LEARNING MATERIAL

SEMESTER & BRANCH : 4TH SEMESTER ELECTRICAL ENGINEERING

THEORY SUBJECT : ENERGY CONVERSION – I (TH – 1)

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D.C Generator

(1) Generator is a machine which converts mechanical energy in to electrical energy.

According to the faraday's Laws of electro-magnetic induction whenever a conductor cuts magnetic lines of force an emf will induced in it. This is known as dynamically induced emf. The principle of D.C Generator is based on it. The direction of the induced emf is given by Fleming's right hand rule.

* Principle of operation of D.C Generator :-

Construction :-

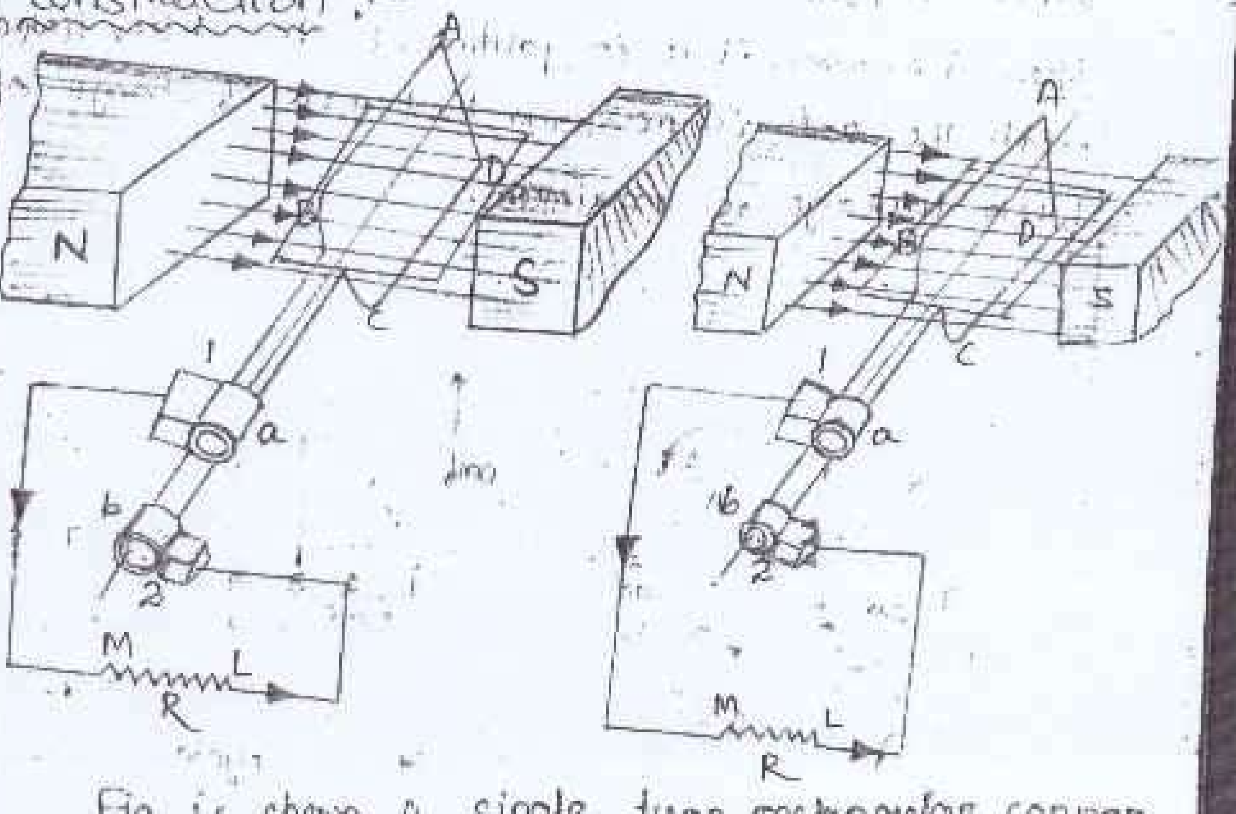


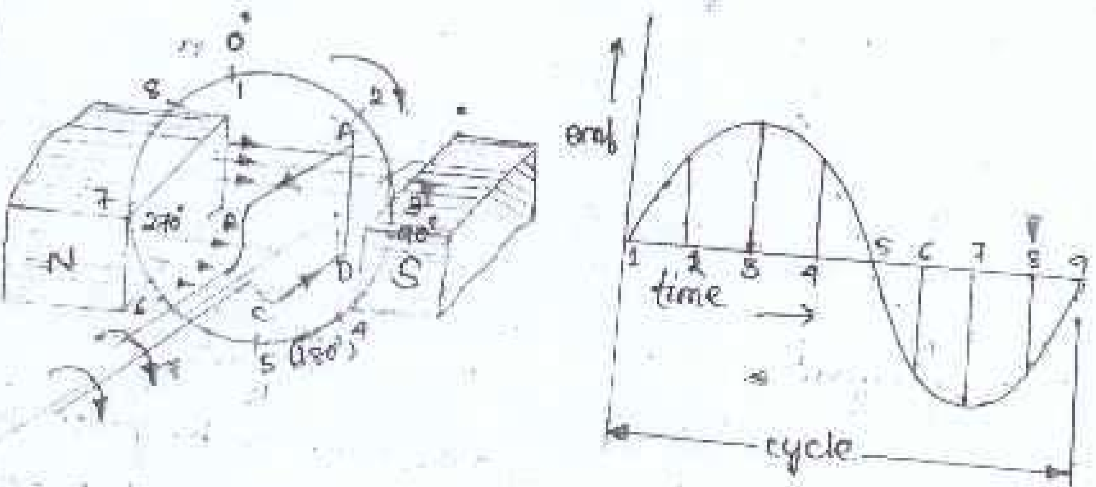
Fig is shown a single-turn rectangular copper coil ABCD rotating about its own axis in magnetic field provided by either permagnet magnet is or electromagnet. The two ends of the coil are joined to two slip-rings 'a' and 'b' which are insulated from each other and from the central shaft. Two collecting brushes (of carbon or copper) press against the slip rings.

their function is to collect the current induced in the coil and to convey it to the external load resistance R.

The rotating coil may be called armature and the magnets as field magnets.

Working Principle :-

Imagine the coil to be rotating in clock-wise direction. As the coil assumes successive positions in the field, the flux linked with it changes. Hence, an emf is induced in it which is proportional to the rate of change of the flux linkages ($e = N d\phi/dt$). When the plane of the coil is a right angles to lines of flux i.e. when it is in position 1, then flux linked with the coil is maximum but rate of change of flux linkage is maximum.



As the coil continues rotating further, the rate of change of flux linkages (and hence induced emf in it) increases, till position 3 is reaches where $\theta = 90°$. Here the coil plane is horizontal i.e. parallel to the lines of flux. As seen, the flux linked with the coil is minimum but rate of change of flux linkage is maximum.

In the next quarter revolution i.e. from 90°-180°, the flux linked with the coil gradually increases, but the rate of change of flux linkages decreases. Hence, the induced e.m.f decreases gradually till in position 5 of the coil; it is reduced to zero value.

So, we find that in the first half revolution of the coil, no (or minimum) emf is induced in it when in position 1, maximum when in position 3 and no e.m.f when in position 5. The direction of this induced emf can be found by applying Fleming's Right-hand rule which gives it's direction from A to B and C to D. Hence, the direction of current flow is ABMLCD. The current through the load resistance R flows from M to L during the first half revolution of the coil.

In the next half revolution i.e. from 180°-360°, the variations in the magnitude of emf are similar to those in the first half revolution. It's value is maximum when the coil is in position 7 and minimum when in position 1. But it will be found that the direction of the induced current is from D to C and B to A. Hence, the path of current flow is along DCLMBA which is just the reverse of the previous direction of flow.

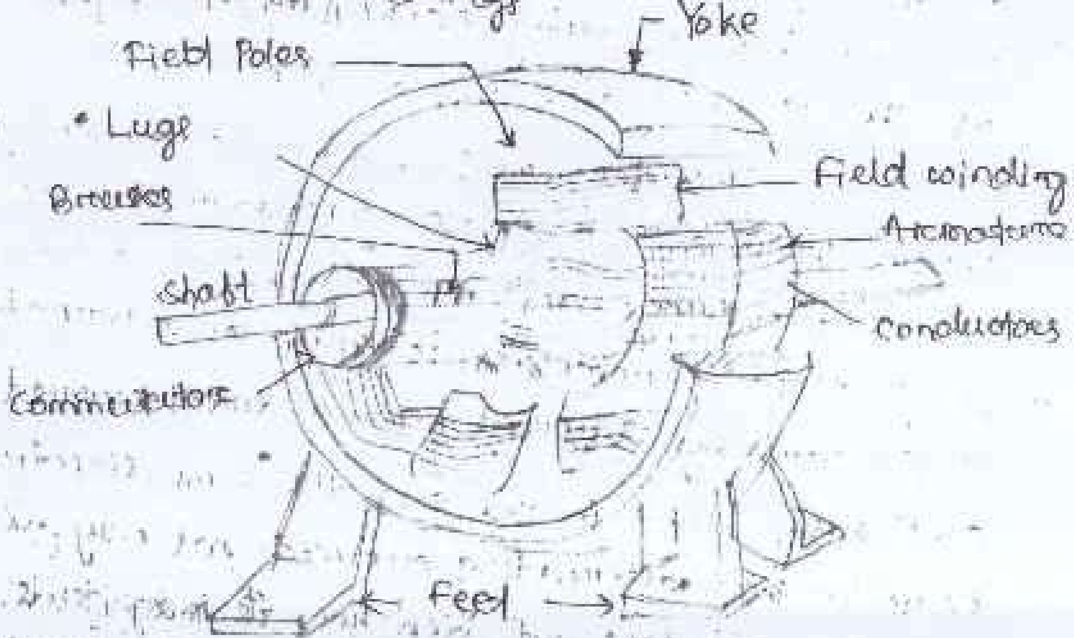
Therefore, we find that the current which we obtain from such a simple generator reverses it's direction after every half revolution. Such a current undergoing periodic reversals is known as alternating current. It is, obviously, different from a direct current which continuously flows in one and the same direction. It should be noted that alternating current not only reverses it's direction, it does not even keep its magnitude constant while flowing in any one direction. The two half-cycles may be called positive and negative half-cycles

For making the flow of current unidirectional in the external circuit, the slip-rings are replaced by split-rings. The split-rings are made out of a conducting cylinder which is cut into two halves or segments insulated from each other by a thin sheet of mica or some other insulating material.

Another important point worth remembering is that even now the current induced in the coil side is alternating as before. It is only due to the rectifying action of the split-rings (also called commutator) that it becomes unidirectional in the external ckt. Hence, it should be clearly understood that even in the armature of a D.C generator, the induced voltage is alternating.

* Parts of Generator:

① Magnetic frame or Yoke ② Pole-cores and pole-shoes
③ Pole coils or field coils ④ Armature Core
⑤ Armature Windings or conductors ⑥ Commutator
⑦ Brushes and bearings



① Magnetic frame or Yoke :-

The outer frame or yoke serves double purpose:

(i) It provides mechanical support for the poles and acts as a protecting cover for the whole machine.

(ii) It carries the magnetic flux produced by the poles.

Yokes are made of cast iron. But for large machines usually cast steel or rolled steel is employed.

② Pole-cores and Pole-shoes :-

The field magnets consist of pole cores and pole shoes. The pole shoes serve two purposes -

(i) They spread out the flux in the air gap and also, being of larger cross-section, reduce the reluctance of the magnetic path.

(ii) They support the exciting coils (or field coils).

There are two main types of pole construction.

(a) The pole core itself may be a solid piece made out of either cast iron or cast steel but the pole shoe is laminated and is fastened to the pole face by means of counter sunk.

(b) In modern design, the complete pole cores and pole shoes are built of thin laminations of annealed steel which are rivetted together under hydraulic pressure. The thickness of laminations varies from 1mm to 0.25mm.

③ Pole coils or Field Coils :- The field coils or pole coils, which consist of copper wire or strip, are former wound for the correct dimension. Then, the over the core.

When current is passed through these coils, they electromagnetise the poles which produce the necessary flux that is cut by revolving armature conductors.

(4) Armature Core :-

It houses the armature conductors or coils and causes them to rotate and hence cut the magnetic flux of the field magnets. In addition to this, its most important function is to provide a path of very low reluctance to the flux through the armature from a N- pole to a S- pole.

It is cylindrical or drum - shaped and is built up of usually circular sheet steel discs or laminations approximately 0.5 mm thick.

(5) Armature Windings or conductor :-

These are first wound in the form of flat rectangular coils and are then pulled into their proper shape in a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slot which are lined with tough insulating material.

(6) Commutator

The function of the commutator is to facilitate collection of current from the armature conductors. It rectified i.e. converts the alternating current (A.C) induced in the armature conductors into unidirectional current in the external load

These segments are insulated from each other by thin layers of mica. The number of segments is equal to the no. of armature coil.

(7) Brushes and Bearings :-

The brushes whose function is to collect current from commutator, are usually made of carbon or graphite and are in the shape of a rectangular copper block.

* Working Principle :-

D.C Generator works according to the principle of Faraday's laws of electromagnetic induction.

Whenever a conductor cuts the magnetic lines of force an emf is induced in it. Here the mechanical power is utilized to rotate the armature. The armature cut and the magnetic field an emf is induced on the armature conductors. The induced emf is $\boxed{e = -N\frac{d\phi}{dt}}$

* Types of armature winding :-

There are two types of armature windings.
(i) LAP winding (ii) WAVE winding

(i) LAP winding - In case of lap winding the no of poles is equal to no of parallel paths (A = P). It is used where high current and low voltage is required.

(ii) WAVE winding : In case of wave winding the no. of parallel paths is always equal to two (A = 2). It is used where high voltage and low current is reqd.

Let P = No of poles

ϕ = flux per pole in web.

Z = Total no. of conductors

N = Speed of armature in rpm

$\frac{Z}{A}$ = No. of conductors / parallel path

The emf induced in the armature due to flux linkage in the conductor is given by $e = -N\frac{d\phi}{dt}$

EMF induced per conductor $(e) = \frac{d\phi}{dt}$ $(\because N = 1)$

Now flux cut per conductor in one revolution $d\phi = P\phi$

N = No. of rotation per min.

No. of rotation / s $= \frac{N}{60}$

Time taken to complete one revolution

$$dt = \frac{1}{N/60} = \frac{60}{N}$$

Now, emf generated per conductor

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

$$= \frac{P\phi}{60/N} = \frac{P\phi N}{60}$$

Emf induced per parallel path $= \frac{P\phi N}{60} \times \frac{Z}{A} = \frac{P\phi ZN}{60A}$

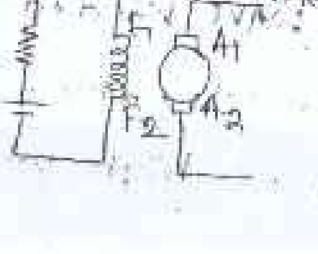
Generated emf $(E_g) = \frac{P\phi ZN}{60A}$ i.e. $\boxed{E_g = \frac{P\phi ZN}{60A}}$

* **Classification of D.C Generator :-**

① Separately excited D.C Generator

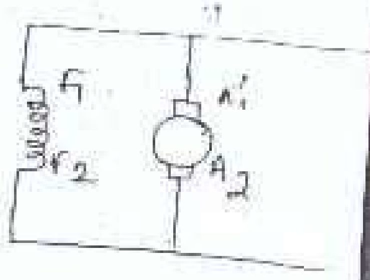
Field winding is excited by some external independent D.C source then it is known as separately excited D.C Generator.

Separated excited D.C Generator



(B) Self-excited D.C generator :-

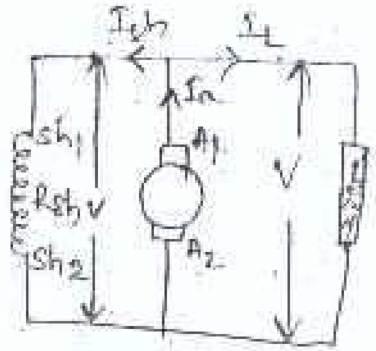
If the field magnets are excited by it's own current, then it is known as self excited D.C Generator. It doesn't require any external source.



According to the connection of the field winding self-excited generators are classified into 3 types.

(A) D.C Shunt Generator
(B) D.C Series Generator
(C) D.C Compound Generator

(A) D.C Shunt Generator



The field winding is connected in parallel with the armature. The field winding is excited by the terminal voltage.

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

where V = Terminal voltage or the voltage across the load.

R_{sh} = shunt field resistance

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

$$E_g = V + I_a R_a + b.d$$

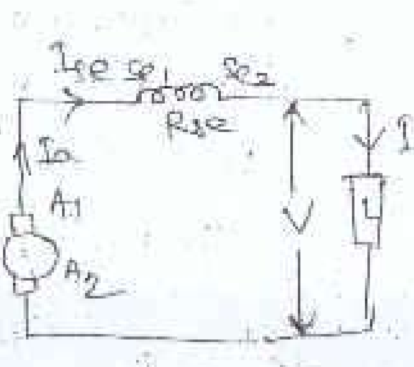
where R_a = Armature resistance which is very very small.

$I_a R_a$ = Armature resistance drop

b.d = brush contact drop

E_g = Generated emf in the armature

(B) D.C Series Generator



The field winding is connected in series with the armature.

Here $I_a = I_{se} = I$

$$E_g = V + I_a(R_a + R_{se}) + b.d$$

Here the field is excited by the load current.

The efficiency will be max^m when $\frac{d\eta}{dI} = 0$

$$\Rightarrow \frac{d}{dI}\left(\frac{VI}{VI + W_c + I^2 R_a}\right) = 0$$

$$\Rightarrow \frac{V[VI + W_c + I^2 R_a] - VI[V + 2IR_a]}{(VI + W_c + I_a^2 R_a)^2}$$

$$\Rightarrow V[VI + W_c + I^2 R_a] - V^2 I + 2VIR_a = 0$$

$$\Rightarrow V[VI + W_c + I^2 R_a] - VI[V + 2IR_a] = 0$$

$$\Rightarrow [VI + W_c + I^2 R_a] = I[V + 2IR_a]$$

$$\Rightarrow VI + W_c + I^2 R_a = VI + 2I^2 R_a$$

$$\Rightarrow W_c - I^2 R_a + 2I^2 R_a$$

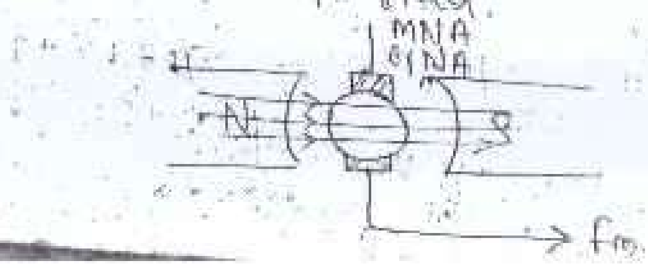
$$\Rightarrow W_c = I^2 R_a$$

Efficiency will be max^m when constant loss is equal to variable. The load current corresponding to max^m efficiency is given by $I = \sqrt{\frac{W_c}{R_a}}$

× **Armature Reaction**:- When current flows through the armature conductors a magnetic field is produced. The magnetic field due to armature current weakens and distorts the main magnetic ~~the~~ field produced by the field poles. This effect is known as armature reaction.

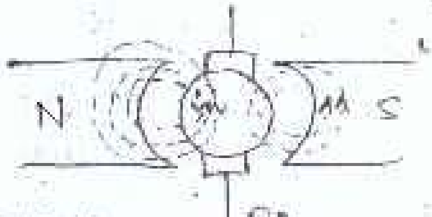
AT NO-LOAD →

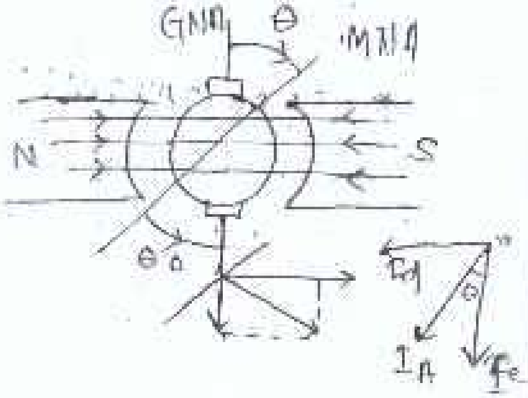
The armature current is zero or small volume. This is due to field flux. The vector of m represents the MMF producing the main field. Here MNA (Magnetic Natural Axis) and GNA (Geometrical Natural Axis) are coincident with each other. The MNA & GNA are perpendicular to field.

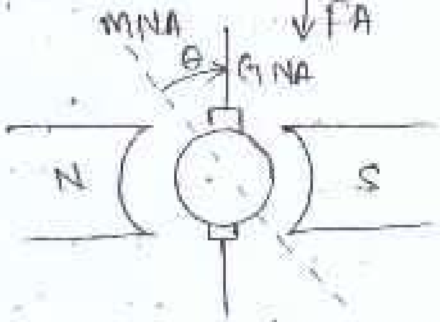


AT LOAD

When the generator is loaded. It will produce a magnetic field considering only the armature current. The vector of A represents both in magnitude & direction of the MMF due to armature winding.







Demagnetising Ampere Turn

Let z = Total no. of armature conduction

I = Armature current

ϕ_m = mechanical degree in forward movement

Total no. of armature conduction in angle

$\angle AOC$ and $\angle BOD = \frac{Z}{360} \times 4\phi_m$

No. of turn under $\angle AOC$ & $\angle BOD = \frac{Z}{360} \times 2\phi_m$ ($\because$ two conduction constitute one turn)

Demagnetizing ampere turns per pair of poles $= \frac{ZI}{360} \times 2\phi_m$

Demagnetizing ampere turns per pole $= \frac{ZI}{360} \times \phi_m$

CROSS MAGNESING AMPERE TURN

Total no. of conductors per pole $= \frac{Z}{P}$

Help Demagnetizing conductors per pole $= \frac{ZI}{360} \times 2\phi_m$

Cross magnetising conductors pole = Total no. of conductors per pole

$= \frac{Z}{P} - \frac{Z}{360} \times \frac{2\phi_m}{360}$

$= Z\left(\frac{1}{P} - \frac{2\phi_m}{360}\right)$

Cross magnetizing Ampere turns per pole.

$$= \frac{Z}{P} - \frac{Z}{360} \times \frac{2\phi_m}{360}$$

$$= Z\left(\frac{1}{P} - \frac{2\phi_m}{360}\right)$$

$$\phi_{mech} = \frac{\phi_{elect}}{\text{Pair of poles}}$$ (If the angle is given in electrical degree)

*** COMMUTATION**:- The emf include in the armature conductors of an machine is an alternating in nature. The current in a conductor for. in one direction when it is under north pole & in reverse direction when it is under south pole.

The reversal of current from (+) I to (-) I has to occur when two commutator segments to which the armature coil is connected are short ckted by a brush. This process is known as commutation period. The current is in the coil has to reach it's full value when in the reversed direction at the end of commutation period. If this doesn't happen the difference of current would pass from commutator to brush in the form of an AC arc. This arcing causes sparking, pitting and roughing of the commutator surface.

Two major effect of disturb the commutation process are armature reaction and reactance voltage. The armature reactance causes a shift of the M.N.P (magnetic Neutral Plane) in the forward direction for the generator & in the back direction for the motors. For proper commutation in the commutator brush should short circuited.

Through the magnitude of inductance of very high and therefore the magnitude of induced emf coil be appreciable. This EMF is known as reactance voltage and oppose the reversal of current. Thus sparking occurs at the brushes

Commutation problem can be minimized by different method.

(i) EMF commutation
(ii) By using interpoles
(iii) By resistance commutation
(iv) By using compensating winding

By Emf Commutation

In this method, a voltage which cancels the reactance voltage is used to ensure good commutation. One way to cancels the reactance voltage by shifting the brush a little further than the MNP. so that they lie in the fringe of the field of the next pole. The Emf induced in the coil opposes the reactance voltage and opposes forces the reversal of current in the coil. Howevere this method isn't used because the extend of shifting of brushes depends on the load current and it isn't practicable to shift the brushes every time as the load current changes.

By using Interpoles Or Compoles:

The interpoles helps on reducing the sparking due to commutation problem of current from A.C to D.C. They are small poles fixed to the yoke and placed in between the main poles. The windings of these poles has few turns of thick copper wire and is connected in series with the armature ckt. Therefore the MMF of an interpole is proportional to armature current. It's function is

(i) Ensure automatic neutralization of reactance voltage.
(ii) Cancellation of cross-magnetization effect of armature reaction.

Resistance Commutation :-

The next approach to achive two commutation by the use of brushes with high contact resistance than the brushes made from other materials. Hence carbon is used as a brush universally. Also carbon has(-)ve temp. co-efficient of resistance property.

Compensating Winding :-

In order to neutrallisation the cross magnetizing effect, compensating winding are used. It is used only in case of large machine. These windings are embeded in slots in the poles shoes in series with armature in such a way that the current in them flows in opposite directiction to that of in the armature induction directly below the poles - shoes.

No. of compensating winding ampere turns per pole $= \frac{0.7 \times Z I}{2P} = \frac{0.7 \times Z}{2P}$

DUMMY COILS

When a machine has a wave winding is very necessary to use extra coils to maintain the mechanical balance of the armature. This coil is completely insulated from the remaining winding and it is used for only mechanical balance. It is known as dummy coils.

$$Y_C = \frac{2(C \pm 1)}{P}$$

$$\boxed{Y_C = \frac{Z \pm 2}{P}}$$

C = No. of coils

Y_C = Commutator pitch

P = No. of poles

Critical field resistance of a shunt Generator

The max^m efficiency emf generated is OC, if the shunt field resistance is increased, then the maximum generated emf is represented by OC. So that if becomes a tangent to the curve. The value of field resistance corresponding to the point of intersection of the field resistance for a given speed again it is seen that if the field resistance is increased further beyond the critical resistance the generator doesn't excite at all in other words the critical field resistance R_C of a shunt generator is the max^m value of field resistance beyond which the generator can't build up voltage.

~~Critical speed for which a given shunt fie~~

Critical speed of a shunt Generator →

The speed for which a given shunt field resistance acts as critical field resistance is known as critical speed.

* Characteristics of D.C Generator →

There are three different types of characteristics

① No-load / Magnetization / open ckt characteristics (OCC)

② Internal characteristics

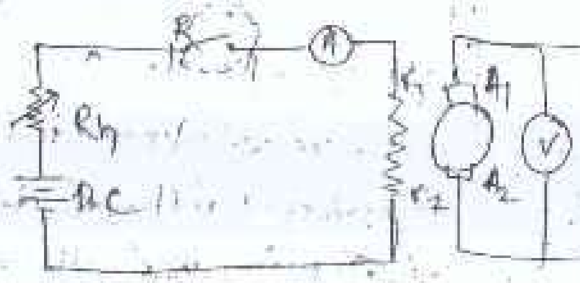
③ Load / External characteristics

① No-load / Magnetisation / Open ckt characteristics (O.C.C)

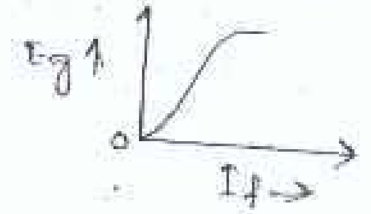
It is graphical relationship between generated emf and field current ($E_g \sim I_f$)

For a separately excited Generator

Let, the switch is open, but the generator is driven by some external source (Prime-mover or d.c motor). It is seen that the generated

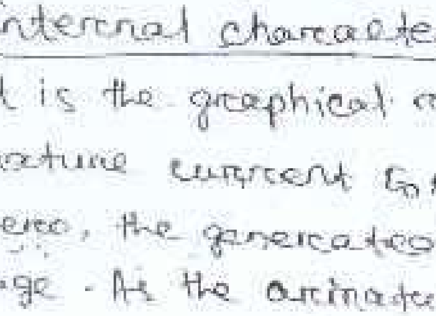


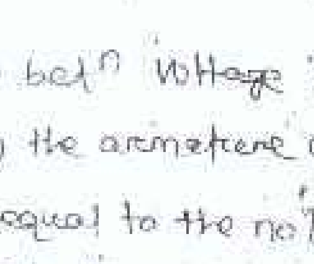
Now, the switch is closed and the field current increases gradually. It is seen that as the field current increases, the generated emf is proportional to the field flux. This will continue till saturation. After saturation of magnet field, the field current may be increases but the field flux remains constant. So the generated emf remains constant even if the field current increases.



For self-excited D.C Generator

When the field current is zero, the EMF induced in the armature is (OA). This is due to the presence of residual magnetisation. Again if the field current increases the EMF increases and it will continue up to the point of saturation. After saturation the field current may increase, but field flux remains constant, so that EMF induced will remain constant.





② Internal characteristics →

It is the graphical relationship betn voltage & armature current Eg & Ia. When the armature current is zero, the generated EMF is equal to the no load voltage. As the armature current increase the resistance drop is (IaRa drop) increases. So, the terminal voltage decreases. At heavy loads, due to armature reaction the terminal voltage decreases to a lower value we know that, $E_g = V + I_aR_a$

$$V = E_g - I_aR_a$$

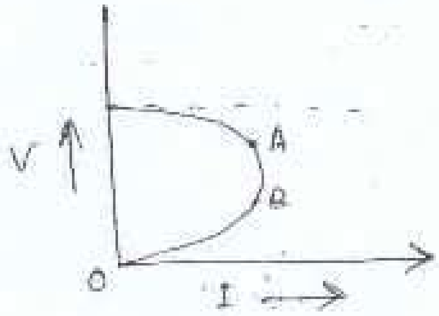
③ External / Load characteristics :- ($V \sim I$)

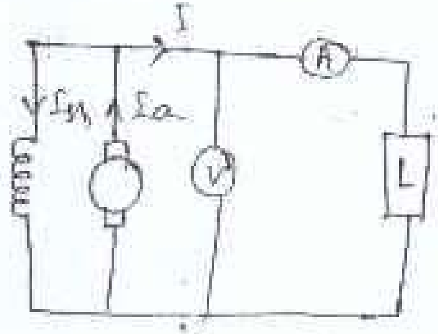
It is the graphical relationship between the two terminal voltage and the load current. $V \sim I$

For shunt Generator ->

It is see that when the load current increase, the terminal voltage decreases. As the load current increase I_aR_a drop also increases.

But at 'point A' if further the load increases the terminal voltage decrease suddenly. This is due to the armature reaction. $V = E_g - I_aR_a$





The drops are due to,

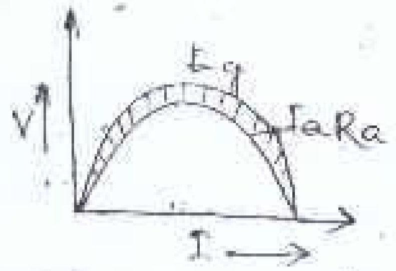
① Armature resistance drop (I_aR_a drop)
② Armature reaction
③ The combining effect, the terminal voltage decreases suddenly as the load current increases it is represented by A to B.

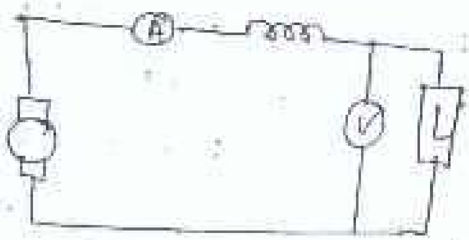
If further the load increases, the generator will come to it's unstability condition, which is shown by dotted lines. If the load increases further the terminal voltage decrease to a very lower value & the generator can't main-tain it's stability. Automatically it will come to 'OFF' position.

This is known as dropping characteristic of the shunt generator. Due to this reason it's suitable for lighting purposes & battery charging

For series Generator:

It is seen that load current increases the terminal voltage increases. This is due to load current passes through the field. It continue upto the point of saturation. After saturation, if the load current increases, the terminal voltage decreases. This is known as rising characteristics of a D.C series generator. So it is used as a booster. $V = E_g - I_a R_a - I_a R_{se}$



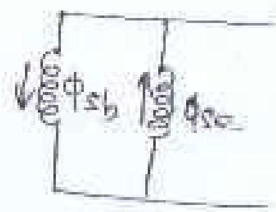


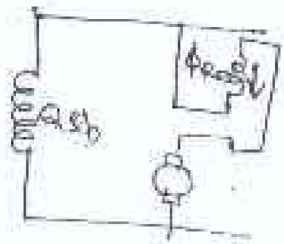
The drops are due to

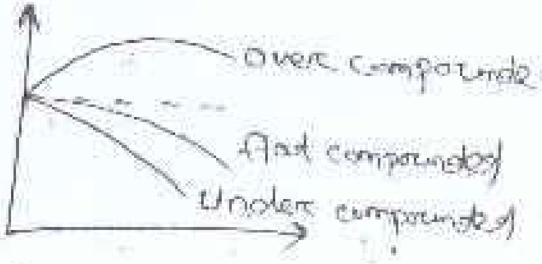
(i) $I_a R_a$ drop. (ii) $I_a R_{se}$ drop

(iii). Armature reaction

For compound Generator →



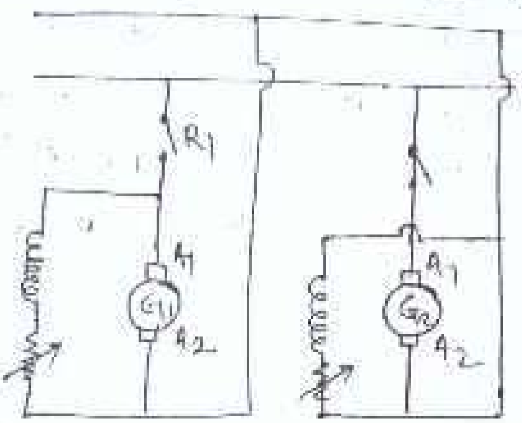




Differential compound D.C Generator Net phase $= \phi_{sh} - \phi_{se}$

Commulatively " D.C " Net phase $= \phi_{sh} + \phi_{se}$

Parallel operation of a D.C Generator



* Condition for parallel operation :-

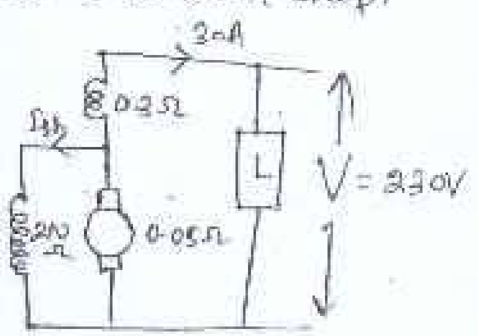
(i) Polarity must be maintained.

(ii) The terminal voltage of generator must be equal to the bus-bar voltage $V_1 = V_2 = V$

(iii) The load sharing should be equal.

Prob① A short shunt compound D.C generator deliver a load current of 30A at 220V, and has armature, series field, and shunt field resistance of 0.05Ω, 0.30Ω & 200Ω respectively. Calculate the induced emf and armature current. Allow 1.0V per brush for contact drop.

Solⁿ: Given data



$I = 30A$, $V = 220V$

$R_a = 0.05\Omega$, $R_{se} = 0.30\Omega$

$R_{sh} = 200\Omega$, $I_a = ?$

$E_g = ?$

Shunt field voltage drop = V + Series field drop

$= 220 + I \times 0.03$

$= 220 + 30 \times 0.03 = 229V$.

$I_{sh} = \frac{229}{200} = 1.145A$

$E_g = V + I_a R_{se} + I_a R_a + ...$

$= 220 + 30 \times 0.03 + ... 1.145 \times 0.05$

② A 4-pole D.C shunt generator with a shunt field resistance of 100 Ω & an armature resistance of 1 Ω has 378 wave wound conductor in armature. The flux per pole is 0.02 wb. If a load resistance of 10 Ω is connected across the armature terminals and the generator is driven at 1000 rpm, calculate the power absorbed by the load.

Soln

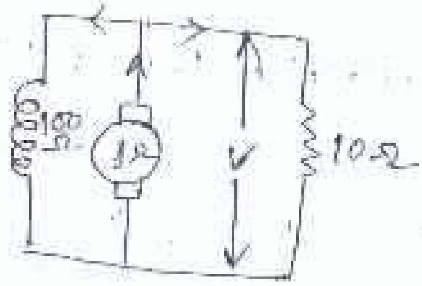
Given data

$P = 4$, $R_{sh} = 100\,\Omega$, $r_a = 1\,\Omega$

$Z = 378$, $A = 2$

$\phi = 0.02\,wb$, $R_L = 10\,\Omega$

$N = 1000$ rpm



$$E_g = \frac{P\phi Z N}{60A} = \frac{4 \times 0.02 \times 378 \times 1000}{60 \times 2} = 252\,V$$

V is the terminal voltage.

$$I = \frac{V}{10}, \quad I_{sh} = \frac{V}{100}\,A$$

$$\text{Armature current} = \frac{V}{10} + \frac{V}{100} = \frac{11V}{100}$$

$\therefore V = E_g - \text{armature drop}$

$= 227\,V$

Ans

Interpoles:- These are also called as compoles, the necessity of these poles are that they produce reversing voltage to neutralize the reactance voltage. Thus the cross magnetising effect of armature reaction is neutralised and commutation becomes spark less and communication is improved.

② D.C MOTOR

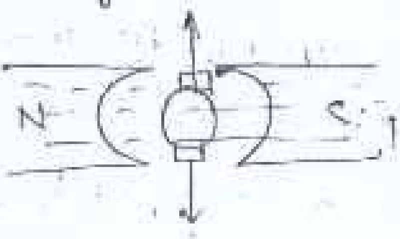
Defn:- It is an electrical machine which converts electrical energy to mechanical energy.

A D.C machine is similar in construction to a D.C generator. The same D.C machine can be employed as a generator or a motor depending upon the use.

Working

It works on the principle of that whenever a current carrying conductor is placed inside a magnetic field, it experience a mechanical force tending to rotate the conductor.

If force experienced by the conductor under the influence of N-pole is upward, then the force under the influence of S-pole will be downward. These two equal and opposite force will produce a torque since the two forces are acting on a common conductor and the line of axis. Production of torque, the conductor start rotating.



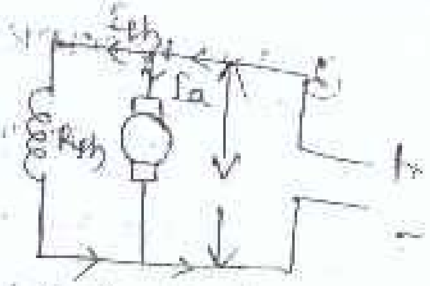
* Significance of back EMF →

When the armature inside the magnetic field rotates, the conductor placed in the slots of armature cuts the magnetic flux and hence an emf is induced in it. This induced emf is known as back EMF. Its direction is opposite to the applied emf.

Applying KVL

$V - E_b - I_a R_a - b.d = 0$

$\Rightarrow I_a R_a = V - E_b$ (neglecting brush drop)



$\Rightarrow I_a = \frac{V - E_b}{R_a} = \frac{\text{net voltage}}{\text{Armature resistance}}$

where, E_b = back emf

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

Voltage eqn of a D.C Motor :-

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

$\Rightarrow I_a R_a = V - E_b$

$\Rightarrow V = E_b + I_a R_a$

$\Rightarrow E_b = V - I_a R_a$

$\therefore \boxed{V = E_b + I_a R_a}$ voltage eqn of motor.

Multiplying I_a in both side we get

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

where, $V I_a$ = Input to armature

$I_a^2 R_a$ = Armature cu. loss

$E_b I_a$ = electrical equivalent of mechanical power known as o/p of the motor

Condition for maxm o/p :-

The mechanical power developed by motor is

$$P_m = E_b I_a = V I_a - I_a^2 R_a$$

$\frac{d P_m}{d I_a} = 0 \Rightarrow \frac{d}{d I_a}(V I_a - I_a^2 R_a) = 0$

$\Rightarrow V - 2 I_a R_a = 0$

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

We know that, $E_b = V - I_a R_a$

$\Rightarrow E_b = V - \frac{V}{2} = \frac{V}{2}$

$\Rightarrow \boxed{E_b = \frac{V}{2}} \rightarrow$ condition for maxm. power o/p.

* Torque eqn.:

The turning or twisting movement of a force about an axis is called torque.

$T = F \times r$ = Newton meter

Work done in one revolution

$W.D = F \times 2\pi r$ joule

Let, n = no. of rotation per second.

Power developed $= F \times 2\pi r \times n$ J/sec

$= (F \times r)\, 2\pi n$ J/sec = watts

where $\omega = 2\pi n$ = angular velocity

Electrical power converted into mechanical power in the armature $E_b I_a = 2\pi n T_a$

$$\Rightarrow T_a = \frac{P\phi ZN}{60A} \times \frac{I_a}{2\pi N/60} \quad (N \text{ in rpm})$$

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

$$\Rightarrow T_a = 0.159\, \phi I_a Z \left(\frac{P}{A}\right) \text{ N.m} = 9.55 \frac{E_b I_a}{N} \quad (N = \text{rpm})$$

i.e. $T_a = K\phi I_a$

where $K = 0.159 Z \left(\frac{P}{A}\right)$ = constant

$T_a \propto I_a$ for (shunt motor since 'ϕ' is constant)

$T_a \propto I_a$ (for series motor since 'ϕ' $\propto I_a$)

$T_{a1} = K\phi_1 I_{a1}$

$T_{a2} = K\phi_2 I_{a2}$

$$\Rightarrow \frac{T_{a2}}{T_{a1}} = \frac{K\phi_2 I_{a2}}{K\phi_1 I_{a1}}$$

$$\Rightarrow \frac{T_{a2}}{T_{a1}} = \frac{I_{a2}}{I_{a1}} \quad (\text{for shunt motor } \phi \text{ is constant})$$

$$\Rightarrow \frac{T_{a2}}{\;} = \frac{I_{a2}}{\;} \quad (\text{for series motor } \phi \text{ is } \propto I_a)$$

Speed Equation

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

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

$$\Rightarrow N = k\frac{E_b}{\phi} \quad (\text{where } k = \frac{60}{PZ} \text{ i.e constant})$$

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

$$\Rightarrow N \propto E_b \quad (\text{for shunt motor})$$

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

Again $N = \frac{E_b}{\phi}$

$$\Rightarrow N \propto \frac{1}{\phi} \quad (\text{If } E_b \text{ is constant})$$

$$\Rightarrow N \propto \frac{1}{f}$$

For shunt motor

N_1 = speed of the 1st case

I_{a1} = Armature current in 1st case

ϕ_1 = flux/oppose in 1st case

N_2 = Speed of the 2nd case

I_{a2} = Armature current in 2nd case

ϕ_2 = Flux/oppose in 2nd case

$$E_{b1} = \frac{P\phi_1 Z N_1}{60A}$$

$$E_{b2} = \frac{P\phi_2 Z N_2}{60A}$$

$$N_1 = k\frac{E_{b1}}{\phi_1}$$

$$N_2 = k\frac{E_{b2}}{\phi_2} \quad (\text{where } k = \frac{60A}{PZ} \text{ is constant})$$

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

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}} \quad (\because \text{ sine } \phi_1 = \phi_2 = \phi)$$

for series motor →

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

$$\Rightarrow \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$$

Shaft torque :- The torque which is available for doing work is known as shaft torque (T_{sh}). It is a available for shaft.

The motor o/p is $= T_{sh} \times 2\pi n$ (watt) (n in rps)

$$T_{sh} = \frac{\text{o/p in watt}}{2\pi n} \text{ N.m (n in rps)}$$

$$T_{sh} = \frac{\text{o/p in watt}}{2\pi N/60} \text{ N.m (n in rps) N.m} = \frac{60}{2\pi} \times \frac{o/p}{N}$$

$$T_{sh} = 9.55 \frac{o/p}{N}$$

The difference of ($T_a - T_{sh}$) is known as lost torque and due to iron & frictional losses of the motor.

* Characteristics of the D.C motor →

(i) $T_a \sim I_a$ (ii) $N \sim I_a$ (iii) $T_a \sim N$

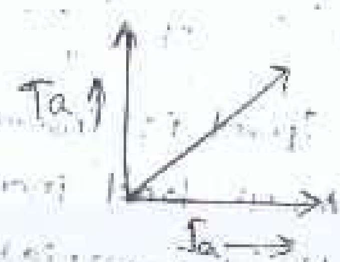
for shunt motor →

It is seen that $T_a \propto \phi I_a$

$T_a \propto I_a$ (for shunt motor, ϕ = constant)

(i) $T_a \sim I_a$ characteristics :-

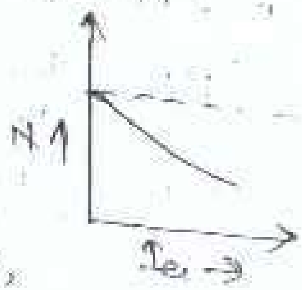
From the ~~abo~~ above derivation it is seen that proportional to the armature current increased. It is straight line passes through origin. A heavy starting load will need a heavy starting current.



(ii) $N \sim I_a$ characteristic

We know that $N \propto \frac{E_b}{\phi}$

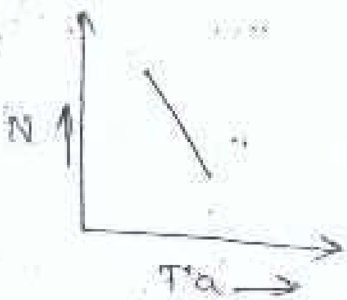
$N \propto E_b \Rightarrow N \propto V - I_a R_a$



When armature current increases, $I_a R_a$ drop increases. The net voltage across the armature decreases. The decreases in speed is about 10%.

(iii) $T_a \sim N$ characteristic

From the above two charact. Is seen that, when the torque increases speed decreases.

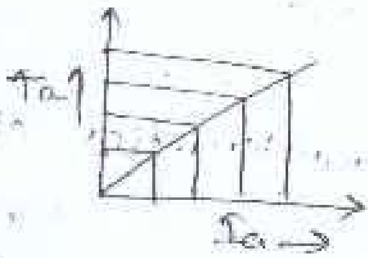


For series motor

(i) $T_a \sim I_a$

$T_a \propto \phi I_a$

$T_a \propto \phi I_a^2$ ($\because \phi \propto I_a$)



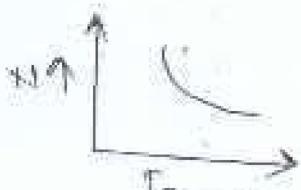
The armature torque (T_a) is directly proportional to the square.

(ii) $N \sim I_a$

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

$N \propto \frac{1}{\phi}$ (if E_b = constant)

$N \propto \frac{1}{I_a}$ ($\phi \propto I_a$)



Speed is inversely proportional to armature current. As the load increases, speed decreases & vice versa. It is a variable speed motor.

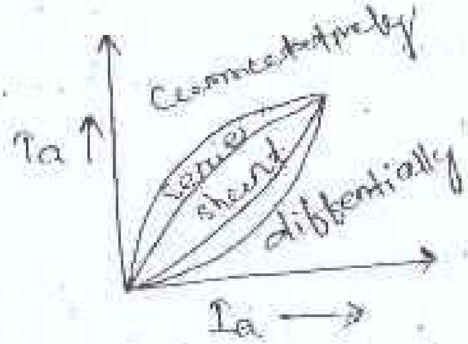
It is advised not to start the series motor without load. Since at no load.

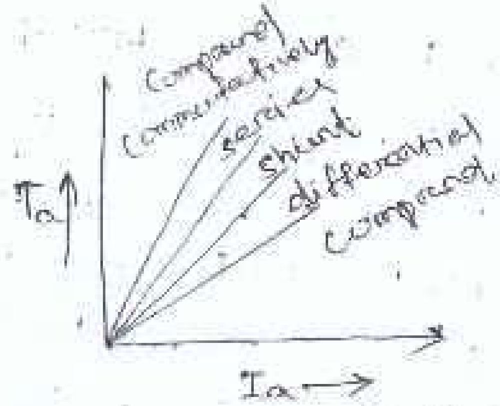
The speed of motor will be dangerously high. It should always be started with load.

(iii) $T_a \sim N$

From the above two characteristics, it is seen that, when the speed is high torque is low & vice versa.

For compound motor →





For differentially compound D.C MOTOR

$T_a \propto \phi I_a$

Torque increases as the armature current increases, but this isn't so rapidly like cummulatively compound D.C motor, since the series field flux and shunt field flux are opposite to each other. Hence the torque increase.

For cummulatively compound D.C MOTOR

$T_a \propto I_a$

Torque increases rapidly as the armature current increases, since $T_a \propto \phi I_a$. As the load current increases, net flux increases.

(i) $N \sim I_a$

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

$N \propto \frac{1}{\phi}$ (if E_b = constant)

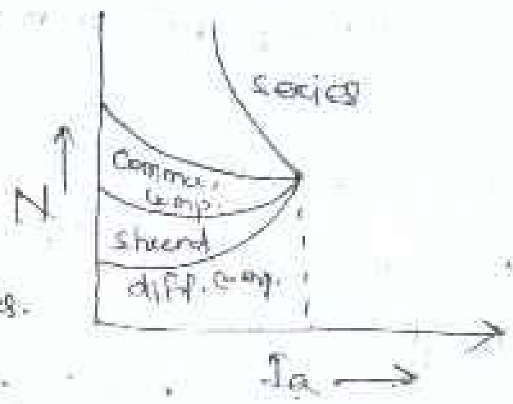
$\Rightarrow N \propto \frac{1}{I_a}$ ($\phi \propto I_a$)

Since 'ϕ' increases as the series field flux & shunt field aids. So the speed decrease as the I_a inc...

For differentially compound D.C motor

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

Since 'ϕ' increases as series field flux aids, So the speed decreases as the armature current increases.



USES OF D.C MOTOR :-

(i) Shunt motor :- It is medium starting torque & nearly constant speed motor. It is used in lathe paper mill, fan etc. It's starting torque is about 1.5 times of full load torque.

(ii) Series motor → It is a high starting torque and variable speed motor. It is used for traction work i.e. electrical locomotives, rapid transit system, cars etc. and increases hoists and conveyers.

(iii) Compound motor →

(i) ~~Differentially~~ Commutatively compound D.C motor is high starting torque, variable speed motor. It is used in elevator, conveyors, heavy planers, rolling mills air compression etc.

(ii) Differentially compound D.C motor can be designed to give an accurately constant speed under all conditions. They find limited application for experimental and research work.

* Speed control of D.C motor →

(I) Shunt motor

(a) Armature voltage control method

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

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

$\Rightarrow N = K \frac{E_b}{\Phi}$ (where $K = \frac{60}{PZ}$ i.e. constant)

$\Rightarrow N \propto \frac{E_b}{\Phi}$

$\Rightarrow N \propto E_b$ (for shunt motor)

$\Rightarrow N \propto V - I_a R_a$

$\Rightarrow N \propto V - I_a(R_a + R)$

An external resistance 'R' is connected in series with the armature ckt in order to vary the drop when the drop increases the voltage across the armature (E_b) decreases. Hence the speed of the motor decreases. In this method speed can be decreased. When the load increases, the speed decreases in speed is about 10%.

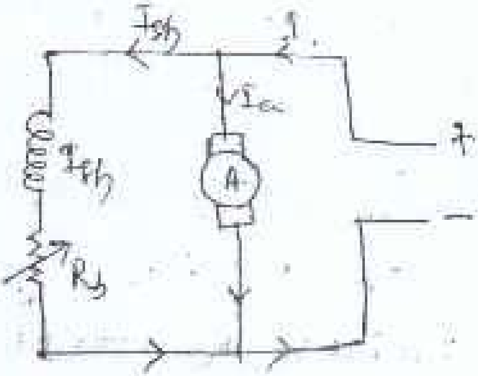
Ⓑ field flux control method :-

$\Rightarrow N \propto \frac{E_b}{\Phi}$

$\Rightarrow N \propto \frac{1}{\Phi}$ (if E_b = const.)

$\Rightarrow N \propto \frac{1}{I_f}$ ($\because \Phi \propto I_f$)

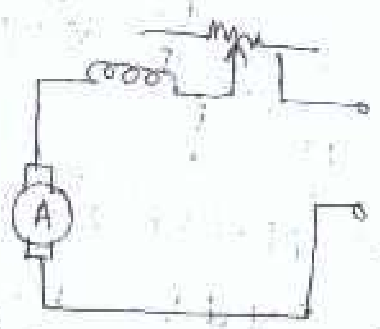
$\Rightarrow I_f = I_{sh} = \frac{V}{R_{sh} + R}$



Hence an external resistance is connected in series with the shunt field. By increasing the shunt resistance, the field current can be decreased since speed is inversely proportional to field current. When the field current decreases, speed increases in ratio 2 : 1. In this method the speed of the motor is increased.

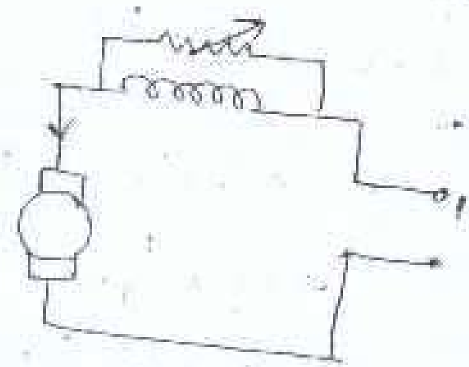
Series Motor

① Field Tapping method :-



In this method, deviator point can be moved one point another and there by increasing or decreasing the flux increases no of turns. If the no. of turns increases, then the flux increases, then two field flux increases result decreasing the speed. If the no. of turns decreases, then the ffield flux decreases result in increasing the speed. This method is often used in, electric fraction.

② Field Diverter Method :→



A diverter is connected across the series field. Any desired amount of current can be passed through the diverter by adjusting the resistance. Hence the flux can be decreased and can continuously, the speed of motor increased.

③ Variable Resistance in series with motor →

By increasing the resistance in series with the armature, the voltage applied across the armature terminal can be decreased.

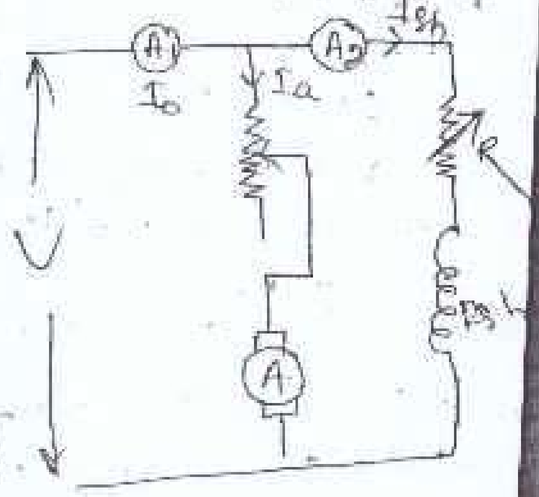
With reduce voltage across the armature, the speed is reduce. However it will be noted that since full motor current passes through the this resistance there is a considerable loss of power in it.

SWIN BURNE'S TEST:-

It is suitable for shunt motor. It is a simple method in which the losses are measured separately & the efficiency at any desired load can be determined in which flux is practically constant.

The machine runs as a motor on no-load at it's rated voltage. The speed is adjusted in the rated speed with the help of shunt Regulator.

The no-load current 'I_0' is measured by the ammeter 'A_1' and shunt field current 'I_{sh}' is measured by ammeter 'A_2'.



Initially there is no-load in motor. Let,

V = supply voltage

I_0 = no-load current

I_{sh} = shunt field current $= \frac{V}{R_{sh}}$

$I_{a0} = I_0 - I_{sh}$ = no-load armature current.

No load I/p to motor $= VI_0$ watt

At no-load, I/p = losses

$VI_0 = W_c + I_{a0}^2 R_a$

Constant loss $W_c = VI_0 - I_{a0}^2 R_a$

WHEN LOAD

I = load current at which efficiency is reqd.

V = supply voltage

∴ motor I/P $= VI$ watt

Armature current $= I - I_{sh}$ (if m/c motoring)

$I_a = I + I_{sh}$ (if m/c in generating)

For motor

$$\eta = \frac{O/P}{I/P} = \frac{I/P - losses}{I/P}$$

$$\eta = \frac{VI - (W_c + I_a^2 R_a)}{VI} \quad (I_a = I - I_{sh} \text{ for motor})$$

For Generator

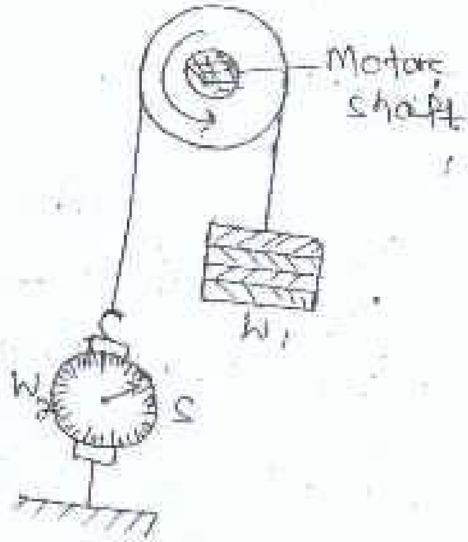
$$\eta = \frac{O/P}{I/P} = \frac{O/P}{O/P + losses}$$

$$\eta = \frac{VI}{VI + (W_c + I_a^2 R_a)} \quad (I_a = I + I_{sh} \text{ for generator})$$

* Determination efficiency by Break Test →

One end of the batol is fixed to earth via spring balance and the other is connected to suspended weight W_1.

The motor reserve and the load on the motor is adjusted till it carries it's full load current.



Let, W_1 = suspended voltage in kg.

W_2 = Reading on spring balance in kg.

The net pull on the band due to friction at the pulley is $(W_1 - W_2)$ kg.

$F = 9.81 (W_1 - W_2)$ Newton.

If R = Radius of pulley in meter

N = Motor or pulley speed in r.p.s.

Then, shaft torque developed be the motor.

$T_{sh} = 9.81 (W_1 - W_2) R$ (N-m.)

Motor O/P power $= T_{sh} \times 2\pi N$ shaft

$= 61.68 N (W_1 - W_2) R$ watt

Let, V = supply voltage

I = full load current taken by motor

Then motor input power = VI watt.

The efficiency of motor is given by

$$\eta = \frac{O/P\ power}{I/P\ Power}$$

$$\boxed{\eta = \frac{61.68\,N(\omega_1 - \omega_2)}{VI}}$$

(Q.)

NECESSITY OF STARTERS →

At the time of starting, the back emf is zero. The armature resistance is also very small. Hence the current that flows through the armature is very large.

$$I_a = \frac{V - E_b}{R_a} = \frac{V - 0}{R_a} = \frac{V}{R_a}$$

At the time of starting the D.C motor draw very very high current which is about 15 to 20 times of their full load current, the motor may burn. In order to save the motor from no-load and over load and also to limit the starting current starter are necessary.

Starter is a device, which will limit the starting current & also provides no-load & over load protection.

There are three types of starters

(i) Two point starter → It is used for starting D.C series motor.

(ii) Three point starter → It is used for starting D.C shunt motors.

(iii) 4 - point starter → It is used for compound

Speed control by series parallel method:

when joined in parallel the voltage across each motor is V through the current drawn by each motor is $\frac{I}{2}$.

$$N \propto \frac{E_b}{\phi} \propto \frac{E_b}{I_f} \propto \frac{E_b}{I/2}$$

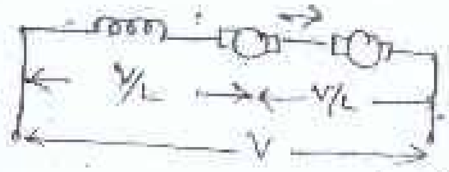
Since E_b is approximately equal to the apply voltage

$$N \propto \frac{V}{I/2} \propto \frac{2V}{I}$$

we know that, $T_a \propto \phi I_a^2$ (since $\phi \propto I$)

i.e. $T_a \propto \left(\frac{I}{2}\right)^2 \propto I_1^2/4$

WHEN IN SERIES



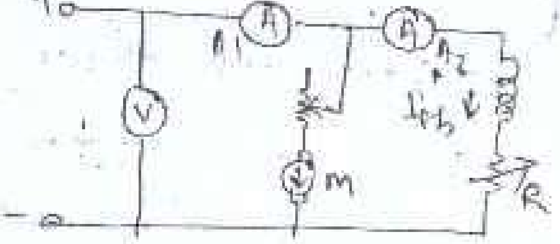
when in series, the two motors have same current the supply voltage becomes half.

$$N \propto \frac{E_b}{\phi} \propto \frac{V/2}{I}$$

$$N \propto \frac{V}{2I}$$

The speed is $\frac{1}{4}$th of the speed as compared to when connected in parallel

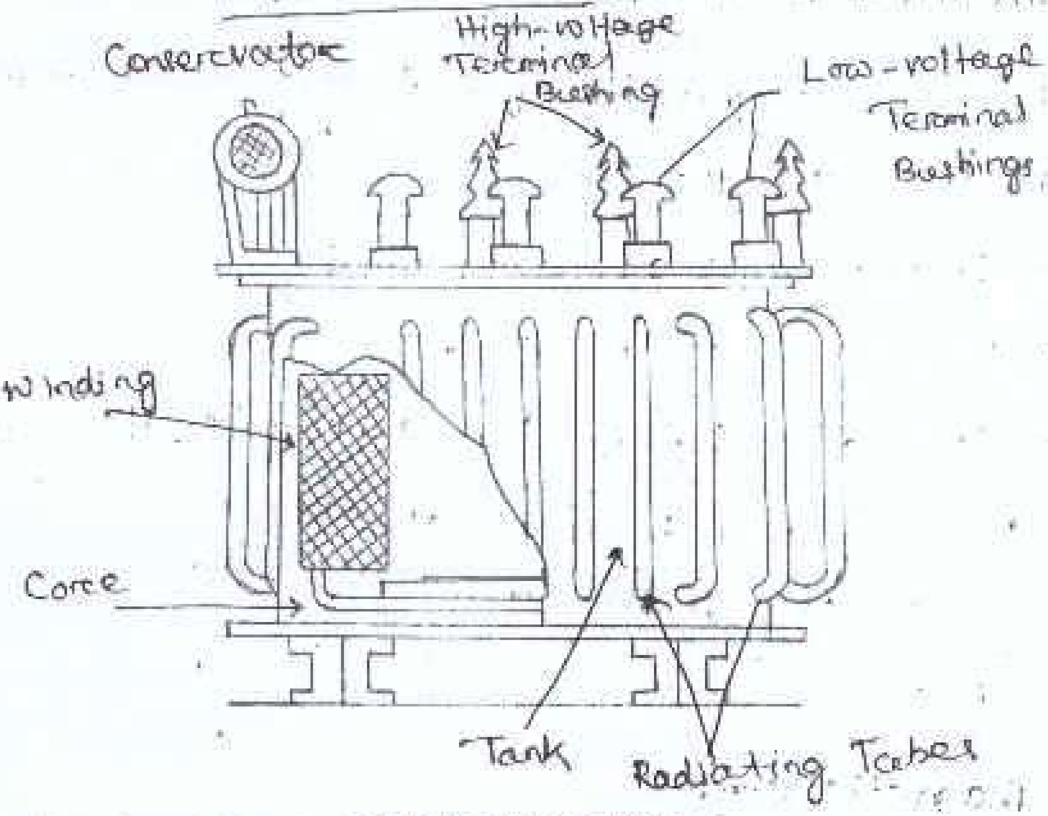
when in parallel



Similarly $T_a \propto \phi I \propto I^2$

The torque is four time of that produced by motor when in parallel. At high speed, the motor join in parallel. At the time of starting, the D.C series motor are connected in series to obtained high starting torque. But at the time of running, they are connected

TRANSFORMER



SINGLE PHASE TRANSFORMER

* TRANSFORMER :- A transformer is a static (stationary) piece of apparatus by means of which electrical power in one circuit is transformed into electric power of the same frequency in another circuit.

→ A transformer is a device that -

(a) Transform electric power from one ckt to another.

(b) It does so without a change of frequency.

(c) It accomplishes this be electromagnetic induction.

(d) Where the two electric ckts are in mutual inductive influence of each other

OR

A transformer is a static device which electric power in one circuit is transformed into another circuit without change in frequency.

(ii) Primary and Secondary :- The primary and secondary windings, basically consist of a series of turns, called coils, wound round the core. The coils of transformer windings are generally of two main types.

(i) Cylindrical Concentric coils

(ii) Sandwich coils

→ For transformers of high ratings a large area of cross-section of winding's wires has to be provided.

→ Conductors of large cross-section give rise to eddy current losses with the winding wire and also they are difficult to handle.

→ The conductor section is therefore subdivided to reduce the eddy-current loss in the winding wire.

→ It also facilitates the control of leakage reactance as it provides better coupling between the primary and secondary windings.

→ In making windings of large transformers, instead of using a single conductor with large cross-section a no. of flat conductor sections are used.

(iii) Insulations of Windings →

→ Enamel insulation is used as the inter-turn insulation of low-voltage transformers. For power transformers enamelled copper with paper insulation is also used.

→ Cotton tape impregnated with varnish is used for reinforcement of insulation between turns and coils.

→ Ordinary porcelain insulators can be used as bushings upto a voltage of 33kV.

→ Due to electric field existing around the conductor, the impurities in oil will try to align themselves in the radial direction, thus creating a possible path for the breakdown of insulation.

→ To avoid this happing a no. of hollow bakelite tubes are placed concentrically around the conductor inside the bushing.

Conservator :- It is a small drum mounted over the top of the main tank. It is connected through a pipe to the transformer tank containing oil. A level indicator is fixed to check the level of transformer oil. The function of conservator is to take up the expansion and contraction of the oil with changes of temperature in service, without allowing the oil to come in contact with the air, from which it is liable to take up moisture.

Buchholz Relay :- It is a safety device, which trips off the transformer circuit in case of short circuit or an excessive heat in the core & oil etc. It is connected in between the transformer tank & conservator tank i.e, in the pipe connecting the tanks. If faults occurs in the transformer, oil is heated up and is formed into a vapour which completes the alarm circuit or trips ckt, thereby giving a warning to operate & control room that a serious fault is developing.

... is a small box attached to the conservator for taking the air pressure, which happens due to the increase in oil volume. It consists of silicate or calcium chloride, which extracts the moisture from the air.

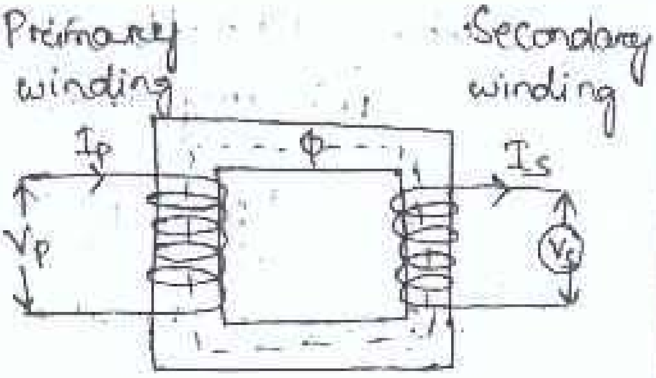
* **Explosion Vent** :- It is an inverted shaped exhaust pipe which is made of steel. It is connected to the tank. It provides an exit to the gases produced in the transformer, due to arcing and short circuiting of winding.

* **Oil Gauge** :- It is used for indicating the oil level present in the conservator. When the level of the oil goes down the alarm gets activated which indicates that the level of oil has decreased.

* **Tap changer** :- It is also known as tapping switch. This changer is used to increase or decrease the o/p voltage and is a manual operated switch. It is connected with a secondary winding tappings. Through this switch, turns of secondary winding are increased or decreased and the voltage is also increased or decreased.

* **Transformer bushing** :- These are bushes made of porcelain of high dielectric strength which are used in all types of transformers. Primary & secondary winding is connected with these bushes i.e., the purpose of these bushes is to keep the connected cables, insulated from the transformer body.

Working principle:-



It works on the Principe of Faraday's law of electromagnetic induction (i.e whenever the flux linked with a coil changes an emf induced it). Basically it works on mutual induction.

→ It consist of two winding and laminated core is made of silicon steel material the order of lamination is 0.35mm to 0.5mm one winding is wound over one limb and other winding is wound over another limb the winding which is connected to supply is known as primary winding and the winding form which the load is taken is called secondary winding.

→ When the primary winding is connected to A.C supply. An alternating current flow through it. Which produces an alternating flux. This alternating flux circulates through the core and also links to the secondary winding.

→ The emf induced in the primary winding is due to flux by the principle of self induction.

$$E_1 = -N_1 \frac{d\phi}{dt} \quad \text{—— (I)}$$

The emf is induced in the secondary winding due to mutual induction E_2.

$$E_2 = -N_2 \frac{d\phi}{dt} \quad \text{—— (II)}$$

where N_1 & N_2 are the no. of turns in primary & secondary respectively.

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

(where 'K' is the turn's ratio or transformation ratio)

* EMF eq^n of transformer →

Let, N_1 = No. of turn in primary winding

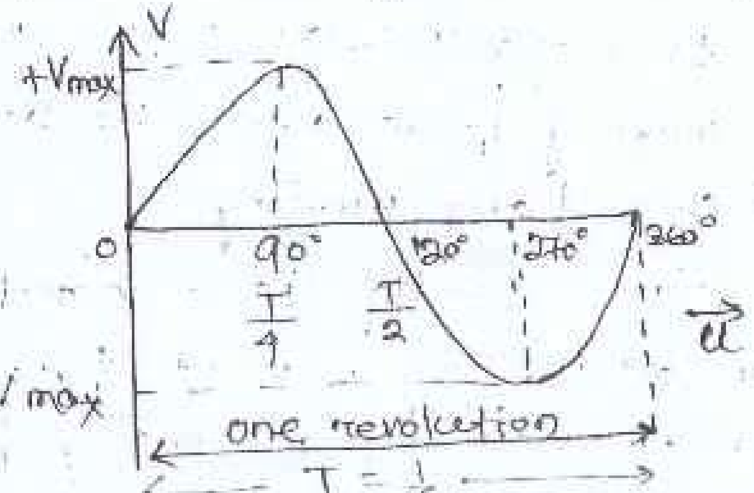
N_2 = No. of turn in secondary winding

ϕ_m = Max^m flux density (in wb)

B_m = Max^m flux density (wb/m^2)

A = Area of cross-section of core m^2

F = Frequency in Hz



The average value of induced emf in primary winding. $E_1 = -N_1 \frac{d\phi}{dt}$

$$= -N_1 \frac{(\phi_m - 0)}{(\frac{T}{4} - 0)}$$

$$= N_1 \left(\frac{\phi_m}{\frac{T}{4}}\right)$$

$$= \frac{4 N_1 \phi_m}{T}$$

$$= 4 N_1 f \phi_m \quad \left(f = \frac{1}{T}\right)$$

RMS value of induced EMF in primary winding

$$E_1 = 1.11 \times 4f\, N_1 B_m A$$

Similarly $E_2 = 4.44 f\, N_2 B_m A$

* Classification of transformer :-

* According to use :-

(i) Step up transformer :- If the secondary voltage is more than the primary voltage then it known as step up transformer.

$$V_2 > V_1\ ,\ N_2 > N_1\ ;\ K > 1$$

(ii) Step-down transformer → If the secondary voltage is less than the primary voltage then it is known as step down transformer.

$$V_2 < V_1\ ,\ N_2 < N_1\ ,\ K < 1$$

(iii) Ideal transformer :- If the secondary voltage is equal to the primary voltage, then it is known as ideal transformer.

$$V_2 = V_1\ ,\ N_2 = N_1\ ;\ K = 1$$

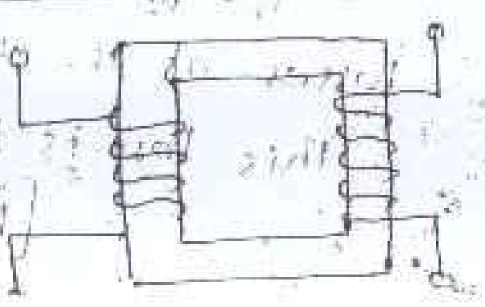
$$\Rightarrow V_1 I_1 = V_2 I_2 \qquad \eta\% = 100\%$$

$$\Rightarrow \frac{V_2}{V_{21}} = \frac{I_1}{I_2} = K$$

$$\boxed{\frac{V_2}{V_1} = \frac{T_2}{T_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K}$$

Construction :-

(iv) Berrary type Transformer →



In this type transformer

secondary winding have been placed side by side or concentrically on each limb. This types of transformer is also known as spiral core type transformer.

Transformer on No-load →

If the primary winding is connected to supply and secondary winding is open circuited then it is known as no-load condition of transformer.

→ The current drawn in this condition i.e 'I_0' is known as no-load current of the transformer. It is known about 1% to 3% of the full load current.

→ The no-load current lags the supply voltage V_1 by an angle ϕ_0. It has two components.

(i) $I_0 \cos\phi_0 = I_w$ is known as working component of no load current.

(ii) $I_0 \sin\phi_0 = I_m$ is called magnetising component of no-load current.

I_w is in phase with supply voltage 'V_1' the magnetising component I_m is in quadrature with supply voltage V_1.

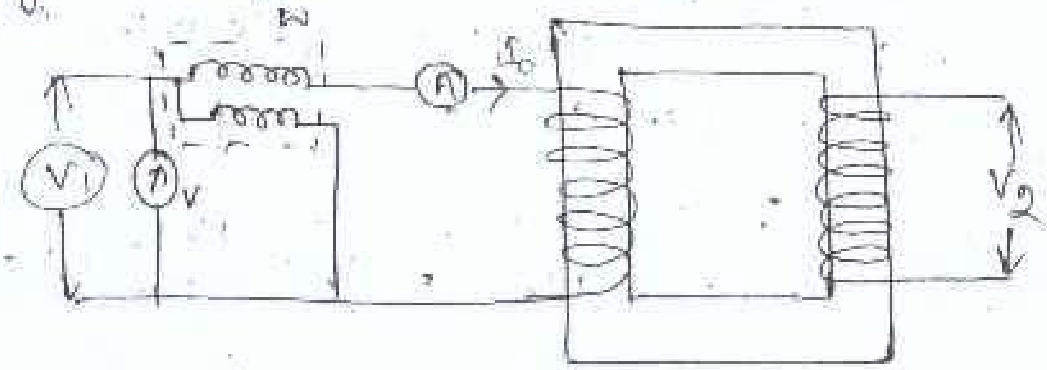
$$I_w^2 + I_m^2 = I$$

The watt meter reading indicates the losses of the transformer.

This loss is known as

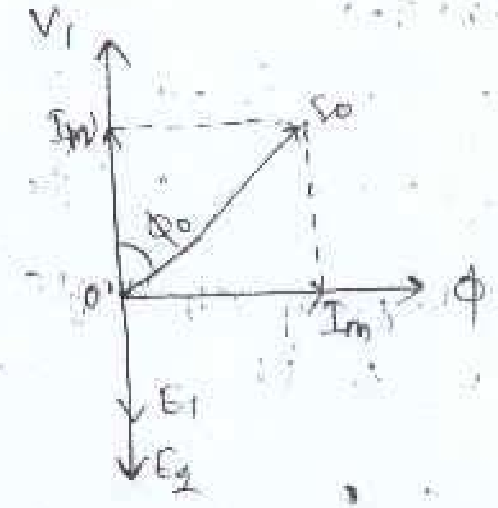
$$W_0 = V_1 I_0 \cos\phi_0$$

The iron loss or constant loss. Since the current drawn by the transformer under no-load condition is very very small that is why the copper loss is neglected.



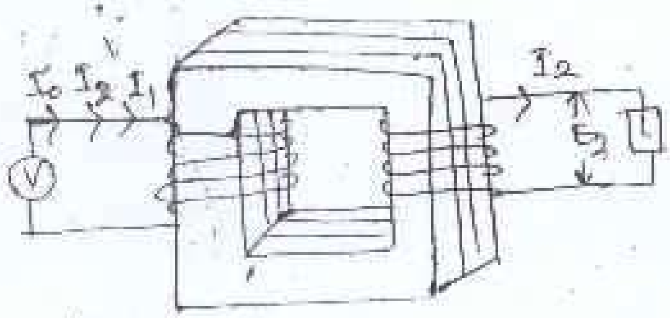
$I_w = I_0 \cos\phi_0$

$I_m = I_0 \sin\phi_0$



Transformer ON Load :-

→ When the load is increases the current should be increased in secondary sides



But at every instant in order to meet the load current, the secondary EMF E_2, Flux ϕ should be increased.

According to Lenz's law every change is opposed at every instant. Hence it not possible to change the flux when the load increases or

→ When the load current increases to 'I_2' in the secondary, the current in primary side will be 'I_2'' which is the additional current drawn by the transformer from the source.

→ Flux produced in primary is equal to the flux produced in the secondary.

$$\phi_2' = \phi_2$$

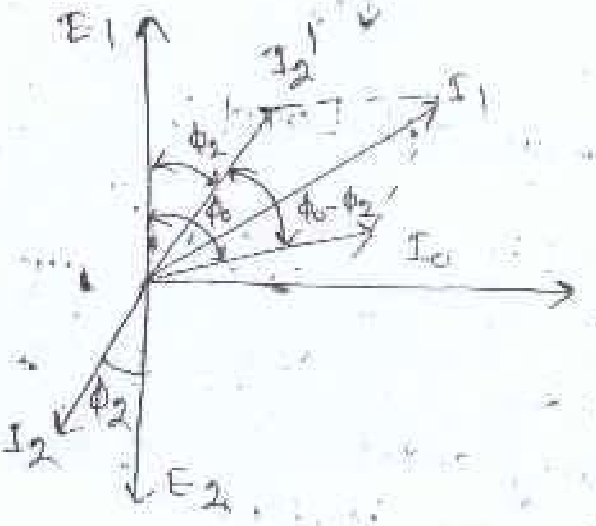
$$N_1 I_2' = N_2 I_2 \Rightarrow I_2' = \frac{N_2 I_2}{N_1} = k I_2$$

Inductive load →

$$I_1 = I_0 + I_2' \text{ (Vector sum)}$$

$$\Rightarrow \sqrt{I_0^2 + (I_2')^2 + 2 I_0 I_2' \cos(\phi_0 - \phi_2)}$$

· Here I_2 lagging of angle ϕ_2 to the voltage V_2 or E_2

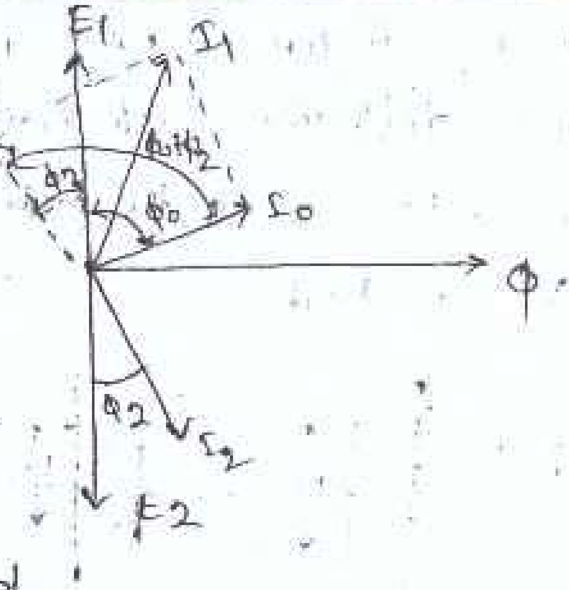


capacitive load:

$$I_1 = I_0 - I_2'$$

$$= \sqrt{(I_0)^2 + (I_2')^2 + 2 I_0 I_2' \cos(\phi_0 - \phi_2)}$$

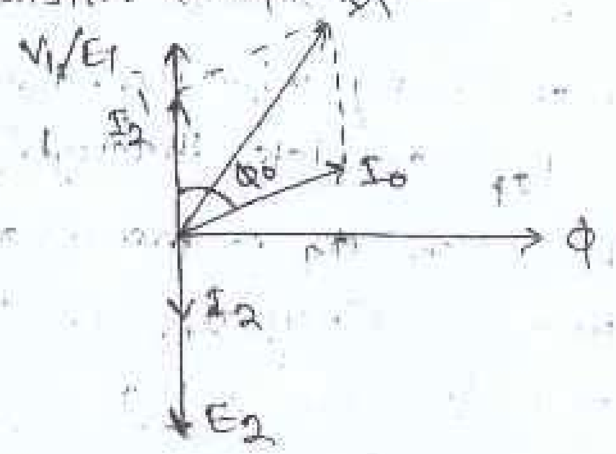
Here I_2 leads voltage of angle ϕ_2



Resistive load

$$I_1 = \sqrt{I_0^2 + (I_2')^2 + 2 I_0 I_2' \cos\phi_0}$$

But here I_2 in phase with E_2, because it is a resistive load.



Transformer with winding resistance :-

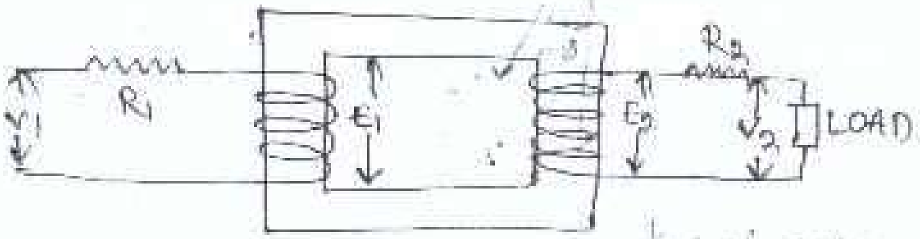
An ideal transformer shouldn't posses resistance but in actual transformer there is always present some resistance of primary and secondary winding due to this resistance.

There is same voltage drops in the two windings.

The secondary voltage 'V_2' is vectorically less than the secondary induced emf 'E_2' by an amount I_2R_2, where R_2 is the resistance of the secondary winding.

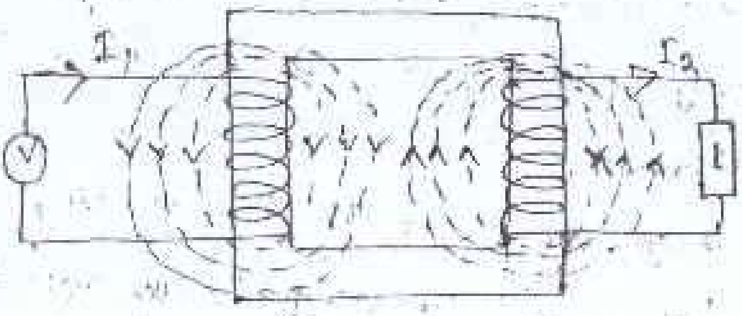
is E_1 equal to the vector difference of V_1 and I_1R_1. where R_1 is the resistance of the primary winding.

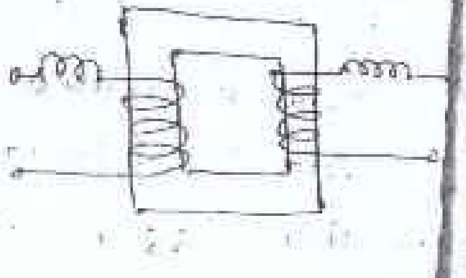
$V_1 = E_1 + I_1R_1$



* <u>Magnetic leakage</u>:- In winding, the secondary winding, but actual practice it as not possible. It is found that, all flux linked with primary doesn't link secondary winding. But a part of it that is ϕ_{L1}, complete through the primary winding. This flux ϕ_{L1} is known as primary leakage flux. Similarly ϕ_{L2} is linked with secondary with is known as secondary leakage flux.

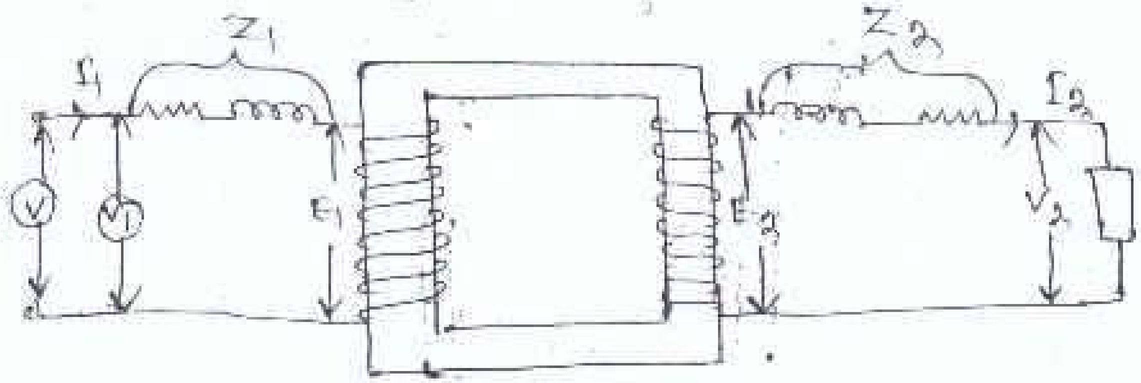
→ If induced a self induced EMF e_{L2} in secondary winding due to leakage flux ϕ_{L2}





$x_2 = \frac{e_{L2}}{I_2}$

where x_1 and x_2 are known as the primary and secondary leakage reactance respectively combining both resistance and reactance.

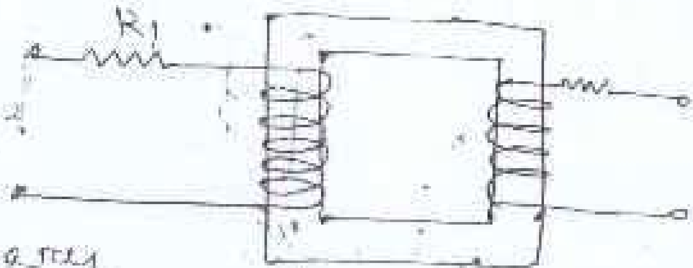


The primary impedance is given by

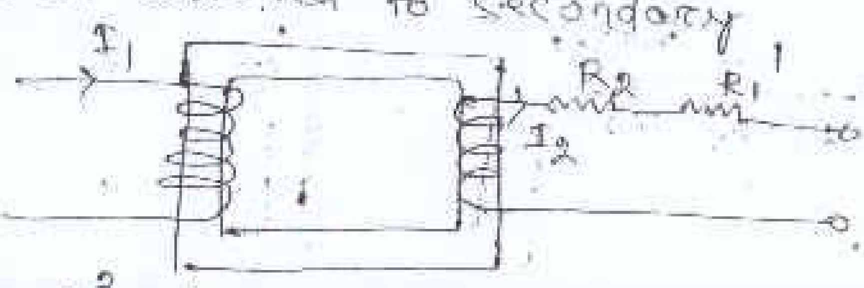
$$z = R_1 + jX_1$$

Let the resistance of primary winding $= R_1$

The resistance of secondary winding $= R_2$



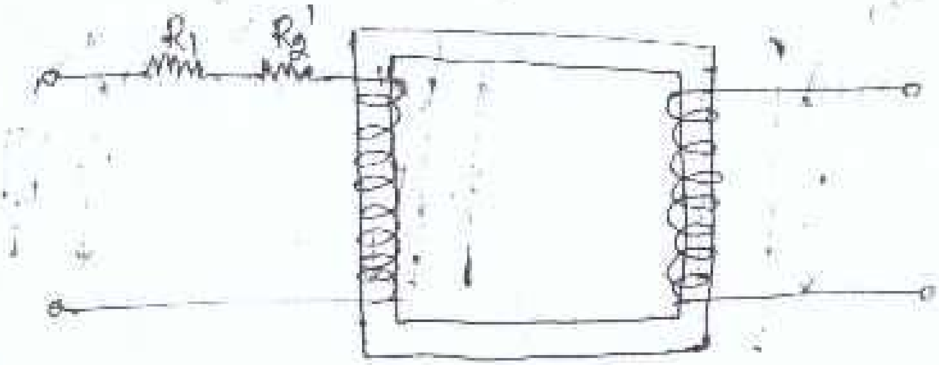
→ Let R_1' be the primary resistance as referred to secondary



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

Equivalent resistance of the transformer as referred to secondary is given by

Similarly, R_2 be the secondary resistance as referred to primary winding.

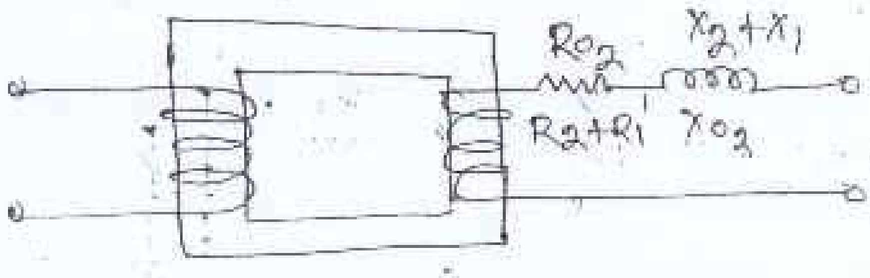


$$I_2^2 R_2' = I_1^2 R_2$$

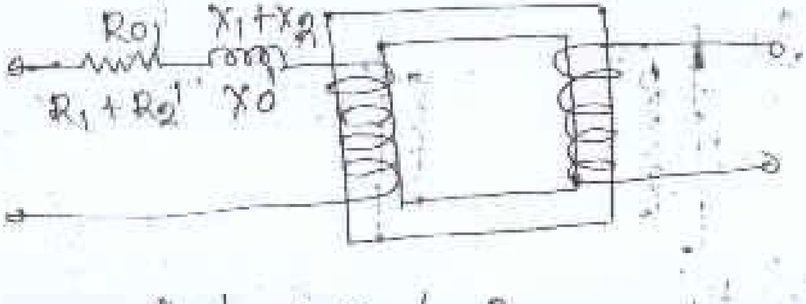
i.e. $$R_2' = \frac{R_2}{K_2^2}$$

Equivalent resistance of the transformer as referred to the primary is given by.

The resistance can also be transformed from one winding to the other in the same way, as resistance.



$$X_1' = \frac{X^2}{X_1}$$



$X_2' = X_2 / K^2$

$$\boxed{X_1' = K^2 X_1}$$

Total equipment reactance as referred to secondary is given by

$$X_{O2} = X_2 + X_1' = X_2 = K^2 X_1$$

Total equipment reactance as referred to primary is given by

$$X_{O1} = X_1 + X_2' = X_1 + X_2/K^2$$

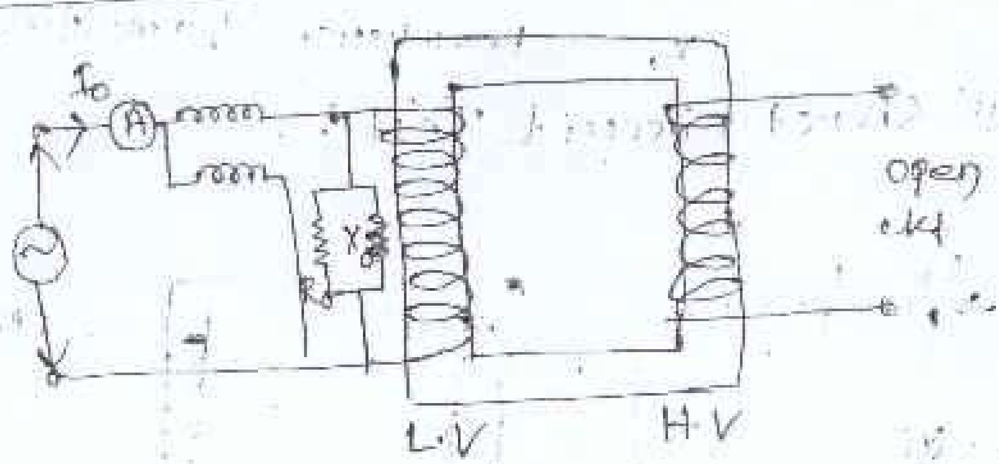
Now, Total equipment impedance as referred to secondary is given by

$$Z_{O2} = R_{O2} + jX_{O2}'$$
$$= \sqrt{(R_{O2})^2 + (X_{O2}')^2}$$

Total equipment impedance as referred to primary is given by

x TEST ON TRANSFORMER:-

① Open-Circuit test or No-load Test



In case of no-load test, the low voltage winding is connected to supply of rated voltage side is open circuited

→ The high voltage side is open circuited. Another voltage 'V_2' is connected across high voltage side. The voltage should be adjusted until the voltage across V_2 is the voltage maintained in the name plate.

→ The watt meter shows the iron loss since the no-load current is very very small. Copper loss is neglected.

→ The iron loss ⇒ $(W_0) = V_1 I_0 \cos\phi_0$

$$I_0 \cos\phi_0 = \frac{W_0}{V_1}$$

$$\Rightarrow I_w = \frac{W_0}{V_1}$$ ... working component of no-load

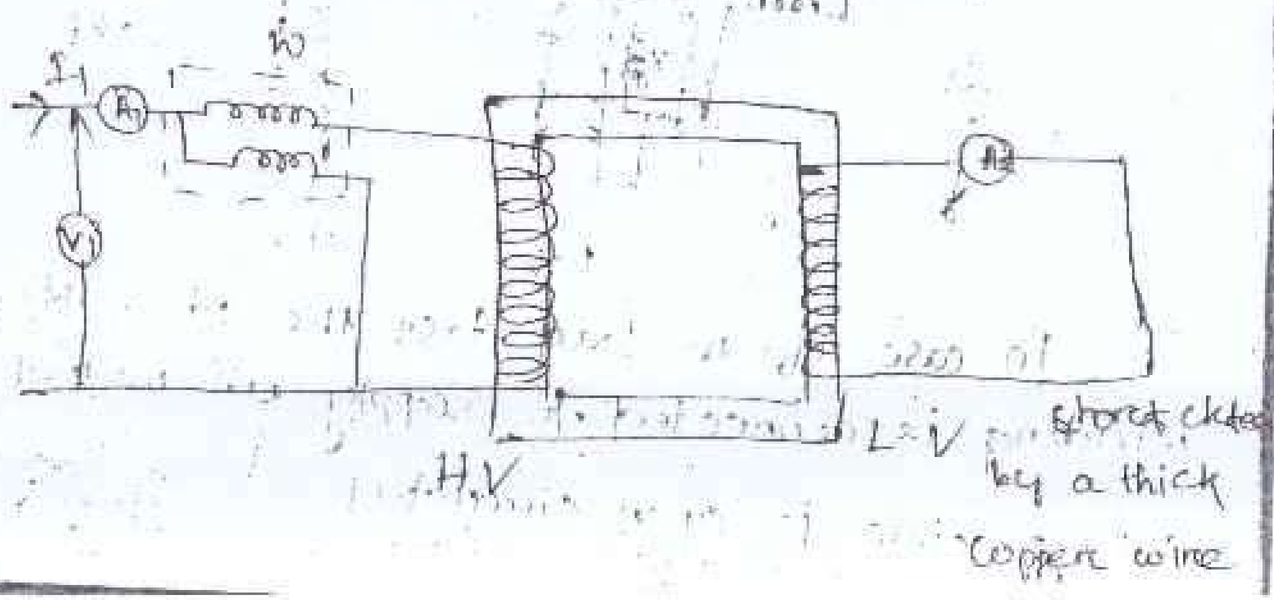
$$I_M = \sqrt{I_0^2 - I_w^2}$$ Magnetising component of no-load current

$$R_0 = \frac{V_1}{I_w}$$ $$X_0 = \frac{V_1}{I_M}$$

where R_0 = Resistance of exciting coil

X_0 = Reactance of exciting coil

(ii) Short circuit Test :-



The H.V side of the transformer is connected to the supply and all the instruments are connected in the primary side.

→ The L.V side is short circuited by a thick copper wire. A small voltage will be applied to the H.V side, and the voltage is adjusted untill the ammeter (A_2) shown the full load current in secondary.

→ If V_C is the voltage required to calculate the related load current, then.

$$Z_{01} = \frac{V_{sc}}{I_1}$$

The wattmeter shown full load cu. loss

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

$$R_{01} = \frac{W}{I_1^2}$$

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

$$R_{02} = K^2 R_{01}, \quad Z_{02} = K^2 Z_{01}$$

$$X_{02} = K^2 X_{01}, \quad R_{01} = \frac{R_{02}}{K^2}$$

$$X_{01} = \frac{Z_{02}}{K^2}$$

$$X_{01} = \frac{X_{02}}{K^2}$$

Taking V_2 as reference

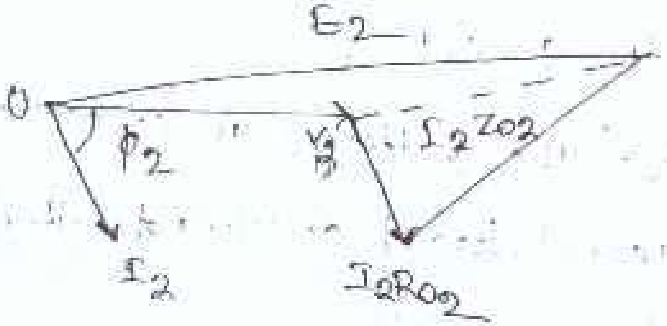
Taking I_2 as reference

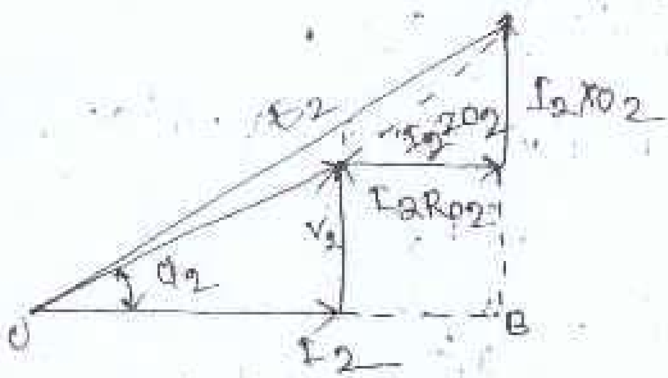
$$E_2 = OX = \sqrt{OB^2 + BX^2}$$

$$= \sqrt{(OA + AB)^2 + (BD + DX)^2}$$

$$= \sqrt{(V_2\cos\phi_2 + I_2R_{O_2})^2 + (V_2\sin\phi_2 + I_2X_{O_2})^2}$$

$$\Rightarrow E_2 = \sqrt{(V_2\cos\phi_2 + I_2R_{O_2})^2 + (V_2\sin\phi_2 + I_2X_{O_2})^2}$$





* Voltage Regulation :

It is defined as the change in secondary terminal voltage from no-load to full load devided by full-load terminal voltage.

$$\% V.R = \frac{E_2 - V_2}{V_2} \times 100$$

$$\% V_R = \frac{\text{No load voltage} - \text{full load voltage}}{\text{full load voltage}} \times 100$$

$$\% V.R = \frac{\text{drop}}{\text{full load voltage}} \times 100$$

$$\text{i.e. } \% V.R = \frac{I_2(R_{02}\cos\phi_2 \pm X_{02}\sin\phi_2)}{V_2} \times 100$$

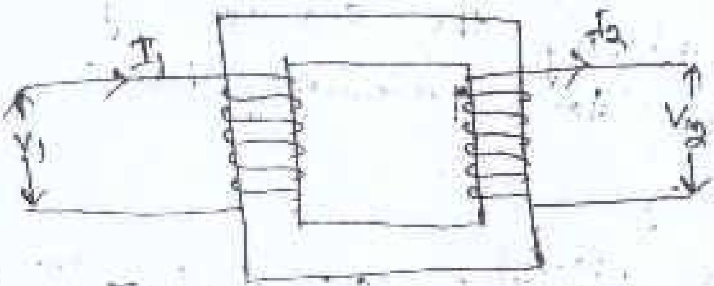
'+' sign for lagging p.f

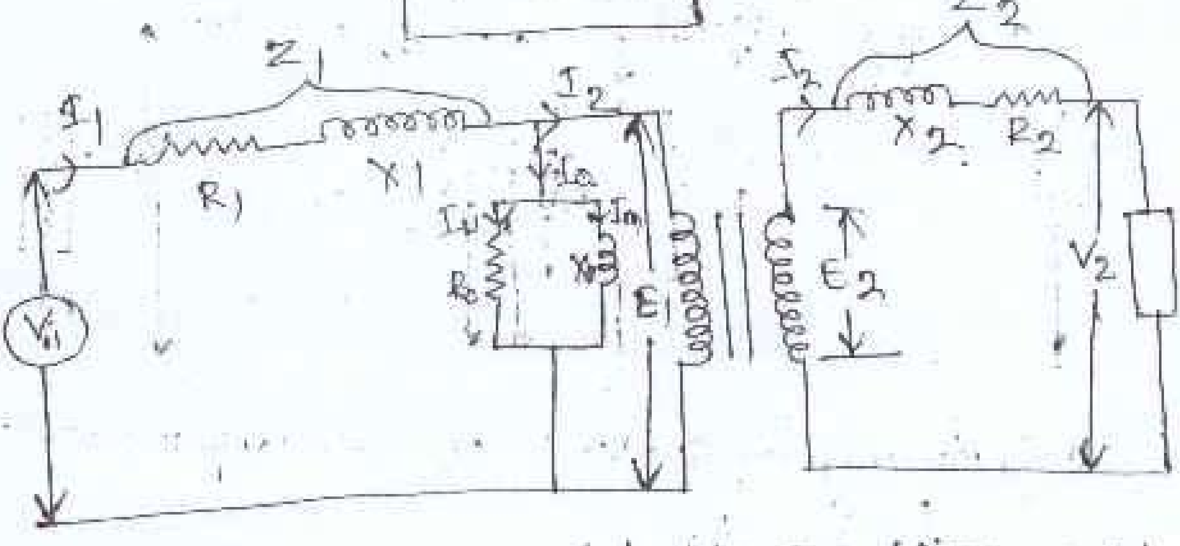
'−' sign for leading p.f

$$\% V.R(\text{up}) = \frac{E_2 - V_2}{V_2} \times 100$$

$$\% V.R(\text{down}) = \frac{E_2 - V_2}{E_2} \times 100$$

* Equivalent circuit of a transformer





R_0 is the resistance of the exciting coil

$$R_0 = \frac{V_1}{I_w}$$

X_0 is the reactance of the exciting coil

$$X_0 = \frac{V_1}{I_m}$$

R_0 is connected in parallel with X_0

$$X_0 \parallel R_0$$

Z_m = Impedance of the coil

$$Z_m = X_0 \parallel R_0 = \frac{X_0 R_0}{X_0 + R_0}$$

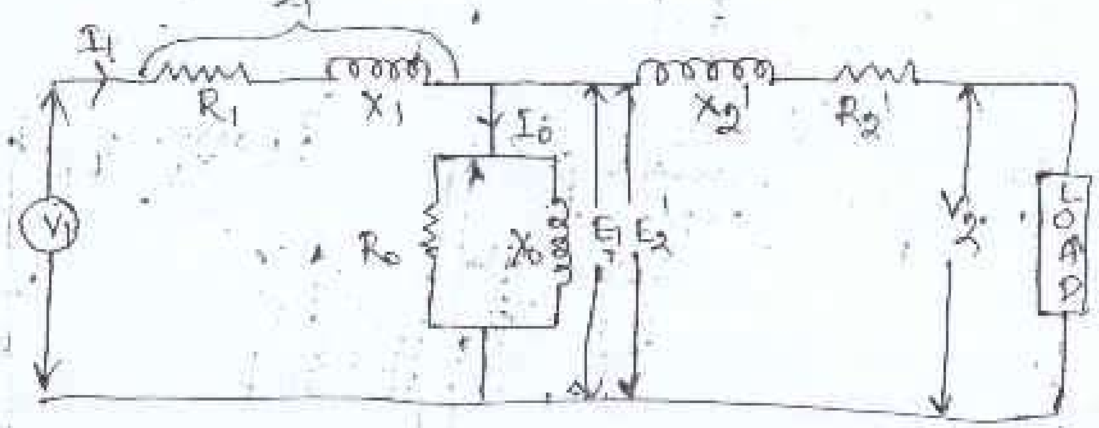
$$Z_1 = R_1 + jX_1$$

$$Z_2 = R_2 + jX_2$$

E_1 and E_2 are related to each other by the expression

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = k$$

Now transforming the secondary side parameters to primary side.



The primary equivalent of secondary induced emf

$$E_2' = \frac{E_2}{k} = E_1$$

Similarly the primary equivalent of secondary terminal voltage

$$V_2' = \frac{V_2}{k}$$

The primary equivalent of secondary terminal current – $\boxed{I_2 = K I_2}$

Transforming the secondary impedance to primary.

$$\boxed{R_2' = \frac{R_1}{K^2}} \quad \boxed{X_2 = \frac{X_1}{K^2}}$$

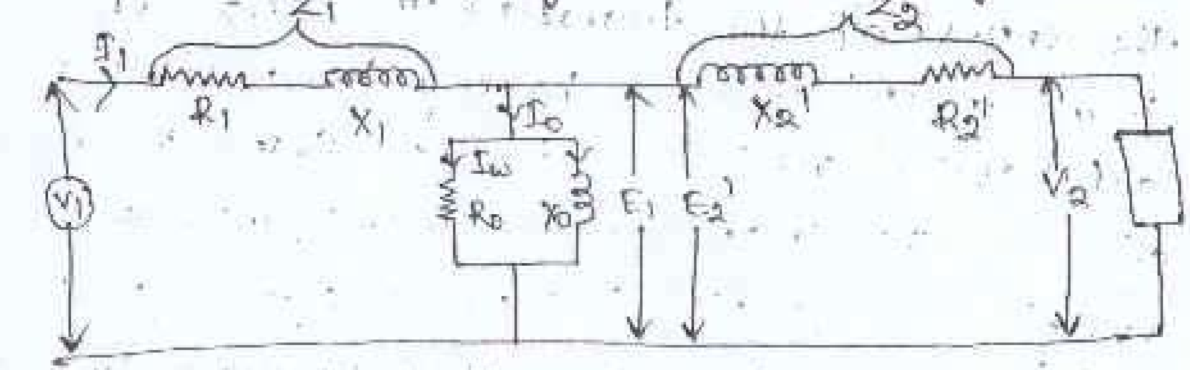
$$\boxed{V_2 = \frac{V_1}{K^2}} \quad \boxed{V_L = \frac{V_L}{K^2}}$$

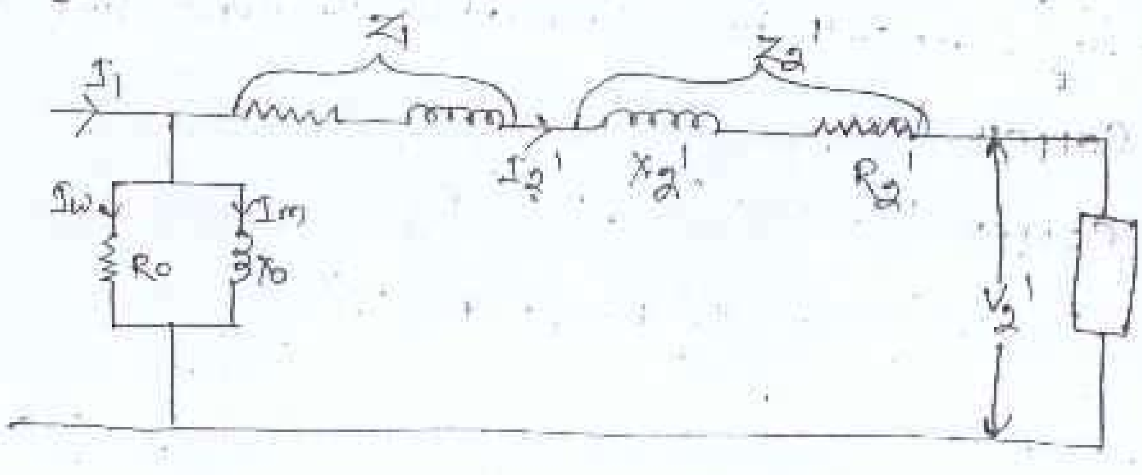
Now, equivalent impedance of transformer in primary side.

$$\boxed{Z = X_1 + X_m \parallel X_2 + X_L}$$

Primary current $= I_1 = Z = (X_1 + X_m) \parallel (X_2 + X_L)$.

→ Further simplifying the ckt for easy calculation.





* Losses in a transformer :-

Since transformer is a static electrical device, hence there no mechanical loss, there occurs only copper and iron loss.

(1) IRON LOSS →

(a) Hysteresis loss :- Hysteris loss occurs due to the reversal of magnetism.

(b) Eddy current loss :- when the transformer is connected to alternating source, an alternating flux is produced on the winding of the transformer, This flux links to the core of the transformer and EMF is induced in the cores of the transformer. Since the transformer core is having low resistance and closed one. So a current flows in the core of the transformer i.e. known as eddy current. The loss which occurs due to eddy current is called eddy current loss.

(2) Copper loss :

$$\text{Copper loss} = I_1^2 R_1 + I_2^2 R_2$$

$$= I_1^2 R_{01} = R_{02} I_2^2$$

* Iron loss + Mechanical loss = Stray loss

Efficiency of the transformer

$$\text{Efficiency} = \frac{\text{output}}{\text{Input}}$$

$$\eta = \frac{\text{output}}{\text{Input}} = \frac{\text{output}}{\text{output} + \text{losses}}$$

$$= \frac{\text{output}}{\text{output} + \text{iron loss} + \text{copper loss}}$$

$$\eta = \frac{V_2 I_2}{V_2 I_2 + W_i + I_2^2 R_{02}}$$

Condition for maximum efficiency →

when $\frac{d\eta}{dI_2} = 0$

$$\Rightarrow \frac{d}{dI_2}\left(\frac{V_2 I_2}{V_2 I_2 + W_i + I_2^2 R_{02}}\right) = 0$$

$$\Rightarrow \frac{(V_2 I_2 + W_i + I_2^2 R_{02}) V_2 - V_2 I_2 (V_2 + 2 I_2 R_{02})}{(V_2 I_2 + W_i + I_2^2 R_{02})^2} = 0$$

$$\Rightarrow (V_2 I_2 + W_i + I_2^2 R_{02}) V_2 = V_2 I_2 (V_2 + 2 I_2 R_{02})$$

$$\Rightarrow V_2 I_2 + W_i + I_2^2 R_{02} = V_2 I_2 + 2 I_2^2 R_{02}$$

$$\Rightarrow W_i + I_2^2 R_{02} = 2 I_2^2 R_{02}$$

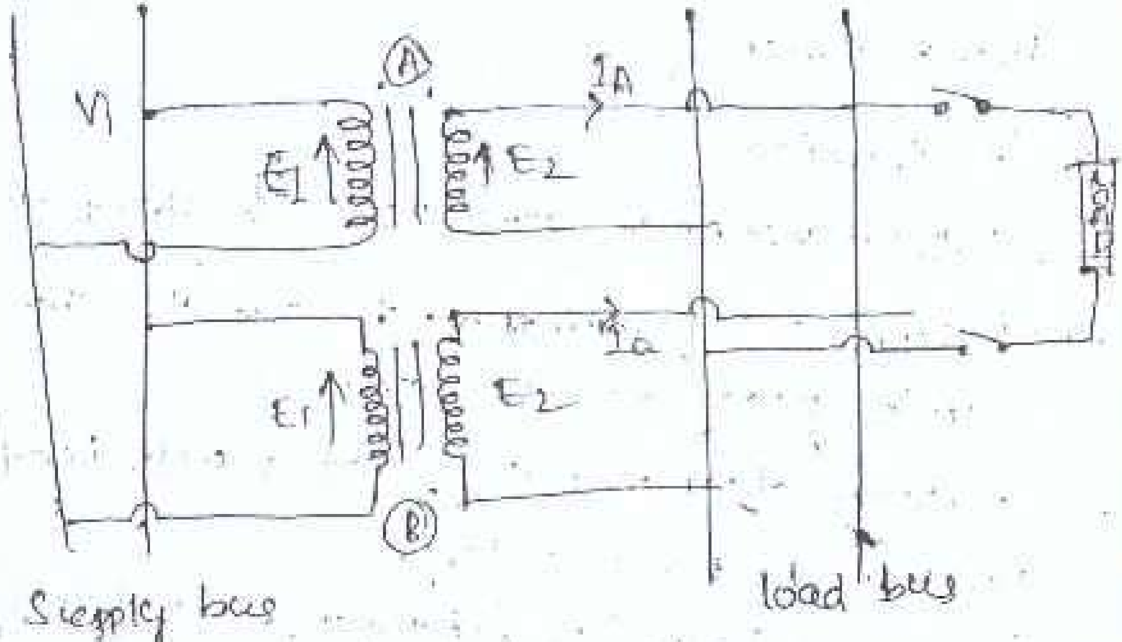
$$\Rightarrow \boxed{W_i = I_2^2 R_{02}}$$

efficiency of the transformer will be max^m. when — iron loss = copper loss or,

Constant loss = Variable loss.

→ The o/p current corresponding to maximum efficiency $I_2 = \sqrt{\frac{W_i}{R_{02}}}$

→ load kVA corresponding to max^m efficiency



Condition →

→ Polarity must be maintained.
→ Voltage and frequency must be same.
→ Turn's ratio must be same.
→ KVA rating should be same.
→ If the KVA rating of the two transformers are different than the percentages of impedance ratio of the transformer inversely proportional to their KVA rating.
→ Percentage of impedance should be equal in magnitude and have the same ratio of the rating of the two transformer and will be equal.
→ The construction of two transformers should be same.

Transformer :-

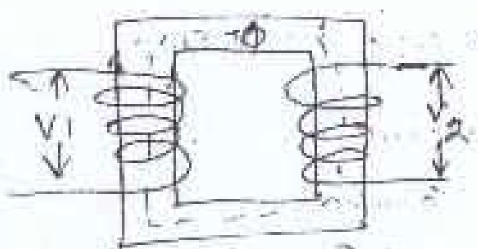
* Construction :-

→ All the transformer core made of sheet steel.

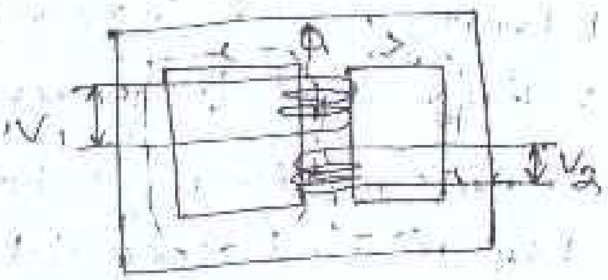
→ Silicon steel lamination is over the sheet to reduce eddy current loss.

→ Silicon steel core is treated with heat to reduce hysteresis loss.

→ Constructionally transformers are two types
(a) Core type
(b) Shell type



(Core type)



→ In core type transformer the winding is surrounded considerable by a part of core.

→ In shell type transformer the core is surrounded considerable by a part of winding.

* Generally transformer is housed tight fitting. A special insulating oil is contained in the tank.

* This oil is provides insulation and cooling.

Working :-

→ Transformer is a static electrical apparatus.
→ It consist of two inductive coils they are electrically not connected but magnetically linked through a low reluctance path.
→ If we applied A.C supply to the primary it established a alternating flux which linked to the other coil named secondary coil by mutually induced EMF by faraday's law of electromagnetic induction.

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

→ since the secondary is short ckt through a load current flow in the secondary & electrical energy transfer from primary to secondary winding.

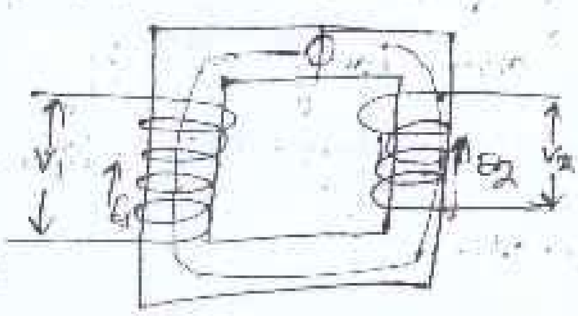
⊛ In brief transformer is —

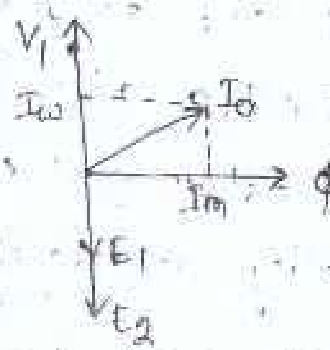
* Based on the principle of electromagnetic induction.
* has no electrical connection between primary and secondary.
* No frequency change.
* The losses (Iron and copper) are very small. So, it's called a efficient static electrically device.

1-Φ transformer On Load Condition:

→ On Load condition the secondary of the transformer is open circuited. The primary will draw a small amount of current to supply.

① Iron loss
② A very small amount of cu loss.





$$\text{No load i/p power } (W_0) = V_1 I_0 \cos\phi_0$$

No load primary current I_0 results in two components.

① Iron loss component supply iron and a very small amount of cu loss.

$$I_w = I_0 \cos\phi_0$$

② The component I_m is lagging 90° under the voltage V_1 and is known as magnetic component, this generated flux in the core.

$$I_m = I_0 \sin\phi_0$$

The power in stator $= I_0 = \sqrt{I_m^2 + I_w^2}$

As cu loss is very very small at no load the no load I/p power is $W_0 = \text{Iron loss}$

Transformer On No load Condition

Here we will consider two cases..

(i) Assuming no winding resistance & no leakage flux.

(ii) Assuming winding resistance and leakage flux

(i) Assuming no winding resistance & no leakage flux

→ With this assumption $E_2 = V_2$, $E_1 = V_1$

→ Secondary current I_2 lag V_2 by ϕ_2 angle.

→ No load total primary current I_1 meet two requirements.

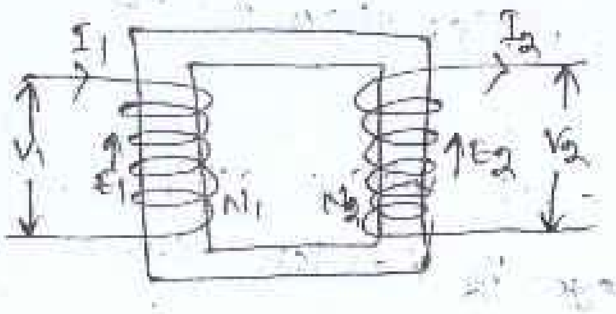
(a) To supply no load current to meet iron loss and generator flux of core.

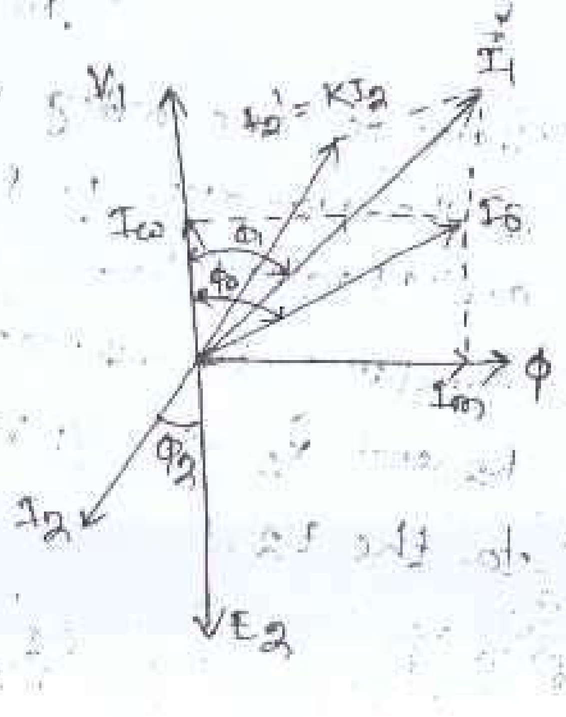
(b) To supply I_2' current to overact the demagnetising effect by I_2.

The magnitude of

I_2' =

$$N_1 I_2' = N_2 I_2 \Rightarrow I_2' = \frac{N_2}{N_1} I_2 = K I_2$$





Phasor Diagram (Explain):

→ E_2 & E_1 Both are lag behind the mutual flux ϕ by 90°.

→ Secondary current I_2 lag behind the V_2 by ϕ_2.

→ The resultant of I_w and I_m is I/P no load current lag behind the V_1 by some angle of ϕ_0.

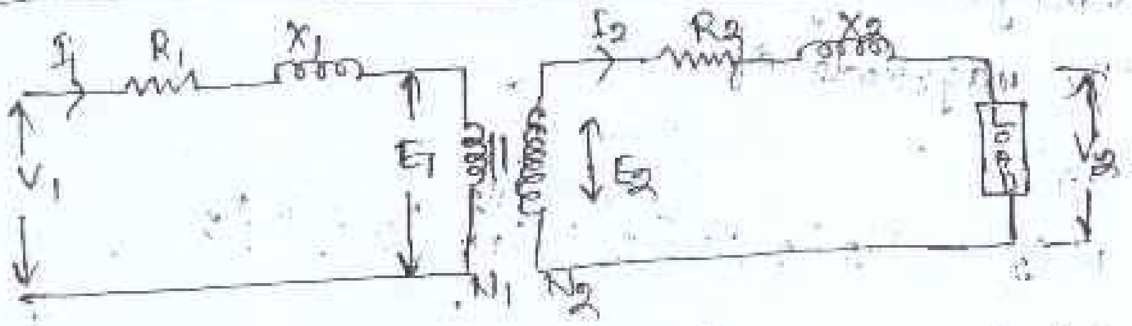
→ As $I_2' = K I_2$, I_2' is antiphase with I_2.

→ No load current I_0 and I_2' current resultant is I_1 current which is lag behind the V_1 by ϕ_1.

So, primary P.F = $\cos\phi_1$, secondary P.f = $\cos\phi_2$

I/P primary power = $V_1 I_1 \cos\phi_1$, I/P se. power = $V_2 I_2 \cos\phi_2$

Assuming winding resistance & leakage reactance



→ There is some voltage drop at primary R_1 & X_1 So the primary EMF E_1 is less than to the applied voltage V_1.

→ Similarly in secondary side voltage drop at R_2 and X_2 So o/p voltage V_2 is less than to the E_2.

* No load ~~total~~ primary current to meet two requirements.

(a) To supply no load current to meet iron loss and generate flux at core.

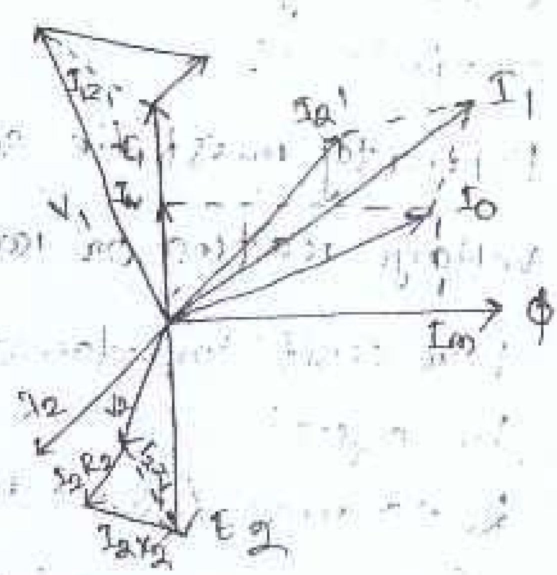
(b) To supply I_2' current to over act the demagnetisation effect of I_2.

The magnitude of I_2' =

$N_1 I_2' = N_2 I_2$

$\Rightarrow \frac{N_1}{N_2} I_2 = K I_2$ (Anti phase)

Phasor Diagram:



→ Here E_1 and E_2 both are lag behind the mutual flux ϕ.

→ Current I_2' is anti-phase with I_2. I_0 is the resultant of I_m and I_w and I_1 is the resultant of I_2' and I_0.

→ Here the primary EMF E_1 oppose the applied voltage V_1 is $-E_1$ So, if we add I_1R_1 & I_1X_1 to $-E_1$ we get V_1.

→ Similarly if I_2R_2 and I_2X_2 is substract to E_2 we get V_2.

State the condition of parallel operation of 1-φ transformer and state it's advantages.

Advantages -

(i) If one transformer fault continuity can be made through other transformer.

(ii) Capacity is more.

(iii) During repairing and daily ~~m~~ rotation maintenance one transformer can taken out if parallely connecting.

Conditions :-

→ Polarity must be same.

→ Voltage rating or ratio must be equal.

→ Per unit impedance of transformer must be equal.

→ Resistance / Reactance ratio must be equal.

(i) Polarity should be same. In wrong connection (polarity is interchanged). Then two secondary E.M.F E_A & E_B are additive. This may lead short circuit condition.

(ii) Voltage rating or ratio should be same →

If in the two secondary EMF E_A & E_B are different the circulating current

$$I_C = \frac{E_A - E_B}{Z_A - Z_B}$$

→ A small change in secondary EMF caused a large circulating current due to low reactance.

→ This secondary circulating current causes a large primary current which result heat due to copper loss.

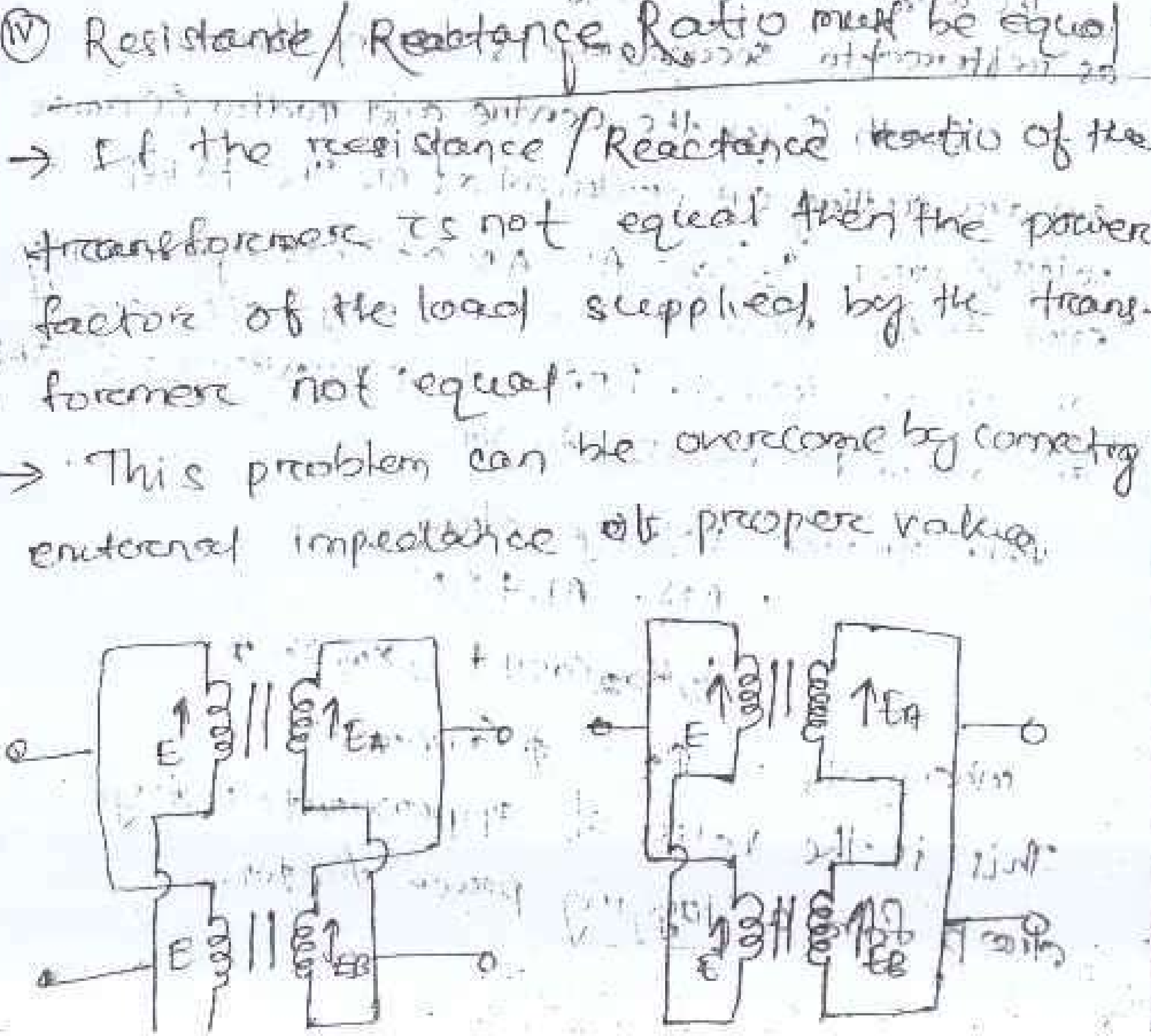
(iii) Per cent impedance of transformer must be same

If percentage impedance of transformer are not same then it will not share the load according to it's KVA ratings.

(iv) Resistance / Reactance Ratio must be equal

→ If the resistance / Reactance ratio of the transformer is not equal then the power factor of the load supplied by the transformer not equal.

→ This problem can be overcome by connecting external impedance of proper value.



* Comparison between auto transformer and a 2-winding transformer:

Ans:- 2-winding transformer:

→ It has two winding which are electrically isolated but magnetically coupled.

Transformer:

* It has high cu. loss.
* This transformer may be power transformer and distribution transformer.

Auto-transformer

* It has one winding
* It has less amount of cu. loss.
* It is used as varial starting of induction motor.

Advantages:

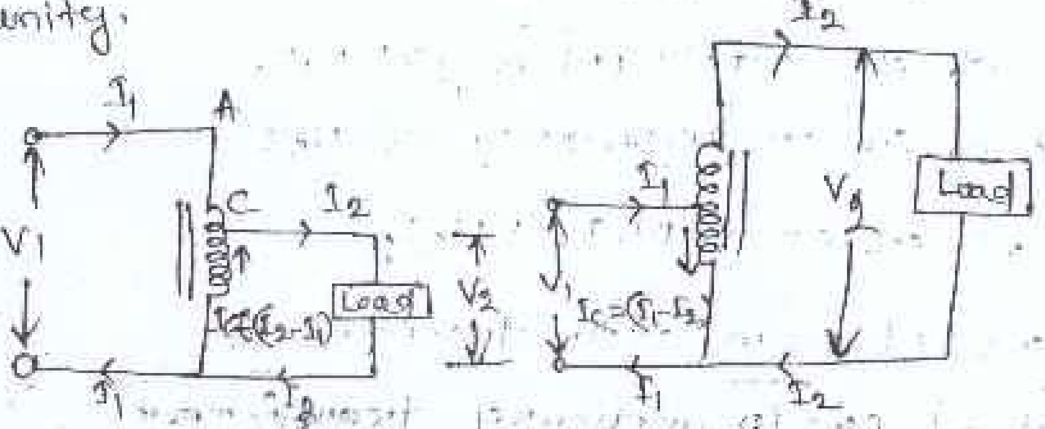
* An auto transformer required less amount of cu. than 2-wdg transformer.
* It operates at higher efficiency than 2-wdg transformer of same rating.
* It has smaller size than 2-wdg of same rating.
* It has better V.R than 2-wdg of " "
* It requires smaller exciting current than 2-wdg types.

Disadvantages

* There is a direct connection between the primary and secondary therefore the O/P is no longer D.C isolated from the I/P.
* The short ckt is much larger than 2-wdg type.

* Cu. saving of cost for an auto-transformer w.r.t ordinary transformer

<u>Auto-transformer</u> :- It is a transformer with one winding only, part of this being common to both primary and secondary. Because of one winding, it uses less copper and hence is cheaper. It is used where transformation ratio differs little from unity.



(a) (b)

As shown in fig (a), AB is primary winding having N_1 turns and B.C. is secondary winding having N_2 turns. Neglecting iron losses and no-load current.

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K$$

As compared to an ordinary 2/wdg transformer of same o/p, an auto-transformer has higher efficiency but smaller size.

<u>Saving of Cu</u>: Volume and weight of Cu is proportional to the length and area of the cross-section of the conductors. So, length of conductor is proportional to the no. of turns and cross-section depends on current. <u>Hence weight is</u> propor-

wt. of Cu in section AC $\propto (N_1 - N_2) I_1$

wt. of Cu in section BC $\propto N_2 (I_2 - I_1)$

∴ Total wt. of Cu in auto-transformer

$$\propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$$

If a two-winding transformer were to perform the same duty, then

wt. of Cu on its primary $\propto N_1 I_1$

wt. of Cu on secondary $\propto N_2 I_2$

Total wt. of Cu $\propto N_1 I_1 + N_2 I_2$

$$\therefore \frac{\text{wt. of Cu in auto-transformer}}{\text{wt. of Cu in ordinary transformer}}$$

$$= \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_1 I_1}$$

$$= 1 - \frac{2\frac{N_2}{N_1}}{1 + \frac{N_2}{N_1} \times \frac{I_2}{I_1}} = 1 - \frac{2k}{k} = 1 - k$$

$$\left(\because \frac{N_2}{N_1} = k \ \& \ \frac{I_2}{I_1} = \frac{1}{k}\right)$$

wt. of Cu in auto-transformer

$W_a = (1-k) \times$ wt. of Cu in ordinary transformer

$$\text{Saving} = W_o - W_a$$

$$= W_o - (1-k)$$

$$= k W_o$$

∴ Saving = $K \times$ (wt. of Cu in ordinary transformer)

* Conditions of parallel operation of 3φ transformer

Ideal parallel operation between transformers occurs when

(i) There are no circulating currents on open circuit and

(ii) The load division betn the transformers is proportional to their KVA ratings.

These requirements necessitate that any two or more three phase Transformers, which are desired to be operated in parallel, should possess:

① The same no-load ratio of transformation.

② The same percentage impedance;

③ The same resistance to reactance ratio;

④ The same polarity.

⑤ The same phase rotation.

⑥ The same inherent phase-angle displacement betn primary and secondary terminals.

The above conditions are characteristic of all 3-φ transformers whether two winding or 3 winding. With 3 winding transformers, however, the following additional requirement must also be satisfied before the transformers can be designed suitable for parallel operation.

⑦ The same power ratio between the corresponding windings.

* Maintenance of power transformer

(i) The oil dielectric strength should be checked on regular basis.

(ii) Oil level in the oil taken should be checked it is below conservator level then oil must be refilled.

(iii) The Buchholz relay should be regularly checked.

(iv) The breather which contain white colour silica gel are to be verified and if the white colour is changed then they must be heated with high temp. in a container.

* Speed Control of a D.C Motor

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

$\Rightarrow N = K \frac{E_b}{\phi}$

$\Rightarrow N = K \frac{V - I_a R_a}{\phi}$

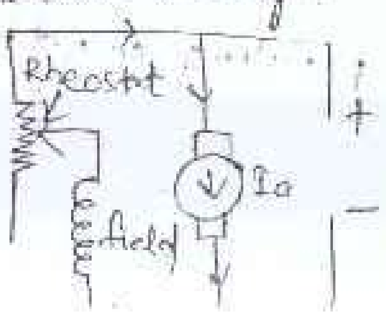
From the above expression we conclude that there are two methods are speed control of D.C motor

① Armature control = $I_a R_a$

② Flux control or field control = ϕ

Speed control of D.C shunt motor using flux control method :-

$$\boxed{N \propto \frac{1}{\phi}}$$



→ By decreasing ϕ the speed can be decrease & increase vice versa.

→ For controlling the speed of D.C motor ϕ is decrease by decrease the I_{sh} with the help of series connection of field with field field rheostat.

→ Since the I_{sh} current is small the rheostat variation amount is also small, I^2R loss is also small, So, the rheostat size is very small.

→ Therefore it is very efficient.

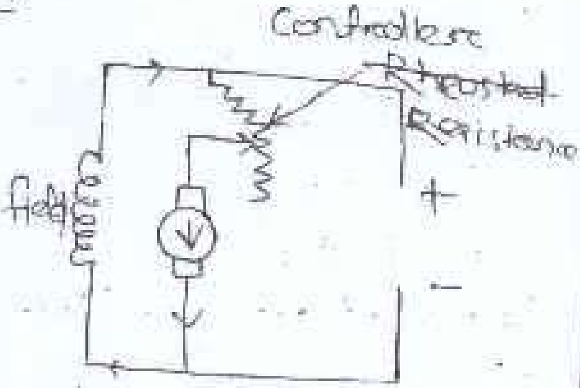
→ In non-polar motor the speed can be increase into the ratio of 2:1.

→ This method is used when speed required more than it's normal speed.

* Speed controll of D.C shunt motor by using

Armature control method

* In armature control method the rheostat (controller resistance) is connected in series with the armature.

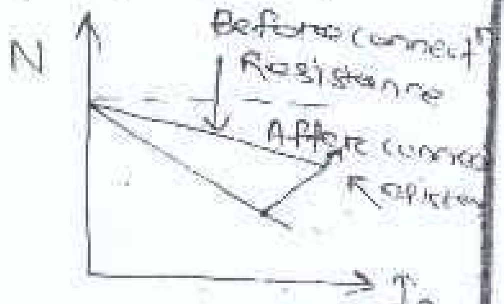


* As in General the supply Voltage is constant the resistance is increase and hence it increase the voltage drop & potential differential across the armature decrease and decrease the speed of the motor.

$$N = K\frac{V - I_a(R_a + R_{sh})}{\phi}$$

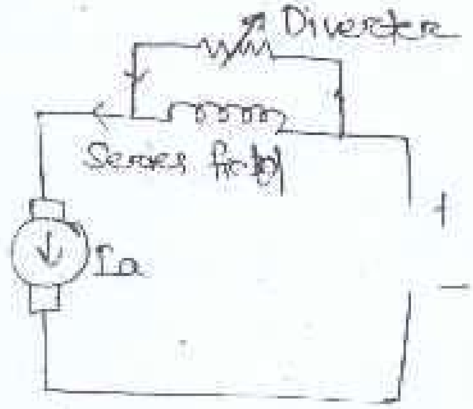
* As we increase the rheostat resistance the potential difference across the armature is decrease and speed decrease gradually.

→ We use this method where the speed is required less than it's no load speed.



* Speed control of D.C Series motor:

① Field control method:



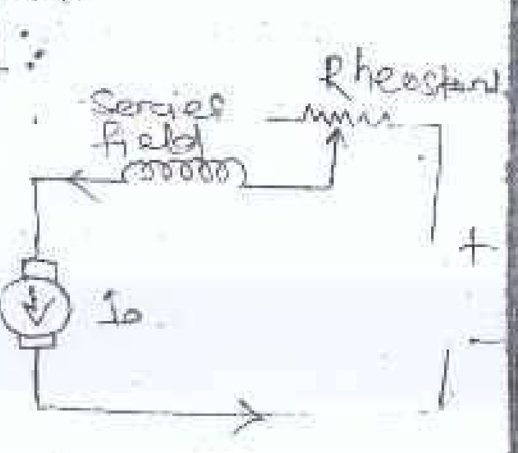
→ A variable resistance is shunt across the series field is called a diverter.

→ Any desired amount of current can be passed through the diverter by adjusting it's resistance.

→ Hence the flux can decrease and consequently the speed of the motor increased.

→ This method is used where the speed need more than it's normal speed.

② Armature control method:



→ In armature control method the series field is connect in series with a Rheostat.

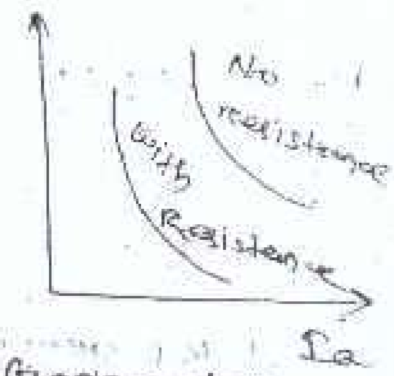
→ As the supply voltage is generally constant the voltage drop ...

and potential difference across the armature decrease & hence the speed is decrease.

→ As much we increase the resistance of rheostat the total resistance increase & increase the voltage drop and potential difference across the armature is decrease and speed decrease gradually.

$$N = K\frac{V - I_a(R_a + R_{sh})}{\phi}$$

→ This method is used where speed require less than it's normal speed



* Derive emf equation of D.C Generator

Let, ϕ = Flux/pole in weber.

Z = total no. of armature conductor

= No. of slots × No. of conductor/slot

P = No. of generator pole

A = No. of parallel path in armature

N = Armature rotation in r.p.m.

E = emf induced in any parallel path in armature.

Generated emf, E_g = e.m.f generated in any one of the parallel path i.e. E.

Average emf generated/conductor $= \frac{d\phi}{dt}$ volt ($\because n = 1$)

Now, flux cut/conductor in one revolution $d\phi = \phi P$ wb

No. of revolutions/second $= \frac{N}{60}$

Time for one revolution, $dt = 60$

Hence, according to Faraday's law of Electromagnetic induction.

E.M.F generated/conductor $= \frac{d\Phi}{dt} = \frac{\Phi PN}{60}$ volt.

For a simplex wave-wound generator

No. of parallel paths = 2

No. of conductors (in series) in one path $= \frac{Z}{2}$.

$\therefore$ E.M.F generated/path $= \frac{\Phi PN}{60} \times \frac{Z}{2}$

$= \frac{\Phi ZPN}{120}$ volt

For a simplex lap-wound generator

No. of parallel paths = P

No. of conductors (in series) in one path $= \frac{Z}{P}$

$\therefore$ E.M.F generated e.m.f $E_g = \frac{\Phi ZN}{60} \times \frac{P}{A}$ volt.

* Geometrical Neutral Axis (G.N.A)

The line which bisect two opposite magnetic poles is called geometrical neutral axis or geometrical neutral plane. It's symbol is G.N.A or G.N.P and remains unchanged for generator.

* Magnetic Neutral Axis (M.N.A) :-

The line which is perpendicular to the flux passing through armature is called magnetic neutral axis or magnetic neutral plane. It's symbol is M.N.A or M.N.P. Brushes are placed at M.N.A because there is no emf at that place.

magneti

E.M.F equation of Generator:-

Let, E = E.M.F induced in generator armature conductor in volt

P = No. of poles

ϕ = Flux per pole in weber

N = Speed of armature rotation in (r.p.m) ($\frac{N}{60}$ in r.p.s)

Z = No. of armature conductors

= No. of slots × No. of conductors/slot

A = No. of parallel paths in armature winding

Generated e.m.f Eg = e.m.f. generated in any one of the parallel paths i.e. E

Cutting of flux per conductor in one rev. = ϕP wb.

Cutting of flux/conductor in 1 sec = $\frac{\phi PN}{60}$ wb/sec

E.M.F generated/conductor = $\frac{\phi PN}{60}$ volts.

E.M.F generated/path = $\frac{\phi PN}{60} \times \frac{Z}{A}$ volts.

In Wave winding:-

The no. of parallel paths are always two (A = 2) So,

E.M.F generated per path = $\frac{\phi PN}{60} \times \frac{Z}{2}$ Volts

$= \frac{\phi ZNP}{120}$ Volts.

In lap winding:-

The no. of parallel path is equal to no. of pole.

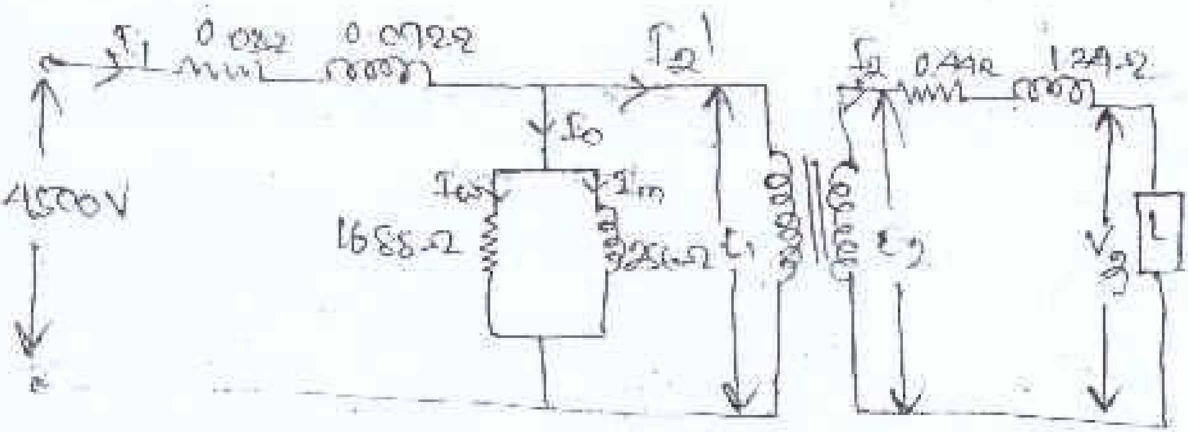
So, E.M.F generated/path = $\frac{\phi PN}{60} \times \frac{Z}{A}$ Volts.

* A 4500/16000 V, 1500 kVA, 50 Hz transformer has the following parameters.

$R_1 = 0.03\Omega$, $R_2 = 0.44\Omega$, $R_0 = 1688\Omega$

$X_1 = 0.092\Omega$, $X_2 = 1.34\Omega$, $X_0 = 256\Omega$

The transformer is supplying full load at a p.f. 0.8 lagging. Using exact equivalent ckt, find the I/P current.



Soln:- fig. shows the exact equivalent ckt of the transformer. Here $K = \frac{16000}{4500} = \frac{160}{45}$. Taking the load voltage as reference phasor, we have, $V_2 = 16000\angle 0° V$

F L secondary current, $I_2 = \frac{kVA \times 10^3}{V_2}$

$= \frac{1500 \times 10^3}{16000} = 93.75 A$

$I_2 = 93.75\angle -36.9° A$

$Z_2 = (0.44 + j1.34)\Omega = 1.41\angle 71.82° \Omega$

$E_2 = V_2 + I_2 Z_2 = 16000(1+j0) + (93.75\angle -36.9° \times 1.41\angle 71.82°)$

$= 16000\angle 0° + 132.19\angle 34.92°$

$= (16108 + j75.7) V$

Now, $E_1 = \frac{E_2}{K} = \frac{1}{k} \times E_2 = \frac{45}{160} \times (16105 + j75.7)$

$= (4530.4 + j21.3)\,V$

and $I_2' = KI_2 = \frac{160}{45} \times 93.75 \angle -36.9^\circ$

$= 333.3 \angle -36.9^\circ\,A$

$= (266.64 - j200)\,A$

$$I_w = \frac{E_1}{(1688 + j0)} = \frac{(4530.4 + j21.3)}{(1688 + j0)} = (2.684 + j0.013)\,A$$

$$I_m = \frac{E_1}{(0 + j256)} = \frac{(4530.4 + j21.3)}{(0 + j256)} = (0.083 - j17.7)\,A$$

$I_0 = I_w + I_m = (2.684 + j0.013) + (0.083 - j17.7)$

$= (2.77 - j17.69)\,A$

$I_1 = I_2' + I_0 = (266.64 - j200) + (2.77 - j17.69)$

$= (269.4 - j217.7)\,A$

$= 346.4 \angle -38.94^\circ\,A$

Ans

* A 4 KVA, 200/400 V, 50 Hz 1-φ transformer gave the following tests result.

No-load – Low Voltage data 200V, 0.7A, 60W

short ckt : High " " 9V, 6A, 21.6W

calculate (i) the magnetising current & the component corresponding to iron loss at normal frequency & voltage (ii) the efficiency of full load at unity p.f (iii) The secondary terminal voltage on full-load at p.f ...

Soln. (i) From O.C. test, we have

No load p.f., $\cos\phi_0 = \frac{W_0}{V_1 I_0} = \frac{60}{200 \times 0.7} = 0.43$

$\therefore \sin\phi_0 = 0.9$

Magnetising current, $I_m = I_0 \sin\phi_0$

$= 0.7 \times 0.9 = 0.63 A$

Iron loss component, $I_w = I_0 \cos\phi_0$

$= 0.7 \times 0.43 = 0.3 A$

(ii) Copper loss at 6 A on 400 V side = 21.6 W

F.L secondary current (400 V side), $I_2 = \frac{4 \times 10^3}{400} = 10 A$

$\therefore$ Total F.L Cu loss $= 21.6 \times \left(\frac{10}{6}\right)^2 = 60 W$

Total F.L losses = 60 + 60 = 120 W

F.L o/p at unity p.f. $= 4 \times 10^3 \times 1 = 4000 W$

F.L efficiency $= \frac{4000}{4000 + 120} \times 100 = 97.1\%$

(iii) From S.C test (HV side), we have,

$Z_{02} = \frac{V_{sc}}{\text{Secondary Current}} = \frac{9}{6} = 1.5 \Omega$

$\cos\phi_s = \frac{\text{Watts}}{\text{Volt-Amp}} = \frac{21.6}{9 \times 6} = 0.4, \sin\phi_s = 0.92$

$\therefore R_{02} = Z_{02} \cos\phi_s = 1.5 \times 0.4 = 0.6 \Omega$

and $X_{02} = Z_{02} \sin\phi_s = 1.5 \times 0.92 = 1.37 \Omega$

Voltage drop in secondary $= I_2 (R_{02} \cos\phi_2 \pm X_{02} \sin\phi_2)$

At unity p.f ($\cos\phi_2 = 1$), Voltage drop in secondary

$= 10(0.6 \times 1 + 0) = 6 V$

Load voltage = 400 − 6 = 394 V

At p.f of 0.8 lagging ($\cos\phi_2 = 0.8$), voltage drop in secondary $= 10(0.6 \times 0.8 + 1.37 \times 0.6) = 13V$

$\therefore$ Load voltage $= 400 - 13 = 387V$

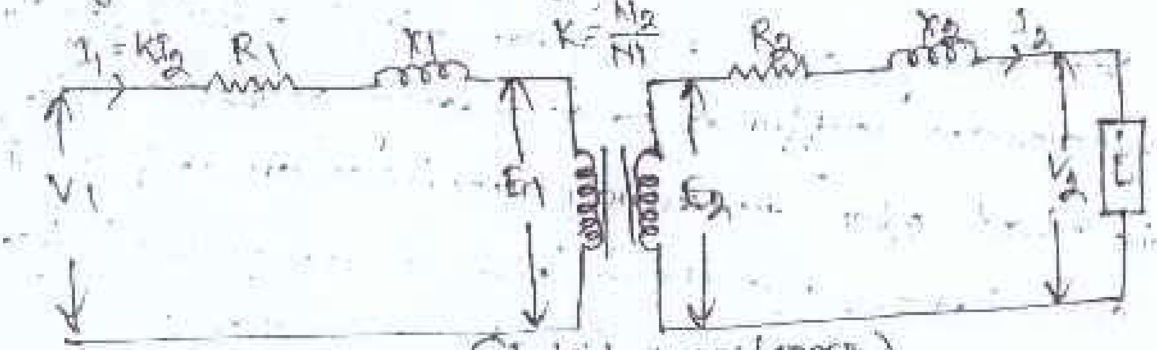
At p.f of 0.8 leading, voltage drop in secondary

$= 10(0.6 \times 0.8 - 1.37 \times 0.6) = -3.4V$

$\therefore$ Load voltage $= 400 + 3.4 = 403.4V$.

* Approximate equivalent ckt of a loaded transformer

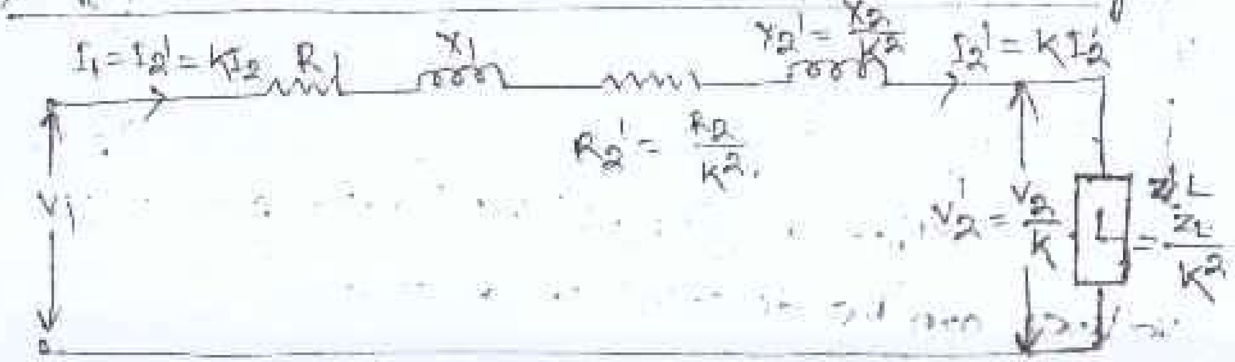
The no-load current I_0 in a transformer is only 1-3% of the rated primary current and may be neglected without any serious error:



(Ideal transformer)

This is an approximate representation because no-load current has been neglected. Note all the circuit elements have been shown external so that the transformer is an ideal one.

(i) Equivalent ckt of trans. referred to primary:



If all the secondary quantities are referred to the primary, we get the equivalent ckt of transformer.

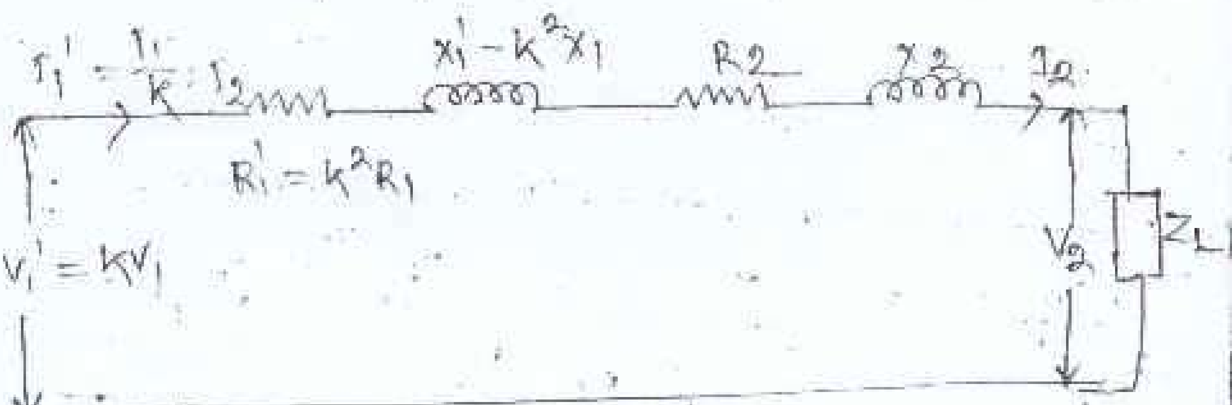
referred to primary as shown in fig. Note that when secondary quantities are referred to primary, ~~shown in fig.~~ resistances/reactances are divided by K^2, voltages are divided by K and are multiplied by K. Thus if we find V_2' and I_2', then actual secondary values can be determined as under:

Actual secondary voltage, $V_2 = KV_2'$

Actual secondary current, $I_2 = \frac{I_2'}{K}$

(ii) Equivalent ckt of transformer referred to secondary

If all the primary quantities are referred to secondary, we get the equivalent circuit of the transformer referred to secondary as shown in fig. Note that when primary quantities are referred to secondary, resistance/reactances are multiplied by K^2, voltages are multiplied by K & currents are divided by K.



Thus we find V_1' & I_1', then actual primary values can be determined as under.

Actual primary voltage, $V_1 = \frac{V_1'}{K}$

Actual primary current, $I_1 = K I_1'$

* Approximate voltage drop in a transformer

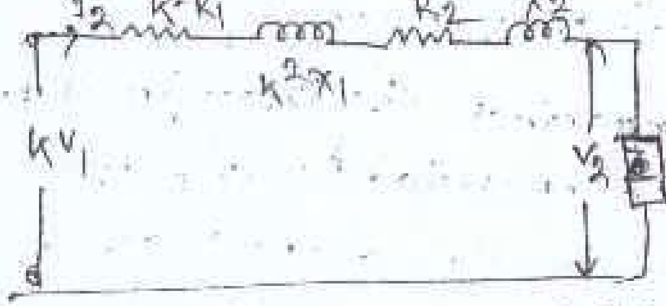
At no load, the secondary voltage is KV_1. When a load having a lagging p.f $\cos\phi_2$ is applied, the secondary carries a current I_2 and voltage drop occurs in $(R_2 + K^2R_1)$ and $(X_2 + K^2X_1)$. Consequently, the secondary voltage falls from KV_1 to V_2.

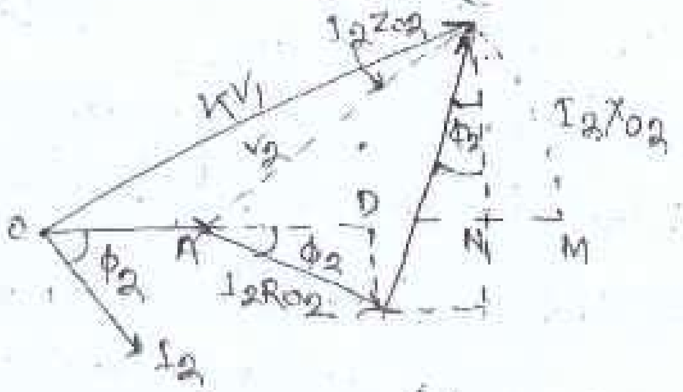
$$V_2 = KV_1 - I_2\left[(R_2 + K^2R_1) + j(X_2 + K^2X_1)\right]$$

$$= KV_1 - I_2(R_{02} + jX_{02})$$

$$= KV_1 - I_2Z_{02}$$

Drop in secondary voltage $= KV_1 - V_2 = I_2Z_{02}$





It is clear from the phasor diagram that drop in secondary voltage is $AC = I_2Z_{02}$. It can be found as follows. With O as centre and OC as radius, draw an arc cutting OA produced at M. Then $AC = AM \simeq AN$. From B, draw BD perpendicular to OA produced. Draw CN perpendicular to OM and draw BL ∥ OM.

Approximate drop in secondary voltage

$$= AN = AD + DN$$

$$= AD + BL \quad (\because BL = DN)$$

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

For a load having a leading p.f $\cos\phi_2$, we have,

Approximate voltage drop $= I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2$

<u>Note</u>:- If the ckt is referred to primary, then it can be easily established that:

$$\text{Appr. V.d} = I_1 R_{01} \cos\phi_2 \pm I_1 X_{01} \sin\phi_2$$

Cooling methods of transformer

In all electrical machines, the losses produce heat and means must be provided to keep the temp. low. Heat is produced in a transformer by the iron losses in the core and I^2R loss in the windings. To prevent undue temp. rise, this heat is removed by cooling.

(i) In small transformers (below 50 kVA), natural air cooling is employed i.e, the heat produced is carried away by the surrounding air.

(ii) Medium size power or distribution transformers are generally cooled by housing them in tanks filled with oil. The oil serves a double purpose:-

(a) Carrying the heat from the windings to the surface of the tank.

(ii) Insulating the primary from the secondary.

(iii) For large transformers, external radiators are added to increase the cooling surface of the oil filled tank. The oil circulates around the transformer and moves through the radiators where the heat is released to surrounding air. Sometimes cooling fans blow air over the radiators to accelerate the cooling process.

* **Armature Reaction:** So far we have assumed that the only flux acting in a DC 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.

$$T_{sh} = 9.55 \times \frac{E_b I_a - \text{Iron loss}}{N}$$

$$T_a = \frac{1}{2\pi} \phi Z I_a \left(\frac{P}{A}\right) \text{ N-m}$$