6)(N_3))(100 kVA 0.6 (N_2))

Equivalent circuit :-



$I_1 = I_1' + I_1''$

$I_1' = -K_{21} I_2$

$I_1'' = -K_{31} I_3$

Procedure to conduct s.c. Test :-

S.C Test - I	S.C. Test - II	S.C. Test - III
P - excited	P - excited	P - opened
S - shorted	S - opened	S - excited
T - opened	T - shorted	T - shorted
V_{SC1}, I_{SC1}	V_{SC2}, I_{SC2}	V_{SC3}, I_{SC3}
$Z_{12} = \frac{V_{SC1}}{I_{SC1}}$	$Z_{13} = \frac{V_{SC2}}{I_{SC2}}$	$Z_{23} = \frac{V_{SC3}}{I_{SC3}}$
$Z_{12} = Z_1 + Z_2'$	$Z_{13} = Z_1 + Z_3'$	$Z_{23} = Z_2' + Z_3'$

On solving 3 eq.s

$Z_1 = \frac{1}{2}(Z_{12} + Z_{13} - Z_{23})$

$Z_2' = \frac{1}{2}(Z_{12} + Z_{23} - Z_{13})$

$Z_3' = \frac{1}{2}(Z_{13} + Z_{23} - Z_{12})$

Q. A 1000 kVA, 11kV/440V Y/Y - is reconnected as Δ/Y then the v. rating and kVA rating of newly connected T/f. is -

Ans:

Y/Y	Δ/Y
11 kV / 440 V	$E_1\|_{ph} : E_2\|_{ph}$
1000 kVA (kVA)	$\frac{11\,kV}{\sqrt{3}} : \frac{440}{\sqrt{3}}$
$N_1\|_{ph} \propto \frac{11\,kV}{\sqrt{3}}$	line trans. ratio
$N_2\|_{ph} \propto \frac{440}{\sqrt{3}}$	$\frac{11\,kV}{\sqrt{3}} : 440\,V$
	1000 kVA — const. since $\left(\frac{V}{\sqrt{3}} \times V\cdot\sqrt{3}\right)$
	$I_1/ph = const.$, $I_L = I_{ph}$ → Y/Y
	$I_L = \sqrt{3} I_{ph}$

Q. 3-ϕ 6.6 kV / 440 V Δ/Y T/f has % R of 2%. and % X of 6%. a). The V. regulation of T/f at FL 0.8 pf leading - b). To maintain S. terminal voltage at 440 V, the voltage required to be applied at the above load condi- -?

Ans: % R = 2%. % reg. at FL 0.8 pf leading

% X = 6%. $= \% R \cos\phi_2 - \% X \sin\phi_2$

$= 2 \times 0.8 - 6 \times 0.6 = -2\%$.

b). Volt. required to be applied on primary to maintain the S. terminal volt. 440 V at FL 0.8 pf lead.

$= 6.6\,kV + 6.6\,kV \times \frac{-2}{100}$

$= 6.46\,kV$

Q. A 3-ϕ T/f is supplied at 6000 V on Δ-connected side, the terminal volt. at Y-connected side when loaded at FL 0.8 pf is 415 V, equivalent resistance and reactance drop are 1% and 5%. find the turns ratio of T/f. -?

Sol: $V_1 = 6000\,V$ — Δ

$V_2 = 415\,V$ at FL 0.8 pf lag - Y

Turns ratio $= E_1/ph : E_2/ph$

$= N_1/ph : N_2/ph$

when volt. drop is referred to primary

$\underset{(line)}{E_2} = \underset{(line)}{V_2}$

$= 415\,V$ Y

$E_2/ph = \frac{E_2}{\sqrt{3}} = \frac{415}{\sqrt{3}}\,V$

E_1 (line) $= V_1 -$ volt. drop   % volt. drop $= 1\times0.8 + 5\times0.6 = 3.8\%$

$= 6000_{(line)} - 6000 \times \frac{3.8}{100}$

$= 5772$ V

$E_1|_{ph} = E_{line}$ Δ

$\therefore E_1|_{ph} : E_2|_{ph} = 5772 : \frac{415}{\sqrt{3}} \Rightarrow 24:1$

Q. A 250 kVA T/f with pu. impedance of 0.015 + j0.04 is operated in ||el with a 500 kVA T/f with a pu Z of 0.01 + j0.05 to supply a load of 750 kVA at 0.8 pf lag. The real powers delivered by the 2 T/f's are – ?

Sol: Z_A (pu) $= (0.015 + j0.04) \times \frac{500}{250} =$ → 0.03 + j0.08 $S_A \angle\theta_A$, $S_B \angle\theta_B$

Z_B (pu) $= (0.01 + j0.05) \times 1$ $P_A = S_A \cos\phi_A$

$P_B = S_B \cos\phi_B$

$S_L = 750$ kVA at 0.8 pf lag

$S_{A\,rated} = 250$ kVA $S_A = S_L \times \frac{Z_B}{Z_A + Z_B}$

$S_{B\,rated} = 500$ kVA $S_B = S_L \cdot \frac{Z_A}{Z_A + Z_B}$

$S_A = 750 \angle{-36.6} \cdot \frac{0.01 + j0.05}{0.04 + j0.13}$

$= 281.6 \angle{-30.8}$ $P_A = 281.6 \times \cos(30.8) =$ kW

$S_B = 750 \angle{-36.6} \cdot \frac{0.03 + j0.08}{0.04 + j0.13}$

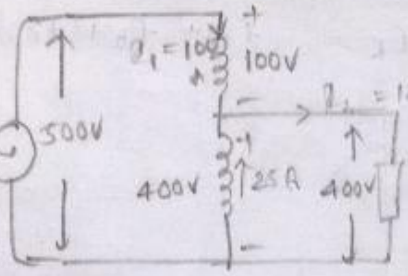
$=$

Q. A 400/100 V, 10 kVA 2wdg T/f is connected as a A. T/f with a source volt. of 500 V. If the η of 2 wdg T/f is 97% at FL 0.8 pf what is the η of A. T/f –

η is independent of nature of load whether leading or lag

Sol: $I_1 = \frac{10\times10^3}{400} = 25\,A$

$I_2 = \frac{10\times10^3}{100} = 100\,A$



$(KVA)_{AT} = 500 \times 100$

$= 50\,kVA$

$\eta_{FL} = \frac{10\times10^3 \times 0.8}{10\times10^3\times0.8 + \text{Total Losses}} = 0.97$

$\Rightarrow$ Total losses = 247.7 W

$\eta_{AT\ FL\ 0.8pf} = \frac{50\times10^3\times0.8}{50\times10^3\times0.8 + 247.7} = 99.38\,\%$

08-06-07

3-φ INDUCTION MACHINES

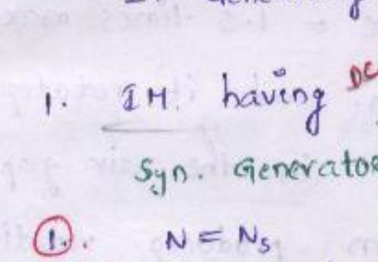
1. Motoring mode → $N < N_s$
2. Generating mode → $N > N_s$

But at $N = N_s$ no operation. So Asynchronous M/c.

1. IM having DC shunt type char.s.

Syn. Generator	Indu. Generator
①. $N = N_s$ const. speed prime mover. [①. Diesel engine ②. Steam turbine [using a governor]. ③. Large hydralic turbine [where head is very high]	①. $N > N_s$ variable speed prime movers [①. Wind Mills ②. Tidal power ③. Low head hydro power stations

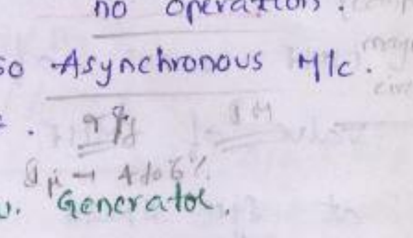
→ production of Rotating magnetic field in 3-φ system:-



a- phase - $N_{ph}\cos\theta$ - Ref

b- phase - $N_{ph}\cos(\theta-120)$

c- phase - $N_{ph}\cos(\theta-240)$



$i_a = I_m \cos\omega t$ - Ref

$i_b = I_m \cos(\omega t - 120)$

$i_c = I_m \cos(\omega t - 240)$

MMF produced by flowing i_a through ph (a-phase).

$f_a = N_{ph}.\cos\theta \cdot I_m \cos\omega t$

$= f_m \cdot \cos\theta \cdot \cos\omega t$

$f_m = N_{ph} I_m$ ↑ max. mmf

$f_b = f_m \cos(\theta-120)\cos(\omega t-120)$

$f_c = f_m \cos(\theta-240)\cos(\omega t-240)$

DC GENERATOR

The electrical machines deals with the energy transfer either from mechanical to electrical form or from electrical to mechanical form, this process is called electromechanical energy conversion. An electrical machine which converts mechanical energy into electrical energy is called an electric generator while an electrical machine which converts electrical energy into the mechanical energy is called an electric motor. A DC generator is built utilizing the basic principle that emf is induced in a conductor when it cuts magnetic lines of force. A DC motor works on the basic principle that a current carrying conductor placed in a magnetic field experiences a force.

Working principle:

All the generators work on the principle of dynamically induced emf.

The change in flux associated with the conductor can exist only when there exists a relative motion between the conductor and the flux.

The relative motion can be achieved by rotating the conductor w.r.t flux or by rotating flux w.r.t conductor. So, a voltage gets generated in a conductor as long as there exists a relative motion between conductor and the flux. Such an induced emf which is due to physical movement of coil or conductor w.r.t flux or movement of flux w.r.t coil or conductor is called dynamically induced emf.

Whenever a conductor cuts magnetic flux, dynamically induced emf is produced in it according to Faraday's laws of Electromagnetic Induction.

This emf causes a current to flow if the conductor circuit is closed.

So, a generating action requires the following basic components to exist.

1. The conductor or a coil
2. Flux
3. Relative motion between the conductor and the flux.

In a practical generator, the conductors are rotated to cut the magnetic flux, keeping flux stationary. To have a large voltage as output, a number of conductors are connected together in a specific manner to form a winding. The winding is called armature winding of a dc machine and the part on which this winding is kept is called armature of the dc machine.

The magnetic field is produced by a current carrying winding which is called field winding.

The conductors placed on the armature are rotated with the help of some external device. Such an external device is called a prime mover.

The commonly used prime movers are diesel engines, steam engines, steam turbines, water turbines etc.

The purpose of the prime mover is to rotate the electrical conductor as required by Faraday's laws

The direction of induced emf can be obtained by using Flemings right hand rule.

The magnitude of induced emf = $e = BLV \sin\text{Ø} = E_m \sin\text{Ø}$

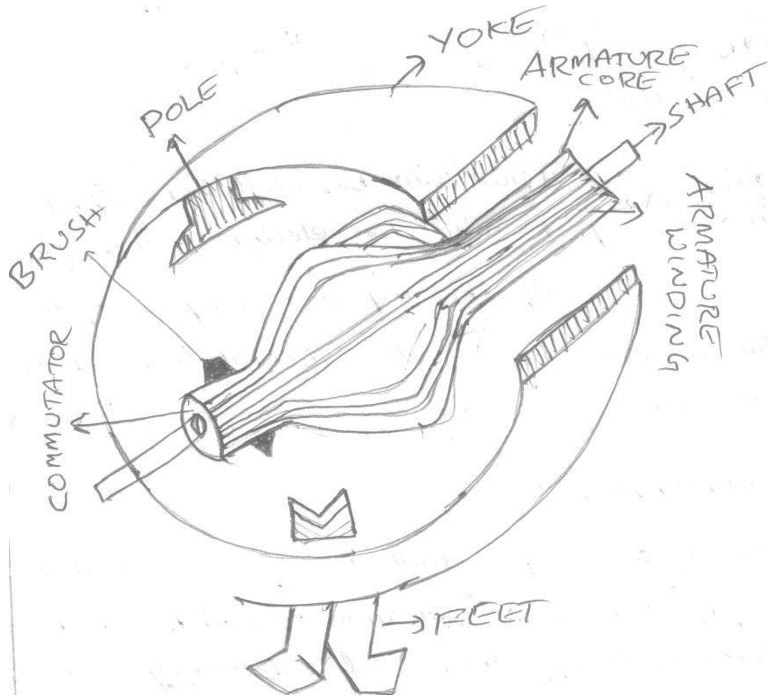
Nature of induced elf:

The nature of the induced emf for a conductor rotating in the magnetic field is alternating. As conductor rotates in a magnetic field, the voltage component at various positions is different. Hence the basic nature of induced emf in the armature winding in case of dc generator is alternating. To get dc output which is unidirectional, it is necessary to rectify the alternating induced emf. A device which is used in dc generator to convert alternating induced emf to unidirectional dc emf is called commutator.

Construction of DC machines :

A D. C. machine consists of two main parts

1. Stationary part: It is designed mainly for producing a magnetic flux.
2. Rotating part: It is called the armature, where mechanical energy is converted into electrical (electrical generate) or conversely electrical energy into mechanical (electric into)



Parts of a Dc Generator:

1) Yoke
2) Magnetic Poles
   a) Pole core
   b) Pole Shoe
3) Field Winding
4) Armature Core
5) Armature winding
6) Commutator
7) Brushes and Bearings

The stationary parts and rotating parts are separated from each other by an air gap. The stationary part of a D. C. machine consists of main poles, designed to create the magnetic flux, commutating poles interposed between the main poles and designed to ensure spark less operation of the brushes at the commutator and a frame / yoke. The armature is a cylindrical body rotating in the space between the poles and comprising a slotted armature core, a winding inserted in the armature core slots, a commutator and brush

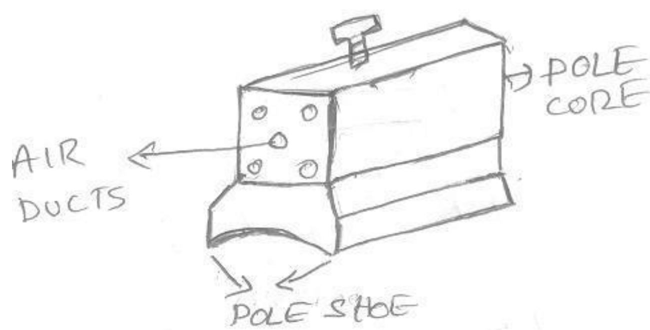
Yoke:

1. It saves the purpose of outermost cover of the dc machine so that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.
2. It provides mechanical support to the poles.
3. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux.

Choice of material: To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is the cheapest. For large machines rolled steel or cast steel, is used which provides high permeability i.e., low reluctance and gives good mechanical strength.

Poles: Each pole is divided into two parts

a) pole core b) pole shoe



Functions:

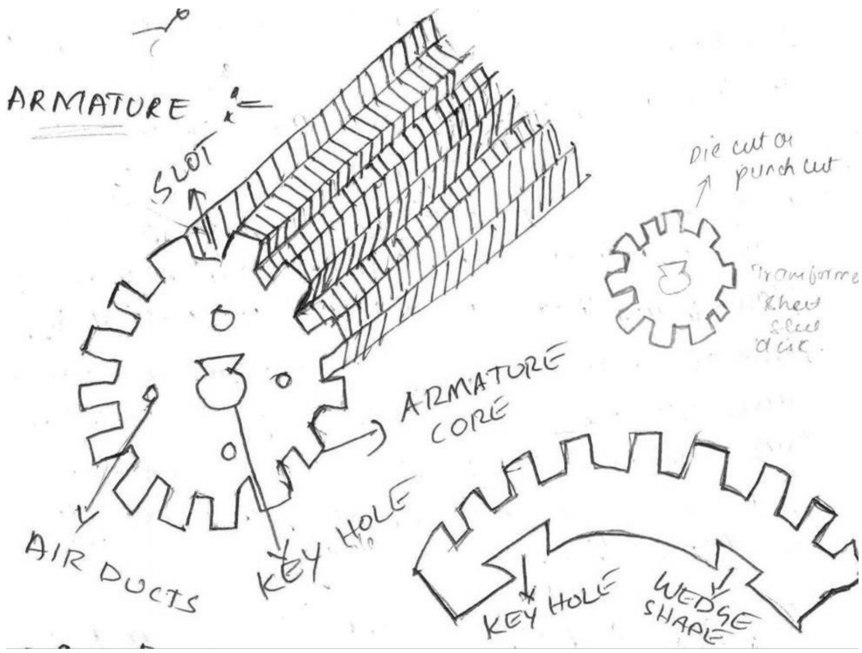
1. Pole core basically carries a field winding which is necessary to produce the flux.
2. It directs the flux produced through air gap to armature core to the next pole.
3. Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced emf. To achieve this, pole core has been given a particular shape.

Choice of material: It is made up of magnetic material like cast iron or cast steel. As it requires a definite shape and size, laminated construction is used. The laminations of required size and shape are stamped together to get a pole which is then bolted to yoke.

Armature: It is further divided into two parts namely,

(1) Armature core (2) Armature winding.

Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.



Functions:

1. Armature core provides house for armature winding i.e., armature conductors.
2. To provide a path of low reluctance path to the flux it is made up of magnetic material like cast iron or cast steel.

Choice of material: As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.

It is made up of laminated construction to keep eddy current loss as low as possible.

A single circular lamination used for the construction of the armature core is shown below.

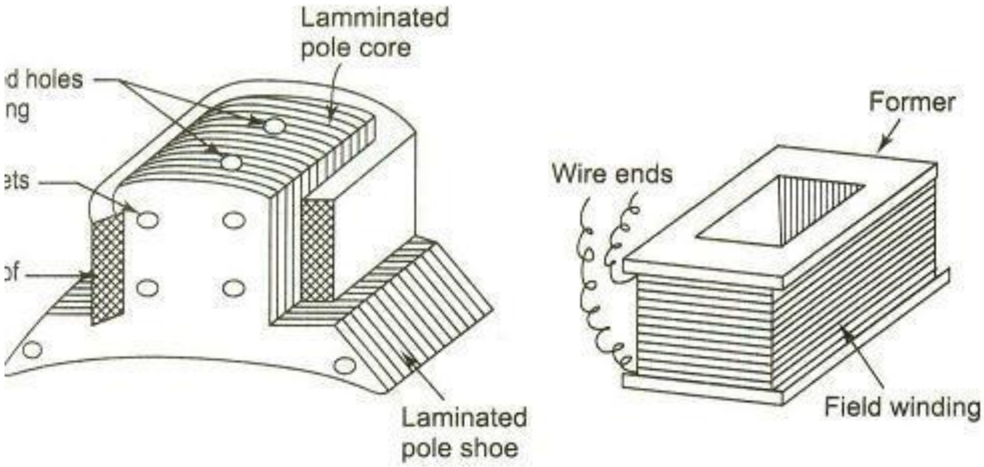
2. **Armature winding:** Armature winding is nothing but the inter connection of the armature conductors, placed in the slots provided on the armature core. When the armature is rotated, in case of generator magnetic flux gets cut by armature conductors and emf gets induced in them.

Function:

1. Generation of emf takes place in the armature winding in case of generators.
2. To carry the current supplied in case of dc motors.
3. To do the useful work it the external circuit.

Choice of material : As armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

Field winding: The field winding is wound on the pole core with a definite direction.



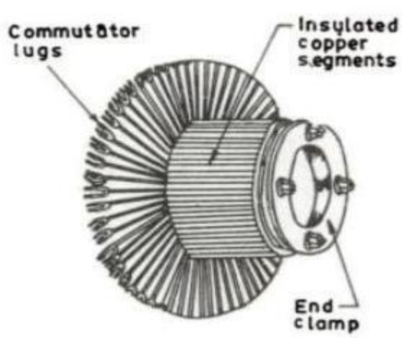
Functions: To carry current due to which pole core on which the winding is placed behaves as an electromagnet, producing necessary flux.

As it helps in producing the magnetic field i.e. exciting the pole as electromagnet it is called '**Field winding'** or '**Exciting winding'.**

Choice of material : As it has to carry current it should be made up of some conducting material like the aluminum or copper.

But field coils should take any type of shape should bend easily, so copper is the proper choice. Field winding is divided into various coils called as field coils. These are connected in series with each other and wound in such a direction around pole cores such that alternate N and S poles are formed.

Commutator: The rectification in case of dc generator is done by device called as commutator.

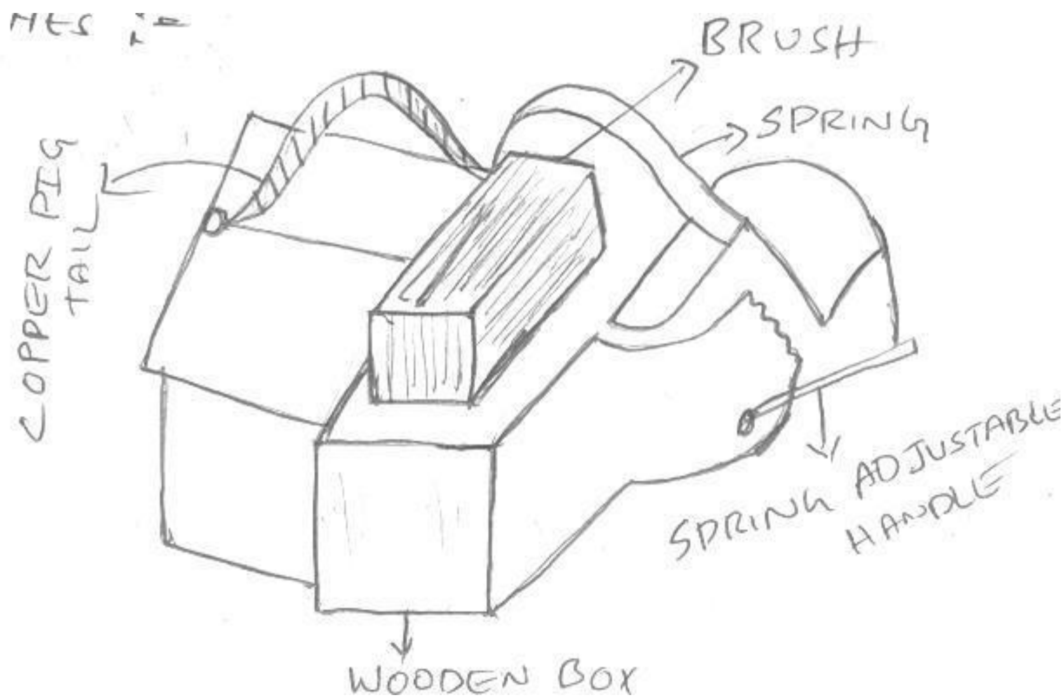


Functions: 1. To facilitate the collection of current from the armature conductors.

2. To convert internally developed alternating emf to in directional (dc) emf
3. To produce unidirectional torque in case of motor.

Choice of material: As it collects current from armature, it is also made up of copper segments. It is cylindrical in shape and is made up of wedge shaped segments which are insulated from each other by thin layer of mica.

Brushes and brush gear: Brushes are stationary and rest on the surface of the Commutator. Brushes are rectangular in shape. They are housed in brush holders, which are usually of box type. The brushes are made to press on the commutator surface by means of a spring, whose tension can be adjusted with the help of lever. A flexible copper conductor called pigtail is used to connect the brush to the external circuit.



Functions: To collect current from commutator and make it available to the stationary external circuit.

Choice of material: Brushes are normally made up of soft material like carbon.

Bearings: Ball-bearings are usually used as they are more reliable. For heavy duty machines, roller bearings are preferred.

Working of DC generator:

The generator is provided with a magnetic field by sending dc current through the field coils mounted on laminated iron poles and through armature winding.

A short air gap separates the surface of the rotating armature from the stationary pole surface. The magnetic flux coming out of one or more worth poles crossing the air gap , passes through the armature near the gap into one or more adjacent south poles.

The direct current leaves the generator at the positive brush, passes through the circuit and returns to the negative brush.

The terminal voltage of a dc generator may be increased by increasing the current in the field coil and may be reduced by decreasing the current.

Generators are generally run at practically constant speed by their prime mores.

Types of armature winding:

Armature conductors are connected in a specific manner called as armature winding and according to the way of connecting the conductors; armature winding is divided into two types.

Lap winding: In this case, if connection is started from conductor in slot 1 then the connections overlap each other as winding proceeds, till starting point is reached again.

There is overlapping of coils while proceeding. Due to such connection, the total number of conductors get divided into 'P' number of parallel paths, where

P = number of poles in the machine.

Large number of parallel paths indicates high current capacity of machine hence lap winding is pertained for high current rating generators.

Wave winding: In this type, winding always travels ahead avoiding over lapping. It travels like a progressive wave hence called wave winding.

Both coils starting from slot 1 and slot 2 are progressing in wave fashion.

Due to this type of connection, the total number of conductors get divided into two number of parallel paths always, irrespective of number of poles of machine.

As number of parallel paths is less, it is preferable for low current, high voltage capacity generators.

Sl. No.	**Lap winding**	**Wave winding**
1.	Number of parallel paths (A) = poles (P)	Number of parallel paths (A) = 2 (always)
2.	Number of brush sets required is equal to number of poles	Number of brush sets required is always equal to two
3.	Preferable for high current, low voltage capacity generators	Preferable for high current, low current capacity generators
4.	Normally used for generators of capacity more than 500 A	Preferred for generator of capacity less than 500 A.

.

EMF equation of a generator

Let P = number of poles

Ø = flux/pole in webers

Z = total number of armature conductors.

= number of slots x number of conductors/slot

N = armature rotation in revolutions (speed for armature) per minute (rpm)
A = No. of parallel paths into which the 'z' no. of conductors are divided.

E = emf induced in any parallel path

E_g = emf generated in any one parallel path in the armature.
Average emf generated/conductor = dØ/dt volt
Flux current/conductor in one revolution
dt = d x p

In one revolution, the conductor will cut total flux produced by all poles = d x p
No. of revolutions/second = N/60

Therefore, Time for one revolution, dt = 60/N second

According to Faraday's laws of Electromagnetic Induction, emf generated/conductor = dØ/dt=□
x p x N / 60 volts

This is emf induced in one conductor.

For a simplex wave-wound generator

No. of parallel paths = 2

No. of conductors in (series)in one path = Z/2

EMF generated/path = ØPN/60 x Z/2 = ØZPN/120 volt

For a simple lap-wound generator
Number of parallel paths = P

Number of conductors in one path = Z/P

EMF generated/path = ØPN/60 (Z/P) =
ØZN/60 A = 2 for simplex – wave winding

A =P for simplex lap-winding

Armature Reaction and Commutation

Introduction

In a d.c. generator, the purpose of field winding is to produce magnetic field (called main flux) whereas the purpose of armature winding is to carry armature current. Although the armature winding is not provided for the purpose of producing a magnetic field, nevertheless the current in the armature winding will also produce magnetic flux (called armature flux). The armature flux distorts and weakens the main flux posing problems for the proper operation of the d.c. generator. The action of armature flux on the main flux is called armature
reaction.

2.1 Armature Reaction

So far we have assumed that the only flux acting in a d.c. machine is that due to the main poles called main flux. However, current flowing through armature conductors also creates a magnetic flux (called armature flux) that distorts and weakens the flux coming from the poles. This distortion and field weakening takes place in both generators and motors. The action of armature flux on the main flux is known as armature reaction.
The phenomenon of armature reaction in a d.c. generator is shown in Fig.(2.1)

Only one pole is shown for clarity. When the generator is on no-load, a small current flowing in the armature does not appreciably affect the main flux f1 coming from the pole [See Fig 2.1 (i)]. When the generator is loaded, the current flowing through armature conductors sets up flux f1. Fig. (2.1) (ii) shows flux due to armature current alone. By superimposing f1 and f2, we obtain the resulting flux f3 as shown in Fig. (2.1) (iii). Referring to Fig (2.1) (iii), it is clear that flux density at; the trailing pole tip (point B) is increased while at the leading pole tip (point
4. it is decreased. This unequal field distribution produces the following two effects:

The main flux is distorted.

Due to higher flux density at pole tip B, saturation sets in. Consequently, the increase in flux at pole tip B is less than the decrease in flux under pole tip A. Flux f3 at full load is, therefore, less than flux f1 at no load. As we shall see, the weakening of flux due to armature reaction depends upon the position of brushes.

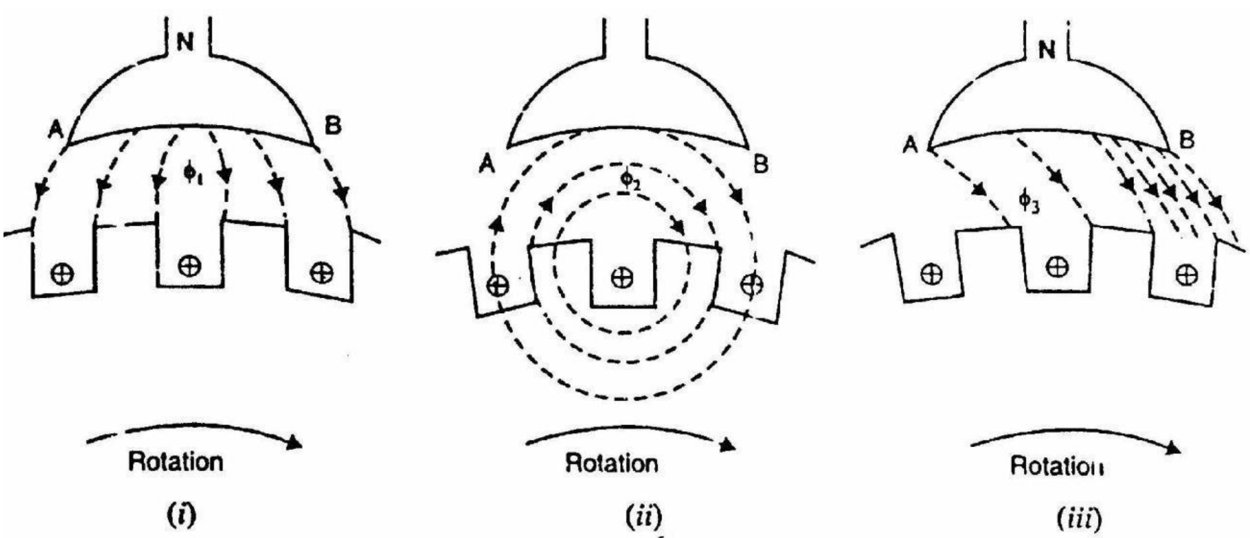


Fig. (2.1)

2.2 Geometrical and Magnetic Neutral Axes

4. The geometrical neutral axis (G.N.A.) is the axis that bisects the angle between the centre line of

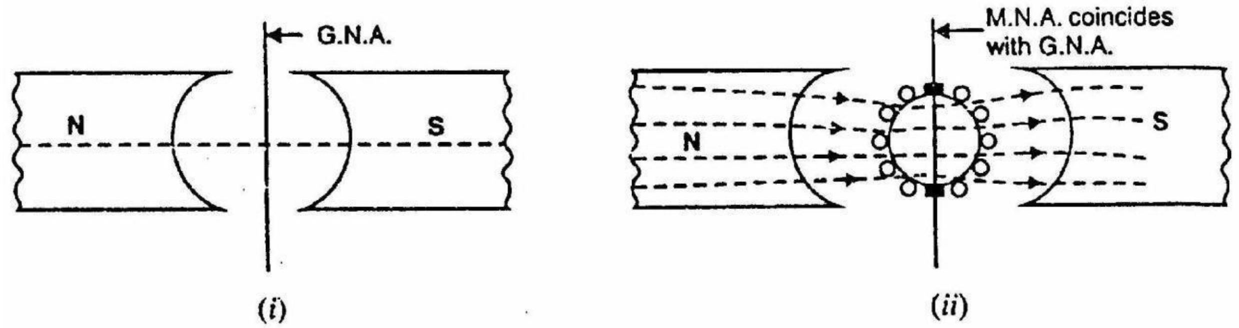


Fig. (2.2)

4. The magnetic neutral axis (M. N. A.) is the axis drawn perpendicular to the mean direction of the flux passing through the centre of the armature. Clearly, no e.m.f. is produced in the armature conductors along this axis because then they cut no flux. With no current in the armature conductors, the M.N.A. coincides with G, N. A. as shown in Fig. (2.2).

5. In order to achieve sparkless commutation, the brushes must lie along M.N.A.

2.3 Explanation of Armature Reaction

With no current in armature conductors, the M.N.A. coincides with G.N.A. However, when current flows in armature conductors, the combined action of main flux and armature flux shifts the M.N.A. from G.N.A. In case of a generator, the M.N.A. is shifted in the direction of rotation of the machine. Inorder to achieve sparkless commutation, the brushes have to be moved along the new M.N.A. Under such a condition, the armature reaction produces the following two effects:

1. It demagnetizes or weakens the main flux.
2. It cross-magnetizes or distorts the main flux.

Let us discuss these effects of armature reaction by considering a 2-pole generator (though the following remarks also hold good for a multipolar generator).

(i) Fig. (2.3) (i) shows the flux due to main poles (main flux) when the armature conductors carry no current. The flux across the air gap is uniform. The m.m.f. producing the main flux is represented in magnitude and direction by the vector OFm in Fig. (2.3) (i). Note that OFm is perpendicular to G.N.A.

(ii) Fig. (2.3) (ii) shows the flux due to current flowing in armature conductors alone (main poles unexcited). The armature conductors to the left of G.N.A. carry current "in" (′) and those to the right carry current "out" (•). The direction of magnetic lines of force can be found by cork screw rule. It is clear that armature flux is directed downward parallel to the brush axis. The m.m.f. producing the armature flux is represented in magnitude and direction by the vector OFA in Fig. (2.3) (ii).

(iii) Fig. (2.3) (iii) shows the flux due to the main poles and that due to current in armature conductors acting together. The resultant m.m.f. OF is the vector sum of OFm and OFA as shown in Fig. (2.3) (iii). Since M.N.A. is always perpendicular to the resultant m.m.f., the M.N.A. is shifted through an angle q. Note that M.N.A. is shifted in the direction of rotation of the generator.

(iv) In order to achieve sparkless commutation, the brushes must lie along the M.N.A. Consequently, the brushes are shifted through an angle q so as to lie along the new M.N.A. as shown in Fig. (2.3) (iv). Due to brush shift, the m.m.f. FA of the armature is also rotated through the same angle q. It is because some of the conductors which were earlier under N-pole now come under S-pole and vice-versa. The result is that armature m.m.f. FA will no longer be vertically downward but will be rotated in the direction of rotation through an angle q as shown in Fig. (2.3) (iv). Now FA can be resolved into

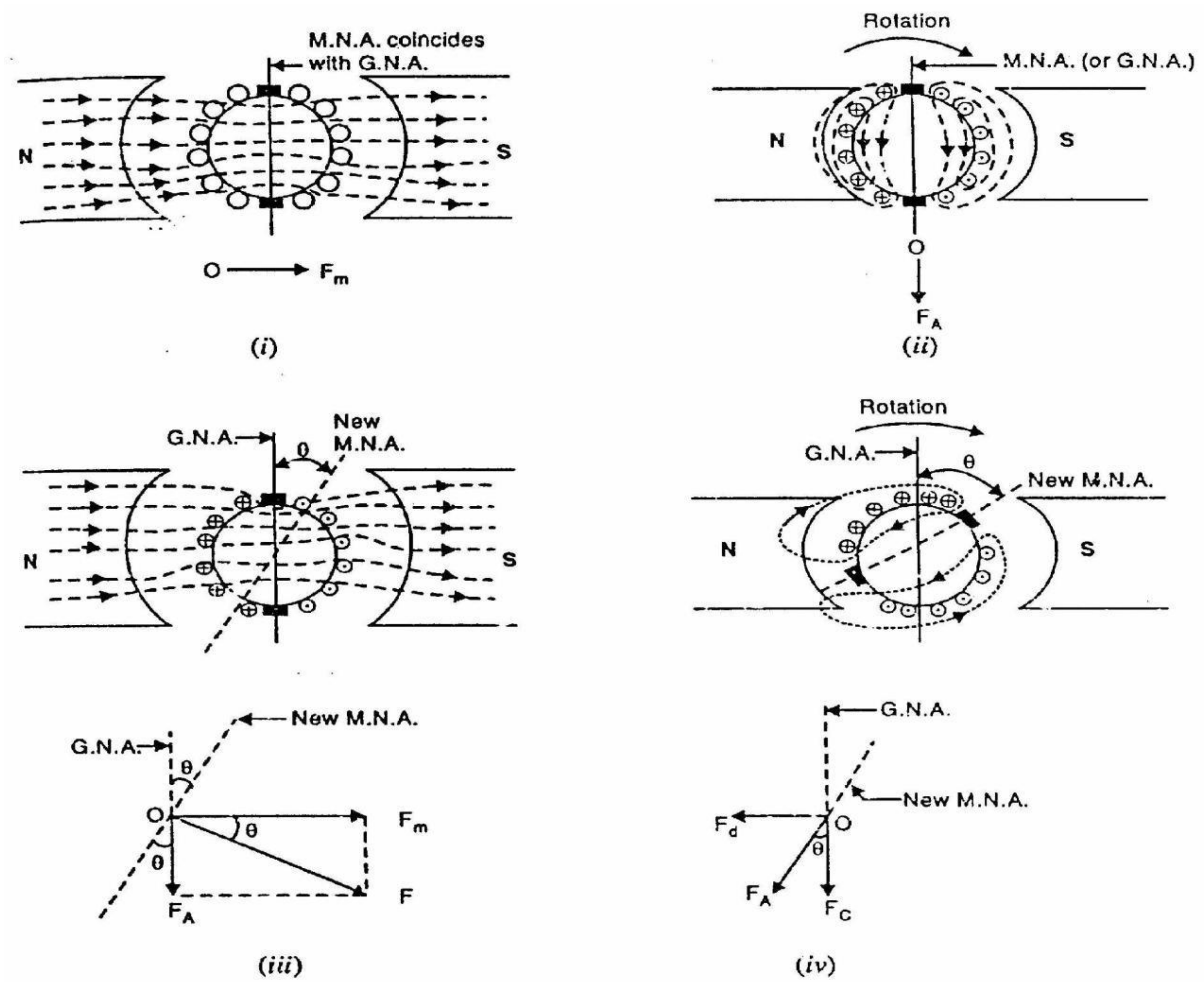


Fig. (2.3)

(a) The component Fd is in direct opposition to the m.m.f. OFm due to main poles. It has a demagnetizing effect on the flux due to main poles. For this reason, it is called the demagnetizing or weakening component of armature reaction.

(b) The component Fc is at right angles to the m.m.f. OFm due to main poles. It distorts the main field. For this reason, it is called the cross magnetizing or distorting component of armature reaction. It

may be noted that with the increase of armature current, both demagnetizing and distorting effects will increase.

Conclusions

(i) With brushes located along G.N.A. (i.e., q = 0°), there is no demagnetizing component of armature reaction (Fd = 0). There is only distorting or cross magnetizing effect of armature reaction.

(ii) With the brushes shifted from G.N.A., armature reaction will have both demagnetizing and distorting effects. Their relative magnitudes depend on the amount of shift. This shift is directly proportional to the Armature current.

(iii) The demagnetizing component of armature reaction weakens the main flux. On the other hand, the distorting component of armature reaction distorts the main flux.

(iv) The demagnetizing effect leads to reduced generated voltage while cross magnetizing effect leads to sparking at the brushes.

2.4 Demagnetizing and Cross-Magnetizing Conductors

With the brushes in the G.N.A. position, there is only cross-magnetizing effect of armature reaction. However, when the brushes are shifted from the G.N.A. position, the armature reaction will have both demagnetizing and cross magnetizing effects. Consider a 2-pole generator with brushes shifted (lead) θm mechanical degrees from G.N.A. We shall identify the armature conductors that produce demagnetizing effect and those that produce cross-magnetizing effect.

(i) The armature conductors θm on either side of G.N.A. produce flux in direct opposition to main flux as shown in Fig. (2.4) (i). Thus the conductors lying within angles AOC = BOD = 2 θm at the top and bottom of the armature produce demagnetizing effect. These are called demagnetizing armature conductors and constitute the demagnetizing ampere-turns of armature reaction (Remember two conductors constitute a turn).

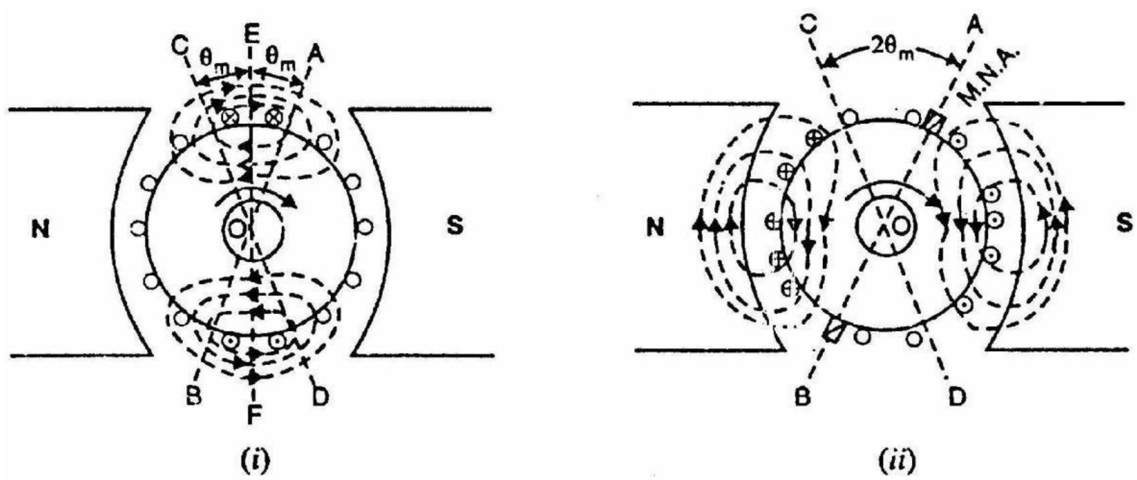


Fig.(2.4)

(ii) The axis of magnetization of the remaining armature conductors lying between angles AOD and COB is at right angles to the main flux as shown in Fig. (2.4) (ii). These conductors produce the cross-magnetizing (or distorting) effect i.e., they produce uneven flux distribution on each pole. Therefore, they are called cross-magnetizing conductors and constitute the cross-magnetizing ampere-turns of armature reaction.

2.5 Calculation of Demagnetizing Ampere-Turns Per Pole (ATd/Pole)

It is sometimes desirable to neutralize the demagnetizing ampere-turns of armature reaction. This is achieved by adding extra ampere-turns to the main field winding. We shall now calculate the demagnetizing ampere-turns per pole (ATd/pole).

Let Z = total number of armature conductors

I = current in each armature conductor

= Ia/2 ... for simplex wave winding

= Ia/P ... for simplex lap winding

θm = forward lead in mechanical degrees

Referring to Fig. (2.4) (i) above, we have,
Total demagnetizing armature conductors

$$= \text{Conductors in angles AOC and BOD} = \frac{4\theta_m}{360} \times Z$$

Since two conductors constitute one turn,

$$\therefore \quad \text{Total demagnetizing ampere-turns} = \frac{1}{2}\left[\frac{4\theta_m}{360} \times Z\right] \times I = \frac{2\theta_m}{360} \times ZI$$

These demagnetizing ampere-turns are due to a pair of poles.

$$\therefore \quad \text{Demagnetizing ampere-turns/pole} = \frac{\theta_m}{360} \times ZI$$

i.e., $$AT_d \,/\, \text{pole} = \frac{\theta_m}{360} \times ZI$$

As mentioned above, the demagnetizing ampere-turns of armature reaction can be neutralized by putting extra turns on each pole of the generator.

$$\therefore \quad \text{No. of extra turns/pole} = \frac{AT_d}{I_{sh}} \qquad \text{for a shunt generator}$$

$$= \frac{AT_d}{I_a} \qquad \text{for a series generator}$$

Note. When a conductor passes a pair of poles, one cycle of voltage is generated. We say one cycle contains 360 electrical degrees. Suppose there are P poles in a generator. In one revolution, there are 360 mechanical degrees and 360 *P/2 electrical degrees.

$$\therefore \quad 360° \text{ mechanical} = 360 \times \frac{P}{2} \text{ electrical degrees}$$

or $$1° \text{ Mechanical} = \frac{P}{2} \text{ electrical degrees}$$

$$\therefore \quad \theta \text{ (mechanical)} = \frac{\theta\text{(electrical)}}{\text{Pair of pols}}$$

or $$\theta_m = \frac{\theta_e}{P/2} \qquad \therefore \quad \theta_m = \frac{2\theta_e}{P}$$

2.6 Cross-Magnetizing Ampere-Turns Per Pole (ATc/Pole)

We now calculate the cross-magnetizing ampere-turns per pole (ATc/pole).
Total armature reaction ampere-turns per pole

$$= \frac{Z/2}{P} \times I = \frac{Z}{2P} \times I \qquad (\because \text{ two conductors make one turn})$$

Demagnetizing ampere-turns per pole is given by;

$$AT_d \,/\, \text{pole} = \frac{\theta_m}{360} \times ZI$$

(found as above)
Cross-magnetizing ampere-turns/pole are

$$AT_d \,/\, \text{pole} = \frac{Z}{2P} \times I - \frac{\theta_m}{360} \times ZI = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$$

$$\therefore \quad AT_d \,/\, \text{pole} = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$$

2.7 Compensating Windings

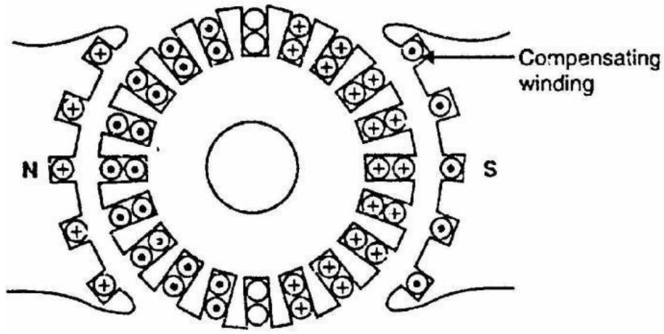


Fig. (2.5)

The cross-magnetizing effect of armature reaction may cause trouble in d.c. machines subjected to large fluctuations in load. In order to neutralize the cross magnetizing effect of armature reaction, a compensating winding is used. A compensating winding is an auxiliary winding embedded in slots in the pole faces as shown in Fig. (2.5). It is connected in series with armature in a manner so that the direction of current through the compensating conductors in any one pole face will be opposite to the direction of the current through the adjacent armature conductors [See Fig. 2.5].

Let us now calculate the number of compensating conductors/ pole face. In calculating the conductors per pole face required for the compensating winding, it should be remembered that the current in the compensating conductors is the armature current Ia whereas the current in armature conductors is Ia/A where A is the number of parallel paths.

Let	Zc	=	No. of compensating conductors/pole face
	Za	=	No. of active armature conductors
	Ia	=	Total armature current
	Ia/A	=	Current in each armature conductor

$$\therefore \quad Z_c I_a = Z_a \times \frac{I_a}{A}$$

or $$Z_c = \frac{Z_a}{A}$$

The use of a compensating winding considerably increases the cost of a machine and is justified only for machines intended for severe service e.g., for high speed and high voltage machines.

2.8 AT/Pole for Compensating Winding

Only the cross-magnetizing ampere-turns produced by conductors under the pole face are effective in producing the distortion in the pole cores. If Z is the total number of armature conductors and P is the number of poles, then,

$$\text{No. of armature conductors/pole} = \frac{Z}{P}$$

$$\text{No. of armature turns/pole} = \frac{Z}{2P}$$

$$\text{No. of armature turns under pole face} = \frac{Z}{2P} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

If I is the current through each armature conductor, then,

$$\text{AT/pole required for compensating winding} = \frac{ZI}{2P} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

$$= \text{Armature AT/pole} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

2.9 Commutation

Fig. (2.6) shows the schematic diagram of 2-pole lap-wound generator. There are two parallel paths between the brushes. Therefore, each coil of the winding carries one half (Ia/2 in this case) of the total current (Ia) entering or leaving the armature.

Note that the currents in the coils connected to a brush are either all towards the brush (positive brush) or all directed away from the brush (negative brush). Therefore, current in a coil will reverse as the coil passes a brush. This reversal of current as the coil passes & brush is called commutation.

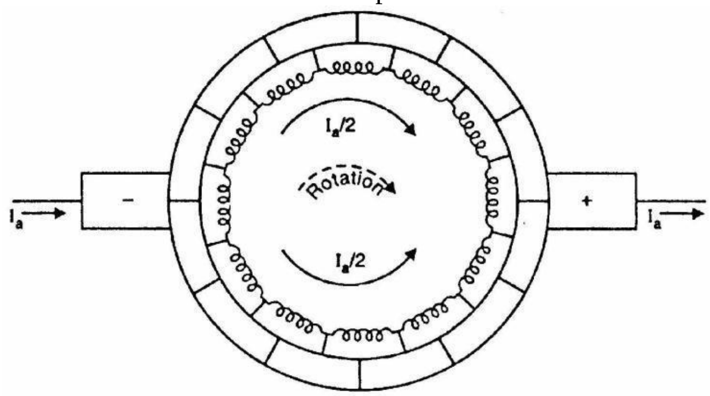


Fig. (2.6)

The reversal of current in a coil as the coil passes the brush axis is called commutation. When commutation takes place, the coil undergoing commutation is short circuited by the brush. The brief period during which the coil remains short circuited is known as commutation period Tc. If the current reversal is completed by the end of commutation period, it is called ideal commutation. If the current reversal is not completed by that time, then sparking occurs between the brush and the commutator which results in progressive damage to both.

Ideal commutation

Let us discuss the phenomenon of ideal commutation (i.e., coil has no inductance) in one coil in the armature winding shown in Fig. (2.6) above. For this purpose, we consider the coil A. The brush width is equal to the width of one commutator segment and one mica insulation. Suppose the total armature current is 40 A. Since there are two parallel paths, each coil carries a current of 20 A.

(i) In Fig. (2.7) (i), the brush is in contact with segment 1 of the commutator. The commutator segment 1 conducts a current of 40 A to the brush; 20 A from coil A and 20 A from the adjacent coil as shown. The coil A has yet to undergo commutation.

(ii) As the armature rotates, the brush will make contact with segment 2 and thus short-circuits the coil A as shown in Fig. (2.7) (ii). There are now two parallel paths into the brush as long as the short-circuit of coil A exists. Fig. (2.7) (ii) shows the instant when the brush is one-fourth on segment 2 and three-fourth on segment 1. For this condition, the resistance of the path through segment 2 is three times the resistance of the path through segment 1 (Q contact resistance varies inversely as the area of contact of brush with the segment). The brush again conducts a current of 40 A; 30 A through segment 1 and 10 A through segment 2. Note that current in coil A (the coil undergoing commutation) is reduced from 20 A to 10 A.

(iii) Fig. (2.7) (iii) shows the instant when the brush is one-half on segment 2 and one-half on segment 1. The brush again conducts 40 A; 20 A through segment 1 and 20 A through segment 2 (Q now the resistances of the two parallel paths are equal). Note that now. current in coil A is zero.

(iv) Fig. (2.7) (iv) shows the instant when the brush is three-fourth on segment 2 and one-fourth on segment 1. The brush conducts a current of 40 A; 30 A through segment 2 and 10 A through segment 1. Note that current in coil A is 10 A but in the reverse direction to that before the start of commutation. The reader may see the action of the commutator in

(v) Fig. (2.7) (v) shows the instant when the brush is in contact only with segment 2. The brush again conducts 40 A; 20 A from coil A and 20 A from the adjacent coil to coil A. Note that now current in coil A is 20 A but in the reverse direction. Thus the coil A has undergone commutation. Each coil undergoes commutation in this way as it passes the brush axis. Note that during commutation, the coil under consideration remains short circuited by the brush.

Fig. (2.8) shows the current-time graph for the coil A undergoing commutation. The horizontal line AB represents a constant current of 20 A upto the beginning of commutation. From the finish of commutation, it is represented by another horizontal line CD on the opposite side of the zero line and the same distance from it as AB i.e., the current has exactly reversed (- 20 A). The way in which current changes from B to C depends upon the conditions under which the coil undergoes commutation. If the current changes at a uniform rate (i.e., BC is a straight line), then it is called ideal commutation as shown in Fig. (2.8). Under such conditions, no sparking will take place between the brush and the commutator.

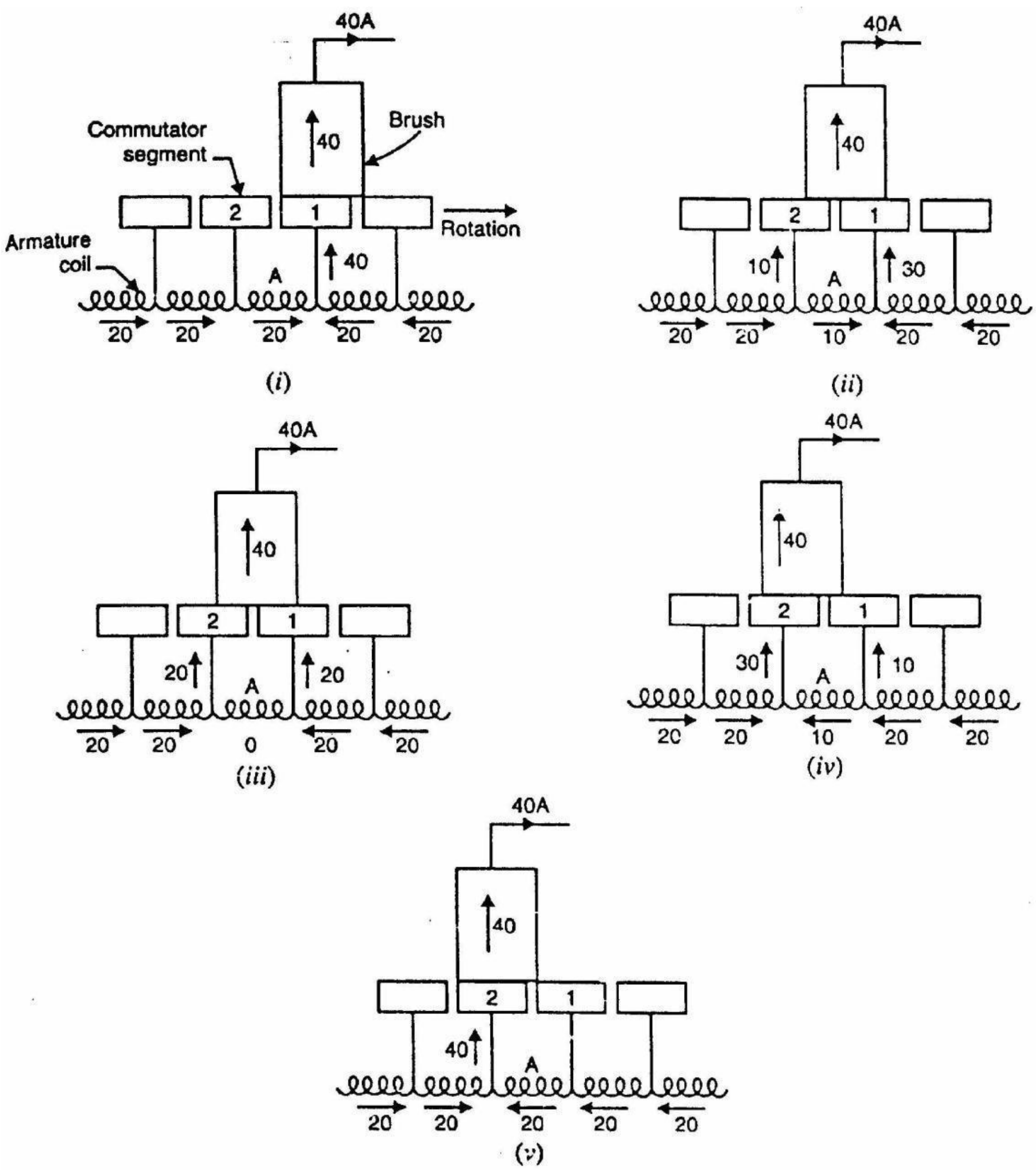


Fig. (2.7)

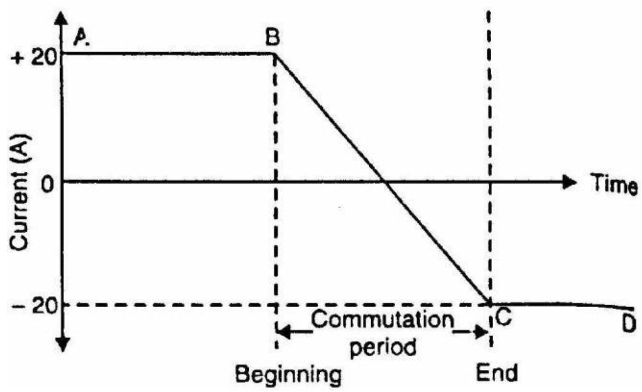


Fig. (2.8)

Practical difficulties

The ideal commutation (i.e., straight line change of current) cannot be attained in practice. This is mainly due to the fact that the armature coils have appreciable inductance. When the current in the coil undergoing commutation changes, self-induced e.m.f. is produced in the coil. This is generally called reactance voltage. This reactance voltage opposes the change of current in the coil undergoing commutation. The result is that the change of current in the coil undergoing commutation occurs more slowly than it would be under ideal commutation.

This is illustrated in Fig. (2.9). The straight line RC represents the ideal commutation whereas the curve BE represents the change in current when self-inductance of the coil is taken into account. Note that current CE (= 8A in Fig. 2.9) is flowing from the commutator segment 1 to the brush at the instant when they part company. This results in sparking just as when any other current carrying circuit is broken. The sparking results in overheating of commutators brush contact and causing damage to both.

Fig. (2.10) illustrates how sparking takes place between the commutators segment and the brush. At the end of commutation or short-circuit period, the current in coil A is reversed to a value of 12 A (instead of 20 A) due to inductance of the coil. When the brush breaks contact with segment 1, the remaining 8 A current jumps from segment 1 to the brush through air causing sparking between segment 1 and the brush.

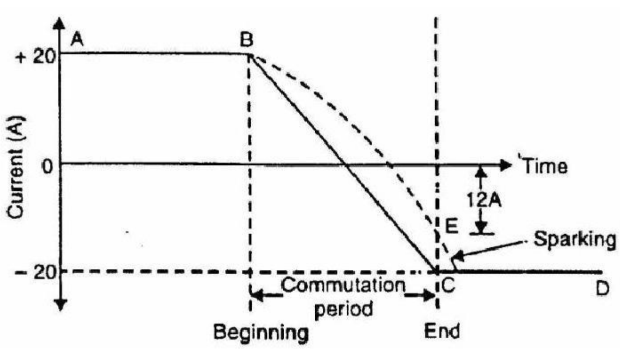


Fig. (2.9)

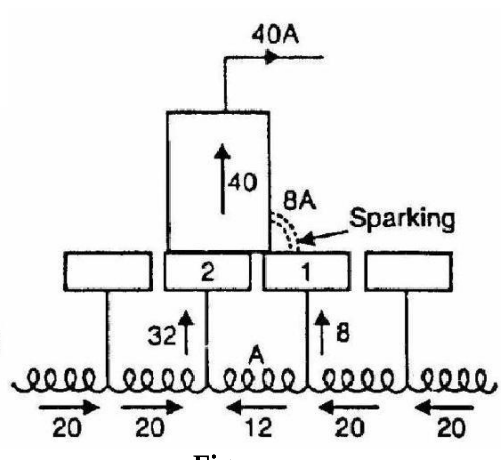


Fig. (2.10)

2.10 Calculation of Reactance Voltage

Reactance voltage = Coefficient of self-inductance *Rate of change of current

When a coil undergoes commutation, two commutator segments remain short circuited by the brush. Therefore, the time of short circuit (or commutation period Tc) is equal to the time required by the commutator to move a distance equal to the circumferential thickness of the brush minus the thickness of one insulating strip of mica

Let Wb = brush width in cm;

Wm = mica thickness in cm

v = peripheral speed of commutator in cm/s

$\therefore$ Commutation period, $T_c = \frac{W_b - W_m}{v}$ seconds

The commutation period is very small, say of the order of 1/500 second.

Let the current in the coil undergoing commutation change from + I to – I (amperes) during the commutation. If L is the inductance of the coil, then reactance voltage is given by;

Reactance voltage, $E_R = L*2I/T_c$

2.11 Methods of Improving Commutation

Improving commutation means to make current reversal in the short-circuited coil as sparkless as possible. The following are the two principal methods of improving commutation:

(i) Resistance commutation

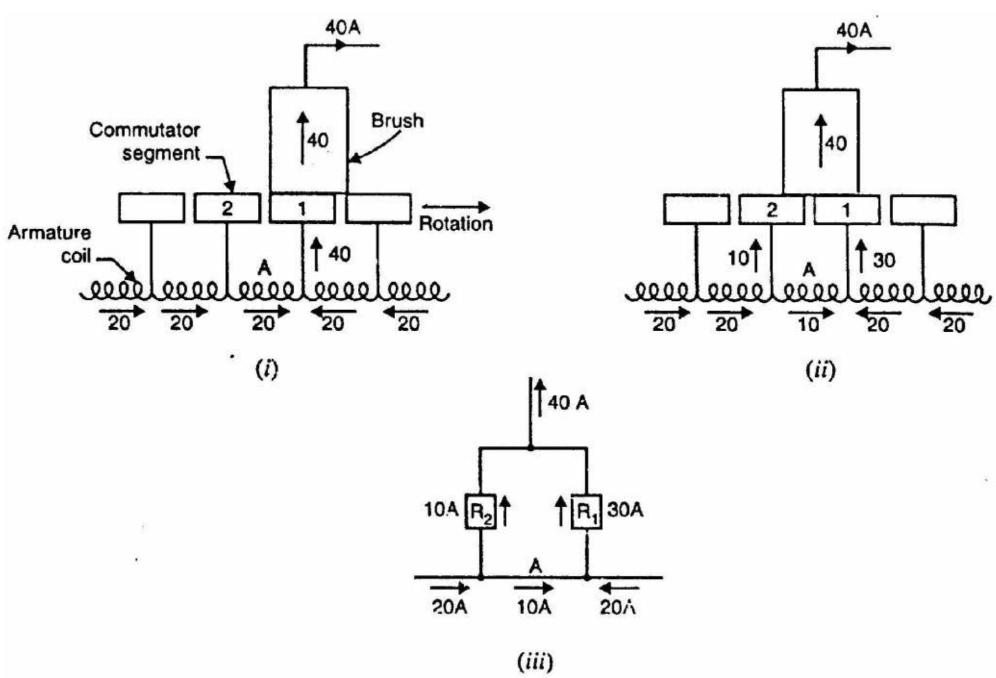
(ii) E.M.F. commutation

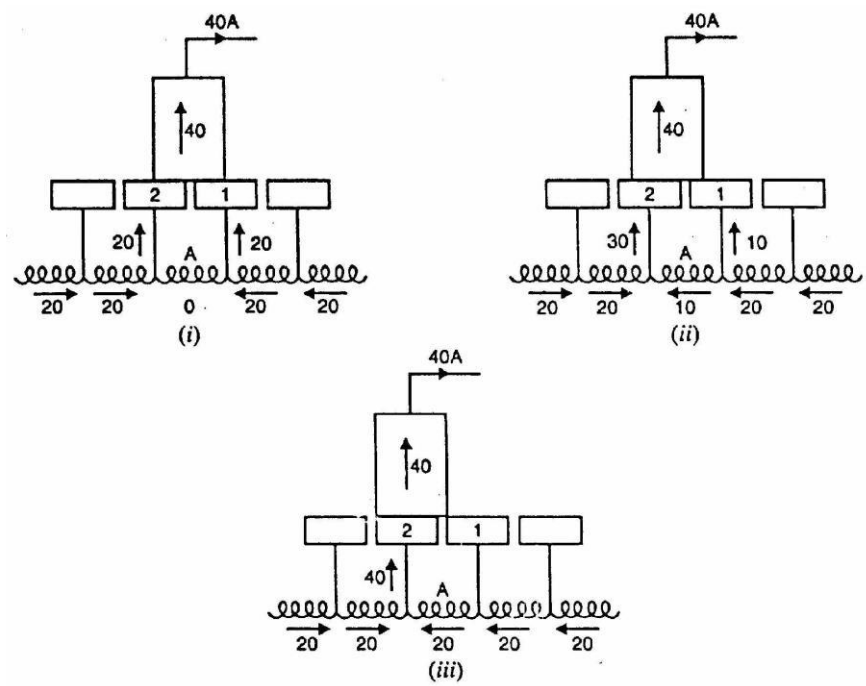
2.12 Resistance Commutation

The reversal of current in a coil (i.e., commutation) takes place while the coil is short-circuited by the brush. Therefore, there are two parallel paths for the current as long as the short circuit exists. If the contact resistance between the brush and the commutator is made large, then current would divide in the inverse ratio of contact resistances (as for any two resistances in parallel). This is the key point in improving commutation. This is achieved by using carbon brushes (instead of Cu brushes) which have high contact resistance. This method of improving commutation is called resistance commutation. Figs. (2.11) and (2.12) illustrates how high contact resistance of carbon brush improves commutation (i.e., reversal of current) in coil A.

In Fig. (2.11) (i), the brush is entirely on segment 1 and, therefore, the current in coil A is 20 A. The coil A is yet to undergo commutation. As the armature rotates, the brush short circuits the coil A and there are two parallel paths for the current into the brush.

Fig. (2.11) (ii) shows the instant when the brush is one-fourth on segment 2 and three-fourth on segment 1. The equivalent electric circuit is shown in Fig. (2.11) (iii) where R1 and R2 represent the brush contact resistances on segments 1 and 2. A resistor is not shown for coil A since it is assumed that the coil resistance is negligible as compared to the brush contact resistance




40A
40
2
1
20
A
20
20
20
0
20
20
(i)
40A
40
2
1
30
A
10
20
20
10
20
20
(ii)
40A
40
2
1
40
A
20
20
20
20
20
(iii)

The values of current in the parallel paths of the equivalent circuit are determined by the respective resistances of the paths. For the condition shown in Fig. (2.11) (ii), resistor R2 has three times the resistance of resistor R1. Therefore, the current distribution in the paths will be as shown. Note that current in coil A is reduced from 20 A to10 A due to division of current in (he inverse ratio of contact resistances. If the Cu brush is used (which has low contact resistance), R1 R2 and the current in coil A would not have reduced to 10 A.

As the carbon brush passes over the commutator, the contact area with segment 2 increases and that with segment 1 decreases i.e., R2 decreases and R1 increases. Therefore, more and more current passes to the brush through segment 2. This is illustrated in Figs. (2.12) (i) and (2.12) (ii), When the break between the brush and the segment 1 finally occurs [See Fig. 2.12 (iii)], the current in the coil is reversed and commutation is achieved. It may be noted that the main cause of sparking during commutation is the production of reactance voltage and carbon brushes cannot prevent it.

Nevertheless, the carbon brushes do help in improving commutation. The other minor advantages of carbon brushes are:

(i) The carbon lubricates and polishes the commutator.

(ii) If sparking occurs, it damages the commutator less than with copper brushes and the damage to the brush itself is of little importance.

2.13 E.M.F. Commutation

In this method, an arrangement is made to neutralize the reactance voltage by producing a reversing voltage in the coil undergoing commutation. The reversing voltage acts in opposition to the reactance voltage and neutralizes it to some extent. If the reversing voltage is equal to the reactance voltage, the effect of the latter is completely wiped out and we get sparkless commutation. The reversing voltage may be produced in the following two ways:

(i) By brush shifting

(ii) By using interpoles or compoles

(i) By brush shifting

In this method, the brushes are given sufficient forward lead (for a generator) to bring the short-circuited coil (i.e., coil undergoing commutation) under the influence of the next pole of opposite polarity. Since the short-circuited coil is now in the reversing field, the reversing voltage produced cancels the reactance voltage. This method suffers from the following drawbacks:

(a) The reactance voltage depends upon armature current. Therefore, the brush shift will depend on the magnitude of armature current which keeps on changing. This necessitates frequent shifting of brushes.

(b) The greater the armature current, the greater must be the forward lead for a generator. This increases the demagnetizing effect of armature reaction and further weakens the main field.

(ii) By using interpoles or compotes

The best method of neutralizing reactance voltage is by, using interpoles or compoles.

2.14 Interpoles or Compoles

The best way to produce reversing voltage to neutralize the reactance voltage is by using interpoles or compoles. These are small poles fixed to the yoke and spaced mid-way between the main poles (See Fig. 2.13). They are wound with comparatively few turns and connected in series with the armature so that they carry armature current. Their polarity is the same as the next main pole ahead in the direction of rotation for a generator (See Fig. 2.13). Connections for a d.c. generator with interpoles is shown in Fig. (2.14).

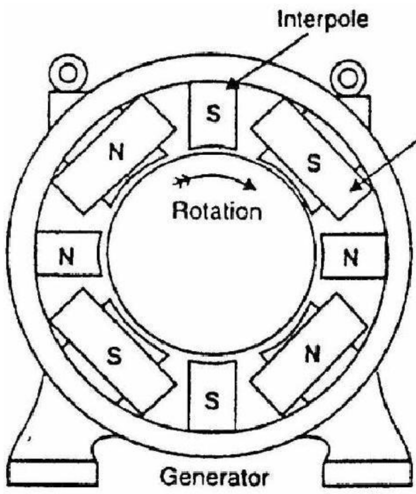


Fig. (2.13)

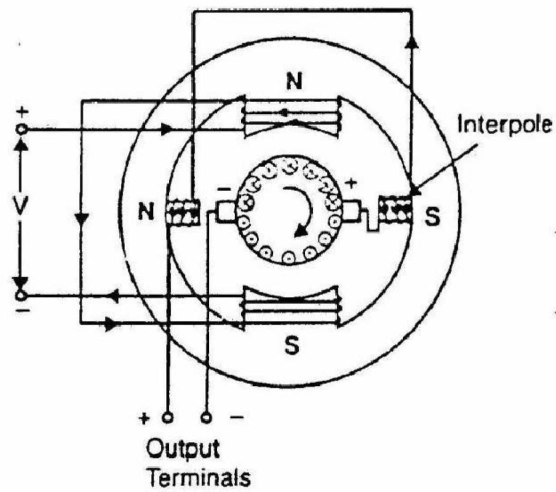


Fig. (2.14)

Functions of Interpoles

The machines fitted with interpoles have their brushes set on geometrical neutral axis (no lead). The interpoles perform the following two functions:

(i) As their polarity is the same as the main pole ahead (for a generator), they induce an e.m.f. in the coil (undergoing commutation) which opposes reactance voltage. This leads to sparkless commutation. The e.m.f. induced by compoles is known as commutating or reversing e.m.f. Since the interpoles carry the armature current and the reactance voltage is also proportional to armature current, the neutralization of reactance voltage is automatic.

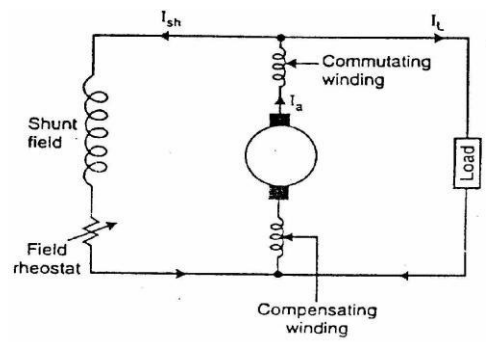
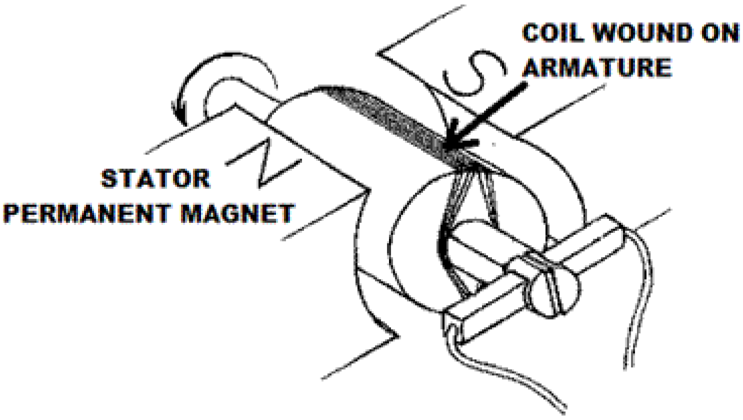


Fig. (2.15)

(ii) The m.m.f. of the compoles neutralizes the cross-magnetizing effect of armature reaction in small region in the space between the main poles. It is because the two m.m.f.s oppose each other in this region. Fig. (2.15) shows the circuit diagram of a shunt generator with commutating winding and compensating winding. Both these windings are connected in series with the armature and so they carry the armature current. However, the functions they perform must be understood clearly. The main function of commutating winding is to produce reversing (or commutating) e.m.f. in order to cancel the reactance voltage. In addition to this, the m.m.f. of the commutating winding neutralizes the cross magnetizing ampere-turns in the space between the main poles. The compensating winding neutralizes the cross-magnetizing effect of armature reaction under the pole faces.

TYPES OF DC GENERATORS

Permanent Magnet DC Generator:



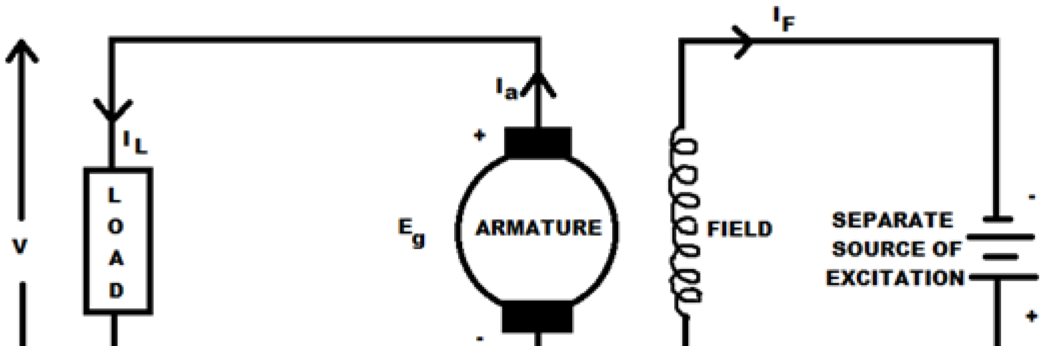
PERMANENT MAGNET DC GENERATOR

When the flux in the magnetic circuit is established by the help of permanent magnets then it is known as Permanent magnet dc generator. It consists of an armature and one or several permanent magnets situated around the armature. This type of dc generators generates very low power. So, they are rarely found in industrial applications. They are normally used in small applications like dynamos in motor cycles.

Separately Excited DC Generator

These are the generators whose field magnets are energized by some external dc source such as battery . A circuit diagram of separately excited DC generator is shown in figure.

I_a = Armature current I_L = Load current V = Terminal voltage E_g = Generated emf



Separately excited DC generator

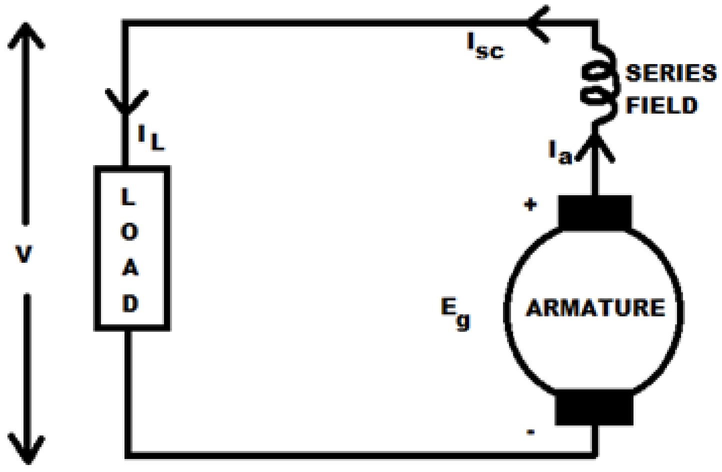
Voltage drop in the armature = $I_a \times R_a$ (R/sub>a is the armature resistance) Let, $I_a = I_L = I$ (say) Then, voltage across the load, $V = IR_a$ Power generated, $P_g = E_g \times I$ Power delivered to the external load, $P_L = V \times I$.

Self-excited DC Generators

These are the generators whose field magnets are energized by the current supplied by themselves. In these type of machines field coils are internally connected with the armature. Due to residual magnetism some flux is always present in the poles. When the armature is rotated some emf is induced. Hence some induced current is produced. This small current flows through the field coil as well as the load and thereby strengthening the pole flux. As the pole flux strengthened, it will produce more armature emf, which cause further increase of current through the field. This increased field current further raises armature emf and this cumulative phenomenon continues until the excitation reaches to the rated value. According to the position of the field coils the Self-excited DC generators may be classified as…

A. Series wound generators B. Shunt wound generators C. Compound wound generators

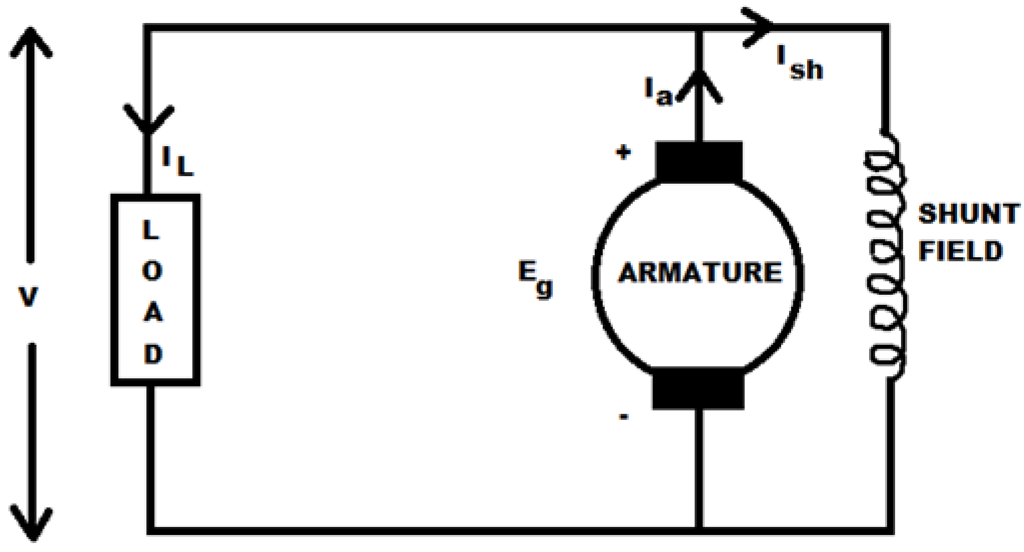
Series Wound Generator
In these type of generators, the field windings are connected in series with armature conductors as shown in figure below. So, whole current flows through the field coils as well as the load. As series field winding carries full load current it is designed with relatively few turns of thick wire. The electrical resistance of series field winding is therefore very low (nearly 0.5Ω). Let, R_{sc} = Series winding resistance I_{sc} = Current flowing through the series field R_a = Armature resistance I_a = Armature current I_L = Load current V = Terminal voltage E_g = Generated emf



Series Wound Generator

Then, $I_a = I_{sc} = I_L = I$ (say) Voltage across the load, $V = E_g - I(I_a \times R_a)$ Power generated, $P_g = E_g \times I$ Power delivered to the load, $P_L = V \times I$

Shunt Wound DC Generators
In these type of DC generators the field windings are connected in parallel with armature conductors as shown in figure below. In shunt wound generators the voltage in the field winding is same as the voltage across the terminal. Let, R_{sh} = Shunt winding resistance I_{sh} = Current flowing through the shunt field R_a = Armature resistance I_a = Armature current I_L = Load current V = Terminal voltage E_g = Generated emf



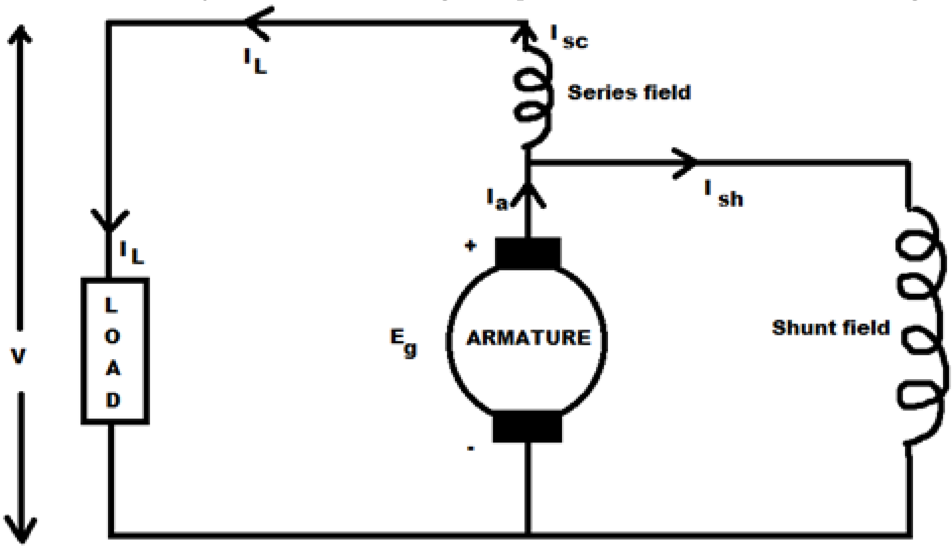
Shunt Wound Generator

Here armature current I_a is dividing in two parts, one is shunt field current I_{sh} and another is load current I_L. So, $I_a=I_{sh} + I_L$ The effective power across the load will be maximum when I_L will be maximum. So, it is required to keep shunt field current as small as possible. For this purpose the resistance of the shunt field winding generally kept high (100 Ω) and large no of turns are used for the desired emf. Shunt field current, $I_{sh} = V/R_{sh}$ Voltage across the load, $V = E_g - I_a R_a$ Power generated, $P_g = E_g \times I_a$ Power delivered to the load, $P_L = V \times I_L$

Compound Wound DC Generator

In series wound generators, the output voltage is directly proportional with load current. In shunt wound generators, output voltage is inversely proportional with load current. A combination of these two types of generators can overcome the disadvantages of both. This combination of windings is called compound wound DC generator. Compound wound generators have both series field winding and shunt field winding. One winding is placed in series with the armature and the other is placed in parallel with the armature. This type of DC generators may be of two types- short shunt compound wound generator and long shunt compound wound generator.

Short Shunt Compound Wound DC Generator
The generators in which only shunt field winding is in parallel with the armature winding as shown in

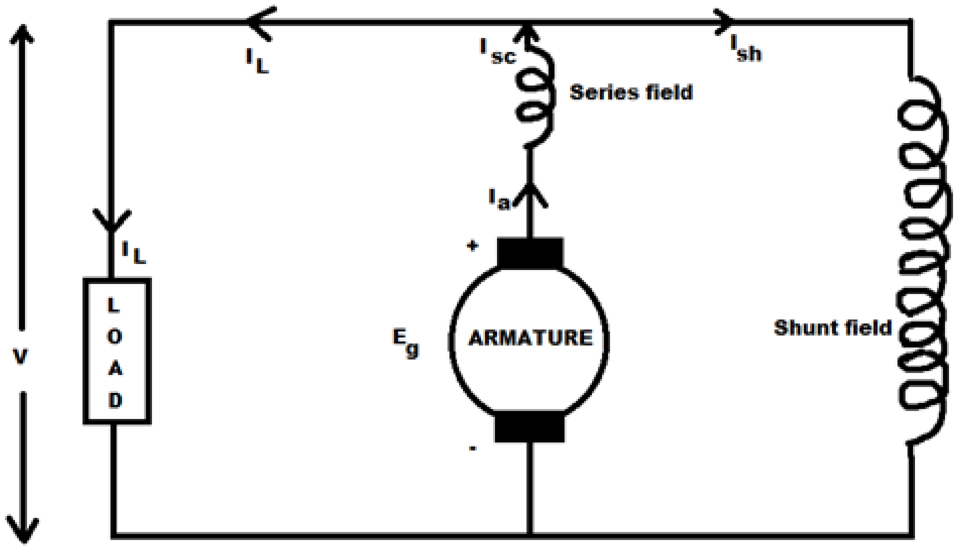


Short Shunt Compound Wound Generator

figure.

Series field current, $I_{sc} = I_L$ Shunt field current, $I_{sh} = (V+I_{sc} R_{sc})/R_{sh}$ Armature current, $I_a = I_{sh} + I_L$ Voltage across the load, $V = E_g - I_a R_a - I_{sc} R_{sc}$ Power generated, $P_g = E_g \times I_a$ Power delivered to the load, $P_L = V \times I_L$

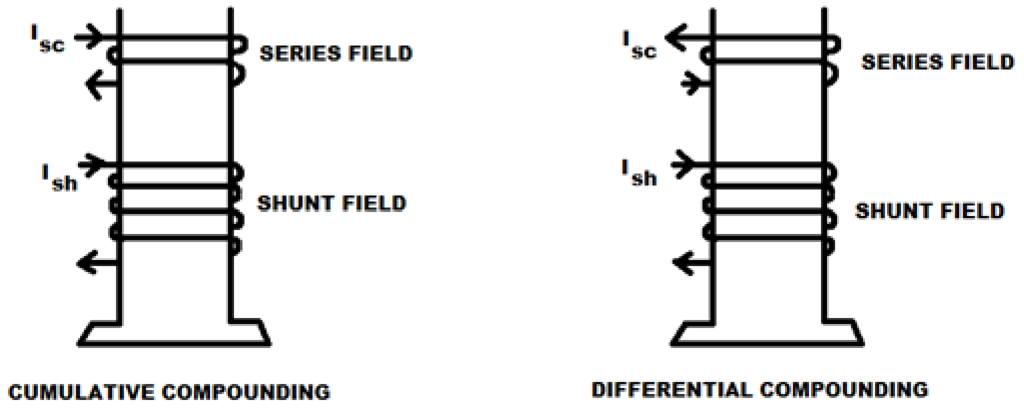
Long Shunt Compound Wound DC Generator
The generators in which shunt field winding is in parallel with both series field and armature winding as



Long Shunt Compound Wound Generator

shown in figure.
Shunt field current, $I_{sh}=V/R_{sh}$ Armature current, I_a= series field current, $I_{sc}= I_L+I_{sh}$ Voltage across the load, $V=E_g-I_a R_a-I_{sc} R_{sc}=E_g-I_a (R_a+R_{sc})$ [$\therefore I_a=I_{cs}$] Power generated, $P_g= E_g \times I_a$ Power delivered to the load, $P_L=V \times I_L$ In a compound wound generator, the shunt field is stronger than the series field. When the series field assists the shunt field, generator is said to be commutatively compound wound. On the other hand if series field

opposes the shunt field, the generator is said to be differentially compound wound.



D.C. GENERATOR CHARACTERISTICS

Introduction

The speed of a d.c. machine operated as a generator is fixed by the prime mover. For general-purpose operation, the prime mover is equipped with a speed governor so that the speed of the generator is practically constant. Under such condition, the generator performance deals primarily with the relation between excitation, terminal voltage and load. These relations can be best exhibited graphically by means of curves known as generator characteristics. These characteristics show at a glance the behaviour of the generator under different load conditions.

3.1 D.C. Generator Characteristics

The following are the three most important characteristics of a d.c. generator:

Open Circuit Characteristic (O.C.C.)

This curve shows the relation between the generated e.m.f. at no-load (E_0) and the field current (I_f) at constant speed. It is also known as magnetic characteristic or no-load saturation curve. Its shape is practically the same for all generators whether separately or self-excited. The data for O.C.C. curve are obtained experimentally by operating the generator at no load and constant speed and recording the change in terminal voltage as the field current is varied.

External characteristic (V/I_L)

This curve shows the relation between the terminal voltage (V) and load current (I_L). The terminal voltage V will be less than E due to voltage drop in the armature circuit. Therefore, this curve will lie below the internal characteristic. This characteristic is very important in determining the suitability of a generator for a given purpose. It can be obtained by making simultaneous measurements of terminal voltage and load current (with voltmeter and ammeter) of a loaded generator.

Internal or Total characteristic (E/I_a)

This curve shows the relation between the generated e.m.f. on load (E) and the armature current (I_a). The e.m.f. E is less than E_0 due to the demagnetizing effect of armature reaction. Therefore, this curve will lie below the open circuit characteristic (O.C.C.). The internal characteristic is of interest chiefly to the designer. It cannot be obtained directly by experiment. It is because a voltmeter cannot read the e.m.f. generated on load due to the voltage drop in armature resistance. The internal characteristic can be obtained from external characteristic if winding resistances are known because armature reaction effect is included in both characteristics.

3.2 Open Circuit Characteristic of a D.C. Generator

The O.C.C. for a d.c. generator is determined as follows. The field winding of the d.c. generator (series or shunt) is disconnected from the machine and is separately excited from an external d.c. source as shown in Fig. (3.1) (ii). The generator is run at fixed speed (i.e., normal speed). The field current (I_f) is increased from zero in steps and the corresponding values of generated e.m.f. (E_0) read off on a voltmeter connected across the armature terminals. On plotting the relation between E_0 and I_f, we get the open circuit characteristic as shown in Fig. (3.1) (i).

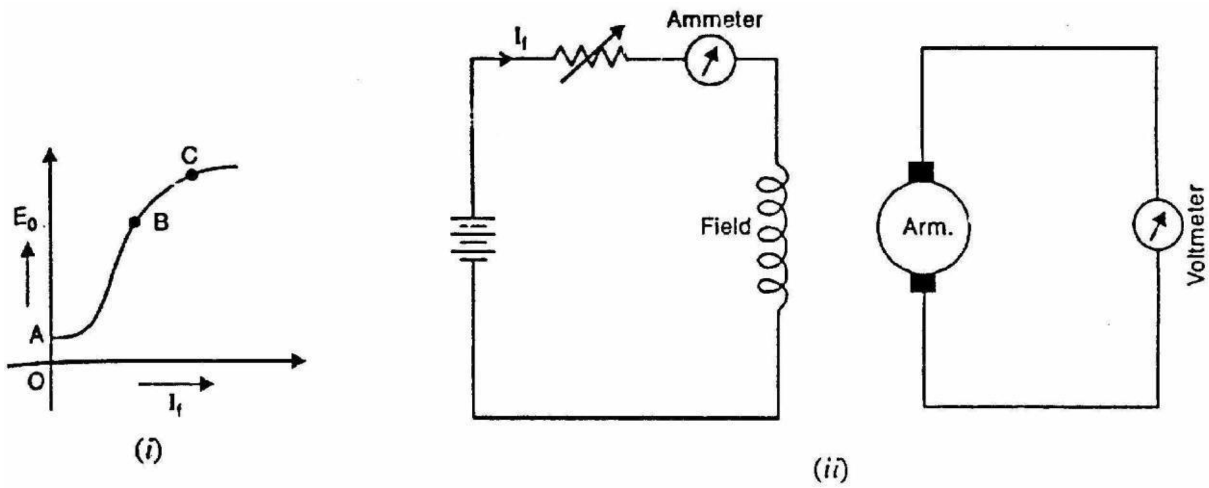


Fig. (3.1)

The following points may be noted from O.C.C.:

4. When the field current is zero, there is some generated e.m.f. OA. This is due to the residual magnetism in the field poles.

5. Over a fairly wide range of field current (upto point B in the curve), the curve is linear. It is because in this range, reluctance of iron is negligible as compared with that of air gap. The air gap reluctance is constant and hence linear relationship.

6. After point B on the curve, the reluctance of iron also comes into picture. It is because at higher flux densities, μ_r for iron decreases and reluctance

of iron is no longer negligible. Consequently, the curve deviates from linear relationship.
(iv) After point C on the curve, the magnetic saturation of poles begins and E_0 tends to level off.

The reader may note that the O.C.C. of even self-excited generator is obtained by running it as a separately excited generator.

3.3 Characteristics of a Separately Excited D.C. Generator

The obvious disadvantage of a separately excited d.c. generator is that we require an external d.c. source for excitation. But since the output voltage may be controlled more easily and over a wide range (from zero to a maximum), this type of excitation finds many applications.

(i) Open circuit characteristic.

The O.C.C. of a separately excited generator is determined in a manner described in Sec. (3.2). Fig. (3.2) shows the variation of generated e.m f. on no load with field current for various fixed speeds. Note that if the value of constant speed is increased, the steepness of the curve also increases. When the field current is zero, the residual magnetism in the poles will give rise to the small initial e.m.f. as shown.

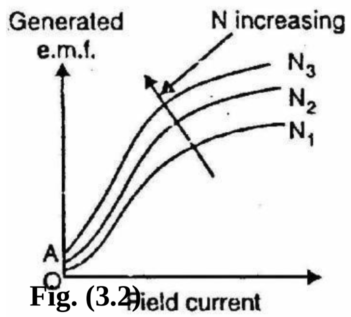


Fig. (3.2)

(ii) Internal and External Characteristics

The external characteristic of a separately excited generator is the curve between the terminal voltage (V) and the load current I_L (which is the same as armature current in this case). In order to determine the external characteristic, the circuit set up is as shown in Fig. (3.3) (i). As the load current increases, the terminal voltage falls due to two reasons:
(a) The armature reaction weakens the main flux so that actual e.m.f. generated E on load is less than that generated (E_0) on no load.
(b) There is voltage drop across armature resistance (= $I_LR_a = I_aR_a$).

Due to these reasons, the external characteristic is a drooping curve [curve 3 in Fig. 3.3 (ii)]. Note that in the absence of armature reaction and armature drop, the generated e.m.f. would have been E_0 (curve 1).

The internal characteristic can be determined from external characteristic by adding I_LR_a drop to the external characteristic. It is because armature reaction drop is included in the external characteristic. Curve 2 is the internal characteristic of the generator and should obviously lie above the external characteristic.

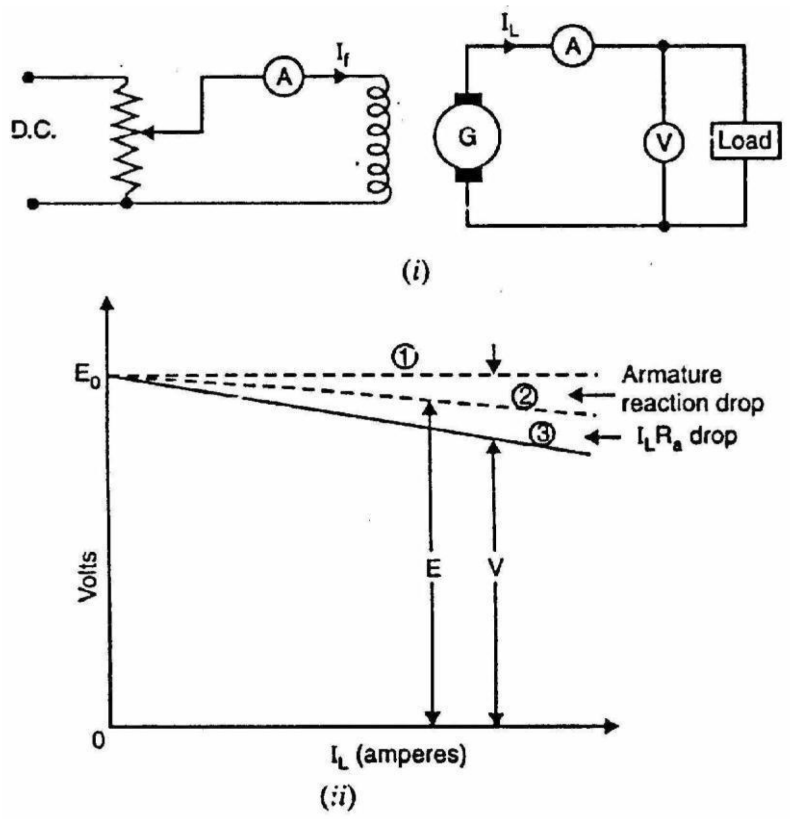


Fig. (3.3)

3.4 Voltage Build-Up in a Self-Excited Generator

Let us see how voltage builds up in a self-excited generator.

(i) Shunt generator

Consider a shunt generator. If the generator is run at a constant speed, some e.m.f. will be generated due to residual magnetism in the main poles. This small e.m.f. circulates a field current which in turn produces additional flux to reinforce the original residual flux (provided field winding connections are correct). This process continues and the generator builds up the normal generated voltage following the O.C.C. shown in Fig. (3.4) (i).

The field resistance R_f can be represented by a straight line passing through the origin as shown in Fig. (3.4) (ii). The two curves can be shown on the same diagram as they have the same ordinate [See Fig. 3.4 (iii)].

Since the field circuit is inductive, there is a delay in the increase in current upon closing the field circuit switch The rate at which the current increases depends upon the voltage available for increasing it. Suppose at any instant, the field current is i (= OA) and is increasing at the rate di/dt. Then,

$$E_0 - i R_f = L \frac{di}{dt}$$

where R_f = total field circuit resistance L = inductance of field circuit

At the considered instant, the total e.m.f. available is AC [See Fig. 3.4 (iii)]. An amount AB of the c.m.f. AC is absorbed by the voltage drop iR_f and the remainder part BC is available to overcome L di/dt. Since this surplus voltage is available, it is possible for the field current to increase above the value OA.

However, at point D, the available voltage is OM and is all absorbed by i R_f drop. Consequently, the field current cannot increase further and the generator build up stops.

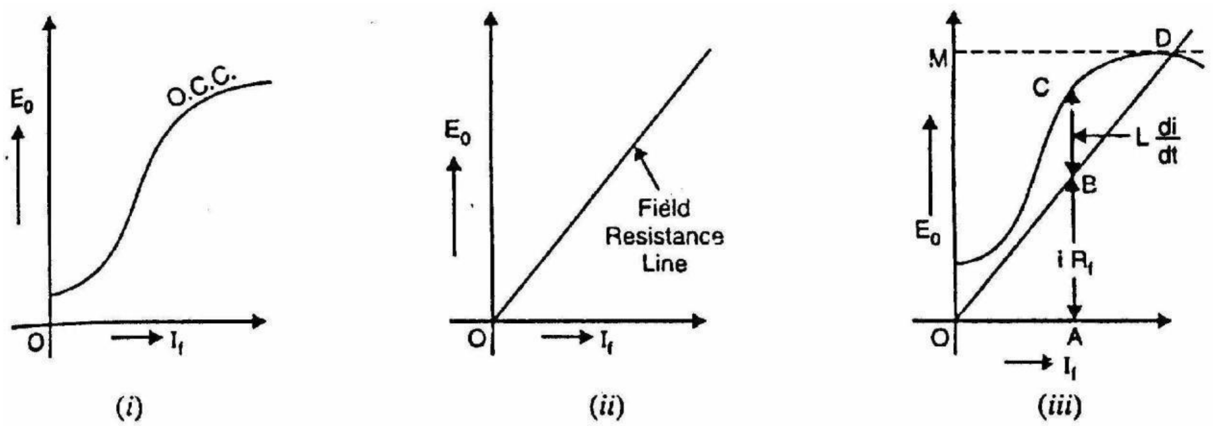


Fig. (3.4)

We arrive at a very important conclusion that the voltage build up of the generator is given by the point of intersection of O.C.C. and field resistance line. Thus in Fig. (3.4) (iii), D is point of intersection of the two curves. Hence the generator will build up a voltage OM.

(ii) Series generator

During initial operation, with no current yet flowing, a residual voltage will be generated exactly as in the case of a shunt generator. The residual voltage will cause a current to flow through the whole series circuit when the circuit is closed. There will then be voltage build up to an equilibrium point exactly analogous to the build up of a shunt generator. The voltage build up graph will be similar to that of shunt generator except that now load current (instead of field current for shunt generator) will be taken along x-axis.

(iii) Compound generator

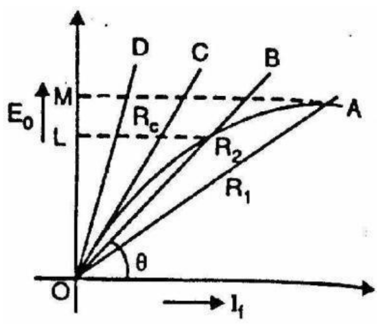
When a compound generator has its series field flux aiding its shunt field flux, the machine is said to be cumulative compound. When the series field is connected in reverse so that its field flux opposes the shunt field flux, the generator is then differential compound.

The easiest way to build up voltage in a compound generator is to start under no load conditions. At no load, only the shunt field is effective. When no-load voltage build up is achieved, the generator is loaded. If under load, the voltage rises, the series field connection is cumulative. If the voltage drops significantly, the connection is differential compound.

3.5 Critical Field Resistance for a Shunt Generator

We have seen above that voltage build up in a shunt generator depends upon field circuit resistance. If the field circuit resistance is R_1 (line OA), then generator will build up a voltage OM as shown in Fig. (3.5). If the field circuit resistance is increased to R_2 (tine OB), the generator will build up a voltage OL, slightly less than OM. As the field circuit resistance is increased, the slope of resistance line also increases. When the field resistance line becomes tangent (line OC) to O.C.C., the generator would just excite. If the field circuit resistance is increased beyond this point (say line OD), the generator will fail to excite. The field circuit resistance represented by line OC (tangent to O.C.C.) is called critical field resistance R_C for the shunt generator. It may be defined as under:

The maximum field circuit resistance (for a given speed) with which the shunt generator would just excite is known as its critical field resistance.



It should be noted that shunt generator will build up voltage only if field circuit resistance is less than critical field resistance.

Fig. (3.5)

3.6 Critical Resistance for a Series Generator

Fig. (3.6) shows the voltage build up in a series generator. Here R_1, R_2 etc. represent the total circuit resistance (load resistance and field winding resistance). If the total circuit resistance is R_1, then series generator will build up a voltage OL. The

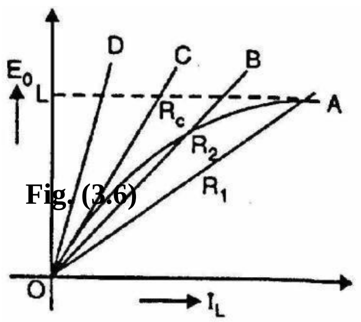


Fig. (3.6)

line OC is tangent to O.C.C. and represents the critical resistance R_C for a series generator. If the total resistance of the circuit is more than R_C (say line OD), the generator will fail to build up voltage. Note that Fig. (3.6) is similar to Fig. (3.5) with the following differences:

(i) In Fig. (3.5), R_1, R_2 etc. represent the total field circuit resistance. However, R_1, R_2 etc. in Fig. (3.6) represent the total circuit resistance (load resistance and series field winding resistance etc.).

(ii) In Fig (3.5), field current alone is represented along X-axis. However, in Fig. (3.6) load current I_L is represented along Y-axis. Note that in a series generator, field current = load current I_L.

3.7 Characteristics of Series Generator

Fig. (3.7) (i) shows the connections of a series wound generator. Since there is only one current (that which flows through the whole machine), the load current is the same as the exciting current.

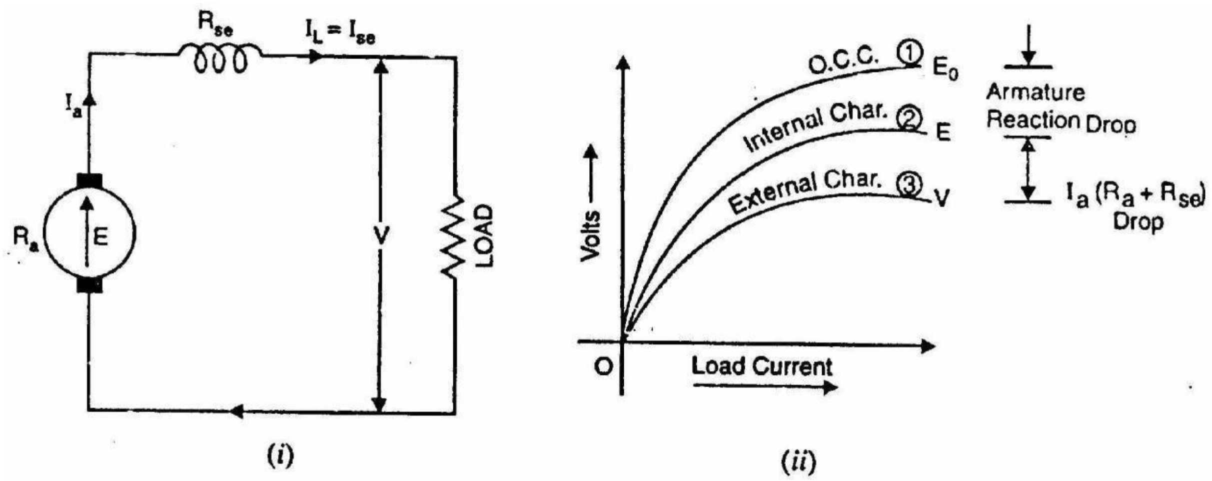


Fig. (3.7)

(i) O.C.C.

Curve 1 shows the open circuit characteristic (O.C.C.) of a series generator. It can be obtained experimentally by disconnecting the field winding from the machine and exciting it from a separate d.c. source as discussed in Sec. (3.2).

(ii) Internal characteristic

Curve 2 shows the total or internal characteristic of a series generator. It gives the relation between the generated e.m.f. E. on load and armature current. Due to armature reaction, the flux in the machine will be less than the flux at no load.

Hence, e.m.f. E generated under load conditions will be less than the e.m.f. E_0 generated under no load conditions. Consequently, internal characteristic curve lies below the O.C.C. curve; the difference between them representing the effect of armature reaction [See Fig. 3.7 (ii)].

(iii) External characteristic

Curve 3 shows the external characteristic of a series generator. It gives the relation between terminal voltage and load current I_L:.

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

Therefore, external characteristic curve will lie below internal characteristic curve by an amount equal to ohmic drop [i.e., $I_a(R_a + R_{se})$] in the machine as shown in Fig. (3.7) (ii).

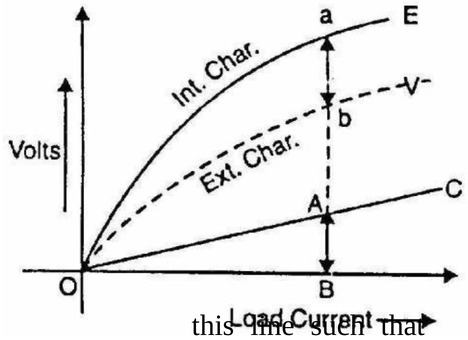


Fig. (3.8)

The internal and external characteristics of a d.c. series generator can be plotted from one another as shown in Fig. (3.8). Suppose we are given the internal characteristic of the generator. Let the line OC represent the resistance of the whole machine i.e. R_a + R_{se}. If the load current is OB, drop in the machine is AB i.e.

AB = Ohmic drop in the machine = OB(R_a + R_{se})

Now raise a perpendicular from point B and mark a point b on this line such that ab = AB. Then point b will lie on the external characteristic of the generator. Following similar procedure, other points of external characteristic can be located. It is easy to see that we can also plot internal characteristic from the external characteristic.

3.8 Characteristics of a Shunt Generator

Fig (3.9) (i) shows the connections of a shunt wound generator. The armature current I_a splits up into two parts; a small fraction I_{sh} flowing through shunt field winding while the major part I_L goes to the external load.

(i) O.C.C.

The O.C.C. of a shunt generator is similar in shape to that of a series generator as shown in Fig. (3.9) (ii). The line OA represents the shunt field circuit resistance. When the generator is run at normal speed, it will build up a voltage OM. At no-load, the terminal voltage of the generator will be constant (= OM) represented by the horizontal dotted line MC.

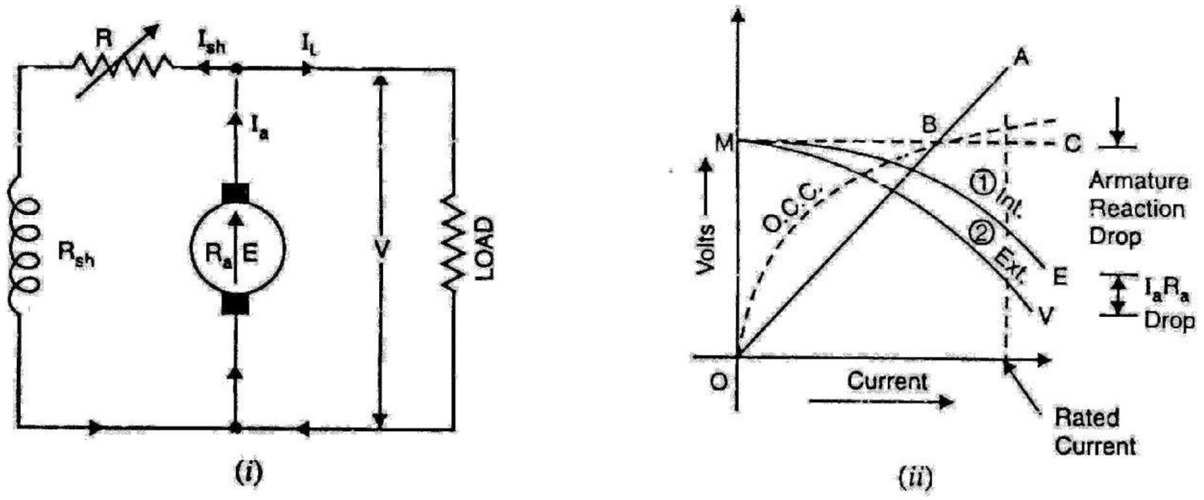


Fig. (3.9)

(ii) Internal characteristic

When the generator is loaded, flux per pole is reduced due to armature reaction. Therefore, e.m.f. E generated on load is less than the e.m.f. generated at no load.
As a result, the internal characteristic (E/I_a) drops down slightly as shown in Fig. (3.9) (ii).

(iii) External characteristic

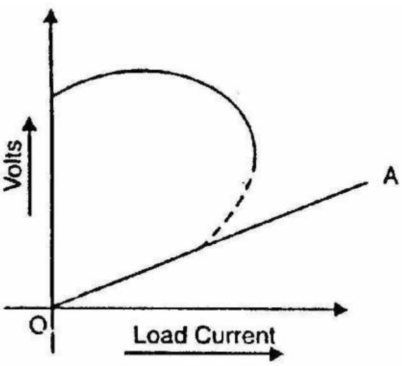
Curve 2 shows the external characteristic of a shunt generator. It gives the relation between terminal voltage V and load current I_L.

$V = E - I_a R_a = E - (I_L + I_{sh}) R_a$

Therefore, external characteristic curve will lie below the internal characteristic curve by an amount equal to drop in the armature circuit [i.e., $(I_L + I_{sh})R_a$] as shown in Fig. (3.9) (ii).

Note. It may be seen from the external characteristic that change in terminal voltage from no-load to full load is small. The terminal voltage can always be maintained constant by adjusting the field rheostat R automatically

3.9 Critical External Resistance for Shunt Generator



If the load resistance across the terminals of a shunt generator is decreased, then load current increase? However, there is a limit to the increase in load current with the decrease of load resistance. Any decreaseof load resistance beyond this point, instead of increasing the current, ultimatelyresults in

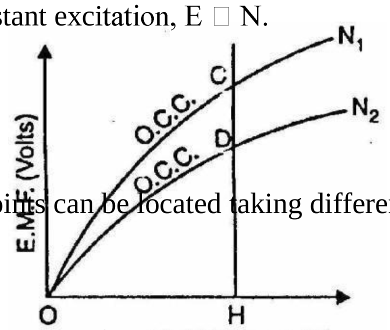
Fig. (3.10)

reduced current. Consequently, the external characteristic turns back (dotted curve) as shown in Fig. (3.10). The tangent OA to the curve represents the minimum external resistance required to excite the shunt generator on load and is called critical external resistance. If the resistance of the external circuit is less than the critical external resistance (represented by tangent OA in Fig. 3.10), the machine will refuse to excite or will de-excite if already running This means that external resistance is so low as virtually to short circuit the machine and so doing away with its excitation.

Note. There are two critical resistances for a shunt generator viz., (i) critical field resistance (ii) critical external resistance. For the shunt generator to build up voltage, the former should not be exceeded and the latter must not be gone below.

3.10 How to Draw O.C.C. at Different Speeds?

If we are given O.C.C. of a generator at a constant speed N_1, then we can easily draw the O.C.C. at any other constant speed N_2. Fig (3.11) illustrates the procedure. Here we are given O.C.C. at a constant speed N_1. It is desired to find the O.C.C. at constant speed N_2 (it is assumed that $n_1 < N_2$). For constant excitation, $E \propto N$.



This locates the point D on the new O.C.C. at N_2. Similarly, other points can be located taking different values of I_f. The locus of these points will be the O.C.C. at N_2.

3.11 Critical Speed (N_C)

The critical speed of a shunt generator is the minimum speed below which it fails to excite. Clearly, it is the speed for which the given shunt field resistance represents the critical resistance. In Fig. (3.12), curve 2 corresponds to critical speed because the shunt field resistance (R_{sh}) line is tangential to it. If the generator runs at full speed N, the new O.C.C. moves upward and the R'_{sh} line represents critical resistance for this speed.

□ Speed □ Critical resistance

In order to find critical speed, take any convenient point C on excitation axis and erect a perpendicular so as to cut R_{sh} and R'_{sh} lines at points B and A respectively. Then,

N

C

□

AC N

N C AC

or

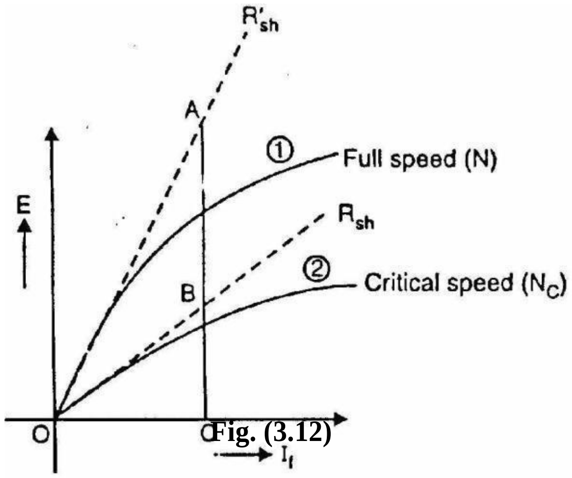


Fig. (3.12)

3.12 Conditions for Voltage Build-Up of a Shunt Generator

The necessary conditions for voltage build-up in a shunt generator are:

(v) There must be some residual magnetism in generator poles.

(vi) The connections of the field winding should be such that the field current strengthens the residual magnetism.

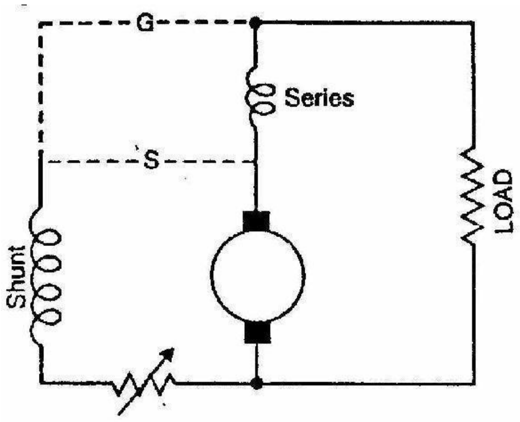
(vii) The resistance of the field circuit should be less than the critical resistance. In other words, the speed of the generator should be higher than the critical speed.

3.13 Compound Generator Characteristics

In a compound generator, both series and shunt excitation are combined as shown in Fig. (3.13). The shunt winding can be connected either across the armature only (short-shunt connection S) or across armature plus series field (long-shunt connection G). The compound generator can be cumulatively compounded or differentially compounded generator. The latter is rarely used in practice. Therefore, we shall discuss the characteristics of cumulatively-compounded generator. It may be noted that external characteristics of long and short shunt compound generators are almost identical.

External characteristic

Fig. (3.14) shows the external characteristics of a cumulatively compounded generator. The series excitation aids the shunt excitation. The degree of compounding depends upon the increase in series excitation with the increase in load current.



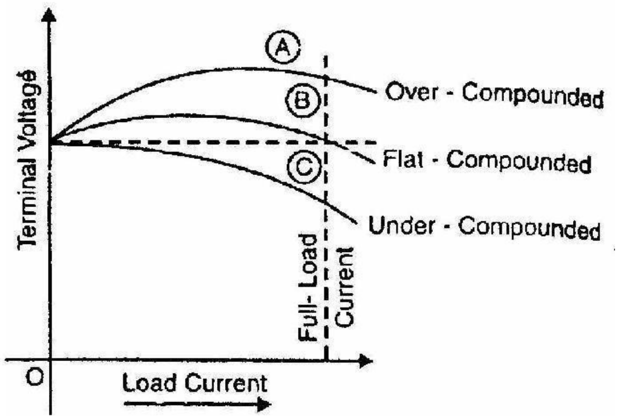


Fig. (3.13) **Fig. (3.14)**

(i) If series winding turns are so adjusted that with the increase in load current the terminal voltage increases, it is called over-compounded generator. In such a case, as the load current increases, the series field m.m.f. increases and tends to increase the flux and hence the generated voltage. The increase in generated voltage is greater than the I_aR_a drop so that instead of decreasing, the terminal voltage increases as shown by curve A in Fig. (3.14).

(c) If series winding turns are so adjusted that with the increase in load current, the terminal voltage substantially remains constant, it is called flat-compounded generator. The series winding of such a machine has lesser number of turns than the one in over-compounded machine and, therefore, does not increase the flux as much for a given load current. Consequently, the full-load voltage is nearly equal to the no-load voltage as indicated by curve B in Fig (3.14).

(d) If series field winding has lesser number of turns than for a flat-compounded machine, the terminal voltage falls with increase in load current as indicated by curve C m Fig. (3.14). Such a machine is called under-compounded generator.

3.14 Voltage Regulation

The change in terminal voltage of a generator between full and no load (at constant speed) is called the voltage regulation, usually expressed as a percentage of the voltage at full-load.

$$\% \text{ Voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

where V_{NL} = Terminal voltage of generator at no load

V_{FL} = Terminal voltage of generator at full load

Note that voltage regulation of a generator is determined with field circuit and speed held constant. If the voltage regulation of a generator is 10%, it means that terminal voltage increases 10% as the load is changed from full load to no load.

3.15 Parallel Operation of D.C. Generators

In a d.c. power plant, power is usually supplied from several generators of small ratings connected in parallel instead of from one large generator. This is due to the following reasons:

(i) Continuity of service

If a single large generator is used in the power plant, then in case of its breakdown, the whole plant will be shut down. However, if power is supplied from a number of small units operating in parallel, then in case of failure of one unit, the continuity of supply can be maintained by other healthy units.

(ii) Efficiency

Generators run most efficiently when loaded to their rated capacity. Electric power costs less per kWh when the generator producing it is efficiently loaded. Therefore, when load demand on power plant decreases, one or more generators can be shut down and the remaining units can be efficiently loaded.

(iii) Maintenance and repair

Generators generally require routine-maintenance and repair. Therefore, if generators are operated in parallel, the routine or emergency operations can be performed by isolating the affected generator while load is being supplied by other units. This leads to both safety and economy.

(iv) Increasing plant capacity

In the modern world of increasing population, the use of electricity is continuously increasing. When added capacity is required, the new unit can be simply paralleled with the old units.

(v) Non-availability of single large unit

In many situations, a single unit of desired large capacity may not be available. In that case a number of smaller units can be operated in parallel to meet the load requirement. Generally a single large unit is more expensive.

3.16 Connecting Shunt Generators in Parallel

The generators in a power plant are connected in parallel through bus-bars. The bus-bars are heavy thick copper bars and they act as +ve and ve terminals. The positive terminals of the generators are .connected to the +ve side of bus-bars and negative terminals to the negative side of bus-bars.

Fig. (3.15) shows shunt generator 1 connected to the bus-bars and supplying load. When the load on the power plant increases beyond the capacity of this generator, the second shunt generator 2 is connected in parallel wish the first to meet the increased load demand. The procedure for paralleling generator 2 with generator 1 is as under:

(i) The prime mover of generator 2 is brought up to the rated speed. Now switch S_4 in the field circuit of the generator 2 is closed.

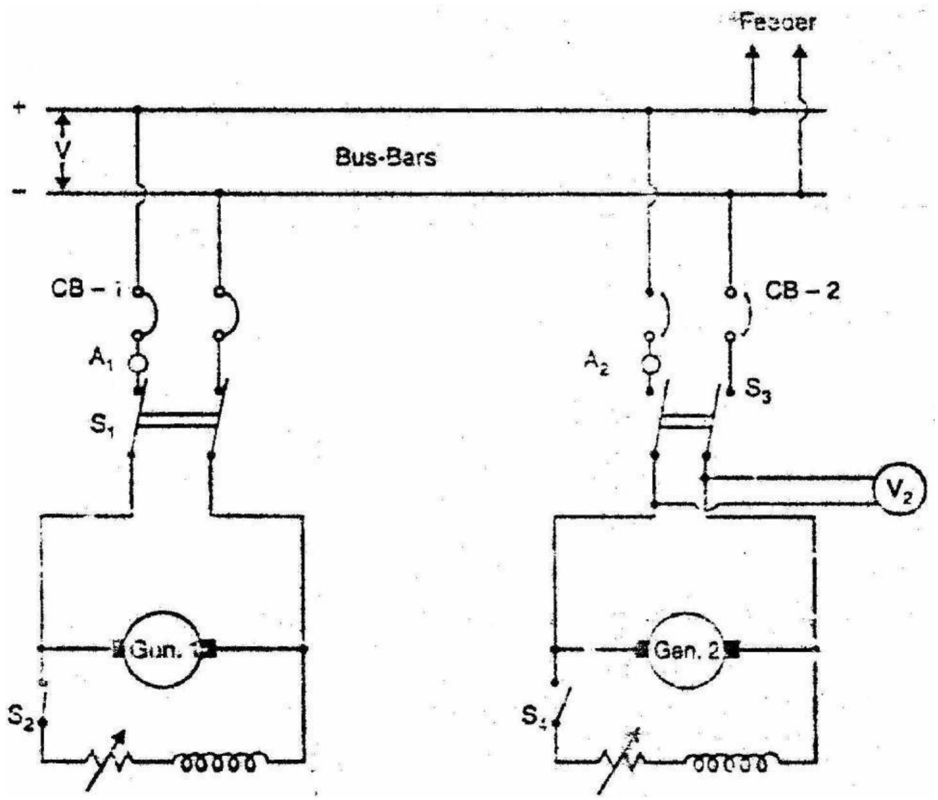


Fig. (3.15)

(ii) Next circuit breaker CB-2 is closed and the excitation of generator 2 is adjusted till it generates voltage equal to the bus-bars voltage. This is indicated by voltmeter V_2.

(v) Now the generator 2 is ready to be paralleled with generator 1. The main switch S_3, is closed, thus putting generator 2 in parallel with generator 1. Note that generator 2 is not supplying any load because its generated e.m.f. is equal to bus-bars voltage. The generator is said to be “floating” (i.e., not supplying any load) on the bus-bars.

(iv) If generator 2 is to deliver any current, then its generated voltage E should be greater than the bus-bars voltage V. In that case, current supplied by it is I = (E − V)/R_a where R_a is the resistance of the armature circuit. By increasing the field current (and hence induced e.m.f. E), the generator 2 can be made to supply proper amount of load.

(v) The load may be shifted from one shunt generator to another merely by adjusting the field excitation. Thus if generator 1 is to be shut down, the whole load can be shifted onto generator 2 provided it has the capacity to supply that load. In that case, reduce the current supplied by generator 1 to zero (This will be indicated by ammeter A_1) open C.B.-1 and then open the main switch S_1.

3.17 Load Sharing

The load sharing between shunt generators in parallel can be easily regulated because of their drooping characteristics. The load may be shifted from one generator to another merely by adjusting the field excitation. Let us discuss the load sharing of two generators which have unequal no-load voltages.

Let E_1, E_2 = no-load voltages of the two generators R_1, R_2 = their armature resistances

V = common terminal voltage (Bus-bars voltage)

Then $$I_1 = \frac{E_1 - V}{R_1} \quad \text{and} \quad I_2 = \frac{E_2 - V}{R_2}$$

Thus current output of the generators depends upon the values of E_1 and E_3. These values may be changed by field rheostats. The common terminal voltage (or bus-bars voltage) will depend upon (i) the e.m.f.s of individual generators and (ii) the total load current supplied. It is generally desired to keep the bus-bars voltage constant. This can be achieved by adjusting the field excitations of the generators operating in parallel.

3.18 Compound Generators in Parallel

Under-compounded generators also operate satisfactorily in parallel but over-compounded generators will not operate satisfactorily unless their series fields are paralleled. This is achieved by connecting two negative brushes together as shown in Fig. (3.16) (i). The conductor used to connect these brushes is generally called equalizer bar. Suppose that an attempt is made to operate the two generators in Fig. (3.16) (ii) in parallel without an equalizer bar. If, for any reason, the current supplied by generator 1 increases slightly, the current in its series field will increase and raise the generated voltage. This will cause generator 1 to take more load. Since total load supplied to the system is constant, the current in generator 2 must decrease and as a result its series field is weakened. Since this effect is cumulative, the generator 1 will take the entire load and drive generator 2 as a motor. Under such conditions, the current in the two machines will be in the direction shown in Fig. (3.16) (ii). After machine 2 changes from a generator to a motor, the current in the shunt field will remain in the same direction, but the current in the armature and series field will reverse. Thus the magnetizing action, of the series field opposes that of the shunt field. As the current taken by the machine 2 increases, the demagnetizing action of series field becomes greater and the resultant field becomes weaker. The resultant field will finally become zero and at that time machine 2 will short-circuit machine 1, opening the breaker of either or both machines.

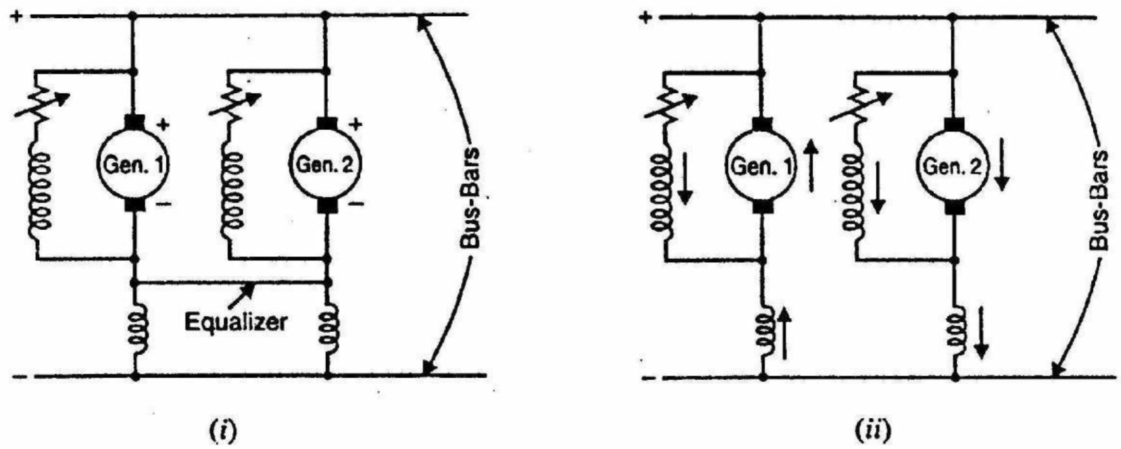


Fig. (3.16)

When the equalizer bar is used, a stabilizing action exist? and neither machine tends to take all the load. To consider this, suppose that current delivered by generator 1 increases [See Fig. 3.16 (i)]. The increased current will not only pass through the series field of generator 1 but also through the equalizer bar and series field of generator 2. Therefore, the voltage of both the machines increases and the generator 2 will take a part of the load.

DC MOTOR

A dc motor is similar in construction to a dc generator. As a matter of fact a dc generator will run as a motor when its field & armature windings are connected to a source of direct current.

The basic construction is same whether it is generator or a motor.

Working principle:

The principle of operation of a dc motor can be stated as when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force. In a practical dc motor, the field winding produces the required magnetic held while armature conductor play the role of current carrying conductor and hence the armature conductors experience a force.

As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductive acts as a twisting or turning force on the armature which is called a torque.

The torque is the product of force and the radius at which this force acts, so overall armature experiences a torque and starts rotating.

Consider a single conductor placed in a magnetic field , the magnetic field is produced by a permanent magnet but in practical dc motor it is produced by the field winding when it carries a current.

Now this conductor is excited by a separate supply so that it carries a current in a particular direction. Consider that it carries a current away from an current. Any current carrying conductor produces its own magnetic field around it, hence this conductor also produces its own flux, around. The direction of this flux can be determined by right hand thumb rule. For direction of current considered the direction of flux around a conductor is clock-wise. Now, there are two fluxes present

5. Flux produced by permanent magnet called main flux
6. Flux produced by the current carrying conductor

From the figure shown below, it is clear that on one side of the conductor, both the fluxes are in the same direction in this case, on the left of the conductor there gathering of the flux lines as two fluxes help each other. A to against this, on the right of the conductor, the two fluxes are in opposite direction and hence try to cancel each other. Due to this, the density of the flux lines in this area gets weakened.

So on the left, there exists high flux density area while on the right of the conductor then exists low flux density area as shown.

The flux distribution around the conductor arts like a stretched ribbed bond under tension. The exerts a mechanical force on the conductor which acts from high flux density area towards low flux density area, i.e. from left to right from the case considered as shown above.

In the practical dc motor, the permanent magnet is replaced by the field winding which produces the required flux winding which produces the required flux called main flux and all the armature conductors, would on the periphery of the armature gram, get subjected tot he mechanical force.

Due to this, overall armature experiences a twisting force called torque and armature of the motor status rotating.

Direction of rotation of motor

The magnitude of the force experienced by the conductor in a motor is given by F = BIL newtons.

The direction of the main field can be revoked y changing the direction of current passing through the field winding, which is possible by interchanging the polarities of supply which is given to the field winding.

The direction of current through armature can be reversed by changing supply polarities of dc supplying current to the armature.

It directions of bot the currents are changed then the direction of rotation of the motor remains undamaged.

In a dc motor both the field and armature is connected to a source of direct current. The current through the armature winding establish its own magnetic flux the interaction both the main field and the armature current produces the torque, there by sensing the motor to rotate, once the motor starts rotating, already existing magnetic flux there wire be an induced emf in the armature conductors due to generator action. This emf acts in a direction apposite to supplied voltage. Therefore it is called Black emf.

Significance of Back emf

In the generating action, when a conductor cuts the lines of flux, emf gets induced in the conductor in a motor, after a motoring action, armature starts rotating and armature conductors cut the main flux. After a motoring action, there exists a generating action there is induced emf in the rotating armature conductors according to Faraday's law of electromagnetic induction. This induced emf in the armature always acts in the opposite direction of the supply voltage. This is according tot he lenz's law which states that the direction of the induced emf is always so as to oppose the case producing it.

In a dc motor, electrical input i.e., the supply voltage is the cause and hence this induced emf opposes the supply voltage.

The emf tries to set u a current throughout he armature which is in the opposite direction to that which supply voltage is forcing through the conductor so, as this emf always opposes the supply voltage, it is called back emf and devoted as Eb.

Through it is denoted as Eb, basically it gets generated by the generating action which we have seen earlier So, $E^b \quad \frac{ZNP}{60\,A}$

Voltage equation of a Motor

The voltage v applied across the motor armature has to (1) over core the back emf Eb and

3. supply the armature ohmic drop Ia Ra

$$v = Eb + Ia\,R_a$$

This is known as voltage equation of a motor

Multiplying both sides by Ia, we get

$Vi_a = E_b\,I_a + E_a^2\,R_a$

VI_a = electrical input to the armature

E_bI_a = electrical equivalent of mechanical Power developed in the armature

$I_a^2 R_a$ = un loss in the armature

Hence, out of the armature input, some in wasted in I2 R loss and the rot is convened into mechanical power within the armature.
Motor efficiency is given by the ratio of power developed by the armature to its input i.e. $E_b I_a / vI_a = E_b/v$.

Higher the value of E_b as compared to v, higher the motor efficiency.

Conduction for maximum powers

The gross mechanical developed by a motor = $p_m = vI_a – I_a^2 R_a$

$$\frac{dP_m}{dI_a} \quad v \square 2I_a R_a \qquad I_a R_a = v/2$$

As $v = E_b + I_a R_a$ and $I_a R_a = v/2$ $E_b = v/2$

Thus gross mechanical power developed by a motor is maximum when back emf is equal to half the applied voltage. This conduction's how ever at realized in practice, because in that case current will be much beyond the normal current of the motor.

More ova, half the input would be wasted in the form of heat and taking other losses into consideration the motor efficiency will be well below 50 %.

1. A 220v – dc machine has an armature resistance of 0.5 □. If the full road armature current is 20A, find the induced emf when the machine acts (1) generator (2) motor.

The dc motor is assumed to be shunt connected in cash case, short current in considered negligible because its value is not given.

(a) As generator $E_g = v + I_a R_a = 220 + 0.5 \times 20 = 230$ v

(b) As motor $E_b = v – I_a R_a = 220 – 0.5 \times 20 = 210$ v

8) A 440 v, shunt motor has armature resistance of 0.8 a and field resistance of 200 □. Determine the back emf when giving an output at 7.46 kw at 85% efficiency.

Motor input power = $\frac{7.46 \times 103}{}$ w 0.85

Motor input current = $\frac{7460}{0.85 \times 440}$ □ 19.95 A

3. A 25kw, 250 w dc such generator has armature and field resistance of 0.06 □ and 100 □ respectively. Determine the total armature power developed when working (1) as generator delivering 25 kw output and (2) as a motor taking 25 kw input.

Voltage equation of dc motor

For a generator, generated emf has to supply armature resistance drop and remaining part is available across the loss as a terminal voltage. But in case of dc motor, supply voltage v has to over come back emf Eb which is opposing v and also various drops are armature resistance drop Ia Ra, brush drop etc. In fact the electrical work done in overcoming the back emf gets converted into the mechanical energy, developed in the armature.

Hence, the voltage equation of a dc motor is
$V = E_b + I_a R_a$ + brush drops
Or $v = E_b + I_a R_a$ neglecting brush drops

The back emf is always less than supply voltage ($E_b < v$) but R_a is very small hence under normal running conditions, the different between back emf and supply voltage is very small. The net voltage across the armature is the difference between the supply voltage and back emf which decals the armature current. Hence from the voltage equation we can write $I_a = v – E_b / R_a$.

3. A 220 v dc motor has an armature resistance of 0.75□ it is drawing on armature current of 30 A, during a certain load, calculate the induced emf in the motor under this condition.

$V = 200$ v, $I_a = 30$A, $R_a = 0.75$□
For a motor , $v = E_b + I_a R_a$
Eb = 197.5 v
This is the induced mef called back emf in a motor.

5. A 4-pole dc motor has lap connected armature winding. The number of armature conductors is 250. When connected to 230 v dc supply it draws an armature current It 4 cm calculate the back emf and the speed with which motor is running. Assume armature is 0.6□

P = 4 A = P = 4 as lap connected

□ = 30 m wb = 30 Ho^{-3} V = 230v, z = 250   Ia = 40 A

From voltage equation $V = E_b + I_a R_a$

230 = Eb + 40 x 0.6

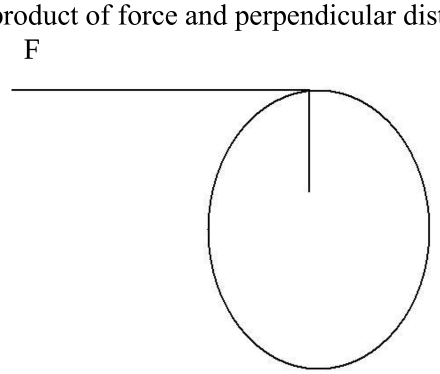
Eb = □ Pnz / 60A

$206 = (30 \times 10^{-3} \times 4 \times N \times 250) / (60 \times 4)$

N = 1648 rpm.

Torque: The turning or twisting movement of a body is called Torque. (Or)

It is defined as the product of force and perpendicular distance Ť=F*R



In case of DC motor torque is produced by the armature and shaft called as armature torque (T_a) and shaft torque(T_{sh}).

Let, N be the speed of the armature in

RPM R be the radius of the armature

Power=Work Done/Time

Work Done=Force X Distance

The distance travelled in rotating the armature for one time =2∏R

If N rotations are made in 60 sec

Then time taken for one rotation is=60/N

So, Power= (F * 2∏R)/ (60/N)

= (F*R)(2∏N)/60

P = Ťω

Here P=$E_b I_a$

But

E_b=ØZNP/60A

(ØZNP/60A)I_a=

Ťω

=

Ťa(2∏N)/60

Ťa=0.159ØZ

I_aP/A

Similarly, Shaft torque T_{sh}=output/ω

T_{sh} =output/((2∏N)/60)

T_{sh} =9.55(output)/N

TESTING OF DC MACHINES

5.1 Introduction

In the previous sections we have learnt about the principle of operation of d.c. generators and motors, (starting and speed control of d.c motor). Motors convert *electrical* power (input power) into *mechanical* power (output power) while generators convert *mechanical* power (input power) into *electrical* power (output power). Whole of the input power can not be converted into the output power in a practical machine due to various losses that take place within the machine. Efficiency η being the ratio of output power to input power, is always less than 1 (or 100 %). Designer of course will try to make η as large as possible. Order of efficiency of rotating d.c machine is about 80 % to 85 %. It is therefore important to identify the losses which make efficiency poor.

In this lesson we shall first identify the losses and then try to estimate them to get an idea of efficiency of a given d.c machine.

5.2 Major losses

Take the case of a loaded d.c motor. There will be copper losses ($I_a^2 r_a$ and $I^2_f R_f = VI_f$) in armature and field circuit. The armature copper loss is variable and depends upon degree of loading of the machine. For a shunt machine, the field copper loss will be constant if field resistance is not varied. Recall that rotor body is made of iron with slots in which armature conductors are placed. Therefore when armature rotates in presence of field produced by stator field coil, eddy current and hysteresis losses are bound to occur on the rotor body made of iron. The sum of eddy current and hysteresis losses is called the *core* loss or *iron* loss. To reduce *core* loss, circular varnished and slotted laminations or *stamping* are used to fabricate the armature. The value of the core loss will depend on the strength of the field and the armature speed. Apart from these there will be power loss due to *friction* occurring at the bearing & shaft and air friction (windage loss) due to rotation of the armature. To summarise following major losses occur in a d.c machine.

7. Field copper loss: It is power loss in the field circuit and equal to $I_f^2 R_f = VI_f$. During the course of loading if field circuit resistance is not varied, field copper loss remains constant.
8. Armature copper loss: It is power loss in the armature circuit and equal to $I_a^2 R_a$. Since the value of armature current is decided by the load, armature copper loss becomes a function of time.
9. Core loss: It is the sum of eddy current and hysteresis loss and occurs mainly in the rotor iron parts of armature. With constant field current and if speed does not vary much with loading, core loss may be assumed to be constant.
10. Mechanical loss: It is the sum of bearing friction loss and the windage loss (friction loss due to armature rotation in air). For practically constant speed operation, this loss too, may be assumed to be constant.

Apart from the major losses as enumerated above there may be a small amount loss called *stray* loss occur in a machine. Stray losses are difficult to account. Power flow diagram of a d.c motor is shown in figure 40.1. A portion of the input power is consumed by the field circuit as field copper loss. The remaining power is the power which goes to the armature; a portion of which is lost as core loss in the armature core and armature copper loss. Remaining power is the gross mechanical power developed of which a portion will be lost as friction and remaining power will
be the net mechanical power developed. Obviously efficiency of the motor will be given by:

$$\eta = \frac{P_{net\ mech}}{P_{in}}$$

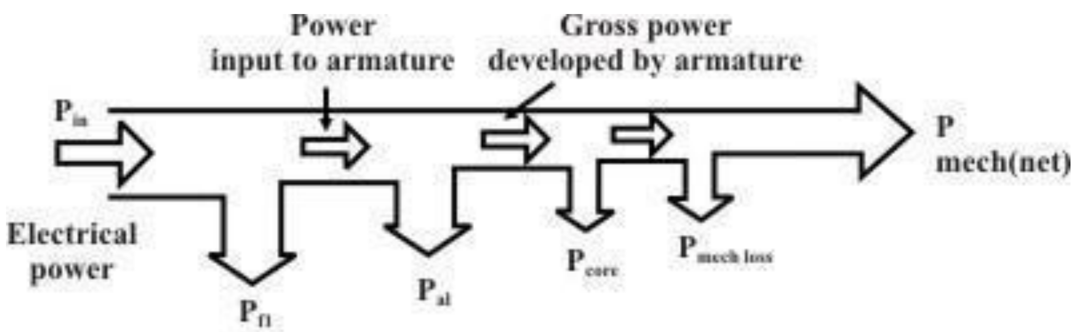


Fig. 40.1: Power flow diagram of a D.C. motor

Similar power flow diagram of a d.c generator can be drawn to show various losses and input, output power (figure 40.2).

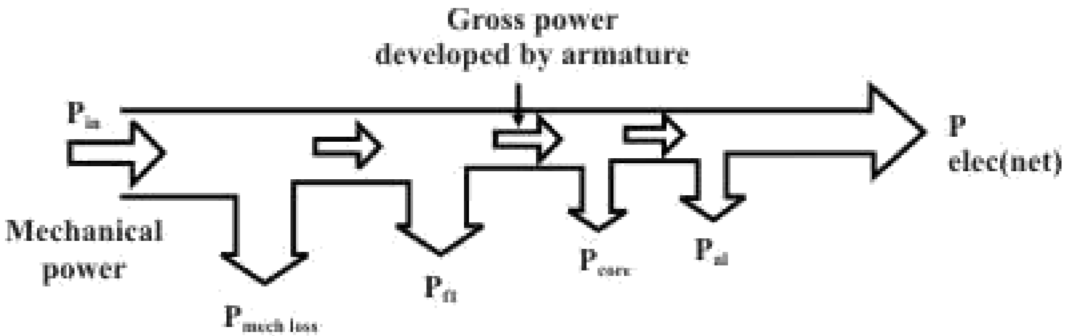


Fig. 40.2: Power flow diagram of a D.C. generator

It is important to note that the name plate kW (or hp) rating of a d.c machine always corresponds to the net **output** at rated condition for both generator and motor.

5.3 Swinburne's Test

For a d.c shunt motor change of speed from no load to full load is quite small. Therefore, mechanical loss can be assumed to remain same from no load to full load. Also if field current is held constant during loading, the core loss too can be assumed to remain same.

In this test, the motor is run at rated speed under *no load* condition at rated voltage. The current drawn from the supply I_{L0} and the field current I_f are recorded (figure 40.3). Now we note that:

Input power to the motor, $P_{in} = VI_{L0}$

Cu loss in the field circuit $P_{fl} = VI_f$

Power input to the armature, $= VI_{L0} - VI_f = V(I_{L0} - I_f) = VI_{a0}$

Cu loss in the armature circuit $= I_{a0}^2 r_a$

Gross power developed by armature $= VI_{a0} - I_{a0}^2 r_a = (V - I_{a0} r_a) I_{a0} = E_{b0} I_{a0}$

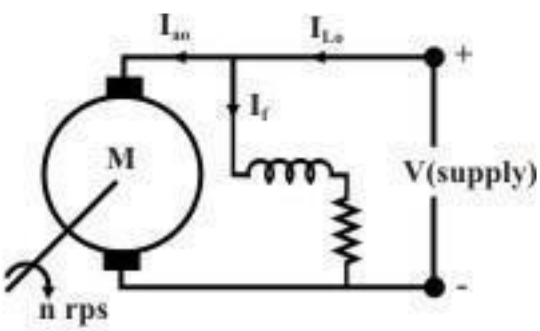


Fig. 40.3: Motor under no load

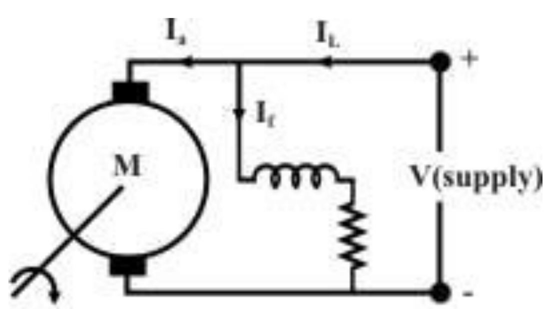


Fig. 40.4: Motor Loaded

Since the motor is operating under no load condition, net mechanical output power is zero. Hence the gross power developed by the armature must supply the core loss and friction & windage losses of the motor. Therefore,

$$P_{core} + P_{friction} = (V - I_{a0} r_a) I_{a0} = E_{b0} I_{a0}$$

Since, both P_{core} and $P_{friction}$ for a shunt motor remains practically constant from no load to full load, the sum of these losses is called constant rotational loss i.e.,

constant rotational loss, $P_{rot} = P_{core} + P_{friction}$

In the Swinburne's test, the constant rotational loss comprising of core and friction loss is estimated from the above equation.

After knowing the value of P_{rot} from the Swinburne's test, we can fairly estimate the efficiency of the motor at any loading condition. Let the motor be loaded such that new current drawn from the supply is I_L and the new armature current is I_a as shown in figure 40.4. To estimate the efficiency of the loaded motor we proceed as follows:

Input power to the motor, $P_{in} = VI_L$

Cu loss in the field circuit $P_{fl} = VI_f$

Power input to the armature, $= VI_L - VI_f$

$= V(I_L - I_f)$

$= VI_a$

Cu loss in the armature circuit $= I_a^2 r_a$

Gross power developed by armature $= VI_a - I_a^2 r_a$

$= (V - I_a r_a) I_a$

$= E_b I_a$

Net mechanical output power, $P_{net\,mech} = E_b I_a - P_{rot}$

$\therefore$ efficiency of the loaded motor, $\eta = \dfrac{E_b I_a - P_{rot}}{VI_L}$

$= \dfrac{P_{net\,mech}}{P_{in}}$

The estimated value of P_{rot} obtained from Swinburne's test can also be used to estimate the efficiency of the shunt machine operating as a generator. In figure 40.5 is shown to deliver a load current I_L to a load resistor R_L. In this case output power being known, it is easier to add the losses to estimate the input mechanical power.

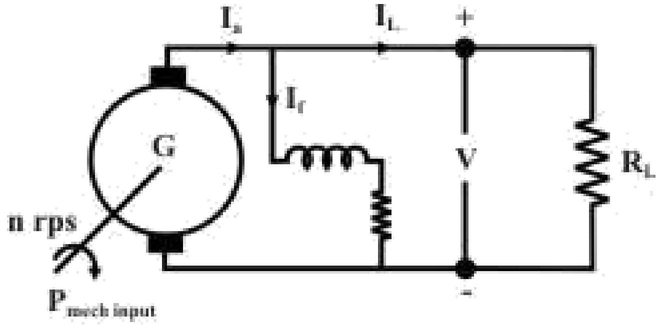


Fig. 40.5: Loaded d.c. generator

Output power of the generator, $P_{out} = VI_L$

Cu loss in the field circuit $P_{fl} = VI_f$

Output power of the armature, $= VI_L + VI_f = VI_a$

Mechanical input power, $P_{in\ mech} = VI_a + I_a^2 r_a + P_{rot}$

∴ Efficiency of the generator, $\eta = \frac{VI_L}{P_{in\ mech}}$

$$= \frac{VI_L}{VI_a + I_a^2 r_a + P_{rot}}$$

The biggest advantage of Swinburne's test is that the shunt machine is to be run as motor under *no load* condition requiring little power to be drawn from the supply; based on the no load reading, efficiency can be predicted for any load current. However, this test is not sufficient if we want to know more about its performance (effect of armature reaction, temperature rise, commutation etc.) when it is actually loaded. Obviously the solution is to load the machine by connecting mechanical load directly on the shaft for motor or by connecting loading rheostat across the terminals for generator operation. This although sounds simple but difficult to implement in the laboratory for high rating machines (say above 20 kW), Thus the laboratory must have proper supply to deliver such a large power corresponding to the rating of the machine. Secondly, one should have loads to absorb this power.

5.4 *Hopkinson’s test*

This as an elegant method of testing d.c machines. Here it will be shown that while power drawn from the supply only corresponds to no load losses of the machines, the armature physically carries any amount of current (which can be controlled with ease). Such a scenario can be created using two similar mechanically coupled shunt machines. Electrically these two machines are eventually connected in parallel and controlled in such a way that one machine acts as a generator and the other as motor. In other words two similar machines are required to carry out this testing which is not a bad proposition for manufacturer as large numbers of similar machines are manufactured.

Procedure

Connect the two similar (same rating) coupled machines as shown in figure 40.6. With switch S opened, the first machine is run as a shunt motor at rated speed. It may be noted that the second machine is operating as a separately excited generator because its field winding is excited and it is driven by the first machine. Now the question is what will be the reading of the voltmeter connected across the opened switch S? The reading may be (i) either close to twice supply voltage or (ii) small voltage. In fact the voltmeter practically reads the difference of the induced voltages in the armature of the machines. The upper armature terminal of the generator may have either + ve or negative polarity. If it happens to be +ve, then voltmeter reading will be small otherwise it will be almost double the supply voltage.

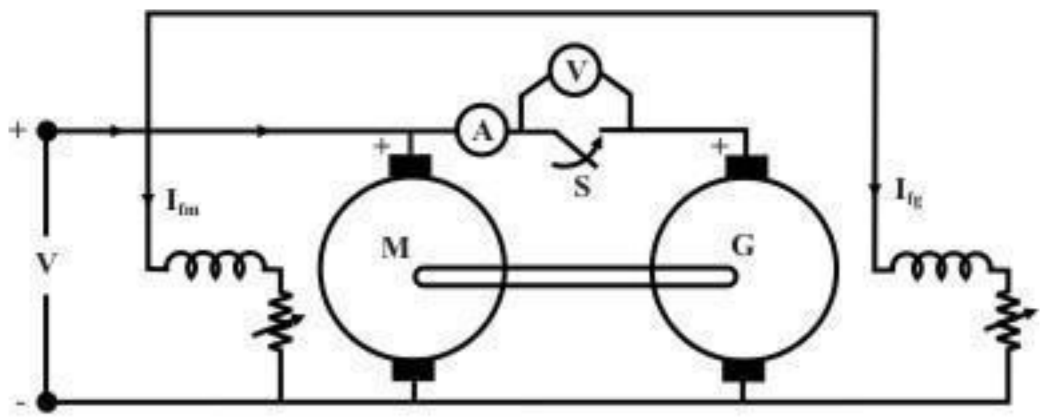


Fig. 40.6: Hopkinson's test: machines before paralleling

Since the goal is to connect the two machines in parallel, we must first ensure voltmeter reading is small. In case we find voltmeter reading is high, we should switch off the supply, reverse the armature connection of the generator and start afresh. Now voltmeter is found to read small although time is still not ripe enough to close S for paralleling the machines. Any attempt to close the switch may result into large circulating current as the armature resistances are small.
Now by adjusting the field current I_{fg} of the generator the voltmeter reading may be adjusted to zero ($E_g \approx E_b$) and S is now closed. Both the machines are now connected in parallel as shown in figure 40.7.

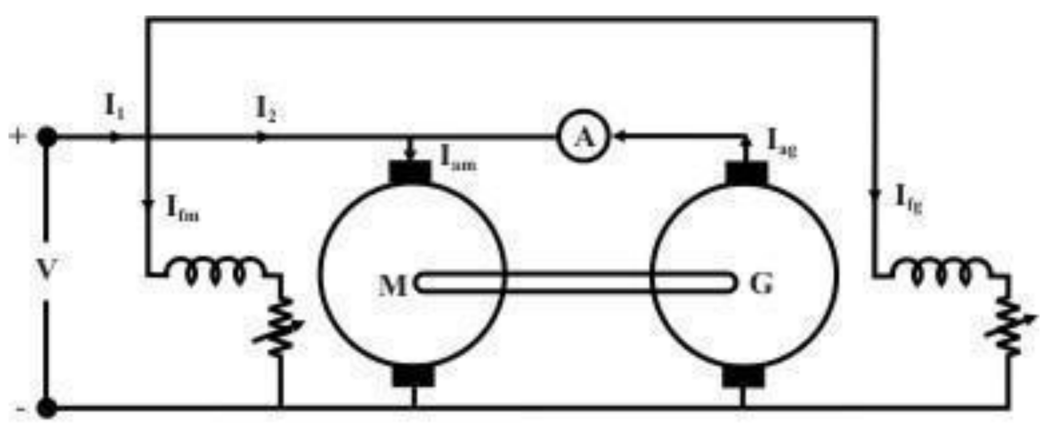


Fig. 40.7: Hopkinson's test: machines paralled

Loading the machines

After the machines are successfully connected in parallel, we go for loading the machines i.e., increasing the armature currents. Just after paralleling the ammeter reading A will be close to zero as $E_g \approx E_b$. Now if I_{fg} is increased (by decreasing R_{fg}), then E_g becomes greater than E_b and both I_{ag} and I_{am} increase, Thus by increasing field current of generator (alternatively decreasing field current of motor) one can make $E_g > E_b$ so as to make the second machine act as generator and first machine as motor. In practice, it is also required to control the field current of the motor I_{fm} to maintain speed constant at rated value. The interesting point to be noted here is that I_{ag} and I_{am} do not reflect in the supply side line. Thus current drawn from supply remains small (corresponding to losses of both the machines). The loading is sustained by the output power of the generator running the motor and vice versa. The machines can be loaded to full load current without the need of any loading arrangement.

Calculation of efficiency

Let field currents of the machines be are so adjusted that the second machine is acting as generator with armature current I_{ag} and the first machine is acting as motor with armature current I_{am} as shown in figure 40.7. Also let us assume the current drawn from the supply be I_1.
Total power drawn from supply is VI_1 which goes to supply all the losses (namely Cu losses in armature & field and rotational losses) of both the machines,
Now:

$$\text{Power drawn from supply} = VI_1$$

$$\text{Field Cu loss for motor} = VI_{fm}$$

$$\text{Field Cu loss for generator} = VI_{fg}$$

$$\text{Armature Cu loss for motor} = I_{am}^2 r_{am}$$

$$\text{Armature Cu loss for generator} = I_{ag}^2 r_{ag}$$

$$\therefore \text{Rotational losses of both the machines} = VI_1 - (VI_{fm} + VI_{fg} + I_{am}^2 r_{am} + I_{ag}^2 r_{ag}) \quad (40.1)$$

Since speed of both the machines are same, it is reasonable to assume the rotational losses of both the machines are equal; which is strictly not correct as the field current of the generator will be a bit more than the field current of the motor, Thus,

$$\text{Rotational loss of each machine, } P_{rot} = \frac{VI_1 - (VI_{fm} + VI_{fg} + I_{am}^2 r_{am} + I_{ag}^2 r_{ag})}{2}$$

Once P_{rot} is estimated for each machine we can proceed to calculate the efficiency of the machines as follows,

Efficiency of the motor

As pointed out earlier, for efficiency calculation of motor, first calculate the input power and then subtract the losses to get the output mechanical power as shown below, Total power input to the motor = power input to its field + power input to its armature

$$P_{inm} = VI_{fm} + VI_{am}$$

$$\text{Losses of the motor} = VI_{fm} + I_{am}^2 r_{am} + P_{rot}$$

$$\text{Net mechanical output power } P_{outm} = P_{inm} - (VI_{fm} + I_{am}^2 r_{am} + P_{rot})$$

$$\therefore \eta_m = \frac{P_{outm}}{P_{inm}}$$

Efficiency of the generator

For generator start with output power of the generator and then add the losses to get the input mechanical power and hence efficiency as shown below,

$$\text{Output power of the generator, } P_{outg} = VI_{ag}$$

$$\text{Losses of the generator} = VI_{fg} + I_{ag}^2 r_{ag} + P_{rot}$$

$$\text{Input power to the generator, } P_{ing} = P_{outg} + (VI_{fg} + I_{ag}^2 r_{ag} + P_{rot})$$

$$\therefore \eta_g = \frac{P_{outg}}{P_{ing}}$$

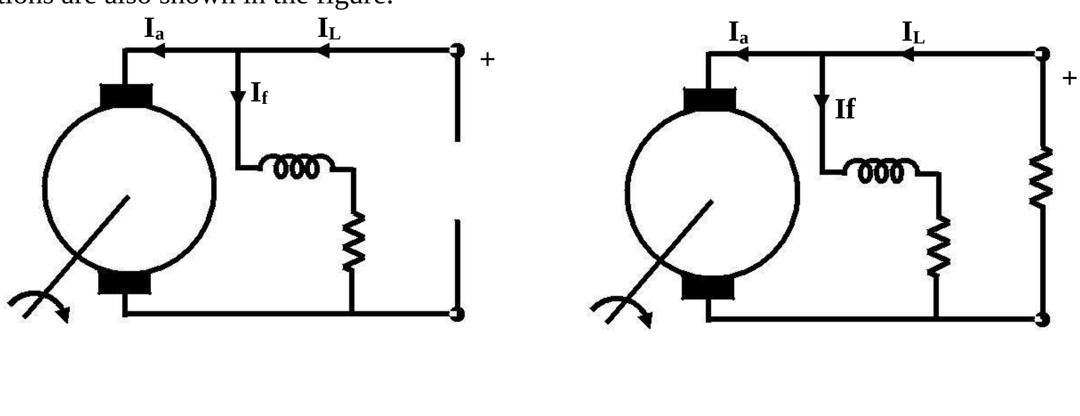
5.5 Condition for maximum efficiency

We have seen that in a transformer, maximum efficiency occurs when copper loss = core loss, where, copper loss is the variable loss and is a function of loading while the core loss is practically constant independent of degree of loading. This condition can be stated in a different way: maximum efficiency occurs when the variable loss is equal to the constant loss of the transformer.

Here we shall see that similar condition also exists for obtaining maximum efficiency in a d.c shunt machine as well.

Maximum efficiency for motor mode

Let us consider a loaded shunt motor as shown in figure 40.8. The various currents along with their directions are also shown in the figure.



We assume that field current I_f remains constant during change of loading. Let,

P_{rot} = constant rotational loss

$V I_f$ = constant field copper loss

Constant loss $P_{const} = P_{rot} + V I_f$

Now, input power drawn from supply = $V I_L$

Power loss in the armature, = $I_a^2 r_a$

$$\text{Net mechanical output power} = VI_L - I_a^2 r_a - (VI_f + P_{rot})$$

$$= VI_L - I_a^2 r_a - P_{const}$$

$$\text{so, efficiency at this load current } \eta_m = \frac{VI_L - I_a^2 r_a - P_{const}}{VI_L}$$

Now the armature copper loss $I_a^2 r_a$ can be approximated to $I_L^2 r_a$ as $I_a \approx I_L$. This is because the order of field current may be 3 to 5% of the rated current. Except for very lightly loaded motor, this assumption is reasonably fair. Therefore replacing I_a by I_f in the above expression for efficiency η_m, we get,

$$\eta_m = \frac{VI_L - I_L^2 r_a - P_{const}}{VI_L}$$

$$= 1 - \frac{I_L r_a}{V} - \frac{P_{const}}{VI_L}$$

$$\frac{d\eta_m}{dI_L} = 0$$

$$\text{or, } \frac{d}{dI_L}\left(\frac{I_L r_a}{V} - \frac{P_{const}}{VI_L}\right) = 0$$

$$\text{or, } -\frac{r_a}{V} + \frac{P_{const}}{VI_L^2}$$

$\therefore$Condition for maximum efficiency is $I_L^2 r_a \approx I_a^2 r$

Pconst

L
a *a* *a*

=*P* *r*
cons
t *a*

So, the armature current at which efficiency becomes maximum is I_a

Thus, we get a simplified expression for motor efficiency η_m in terms of the variable current (which depends on degree of loading) I_L, current drawn from the supply. So to find out the condition for maximum efficiency, we have to differentiate η_m with respect to I_L and set it to zero as shown below.

Maximum efficiency for Generation mode

Similar derivation is given below for finding the condition for maximum efficiency in generator mode by referring to figure 40.9.

We assume that field current I_f remains constant during change of loading. Let,

$$\frac{d\eta_g}{dI_L} = 0$$

or, $$\frac{d}{dI_L}\left(\frac{VI_L}{VI_L + I_L^2 r_a + P_{const}}\right) = 0$$

$\therefore$Simplifying we get the condition as $I_L^2 r_a \approx I_a^2 r_a = P_{const}$

So, the armature current at which efficiency becomes maximum is $I_a = \sqrt{P_{const}/r_a}$

$P_{rot} =$ constant rotational loss

$V I_f =$ constant field copper loss

Constant loss $P_{const} = P_{rot} + V I_f$

Net output power to load $= V I_L$

Power loss in the armature, $= I_a^2 r_a$

Mechanical input power $= VI_L + I_a^2 r_a + (VI_f + P_{rot})$

$= VI_L + I_a^2 r_a + P_{const}$

so, efficiency at this load current $\eta_g = \dfrac{VI_L}{VI_L + I_a^2 r_a + P_{const}}$

As we did in case of motor, the armature copper loss $I_a^2 r_a$ can be approximated to $I_L^2 r_a$ as $I_a \approx I_L$. So expression for η_g becomes,

$$\eta_g = \frac{VI_L}{VI_L + I_L^2 r_a + P_{const}}$$

Thus, we get a simplified expression for motor efficiency η_g in terms of the variable current (which depends on degree of loading) I_L, current delivered to the load. So to find out the condition for maximum efficiency, we have to differentiate η_g with respect to I_L and set it to zero as shown below.

Thus maximum efficiency both for motoring and generating are same in case of shunt machines. To state we can say at that armature current maximum efficiency will occur which will make variable loss = constant loss. Eventually this leads to the expression for armature current for maximum efficiency as $I_a = \sqrt{P_{const}/r_a}$.

ENERGY CONVERSION -1 SHORT QUESTIONS

DC MACHINE

1.Where is field winding mounted in a DC machine?
The field winding (concentrated type) is mounted on salient-poles on the stator and the armature winding (distributed type) is wound in slots on a cylindrical rotor. In AC machines field winding is mounted on rotor.

2.What are the materials used for brushes in dc machines?
On some extent carbon brush can act as a self-lubricating brush. On moment, polishes the commutator segments. Damage to the commutators is less when copper brushes are used on occurrence of sparkover.

3.Function of yoke is to provide the return path for magnetic flux.
The function of yoke is that it protects the entire machine from dust and dirt. It also provides mechanical support for the magnetic poles. It acts as the return path for the magnetic flux.

4. The angle (electrical) made by brushes with axes of adjoining filed poles is ______________
Brushes in a DC machine are normally placed electrically in the interpolar regions and therefore make an angle of 90 degree electrical with the axes of adjoining filed poles.

5. In a DC machine, rectification process is carried out in order to get unidirectional output (DC). This rectification process is carried out by ______________
In a DC machine electronic rectification is not used. Instead they use mechanical rectification with the help of commutator-brush assembly.

6.Which of the following part is used in construction of DC machine but not in AC machine?
Commutator is used in mechanical rectification process, to convert induced AC to output DC. In AC machine, we don't need rectification process.

7. In a DC machine fractional pitch winding is used to _______________
Due to poor performance of brush, poor undercutting of commutator, incorrect spring pressure sparking at brush faces happen. To overcome this sparking fractional pitch winding is used.

8. In normal dc machines operating at full-load conditions, the most powerful electromagnet is _________

Electromagnet is more powerful when its MMF is high. At full-load condition, field winding contains maximum ampere turns, hence it is most powerful electromagnet in a DC machine.

9. If a DC motor is connected to AC supply what will happen then?
If a DC motor is connected to AC supply, an alternating current pass through the brushes and commutator to the armature winding, while it passes through the commutator it is converted into DC so that the group of conductors under successive field poles carry current in same direction. So, the flux per pole will remain constant and not vary. There will be production of heat due to flow of eddy current in field winding and the motor will be burned.

10. The armature of DC motor is laminated to ____________
The armature is built up in a cylindrical or drum shape high grade silicon steel in form of lamination. By using laminations, the circular path of eddy currents is terminated. Hence heating and ultimately damage to the armature can be reduced by lamination.

11. **Why are the DC motors preferred for traction applications?**
DC motors are used for traction as, according to the characteristics of DC motors speed is inversely proportional to torque and square of armature current as well, if linear magnetization is concerned. Thus, DC motors are perfectly suitable for traction.

12. **Which of the following load application normally needs starting torque more than the rated torque?**

Conveyors need high starting torque initially, and constant torque later. Thus, DC series motor is used in conveyors as it provides very high starting torque, which is practically 5 times the rated torque.

13. **Which of the following motors can be used to drive the rotary compressor?** Rotary compressor generally demand constant speed operation throughout the load. Sometimes, DC machines are not able to produce constant speed throughout the process hence, synchronous machine is used.

14. **Which DC motor is used with flywheel for intermittent light and heavy loads?** Cumulative compound DC motor is used with flywheel carrying peaks and so to smooth out the load on the motor as well as to reduce peaks on power system. Without flywheel the motor construction will be much larger.

15. **Separately excited DC generators are still used in ________________** Separately excited DC generators are still used in wide output voltage control like in Ward Leonard speed control. In all power plants today, generally AC generators are used due to low cost and less maintenance required.

16. **In world today, around 25% of the motors are manufactured are DC motors. (TRUE/FALSE**)

For a dc machine, of course, the main attraction lies in its flexibility, versatility and ease of control. This explains why in spite of its rather heavy initial investment it still retains its charm in strong competitive industrial applications.

17. **Maximum torque in a DC machine is limited by ______________** While for all other motors maximum torque is restricted to certain value as various losses in other motors lead to heating of the core materials. In DC machines for maximum torque commutation time will obviously decrease and beyond some point commutation process can't be fastened.

18. **Which of the following motor can replace DC series motor?** DE series motor's closest rival is the wound-rotor induction motor with a rotor resistance control. But ultimately the availability and economics of a dc power is the deciding factor rather than the motor characteristic.

19. **Which motor has almost replaced DC shunt motor from its applications?** Owing to the relative simplicity, cheapness and ruggedness of the squirrel cage induction motor, the shunt motor is less preferred for constant-speed drives except at low speeds. At high or medium speed applications we use induction motor, mostly squirrel caged.

20. **DC shunt motor is still used instead of synchronous motor in ____________** At low speeds, DC shunt motors are comparable with synchronous motors. The outstanding feature of a DC shunt motor however is its superb wide range flexible speed control above and below the base speed using solid-state controlled rectifiers.

21. **Which type motors are preferred for lathes?**
Lathes machines requires uniform torque which is provided with squirrel cage induction or DC shunt motors. Hence, they are preferred for lathes. DC shunt motor and induction motor of squirrel cage type follow same shunt characteristics.

22. **When an electric train is moving down a hill, the DC motor will operate as ____________**
Normally in electric traction purposes DC series motors are employed. At above condition the back emf is greater than supply voltage hence, it will operate as series generator which will provide energy back to the supply.

23.The armature in DC machines is always placed on rotor because _______
A DC machine is a heteropolar structure with stationary poles and the rotating armature. The armature winding of a DC machine is placed on the rotor to improve commutation i.e. to convert the alternating voltage produced in the winding into direct voltage at the brushes.

24. In a DC machine, rectification provided with commutator is ___________
In any electromagnetic machine the voltage generated is always alternating one as per Faraday's law. For a DC machine the output must be unidirectional. This is carried out by a commutator. Hence, commutator provides full wave rectification.

25. Commutator performs rectification so that output of the machine is bi-directional.(T/F)
Commutator and brush assembly of the DC machine performs the mechanical rectification process so induced AC is converted into DC (Unidirectional). Commutation process provides full wave rectification.

26. Which of the following method is used to connect commutator segments to armature conductors?
Commutator in connected to the armature using lugs. Generally, they are made with copper. They are tightly bolted to the armature in order to prevent the centrifugal forces from causing the segments to fly away.

27. In D.C. generators, rapid brush ware causes due to _________
Brushes are the parts in a DC machine which are always in contact with rotating and stationary parts. Thus, imperfect contact, rough surfaces, sparking all these may reduce the life of brushes.

28. What are the number of the brushes in the lap winding?
In a lap winding, the number of parallel paths, A, is always equal to the number of poles, P, and also to the number of brushes. In wave windings, the number of parallel paths, a, is always two (2), and there may be two or more brush positions.

29. **When Copper brushes are used in DC machine?**
Due to various limitations, copper brushes are used in low voltage applications. For various other voltage ratings, different carbon-graphite proportions are used in manufacturing of brush materials.

30. **In DC generators, current is fed up to the external circuit from armature through _______**
In any rotary machine current is induced in Sine wave format, according to Faraday's law. For DC machine commutator provides mechanical rectification so that output is in the unidirectional format.

31. **What are the number of the brushes in the wave winding?**
In wave windings, the number of parallel paths, A, is always two (2), and there may be two or more brush positions. When two adjacent commutator bars make contact with a particular brush, p/2 coils are shorted by the brush in the wave winding.

32. **Which conductors are in point of contact with brushes?**
Because of the diamond shape of coils, the brushes which are physically opposite the pole centres are electrically connected to coil-sides lying close to the interpolar region. Thus, electrically the brushes are displaced 90° elect. from the axes of the main poles

33. In case of DC machine winding, number of commutator segments is equal to ______
Armature current is induced in a DC machine, which is fed up to the external circuit. Thus, it needs to be unidirectional. So, for converting bidirectional current to unidirectional commutators which are equal in number of armature coils need to be used.

34. How total number of brushes in a commutator are determined in a given DC machine?
Brushes are in contact with rotating part and stationary part. Thus, if more amount of current is to be carried, it requires more number of brushes. Hence brush number depends directly on the amount of current that needs to be collected and fed up in or out.

35. In a DC generator the ripples in the direct emf generated can be reduced by________
Brushes carry current to/from rotating parts from/to stationary part. Ripples can be avoided if brushes are maintained. Else, brushes will have some voltage drop in it and we'll not get simple repeating part in emf.

36 The drop in the voltage for which of the following types of brush can be expected to be least?
Metal graphite brushes are ideal for a variety of applications because of their low resistivity. Thus, drop will be less in metal graphite brushes. Metal graphite brushes are used on commutators of plating generators where low voltage and high brush current densities are encountered.

37. What is the requirement of the good commutation?
Brushes are in contact with commutator. So, for good commutation brushes must be of superior quality so that brushes will give/receive appropriate current to and from commutator. Also, the contact between brushes and commutator must be smooth for proper commutation process.

38. How to avoid grooves in the commutation of DC machine with the help of brush?
Brushes are located such that they are displaced 900 electrically from the axes of main poles. The two positive and two negative brushes are respectively connected in parallel for feeding the external circuit.

39. Reason behind the rapid wear of brushes is ___________
Brushes undergo various forces due to their location in a DC machine, they are in contact with rotating and stationary part of the machine. Hence, rough contact between commutator and brushes, inappropriate pressure on brush to rotating part may affect quality of commutation process.

40. Spacing between the brushes for a 4-pole machine in terms of commutator segments for 12 conductor segments is _____
The spacing between adjacent brushes in terms of the commutator segment is ratio of number of commutator segments with poles for a given DC machine. C/P=12/4=3 .It may also be noted that C/P need not necessarily be an integer.

41 **Spacing between the brushes for a 4-pole machine in terms of commutator segments is equal to six. What will be the number of armature slots?**
The spacing between adjacent brushes in terms of the commutator segment which is also equal to armature slots is ratio of number of commutator segments with poles for a given DC machine. C= P*Spacing= 4*6= 24.

42 **What is the range of the brush friction coefficients for medium category?**
Brush friction is influenced by many variables including brush temperature, spring force, current, atmospheric conditions, mechanical conditions, ring or commutator materials, surface films, speed and other factors. Brush friction is of medium category when, coefficient of friction lies in between 0.22 to 0.44.

43 **Specific resistance for a brush is given by __________**
Specific resistance is measured in the length direction of the brush, since resistance in the direction of width or thickness may be considerably different. For, E = voltage drop over length L, I = amps of current passed through the sample, W = width of sample, T = thickness on sample, L = that portion of the length, over which the voltage drop E is measured, R is calculated by R = (E * W * T) / (I * L).

44.Resultant pitch in the lap winding is___________
In a lap winding the "finish" of one coil is connected to "start" of the adjoining coil. The coil side displacement of the front-end connection is called the front-pitch. The coil side displacement of the back-end connection is called the back-pitch. Resultant-pitch is equal to difference between Y_b and Y_f which is equal to 2, irrespective of Y_b and Y_f value.

45.What is the condition of retrogressive winding?
The coil side displacement of the front-end connection is called the front-pitch. The coil side displacement of the back-end connection is called the back-pitch. The direction in which the winding progresses depends upon which is more, Y_b or Y_f. For retrogressive winding $Y_b < Y_f$.

46.Equalizer rings are needed in lap winding.
Each parallel path in lap winding is under the influence of one pair of poles, so if a machine consists of multiple pairs of poles then dissimilarities occurs, due to which unequal voltages may be induced in the paths and a circulating current may flow. In wave winding each path is under the influence of all poles, so voltages are induced in each path causing no such dissimilarities like lap winding. Equalizers in lap windings are used to remove this dissimilarity, they're not needed in wave winding.

47.What is the symmetry requirement of lap winding?
To avoid no-load circulating currents and certain consequential commutation problems, all the parallel paths must be identical so as to have the same number of coil-sides. Symmetry thus requires ratio of 2C/P is equal to the integer. Also, US/P equal to integer represents the same.

48. What is the relation between number of parallel paths(A) and number of poles(P)?
Complex winding can be divided into different parallel paths lying under different pole pairs. It is, therefore, concluded that the number if parallel paths is equal to the number of poles. In wave winding number of parallel paths is equal to 2.

49. Current flowing through the armature conductors Ic is related to total current Ia by_______
Two positive and two negative brushes are respectively connected in parallel for feeding the external circuit. As per the ring diagram Ia splits into the number of poles equally. Poles = Parallel paths. Thus, Ic = Ia /A.

50.Value of commutator pitch in lap winding is_____
Two ends of coil are connected across the adjacent commutator segments. Depending on the type of winding that is, retrogressive or progressive, we have two values for commutator pitch. For progressive winding, commutator pitch = +1. For retrogressive winding, commutator pitch = -1.

51. In which mode machine is operating, given that conductor current is in the same direction of conductor-emf?
If the conductor current is in the same direction of conductor emf then machine outputs electrical power and absorbs mechanical power. So, when mechanical power is absorbed machine is said to be in a generating mode. When conductor emf and conductor current are in opposite directions then machine is said to be in a motoring mode.

52. Nature of the flux density wave in the air gap is__________ (for armature current equal to 0)
In a DC machine magnetic structure is such that the flux density wave in the air gap is flat topped with quarter wave symmetry as long as armature current is equal to 0. For non-zero value of armature current, this quarter wave symmetry is disturbed because of armature reaction.

53. In a DC machine, average energy stored in the magnetic field remains constant independent of the armature rotation.
(T/F)
In a DC machine, barring the irrecoverable losses of both electric and magnetic origin, there is balance between electrical and mechanical powers of the machine; the average energy stored in the magnetic field remains constant irrespective of armature rotation.
54. Emf produced by DC machine, for zero armature current (E1) and non-zero armature current (E2) can be related as__________
In a DC machine flux density wave in the air gap is flat topped with quarter wave symmetry as long as armature current is equal to 0. For non-zero value of armature current, this quarter wave symmetry is disturbed because of armature reaction. Emf produced is independent of B-wave shape, thus we will get same value for both cases.
55. Average coil emf for 20 coil turns (E1) and 40 coil turns (E2), will have ratio E1/E2=____
(assuming all other parameters same for both machines).
Emf generated in a DC machine is directly proportional to number of coil turns, Flux per pole, number of poles and armature speed in rad/s. Thus, ratio E1/E2= 20/40 (assuming all other parameters same for both machines).
56. Emf and torque produced in a DC machine are proportional to ________ and _________ respectively.
Average coil emf generated= ØωNP/π. Machine torque = ka*Ø*Ia. Thus, average coil emf generated can also be represented as ka*Ø*ω. So, average coil emf is directly proportional to ω (armature speed) and average torque is directly proportional to Ia (armature current).
57. What is the value of Np in an average coil emf equation, for 10 armature conductors with 2 parallel paths?
In an emf equation Nc= Cp * Np. Here, Cp= coils/ parallel path. Np is defined as number of turns per parallel paths which is also called as ratio of total armature conductors to the twice of number of parallel paths. Np= 10/(2*2)= 10/4= 2.5.
58.What is the torque equation in terms of B, Ic, l, Zr (r= mean air gap radius)?
Avg. conductor force f= Bav*l*Ic. Here, Bav= Average flux density over pole, l= acyive conductor length. Thus, torque T= Z*f = Bav*l*Ia*Z. This torque is constant because both the flux density wave and current distribution is fixed in space at all times.
T developed= Bav*Ic*l*Zr (Here, r= mean air gap radius).
59. In a DC machine, the form of armature mmf waveform is __________
All the conductors on the armature periphery between adjacent brushes carry currents (of constant value, UNcIc) in one direction and the current distribution alternates along the periphery. Because of commutator action, armature current distribution is in the steps of UNcIc. Thus, mmf waveform can be generalized by joining peak points to get triangular wave.
60. **In a DC machine, the direct axis is __________**
Direct axes is simply defined as the line passing through the axes of main poles. Maximum flux passes through this line. It's also called as Direct Axis. Direct axes is always perpendicular to the geometrical neutral axis of machine.
61. **In a DC machine, the form of flux density distribution (main field only) waveform is __________**
Flux density waveform is symmetrical and square wave with distortion at the zero points, causing wave to be in trapezoidal shape. The wave is flat topped, which get distributed due to armature mmf distribution, giving rise to the resultant flux distribution wave.

62. **Due to the effect of armature reaction in DC machine, the flux per pole and generated voltage ______ and ________ respectively**.

The nature of armature reaction in a dc machine is cross-magnetizing with its axis (stationary) along the q-axis (at 90° elect. to the main pole axis). It causes no change in flux/pole if the iron is unsaturated but causes reduction in flux/pole (demagnetizing effect) in presence of iron saturation.

63**. Armature reaction of an unsaturated DC machine is (in terms of magnetization) ________**

: Initially at unsaturated condition in a DC machine armature reaction lies along the q-axis. It will cause no change in flux/pole if iron is unsaturated. Now, when iron gets saturated axis gets shifted which will cause reduction in flux/pole.

64. **What is the effect of demagnetizing component of armature reaction?**
When the armature of a dc machine carries current, the distributed armature winding produces its own mmf (distributed) known as armature reaction. The demagnetizing component acts in the opposite direction, reducing flux/pole in a machine, which will ultimately reduce generator emf.

65. **What is the reason behind short circuit in armature?**
Armature short circuit may occur due to contact of two commutator bars or due to contact in of two coil turns as commutators are connected to respective coil sides. If two or more turns of coil are grounded then they have common end which again leads to short circuit.

66. **What will happen at poles due to armature reaction in DC generator?**
Leading pole tip (LPT) and trailing pole tip (TPT) are the two edges of the pole, they depend upon the direction of motion of the armature (in case of DC). While performing a motion the armature first saws an edge of the pole, that edge is called leading pole tip. Thus, at leading pole tip there will be demagnetization.

67**. In DC generator, how armature reaction is produced?**
When the armature of a dc machine carries current i.e. load current in armature, the distributed armature winding produces its own mmf (distributed) known as armature reaction. The tothe field ampere-turns (AT_f) and armature ampere-turns (AT_a).

68. **In a DC generator, the effect of armature reaction on the main pole flux is to __________**
When non-zero load current is passed through the armature winding, the distributed armature winding produces its own mmf known as armature reaction. According to its nature cross-magnetizing and demagnetizing, it will distort or reduce the main flux distribution.

69. **In a DC machine brushes are normally located along GNA. True/False**

Brushes are generally located at 900 to direct axis. The axis 900 to the direct axis is called as quadrature axis (q-axis). Generally, q-axis is along the geometric neutral axis (GNA) of machine. The brushes in a DC machine are normally located along the q-axis.

70. Armature reaction at 90^0 to the main field is called as ____________
The armature reaction flux strengthens each main pole at one end and weakens it at the other end (cross magnetizing effect). Armature reaction with axis at 90° to the main field axis is known as cross-magnetizing mmf.

71. Flux density in the interpolar region drops down because of ______
The exact way to find the flux density owing to the simultaneous action of field and armature ampere-turns is to find the resultant ampere-turn distribution $AT_{resultant}(\emptyset) = AT_f(\emptyset) + AT_a(\emptyset)$. The flux density of $AT_a(\emptyset)$ which, because of large air-gap in the interpolar region, has a strong dip along the q-axis even though AT_a(peak) is oriented along it.

72. Resultant ampere-turn distribution of a DC machine is given by _________
The exact way to find the flux density owing to the simultaneous action of field and armature ampere-turns is to find the resultant ampere-turn distribution $AT_{resultant}(\emptyset) = AT_f(\emptyset) + AT_a(\emptyset)$, where $\emptyset$ is the electrical space angle.

73. Which axis undergo shifting as a result of armature reaction?
Apart from distortion of the resultant flux density wave, its MNA also gets shifted from its GNA by a

small angle α so that the brushes placed in GNA are no longer in MNA as is the case in the absence of armature current.

74. Armature reaction in a machine is demagnetizing due to _________

The armature reaction in a DC machine is cross-magnetizing causing distortion in the flux density wave shape and a slight shift in MNA. It also causes demagnetization because a machine is normally designed with iron slightly saturated.

75. Which of the following are effects of armature reaction?

Armature reaction in a DC machine is a result of distortion of main field flux distribution by armature current, which produces its own mmf called armature mmf. Directly or indirectly armature reaction is the problem occurring in DC machine as it causes various effects, which reduce machine efficiency.

76. A 250 kW, 400 V, 6-pole dc generator has 720 lap wound conductors. Armature current is ____

Armature current multiplied by the armature voltage is called as rating of a DC generator. Thus, 250 kW is the given rating while 400 V is the armature voltage. So, armature current is equal to 250*1000/400 = 625A.

77. What is the total ampere conductors/pole (in SI) if 600 lap wound conductors carry 120A current through conductors (P=4)?

Ampere-conductors/pole =ZIc/P= ZIa/AP. Ampere conductors per pole is calculated by multiplying total no. of conductors with the current carried by them divided by the total no. of poles. Ampere-conductors/pole = 600*120/4 =18000.

78. What is the total ampere turns/pole (in AT/pole) if 600 lap wound conductors carry 120A current through conductors (P=4)?

Ampere-conductors/pole =ZIc/P= ZIa/AP. Ampere turns per pole is calculated by multiplying total no. of conductors with the current carried by them divided by the twice the total no. of poles. Ampere-turns/pole = 600*120/8 =18000/2= 9000 .

79. If total ampere turns per pole is equal to 6000 A-turns, peak ampere turns for a 4-pole machine is _____

Peak flux density in terms of total flux density is given by ATa (peak) = ATa (total) /P. Thus, for a 4-pole machine, ATa (total)= 6000 and P=4. Thus, Peak flux density is equal to 6000/4= 1500.

80. What is the total ampere turns per pole for 720 lap wounded conductors with carrying armature current equal to 625A in a 6-pole machine?

For a given machine number of parallel paths is equal to 6. So, conductor current will be equal to armature current divide by no. of parallel paths i.e. 625/6. Conductor current = 104.2 A. Total armature ampere-turns, ATa = ½(720*104.2/6)= 6252 AT/pole.

81. For 6252 AT/Poles, if brush shift is of 2.50 mech. Degrees, what will be the cross-magnetizing ampere-turns per pole for a 6-pole DC machine?

For calculations, from given mech. Degrees shift we need to find electrical degrees shift. Electrical shift= mechanical shift*(P/2). Thus, electrical shift is equal to 7.50. Cross-magnetizing ampere-turns is given by 6250*(1-2*7.5/180) = 5731 AT/Pole

82. **Flux density in the interpolar region drops down because of ______**

The exact way to find the flux density owing to the simultaneous action of field and armature ampere-turns is to find the resultant ampere-turn distribution $AT_{resultant}(\emptyset) = AT_f(\emptyset) + AT_a(\emptyset)$. The flux density of $AT_a(\emptyset)$ which, because of large air-gap in the interpolar region, has a strong dip along the q-axis even though AT_a(peak) is oriented along it.

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91. For machine tools, which DC motor can be used?
Shunt characteristics is the speciality of DC shunt motor. The speed of the motor almost remains constant on various loads, thus it suits perfectly to the application, where speed requirement is constant like in machine tools.

92. In a DC shunt motor, speed is related to armature current as ______________
When armature reaction is ignored in a DC shunt motor, flux almost remains constant but the speed of the motor decreases according to the increase armature current, increasing Ia*Ra drop. Hence, inverse proportionality.

93. In a DC shunt motor for zero armature current we get speed _______
For zero armature current we get some non-zero value, indicated by positive intercept on speed characteristics. As armature current is increased speed of DC shunt motor starts decreasing due to increase in voltage drop at armature resistance.

94. What will be the effect of opening of field of a DC shunt motor while motor is running?
In a DC shunt motor if supply for the field winding is cut down, the speed would dangerously increase in order to maintain the back emf of the motor. For a constant back emf, flux is inversely proportional to the speed of DC shunt motor. So, if flux drops to zero theoretically speed will tend to infinity.

95. What will be the effect of reducing load on DC shunt motor?
For DC shunt motor, speed-armature current characteristics is called as a shunt characteristic as speed almost remains constant. Thus, by reducing load speed will increase negligibly, thus remaining almost constant.

96. How speed of the DC shunt motor can be increased?
For a constant load, load current will remain constant. Decreasing armature current will help in increasing speed for DC shunt motor. Since load current is addition of armature current and field current we'll get less armature current for more field current.

97. Practical reason behind speed of DC shunt motor is proportional to back emf only is ____________

The field winding in DC shunt motor is connected in parallel to the armature winding and the supply. If we assume that the supply voltage for motor is constant then flux also becomes constant. At the rated speed the back emf also becomes alm

98. In a DC shunt motor, what will be the armature current at maximum load?

As the load will increase in rapid manner, speed change in DC shunt motor will be visible. As load increase, speed will decrease, though by some small value. From, current armature characteristic armature current will be more than the earlier case.

99. While conducting OCC, in order to avoid hysteresis loop, in which direction

In conducting the OCC test, If must be raised gradually only in the forward direction otherwise the curve would exhibit local hysteresis loops. In OCC at If =0 there exists small residual voltage shown by non-zero Voc.

100.For connecting two generators in parallel, they should have ___________________

For connecting two DC generators in parallel we equal voltage ratings. As the generator voltage is easily adjustable in a range, so the condition stated above is not a must. But, it is desirable condition.

101. While connecting two DC generators in parallel, which of the following is not a desirable condition?

a) Same voltage rating
b) Same percentage voltage regulation
c) Same percentage speed regulation of the prime movers
d) Same current rating
Answer: d
Explanation: Same voltage rating, same percentage voltage regulation, same percentage speed regulation are the desirable conditions for connecting two generators in parallel, though these conditions are not a must.

102. We connect two generators in parallel _____________

a) For large DC load
b) For small DC load
c) For any DC load
d) For any AC or DC load
Explanation: a
Answer: We connect two generators in parallel for supplying large DC load. It is desirable to use more than one generator in parallel. This arrangement provides the security that if one generator gives way, the other(s) can feed part load.

103. Load sharing of two generators connected in parallel is determined by __________

a) Internal characteristics
b) External characteristics
c) Both internal and external characteristics
d) It doesn't depend on load sharing
Answer: b
Explanation: Two generators are connected in parallel such that, summation of current carried by both generators is equal to load current. In such cases we need to see external characteristics on loaded condition.

104. For a parallel operation of 2 DC shunt generators, we get net external characteristics ___________

a) Starting from the same no-load point and between generator 1 and generator 2
b) Starting from the same no-load point and below generator 1 and generator 2
c) Starting from the same no-load point and above generator 1 and generator 2
d) Can't be determined

Answer: c
Explanation: The load sharing by these generators is determined by addition of external characteristics of both of generators. Thus, at no load generators will have common point, on y- axis so parallel characteristic will start from same point and will lie above of both.

105. When two compound generators are connected in parallel, when load current in generator 1 is increased __________

a) Both generator will share same load
b) Generator 1 will start running as motor
c) Generator 2 will be overloaded
d) Generator 2 will start running as motor
Answer: d
Explanation: If load current in G1 increases, load current in G2 decreases. Series excitation and internal voltage in G1 increases and for G2, these quantities decrease. Finally, all load shifts, which may turn to run G2 as a motor. All this leads to heavy overloading of G1.

106. While running two compound motors in parallel, we connect equalizer ring between ___________

a) Two armatures
b) Two fields
c) Two load points
d) Anywhere
Answer: a
Explanation: A low-resistance equalizer connection is made directly between the two armatures before the series fields. Any emf variations of the armatures causes equalizing circulating current which do not affect the current through the series windings. Thereby the parallel operation is stabilized.

TRANSFORMER

1. Transformer core is generally made of ___________

:Transformer core experiences eddy current losses when transformer is in the operations. In order to reduce eddy current losses, it is advisable to use large number of sheets laminated from each other are stick together than using one single block.

2. Transformer core is constructed for ______________

Transformer core is so chosen that it will provide low reluctance path and will transfer maximum amount of flux from one winding to other, providing most effective magnetic linkage between two windings.

4. Transformer operating at 25-400 Hz frequency contain core made of _____________

When core is made of highly permeable iron or steel alloy (cold-rolled, grain oriented sheet steel). This transformer is generally called an iron-core transformer. Transformers operated from 25–400 Hz are invariably of iron-core construction.

5. In various radio devices and testing instruments we use ______________

In special cases, the magnetic circuit linking the windings may be made of nonmagnetic material, in which case the transformer is referred to as an air-core transformer. The air-core transformer is of interest mainly in radio devices and in certain types of measuring and testing instruments.

6. Which type of flux does transformer action need?

The energy transfer in a transformer, is from one winding to another, entirely through magnetic medium it is known as transformer action. Therefore, transformer action requires an alternating or time varying magnetic flux in order to transfer power from primary side to secondary side. Since induced emf in the winding is due to flux linkage.

8. There is only one magnetic flux path in the circuit. The transformer is definitely ________________

In core type transformer, winding is placed on two core limbs, while in case of shell type transformer, winding is placed on mid arm of the core. Other limbs will be used as mechanical support. Core type transformers have only one magnetic flux path.

9. What is the purpose of providing an iron core in a transformer?
Iron core is used in a transformer to carry flux from one winding to another winding, so there should be minimum opposition to flux passing through iron core. Hence, transformer function is to decrease the reluctance of magnetic path.

10. What is the thickness of laminations used in a transformer?
Laminations are made to reduce the eddy currents and is made of thin strips. Generally, the steel transformer lamination range for 50 Hz varies from 0.25mm to 0.5mm, if it is a 60 Hz transformer then it ranges from 0.17–0.27mm.

11. Which is the most common, famous and adopted method of cooling of a power transformer?
Oil acts as a best coolant material, for transformer cooling. Due to its high efficiency as a coolant it is most widely used in transformers. Not only same but Oil with suitable properties can be used for various power transformers according to their ratings.

12. Function of conservator in an electrical transformer is ___________
When transformer is loaded and when ambient temperature rises, the volume of oil inside transformer increases as oil expands. A conservator tank properly installed on transformer provides required space to this expanded transformer oil. It performs another function as a reservoir for transformer insulating oil.

13. Natural oil cooling method have some limitations due to which it is adopted for transformers up to a rating of ____________
For the transformers n higher kVA ratings can be used with this cooling method. While transformers having capacity beyond 5 MVA, due to some improper limitations forced cooling is used. Natural cooling is based on the important phenomenon seen in fluids that when oil is heated up, moves in upward direction.

14. What is the function of spacers?
The winding layers of transformer are separated by spacers. One or more spacers are provided here, along with at least one integrated electrical discharge barrier extending off the central body of the spacer in the vicinity of the area where the spacer is in contact with a winding.

15. Which of the following is the most important quality required for chemical in breather, so that it can be used perfectly in an electrical transformer?
Most of the power generation plants use silica gel breathers fitted to the conservator of oil filled transformers. The purpose of silica gel breathers is to absorb the moisture in the air sucked in by the transformer during the breathing process.

16. Which chemical is used in breather?
In order to absorb moisture from air while breathing process, breather chemical is used. So, breather chemical should possess the required ability of absorbing moisture. In all chemicals available as on today, silica gel is most perfect and best material that can be used for such process.

17. A transformer oil used in an electrical transformer must be free from ________
Transformer oil serves the purpose of cooling and it also acts as an insulator between primary and secondary winding, thus it must be free from moisture else it will conduct electric current through it, leading to failure of a transformer.

18. On which of the following transformer, Buchholz's relay can be fixed on?
Buchholz relay is used in transformers for protection against all kinds of faults. Buchholz relay is a famous and mostly used gas-actuated relay, which is installed to serve its best in oil-immersed transformers. It gives an alarm, via its electrical circuitry, if any fault occurs in the transformer.

19. Gas is liberated due to temperature limit and due to dissociation of transformer oil after ___________
Gas is usually not liberated due to dissociation of transformer oil. But when the oil temperature exceeds 1500, it dissociates and liberates. It is found that hydrogen H_2 and methane CH_4 are

produced in large quantity if internal temperature of transformer rises up to 150°C to 300°C due to abnormal thermal stresses.

20. Buchholz's relay will give warning and protection against ___________

Buchholz relay is used in transformers for protection against all kinds of faults which are tend to happen inside a transformer. It is most famous gas-actuated relay which is installed in an oil-immersed transformer.

21. Which of the following listed component will see and perform according to changes in volume of transformer cooling oil due to variation of atmospheric temperature during day and night?

Conservator is an additional tank provided with transformer which stores oil when it gets expanded due to temperature rise. It also serves another important purpose that is, as a reservoir of transformer oil. Thus, at all temperature variations of day and night transformer can work without any problem.

22. What should be ideal volatility and ideal viscosity of the transformer oil?

Transformer oil has a low viscosity, high flash point, high dielectric strength, high resistivity. It has a low pour point and low volatility with good gas absorbing properties, while It resists oxidation, sludging and emulsification with water.

23. What is the function of breather in a transformer?

Most of the power generation stations use silica gel breathers fitted to conservator of oil filled transformers. The most used purpose of these silica gel breathers is to arrest the moisture when the outside air is sucked in by the transformer during the breathing process.

24. Natural air cooling method can't be adopted because of some unavoidable effects, beyond _______

Smaller size transformers are immersed in a tank containing transformer oil. The transformer oil because temperature properties, which is surrounding the core and windings gets heated, expands and moves upwards. It then flows downwards by the inside of tank walls which cause it to drop temperature and oil goes down to the bottom of the tank from where it rises once again completing the circulation cycle.

25. What is the no-load current drawn by transformer?

The no load current is about 2-5% of the full load current and it accounts for the losses in a transformer. These no-load losses include core(iron/fixed) losses, which contains eddy current losses & hysteresis losses and the copper(I2*R) losses due to the no Load current.

26. Purpose of no-load test on a transformer is ___________

No-load current is little bit greater than actual magnetizing current. Total no-load current supplied from the source has two components, one is magnetizing current which is utilized for magnetizing the core and other component is consumed for compensating the core losses in transformer.

27. In no-load test we keep secondary terminals ___________

In no-load test, as we don't require any load, we are not allowed to connect any resistor (fixed/variable) to the transformer secondary. We don't short the secondary terminals either.

28. For a linear B-H relationship, which option is correct?

For a linear B-H relationship it is assumed that, there are no losses present in the core like eddy current losses and hysteresis losses are neglected. Thus, core loss current is equal to 0, which ultimately confirms exciting current is purely magnetizing one.

29.Turns ratio of the transformer is directly proportional to ____________

According to the voltage expression, emf induced in the primary is directly proportional to the change in the flux with respect to the time and number of turns of the primary winding. Similarly, for secondary winding.

30.Ideal transformer core has permeability equal to _____

The core has infinite permeability so that zero magnetizing current is needed to establish the requisite amount of flux in the core. The core-loss (hysteresis as well as eddy-current loss) is considered zero.

31. An ideal transformer will have maximum efficiency at a load such that ____________

Maximum efficiency of a transformer is defined at the that values when, copper losses become completely equal to the iron losses. In all other cases the efficiency will be lower than the maximum value.

32. In a transformer the resistance between its primary and secondary is _____________

Since the primary and secondary windings are not connected to each other, one can say there exists the resistance of infinite ohms. These windings are connected to each other magnetically not electrically.

33. A transformer cannot work on the DC supply because _________________

For DC supply the direction and the magnitude of the supply remains constant, produced flux will be constant. Thus, rate of change of flux through the windings will be equal to zero. As a result, voltage at secondary will always be equal to 0.

34. The use of higher flux density in the transformer design _______________

If a material is having higher flux density it will store and transfer maximum amount of flux from primary to secondary, which will be very helpful as less core material will be required and weight per KVA will get reduced.

35. Which winding of the transformer has less cross-sectional area?

Winding having less cross-sectional area may be primary or secondary winding. For high voltage winding cross sectional area is less while for low voltage winding cross sectional are is more, due to inverse proportionality.

36. In approximate equivalent circuit of the transformer ______________

Since Io is very small compare to like about 5-10% of full load current, voltage drop can be approximated to very large extent. These all resistances and inductances are in series, combined with each other to give approximate equivalent circuit.

37. Hysteresis loss and eddy current loss is directly proportional to __________

Hysteresis loss is directly proportional to frequency according to Steinmetz's formula. While eddy current losses are directly proportional to square of flux density, thickness, frequency. Both losses are load independent.

38. If a transformer is made to run on to a voltage which is more than the rated voltage ______________

Every electric device works in appropriate condition with maximum output and minimum losses when it is operated at rated conditions. Thus, if transformer is made to run at higher operating voltage its power factor will deteriorate.

39. The maximum load that a power transformer can carry is limited because of its ___________

One can increase the dielectric strength of oil, by changing the oil. Similarly, temperature rise and copper losses can also be controlled by using various techniques. The only thing which is constant is voltage ratio which can't be altered.

his set of Transformers Problems focuses on "OC Test on Transformer".

40 Open circuit test on transformers is conducted so as to get _____________

Open circuit test gives the core losses also called as iron losses and shunt parameters of the equivalent circuit of transformer. Open circuit test and short circuit test both provide all the parameters of equivalent circuit.

41. Why OC test is performed on LV side?

: Open circuit test can be performed on any side but for our convenience and supply voltage available we generally conduct the test on LV side, to get corresponding parameters on HV side we can use transformation ratio.

42. While conducting short-circuit test on a transformer which side is short circuited?
It's a common practice to conduct SC test from HV side, while keeping LV side short circuited. Thus, short circuited current is made to flow from shorted low voltage terminals i.e. LV side.

43. During short circuit test why iron losses are negligible?
Very small amount of voltage is given to the transformer primary thus the magnetic losses which are dependent on magnetic flux density will get minimum value, hence iron losses are negligible.

44 Short circuit test on transformers is conducted to determine ______
Short circuit test is used to determine the copper losses taking place in the transformer under operation, while open circuit test gives us the value of core losses taking place in the transformer.

45. When will be the efficiency of a transformer maximum?
When the variable copper losses of a transformer becomes equal to the fixed iron losses of a transformer then we will get maximum efficiency. From these losses we'll get the value of current required

46. Power transformers other than distribution transformers are generally designed to have maximum efficiency around ______
Similar to normal transformers power transformers are also designed to get maximum efficiency at load which is near to the full load of a transformer specified. Only in the case distribution transformer maximum efficiency is achieved at 60% of full load.

47. Why efficiency of a transformer, under heavy loads, is comparatively low?
At heavy loads current drawn by the transformer circuit increases, as we know, variable copper losses are proportional to the square of the current. Thus, we'll get higher copper loss in proportion to the output.

48 A transformer can have zero voltage regulation at _______
of angle ϕ we may get zero voltage regulation. While in lagging power factor case we have + sign in the above formula.

49. What will happen to a given transformer if it made to run at its rated voltage but reduced frequency?
E=4.44fNAB is the emf equation for a transformer, now as E is kept constant we can say frequency is inversely proportional to the B value. Thus, as frequency increases we will get less core flux density and vice-versa.

50. In an actual transformer the iron loss remains practically constant from no load to full load because ___________
The reason behind core-iron loss being constant is that hysteresis loss and eddy current loss both are dependent on the magnetic properties of the material which is used in the construction and design of the core of the transformer.

51. Negative voltage regulation indicates ___________
The sign -ve arises in the voltage regulation calculations when, the load connected to the transformer is leading in the nature. The only condition when we'll get negative voltage regulation when second term is higher than first term.

52. When will a transformer have regulation closer to zero?
Since voltage regulation of a transformer in the leading loading condition is not additive in nature, at particular power factor in leading we can get zero voltage regulation. While, in lagging condition we'll get ultimately non-zero VR.

AUTO-TRANSFORMER

1. Which of the following is the main advantage of an auto-transformer over a two-winding transformer?

Auto transformer is a special type of transformer which has primary and secondary winding both located on same winding. Thus, winding material required for a transformer is very less in the case of autotransformer.

2. Auto-transformer makes effective saving on copper and copper losses, when its transformation ratio is

Copper In auto transformer /copper in two-winding transformer = 1- T2/T1. This means that an auto transformer requires the use of lesser quantity of copper given by the ratio of turns. Hence, if the transformation ratio is approximately equal to one, then the copper saving is good and the copper loss is less.

3. Total windings present in a autotransformer are ___________

Autotransformer is the special transformer for which the single winding acts as a primary and secondary both. Thus, by taking the appropriate winding into consideration a variable secondary voltage is obtained.

4. Autotransformers are particularly economical when __________

Autotransformer is economical where the voltage ratio is less than 2 in which case electrical isolation of the two windings is not essential. The major applications are induction motor starters, interconnection of HV systems at voltage levels with ratio less than 2, and in obtaining variable voltage power supplies (low voltage and current levels).

5. Which of the following is not true regarding the autotransformer compare to two-winding transformer?

Autotransformer is the advance version of normal transformer. It is having better voltage regulation, higher efficiency due to lower losses, lower reactance and thus it also requires very small exciting current.

6. Two-winding transformer of a given VA rating if connected as an autotransformer can handle ____________

A two-winding transformer of a given VA rating when connected as an autotransformer can handle higher VA. This is because in the autotransformer connection part of the VA is transferred conductively.

7. What are the modes in which power can be transferred in an autotransformer?

In two winding transformer there is no electrical connection between primary and secondary. So, the power is transferred through induction. But in auto-transformer there is a common electrical path between primary and secondary. So, power is transferred through both conduction and induction processes.

DC GENERATOR

1.Explain working principle of dc generator.

Generator Principle An electric generator is a machine that converts mechanical energy into electrical energy. An electric generator is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced which will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by Fleming's right hand rule. Therefore, the essential components of a generator are: (a) a magnetic field (b) conductor or a

Simple Loop Generator

Consider a single turn loop ABCD rotating clockwise in a uniform magnetic field with a constant speed as shown in Fig.(1.1). As the loop rotates, the flux linking the coil sides AB and CD changes continuously. Hence the e.m.f. induced in these coil sides also changes but the e.m.f. induced in one coil side adds to that induced in the other. (i) When the loop is in position no. 1 [See Fig. 1.1], the generated e.m.f. is zero because the coil sides (AB and CD) are cutting no flux but are moving parallel to it.

(ii) When the loop is in position no. 2, the coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated as indicated by point 2 in Fig. (1.2). (iii) When the loop is in position no. 3, the coil sides (AB and CD) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate. Hence at this instant, the generated e.m.f. is maximum as indicated by point 3 in Fig. (1.2). (iv) At position 4, the generated e.m.f. is less because the coil sides are cutting the flux at an angle. (v) At position 5, no magnetic lines are cut and hence induced e.m.f. is zero as indicated by point 5 in Fig. (1.2). (vi) At position 6, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f. is reversed. The maximum e.m.f. in this direction (i.e., reverse direction, See Fig. 1.2) will be when the loop is at position 7 and zero when at position 1. This cycle repeats with each revolution of the coil.

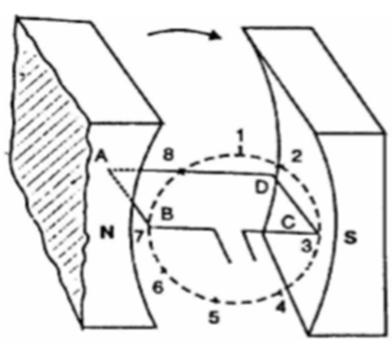


Fig. (1.1)

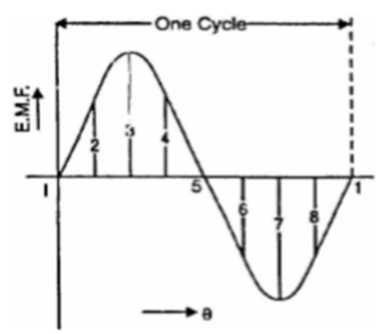


Fig. (1.2)

Note that e.m.f. generated in the loop is alternating one. It is because any coil side, say AB has e.m.f. in one direction when under the influence of N-pole and in the other direction when under the influence of S-pole. If a load is connected across the ends of the loop, then alternating current will flow through the load. The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator. We then have the d.c. generator. In fact, a commutator is a mechanical rectifier.

2.Explain action of commutator with a neat diagram.

If, somehow, connection of the coil side to the external load is reversed at the same instant the current in the coil side reverses, the current through the load will be direct current. This is what a commutator does. Fig. (1.3) shows a commutator having two segments C1 and C2. It consists of a cylindrical metal ring cut into two halves or segments C1 and C2 respectively separated by a thin sheet of mica. The commutator is mounted on but insulated from the rotor shaft. The ends of coil sides AB and CD are connected to the segments C1 and C2 respectively as shown in Fig. (1.4). Two stationary carbon brushes rest on the commutator and lead current to the external load. With this arrangement, the commutator at all times connects the coil side under S-pole to the +ve brush and that under N-pole to the –ve brush.

(i) In Fig. (1.4), the coil sides AB and CD are under N-pole and S-pole respectively. Note that segment C1 connects the coil side AB to point P of the load resistance R and the segment C2 connects the coil side CD to point Q of the load. Also note the direction of current through load. It is from Q to P.

(ii) (ii) After half a revolution of the loop (i.e., 180° rotation), the coil side AB is under S-pole and the coil side CD under N-pole as shown in Fig. (1.5). The currents in the coil sides now flow in the reverse direction but the segments C1 and C2 have also moved through 180° i.e., segment C1 is now in contact with +ve brush and segment C2 in contact with –ve brush. Note that commutator has reversed the coil connections to the load i.e., coil side AB is now connected to point Q of the load and coil side CD to the point P of the load. Also note the direction of current through the load. It is again from Q to P.

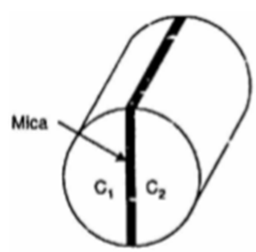


Fig.(1.3)

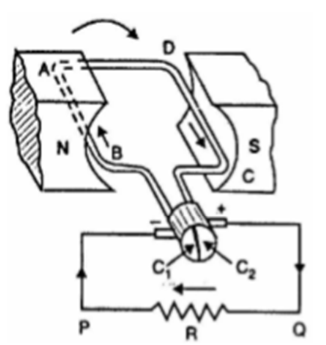


Fig.(1.4)

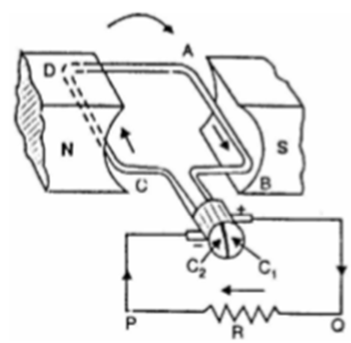


Fig.(1.5)

Thus the alternating voltage generated in the loop will appear as direct voltage across the brushes. The reader may note that e.m.f. generated in the armature winding of a d.c. generator is alternating one. It is by the use of commutator that we convert the generated alternating e.m.f. into direct voltage. The purpose of brushes is simply to lead current from the rotating loop or winding to the external stationary load. The variation of voltge with respect to angular displacement is not a steady direct voltage but has a pulsating character. It is because the voltage appearing across the brushes varies from zero to maximum value and back to zero twice for each revolution of the loop. A pulsating direct voltage such as is produced by a single loop is not suitable for many commercial uses. What we require is the steady direct voltage. This can be achieved by using a large number of coils connected in series. The resulting arrangement is known as armature winding.

3. **Derive e.m .f equation of DC generator.**

We shall now derive an expression for the e.m.f. generated in a d.c. generator.

Let
φ= flux/pole in Wb
Z = total number of armature conductors
P = number of poles
A = number of parallel paths = 2 ... for wave winding
= P ... for lap winding
N = speed of armature in r.p.m.
E_g = e.m.f. of the generator = e.m.f./parallel path

Flux cut by one conductor in one revolution of the armature,

$d\varphi = P\varphi$ webers

Time taken to complete one revolution,

dt = 60/N second

e.m.f generated/conductor $= \frac{d\varphi}{dt} = \frac{P\varphi}{60/N} = \frac{P\varphi N}{60}$ volts

e.m.f. of generator,

E_g = e.m.f. per parallel path
= (e.m.f/conductor) × No. of conductors in series per parallel path

$$= \frac{P\varphi N}{60} \times \frac{Z}{A}$$

$$\therefore \quad E_g = \frac{P\varphi ZN}{60\,A}$$

4.Explain Armature Reaction In case of dc machine.

With no current in armature conductors, the M.N.A. coincides with G.N.A. However, when current flows in armature conductors, the combined action of main flux and armature flux shifts the M.N.A. from G.N.A. In case of a generator, the M.N.A. is shifted in the direction of rotation of the machine. In order to achieve sparkless commutation, the brushes have to be moved along the new M.N.A. Under such a condition, the armature reaction produces the following two effects: 1. It demagnetizes or weakens the main flux. 2. It cross-magnetizes or distorts the main flux.

Let us discuss these effects of armature reaction by considering a 2-pole generator (though the following remarks also hold good for a multipolar generator).

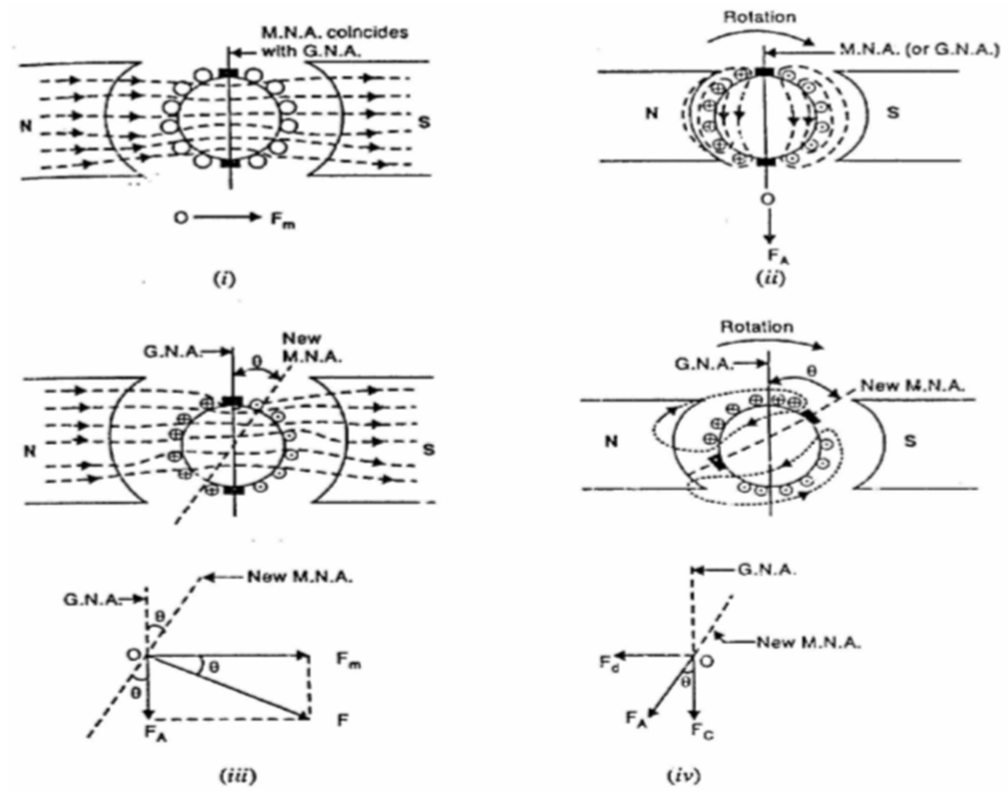
(i) Fig (i) shows the flux due to main poles (main flux) when the armature conductors carry no current. The flux across the air gap is uniform. The m.m.f. producing the main flux is represented in magnitude and direction by the vector OFm in Fig. (i). Note that OFm is perpendicular to G.N.A.

(ii) (ii) Fig. (ii) shows the flux due to current flowing in armature conductors alone (main poles unexcited). The armature conductors to the left of G.N.A. carry current "in" (×) and those to the right carry current "out" (•). The direction of magnetic lines of force can be found by cork screw rule. It is clear that armature flux is directed downward parallel to the brush axis. The m.m.f. producing the armature flux is represented in magnitude and direction by the vector OFA in Fig. (ii).

(iii) Fig. (iii) shows the flux due to the main poles and that due to current in armature conductors acting together. The resultant m.m.f. OF is the vector sum of OFm and OFA as shown in Fig. (iii). Since M.N.A. is always perpendicular to the resultant m.m.f., the M.N.A. is shifted through an angle θ. Note that M.N.A. is shifted in the direction of rotation of the generator.

(iv) In order to achieve sparkless commutation, the brushes must lie along the M.N.A. Consequently, the brushes are shifted through an angle θ so as to lie along the new M.N.A. as shown in Fig (iv). Due to brush shift, the m.m.f. FA of the armature is also rotated through the same angle θ. It is because some of the conductors which were earlier under N-pole now come under S-pole and vice-versa. The result is that armature m.m.f. FA will no longer be vertically downward but will be rotated in the direction of rotation through an angle θ as shown in Fig. (iv). Now FA can be resolved into rectangular components Fc and Fd. fig (iv) The component Fd is in direct opposition to the m.m.f. OFm due to main poles. It has a demagnetizing effect on the flux due to main poles. For this reason, it is called the demagnetizing or weakening component of armature reaction. (b) The component Fc is at right angles to the m.m.f. OFm due to main poles. It distorts the main field. For this reason, it is called the cross-magnetizing or distorting component of armature reaction.

It may be noted that with the increase of armature current, both demagnetizing and distorting effects will increase.



Conclusions

(i) With brushes located along G.N.A. (i.e., θ = 0°), there is no demagnetizing component of armature reaction (Fd = 0). There is only distorting or crossmagnetizing effect of armature reaction.

(ii) With the brushes shifted from G.N.A., armature reaction will have both demagnetizing and distorting effects. Their relative magnitudes depend on the amount of shift. This shift is directly proportional to the armature current.

(iii) The demagnetizing component of armature reaction weakens the main flux. On the other hand, the distorting component of armature reaction distorts the main flux.

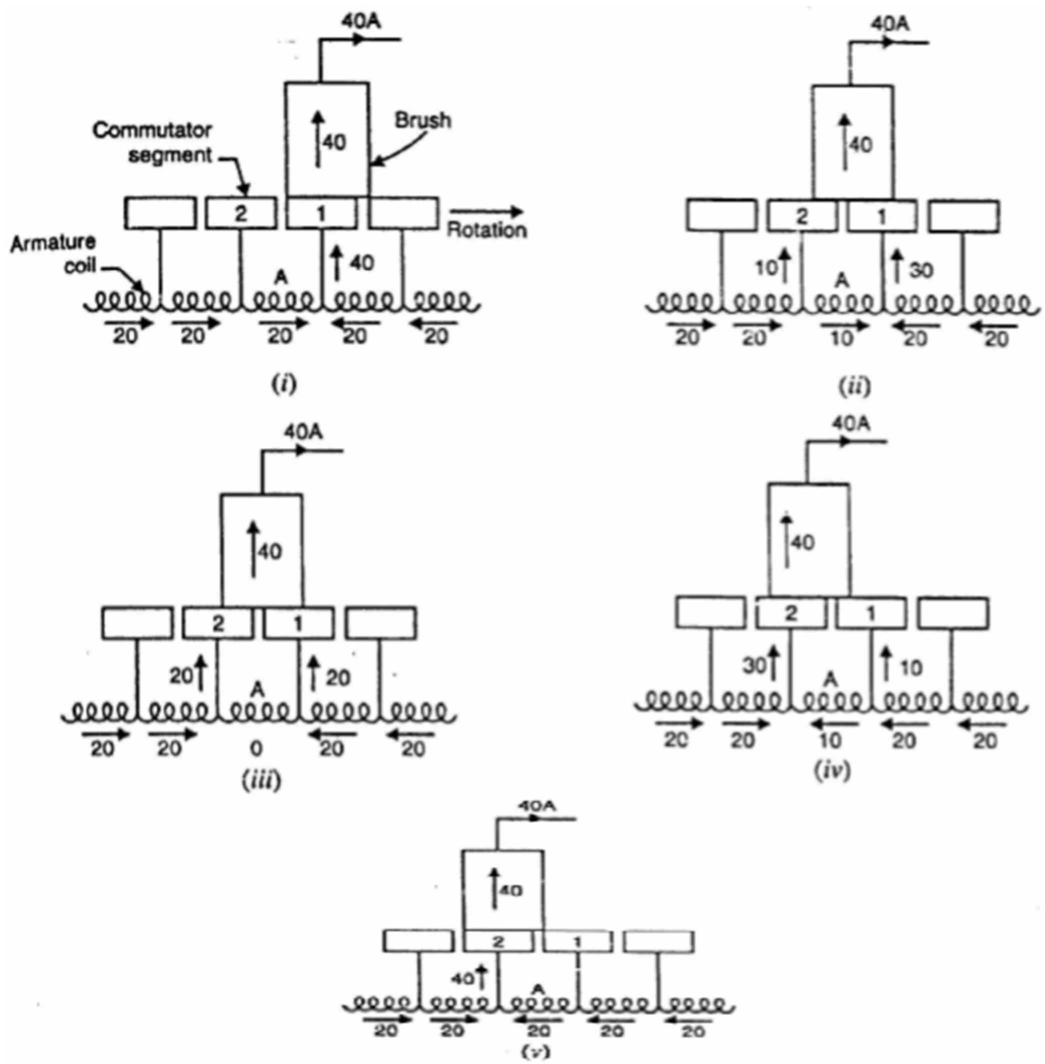
(iv) The demagnetizing effect leads to reduced generated voltage while crossmagnetizing effect leads to sparking at the brushes.

5. Explain process of commutation with a neat diagram.

Current in a dc machine coil will reverse as the coil passes a brush. This reversal of current as the coil passes & brush is called commutation.

Let us consider the coil A. The brush width is equal to the width of one commutator segment and one mica insulation. Suppose the total armature current is 40 A. Since there are two parallel paths, each coil carries a current of 20 A.

(i) In Fig.(i), the brush is in contact with segment 1 of the commutator. The commutator segment 1 conducts a current of 40 A to the brush; 20 A from coil A and 20 A from the adjacent coil as shown. The coil A has yet to undergo commutation.



(ii)As the armature rotates, the brush will make contact with segment 2 and thus short-circuits the coil A as shown in Fig.(ii). There are now two parallel paths into the brush as long as the short-circuit of coil A exists. Fig. (ii) shows the instant when the brush is one-fourth on segment 2 and three-fourth on segment 1. For this condition, the resistance of the path through segment

2 is three times the resistance of the path through segment 1 (Q contact resistance varies inversely as the area of contact of brush with the segment). The brush again conducts a current of 40 A; 30 A through segment 1 and 10 A through segment 2. Note that current in coil A (the coil undergoing commutation) is reduced from 20 A to 10 A.

(iii) Fig. (iii) shows the instant when the brush is one-half on segment 2 and one-half on segment 1. The brush again conducts 40 A; 20 A through segment 1 and 20 A through segment 2 (Q now the resistances of the two parallel paths are equal). Note that now. current in coil A is zero.

(iv) Fig. (iv) shows the instant when the brush is three-fourth on segment 2 and one-fourth on segment 1. The brush conducts a current of 40 A; 30 A through segment 2 and 10 A through segment 1. Note that current in coil A is 10 A but in the reverse direction to that before the start of commutation. The reader may see the action of the commutator in reversing the current in a coil as the coil passes the brush axis.

(v) Fig. (v) shows the instant when the brush is in contact only with segment 2. The brush again conducts 40 A; 20 A from coil A and 20 A from the adjacent coil to coil A. Note that now current in coil A is 20 A but in the reverse direction. Thus the coil A has undergone commutation. Each coil undergoes commutation in this way as it passes the brush axis. Note that during commutation, the coil under consideration remains shortcircuited by the brush.

6. Explain voltage build up process in case of dc shunt machine.

(i) Shunt generator Consider a shunt generator. If the generator is run at a constant speed, some e.m.f. will be generated due to residual magnetism in the main poles. This small e.m.f. circulates a field current which in turn produces additional flux to reinforce the original residual flux (provided field winding connections are correct). This process continues and the generator builds up the normal generated voltage following the O.C.C. shown in Fig. (i).

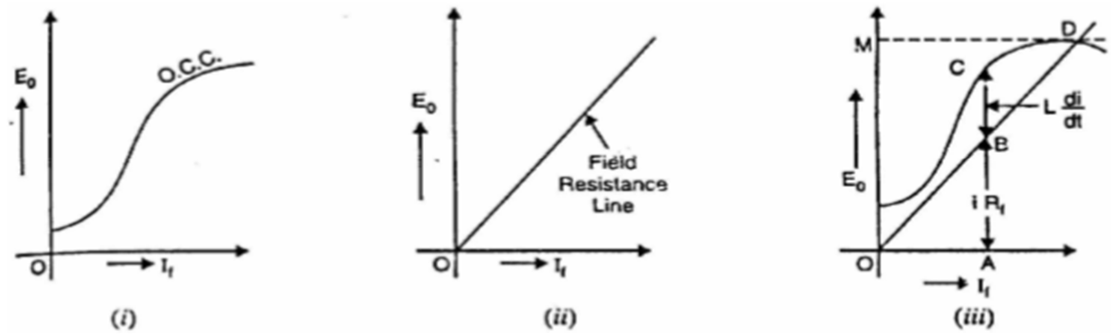
The field resistance Rf can be represented by a straight line passing through the origin as shown in Fig. (ii). The two curves can be shown on the same diagram as they have the same ordinate [Fig. (iii)]. Since the field circuit is inductive, there is a delay in the increase in current upon closing the field circuit switch The rate at which the current increases depends

upon the voltage available for increasing it. Suppose at any instant, the field current is i (= OA) and is increasing at the rate di/dt. Then,

$$E_0 = iR_F + L\,(d/dt)$$

where R_f = total field circuit resistance L = inductance of field circuit

At the considered instant, the total e.m.f. available is AC [See Fig.(iii)]. An amount AB of the c.m.f. AC is absorbed by the voltage drop iRf and the remainder part BC is available to overcome L di/dt. Since this surplus voltage is available, it is possible for the field current to increase above the value OA. However, at point D, the available voltage is OM and is all absorbed by i Rf drop. Consequently, the field current cannot increase further and the generator build up stops.



We arrive at a very important conclusion that the voltage build up of the generator is given by the point of intersection of O.C.C. and field resistance line. Thus in Fig. (iii), D is point of intersection of the two curves. Hence the generator will build up a voltage OM.

DC MOTOR

1. Explain with a neat sketch working of dc motor.

D.C. Motor Principle

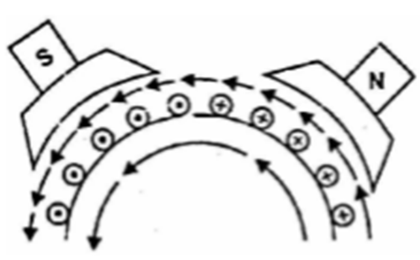
A machine that converts d.c. power into mechanical power is known as a d.c. motor. Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of this force is given by Fleming's left hand rule and magnitude is given by; newtonsBIF l= Basically, there is no constructional difference between a d.c. motor and a d.c. generator. The same d.c. machine can be run as a generator or motor.

Working of D.C. Motor

Consider a part of a multipolar d.c. motor as shown in Fig. . When the terminals of the motor are connected to an external source of d.c. supply:

(i) the field magnets are excited developing alternate N and S poles.

(ii) the armature conductors carry currents. All conductors under N-pole carry currents in one direction while all the conductors under S-pole carry currents in the opposite direction.



Suppose the conductors under N-pole carry currents into the plane of the paper and those under S-pole carry currents out of the plane of the paper as shown in Fig. Since each armature conductor is carrying current and is placed in the magnetic field, mechanical force acts on it. Referring to Fig. and applying Fleming's left hand rule, it is clear that force on each conductor is tending to rotate the armature in anticlockwise direction. All these forces add together to produce a driving torque which sets the armature rotating. When the conductor moves from one side of a brush to the other, the current in that conductor is reversed and at the same time it comes under the influence of next pole which is of opposite polarity. Consequently, the direction of force on the conductor remains the same.

2. Derive torque expression of dc motor.

Torque is the turning moment of a force about an axis and is measured by the product of force (F) and radius (r) at right angle to which the force acts i.e. D.C. Motors 113 T = F× r In a d.c. motor, each conductor is acted upon by a circumferential force F at a distance r, the radius of the armature (Fig. 4.8). Therefore, each conductor exerts a torque, tending to rotate the armature. The sum of the torques due to all armature conductors is known as gross or armature torque (Ta).

Let in a d.c. motor
r = average radius of armature in m
l = effective length of each conductor in m
Z = total number of armature conductors
A = number of parallel paths
i = current in each conductor = Ia/A
B = average flux density in Wb/m2
ϕ = flux per pole in Wb
P = number of poles Force on each conductor,
F = B i l newtons
Torque due to one conductor = F × r newton- metre Total armature torque,
Ta = Z F r newton-metre
= Z B i l r
Now i = Ia/A, B = ϕ/a where a is the x-sectional area of flux path per pole at radius r. Clearly, a = 2πrl/P.

$$T_a = Z \times \left(\frac{\varphi}{2}\right) \times \left(\frac{I_a}{A}\right) \times \ell \times r$$

$$= Z \times \frac{\varphi}{2\pi r\ell/P} \times \frac{I_a}{A} \times \ell \times r = \frac{Z\varphi I_a P}{2\pi A} \text{ N - m}$$

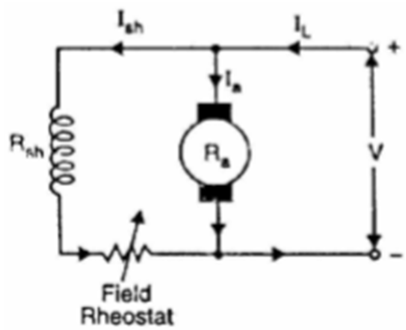
$$T_a = 0.159\, Z\varphi I_a \left(\frac{P}{A}\right) \text{ N - m}$$

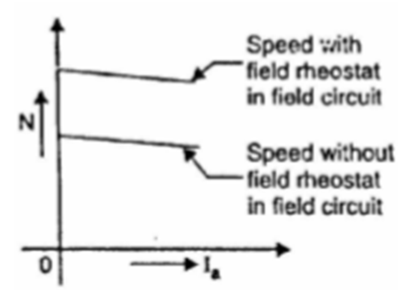
3. Explain speed control of dc shunt machine.

Speed Control of D.C. Shunt Motors The speed of a shunt motor can be changed by (i) flux control method (ii) armature control method (iii) voltage control method. The first method (i.e. flux control method) is frequently used because it is simple and inexpensive.

Flux control method

It is based on the fact that by varying the flux ϕ, the motor speed (N ∝ 1/ϕ) can be changed and hence the name flux control method. In this method, a variable resistance (known as shunt field rheostat) is placed in series with shunt field winding as shown in Fig.





The shunt field rheostat reduces the shunt field current Ish and hence the flux ϕ. Therefore, we can only raise the speed of the motor above the normal speed (See Fig.). Generally, this method permits to increase the speed in the ratio 3:1. Wider speed ranges tend to produce instability and poor commutation.

Advantages:

(i) This is an easy and convenient method.

(ii) It is an inexpensive method since very little power is wasted in the shunt field rheostat due to relatively small value of Ish.

(iii) The speed control exercised by this method is independent of load on the machine.

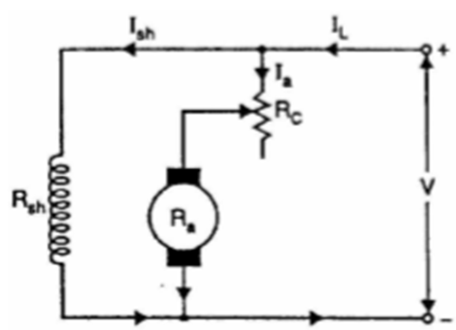
Disadvantages:

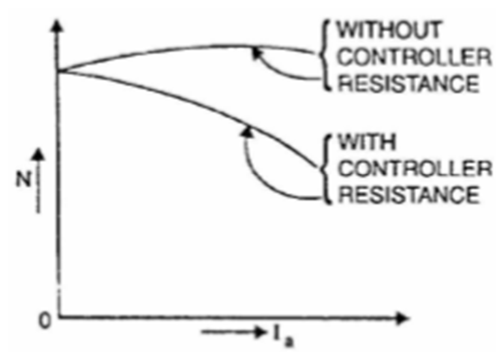
(i) Only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below Rsh—the shunt field winding resistance.

(ii) There is a limit to the maximum speed obtainable by this method. It is because if the flux is too much weakened, commutation becomes poorer.

Armature control method

This method is based on the fact that by varying the voltage available across the armature, the back e.m.f and hence the speed of the motor can be changed. This is done by inserting a variable resistance RC (known as controller resistance) in series with the armature as shown in Fig.





$N \propto V - I_a(R_a+R_c)$ where R_c = controller resistance

Due to voltage drop in the controller resistance, the back e.m.f. (Eb) is decreased. Since N ∝ Eb, the speed of the motor is reduced. The highest speed obtainable is lhat corresponding to RC = 0 i.e., normal speed. Hence, this method can only provide speeds below the normal speed (See Fig.).

Disadvantages

(i) A large amount of power is wasted in the controller resistance since it carries full armature current Ia.

(ii) The speed varies widely with load since the speed depends upon the voltage drop in the controller resistance and hence on the armature current demanded by the load.

(iii) The output and efficiency of the motor are reduced.

(iv) This method results in poor speed regulation.

4. Explain with a neat diagram 3-point stater operation.

This type of starter is widely used for starting shunt and compound motors.

Schematic diagram Fig. shows the schematic diagram of a three-point starter for a shunt motor with protective devices. It is so called because it has three terminals L, Z and A. The starter consists of starting resistance divided into several sections and connected in series with the armature. The tapping points of the starting resistance are brought out to a number of studs. The three terminals L, Z and A of the starter are connected respectively to the positive line terminal, shunt field terminal and armature terminal. The other terminals of the armature and shunt field windings are connected to the negative terminal of the supply. The no-volt release coil is connected in the shunt field circuit. One end of the handle is connected to the terminal L through the over-load release coil. The other end of the handle moves against a spiral spring and makes contact with each stud during starting operation, cutting out more and more starting resistance as it passes over each stud in clockwise direction.

Operation

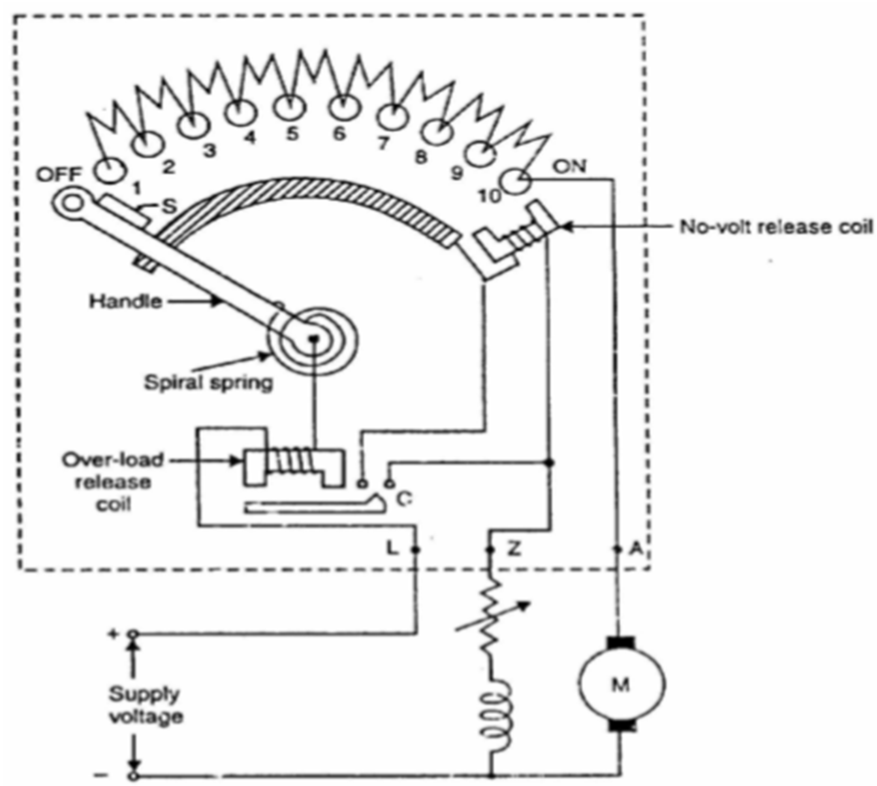
(i) To start with, the d.c. supply is switched on with handle in the OFF position.

(ii)The handle is now moved clockwise to the first stud. As soon as it comes in contact with the first stud, the shunt field winding is directly connected across the supply, while the whole starting resistance is inserted in series with the armature circuit.

(iii)As the handle is gradually moved over to the final stud, the starting resistance is cut out of the armature circuit in steps. The handle is now held magnetically by the no-volt release coil which is energized by shunt field current.

(iv) If the supply voltage is suddenly interrupted or if the field excitation is accidentally cut, the no-volt release coil is demagnetized and the handle goes back to the OFF position under the pull of the spring. If no-volt release coil were not used, then in case of failure of supply, the handle would remain on the final stud. If then supply is restored, the motor will be directly connected across the supply, resulting in an excessive armature current.

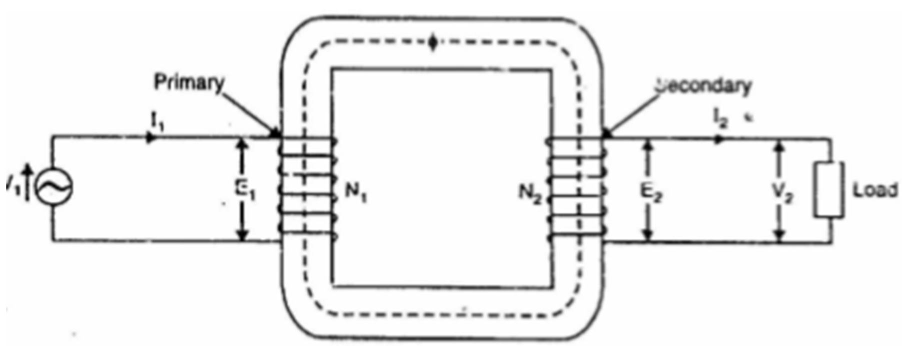
(v) If the motor is over-loaded (or a fault occurs), it will draw excessive current from the supply. This current will increase the ampere-turns of the over-load release coil and pull the armature C, thus short-circuiting the novolt release coil. The no-volt coil is demagnetized and the handle is pulled to the OFF position by the spring. Thus, the motor is automatically disconnected from the supply.



TRANSFORMER

1.Explain transformer working principle .

A transformer is a static piece of equipment used either for raising or lowering the voltage of an a.c. supply with a corresponding decrease or increase in current. It essentially consists of two windings, the primary and secondary, wound on a common laminated magnetic core as shown in Fig. (7.1). The winding connected to the a.c. source is called primary winding (or primary) and the one connected to load is called secondary winding (or secondary). The alternating voltage V1 whose magnitude is to be changed is applied to the primary. Depending upon the number of turns of the primary (N1) and secondary (N2), an alternating e.m.f. E2 is induced in the secondary. This induced e.m.f. E2 in the secondary causes a secondary current I2. Consequently, terminal voltage V2 will appear across the load. If V2 > V1, it is called a step up-transformer. On the other hand, if V2 < V1, it is called a step-down transformer.



Working

When an alternating voltage V1 is applied to the primary, an alternating flux ϕ is set up in the core. This alternating flux links both the windings and induces e.m.f.s E1 and E 2 in them according to Faraday's laws of electromagnetic induction. The e.m.f. E1 is termed as primary e.m.f. and e.m.f. E2 is termed as secondary e.m.f.

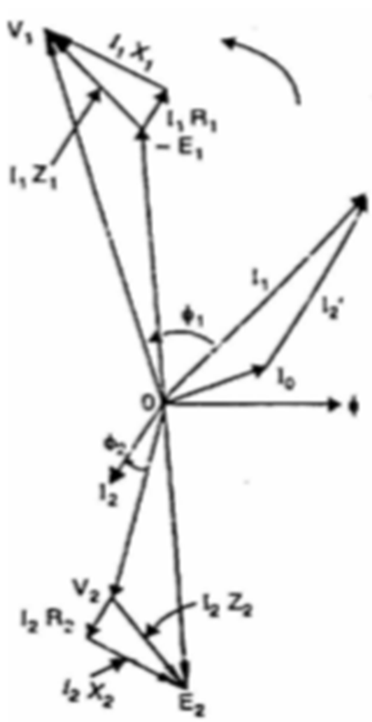
$$E_1 = -N_1 \frac{d\varphi}{dt}$$

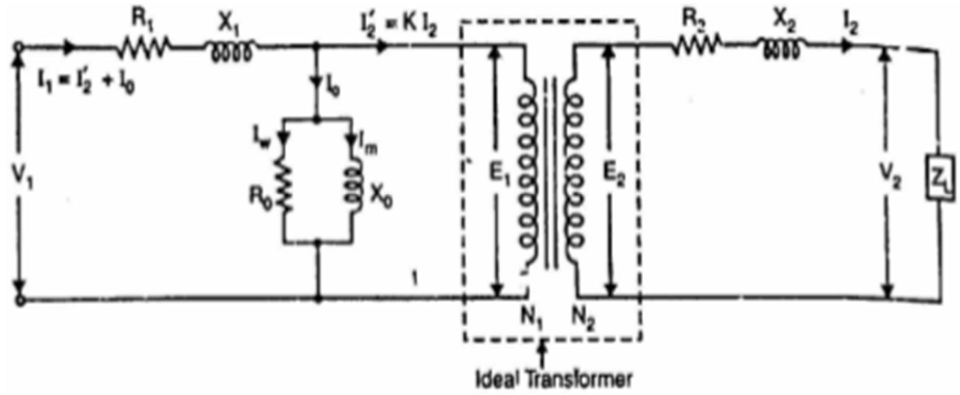
$$E_2 = -N_2 \frac{d\varphi}{dt}$$

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

Note that magnitudes of E2 and E 1 depend upon the number of turns on the secondary and primary respectively. If N2 > N1, then E2 > E1 (or V2 > V1) and we get a step-up transformer. On the other hand, if N2 < N1, then E2 < E1 (or V2 < V 1) and we get a step-down transformer. If load is connected across the secondary winding, the secondary e.m.f. E2 will cause a current I2 to flow through the load. Thus, a transformer enables us to transfer a.c. power from one circuit to another with a change in voltage level.

2. Draw phasor diagram of transformer for lagging load .Also .Draw exact equivalent circuit of transformer.





4.What is efficiency and derive condition for maximum efficiency in single phase transformer.

The **Efficiency** of the transformer is defined as the ratio of useful power output to the input power, the two being measured in the same unit. Its unit is either in Watts (W) or KW. Transformer efficiency is denoted by η.

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power + losses}}$$

$$\eta = \frac{\text{output power}}{\text{output power + iron losses + copper losses}}$$

$$\eta = \frac{V_2 I_2 \text{Cos}\varphi_2}{V_2 I_2 \text{Cos}\varphi_2 + P_i + P_c}$$

V2= Secondary terminal voltage.
I2= Full load secondary current.
Cosφ2= Power factor of the load.
pi= Iron loss= eddy current loss + Hysteresis loss = Constant loss.
Pc= Full load Copper losses.

Condition for maximum Efficiency:

$d\eta / dI_2 = 0$

Now $\eta = (V_2 I_2 \cos \Phi_2)/(V_2 I_2 \cos \Phi_2 + P_i + I_2^2 R_{2e})$

$$\therefore \quad \frac{d\eta}{dI_2} = \frac{d}{dI_2}\left[\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e}}\right] = 0$$

$$\therefore (V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e}) \frac{d}{dI_2}(V_2 I_2 \cos\phi_2) - (V_2 I_2 \cos\phi_2)\cdot\frac{d}{dI_2}(V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e}) = 0$$

$\therefore \quad (V_2 I_2 \cos \Phi_2 + P_i + I_2^2 R_{2e})(V_2 \cos \Phi_2) - (V_2 I_2 \cos \Phi_2)(V_2 \cos \Phi_2 + 2I_2 R_{2e}) = 0$

Cancelling ($V_2 \cos \Phi2$) from both the terms we get,

$V_2 I_2 \cos \Phi_2 + P_i + I_2^2 R_{2e} - V_2 I_2 \Phi_2 - 2I_2^2 R_{2e} = 0$

$\therefore \quad P_i - I_2^2 R_{2e} = 0$

$\therefore \quad P_i = I_2^2 R_{2e} = P_{cu}$

So condition to achieve maximum efficiency is that,

Copper losses = Iron losses

4.Write down condition for successful parallel operation and prove that $S_a = S[Z_{eb} / (Z_{ea}+Z_{eb})]$.

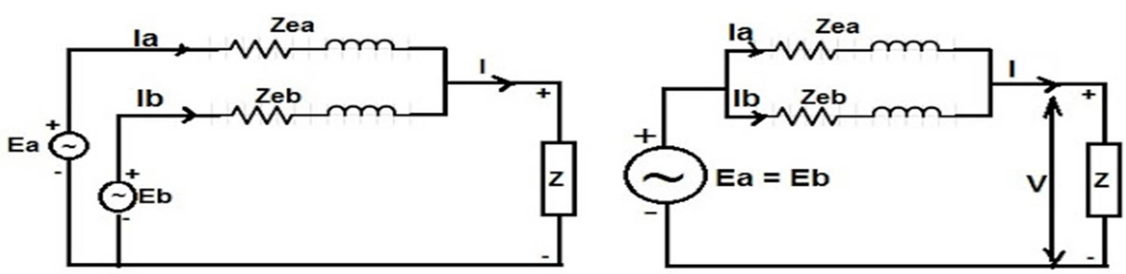
Condition for Parallel Operation of Transformers:

a) The Transformers must have the same voltage ratio i.e. with Primaries of Transformers connected to the same supply; their Secondaries must have the same voltage.

b) The equivalent leakage impedance in Ohm should be inversely proportional to their respective kVA rating. In other words, we can say that all the Transformers should have their per unit leakage impedance based on their own kVA rating equal.

c) The ratio of equivalent leakage reactance to equivalent resistance i.e. xe / re should be same for all the Transformers.

Theory: If the two Transformers A and B are of equal voltage ratio, that means equal secondary no load voltage. If the primary leakage impedance drop for the Transformers A and B are same then their Secondary terminal voltages E_a and E_b must be same and hence there will not be any circulating current.



Let us consider the left side figure shown above. Here V is the common Secondary terminal voltage, load current I is shared as I_a and I_b by the Transformers A and B respectively. The Load impedance is Z.

The voltage equation for Transformer A,

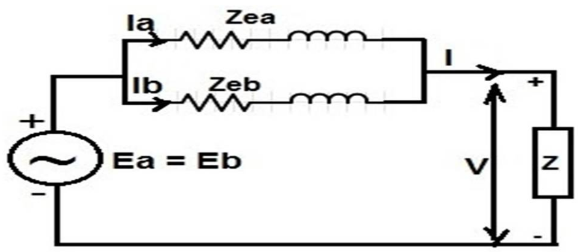
$E_a - I_a Z_{ea} = V = IZ$

Since, $E_a = E_b$ so

$E_b - I_a Z_{ea} = IZ$ …………………(1)

Voltage equation for Transformer B,

$E_b - I_b Z_{eb} = V = IZ$ ………………(2)
From equation (1) and (2),
$E_b - I_a Z_{ea} = E_b - I_b Z_{eb}$
Therefore,
$I_a Z_{ea} = I_b Z_{eb}$
We see that equivalent leakage impedance drop for both the Transformers are equal, therefore we can redraw the circuit model as shown below.

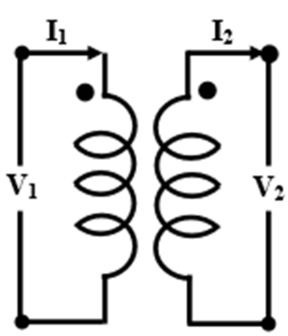


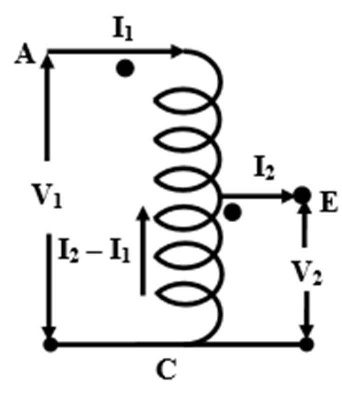
As the total load current I is shared by the Transformers A and B, therefore using Kirchhoff's Current Law,
$I_a = [\ Z_{eb} \ / \ (Z_{ea}+Z_{eb})\ ]xI$
$I_b = [\ Z_{ea} \ / \ (Z_{ea}+Z_{eb})\ ]xI$
Multiplying both sides by load voltage V,
$VI_a = IVx[\ Z_{eb} \ / \ (Z_{ea}+Z_{eb})\ ] \ \Rightarrow S_a = S[\ Z_{eb} \ / \ (Z_{ea}+Z_{eb})\ ]$
$VI_b = IVx[\ Z_{ea} \ / \ (Z_{ea}+Z_{eb})\ ] \ \Rightarrow S_b = S[\ Z_{ea} \ / \ (Z_{ea}+Z_{eb})\ ]$

AUTO TRANSFORMER

1.What is auto-transformer. Show that amount of copper saving in auto transformer is more as compared to two winding transformer.

An **autotransformer** is a kind of electrical transformer where primary and secondary shares same common single winding.





Let us now right down the mmf balance equation of the transformers.
For the two winding transformer:
MMF balance equation is N1I1 = N2I2
For the autotransformer:
MMF balance equation is (N1 – N2)I1 = N2(I2 – I1)

It may be noted that in case of an autotransformer, the portion EC is common between the primary and the secondary. At loaded condition current flowing through NEC is (I2 – I1). Therefore, compared to a two winding transformer lesser cross sectional area of the conductor in the portion EC can be chosen, thereby saving copper. We can in fact find out the ratio of amount of copper required in two types of transformers noting that the volume of copper required will be proportional to the product of current and the number of turns of a particular coil. This is because, length of copper wire is proportional to the number of turns and crossectional area of wire is proportional to the current value i.e.,

Volume of copper ∝ length of the wire × cross sectional area of copper wire ∝ N × I

$$\frac{\text{Amount of copper required in an autotransformer}}{\text{Amount of copper required in a two winding transformer}} = \frac{(N_1 - N_2)I_1 + N_2(I_2 - I_1)}{N_1 I_1 + N_2 I_2}$$

$$\text{Noting that } N_1 I_1 = N_2 I_2 = \frac{2N_1 I_1 - 2N_2 I_1}{2N_1 I_1}$$

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

Here we have assumed that N1 is greater than N2 i.e., a is greater than 1. The savings will of course be appreciable if the value of a is close to unity. For example if a = 1.2, copper required for autotransformer will be only 17% compared to a two winding transformer, i.e, saving will be about 83%. On the other hand, if a = 2, savings will be only 50%. Therefore, it is always economical to employ autotransformer where the voltage ratio change is close to unity. In fact autotransformers could be used with advantage, to connect two power systems of voltages say 11 kV and 15 kV.

2. Explain advantage and disadvantage of auto transformer over two winding transformer.

Advantages of using Auto Transformers

1. For transformation ratio = 2, the size of the **auto transformer** would be approximately 50% of the corresponding size of two winding transformer. For transformation ratio say 20 however the size would be 95 %. The saving in cost of the material is of course not in the same proportion. The saving of cost is appreciable when the ratio of transformer is low, that is lower than 2. Thus auto transformer is smaller in size and cheaper.
2. An auto transformer has higher efficiency than two winding transformer. This is because of less ohmic loss and core loss due to reduction of transformer material.
3. Auto transformer has better voltage regulation as voltage drop in resistance and reactance of the single winding is less.

Disadvantages of Using Auto Transformer

1. Because of electrical conductivity of the primary and secondary windings the lower voltage circuit is liable to be impressed upon by higher voltage. To avoid breakdown in the lower voltage circuit, it becomes necessary to design the low voltage circuit to withstand higher voltage.
2. The leakage flux between the primary and secondary windings is small and hence the impedance is low. This results into severer short circuit currents under fault conditions.
3. The connections on primary and secondary sides have necessarily needs to be same, except when using interconnected starring connections. This introduces complications due to changing primary and secondary phase angle particularly in the case of delta/delta connection.

4. Because of common neutral in a star/star connected auto transformer it is not possible to earth neutral of one side only. Both their sides should have their neutrality either earth or isolated.
5. It is more difficult to maintain the electromagnetic balance of the winding when voltage adjustment tappings are provided. It should be known that the provision of tapping on an auto transformer increases considerably the frame size of the transformer. If the range of tapping is very large, the advantages gained in initial cost is lost to a great event.

3.Draw phasor diagram of auto transformer.