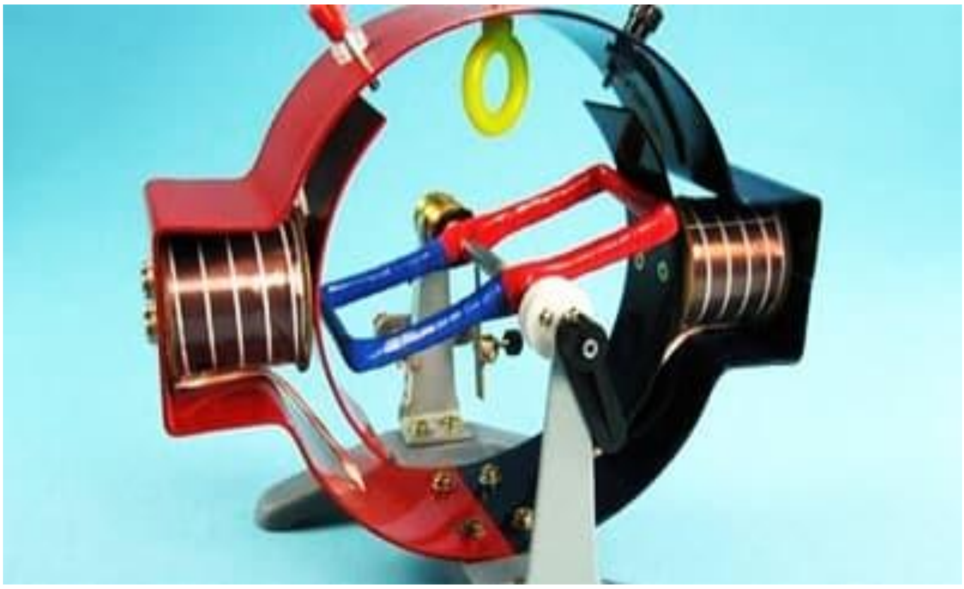
BHADRAK ENGINEERING SCHOOL & TECHNOLOGY (BEST), ASURALI, BHADRAK

Energy Conversion-I (Th- 01)

(As per the 2019-20 syllabus of the SCTE&VT, Bhubaneswar, Odisha)



Fourth Semester

Electrical Engg.

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ENERGY CONVERSION-I

CHAPTER-WISE DISTRIBUTION OF PERIODS & MARKS

Sl. No.	Chapter No.	Topics	Periods as per Syllabus	Expected Marks
01	01	D.C. Generator	17	30
02	02	D.C. Motor	15	25
03	03	Single phase T/F	20	25
04	04	Auto T/F	03	15
05	05	Instrument T/F	05	15
TOTAL			60	110

CHAPTER NO.-01
D.C.GENERATOR

Learning objectives

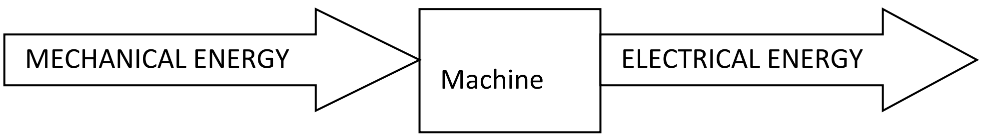
1.1. Operating principle of generator
1.2. Constructional features of DC machine.
1.2.1. Yoke, Pole & field winding, Armature, Commutator.
1.2.2. Armature winding, back pitch, Front pitch, Resultant pitch and Commutator- pitch.
1.2.3. Simple Lap and wave winding, Dummy coils.
1.3. Different types of D.C. machines (Shunt, Series and Compound)
1.4. Derivation of EMF equation of DC generators. (Solve problems)
1.5. Losses and efficiency of DC generator. Condition for maximum efficiency and numerical problems.
1.6. Armature reaction in D.C. machine
1.7. Commutation and methods of improving commutation.
1.7.1. Role of inter poles and compensating winding in commutation.
1.8. Characteristics of D.C. Generators
1.9. Application of different types of D.C. Generators.
1.10. Concept of critical resistance DC shunt generator
1.11. Conditions of Build-up of emf of DC generator.
1.12. Parallel operation of D.C. Generators.
1.13. Uses of D.C generators.

1.1-Operating principle of generator

Definition:

It is defined as a d.c Electric Machine which converts Mechanical Energy in to Electrical Energy. This energy conversion takes place in the armature only.

Block Diagram:

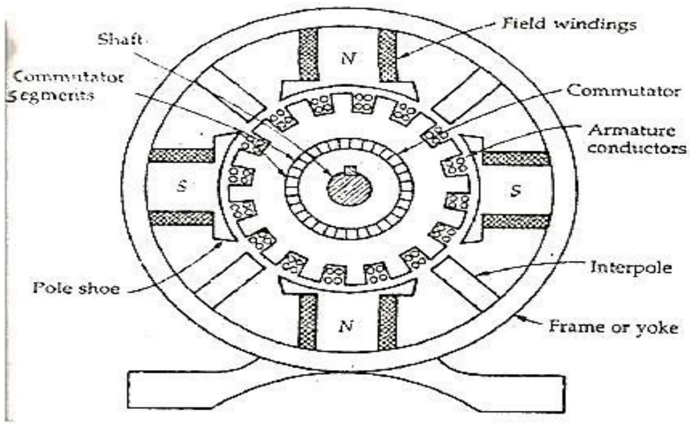


Principle:

It works under the principle of dynamically induced e.m.f.(i.e. whenever a conductor moves under the influence of uniform magnetic field ,then according to faradays laws of electromagnetic induction , certain emf will be induced in the conductors.)

1.2. Constructional features of DC machine

A D.C. generator has following important parts

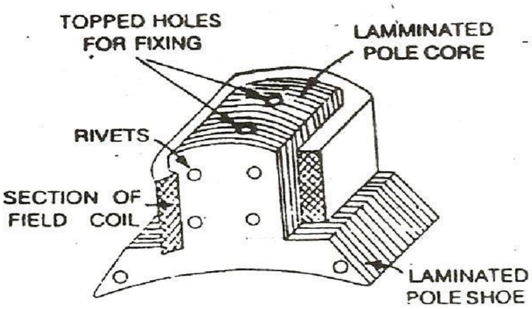


1.2.1. Yoke, Pole & field winding, Armature, Commutator:

Yoke

This is a outer covering of the machine which protects to all of its internal parts from entry of exteriors. This is a cylindrical drum like structure and made with Rolled steel or cast Iron. This is also called as magnetic frame.

Magnetic Poles:



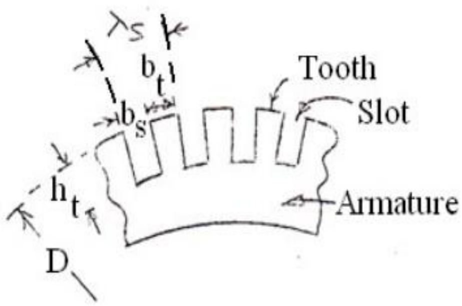
This is made up of cast iron or Cast steel having high permeability. It's core is always laminated in order to reduce eddy current loss. It's face or pole shoe is made curved in order to get uniform flux distribution. It is always fixed with the yoke of the machine.

Eye Bolt:

This is a provision made on the yoke of a machine to lift or shift the machine from one place to another place easily. This is also called as magnetic frame.

Pole winding or Field Windings:

Several turns of copper wire with required gauge are wound over the pole body are called as field windings. Flux is produced from the magnetic pole when this winding is excited by a d.c. source.



Armature:

This is rotating part of the machine. It is a cylindrical drum like structure made up of ferromagnetic material like sheet still having high permeability. It's core is laminated approximately 0.5 mm thick to reduce eddy current loss. Its surface has a number of slots & teeth. The grooves or holes are called as Slots but projected portions are called as teeth.

Commutator:

This is off course a rotating part of the machine mounted on the shaft and rotates in the same speed of the armature. The Commutator is also called as Split Ring. This is made up of wedge –shaped hard drawn copper lugs or drop forged copper segments. These segments have V grooves insulated by conical micanite rings. It has as many Segments as the number of armature coils. The main function of this Commutator is to convert a.c. to d.c.

1.2.2. Armature winding, back pitch, Front pitch, Resultant pitch and Commutator- pitch.

Armature windings:

Several turns of copper wires are embedded through the slots of the armature & are called as armature winding. These windings are of Lap & Wave connected.

Brush:

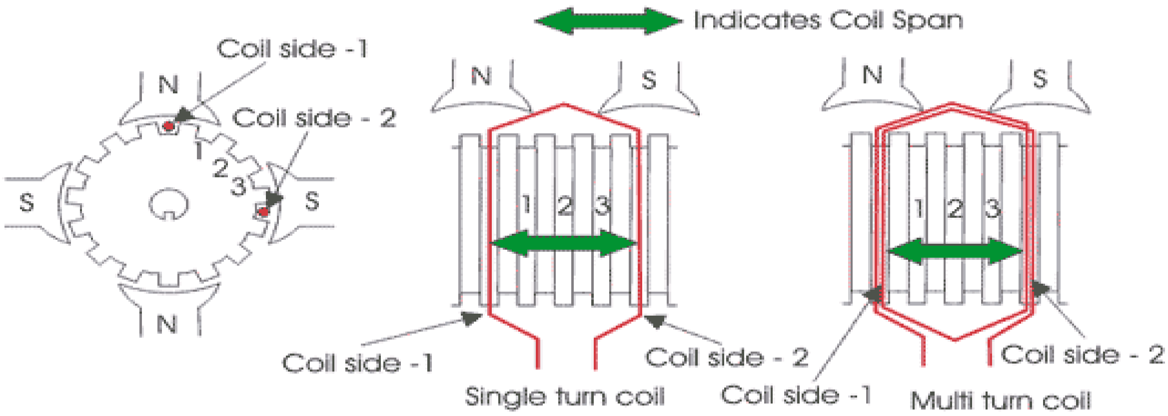
This is a fixed part & kept in a holder called as brush holder. It is always pressed against the Commutator surface. It is generally made up of Carbon which is a hardest material. The main function of this carbon is to collect direct current from the Commutator surface. It also polishes the Commutator surface.

Pole pitch

It is defined as the peripheral distance between the center of two adjacent poles in a DC machine
This distance is measured in terms of armature slots or armature conductors that come between two adjacent pole centers.
Pole Pitch is equal to the total number of armature slots divided by the total number of poles in the machine.
For example, if there are 96 slots on the armature periphery and 4 poles, the number of armature slots that come between two adjacent pole centers would be 96/4 = 24. Hence, the pole pitch of that DC machine would be 24.
Hence pole pitch is equal to total numbers of armature slots divided by total numbers of poles, we alternatively refer to it as armature slots per pole.

Coil span (also known as coil pitch)

It is defined as the peripheral distance between two sides of a coil, measured in terms of the number of armature slots between them. That means, after placing one side of the coil in a particular slot, after how many conjugative slots, the other side of the same coil is placed on the armature. This number is known as coil span.

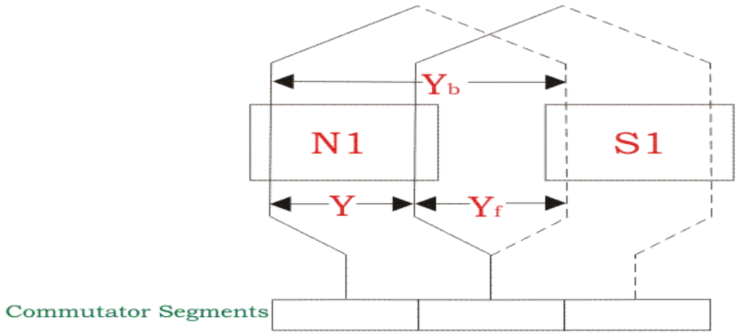


Commutator pitch

It is defined as the distance between two Commutator segments in which two ends of the same armature coil are connected. We measure Commutator pitch in terms of Commutator bars or segments.

Back Pitch(Y_b)

A coil advances on the back of the armature. This advancement is measured in terms of armature conductors and is called back pitch. It is equal to the number difference of the conductor connected to a given segment of the Commutator.



front pitch(Y_f).

The number of armature conductors or elements spanned by a coil on the front is called front pitch. Alternatively, we define the front-pitch as the distance between the second conductor of the next coil which connects the front, i.e., Commutator end of the armature.

It is the distance between the beginning of one coil and the beginning of the next coil to which it is connected.

Resultant Pitch (Y_R)

It is the distance between the beginning of one coil and the beginning of the next coil to which it is connected.

In other ward The difference between Back & Front Pitches is known as Resultant Pitch

Hence $Y_R = Y_b - Y_f$ in case of lap windings

$Y_R = Y_b + Y_f$ in case of wave windings

Working:

Using any prime mover, the armature of d.c. generator is rotated at its rated speed. At the same time, flux from the magnetic poles comes & links with the rotating armature conductors. According to the Faradays Electro Magnetic Induction, certain emf is induced in the armature conductors. This emf is alternating in nature but converted in to d.c. by means of Commutator. This d.c. is being collected by the brushes & send to the external circuit for use.

1.2.3. Simple Lap and wave winding, Dummy coils

Types of Armature Windings:

Simplex Lap Winding:

It is defined as the armature winding in which windings are divided as many parallel paths as the number of poles used.

Let, a=No. Of parallel path

P=No. Of Poles used

Z=Total No. of armature conductors

I_a=Total Armature current, A

Then according to the definition, a=p

Each path will contain Z/a number of conductors

Each path will carry I_a/ a amount of current.

Properties of Lap winding:

Following are the few important properties of lap windings.

i) It has as many parallel paths as the no. of poles, i.e. a=P

ii) Back & Front pitches must be an odd number

iii) Resultant pitch must be an even number, i.e. $Y_R = Y_b - Y_f$

Simplex Wave Winding:

It is defined as the armature winding in which there are only two parallel paths irrespective of the number of poles used.

Let, a=No. Of parallel path

P=No. Of Poles used

Z=Total No. of armature conductors

I_a=Total Armature current, A

Then according to the definition,

$$a=2$$

Each path will contain Z/a number of conductors

Each path will carry I_a/ a amount of current.

Properties of wave winding:

Following are the few important properties of lap windings.

i) It has as many parallel paths as the no. of poles, i.e. a=2

ii) Back & Front pitches must be an odd number

iii) Resultant pitch must be an odd number, i.e. $Y_R = Y_b + Y_f$

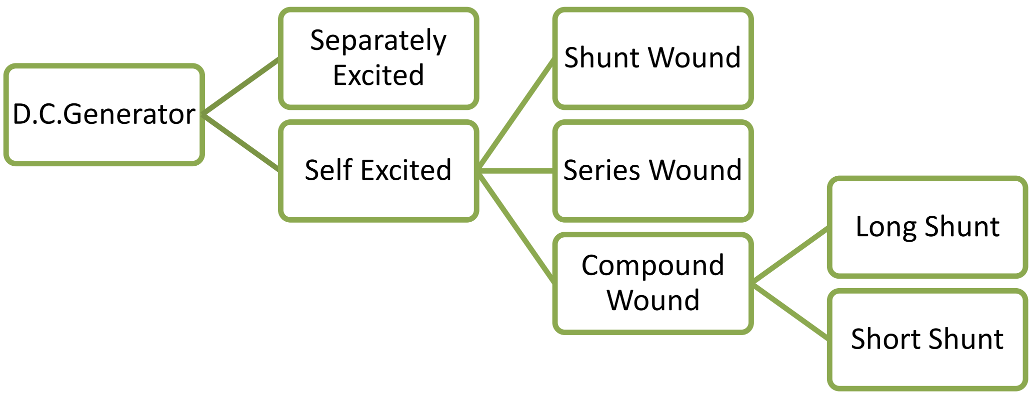
iv) Y_b & Y_f are nearly equal to the pole pitch or may be equal ($Y_b = Y_f$)

Dummy coils

Wave winding is actually called as incomplete winding because after completion of winding some slots are left empty. These empty slots are generally filled with some extra coils namely called as dummy coils.

These dummy coils are used for providing mechanical balance for the rotor only.

1.3. Different types of D.C. machines (Shunt, Series and Compound generator



1.3.1-Separately Excited D.C. Generator:

It is defined as a D.C. Generator in which it's field windings are excited or energized by the help of external d.c. source.

Voltage Equation:

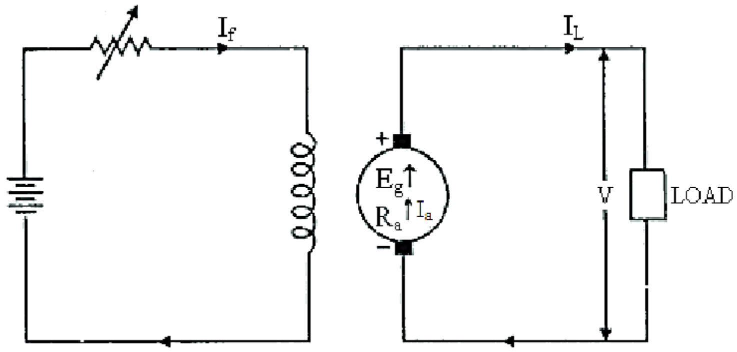
Let, E_g =Generated emf , V

V=Terminal or Supplied or Load Voltage, V

V_b= Brush contact drop or voltage drop in each brush, V

I_a = Armature Current , A

R_a = Armature winding Resistance or Armature Resistance, Ω



Applying KVL to the above closed circuit we get,

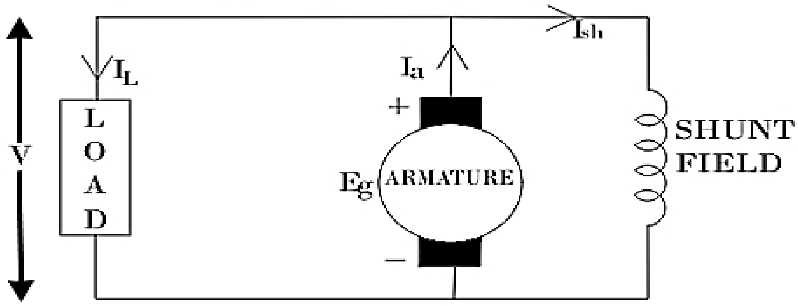
$$E_g = V + I_a R_a + 2 V_b$$

1.3.2-Self Excited D.C. Generator:

It is defined as a D.C. Generator in which it's field windings are excited or energized by the help of current produced of it's own. It is of following three types

a)D.C. Shunt Generator

If field windings of a self excited d.c. generator are connected in parallel with the Armature windings or circuits then that type of generator is known as d.c. shunt generator.



Shunt Wound Generators

Let, E_g =Generated emf , V

V=Terminal or Supplied or Load Voltage, V

V_b= Brush contact drop or voltage drop in each brush, V

I_a = Armature Current, A

I_{sh}=Shunt field current, A

I_L=Line or Load Current, A

R_a = Armature winding Resistance or Armature Resistance, Ω

R_{sh} =Shunt field winding Resistance or Shunt Resistance, Ω

Current Relation:

In the above figure, applying KCL at the node "B" we get

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

Voltage Equations or Voltage Relations :

Applying KVL to the mesh relating to Load & Armature, we get

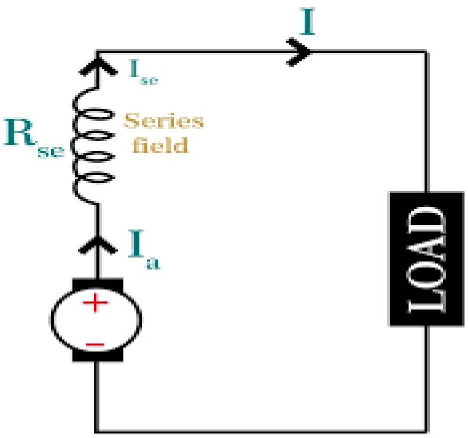
$$E_g = V + I_a R_a + 2V_b \quad V$$

Applying KVL to the mesh relating to Load &Field, we get

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

b)D.C. Series Generator

If field windings of a self excited d.c. generator are connected in series with the Armature windings or circuits then that type of generator is known as d.c. series generator.



Let, E_g =Generated emf , V

V=Terminal or Supplied or Load Voltage, V

V_b= Brush contact drop or voltage drop in each brush, V

I_a = Armature Current, A

I_{se}=Series field current, A

I_L=Line or Load Current, A

R_a = Armature winding Resistance or Armature Resistance, Ω

R_{se} =Series field winding Resistance or Series Resistance, Ω

Current Relation:

In the above figure,

$$I_a = I_{se} = I_L \quad A$$

Voltage Equation or Voltage Relation :

Applying KVL to the mesh relating to Load & Armature, we get

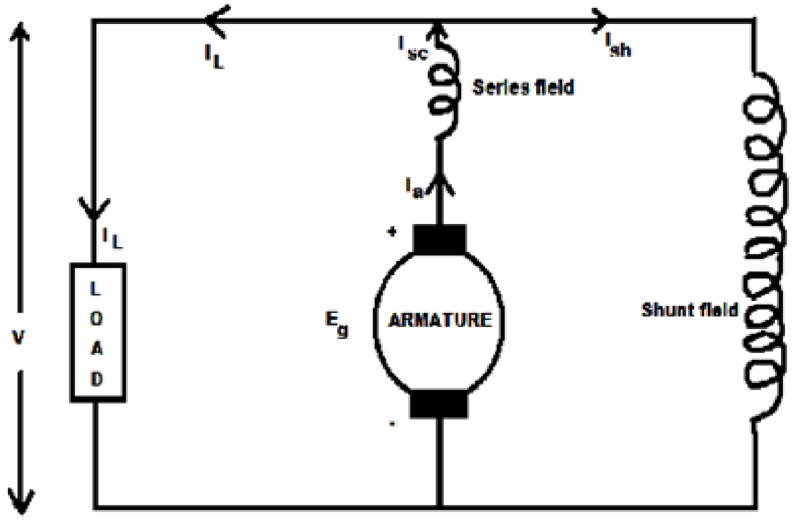
$$E_g = V + I_a (R_a + R_{se}) + 2V_b \quad V$$

c)D.C. Compound Generator

If field windings of a self excited d.c. generator are connected partially in series & parallel with the Armature windings or circuits then that type of generator is known as d.c. Compound generator. It is again of two types based on how the shunt field is connected with the armature.

i)Long Shunt Compound Generator :

In a compound generator, if the shunt field windings are connected across the armature & series field windings then it is called as Long Shunt Compound Generator.



Long Shunt Compound Wound Generator

Let, E_g =Generated emf , V

V=Terminal or Supplied or Load Voltage, V

V_b= Brush contact drop or voltage drop in each brush, V

I_a = Armature Current, A

I_{se}=Series field current, A

I_{sh}=Shunt field current, A

I_L=Line or Load Current, A

R_a = Armature winding Resistance or Armature Resistance, Ω

R_{se} =Series field winding Resistance or Series Resistance, Ω

R_{sh} =Shunt field winding Resistance or Shunt Resistance, Ω

Current Relations:

In the above figure, applying KCL at the node "B" we get

$$I_a = I_L + I_{sh} \quad A$$

Again

$$I_a = I_{se} \quad A$$

Voltage Equations or Voltage Relations :

Applying KVL to the mesh relating to Load & Armature, we get

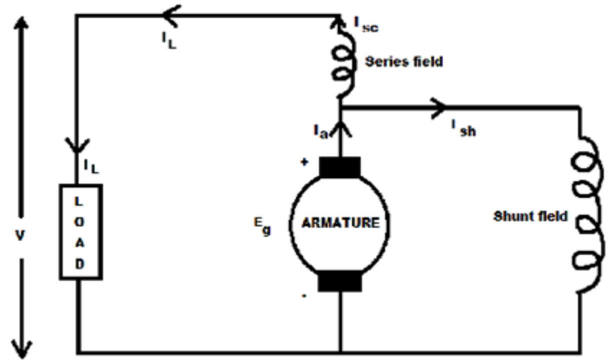
$$E_g = V + I_a (R_a + R_{se}) + 2V_b \quad V$$

Applying KVL to the mesh relating to Load &Field, we get

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

ii)Short Shunt Compound Generator :

: In a compound generator, if the shunt field windings are connected across the armature only leaving the series field windings then it is called as Short Shunt Compound Generator.



Short Shunt Compound Wound Generator

Let, E_g =Generated emf , V

V=Terminal or Supplied or Load Voltage, V

V_b= Brush contact drop or voltage drop in each brush, V

I_a = Armature Current, A

I_{se}=Series field current, A

I_{sh}=Shunt field current, A

I_L=Line or Load Current, A

R_a = Armature winding Resistance or Armature Resistance, Ω

R_{se} =Series field winding Resistance or Series Resistance, Ω

R_{sh} =Shunt field winding Resistance or Shunt Resistance, Ω

Current Relations:

In the above figure, applying KCL at the node "B" we get

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

$$I_{se} = I_L$$

Voltage Equations or Voltage Relations :

Applying KVL to the mesh relating to Load & Armature,
we get

$$E_g = V + I_L R_{se} + I_a R_a + 2 V_b \quad V$$

Applying KVL to the mesh relating to Load, Series field & Shunt field, we get

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

Applying KVL to the mesh relating to Armature & Shunt field, we get

$$E_g = I_{sh} R_{sh} + I_a R_a + 2 V_b \quad V$$

1.4. Derivation of EMF equation of DC generators. (Solve problems)

Let,

Φ=Amount of useful flux per pole, wb

P= No. of poles used in the generator

a=Number of armature paths

Z=Total number of armature conductors

N=Speed of armature. R.P.M.

Change of flux linking with armature windings, dϕ =pϕ , web

For N number of rotation of armature, time taken = 1 min

=60 sec

For 1 rotation of the armature, time taken =60/N sec

Hence dt =60/N sec

According to Faraday's laws of Electro Magnetic Induction,

emf induced in one armature conductor = dϕ/dt

= pϕ/60/N

= pϕN/60

Since there are Z/a number of armature conductors in each path,

So total generated emf for Z/a no of conductors = (pϕN/60) Z/a

$$E_g = \frac{Z\phi N}{60}\left(\frac{p}{a}\right) \text{ in volt}$$

Where a=2 for Wave windings

a=P for Lap windings

Numeric Problems:

Q1: A 4 pole, lap wound d.c. generator has 56 slots and each slot contains two conductors. If the armature rotates at a speed of 1000 r.p.m. find the value of generated e.m.f. if flux per pole is 10 mwb.

solution

Given Data:	**Required Data**
P=4	E_g = ?

a=P=4

S=56

Z/S=2

N=1000 r.p.m.

$\Phi=10 \text{ X}10^{-3}$ wb

Total armature conductors Z=56X2= 112

We know generated emf $E_g = \frac{Z\phi N}{60}\left(\frac{p}{a}\right)$

$$= \frac{10 \times 10^{-3} \times 112 \times 1000}{60} \times (1)$$

=18.67, V

Q2: A d.c. generator generates an emf of 520V .It has 2000 armature conductors , flux per pole of 0.013wb, speed of 1200 rpm & the armature winding has four parallel paths. Find the number of poles.

solution

Given Data: **Required Data**

E_g =520 V P= ?

Z=2000

Φ=0.013 wb

N=1200 RPM.

a=4

We know generated emf , $E_g = \frac{Z\phi N}{60}(\frac{p}{a})$

P=$\frac{E_g \times a \times 60}{\varphi \times Z \times N}$ =$\frac{520\times4\times60}{0.013\times2000\times1200}$=4 (Ans)

Q3:A 4 pole machine running at 1500 rpm has an armature with 90 slots & 6 conductors per slot. The flux per pole is 10 mWb. Determine the terminal emf as a d.c. generator, if the coils are lap connected.

solution

Given Data: **Required Data**

P=4

N=1500 rpm V=?

S=90

Z/S=6

Φ=10 X10^{-3} wb

a=p

Total armature conductors Z=6X90=540

We know that, $E_g = \frac{Z\phi N}{60}(\frac{p}{a})$

=10 ×10^{-3} ×540 ×1500/60 = 135 V (Ans)

Q4: A 4 pole, d.c. generator runs at 750 rpm & generates an emf of 240V . The armature is wave connected & has 792 conductors. If the total flux from each pole is 0.0145 Wb, what is the leakage coefficient?

solution

Given Data: **Required Data**

P=4

N=750 rpm ʎ=?

E_g =240 V

a=2

Z=792

Φ_T =0.0145 Wb

We know that, $E_g = \frac{\Phi\times Z\times N\times p}{60\times a}$

so $\Phi= \frac{Eg\times60\times a}{Z\times N\times p}$

$\Phi= \frac{240\times60\times2}{792\times750\times4}$=0.0121 Wb

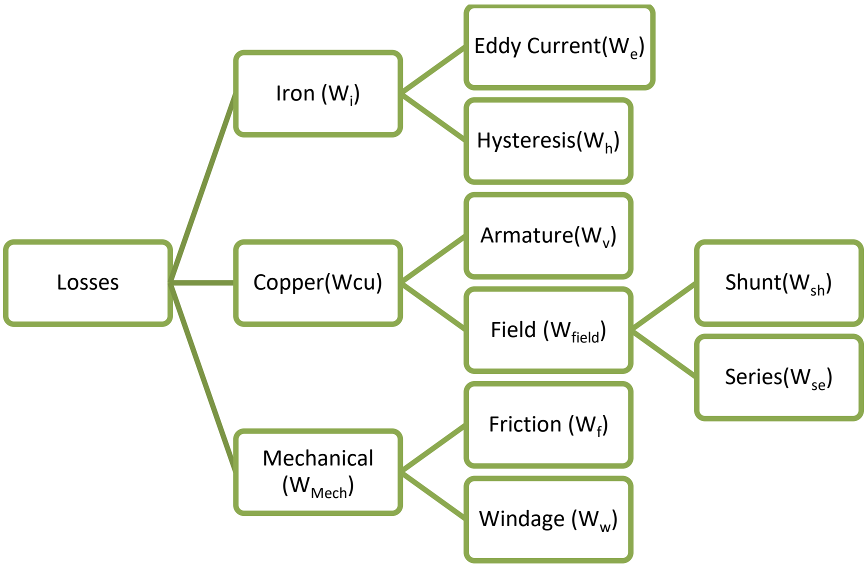
But Leakage Coefficient, ʎ=$\frac{Total\ flux\ per\ pole}{Useful\ flux\ per\ pole}$

=0.0145/0.0121

=1.2 (Ans)

1.5. Losses and efficiency of DC generator. Condition for maximum efficiency and numerical problems.

During operation of a d.c. generator, various losses take place in different parts of the d.c. generator which are explained below.



Iron Loss:

During rotation of the armature under the influence of magnetic field, eddy current is set up .This eddy current flowing through the armature core generates heat which we say eddy current loss (W_e). Similarly the armature core is made with different materials which have various hysteresis loop area, accordingly hysteresis loss (W_h) takes place.

$W_i = W_e + W_h$

Therefore Iron loss is the sum of eddy current & hysteresis loss.

Copper Loss:

When electric current will flow through the copper wires then I^2R loss takes place in the form of heat which is called as copper loss. This loss takes place in the armature windings called as armature copper loss or variable loss (W_v) & also in the field windings (May be series field or shunt field) and is called as field copper loss.

Hence total copper loss is the sum of armature copper loss & field copper loss.

$$W_{cu} = W_v + W_f$$
$$= W_v + (W_{se} + W_{sh})$$

Mechanical Loss:

While rotating the armature, the shaft rotates over the bearings where friction losses take place. To overcome this loss some power is utilised & is called as frictional loss.

Similarly while rotating the armature, a wind develops against the rotation of the armature for which it's speed gets affected. So to overcome this, small amount of power is lost & is called as windage loss.

Therefore Mechanical loss is the sum of windage & friction.

$$W_{Mech} = W_w + W_f$$

Abstract of Losses:

i)Stray Loss = Iron Loss + Mechanical Loss

$$W_S = W_I + W_{Mech}$$

ii)Constant Loss = Stray loss + Shunt Field copper Loss

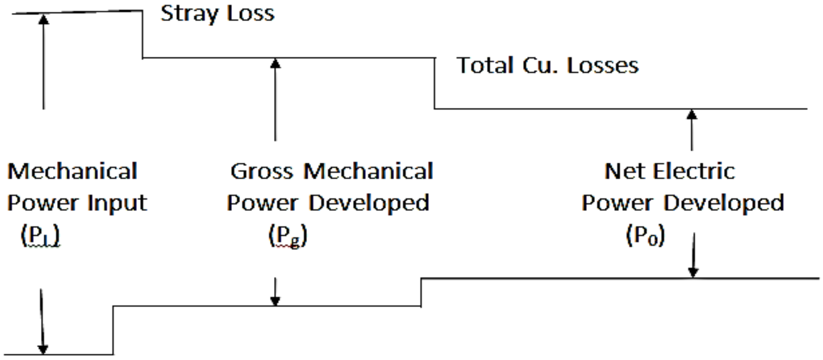
$$W_C = W_S + W_{sh}$$

III) Total Losses = Constant loss + Armature or variable loss [$I_a^2 (R_a + R_{Se})$]

$$W_T = W_c + W_v$$

Power Stage Diagram

We have seen that, various losses take place at different parts of the d.c. generator. Hence the output power cannot be equal to the input power rather it will be less than that of input power. So after various losses in different stages the power obtained and mentioned in a diagram is called as power stage diagram.



a) Mechanical Efficiency, $\eta_{mech} = \frac{P_g}{P_I}$ & % $\eta_{mech} = \frac{P_g}{P_I} \times 100$

b) Electrical Efficiency, $\eta_{elect} = \frac{P_o}{P_g}$ & % $\eta_{elect} = \frac{P_o}{P_g} \times 100$

c) Overall Efficiency $\eta = \frac{P_o}{P_I}$ & % $\eta = \frac{P_o}{P_I} \times 100$

Efficiency & Condition for maximum Efficiency:

Let,

V= Supplied Voltage, V

I_a= Armature Current, A

R_a=Armature Resistance, Ω

W_C=Constant Loss , W

W_V=Variable loss or Armature Copper Loss, W

We know that, Efficiency, η=Output Power /Input Power $= \frac{P_O}{P_I}$

So $$\eta = \frac{VIa}{P_O + \text{Losses}}$$

$$= \frac{VI_a}{VI_a + (W_c + I_a^2 R_a)}$$

For Maximum Efficiency, $d\eta/dI_a = 0$

So $$\frac{d}{dI_a}\left(\frac{VIa}{VI_a + (W_c + I_a^2 R_a)}\right) = 0$$

so [$(VI_a + W_C + Ia^2 Ra) \frac{d}{dIa}(VI_a) - VI_a \frac{d}{dIa}(VI_a + W_C + Ia^2 Ra)] / [VI_a + W_C + Ia^2 Ra]^2=0$

so $VI_a + W_C + Ia^2 Ra)V - VI_a (V+2I_aR_a)=0$

so $(VI_a + W_C + Ia^2 Ra)V = VI_a (V+2I_aR_a)$

so $(VI_a + W_C + Ia^2 Ra) = VI_a + 2I_a^2 R_a$

$W_C = Ia^2 Ra=W_V$

Hence the efficiency of a d.c. generator will be maximum only when Variable Loss is equal to the Constant loss.

*Load current corresponding to the maximum efficiency is given by

$I_L=I_a= \sqrt{\frac{Wc}{Ra}}$, A

Numeric Problem On Losses

Q1.A short shunt compound generator supplies a current of 100 A at a voltage of 230 V.If the resistances of shunt field, series field & armature are 50 Ω , 0.025 Ω & 0.05 Ω respectively, the total brush drop is 2V & the iron and friction losses amount to 1 KW ,find

a) The generated emf b) Total copper loss c) The output power d) efficiency.

solution

Given Data:

Short shunt d.c. generator

$I_L = I_{se}$ =100 A

V=230 V

R_{sh}=50 Ω

R_{se} = 0.025 Ω

Ra=0.05 Ω

V_b =2 V

$W_I + W_f$ =1 KW

Require Data:

a) E_g = ?

b)W_{cu} =?

c) P_I =?

d) ɳ =?

We know

$I_{sh} = (V+ I_LR_{se}) / R_{sh}$

= (230+(100×0.025))/50

= 232.5 /50

=4.5

$I_a = I_L + I_{sh}$

=100+4.5

=104.5

$E_g = V+ I_LR_{se}+ I_aR_a +2 V_b$

=230+(100×0.025)+(104.5×0.05)+(2)

=230+2.5+5.225+2

=239.72

=240v

Total cu loss= $W_{cu} = W_v + W_f$

$= W_v + (W_{se} + W_{sh})$
$= Ia^2 Ra + Ise^2 Rse + Ish^2 Rsh$
$= (104.5)^2\ 0.05 + (100)^2\ 0.025 + (4.5)^2\ 50$
$= 556.5125+250+1012.5$
$=1819.01$watt
$=1.8$ kw

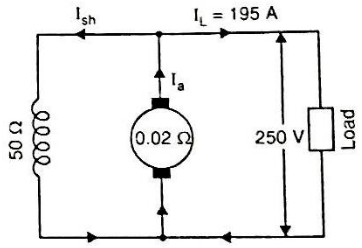
The output power = VI_a = 230× 104.5 =24035

Efficiency = $\frac{P_o}{P_I} = \frac{VIa}{P_o+\text{Losses}} = \frac{24035}{24035+1819+1000}$
$= \frac{24035}{26854}$
$=0.895$ $=89.5\%$

Q2 A shunt generator delivers 195 A af a terminal p il of 250 Y The ammare nesismence and shtant field resisfance are 0.02Ω and 50Ω rospectively The inon and friction lossex equal 950 W. Find (i) em.f.generared (ii) Cu losses (iit) oudput of the prime mover (iv) mechanical. elecirical and commerical efficiencies.

Solution.

Fig. 2,63 shows the generanor circuit.



(i) $I_{si} = \frac{250}{50} - 5$ A: $I_n = 195 + 5 = 200$ A

$\therefore$ Generated e.m.f., $E_g = V + I_4 R_a$
$= 250 + 200 \times 002 = 254$ V

(ii) Armature Cu loss $= r_a^2 R_p = (200)^2 \times 0.02$
$= 800$ W

Shunt Cu loss = $Vl_{10} - 250 \times 5 = 1250$ W Total Cu loss $= 800 + 1250 = 2050$ W
Total losses $-2050 + 950 = 3000$ W
Output $= 250 \times 195 = 48750$ W
Input $= 48750 + 3000 = 51750$ W
$\therefore$ Output of prime nover $= 51750$ W
(iv) Elcetrical power produced in armature

$$= 51750 - 950 = 50800 \text{ W}$$

$$\text{Mechanical efficiency, } \eta_{en} = \frac{50800}{51750} \times 100 = 98 - 2\%$$

$$\text{Electrical efficiency, } \eta_e = \frac{48750}{50800} \times 100 = 95.9\%$$

$$\text{Overall efficiency, } \eta_c = \frac{48750}{51750} \times 100 = 94.2\%$$

1.6. Armature reaction in D.C. machine:

Definition:

It is defined as the interaction between main field flux & Armature flux.

Explanation:

While rotating the armature, the armature conductors are also rotated in the uniform magnetic field .According to the Faraday's laws of electromagnetic induction, certain emf & hence current is induced in the armature conductors. Now the current carrying armature conductors create magnetic field and is called as armature flux (ϕ_a) whose direction becomes just opposite to the direction of main field flux (ϕ_m). So resultant flux per pole gets decreased. Hence induced emf is also affected. The intensity of armature flux depends on the external load connected. More is the load higher will be the armature current & hence armature flux.

Remedies:

Since armature reaction affects on the generated emf & the terminal voltage, so care must be taken to reduce this reaction. However the armature reaction can be reduced by introducing compensating windings.

Compensating Windings are embedded in the slots of the pole shoes .These Windings are connected in series with the armature windings, such that the flux produced from these windings will act along the direction of main poles by which armature flux can be minimised.

1.7. Commutation and methods of improving commutation:

Commutation:

It is defined as the process by which the current in the short circuited armature coil gets reversed in the Magnetic Neutral Axis (MNA) .

Explanation:

As we know that, the emf induced in the armature is Alternating in nature. So in each period it will get reversed. But it is observed that, due to the more inductance property in the armature coil, the reversal of current could not be held in commutating period (T_C), rather it gets delayed. If the reversal of current takes palce in the commutating period then we say the commutation is Ideal or good if not then poor commutation. However this delay of reversal process causes poor commutation for which more spark is produced at the brush surface. Due this spark the commutator or both commutator & brush may damage. To improve the commutation (means to make reversal in commutating period), following methods are adopted.

Geometrical Neutral Axis (G.N.A) & Magnetic Neutral Axis (M.N.A):

The geometrical neutral axis is always perpendicular to the stator field axis or main flux axis

or

The geometrical neutral axis (GNA) is the axis that bisects the angle between the centre line of adjacent poles.

The magnetic neutral axis (MNA) is the axis drawn perpendicular to the mean direction of the flux passing through the centre of the armature.

magnetic neutral axis the axis where no electromotive force induces in the armature conductor

Methods of Improving Commutation:

(a) Resistance Commutation method

(b) Voltage Commutation Method

Resistance Commutation Method

It is defined as a process of improving commutation in which Low Resistance copper brush is replaced by the high resistance Carbon brush.

Voltage Commutation Method

In this method ,an arrangement is made to neutralize the reactance voltage by producing a reversing voltage in the coil undergoing commutation, if the reversing voltage is equal to the reactance voltage, the effect is completely wiped out & we get sparkles commutation. The reversing voltage may be produced by two ways

(i) By brush shifting

(ii) By using interpoles

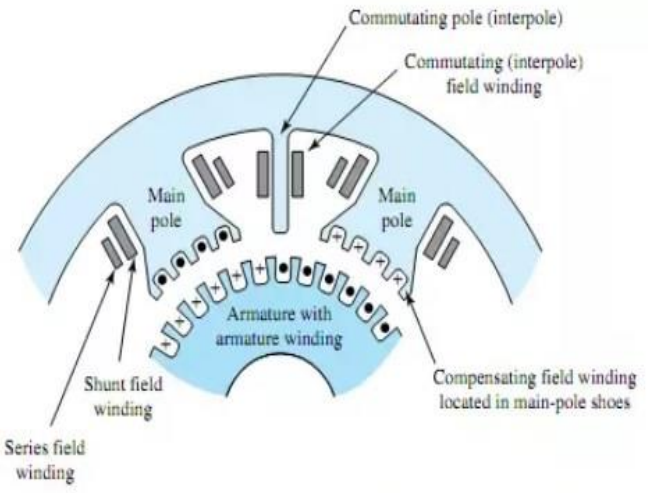
1.7.1. Role of inter poles and compensating winding in commutation :

Interpoles (Commutator Field Winding)

The best way to produce reversing voltage to neutralize the reactance voltage is by using inter poles. Another way to reduce the effects of armature reaction is to place small auxiliary poles called "inter poles" between the main field poles. The inter poles have a few turns of large wire and are connected in series with the armature.

Inter poles are wound and placed so that each inter pole has the same magnetic polarity as the main pole ahead of it, in the direction of rotation. The field generated by the inter poles produces the same effect as the compensating winding.

This field, in effect, cancels the armature reaction for all values of load current by causing a shift in the neutral plane opposite to the shift caused by armature reaction. The amount of shift caused by the inter poles will equal the shift caused by armature reaction since both shifts are a result of armature current. The commutating pole (Inter pole) windings are all connected in series with each other and with the armature circuit. A resistor connected in parallel with the commutating pole (Inter pole) windings is adjusted and permanently set at the factory to give the commutating pole strength that results in the best commutation.



Section of a dc machine illustrating the arrangement of various field windings.

Compensating Windings

To neutralize completely the effects of armature reaction, a second set of auxiliary field windings, known as the **compensating windings**, is used in high-power d.c. machines.

The **cross-magnetizing effect** of armature reaction may cause trouble in d.c. machines subjected to large fluctuations in load. In order to neutralize the cross magnetizing effect of armature reaction, a compensating winding is used.

The compensating windings consist of a **series of coils embedded in slots in the pole faces**. These coils are connected in series with the armature as shown in above fig.

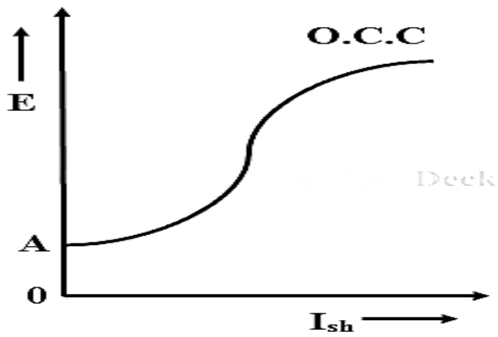
1.8. Characteristics of D.C. Generators:

To understand the behaviour & performance of a d.c. generator, characteristics must be properly analysed. Following are the various characteristics of d.c. generators.

1.8.1. Characteristics of D.C. shunt Generators:

Open Circuit Characteristic (OCC):

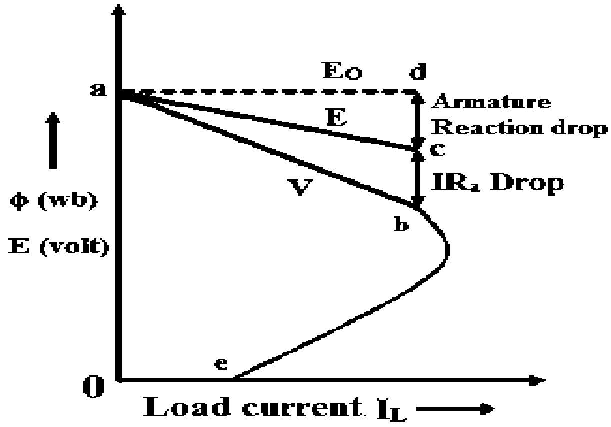
If Field (I_f) is taken along X-axis and No load voltage (E_0) along Y-axis, with different values of field current & voltage , a graph such plotted is called as open circuit characteristic of d.c. generators. No-load or open circuit characteristics of a shunt generator are obtained by plotting ammeter reading (field current) i.e. I_{sh}, versus voltmeter reading E (generated voltage).
Under the no-load condition, the generator is said to be open-circuited and rotating at a constant speed. From the EMF equation of dc generator, generated voltage E is directly proportional to flux φ. As φ is directly proportional to field current I_{sh}, an increase in I_{sh} also increases E.



Also if there is no field current I_{sh} at starting, we can notice some voltage E in the armature. This is mainly due to magnetism present in the field poles, known as residual magnetism. That is why the graph starts from point A but not from origin 0.
Now as the field current I_{sh}, flux φ, increases with an increase in voltage E. But, after reaching certain current I_{sh} the field gets saturated and therefore φ and E remain constant as shown in the above figure.

Load Characteristics :

When a shunt generator is loaded, voltage builds up, then its terminal voltage drops due to armature resistance and armature reaction. The terminal voltage V and load current I_L can be measured, the relation between these V and I_L can be drawn like (a-b), known as the external characteristic curve.



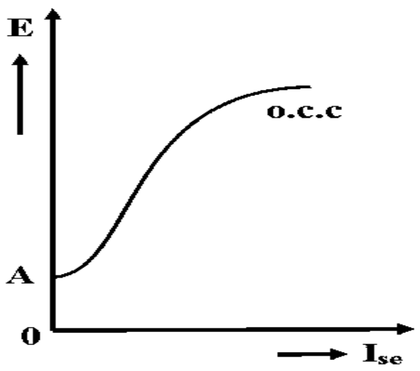
If armature resistance drop components are added to the curve (a-b), we get the internal characteristic curve (a-c), as shown. If armature reaction drop components are added to this curve ac we get curve or line (a-d), which can be called no-load characteristics, but on no-load the $I_L = 0$. Therefore it is imaginary and hence shown with a dotted line.
If it is increased beyond the rated value, the terminal voltage decreases rapidly due to increased armature reaction, represented by the curve (b-e). It is known as drooping characteristics.

Characteristics of DC Series Generator :

In a dc series generator the field winding, armature, and load are connected in series with each other i.e., $I_L = I_{se} = I_a$.

No-load Characteristics :

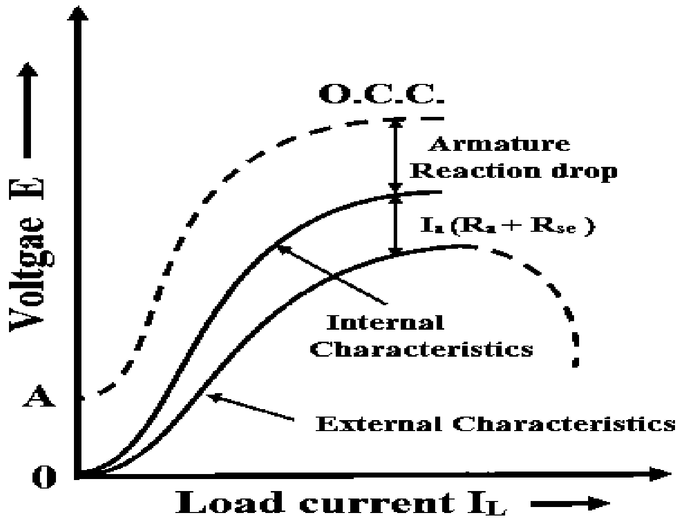
The no-load characteristics of a dc series generator are similar to the no-load characteristics of a shunt generator. But, at no-load condition, the generator is running at a constant speed due to series connection no field current flows as the load current I_L, is zero. Hence it is difficult to obtain no-load characteristics.



To draw the O.C.C. of a series generator the field winding should be given a separate d.c. supply. The diagram below shows the O.C.C. of a separately excited series generator.
Now if the field current IL, increases the voltage E will also build up proportionally. Here also the curve starts from point A due to residual magnetism.

Load Characteristics :

When the series generator is loaded it starts drawing the current. Here, we know that I_L = Ise = Ia. So as the load current I_L increases e.m.f. induced E also increases. The curve a-c between I_L and E shows internal characteristics. This curve lies below the curve of O.C.C. due to the armature reaction effect.



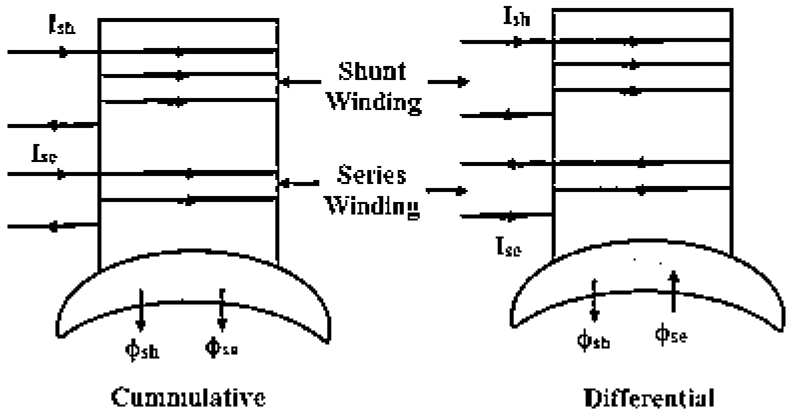
The external characteristics are shown with a curve, it lies below the internal characteristics due to a drop in armature and field windings. From the curves obtained we notice that an increase in I_L, increases E. Therefore, the series generator characteristics are also called Raising Characteristics.

Characteristics of DC Compound Generator :

A compound generator or compound wound generators is a combination of both shunt and series wound generators. One winding is connected in series and the other is connected in parallel with the armature.

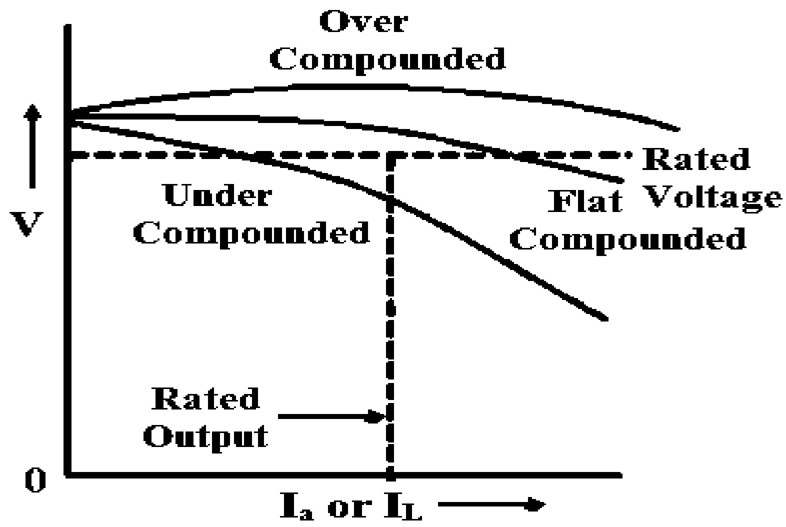
Load Characteristics :

A shunt generator can be made to supply a constant voltage by connecting a few turns in series with the armature terminals. This arrangement is known as a compound generator. There are two types of connections for connecting a series and shunt windings in a compound generator.
If the connection is in such a way that flux produced by both series and shunt windings (φ_{se} and φ_{sh}) are both in the same direction then the connection is said to be a Cumulative Compound. If the connection is in such a way that both the fluxes (φ_{se} and φ_{sh}) produced, are opposite to each other, then it is known as Differential Compound. The below figure shows the two different connections of a compound generator.



Now, in a compound generator when load current I_L increases. The current I_{se} in series turns also increases which in turn produces more flux and thereby generating more e.m.f. But due to increase an in armature current I_a, there will be an increase in voltage drop due to armature resistance and armature reaction.

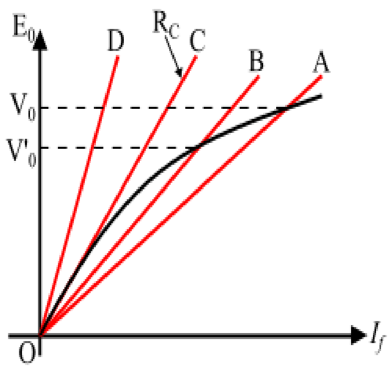
If the series field turns are such as to produce e.m.f. equal to drop due to armature resistance and armature reaction, then the generator is called flat compounded or level compounded.



If the series field turns produce e.m.f. more or less than the drop due to armature resistance and reaction, then the generator is called over compounded or under compounded respectively.

1.10. Concept of critical resistance DC shunt generator:

The critical field resistance (R_C) of a DC shunt generator is defined as the maximum field circuit resistance with which the shunt generator would just excite.



The voltage build-up in a shunt generator depends upon field circuit resistance. If the field circuit resistance is R_1, then the generator will build-up a voltage V_0 (see the E_0 versus If curve). If the field circuit resistance is increased to R_2, then the generator will build-up a voltage V_0 slightly less than V_0. As the resistance of the field circuit is increased, the slope of the field resistance line also increases. When the field resistance line becomes tangent (line OC) to magnetisation characteristics, the generator would just excite. Now, if the field circuit resistance is increased beyond this point (as line OD), then the generator will fail to excite. Therefore, the field circuit resistance represented by the line OC, which is tangent to the magnetisation curve is known as critical field resistance (R_C) of a shunt generator. Therefore, a shunt generator will build up voltage only if the field circuit resistance is less than the critical field resistance.

Explanation of magnetisation curve:

By using any prime mover, the armature of the generator is rotated at it's rated speed. The residual flux from the magnetic pole gets linked with the rotating armature coil, so certain emf will be induced. This emf will drive a small current in the shunt field winding due to which more flux is created from the pole. Again this more flux links with the rotating armature coil, which in turn comparatively more emf will be induced. Due this more emf , again more current in the field .Due to linkage of such more flux again much more emf. This process is continued till the magnetic saturation. Once the magnetic field gets saturated, there will be no further increase of emf rather it will remain constant. The Ammeter reading of field circuit & Voltmeter reading of armature circuit are recorded in each step .With this readings a graph can be plotted which looks like magnetisation curve

1.11. Conditions of Build-up of emf of DC generator.

--There must be some residual magnetism in the generator poles.

--open circuit its shunt field resistance should be less then the critical resistance.

1.12. Parallel operation of D.C. Generators:

Parallel operation is the connec- tion of two or more power sources of the same size and output volt- age to obtain a higher output cur- rent.

parallel operation of dc generators and load sharing among them for the continuous power supply.In a d.c power plant, power is usually supplied from several generators of small ratings connected in parallel instead of from one large generator. This is due to the following reasons:

(i)Continuity of service:

(ii) Efficiency:

(iii) Increasing plant capacity

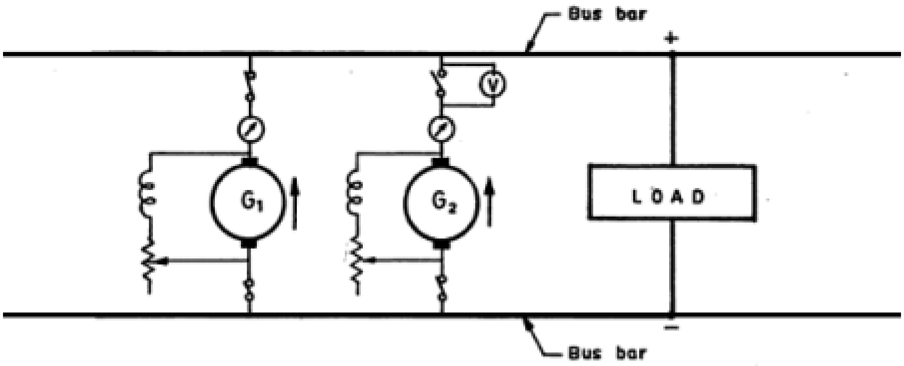
(Iv) Maintenance and repair:

Parallel operation of DC Shunt generator

Before connecting the two machines the voltages of the two machines are made equal and opposing inside the loop formed by the two machines.

This avoids a circulating current between the machines. The circulating current produces power loss even when the load is not connected.

In the case of the loaded machine the difference in the induced emf makes the load sharing unequal.



Load Sharing of Parallel Connected DC Generators

The load sharing between shunt generators in parallel can be easily regulated because of their drooping characteristics.

The load may be shifted from one generator to another merely by adjusting the field excitation. Let us discuss the load sharing of two generators which have unequal no-load voltages.

Let E_1, E_2 = no-load voltages of the two generators

R1, R2 = their armature resistances

V = common terminal voltage (Bus-bars voltage)

Then $V = E_1 - I_1 R_1$

$= E_2 - I_2 R_2$

Thus current output of the generators depends upon the values of E_1 and E_2. These values may be changed by field rheostats.

The common terminal bus-bar voltage will depend upon

the emfs of individual generators and

the total load current supplied.

It is generally desired to keep the bus-bars voltage constant.

1.9/1.13. Application of different types of D.C. Generators.

Applications of Shunt Wound DC Generators

The application of shunt generators is very much restricted for its dropping voltage characteristic. They are used to supply power to the apparatus situated very close to its position. These type of DC generators generally give constant terminal voltage for small distance operation with the help of field regulators from no load to full load.

1. They are used for general lighting.
2. They are used to charge battery because they can be made to give constant output voltage.
3. They are used for giving the excitation to the alternators.
4. They are also used for small power supply (such as a portable generator).

Applications of Series Wound DC Generators

These types of generators are restricted for the use of power supply because of their increasing terminal oltage characteristic with the increase in load current from no load to full load. We can clearly see this characteristic from the characteristic curve of series wound generator. They give constant current in the dropping portion of the characteristic curve. For this property they can be used as constant current source and employed for various applications.

1. They are used for supplying field excitation current in DC locomotives for regenerative breaking.
2. This types of generators are used as boosters to compensate the voltage drop in the feeder in various types of distribution systems such as railway service.
3. In series arc lightening this type of generators are mainly used.

Applications of Compound Wound DC Generators

Among various types of DC generators, the compound wound DC generators are most widely used because of its compensating property. Depending upon number of series field turns, the cumulatively compounded generators may be over compounded, flat compounded and under compounded. We can get desired terminal voltage by compensating the drop due to armature reaction and ohmic drop in the in the line. Such generators have various applications.

1. Cumulative compound wound generators are generally used for lighting, power supply purpose and for heavy power services because of their constant voltage property. They are mainly made over compounded.
2. Cumulative compound wound generators are also used for driving a motor.
3. For small distance operation, such as power supply for hotels, offices, homes and lodges, the flat compounded generators are generally used.
4. The differential compound wound generators, because of their large demagnetization armature reaction, are used for arc welding where huge voltage drop and constant current is required.

problems

Q.The hysteresis & eddy current losses in a d.c. machine running at 1000 rpm are 250W & 100W respectively. If the flux remains constant, at what speed will be total iron losses be halved?

Given Data: Required Data:

W_h= 250 W N_2 =? For W_{i2} =1/2 W_{i1}

W_e = 100 W

N_1=1000 rpm.

Solution:

As we know that, N=120 f/ P

Hence f α N

But $W_h \alpha f$

$W_h \alpha N$

so W_h = A N (where A is a constant)

so 250=A1000

or A=0.25

Similarly We α N^2

So, We =B N^2 (Where B is a constant).

100=B1000

So B=0.1

But Iron loss = Hysteresis + Eddy current loss

$W_I = W_h + We$

$=0.25 N + 0.1 N^2$

According to the question

$W_{I2} = A N_2 + B N_2^2$

$175=0.25 N_2 + 0.1 N_2^2$

$N_2^2 + 2.5 N_2 – 1750 =0$

N_2 = 570 RPM. (Ans)

Q. The terminal voltage of a generator falls from 250 V on open-circuit to 238 V when delivering 60 A. It is connected to a load in parallel with a battery having a constant e. m f. of 245 V and a nesistance of 0.1Ω. Find the current supplied by the generator when the total load current is (i) 50 A (ii) 100 A (iii) zero.

Solution.

Internal resistance of generator $= \frac{250-238}{60} = 0.2\Omega$

Let I = total load current

I_1 = current supplied by generator

l_2 = current supplied by battery

V = terminal voltage

$I_1 = \frac{250-V}{0\cdot 2}$ and $I_2 = \frac{245-V}{0\cdot 1}$

Now $I_1 + I_2 = l$

or $\frac{250-V}{0\cdot 2} + \frac{245-V}{0\cdot 1} = l$

or $V = \frac{3700-I}{15}$

(i) When total load current $I = 50$ A

$$V = \frac{3700-50}{15} = \frac{3650}{15} = 243\cdot 3 \text{ volts}$$

$$I_1 = \frac{250-V}{0\cdot 2} = \frac{250-243\cdot 3}{0\cdot 2} = 33\cdot 5 \text{ A}$$

(ii) When total load current $I = 100$ A

$$V = \frac{3700-100}{15} = \frac{3600}{15} = 240 \text{ volts}$$

$$I_1 = \frac{250-V}{0.2} = \frac{250-240}{0.2} = 50 \text{ A}$$

(iii) When total load current $I = 0$

$$V = \frac{3700-0}{15} = 246.7 \text{ volts}$$

$$l_1 = \frac{250-V}{0.2} = \frac{250-246.7}{0.2} = 16-5 \text{ A}$$

POSSIBLE SHORT TYPE QUESTION WITH ANSWER

Q.1- What is geometrical neutral axis (G.N.A) & magnetic neutral axis (M.N.A) ?[S-19]

Ans- The geometrical neutral axis (GNA) is the axis that bisects the angle between the centre line of adjacent poles.

The magnetic neutral axis (MNA) is the axis drawn perpendicular to the mean direction of the flux passing through the centre of the armature.

magnetic neutral axis the axis where no electromotive force induces in the armature conductor.

Q.2-What is resultant pitch in armature winding of DC generator[S-17]

Ans- It is the distance between the beginning of one coil and the beginning of the next coil to which it is connected.

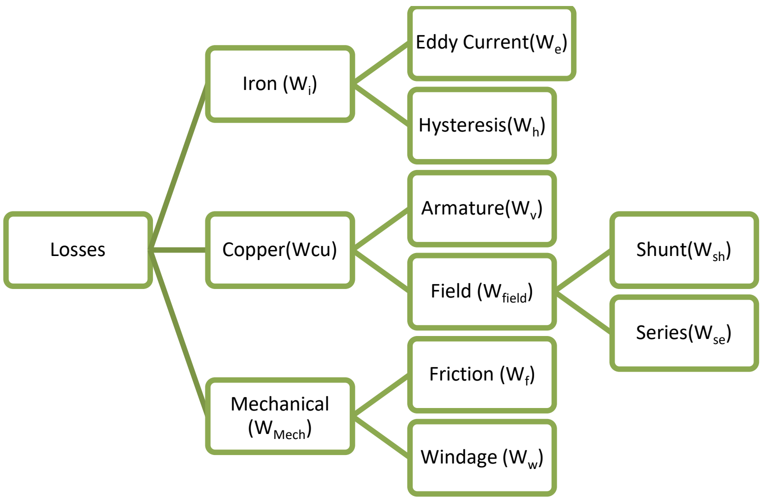
In other ward The difference between Back & Front Pitches is known as Resultant Pitch

Hence $Y_R = Y_b - Y_f$ in case of lap windings

$Y_R = Y_b + Y_f$ in case of wave windings

Q.3-state the various losses in D.C machine[S-18]

Ans- During operation of a d.c. generator, various losses take place in different parts of the d.c. generator which are explained below.



Q.4 state the condition of maximum efficiency of a D.C generator.[S-14,18]

Ans- $W_C = Ia^2 Ra = W_V$

Hence the efficiency of a d.c. generator will be maximum only when Variable Loss is equal to the Constant loss.

Q.5 define commutation.[S-17]

Ans- It is defined as the process by which the current in the short circuited armature coil gets reversed in the Magnetic Neutral Axis (MNA)

Q.6 what is function of poleshoe in a DC m/c ?

Ans- the main function of pole shoe used in DC m/c is to distributes the magnetic flux uniformly.

Q.7- What is critical resistance of a DC shunt generator? [S-19]

Ans- The critical field resistance (R_C) of a DC shunt generator is defined as the maximum field circuit resistance with which the shunt generator would just excite.

Q.8- What is critical speed?[S-16,18]

Ans- critical speed is speed below which the shunt generator fails to excite.

Q.9- Define Commutator pitch.[S-19]

Ans- it is defined as the distance between two Commutator segments which two end of same armature coil are connected.

Q.10- What is the number of parallel path in lap winding and wave winding in D.C machine? [S-22]

Ans- number of parallel path in lap winding is P=A

Number of parallel path in wave winding A=2

Q.11- State the function of yoke and Commutator in D.C machine. [S-23,24]

Ans- Yoke provides mechanical support for the poles and acts as a low-reluctance path for the magnetic flux, protecting the inner parts of the machine

In a DC motor, the commentator's primary function is to reverse the current flow in the armature windings every half rotation, ensuring continuous, unidirectional torque and rotation

POSSIBLE Long TYPE QUESTION

Q.1- describe about armature reaction of a D.C generator.[W-18,S-19]

Q.2- derive the e.m.f equation of D.C generator[S-17,18,19, W-19]

Q.3-define critical resistance & discuss O.C.C of a D.C shunt generator.

Q.4-A 4 pole dc shunt generator with a shunt field resistance of 100 ohm & an armature resistance of 1ohm has 378 wave connected conductors in it's armature. The flux per pole is 0.01 wb . if a load resistance of 10 ohm is connected across the external terminals and the generators is driven at speed of 1000 rpm . calculate power observed by the load.[S-16]

Q.5- A shunt generator has a full-load current of 196 A at 220 V. The stray losses are 720 W and the shunt field resistance is 55Ω. If it has a full-load efficiency of 88%, find armature resistance. Also find load current corresponding to maximum efficiency.[S-16]

Q.6 A shunt wound de machine has an armature resistance of 0.12Ω and a field resistance of 100Ω. The machines rated terminal voltage is 250 V. Find the ratio of speeds as a gencrator and motor if line current is 50 A in each case?[S-17]

Q.7 An 8-pole de shunt generator with 778 wave connected armature conductors and running at 500rpm supplies a load of 12.5Ω resistance at terminai voltage of 250 V. The armature resistance is 0.24Ω and field resistance is 250Ω. Find the armature current induced emf and flux per pole.

Q.8 Describe the external characteristic of D.C shunt generator.[S-24]

Q.9 Explain process of commutation in a D.C generator with neat sketch.[S-18,19,22,24]

CHAPTER NO.-02
D.C MOTOR

Learning objectives:

2.1. Basic working principle of DC motor.
2.2. Significance of back emf in D.C. Motor.
2.3. Voltage equation of D.C. Motor and condition for maximum power output(simple problems) .
2.4. Derive torque equation (solve problems).
2.5. Characteristics of shunt, series and compound motors and their application.
2.6. Starting method of shunt, series and compound motors.
2.7. Speed control of D.C shunt motors by Flux control method. Armature voltage Control method. Solve problems.
2.8. Speed control of D.C. series motors by Field Flux control method, Tapped field method and series-parallel method.
2.9. Determination of efficiency of D.C. Machine by Brake test method(solve numerical problems).
2.10. Determination of efficiency of D.C. Machine by Swinburne's Test method(solve numerical problems).
2.11. Losses, efficiency and power stages of D.C. motor(solve numerical problems).
2.12. Uses of D.C. motors.

2.1. Basic working principle of DC motor:

Definition.

It is defined as a DC electric machine which converts electrical energy in to mechanical energy.

Principle:

It works under the principle that whenever a current carrying conductor is placed in a magnetic field then a mechanical force is experienced by the conductor.

Construction of dc motor:

The construction of dc motor is same as that of dc generator. So the same machine can be used as motor and generator.

Working:

When DC supply is given to the armature conductor through carbon brushes and commutator then direct current starts to flow through the armature windings at the same time magnetic flux from north poles. Now the current carrying armature conductors are in the uniform magnetic field. So a mechanical force is experienced by the armature conductor. Since two ends of the armature shaft are mounted by ball bearing. So the armature will start rotating in one direction. The direction of rotation can be determined by Flemings left hand rule.

2.2 significance of back emf of DC motor

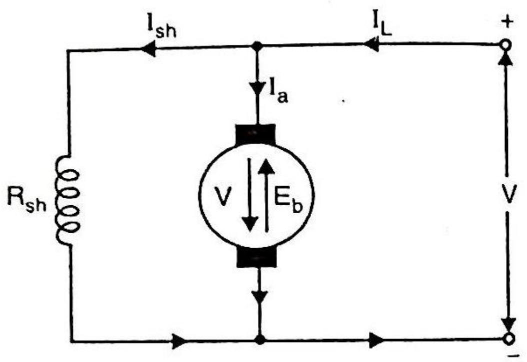
When the armature of the DC motor rotates under the influence of driving torque, the armature of the conductors moves through a magnetic field inducing an emf in them. The induced emf is in the opposite direction to the applied voltage and is known as the back emf.

The formula for back emf is given by

$$E_b = \frac{\emptyset z N}{60} \times \frac{P}{A}$$

$E_b \alpha \emptyset N$ [Since Z.P.A are constant]

Symbol and circuit diagram:



Let

E_b= back emf / counter emf , v

V= applied voltage, V

V_b = Brush contact drop ,V

I_L = line current , A

I_a = armature current ,A

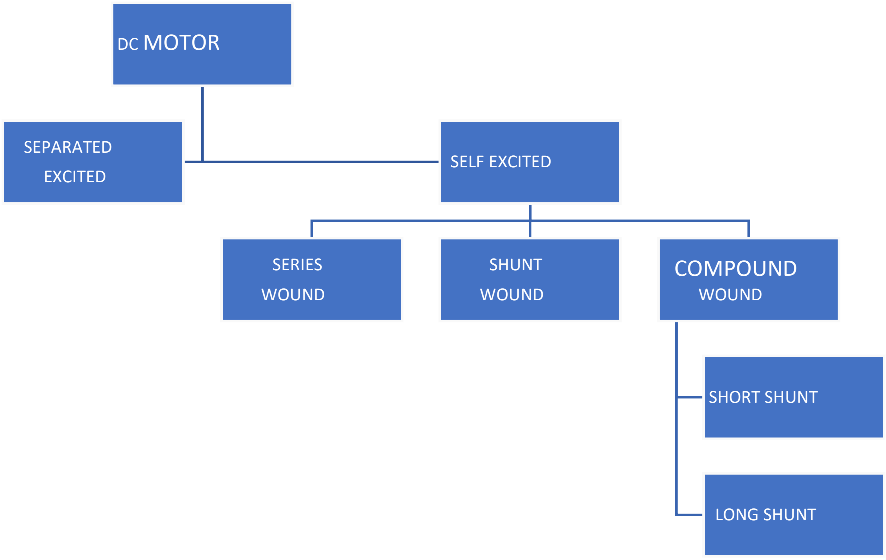
Ra = armature winding resistance , Ω

Applying KVL to the above closed circuit we get

$-I_a R_a - E_b + V - 2 V_b = 0$

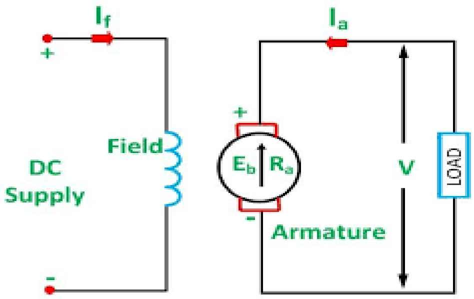
This is called voltage equation of a DC motor

Types of Dc motors



Separated Excited DC motor

If the field winding of a DC motor are excited by some external DC source then it is called as separately excited DC motor.



Applying KVL to the above closed circuit we get

$-I_aR_a - E_b - 2\,V_b + V = 0$

$E_b = V - I_aR_a - 2\,V_b$

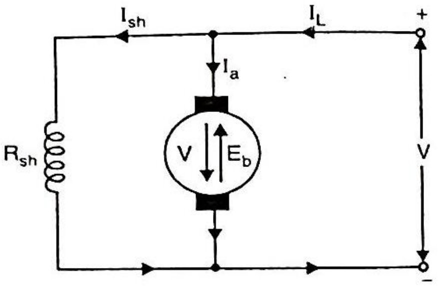
$I_a = \frac{E_b - V}{R_a}$ (where brush voltage drop taken neglegible)

self excited DC motor:

- If the fixed windings of a DC motor are excited or energized by the current produced of its own it is said to be self excited DC motor.
- It is three types

DC shunt motor:

- If the field windings of a self excited DC motor are connected in parallel with the armature then it is called shunt motor



Applying KVL across the armature and supply voltage we get

$-I_aR_a - E_b - 2V_b + V = 0$

$E_b = V - I_aR_a - 2V_b$

Applying KVL to the circuit shunt field and supply voltage we get

$-V + I_{sh} R_{sh} = 0$

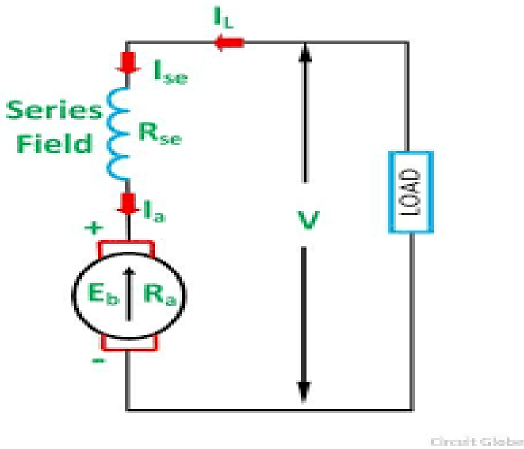
$V = I_{sh} R_{sh}$

According KCL

$I_L = I_a + I_{sh}$ (for shunt motor)

DC series motor.

If the field winding of a self excited DC motor are connected in series with the armature then it is called as DC series motor



Applying KVL to circuit we get

$-V + E_b + I_a R_a + I_{se} R_{se} + 2V_b = 0$

$E_b = V - I_a R_a - I_{se} R_{se} - 2V_b$

$E_b = V - I_a(R_a - R_{se}) - 2V_b$

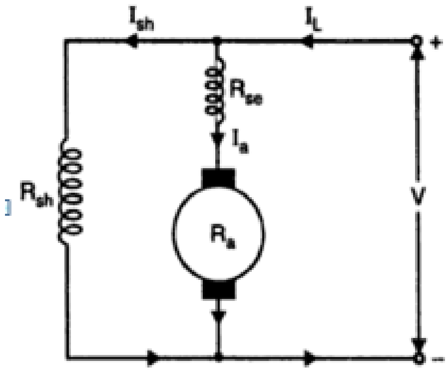
Where in series motor $I_L = I_a = I_{se}$

DC compound motor :

In a self excited dc motor , if shunt field and series field windings are simultaneously used then it is called as dc compound motor.

Long shunt compound motor:

In a compound motor if shunt field winding is connected across both series field and armature winding then it called as long shunt compound motor.



Long shunt

Current relation

$I_a = I_{se}$

$I_a = I_L - I_{sh}$

Voltage relation

Applying KVL to the circuit armature and supplying voltage so we get,

$-V + E_b + I_a R_a + I_{se} R_{se} + 2V_b = 0$

$E_b = V - I_a R_a - I_{se} R_{se} - 2V_b$

$E_b = V - I_a(R_a - R_{se}) - 2V_b$

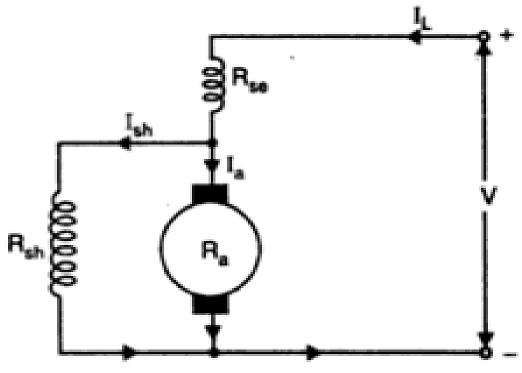
Applying KVL to the circuit shunt field and supply voltage we get

$-V + I_{sh} R_{sh} = 0$

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

Short shunt compound motor:

If the shunt field winding of a compound motor is connected across the armature only leaving the series field then it is called as shunt compound motor.



Short shunt

Current relation

$I_{se} = I_L$

$I_a = I_{se} - I_{sh}$

Voltage relation

Applying KVL to the circuit of armature and supply voltage

$-V+E_b+I_a R_a + I_{se}R_{se}+2V_b = 0$

$E_b = V-I_a R_a - I_{se}R_{se}-2V_b$

Applying KVL to circuit of supply voltage and shunt field

$--V+ I_{sh}R_{sh} + I_{se} R_{se} = 0$

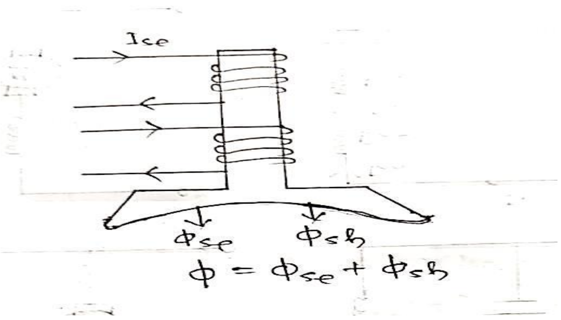
$V= I_{sh}R_{sh} + I_{se} R_{se}$

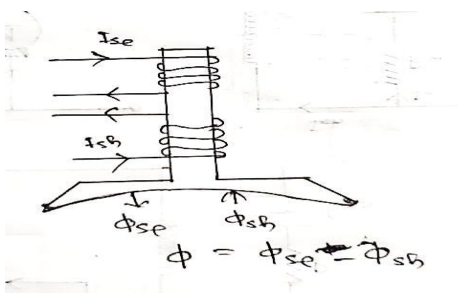
Types of compound motor :

Depending on the nature of winding on the magnetic pole a compound motor may be of cumulative motor differential motor.

Cumulative compound motor:

The series field and shunt field windings are worked in a such a manner that flux produced from each winding if are added then it is called so in this motor resultant flux is increased.





Differential compound motor :

If two field winding are wound such a manner that the flux produced from them are opposite to each other. Then it is called as differential compound motor so in this motor resultant flux is decrease.

2.3. Voltage equation of D.C. Motor and condition for maximum power output(simple problems)

We know that in a dc motor

$E_b = V-I_aR_a- 2V_b$

Now we neglecting the brush contact drop so

$E_b = V - I_aR_a$ -----------(i)

If we multiply I_a in both sides of equation I we get

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

$P_M = V I_a - I_a^2 R_a$ ---------(ii)[$E_b I_a = P_M$]

For maximum power

$$\frac{d(P_M)}{d\text{la}} = 0$$

Differentiating power wrt l_a

$$\Rightarrow \frac{d(V \text{ la} - \text{la2Ra})}{d\text{la}} = 0$$

$$\Rightarrow \frac{d(V \text{ Ia})}{d\text{la}} - \frac{d(\text{la2Ra})}{d\text{la}} = 0$$

$$\Rightarrow \text{V} - 2\text{I}_\text{a}\text{R}_\text{a} = 0$$

$$\Rightarrow \text{V} = 2\text{I}_\text{a}\text{R}_\text{a}$$

$$\Rightarrow \text{I}_\text{a}\text{R}_\text{a} = \text{V}/2$$

Now we putting value of $\text{I}_\text{a}\text{R}_\text{a}$ in equation(I) We get

$$\text{E}_\text{b} = \text{V} - \frac{V}{2}$$

$$\Rightarrow \text{E}_\text{b} = \frac{2V-V}{2}$$

$$\Rightarrow \text{E}_\text{b} = \frac{V}{2}$$

When the back emf is half of the supply voltage the motor gives maximum power. This is the condition for maximum power developed of the DC motor.

2.4. Derive torque equation (solve problems):

Torque

It is the twisting moment of a force about an axis its magnitude is the product of force F and radius (r)

Mathematically

T=F×r

Let in a dc motor r= radius of the armature in meter

L= effective length of each conductor

Z= total no of armature conductor

A=no of parallel path

I=flux per pole in weber.

P=no of poles

Tg= the gross of armature torque in N-m

The force F=BIL

$= \frac{\varphi}{a} \times \frac{I_a}{A} \times L$ (where B=φ /a and $I=I_a/A$)

torque in each conductor T=FXr

$$= \frac{\varphi}{a} \times \frac{I_a}{A} \times L \times r$$

Where a = cross sectional area of the pole the cross Sectional area per pole,

$$A = \frac{2\pi rL}{P}$$

$$T_g = \frac{\varphi}{a} \times \frac{I_a}{A} \times L \times r$$

$$= \frac{\varphi I_a}{2\pi} \frac{P}{A}$$

$$= 0.159\ \varphi I_a (\frac{P}{A})$$

Total conductor of torque

$$T_g = 0.159Z\,\varphi I_a(\frac{P}{A}) \quad \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

T_g α I_a and all other are constant.

Another expression for Torque

We know

$$E_b = \frac{\varphi ZN}{60} \times \frac{P}{A}$$

$$so \qquad \frac{\varphi ZP}{A} = \frac{E_b \times 60}{N}$$

Now put value of ($\varphi zP\ /A$) in the eq -1 we get

$$T_g = 0.159 I_a \times \frac{E_b \times 60}{N}$$

$$T_g = 0.159 I_a \times \frac{E_b \times 60}{N}$$

$$T_g = 9.55 \times \frac{E_b \times I_a}{N} \quad \text{N.m}$$

Shaft torque The torque which is available at the motor shaft from doing usefull work is known as shaft torque.

- It is represented by T_{sh}
- Shaft torque is less than the armature torque

$$T_{sh} = 9.55 \times \frac{\text{Psh}}{N}$$

Where P_{sh} the shaft output power.

Speed regulation

It is defined as the ratio between drop in speed (from no load to full load) and full load speed.

It is calculated in percentage

Mathematically

$$R\% = \frac{\text{no load speed} - \text{full load speed}}{\text{full load speed}} \times 100$$

$$R\% = \frac{N_0 - \text{N}}{\text{N}} \times 100$$

Speed relations:

Let Eb_1 = Back emf of a motor in 1st case

Eb_2 = back emf motor on 2nd case

N_1 = speed of motor in first case

N_2 = speed of motor in 2nd case

Φ_1 =flux / pole in 1st case

Φ_2 = flux/ pole in 2nd case.

we know that

E_b α φ N

In 1st case E_{b1} α φ_1 N_1

In 2nd case E_{b2} α φ_2 N_2

$$=\frac{E_{b2}}{E_{b1}} = \frac{\varphi_2}{\varphi_2} \times \frac{N_2}{N_1}$$

$$=\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1} \quad (\Phi_1 = \varphi_2 = \varphi \text{ constant for DC shunt motor})$$

$$=\frac{E_{b2}}{E_{b1}} = \frac{I_{a2}}{I_{a1}} \times \frac{N_2}{N_1} \quad (\varphi \propto I_{a1} \text{ constant for DC shunt motor})$$

Problem -1

A 4 pole 500 v shunt motor has 720 wave connected in the armature. The full load armature current is 60 A and the flux per pole is 03wb the armature resistance is 2Ω and the contact drop Iv per brush calculate the full load speed of the motor.

Solution

Data given

P=4

V=500v

Ia= 60A

Z=720

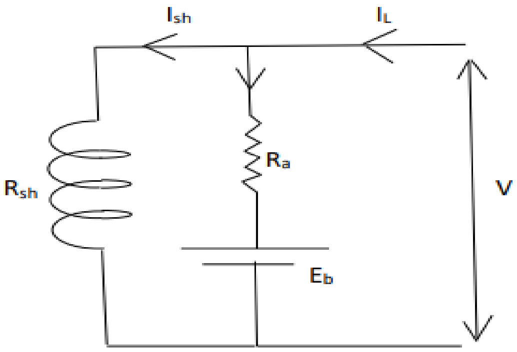
A=2

φ =03 wb

Ra= 2 Ω

2vb= 2

Required data= N=?



We know for shunt motor

$E_b = V - I_a R_a - 2 v_b$

= 500-60x0.2-2

=486v

For emf equation we know that

$$E_b = \frac{\varphi ZN}{60} \times \frac{P}{A}$$

$$so \qquad 486 = \frac{3720N}{60} \times \frac{4}{2}$$

N=675 rpm

Problem -2

Determine developed torque and shaft of 220v , 4 pole series motor with 800 conductor wave connected supplying a load of 802 kw by taking 45 A from the mains. The flux per pole is 250 mwb and its armature circuit resistance is 0.6Ω .

Solution

Given data DC series motor

V=220V

P=4

Z=800

I_L =45 A

φ = 250mwb =0.025 wb

Rse+ R_a = 0.6 Ω

A=2

P_o =8.2 KW

Required data T_g=? ,T_{sh}=?

We know that

$$T_g = 0.159 Z\, \varphi I_a (\frac{P}{A})$$

$$T_g = 0.159 \times 800 \times 0.025 \times 45(\frac{4}{2}) \quad (I_L = I_a = 45A)$$

=286.4 N.m

$E_b= V- I_aR_a-I_{se}R_{se}$

$=V- Ia(Ra-R_{se})$ $[I_a=I_{se}]$

=220-45X0.6

=193 V

We know that

$$E_b = \frac{\varphi ZN}{60} \times \frac{P}{A}$$

$193 = \frac{0.025\times 800\times N}{60} \times \frac{4}{2}$ (in wave winding A=2)

So N= 289.5 rpm

$$T_{sh} = 9.55 \times \frac{8.2\times 10^3}{N} \text{ Nm}$$

2.5. Characteristics of shunt, series and compound motors and their application:

Generally for each motor three important characteristics are seen such as

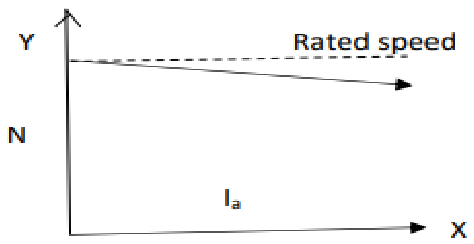
- Speed current characteristics
- Torque current characteristics
- Speed torque characteristics

Speed current Characteristics of DC shunt motor

Definition

If armature current is taken along X-axis but speed along Y-axis then with two different values of armature current Ia and speed N a graph such plotted is called speed current characteristics.

Explanation



We know that in a DC motor ,

$E_b \alpha \varphi N$

$\rightarrow N \alpha E_b /\varphi$

But φ is constant normal shunt motor

So $N=k(E_b)$

$N=k(v-I_aR)$

When a DC motor runs at light load then current drawn by the armature (I_a) is very small ,so the armature rotates at its rated speed.

If load on the motor is generally increased then armature current will increase but armature resistance drop (I_aR_a) will increase but with very small value hence speed of the motor decreases slightly. Therefor a dc shunt motor is treated as an approximately a constant speed motor.

Torque current characteristics

Definition

If armature current is taken along x-axis but torque along y-axis then with two different value of torque and current a graph such plotted is called as torque current characteristics.

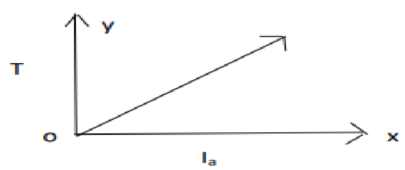
Explanation

We know that $T\alpha \varphi I_a$

In a shunt motor

Φ remains constant

So $T=k I_a$

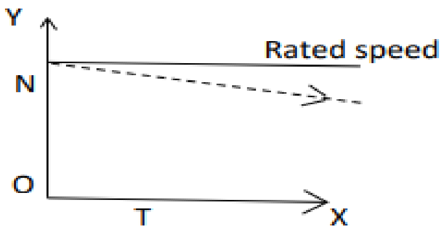


From the above relation it is clear that the graph is a straight line passing through the origin. Hence with increase of load on the motor armature current (I_a) will increase their by increasing the torque proportionately.

Speed torque characteristics

Definition:

If torque is taken along x-axis but speed along y-axis then with different values of speed and torque a graph such plotted is called as speed torque characteristics.



Explanation:

When the motor runs at no load then armature current I_a assumed to be o So torque T becomes 0 but speed N becomes maximum.

As the total load on the motor goes on increasing very slightly an shown in the figure.

Application of dc shunt motor .

- Saw mills
- Lathe machines
- Press mills
- Conveyor belts

Characteristics of a DC series motor

speed current characteristics :

If the armature current is taken along X-axis but speed along Y-axis then with different values of armature current (I_a) and speed (N) a graph such plotted is called as speed current characteristics

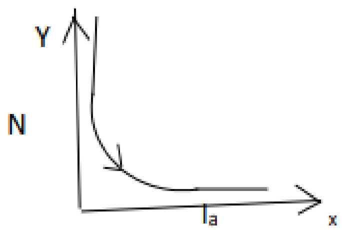
Explanation

We know that.

$E_b \alpha \varphi N$

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

But in a DC series motor $\varphi \alpha I_a$



Hence

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

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

In the above relation it is clear that speed (N) is inversely proportional to the armature current (Ia) So in light load the dc motor rotates at enramously high speed , it creates racing problem hence it is advisable.

Torque current characteristics:

If the armature current is taken along x-axis but torque (T)along Y-axis then with different values of armature current (Ia) and torque (T) a graph such plotted is called as torque current characteristics.

Explanations :

We know that

$T \alpha I_a$

But I series motor

$\Phi \alpha I_a$
$T \alpha I_a^2$
$T= K I_a^2$
$I_a^2= k T$
at the time of starting and from the above equation it is clear that the graph is a parabola symmetrical about Y- axis. Hence with increases square of the current. This concept is there till the magnetic saturation. Beyond the magnetic saturation even through current increases but flux remains constant. So that graph behaves like straight line so with increase of load armature current (Ia) will increase and the torque (T) will also increase proportionately.

Speed torque characteristics

If the torque (T) is taken along X-axis but speed N along Y-axis then with different values of speed N and torque T graph such plotted is called as speed torque characteristics.

Explanation

In no load when armature current is assumed to be o then torque is o but speed is infinite.

As load on the motor is increased torque developed by the motor will also increase. But speed will decrease inversely as shown in the above figure.

Conclusion

A dc series motor is treated as a variable speed motor.

Applications

Due to its high starting torque it is used in

i. Trolleys
ii. Heavy cranes

Characteristics of DC compound motors.

We know in a cumulative motor series field flux (φsc) and shunt field flux (φsh) are added together. So net flux is increased .

Similarly in differential compound motor net flux is decreased.

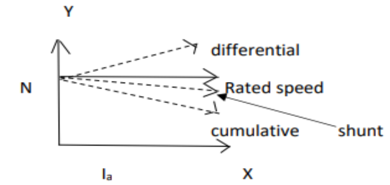
Speed current characteristics :

If the armature current is taken along x-axis but speed along Y-axis then with different values of speed N and armature current (I_a) a graph such plotted is called as speed current characteristics.

We know that.

$E_b \alpha \varphi N$

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



As we know that in a cumulative compound motor net flux is increased from the above relation it is understood that with increase of flux speed of the motor will decrease more than the speed of shunt motor

In case of different compound motor since net flux is decreased. So speed of this motor will increase comparatively higher the speed of shunt motor .

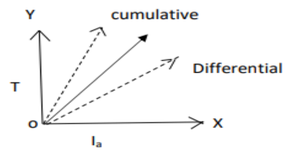
Torque current characteristics

If armature current (Ia) is taken along X-axis but torque T is along Y-axis then with different values of armature current Ia and torque T a current such plotted is called torque current characteristics

We know that

$T\alpha \varphi I_a$

In case of cumulative compound motor since



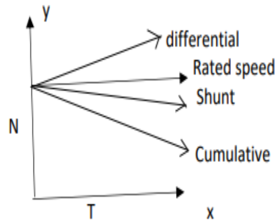
resultant flux is increased so from the above torque will also increase.
In case of differential compound motor since flux is decreased so the torque will also decreased

Torque speed characteristics :

If torque T is taken along X-axis but speed N along Y- axis then with different values of torque T and speed N a graph such plotted is called as torque speed characteristics.

Explanations:

In differential compound motor with increase of load even through torque is decreased. But speed will increased.
Similarly in case of cumulative compound motor with increase of torque speed will decrease as shown in above figure



Conclusion

A DC compound motor is treated as a partially variable speed motor.
Application
It is used in

i. drilling machines
ii. punching machines
iii. small cranes.

2.6. Starting method of shunt, series and compound motors:

We know that

$E_b = V - I_a R_a$

$I_a R_a = V - E_b$

$I_a = V - E_b / R_a$

At this time of starting of DC motor speed N is zero. Since Eb α N then Eb become zero at this time of starting. In this equation of Eb and we know value of Ra is very very small so armature current will become dangeriously high. Hence to limit such heavy current at the time of starting we use starters

Starter:

It is defined as a safety device which limits the starting current to a safe value.

Three -point stator and four-point stator

It is defined as a safety device which limits the starting current to a safe value.
Types of starter used in DC motors
Following are the important starter used for various DC motors.

• 3-point starter – for DC shunt motor
• 4 -point starter- for DC compound motor

3-point stator

Definition

The three point stator is mostly used for starting shunt motor and minimize the starting current.

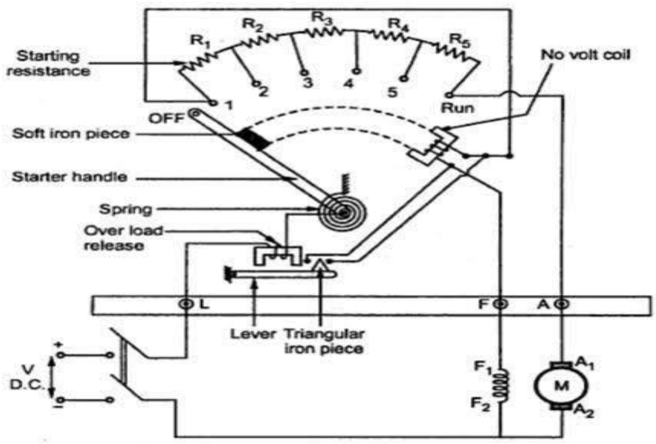
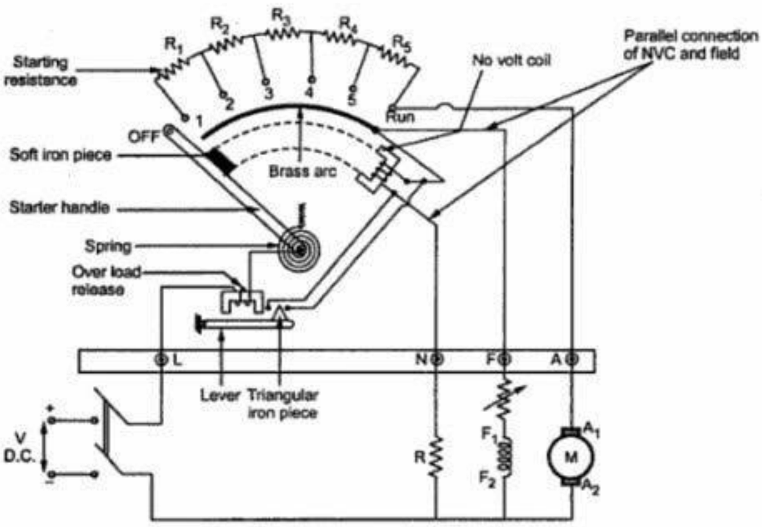


Figure shows the schematic diagram of a three point starter for a shunt motor it has three terminals namely L,Z and A . The starter resistance divided into several sections and connected in series with the armature. The tapping points of the starting studs. The three terminals L ,Z and A of the positive line terminal shunt field terminal and armature terminal. The other terminal of Z and A are connected to the negative terminal of the supply. The no-volt release coils connected in the shunt field circuit. One end of the handle is connected to the terminal L through over load release coil. The other end of the handle moves against a spiral spring and makes contact with each stud during starting operation cutting out more and more starting resistance as it passes each stud in clockwise direction.

4-point starter

The 4-point starter acts a protective device that helps in safe guarding the armature of the shunt or compound excited DC motor against the high starting current produced in the absence of back emf at starting.



Four Point Starter

Explanation

Hence NVC is connected independently across the supply the fourth terminal called N in addition to the L , F and A so any change in the field supply current does not bring always produce a force at a hold against force of the spring under all the operational conditions. Such a current is adjusted through No voltage coil. With help of fixed resistance R connected is series with the NVC using fourth point N as shown in the above figure.

When handle is taken to stud no 1 and supply is given circuits is found to be closed and current starts flowing in the following manner.

1. 1 st point flows through the starting resistance ($R_1+R_2+R_3$…….) and then to the armature.
2. 2 nd point flows through the soil windings
3. 3 rd point flows through the NVC in series with the protective resistance R electromagnetic pole is subjected upon the soft iron bar of the handle by the NVC which should be high enough to keep the handle of its running position or rather of its running position or rather prevent the spring the from restoring the handle at its original position.

2.7. Speed control of D.C shunt motors by Flux control method. Armature voltage Control method. Solve problems:

We know that speed of a dc motor

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

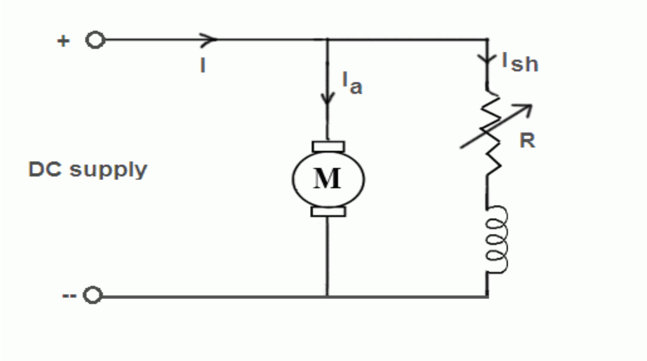
$$N \propto \frac{V-I_aR_a}{I_a}$$

The speed of a motor depends on applied voltage (v) ,field flux (φ) and armature voltage drop (Ia Ra) .so controlling these three important factors we can regulate ,the speed of a dc motor.

Speed control of DC shunt motor:

a. Field or flux control method:

Explanation A dc ammeter and a rheostat are connected in series with the shunt field winding as shown in the above figure

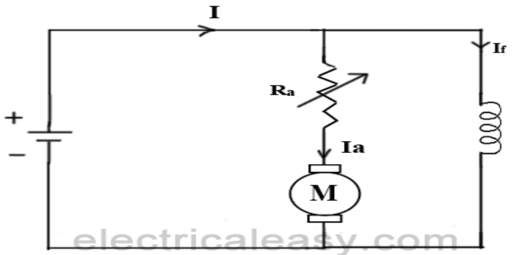


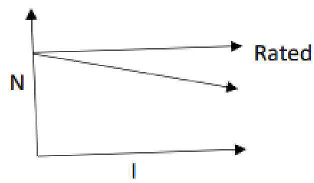
We know that Nα 1/φ

When the rheostat value is kept maximum point or position then field circuit resistance gets increase so current through the field winding will decrease. Hence flux produced from the field will also decrease. When rheostat value is decreased and field current is increased then flux produced from the pole will also increase. In the above relation with increase of flux speed of the motor gets decreased.

B . Armature control method

It is defined as a method in which speed is controlled by controlling the armature current.





Explanation

We know that

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

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

$$N = K(V - I_a R_a)$$

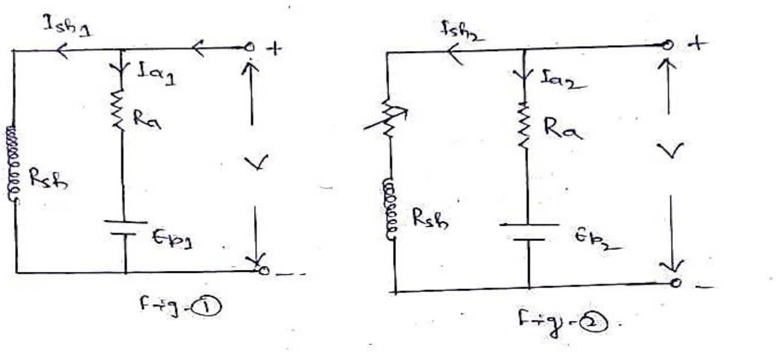
In this control method , a variable resister and a DC ammeter are connected in series with the armature as shown in the figure.

When rheostat value is gradually decreased then armature current (Ia) will increase. Due to this increase of armature current armature resistance drop will also increase from the above drop will also increase from the above relation understood that with increase of drop , speed of the motor will decrease from its rated value. Hence this method is very useful where speed lower than the rated speed is necessary.

Problem-1

A 250 V , DC shunt motor has armature resistance of 0.25 Ω on load it takes an armature current of 50 A and runs at 750 rpm . if the flux of motor is reduced by 10 % without changing the load torque find the new speed of the motor.

Solution



Given data

A DC shunt motor

V= 250 V

Ra=0.25 Ω

Ia1=50 A

N1=750 rpm

φ2=0.9φ1

T1=T2

Required data N2=?

From figure-1

Back emf

$E_{b1}=V-I_{a1}R_a$

=250-50x0.25

=237.5 v

From figure-2

Back emf

$E_{b2}=V- I_{a2}R_a$

We know that $T_1=T_2$

=> $\varphi_1 I_{a1}= \varphi_2 I_{a2}$

So $I_{a2} = \frac{\varphi_1 \times I_{a1}}{\varphi_2}$

So $I_{a2} = \frac{1\times 50}{0.9}$ = 55.56A

Again $E_{b2}=V- I_{a2}R_a$

=250-55.56 X 0.25

=236.1 V

We have $\frac{E_{b2}}{E_{b1}} = \frac{\varphi_2}{\varphi_2} \times \frac{N_2}{N_1}$

$$N_2 = \frac{E_{b2}}{E_{b1}} \times \frac{\varphi_1}{\varphi_2} \times N_1$$

$$=\frac{236.1}{237.5} \times \frac{1}{0.9} \times 750$$

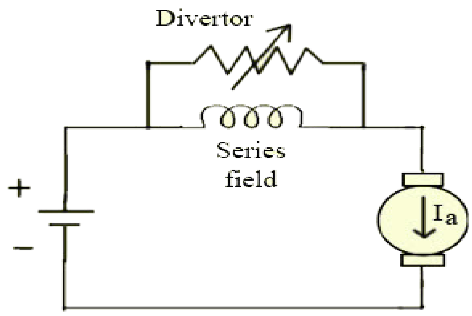
=828.42 rpm

2.8. Speed control of D.C. series motors by Field Flux control method, Tapped field method and series-parallel method:

A. Flux or field control method

Definition

It is defined as a control method in which we can regulate the speed of motor by controlling the field flux. Sometimes it is also called as field diverter method.



Explanation

We know that

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

In this method a variable resistance is connected across the series field winding. This resistor is also called as divertor resistor. If divertor current is increased then less current will flow through it but more current through the field winding. So more flux is produced from the field.

Hence speed will decrease.

Similarly by decreasing the rheostat value speed of the value can be increased.

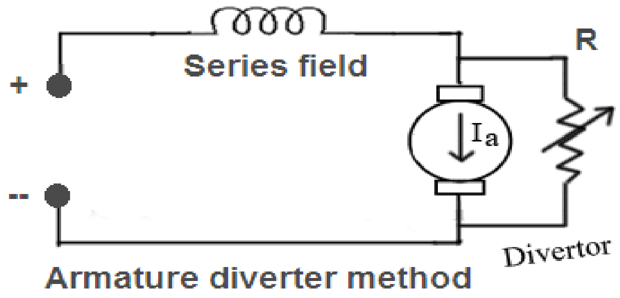
Armature divertor method

It is defined as a speed control method in which a variable resistor so called divertor is connected across the armature.

Explanation

In this method a variable resistor is connected across the armature circuit. So this variable resistor is also called as divertor resistance.

When divertor resistance is made increased, less current will flow through it but more armature. Due to more armature current, armature resistance drop (IaRa) will also increase but speed of the motor will decrease from its rated value.



Series parallel method

It is defined as a method in which speed of the motor is controlled by grouping the field winding in series parallel.

Explanation

This is one of the convenient speed control method where we can get multiple of speeds.

To control the DC series motor this is another way called series parallel technique. This is the method normally used in traction by connecting two or more than that of the series motor are couple mechanically at the same load.

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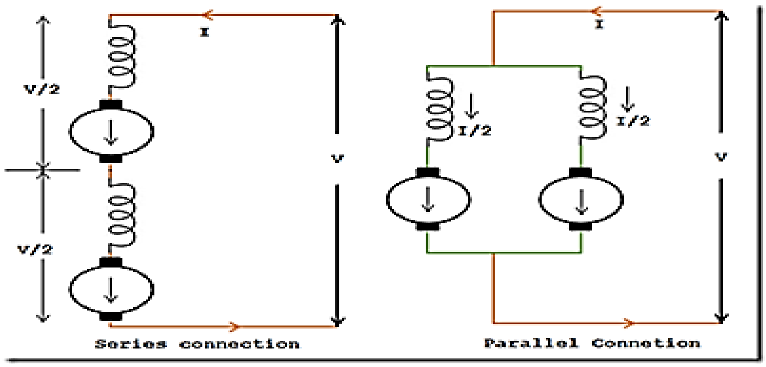

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Whenever the series motors are connected in sequence (series) like shown in the figure, each and every armature of the motor receive the one-half of the rated voltage. Thus the speed will be less. If the series motors are connected in parallel, each and every armature of the motor receives the full normal voltage and hence the speed is also high. Thus we can achieve the two speeds (low or high) by connecting the motor either in series or parallel. Note for the same load on the pair of motors, the speed of the system would run nearly 4 times once motors are in parallel as while they are in series.

Determination of efficiency of DC motors:

To determine the efficiency of DC motors following tests are conducted.

1. Brake test
2. Swinburn's test

2.9. Determination of efficiency of D.C. Machine by Brake test method(solve numerical problems):

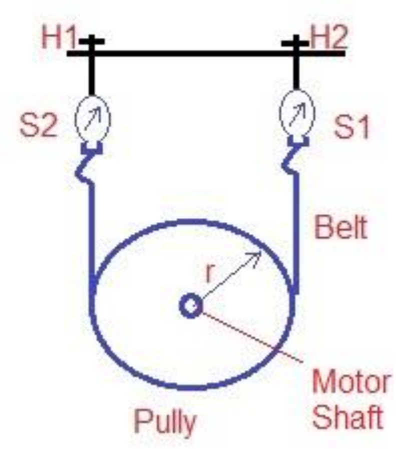
It is one of the easiest method to determine efficiency of DC motors. But especially for series motors.

Theory

Let us take a water cooled pulley and mounted on the shaft of the motor. A horizontal flat rod over which a load adjustment handle or wheel is fixed at its centre it is also supported by two vertical bars. Two spring balance are also attached with the hooks as shown in the figure. A canvas belt with grooves of the pulley. Two of its ends are fixed with two spring balances.

A DC voltmeter and ammeter are also connected at the input of this motor. After starting the motor, appropriate load is given to the pulley through load adjustment wheel. At this time the speed of armature is recorded by using tachometer. Similarly supplied voltage and current by voltmeter and ammeter.

Derivation



Let

v= supplied voltage shown by the voltmeter

I= supplied current shown by the ammeter A

R= radius of the pulley, m

W_1 & W_2 =Weight shown by the spring balance, kgf

N= speed of the armature , rpm

T_{sh}= shaft torque , N-m

Effective weight on the pulley

W= (W_1 –W_2), kgf

=9.81 (w1-w2) N

Hence shaft torque=T_{sh}=W X R N-m

So output power $P_0 = \frac{2\pi N}{60} T_{sh}$ W

But input power , P_i= VI_L, W

Efficiency of the motor,

So $\eta = \frac{P_0}{P_i} \times 100$

Problem-

In a brake test the effective load on the branch pulley was 38.1 kg . the effective diameter of the pulley is 63.5 cm and speed is 12 rps the motor to 49 A at 220 v find out the power and efficiency at this load.

Solution

Data given

W_1 –W_2 = 38.1 kg = 38.1X9.81 =373.76

Diameter d = 63.5 cm

Radius R= 63.5/2=31.75 =0.3175 m

N=120rps

I=49A

V=220 V

Required dataP_0=? ,η=?

P_0= Tshw Shaft torque

T_{sh} = (W1-W2)xR =373.76x 0.3175 =118.6 N-m

P_0 = Tsh w = T_{sh} x 2πn = 118.6x2xπx12 =8942.2 watt

The i/p to the machine or motor

P_{in}=VI =220x49 =10780 w

Efficiency of the motor

So $\eta = \frac{P_0}{P_i} \times 100$

$= \frac{8942.2}{10780} \times 100$

=83%

2.10. Determination of efficiency of D.C. Machine by Swinburne's Test method(solve numerical problems).

This is also a suitable method to determine efficiency of DC motors which is explained before.

Explanation

Under no load

Input power,

$P_i = V I_{L1}$

Out put power, P_o =0

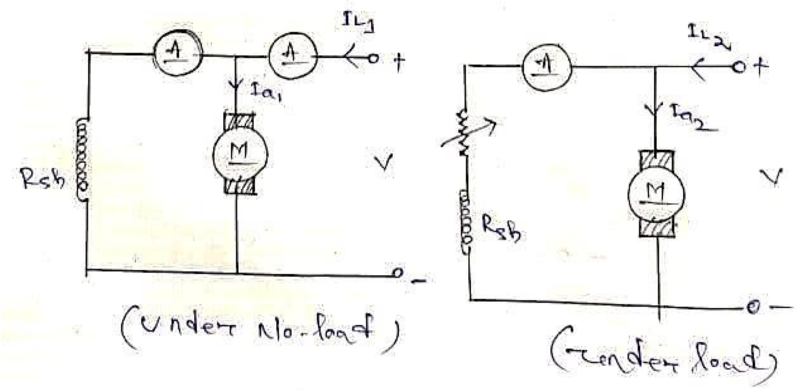
Total losses , $W_T = P_i - P_o$

$= VI_{L1}$

$W_c + W_v = VI_{L1}$

$W_c + I^2_{a1} R_a = V I_L$

$W_c = VI_{L1} - I^2_{a2} R_a$, W



Under load

Input power, $P_i = VI_{L2}$, w

Variable loss , $w_v = VI_a^2 R_a$

Total losses $W_T = W_c = W_v$

$= V I_{L1} = (VI_1 - I_{a1}^2 R_a) + I_{a2}^2 R_a$

= Power $P_o = (P_i - W_T)$

$= VI_{L2} - W_T$

Efficiency of the motor

So $\eta = \frac{P_0}{P_i} \times 100$

Problem

220 Vdc shunt motor at no-load takes a current of 2.5 A. The resistances of the armature and shunt field are 0.8Ω and 200Ω respectively. Estimate the efficiency of the motor when input curnent is 32 A.

Solution.

No-load input power $= VI_0 = 220 \times 2.5 = 550$ W

$I_{nk} = 220/200 = 1 \cdot 1$ A; No-load armature current, $I_\infty = 2 \cdot 5 - 1 \cdot 1 = 1.4$ A

No-load armature Cu loss $= P_{a0}^2 R_= = (1.4)^2 \times 0.8 = 1.6$ W

Constant losses $= 550 - 1 \cdot 6 = 548 \cdot 4$ W

When input current is 32 A

Armature current, $I_a = 32 - 1.1 = 30.9$ A

Armature Cu loss $= \Gamma_a^2 R_a = (30.9)^2 \times 0.8 = 764$ W

Total losses = Constant losses $+ I_a^2 R_a = 548 \cdot 4 + 764 = 13124$ W

Input power $= 220 \times 32 = 7040$ W

Output power $= 7040 - 1312 \cdot 4 = 5727 \cdot 6$ W

Efficiency, $\eta = \frac{5727.6}{7040} \times 100 = 81.36\%$

2.11. Losses, efficiency and power stages of D.C. motor(solve numerical problems):

Losses in dc motor

All the losses in motor are same as all the losses in generator.

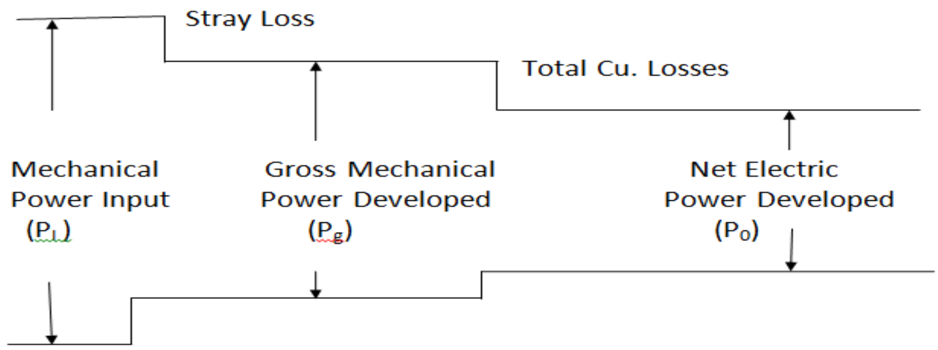
Efficiency of a dc motor

$\eta = \frac{P_0}{P_i} \times 100$

Condition for maximum efficiency

Variable loss = constant loss

Power stage Diagram



- Electrical efficiency = $\eta_{elect} = \frac{P_g}{P_i} \times 100$

- Mechanical efficiency= $\eta_{mech} = \frac{P_o}{P_g} \times 100$

- Overall commercial standard efficiency =$\eta = \frac{P_o}{P_i} \times 100$

2.12. Uses of D.C. motors:

Application of dc shunt motor .

- Saw mills
- Lathe machines
- Press mills
- Conveyor belts

Application of dc series motor

Due to its high starting torque it is used in

i. Trolleys
ii. Heavy cranes

Application of dc compound motor

A DC compound motor is treated as a partially variable speed motor.

Application

It is used in

i. drilling machines
ii. punching machines
small cranes

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER

(Q-1) What is difference between the DC motor and generator answer in one line?
Ans : DC motor is an electrical machine which coverts electrical energy into mechanical energy but DC generator does the reverse.

(Q-2) What is back emf or counter emf of a dc motor? [S-18,19]
Ans: the back emf is defined as an induced emf which opposes or counter paths the supplied voltage. It is denoted by E_b and its unit is volt.

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

(Q-3) Write the voltage equation of a DC motor? [S-12]
Ans-The voltage equation of a DC motor is
$Eb=V-IaRa-2V_b$ (V_b is brush voltage drop)

(Q-4) How can you reverse the direction of the armature of a dc motor?
Ans: The rotation of an armature of a DC motor can be reversed by inter changing the terminals either of armature or field circuit. .

(Q-7) At what condition the power developed by a motor is maximum?
The power developed or delivered by a DC motor is maximum only when the back emf is half of the supplied voltage.
$E_b=V/2$

(Q-8) Which DC motor is most suitable for electric traction?
Ans: Dc series motor is most suitable for electrical traction.

(Q-9) For lathe machines which DC motor is suitable?
Ans :Dc shunt motor is suitable for lathe machines.

(Q-10) For drilling purposes which DC motor is used?
Ans: for drilling purposes DC compound motor is used.

(Q-11) Which DC motor can be operated in a wide range of speed?
Ans : DC series motor can be operated in a wide range of speeds.

(Q-12) Which DC motor gives high torque at the time of starting ?
Ans : DC series motor gives high torque at the time of starting
(Q-13) What is the significance of back emf in a D.C motor ? [S-17,24]
Ans- Back electromotive force (back EMF) in a DC motor is crucial for regulating speed, limiting armature current, and improving efficiency by opposing the applied voltage, ensuring the motor draws only the necessary current for the load.

POSSIBLE LONG TYPE QUESTIONS

(Q-1) Explain the working of a DC motor with neat sketch. [S-19]

(Q-2) Draw the circuit diagram of different self excited dc motors also establish various voltage equations of each motor.

(Q-3) Derive the torque equation of a dc motor? [S-14,16,17,19 W-18]

(Q-4) Discuss three important characteristics of DC shunt motor series motor and compound motor?

(Q-5) Explain any one speed control method of DC shunt or series motors?[S-17,W-18]

(Q-6) With neat sketch explain 3-point starter and 4- point starter? [S-13]

(Q-7) How can you determine the efficiency of DC motor by using brake test method? [S-18]

(Q-8) A 230V dc shunt motors runs at 800 rpm & takes armature current of 50A.find the resistance to be added to the field ckt to increase the speed to 1000 rpm at armature current of 80A. assume flux proportional to field current . (R_a=0.1 Ω & R_f =250Ω)
[S-19]

(Q-9) A 500 v, 37.3 KW ,1000 rpm dc shunt motor has on full load an efficiency of 90%.the armature circuit resistance is 0.24 ohm & there is total voltage drop of 2V at the brushes. The field current is 1.8A . determine

(i) Full-load line current
(ii) Full-load shaft torque
(iii) Total resistance in motor starter to limit starting current to 1.5 times of full load current. [W-18]

(Q-10) Determine the efficiency of D.C machine Swinburne's test method.[S-24]

CHAPTER NO.-03
SINGLE PHASE TRANSFORMER

Learning objectives:

3.1 Working principle of transformer.
3.2 Constructional feature of Transformer.
3.2.1 Arrangement of core & winding in different types of transformer
3.2.2 Brief ideas about transformer accessories such as conservator, tank, breather, and explosion vent etc.
3.2.3 Explain types of cooling methods
3.3 State the procedures for Care and maintenance.
3.4 EMF equation of transformer.
3.5 Ideal transformer voltage transformation ratio
3.6 Operation of Transformer at no load, on load with phasor diagrams.
3.7 Equivalent Resistance, Leakage Reactance and Impedance of transformer.
3.8 To draw phasor diagram of transformer on load, with winding Resistance and Magnetic leakage with using upf, leading pf and lagging pf load.
3.9 To explain Equivalent circuit and solve numerical problems.
3.10 Approximate & exact voltage drop calculation of a Transformer.
3.11 Regulation of transformer.
3.12 Different types of losses in a Transformer. Explain Open circuit and Short Circuit test.(Solve numerical problems)
3.13 Explain Efficiency, efficiency at different loads and power factors, condition for maximum efficiency (solve problems)
3.14 Explain All Day Efficiency (solve problems)
3.15 Determination of load corresponding to Maximum efficiency.
3.16 Parallel operation of single phase transformer

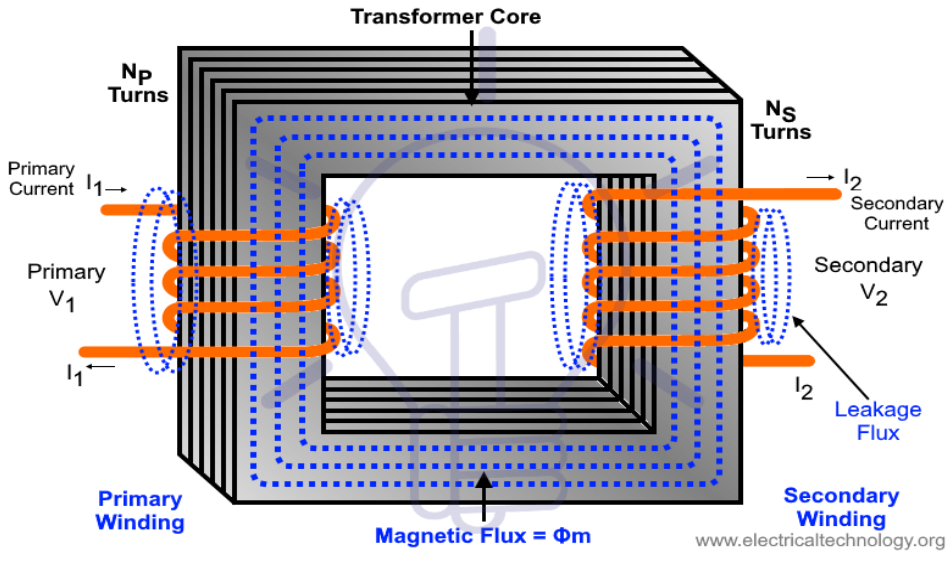
3.1 Working principle of transformer.

Definition:-

It is defined as a static electrical device which transfer electrical energy or power from one circuit to another circuit through a magnetic medium with same frequency.

Working principle

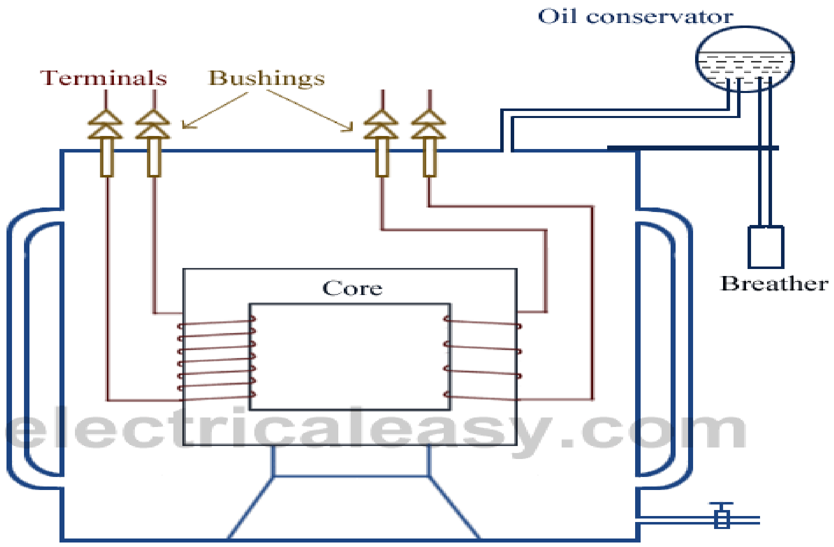
It works under the principle of mutual induction.



In a transformer basically their are two windings which are wound in a common magnetic core. The winding which is connected to the supply is known as primary winding from which the power is taken is known as secondary winding i.e load is connected in this secondary winding.

When single phase AC supply is given to the primary winding a current is flowing through the winding which produces an alternating flux which link with the primary coil it self and produces an induce e.m.f (E_1) or back e.m.f Then the flux passes through the core and link with the secondary winding and induced voltage (E_2).This voltage E_2 is known as mutual induced e.m.f.

3.2 Constructional feature of Transformer.



Following are the important parts of a transformer-

- Windings
- Core
- Tank
- Conservator
- Breather
- Bushings

3.2.1 Arrangement of core & winding in different types of transformer:

Winding:-

The winding are made up of copper wire in the form of rectangular or circular shape.

Core:-

The core is constructed from sheet steel laminations in the form of rectangular shape. The steel is of high silicon contain to reduce the hysteresis loss. It is laminated to reduce the eddy current loss.

Types of transformers:-

The transformer can be divided into various types various types in various ways.

According to construction –

It is divided in two types

1. Core type transformer.
2. Shell type transformer.

Core type transformer:-

If in a transformer cores are surrounded by the winding then it is called as core type transformer .

Example- In generating stations, grids and distribution purposes.

Shell type transformer:-

If in a transformer windings are surrounded by the cores then it called as shell type transformer. Example- Stabilizers and application in all electronic circuits.

According to voltage – The transformer is divided into two types

Step up transformer

Step down transformer

Step up transformer: -

It is defined as a transformer which makes low voltage into high voltage.

Condition-

$E_2 > E_1$

& $N_2 > N_1$

Application:-It is used in generating stations and transmission lines.

Step down transformer:-It is defined as a transformer which makes high voltage into low voltage.

Condition-

$E_1 > E_2$

&$N_1 > N_2$

Application:-

It is used in secondary transmission and distribution purposes.

3.2.2 Brief ideas about transformer accessories such as conservator, tank, breather, and explosion vent etc.

Tank:-

After winding the transformer is kept inside a tank which is made of sheet steel and is air tight inside the tank some insulating oil is kept so that the core of the transformer is not electrically contact with the tank. The additional function of the oil is to cool the winding.

Conservator:-

In the top of the tank there is a small cylindrical tank known as conservator. when the transformer oil heat it expand so for expansion of the oil the conservator is required.

Breather:-

For expansion and contraction or compression of oil in the conservator a breather is kept on the top of the conservator. In the breather some silica gel are kept to observe moisture and dust from the atmosphere and allow pure air into the tank.

Bushings:-

The transformer winding which are kept inside the tank are brought out of the tank through the bushings. These bushings are either porcelain or oil field or capacitor type.

3.2.3 Explain types of cooling methods :

Following important method are used to cool the transformer-

For dry type transformer:-

(a)Air Natural (AN) cooling method:-

Generally heat produced in the windings has to be radiated to the air in this method natural air cool the transformer.

(b)Air Forced (AF) Cooling method:-

In this method air is forced into the transformer by using blower's.

This method is used for high rating transformer.

For oil immersed Transformer:-

(a)Oil Natural Air Natural(ONAN):-

This method the winding is must in the oil and cooling fans are used for circulation of oil.

In this method due to maximum heat ,the transformer oil is expanded and flows through the cooling tubes .

These tubes are always contact with in natural air, so the heat is radiated very quickly by this method.

(b)Oil Natural Air force (ONAF):-

In this method in addition to the cooling tubes ,extra fans are used which forced the air to strike to the cooling tubes by this way the heat is radiated very quickly.

(c)Oil forced Air forced (OFAF):-

In this method a pump is connected between the tank and heat exchanger .This pump forced to circulates the oil through the pipe of the exchanger at the same time using fans air is forced on the tubes on which cooling is possible very quickly .this system is used in high rating machine.

(d)Oil Natural water forced (ONWF):-

In this method not transformer oil naturally flow through the tubes. This time water is forced on to these tubes .such that no water go to in tank.

(e)Air Forced water Forced (AFWF):-

In this method using a circulating pumps, the transformer oil is circulated through the cooling tubes in the heat exchanger and at the same time water is forced to spread the heat exchanger.

3.3- State the procedure for care and maintenance:-

- To increase durability (life span) of a transformer, periodical maintenance is highly essential. Hen following are the few important schedules of a single -phase Transformers –
- To check and verify the insulating quality or grade of the transformer oil and accordingly replace it.
- Check whether conductors are tightly connected with the bushings or not.
- Check the signals of Buchholz's relay in a regular interval to know anything goes run inside the transformer tank for which gases are formed accordingly precautionary steps must be taken.
- Check and verify the colour of dry silica gel whether changing or not. if changing then pour the new dry silica gel.
- Check three pipe earthing's are properly installed.
- Periodically check the earth resistance of the earthing's for safety purposes.
- In a regular interval measure the insulation resistance of the transformer winding.

3.4-Derivation of EMF equation:

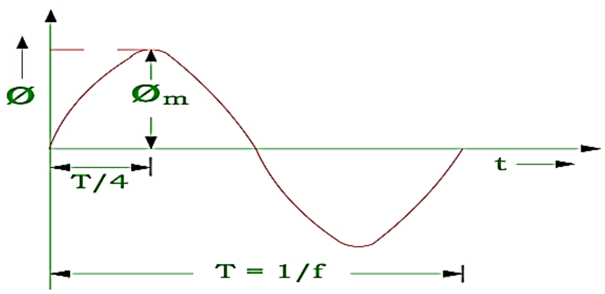


FIG A : AN ALTERNATING FLUX WAVEFORM

Let,

V_1=supply voltage to the primary, V

V_2=secondary terminal voltage, V

N=No. of turns in the winding.

N_1=No. of turns in the primary windings.

N_2= No. of turns in the secondary windings.

E_1=Primary induced e.m.f V

E_2=secondary induced e.m.f, V

f= frequency of the supply voltage, Hz

$(\varphi)_m$=Maximum flux in the core, W

When a voltage V_1 is applied to the primary a flux (φ)m is produce. whose nature is alternating (sinusoidal) as in figure.

The flux will be maximum after T/4 sec i.e 1/(4f) sec.

The change in flux to achieve maximum flux i.e $d\varphi=\varphi_m$

The change in time dt=1/4f

According Faraday's laws of electromagnetic induction, the average induced e.m.f for N no. of turns is given by,

$$e= N\,(d\varphi/dt)$$

$$=N\times\varphi_m/(1/4f)$$

$$e =4f\varphi_m N$$

R.M.S value of e.m.f,

$$E_{rms}=\text{Form factor} \times \text{Avg e.m.f}$$

$$=K\,f \times e$$

$$E=1.11\times 4f\,\varphi_m N$$

$$\Rightarrow E=4.44f\,\varphi_m N, V$$

Now $E_1=4.44f\,\varphi_m N_1$,V (for primary)

& $E_2=4.44f\,\varphi_m N_2$,V (for secondary)

3.5 Ideal transformer voltage transformation ratio

Let,

E_1=primary induced e.m.f , V

E_2=secondary induced e.m.f ,V

V_1=primary supplied voltage, V

V_2=secondary load voltage, V

I_1= primary current, A

I_2=Secondary current,A

N_1=primary no. of turns.

N_2=Secondary no. of turns.

K= Transformation Ratio.

From e.m.f equation we know that

$E_1 \,\alpha\, N_1$

$E_2 \;\; N_2$

$\Rightarrow E_2/E_1 =N_2/N_1$---------(1)

In an Idea transformer,

$E_1 =V_1$

& E_2=V

$\Rightarrow E_2/E_1 =V_2/V_1$ --------------(2)

Again in an ideal transformer losses are neglected .
Hence input power=Out put power
$V_1 I_1 = V_2 I_2$
$\Rightarrow V_2/V_1 = I_1/I_2$ -------------(3)

Comparing equation (1),(2)&(3) we get,
$E_2/E_1 = V_2/V_1 = N_2/N_1 = I_1/I_2 = K$

3.6 Operation of Transformer at no load, on load with phasor diagrams.

Definition:-

The transformer which has no copper loss, no iron loss ,no winding resistance ,No magnetic leakage is known as ideal transformer.

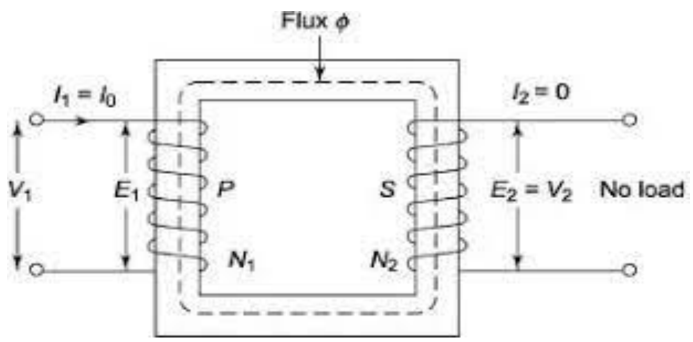
• There is practically no ideal transformer.

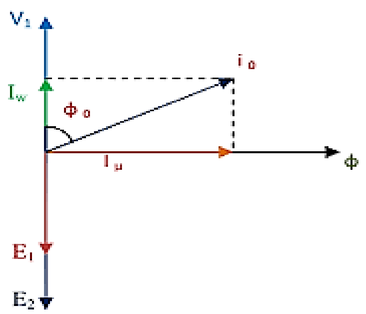
Explanation:-

When the transformer on No load:-

When a transformer is loaded there is some iron loss and copper loss. when the transformer is on no load the primary current is not 90°lagging behind the supply voltage but makes an angle less than 90°and taking flux as reference vector,

Let it be (φ_0)
i.e $\varphi_0 < 90°$
Where Io is the no load current in the primary.





• The current (Io) can be resolved into two components such as magnetising component and wattfull component or iron loss component.

Magnetising component ($I\mu$):-

The resolved component of no load current along the Flux-axis is called magnetising component or magnetising current.
$I\mu = I_0 \sin \varphi_0$

Wattfull or iron loss component (Iw):-

The resolved component of no load current along primary voltage axis is called wattfull or iron loss components.
$I_w = I_0 \cos \varphi_0$

The power input to the transformer at no load:-

Let

V_1=Primary voltage

V_2=secondary voltage

E_1 =Primary induced e.m.f

E_2=secondary induced e.m.f

I_0=No load current on primary side

R_1=primary winding resistance

R_2=Secondary winding resistance

Cos φ_0 = No load power factor

We know that

Input power= output power + total losses

Pi =Po+ W_t

=0+ Iron loss + Total copper loss

=Wo + primary Cu. Loss + Secondary Cu. Loss.

=$W_0 + I_0^2 R_1 + 0$

= $Wo + I_0^2 R_1$

As no load current is very small so the no load primary Cu. Loss ($I_0^2 R_1$+) is very very small ,Hence it can be neglected. The primary input to the transformer is practically the iron loss in the transformer.

Pi = Wo = V Io Cos φ_0, W

-

Problem-1

A single phase transformer has 400 primary and secondary turns. The met cross-sectional area of the core is 60 cm^2 .if the primary winding is connected a 50 hz supply at 520v then calculate Peak value flux density

And The voltage induced in the secondary winding.

solution

Data given

N_1=400

N_2= 1000

A= 60 cm^2

f= 50 hz

V_1= 520V

Required data= B_m=?

E_2=?

If it is at ideal transformer $V_1 = E_1$= 520 v

We know that

$E_1 = 4.44\ f\ \varphi_m\ N_1$ [BM=$\frac{\emptyset_M}{A}$, $\frac{W_b}{m^2}$] [$\varphi_m = B_m A$]

$E_1 = 4.44\ f\ B_m\ A\ N_1$

$B_m = \frac{E_1}{4.44\ f\ A\ N_1}$

$= \frac{520}{4.44\ X\ 50\ X 60\ X 10^{-4} X\ 4000}$

= 0.97 Wb/ m2

Problem-1

A 25 KvA transformer has 500 turns on the primary and so turns on the secondary the primary is connected to 3000 v at 50 hz frequency find the full load primary secondary currents. The secondary emf and the maximum flux in the core.

solution

Data given

P= 25 KvA = 25×10^3 VA

N_1=500

N_2= 50

V_1= E_1=3000 V

f= 50 hz

required data

I_1= ?

I_2= ?

Φ_M=?

E_2=?

Let it be a ideal transformer $V_1I_1= V_2I_2$= 25 X 1000 KvA

Let I_1 Rated full load current in the primary

I_2 is the rated full load current in the secondary

V_1I_1= 25X 10^3

$I_1 = \frac{25\text{X } 103}{\text{V1}}$

$= \frac{25\text{X } 103}{3000} =$ 8.3 A

K= N_2/N_1

= 50/ 500

= 0.1

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

$I_2 = \frac{I_1}{K} = \frac{8.3}{0.1}$ = 83 A

$E_1 = 4.44\ f\ \varphi_m\ N_1$

= $\varphi_m = \frac{3000}{4.44\ X\ 50\ X\ 500}$ = 0.027 Wb

E_2/E_1 = K

$E_2 = K\times E_1$ = 0.1 X 3000

= 300 V

Problem-

A 2200 /250 transformer draws current of 0.5 A at a power factor of 0.3 on open circuit find the magnetising component and the working component of the load current.

solution

Data given

V_1= 2200 V

V_2 = 250 V

I_0 = 0.5 A

Cos φ_0 = 0.3

Required data

$I\mu$= ?

I_W=?

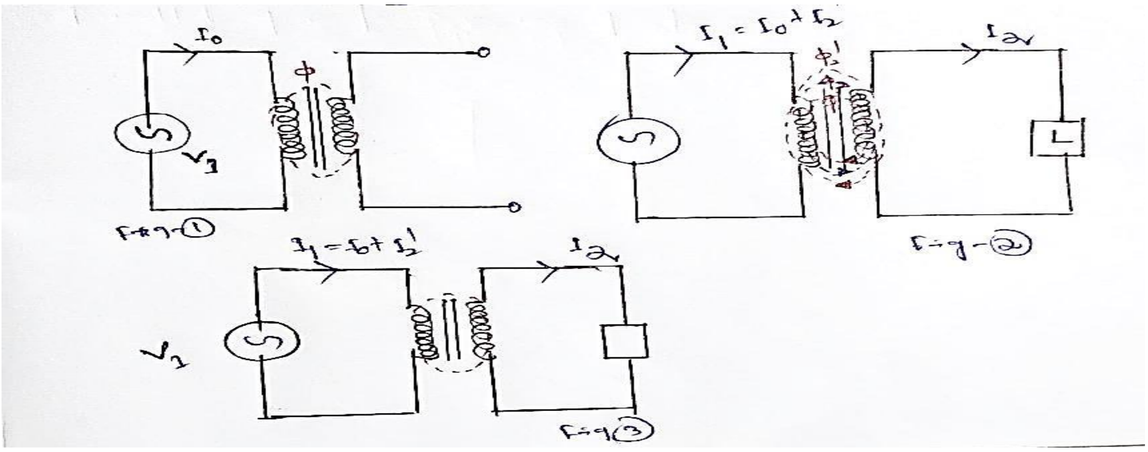
Solution

Sin $\varphi_0 = \sqrt{1 - cos^2\emptyset_0}$
$= = \sqrt{1 - 0.3^2}$
$= \sqrt{1 - 0.09}$
$= \sqrt{0.09}$
= 0.95
The magnetising component
$I\mu = I_0 \sin \varphi_0$
=0.5 x 0.95
= 0.476 A
The working component or iron loss current
$I_W = I_O \cos \varphi_0$
= 0.5 × 0.3
= 0.15 A

Phasor diagram of an ideal T/F on load(UPF, Lagging & Leading P.F):-

Explanation:-

When the transformer is loaded a current I_2 is flowing through the secondary winding due to this current a flux is produced in the secondary winding and it is opposes the flux due to the primary winding.



Let this flux is φ_2
Hence the net flux in the core decreases momentarily and the E_1 decreases .For the time being the potential difference between V_1& E_1 increases and hence a high amount of current flowing through the primary.
Let I_2' be the additional current flowing through the primary this current is known as load component of primary .Due to this current an additional flux (φ_2') is produced and which opposes the flux φ_2 and it is can solve each other and the net flux in the core remains constant.
Hence whatever may be the load the flux remain constant in the core. As the flux remain constant the iron loss or core loss is also constant from no load to full load.
From above discussion.
$(\varphi_2') = \varphi_2$
$\Rightarrow N_1 I_2' = N_2 I_2$
$\Rightarrow I_2' = (N_2/N_1) \times I_2$
$\Rightarrow I_2' = KI_2$
$\Rightarrow I_2' = -KI_2$
I_2' is opposite to the I_2
Hence we can say the primary current

(I_1`) is sum of (vectorically) no load current (Io) and I_2' i.e

I_1=Io+I_2'(vector sum)

Where,

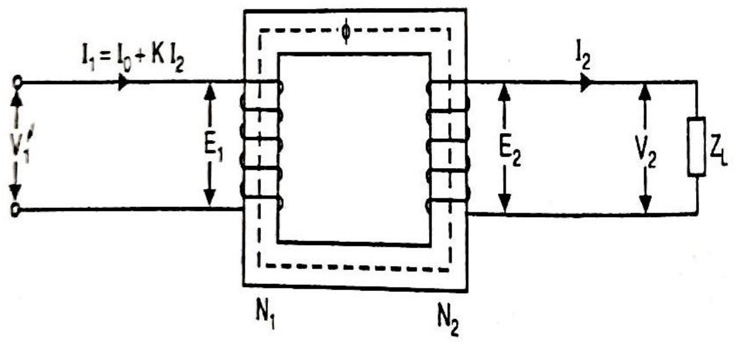
I_1=primary current, A

I_2=Secondary current, A

I_0=No load primary current, A

I_2'=Reflected current of secondary on primary side, A

Phasor diagram:



We know that,

$I_2' = -k\ I_2$

In ideal T/F

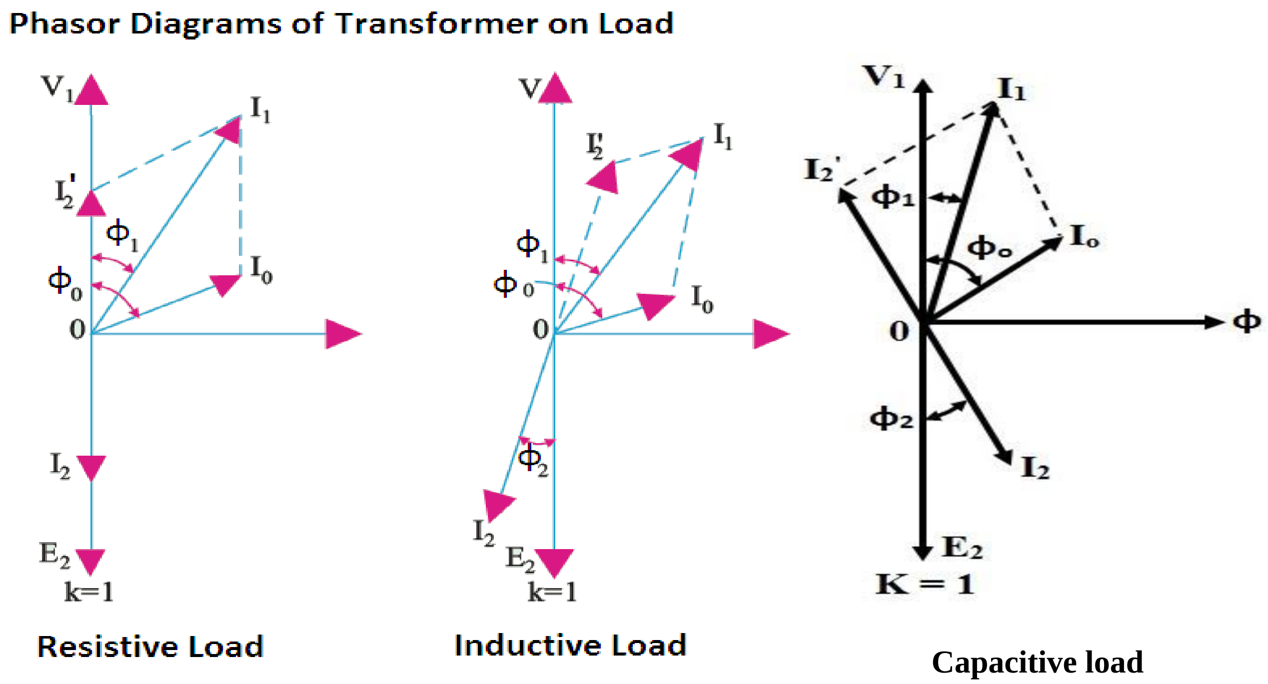
K=1

So $I_2' = -I_2$

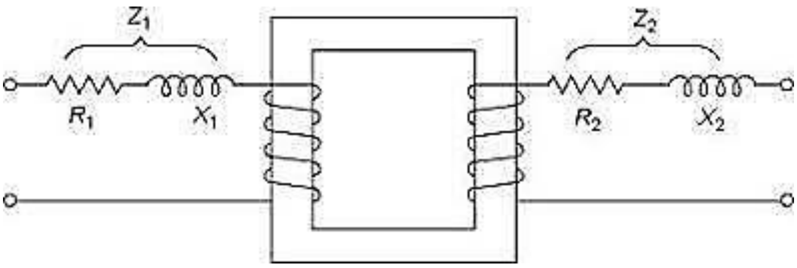
Again

$$\vec{I_1} = \vec{I_0} + \vec{I_2'}$$

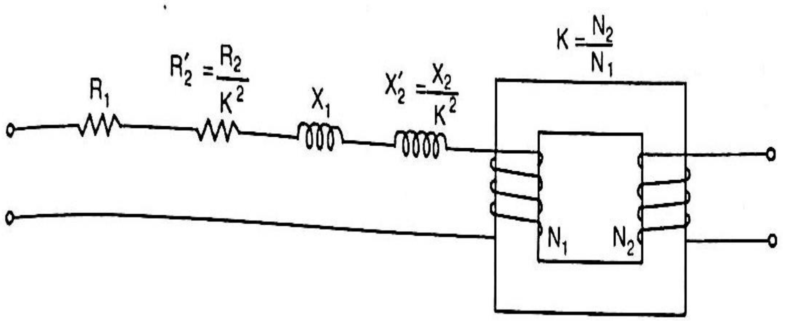
We will discuss the phaser diagram for resistive load (Unity power factor), Inductive load(Lagging power factor) & Capacitive load (leading power factor).

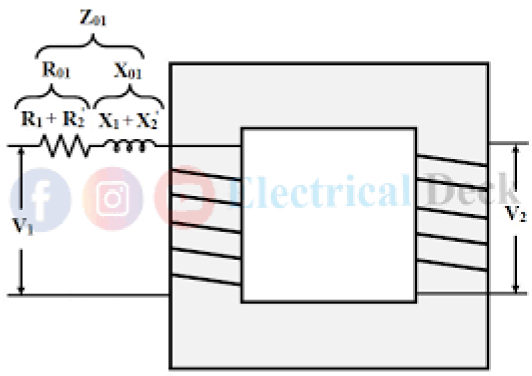


3.7 Equivalent Resistance, Leakage Reactance and Impedance of transformer.



- When secondary resistance ,reactance and impedance are shifted to primary that its value in primary side is
  $= \frac{R_2}{K^2}, \frac{X^2}{K^2}$ & $\frac{Z_2}{K^2}$ respectively
  Where we can represent
  $R^I_2 = \frac{R_2}{K^2}$, $X^I_2 = \frac{X^2}{K^2}$, $Z^I_2 = \frac{Z_2}{K^2}$



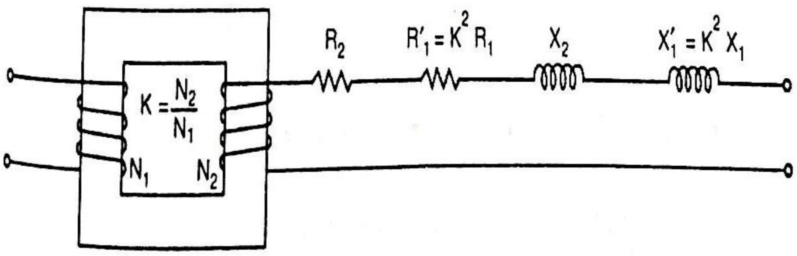


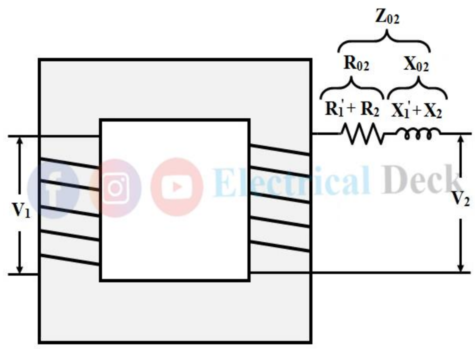
R^I_2 is known as secondary resistance as refer to primary
X^I_2 is the secondary reactance as refer to primary
Z^I_2 is the secondary impedance as refer to primary
R_{01} → is known as equivalent resistance of the transformer as refer to primary
X_{01} → is known as equivalent reactance of the T/F as refer to primary
Z_{01} → is known as equivalent impedance of the T/F as refer to primary

$R_{01} = R_1 + R_2^I$
$= R_1 + \frac{R_2}{K^2}$
$X_{01} = X_1 + X_2^I$
$= X_1 + \frac{X_2}{K^2}$
$Z_{01} = \sqrt{(R_{01})^2 + (X_{01})^2}$

Similarly when secondary voltage as transfer to primary K is divided for eg→
$E_2^I = \frac{E_2}{K}$ $V_2^I = \frac{V_2}{K}$
When secondary current are transfer to primary K is multiplied
$I_2^i = K\, I_2$

Primary parameter shifted secondary





When primary parameter shifted to secondary the K^2 is multiplied and is represented as

$R_1^I = K^2 R_1$, $X_1^I = K^2 X_I$, $Z_1^1 = K^2 Z_1$

Where R_1^i is known primary resistance as refer to secondary

X_1^I Is known as primary reactance as refer to secondary

Z_1^1 Is known as primary impedance as refer to secondary

$R_{02} = R_2 + R_1^I$

$= R_2 + K^2 R_1$

$X_{02} = X_2 + X_1^I$

$= X_2 + K^2 X_I$

$Z_{02} = \sqrt{(R_{02})^2 + (X_{02})^2})$

R_{02} →Is the equivalent resistance of the transformer as refer to secondary

X_{02}→is the equivalent reactance of the T/F as refer to secondary

Z_{02} → is the equivalent impedance of the T/F as refer to secondary

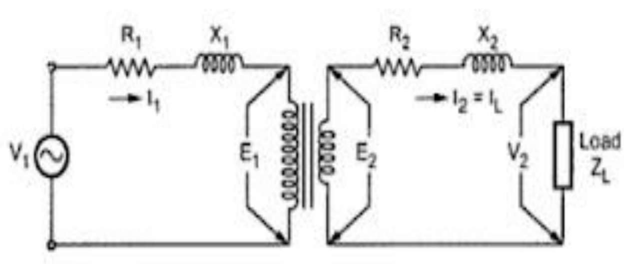
When primary voltage shifted to the secondary K is multiplied i.e

$V_1^I = K V_1$

When current transfer secondary is divided i.e

$I_1^I = \frac{I_1}{K}$

3.8 To draw phasor diagram of transformer on load, with winding Resistance and Magnetic leakage with using upf, leading pf and lagging pf load.



The various transformer parameters are,

R_1 = Primary winding resistance

X_1 = Primary leakage reactance

R_2 = Secondary winding resistance

X_2 = Secondary leakage reactance

Z_L = Load impedance

I_1= Primary current

I_2 = Secondary current = I_L = Load current now $\bar{I}_1 = \bar{I}_o + \bar{I}_2'$

where I_o = No load current

I_2'= Load component of current decided by the load

= K I_2 where K is transformer component

The primary voltage V_1 has now three components,

1. $-E_1$, the induced e.m.f. which opposes V_1
2. $I_1 R_1$, the drop across the resistance, in phase with I_1
3. $I_1 X_1$, the drop across the reactance, leading I_1 by 90

$$\vec{V}_1 = -\vec{E}_1 + \vec{I_1}R_1 + J\vec{I_1}X_1$$
$$= -\vec{E}_1 + \vec{I_1}(R_1 + JX_1)$$
$$= -\vec{E}_1 + \vec{I_1}Z_1$$

Where $Z_1 = R_1 + jX_1$

IZI $= \sqrt{((R_1)^2 + (X_1)^2)}$

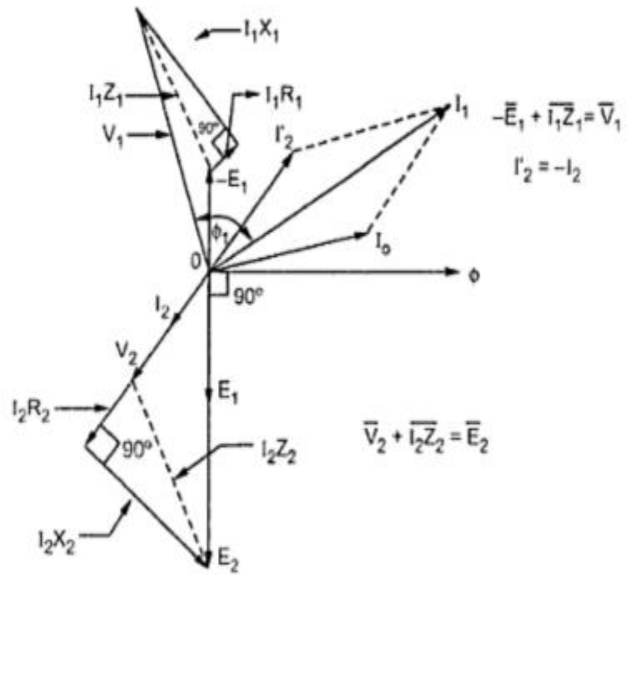
similary the voltage equation in secondary side

$$\vec{V}_2 = \vec{E}_2 - \vec{I_2}R_2 - J\vec{I_2}X_2$$
$$= -I_1(R_2 + JX_2)$$
$$= -\vec{E}_2 - \vec{I_2}Z_2$$

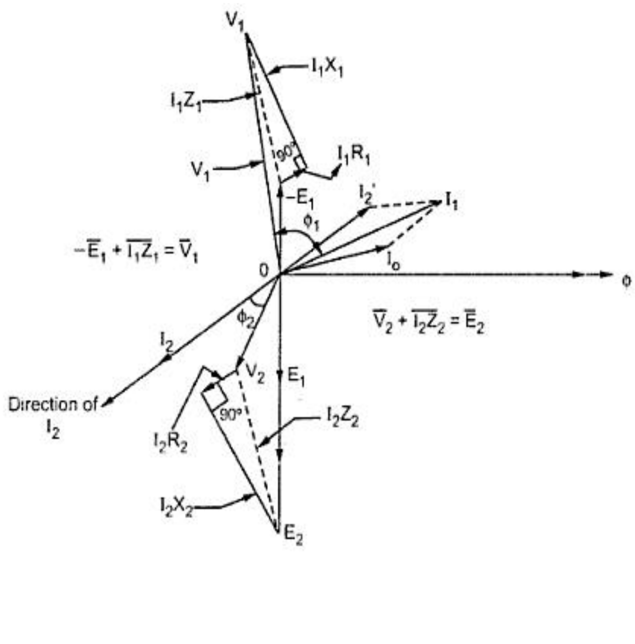
Where $Z_2 = R_2 + jX_2$

$$|Z_2| = \sqrt{((R_2)^2 + (X_2)^2)}$$
$$E_2 = V_2 + \vec{I_2}Z_2$$
$$E_2 = \vec{V}_2 + \vec{I_2}R_2 + jI_2X_2$$

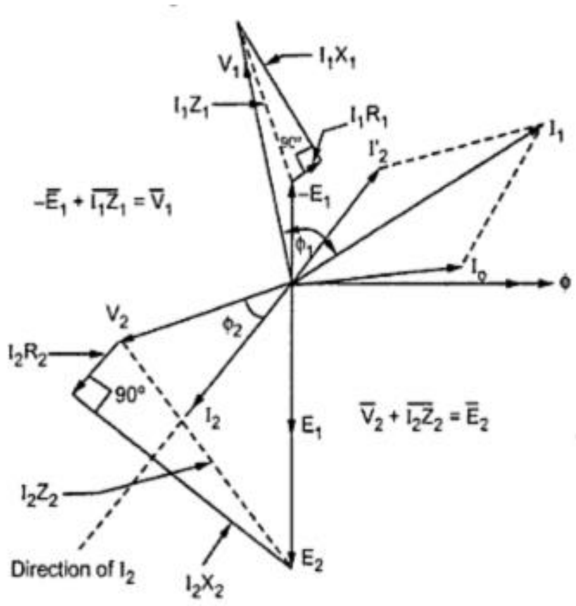
For resistive load



For inductive load



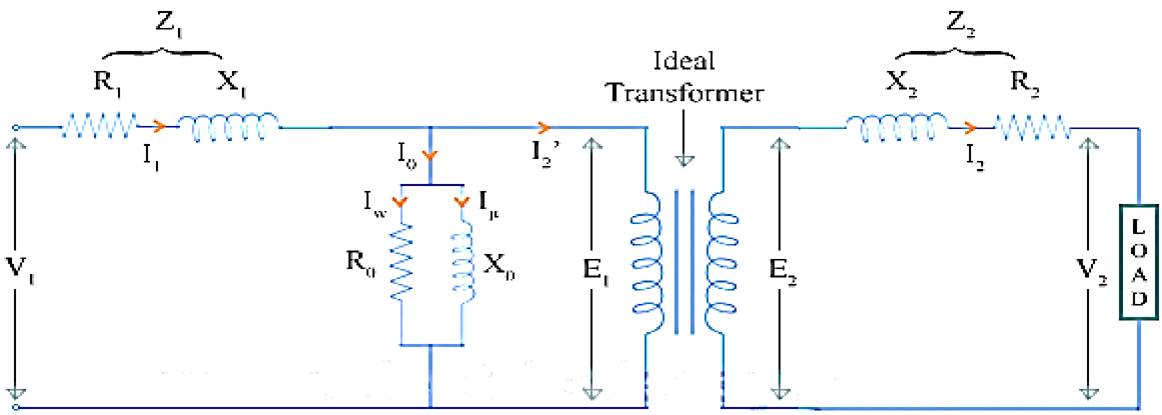
For capacitive load



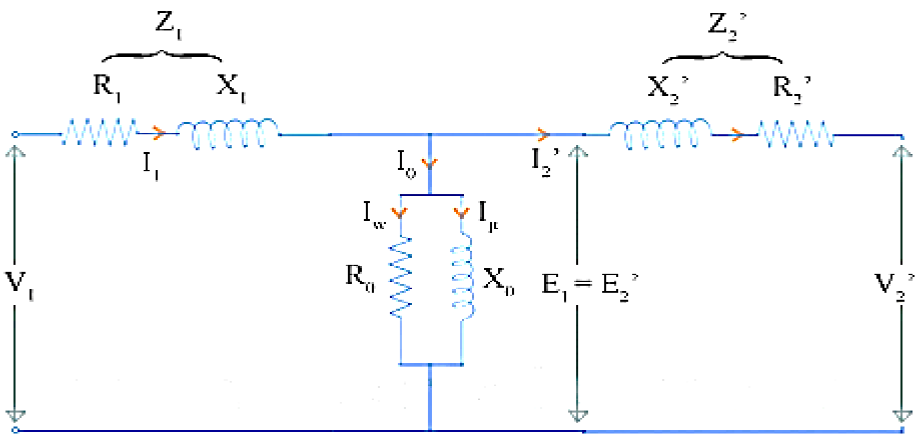
3.9 To explain Equivalent circuit and solve numerical problems

The transformer shown in figure can be resolved into an equivalent circuit giving all the parameter as shown in figure.

The transformer shown in figure can be resolved into an equivalent circuit giving all the parameter as shown in figure.



Now we can transfer the secondary parameter to the primary side

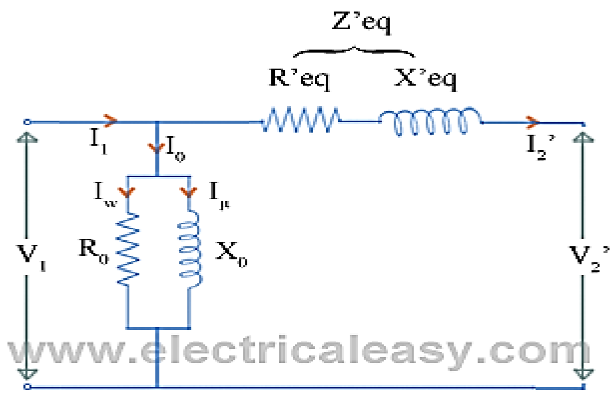


The above equivalent diagram is some what harder circuit to solve so to simplify the exciting circuit can be moved to the beginning. So the circuit diagram is as below.

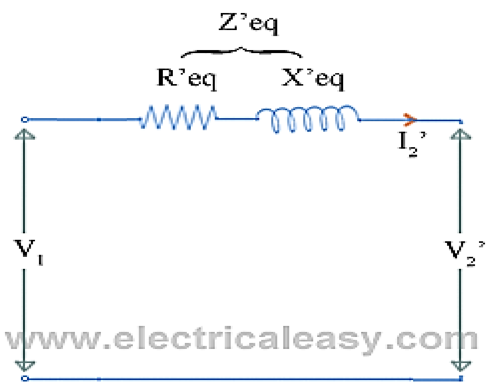
$R_{eq} = R_{01} = R_1 + R_2^{I}$

$X_{eq} = X_{01} = X_1 + X_2^{I}$

$Z_{eq} = Z_{01} = \sqrt{(R_{01})^2 + (X_{01})^2)}$

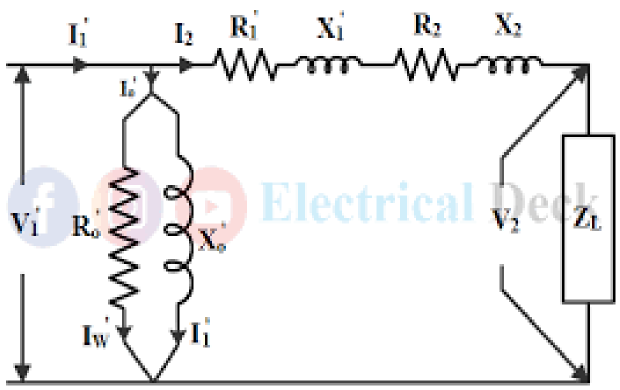


For further simplification we can neglect the exciting parameter.



(simplified equivalent circuit of a transformer as refer to primary)

Similarly equivalent circuit diagram as refer secondary :-



Approximate Equivalent Circuit Referred to Secondary

For further simplification we can neglect the exciting parameter.

$R_{eq} = R_{02} = R_2 + R_1^{I}$

$X_{eq} = X_{02} = X_2 + X_1^{I}$

$Z_{eq} = Z_{02} = \sqrt{(R_{02})^2 + (X_{02})^2})$

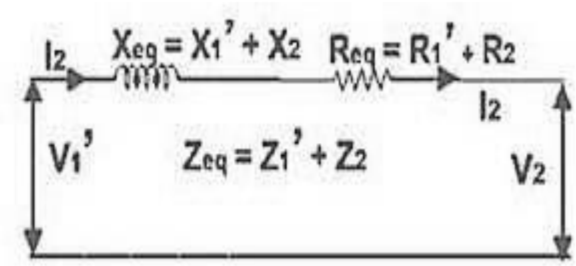


Fig. 2.12 Approximate Equivalent Circuit of Transformer Referred to Secondary

This equivalent ckt refered to secondary helps to calculate voltage regulation easily

Problem

A 100kVA, 2200/440 V transformer has $R_1 = 0.3\Omega; X_1 = I.1\Omega; R_2 = 0.01\Omega$ and $X_2 = 0.035\Omega$. Calculare (i) the equivilent impedance of the transformer referred to the primary and (ii) total copper losses.

Solution.

Voltage transformation ratio, $K = 440/2200 = 1/5$

Assuming the efficiency of transformer to be 100%,

Full-load primary current, $I_1 = \frac{100\times1000}{2200} = 45.45$ A

Full-load secondary current, $I_2 = \frac{100\times1000}{440} = 227.25$ A

Alternatively: $l_2 = I_1/K = 45.45 \times 5 = 227.25$ A

(i) $R_{01} = R_1 + \frac{R_2}{K^2} = 0.3 + \frac{0.01}{(1/5)^2} = 0.55\Omega$

$$X_{01} = X_1 + \frac{X_2}{K^2} = 1.1 + \frac{0.035}{(1/5)^2} = 1.975\Omega$$

$$\therefore Z_{01} = \sqrt{R_{01}^2 + X_{01}^2} = \sqrt{(0\cdot55)^2 + (1\cdot975)^2} = 2\cdot05\Omega$$

(ii) Total Cu losses $= I_1^2 R_{01} = (45.45)^2 \times 0.55 = 1136.14$ W

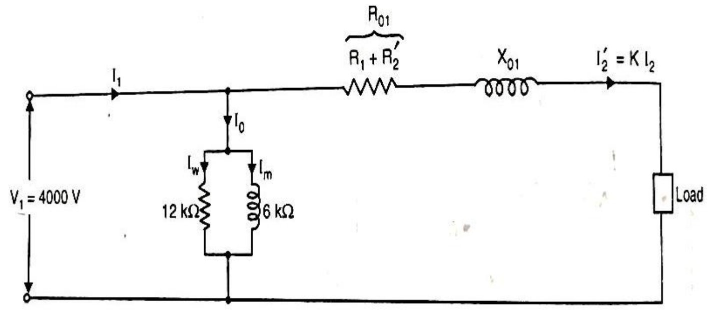
Ahernathely : Total Cu losses $= I_1^2 R_1 + I_2^2 R_2$

$$= (45.45)^2 \times 0.3 + (227\cdot25)^2 \times 0\cdot01 = 1136\cdot14 \text{ W}$$

Problem

A 4000/400 V, 10kVA transformer has primary and secondary winding resistances of 13Ω and 0.15Ω respectively. The leakage reaciance refered to primary is 45 ohm. The magnetising impedance referred to primary is 6kΩ and the resistance corresponding to the core loss is 12kΩ. Determine the input current (i) when the secondary terminals are open-circuited and (ii) when the Determine the input current (i) when the secondary terminals are open-circuited and (ii) when the secondary load current is 25 A at a power factor of 0.8 lagging. Use simplified equivalent circuith

solution



Refered to primary

The value of $K = 400/4000 = 1/10$.

$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2} = 13 + \frac{0\cdot15}{(1/10)^2} = 28\Omega$

; $X_{01} = 45\Omega$ (given)

(1) Core loss component of current is given by;

$$I_W = \frac{V_1}{R_0} = \frac{4000}{12 \times 10^3} = 0.333 \text{ A}$$

$$\text{Magnetising current, } I_m = \frac{V_1}{X_0} = \frac{4000}{6 \times 10^3} = 0.667 \text{ A}$$

No-load current, $I_0 = (0.333 - j0 - 667)\text{A} = 0.745\angle - 63.5°\text{A}$

(ii) Secondary load current, $I_2 = 25\angle - 36 - 9°\text{A}$

$$I_2' = KI_2 = \frac{1}{10} \times 25\angle - 36.9° = 2.5\angle - 36.9°A = (2 - j1.5)A$$

$$\text{Input current, } I_1 = I_2' + I_0 = (2 - j1.5) + (0.333 - j0.667)$$

$$= (2.333 - j2.167)A = 3.18\angle - 43°A$$

3.10 Approximate & exact voltage drop calculation of a Transformer:

Approximate voltage drop in a single phase transformer

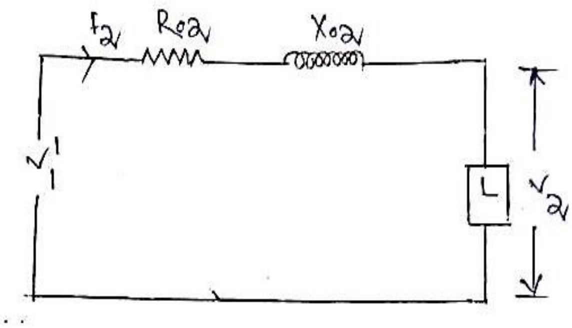
From the above diagram we have

$V_1^I - (I_2R_{02} + j\, I_2X_{02}) = V_2$

$V_1^I = V_2 + (I_2R_{02} + j\, I_2X_{02})$-------------------(1)

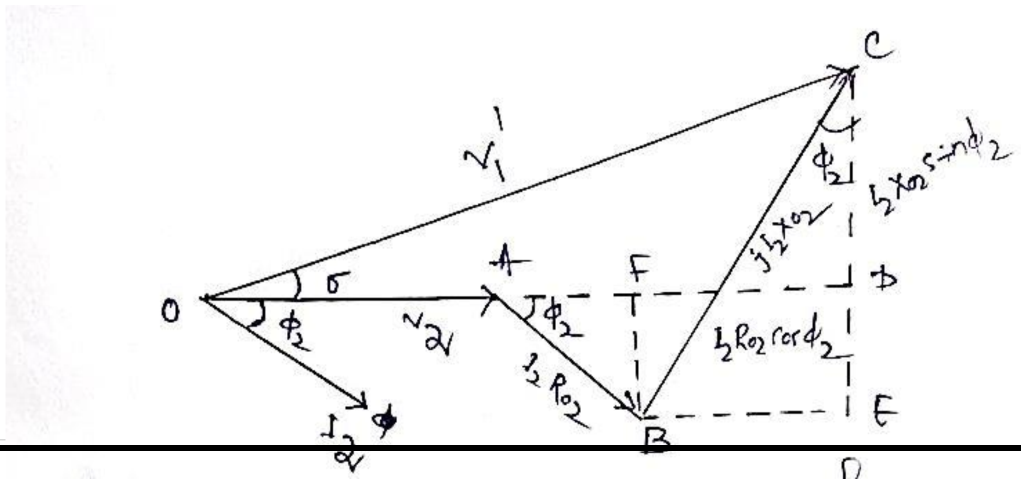
$V_1^I - V_2 = I_2R$

Drop= $I_2R_{02} + j\, I_2X_{02}$



Vector diagram

Taking V_2 as reference vector, the vector diagram of V_1^I for lagging power factor is drawn below.



To minimise the drop the angle φ should be reduced to zero (0)
Hence drop = $V_1^I - V_2$
=OD-OA
=AD
=AF+FD
=$I_2 R_{02} COS\ \varphi_2 + I_2 X_{02} Sin\ \varphi_2$
Approximate voltage drop
=$I_2 R_{02} COS\ \varphi_2 + I_2 X_{02} Sin\ \varphi_2$
+ve sign for lagging power factor
-ve sign for leading power factor

3.11 Regulation of transformer:

Voltage regulation:

Voltage regulation of a transformer is the arithmetic difference between the no load secondary voltage (ov_2 or E_2) and secondary voltage of full load and expressed as percentage of no load voltage.

% VR= $\frac{OV_{2-V2}}{OV_2}\ X\ 100$

Voltage regulation are two types-

% VR (down)= $\frac{OV_{2-V2}}{OV_2}\ X\ 100$

% VR (up)= $\frac{OV_{2-V2}}{V_2}\ X\ 100$

OV_2-V_2 is the drop of the transformer so we can write ,

%VR =$\frac{I_2 R_{02} COS\ \emptyset_2 \pm I_2 X_{02} Sin\emptyset_2}{OV_2}\ X\ 100$

=$\frac{I_2 R_{02}}{OV_2}\ X\ 100\ COS\ \emptyset_2\ \pm \frac{I_2 X_{02}}{OV_2}\ X\ 100\ Sin\emptyset_2$

=V_R Cos $\varphi_2 \pm V_X$ Sin φ_2

Where V_R is the percentage resistive drop =$\frac{I_2 R_{02}}{OV_2}\ X\ 100$

V_R is also known as % R
(V_R = % R)

Similarly V_X is the percentage of reactance drop = $\frac{I_2 X_{02}}{OV_2}\ X\ 100$

Percentage of impedance ,

% Z = $\sqrt{((\%R)^2 + (\%\ X)^2)}$

% Z=$\frac{I_2 Z_{02}}{OV_2}\ X\ 100$

As refer to primary

% R= VR= $\frac{I_1 R_{01} COS\ \emptyset_1 \pm I_1 X_{01} Sin\emptyset_1}{V_1}$

V_R= $\frac{I_1 R_{01}}{V_1}\ X\ 100$, V_X=$\frac{I_1 X_{01}}{V_1}\ X\ 100$

% Z = $\frac{I_1 \mu_1}{V_1}$

The vector diagram for different power factors are as follows:-

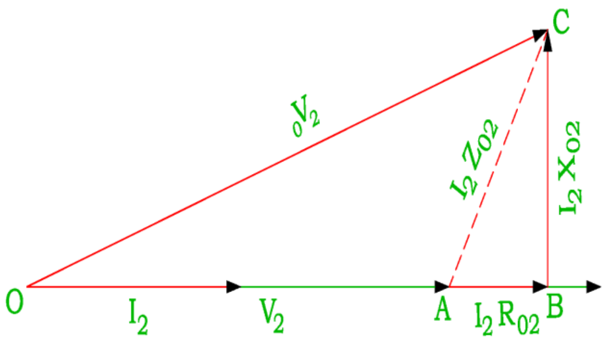


FIG C : VOLTAGE DROP : UNITY POWER FACTOR LOAD

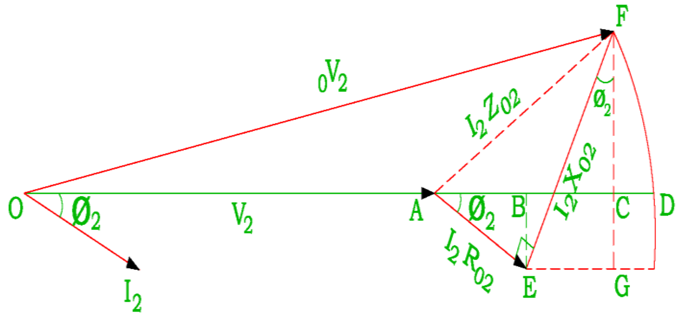
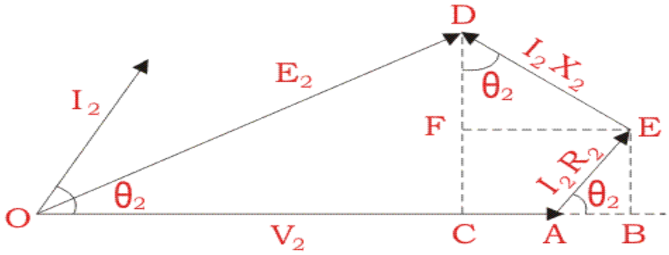


FIG A : VOLTAGE DROP : LAGGING POWER FACTOR LOAD



Voltage Regulation at Leading Power Factor

Problem

A 10kVA, 2000/400 V single-phase transformer has the following data. $R_l = 5\Omega$; $X_l = 12\Omega$; $R_2 = 0.2\Omega$; $X_2 = 0.48\Omega$

Determine the secondary terminal voltage at full-load, 0.8 p. f. lagging when the primary supply voltage is 2000 V.

Solution.

$$K = 400/2000 = 1/5$$
$$R_{02} = R_2 + K^2R_1 = 0.2 + (1/5)^2 \times 5 = 0.4\Omega$$
$$X_{02} = X_2 + K^2X_1 = 0.48 + (1/5)^2 \times 12 = 0.96\Omega$$
$$\text{F.L secondary current, } I_2 = \frac{10 \times 1000}{400} = 25 \text{ A}$$
$$\cos\phi_2 = 0.8 \therefore \sin\phi_2 = 0.6$$
$$\text{Voltage drop} = I_2(R_{02}\cos\phi_2 + X_{02}\sin\phi_2)$$
$$= 25(0.4 \times 0.8 + 0.96 \times 0.6) = 25(0.32 + 0.576) = 22.4 \text{ V}$$

∴ Secondary terminal voltage at full-load is

$$V_2 = 400 - 22.4 = 377.6 \text{ V}$$

Problem

The primary and secondary windings of a 40kVA, 6600/250 V single-phase trussformer have resistances of 10Ω and 0.02Ω respectively. The leakage reactance of the transformer referned to the primary side is 35Ω Calculate the percentage voltage regulation of the transformer when supplying full-load current at a pf of 0.8 lagging.

Solution.

$K = 250/6600 = 25/660$

$$R_{01} = R_1 + \frac{R_2}{K^2} = 10 + 0.02 \times (660/25)^2 \quad = 23.93\Omega, \quad X_{01} = 35\Omega \text{ (given)}$$

$$\text{F.L. primary current, } I_1 = \frac{40 \times 1000}{6600} = 6.06 \text{ A}$$

$$\cos\phi_2 = 0.8 \ \therefore \sin\phi_2 = 0.6$$

$$\text{Voltage drop} = I_1(R_{01}\cos\phi_2 + X_{01}\sin\phi_2)$$

$$= 6.06(23.93 \times 0.8 + 35 \times 0.6) = 243 \text{ V}$$

3.12 Different types of losses in a Transformer. Explain Open circuit and Short Circuit test.(Solve numerical problems)

Losses in a transformer

Loss are two types of 1- φ transformer

(i)Iron loss, (ii)Copper loss

Iron loss

Iron loss are in 2 types

(a)Eddy current loss , (b)Hysteresis loss

Eddy current loss: $W_e = \eta_e B^2 f^2 t^2 v$

Hysteresis loss: $W_h = \eta_h B^{1.2}{}_{max} f v$

Where t → thickness of the lamination

v→ volume of the magnetic

B_{max}→ maximum flux density

Iron loss is known as constant loss because as the flux in the core is constant from no load to full load. Iron loss can be find from the no load test i.e o.c test.

Copper loss:

In transformer iron loss occurs in primary and in the secondary winding.

Hence copper loss $W_C = I_1^2 R_1 + I_2^2 R_2$

$I_1^2 R_1$= Primary winding cupper loss

$I_2^2 R_2$= secondary cupper loss

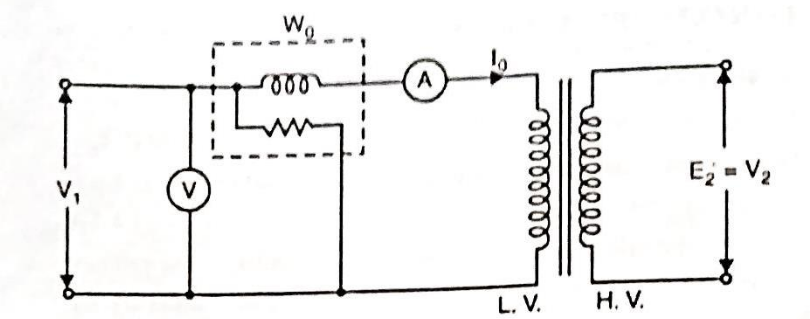
The cupper loss can be find out from sc test.

Open circuit test & S.C test of 1-ph T/F:-

Open circuit test

This is also called as no-load test and it is conducted to determine iron loss or core loss of the transformer.

Circuit diagram:-



This test is normally conducted on L V side keeping H.V open circuited.

• The measuring instruments like A.C voltmeter ,A C ammeter and wattmeter are connected on the L.V side of the transformer as shown in the above figure.

Procedure:-

After connecting all necessary measuring instruments on the L.V side, The variance is gradually increased till the voltmeter reads its rated value. Then ammeter and wattmeter readings are noted down. The wattmeter will indicate the iron or core loss.

Theory:-

From this test, the exciting coil parameters of an equivalent circuit of the transformer are determined as follows.

Let,

$W_o = W_i$ =Iron loss shown by the wattmeter, w

V=No-Load L.V. side rated voltage shown by the voltmeter, v

I_o= No load current shown by the ammeter, A

$\cos\varphi_0$ =No load power factor

$W_i = V I_0 \cos \varphi_0$

$\Rightarrow \cos\varphi_o = W_0/V I_0$

Hence watt full current, $I_w = I_0 \cos \varphi_0$,A

Similarly

magnetising current, $I_m = I_0 \sin \varphi_0$

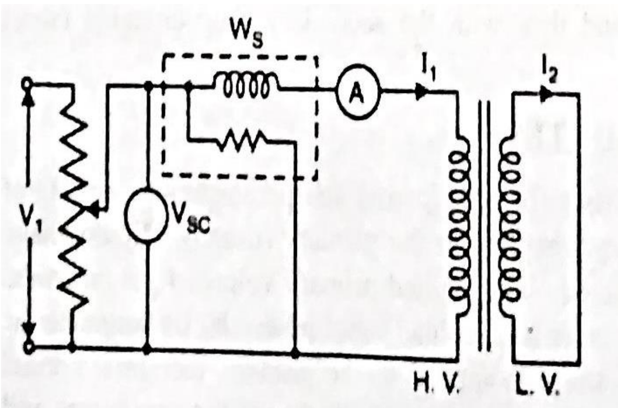
So exciting coil resistance, $R_0 = V / I_w$,ohm

Exciting coil resistance, $X_0 = V / I_m$,ohm

Short circuit test:-

This is also called as full load test. It is connected to determine full load copper loss of the transformer.

Circuit Diagram:-



This test is normally conducted on H.V. side keeping L.V. shorted.

• The measuring instruments like A.C voltmeter, ammeter and wattmeter are connected on H.V. side of the transformer as shown in the above figure. Using a thick copper wire, L.V. terminals shorted.

Procedure:-

After connecting all the measuring instruments, the variance is gradually increased till the ammeter reads it’s rated current. It is observed that the rated current is achieved at reduced voltage. Then voltmeter reading, ammeter reading and wattmeter reading are recorded. The wattmeter reading gives full load copper loss.

Theory:-

From this test , winding parameters can be determined as below.

Let,

W_{sc}= wattmeter reading under short circuit/Full load Cu. Loss, w

V_{sc}= short circuit voltage, v

$I_{sc}=I_1$= short circuit/Full load current shown by the ammeter, A

R_{01}=Equivalent resistance referred to primary side, ohm

X_{01}= Equivalent reactance referred to primary side, ohm

X_{01}=Equivalent impedance referred to primary side, ohm

If the test is conducted on primary side

$V_{SC} = I_{sc} Z_{01}$

$Z_{01} = V_{sc} / I_{sc}$

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

$R_{01} = W_{sc} / I_{sc}^2$,ohm

$X_{01} = \sqrt{(Z_{01}^2 - R_{01}^2)}$, ohm

Problems

In a no-load test of a single-phase transformer, the following test data were obtained:

Primary voltage: 220 V: Secondary voltage : 110 V

Primary current : 0.5 A; Power input 30w

Find (i) the turns ratio (ii) the magnetising component of no-load current (iii) the iron-loss component of no-load current (iv) iron loss. The resistance of primary winding is 0.6Ω

Solution.

(i) Turns ratio $= \frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{V_1}{V_2} = \frac{220}{110} = 2$

(ii) $W_0 = V_1 I_0 \cos\phi_0$

No-load p.f., $\cos\phi_0 = \frac{W_0}{V_1 I_0} = \frac{30}{220\times 0.5} = 0.273; \sin\phi_0 = 0.962$

Magnetising current, $I_m = I_0 \sin\phi_0 = 0.5 \times 0.962 = 0.48$ A

(iii) Component of no-load current corresponding to core loss is

$$I_W = I_0 \cos\phi_0 = 0.5 \times 0.273 = 0.1365 \text{ A}$$

(iv) Primary Cu loss $= I_0^2 R_1 = (0.5)^2 \times 0.6 = 0.15$ W

Iron loss $= 30 - 0.15 = 29.85$ W

Problems

In a test for the determination of losses of a 440 V, 50 Hz transformer, the folal iron losses were found to be $2500W$ at normal voltage and frequency. When the applied voltage and frequency were 220 V and 25 Hz, the inon losses were found to be 850 W. Calculate the eddy current lass at normal voltage and frequency.

Solution.

In a transformer, $\phi_m \propto V_1/f$. Since in the second case, voltage as well as frequency is halved, the ratio V_1/f remains the same. Therefore, maximum flux density in the two cases is the same.

Total iron losses, $P_f = af + bf^2$

or $\frac{P}{f} = a + bf$

For the first case, $\frac{2500}{50} = a + 50b$

For the second case, $\frac{850}{25} = a + 25b$

Solving these two equations, we have, $b = 0.64$.

$\therefore$ Eddy current loss $= bf^2 = 0 \cdot 64 \times 50^2 = 1600$ W

We can also find the hysteresis loss by subtracting 1600 W from 2500 W.

3.13 Explain Efficiency, efficiency at different loads and power factors, condition for maximum efficiency (solve problems):

Efficiency of 1-φ transformer

η= $\frac{output}{input}\ x\ 100$

η= $\frac{o/p\ in\ watt}{i/pin\ watt}\ x\ 100$

η= $\frac{o/p}{o/p+losses}\ x\ 100$

Condition for maximum efficiency :-

η= $\frac{output}{input}$

= $\frac{o/p}{o/p+losses}$

= $\frac{V_2 I_2 \cos\emptyset_2}{V_2 I_2 \cos\emptyset_2 + Iron\ loss + copper\ loss}$

Let full load iron loss = W_i

Full load copper loss = W_c

=$\frac{V_2 I_2 \cos\emptyset_2}{V_2 I_2 \cos\emptyset_2 + (W_i + W_c)}$

η=$\frac{V_2 I_2 \cos\emptyset_2}{V_2 I_2 \cos\emptyset_2 + W_i + I_2^2 R_{02}}$

At maximum efficiency

- ⇨ $\frac{d(\eta)}{d\ I_2} = 0$
- ⇨ $\frac{d}{d\ I_2}\left(\frac{V_2 I_2 \cos\emptyset_2}{V_2 I_2 \cos\emptyset_2 + W_i + I_2^2 R_{02}}\right) = 0$
- ⇨ $\frac{\left(V_2 I_2 \cos\emptyset_2 + W_i + I_2^2 R_{02}\right) V_2 \cos\emptyset_2 - V_2 I_2 \cos\emptyset_2 (V_2 \cos\emptyset_2 + 2 I_2 R_{02})}{(V_2 I_2 \cos\emptyset_2 + W_i + I_2^2 R_{02})^2}$
- ⇨ $(V_2 I_2 \cos\emptyset_2 + W_i + I_2^2 R_{02}) V_2 \cos\emptyset_2 - V_2 I_2 \cos\emptyset_2\ (V_2 \cos\emptyset_2 + 2 I_2 R_{02})$=0
- ⇨ $V_2 I_2 \cos\emptyset_2 + W_i + I_2^2 R_{02} - I_2 (V_2 \cos\emptyset_2 + 2 I_2 R_{02})$=0
- ⇨ $V_2 I_2 \cos\emptyset_2 + W_i + I_2^2 R_{02}$-$V_2 I_2 \cos\emptyset_2 + 2 I_2 R_{02}$=0
- ⇨ $W_i + I_2^2 R_{02} - 2 I_2 R_{02}$=0
- ⇨ $W_i = 2 I_2 R_{02} - I_2^2 R_{02}$
- ⇨ $W_i = I_2^2 R_{02}$
- ⇨ W_i=W_c
- ⇨ Iron loss= copper loss

Hence efficiency will be maximum when

Iron loss = copper loss

At maximum efficiency the load current $I_2=\sqrt{\frac{W_i}{R_{02}}}$

Problem

20kVA, single-phase, 50 Hz, 2200/200 V transformer gave the following test results
O.C test : 2200 V applied to primary, power taken 220 W
SC. test: Power required to circulate FL current in short-circuited secondary 240 W Calculate the efficiency af full-load and half full-load at p.f. 0.8 lagging.

Solution.

Iron losses $= 220$ W; F.L. Cu losses $= 240$ W

At full-load, 0.8 p.f. lagging

Output $= 20 \times 10^3 \times$ p.f. $= 20 \times 10^3 \times 0.8 = 16000$ W

Total losses $= 220 + 240 = 460$ W

Input $= 16000 + 460 = 16460$ W

FL efficiency $= \frac{16000}{16460} \times 100 = 97.21\%$

At half full-load, 0.8 p.f. Iagging

Cu losses $= \left(\frac{1}{2}\right)^2 \times 240 = 60$ W

Iron losses $= 220$ W

Total losses $= 220 + 60 = 280$ W

Output $= 10 \times 10^3 \times 0 - 8 = 8000$ W

Input $= 8000 + 280 = 8280$ W

Efficiency $= \frac{8000}{8280} \times 100 = 96.63\%$

Problem

In a 50kVA transformer, the iron loss is 500 W and full-load copper loss is 800 W. Find the efficiency at full-load and half full-load at 0.8 p f. lagging.

Solution.

Full-load, 0.8 p.f.

Full-load output $= 50 \times 0.8 = 40$ kW

Total Full-load losses $= 500 + 800 = 1300$ W $= 1.3$ kW

Full-load input $= 40 + 1.3 = 41 - 3$ kW

Full-load $\eta = \frac{40}{41\cdot 3} \times 100 = 96.85\%$

Half full-load, 0.8 p.f.

Output at half full-load $= (50 \times 1/2) \times 0.8 = 20$ kW

Total loss at half full-load $= 500 + (1/2)^2 \times 800 = 700$ W $= 0.7$ kW

Input at half full-load $= 20 + 0.7 = 20.7$ kW

Half full-load $\eta = \frac{20}{20\cdot 7} \times 100 = 96.6\%$

3.14 Explain All Day Efficiency (solve problems):

Definition:-

It is defined as ratio of output energy to the input energy.

Mathematically-,

η_{all} =(O/P) energy /(I/P) energy for 24 hours

Explaination:-

As we know that a transformer is designed to operate at different loads with different power factors.Some times the transformer may be full loaded ,half loaded or one fourth loaded etc. and may be operated with unity power factor, Lagging and leading power factor.

Since it is understood that a Transformer operating at different loads and power factors will have copper losses accordingly ,so it's efficiency in a day is necessary to determine .Hence all day efficiency of a Transformer can give the overall performance.

Question

A $150KVA$ transformer is loaded as under

Load increases from zero to 100kVA in 3 hours from 7a. mo to 10a. m, stays at 100kVA from 10 am to 6pm and then the transformer is disconnecred till next day. Assuming the load to be resistive and core loss equal to full-load copper loss of kW, determine the commercial and all-day efficiency of the transformer.

Solution.

Since the load is resistive, its power factor is unity.

Average load from 7a. m, to $10\text{a. m.} = \frac{0+100}{2} = 50\text{kVA}$

Load from 10a. m. to $6\text{pm.} = 100\text{kVA}$

F.L Cu loss $= 1$ kW; Iron loss $= 1$ kW

Commercial efficiency

For commercial efficiency of a transformer, the load cycle is not relevant.

Output $= 150 \times 1 = 150$ kW : Total losses $= 1 + 1 = 2$ kW

∴ Commercial efficiency $= \frac{150}{150+2} \times 100 = 98.68\%$

All-day efficiency

Iron loss remains the same at all loads.

Cu loss at $50\text{kVA} = (50/150)^2 \times 1 = 1/9$ kW

Cu loss at $100\text{kVA} = (100/150)^2 \times 1 = 4/9$ kW

Cu loss in 24 hrs $= 1/9 \times 3 + 4/9 \times 8 = 3.888\text{kWh}$

Iron loss in $24\text{hrs} = 1\text{ kW} \times 24\text{hrs} = 24\text{kWh}$

Total losses in $24\text{hrs} = 3.888 + 24 = 27.888\text{kWh}$

Output in 24 hrs $= (50 \times 1) \times 3 + (100 \times 1)8 = 950\text{kWh}$

All-day efficiency $= \frac{950}{950+27.888} \times 100 = 97.15\%$

problem

A 10kVA transformer is given an open-circail test from which the inon loxs is Cond to be 160 W A short-circuit lest shows the copper loss to be 240 W, with fill-load current fow ing. Calculate the all-day efficiency if it operates at unity pf. 6 hours per day on full-load, 2 howers on half fall-load and the remainder of the time on no load.

Solution. Fl. Cu loss $= 240$ W; Iron loss $= 160$ W

Cu loss at half full-load $= \left(\frac{1}{2}\right)^2 \times 240 = 60$ W

Iron loss in 24hrs $= 0.160 \times 24 = 3.84$kWh

Cu loss in 24 hrs $= 0.240 \times 6 + 0.06 \times 2 = 1.56$ kW

Total losses in 24 hrs $= 3.84 + 1.56 = 5.4$kWh

Output in 24 hrs $= 10 \times 6 + 5 \times 2 = 70$kWb

All-day efficiency $= \frac{70}{70 + 5.4} \times 100 = 92.54\%$

3.15 Determination of load corresponding to Maximum efficiency:

output KvA corresponding to maximum efficiency:

let W_C is the full load copper loss.

W_i is iron loss

Let X be the fraction of the full load kvA at which maximum efficiency occurs.

C_u loss at max^m efficiency = x^2 W_c

At max^m efficiency the iron loss is W_i

Iron loss = cu. Loss

$$x = \sqrt{\frac{W_i}{W_C}}$$

KvA at max^m efficiency

$$= \text{F.L KvA} \sqrt{\frac{W_i}{W_C}}$$

$$\eta_{max}{}^m = \frac{o/p\ at\ maximum\ efficiency}{o/p\ at\ maximum + W_i + W_C}$$

3.16 Parallel operation of single phase transformer:

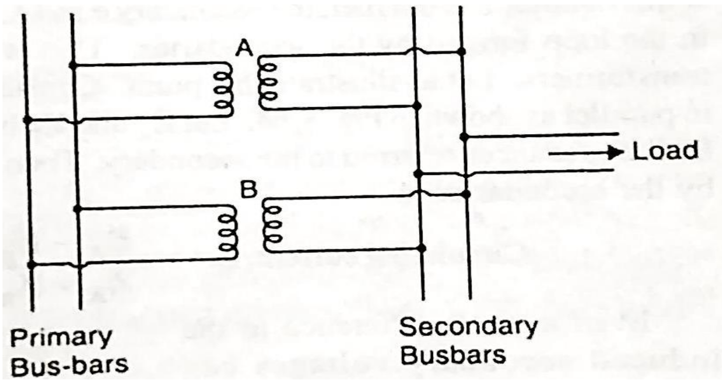
3.16-parallel operation of single phase transformer:-

Definition:-

It is defined as a process by which electrical loads are equally shared among the transformer.

Explanation:-

As we know that a transformer is designed to deliver rated load. If load on this transformer exceeds from its rated value then it is said to be over loaded. During this period, due to heavy current through the winding, windings may be damaged. At the same time this transformer can not meet demand of the consumers. Hence to meet extra load of consumers, another Transformer must be connected in parallel with this transformer. While operating two transformer in parallel following condition must be satisfied.



1 .Polarity of primary and secondary winding must be properly matched .
2 .Primary windings are properly connected with the supply mains.
3 .Supply frequency should be equal to that of frequency of the Transformer.
4 .transformation ratio in both the Transformers should be same.
5 .Impedance of windings should be equal in both the Transformers.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER:-

(Q1)Does a transformer work on DC? If not why .
Ans:-No because in a DC machine flux produced in the primary winding remains constant, Accordingly Faraday's laws of electromagnetic induction, no emf can be induced in secondary side($e=d\varphi dt=d(constant)/dt=0$)
Hence a Transformer can not work on DC.

(Q2) which loss is constant irrespective of loads?
Ans-Irrespective of loads iron or core loss remains constant.

(Q3) why Transformer is rated in KVA?[S-17,19]
Ans:- Generally the transformer is rated in volt ampere because the rating of Transformer depends open the heating of the transformer i.e depends open the losses. The iron loss depends open the voltage and copper loss depends open the current so the total loss depends open voltage and current i.e depend open the VA and not depend open the power factor of the load so Transformer is rated in VA.

(Q4) If full load copper loss in a transformer is 400w,what is the loss for the half load ?
Ans:-At half load the copper loss will be 100w.
$X^2 W_{cu} = (1/2)^2 \times 400 = 100w$

(Q5)At what condition efficiency of a Transformer is maximum?[S-19]
Ans:-The efficiency of a Transformer will be maximum only when copper loss at any load is equal to the iron loss.

(Q6)Why the efficiency of a Transformer is higher than that of other electrical machines?
Ans:-The efficiency of a Transformer is more than that of other electric machines because the transformer has comparatively less losses due to absent of mechanical loss.

(Q7)what is voltage regulation ?[S-16,17,18]
Ans- It is defined as the ratio of drop and the full load voltage.
• It is calculated in percentage.
%R=(Drop in voltage/full load voltage)×100.

(Q8)Which loss gives core loss of the transformer?
Ans:-Generally O.C test gives core loss of a Transformer.

(Q9) Using which test, we can find out the full load Cu. Loss.
Ans:- Using S.C test ,we can calculate the full load Cu. Loss.

(Q10) What is the principle of operation of a transformer? [S-24]
Ans- A transformer operates on the principle of electromagnetic induction, specifically mutual induction, where a changing magnetic field in one coil (the primary) induces a voltage in a nearby coil (the secondary).
(Q10) Define all-day efficiency of a transformer.[S-24]
Ans- All-day efficiency of a transformer, also known as energy efficiency, measures its overall efficiency over a 24-hour period, considering both load and no-load conditions, and is calculated as the ratio of total energy output (kWh) to total energy input (kWh) over 24 hours.

POSSIBLE LONG TYPE QUESTIONS:-

1. Explain various parts and working of single -phase Transformer.
2. Derive at what condition the efficiency of a Transformer is maximum. [S-16,18]
3. Explain with phasor diagram of an ideal transformer on -load.[S-15]
4. Derive the approximate voltage drop of a single -phase Transformer.[S-19]
5. Draw the equivalent circuit diagram of a single-phase Transformer with all the parameters.
6. What are the different methods for cooling the Transformer?
7. Explain with circuit diagram the open circuit and short circuit test of the transformer? [S-19]
8. Explain parallel operation of the single-phase Transformer.[S-19]
9. The no load current of transformer is 15 A at a power factor of 0.2(lag) when connected to a 460 V,50 hz supply . if the primary winding has 550 turns,
   a. Calculate-

   (i) The magnetising components of no load current
   (ii) Iron loss
   (iii) The maximum value of flux in the core [S-16]

10. The total iron loss in a 460 v,50 hz single transformer
11. In a 25 KVA, 2000/200 V transformer Wi & Wcu are 250 watt and 350 watt respectively. Calculate the efficiency on UPF at half load.[S-24]

CHAPTER NO.-04
AUTO TRANSFORMER

Learning objectives:

4.1. Constructional features of Auto transformer.
4.2. Working principle of single phase Auto Transformer.
4.3. Comparison of Auto transformer with an two winding transformer (saving of Copper).
4.4. Uses of Auto transformer.
4.5. Explain Tap changer with transformer (on load and off load condition)

4.1. Constructional features of Auto transformer:

Definition:

It is defined as a transformer in which a single winding can act both for primary as well as secondary windings.

Principle:

It works under the principle of conduction as well as induction principle.

Construction:

An Auto Transformer consists of laminated core and windings. A large number of turns are wound over the core and called as windings. From this single winding, tapping is done to Secondary windings. In this transformer we can save copper as compared to the two winding transformers.

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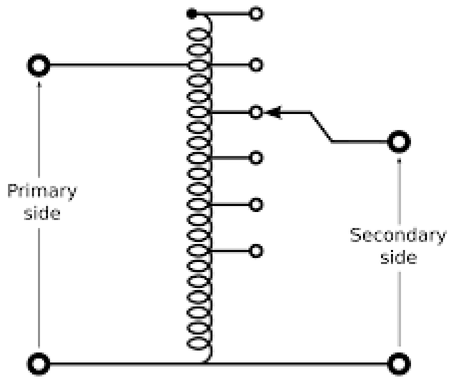
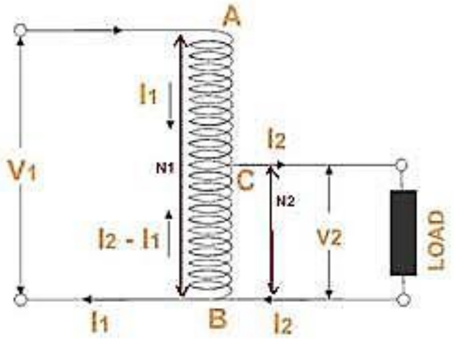


4.2. Working principle of single phase Auto Transformer.:

When a.c. supply is given to the primary windings, as like 1- phase T/F ,an alternating flux starts to flow through the core and hence the windings also . So this flux links with the secondary turns by which certain emf will be induced. This secondary induced emf depends on the tapping.

4.3. Comparison of Auto transformer with an two winding transformer (saving of Copper):



Let

N_1=Primary number of turns

N_2=Secondary number of turns

I_1 =Primary current, A

I_2 =Secondary Current, A

V_1=Primary voltage, V

V_2=Secondary Voltage, V

K=Transformation ratio

W_O =Weight of Copper in an Ordinary or two winding transformer, Kg

W_a = Weight of Copper in an Auto transformer, Kg

We know that, MMF $\propto$ NI

But $N \propto L$ and $I \propto A$

Hence $NI \propto LA$

$\propto$ Volume

$\propto$ Weight of Copper

So MMF $\propto$ Weight of the copper $\propto$ NI

Now , $W_O \propto$ weight of copper in (primary + secondary) windings

$\propto (N_1 I_1 + N_2 I_2)$

Similarly $W_a \propto MMF_{AC} + MMF_{CB}$

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

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

$\propto N_1 I_1 + N_2 I_2 - 2 N_2 I_1$

Now

$$\frac{W_a}{W_o} = \frac{N_1 I_1 + N_2 I_2 - 2 N_2 I_1}{N_1 I_1 + N_2 I_2}$$

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

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

In an ideal transformer, primary MMF = Secondary MMF

i.e. $N_1 I_1 = N_2 I_2$

Hence, $$\frac{Wa}{WO} = 1 - \frac{2 N_2 I_1}{2 N_2 I_2}$$

$$= 1 - \frac{I_1}{I_2}$$

$$\boxed{W_a = (1-K)\ W_O}$$ Kg where $K < 1$

Saving of copper = $W_O - W_a$

$= W_O - W_O + K W_O$

$= K W_O$

$$\boxed{\text{Saving of Copper} = K\ W_O}$$ Kg

Power Transfer Formula:

1. Power transferred Inductively = $V_2(I_2 - I_1)$
   $= V_2(I_2 - I_2K)$
   $= V_2I_2\,(1\text{-}K)$
   $= V_1I_1(1\text{-}K)$ (where in ideal case $V_2I_2 = V_1I_1$)
   $= P_I\,(1\text{-}K)$
2. Power Transferred Conductively =input - Power transferred Inductively
   $= P_I - P_I\,(1\text{-}K)$
   $= P_I\,K$

4.4. Uses of Auto transformer:

An auto transformer is used

i) In Electric locomotives to control equipments

ii) In Transmission lines as 1:1 transformer

iii) As starter in 3-phase induction motor

iv) As furnace transformer

problem:

An Auto transformer supplies a load of 3Kw at 115V at a unity power factor. If the applied primary voltage is 230V, find the power transferred to the load a) Inductively b) Conductively.

solution

Given Data:

P_O=3KW

V_2=115V

CosØ=1

V_1=230V

Required Data

a) Power inductively

b) Power Conductively

Transformation ratio K= $\frac{V_2}{V_1} = \frac{115}{230}$=0.5

Here $P_i = P_o$=3KW

a)Power transferred Inductively = P_I (1-K)

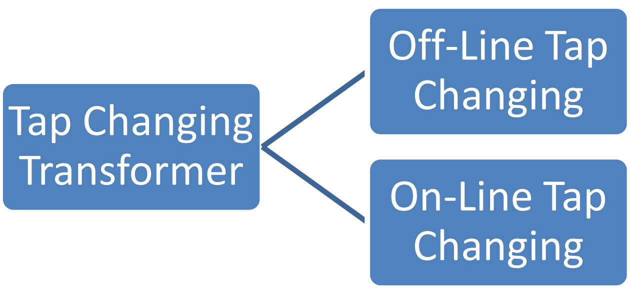
= 3(1-0.5)=1.5KW (Ans)

b)Power Transferred Conductively = K P_I

=0.5x3=1.5 KW (Ans)

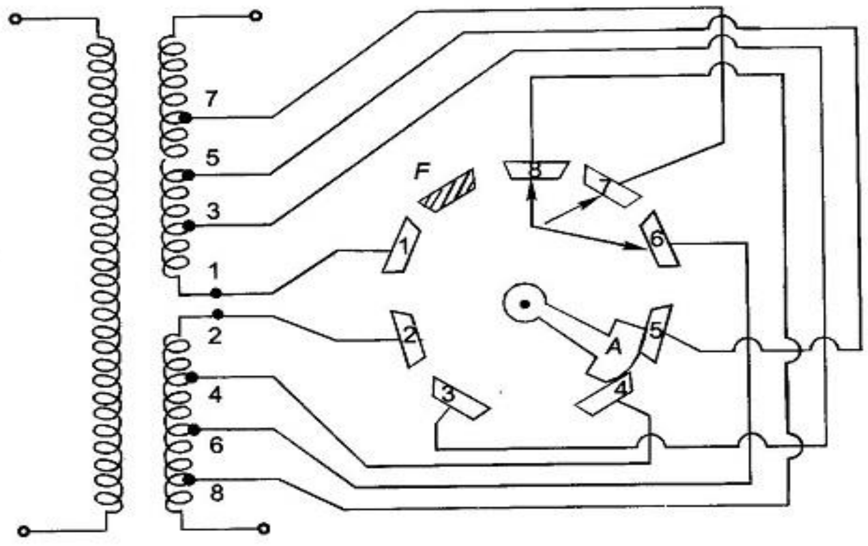
4.5.Explain Tap changer with transformer (on load and off load condition): Definition:

It is defined as a transformer in which, voltage is obtained or affected by changing the number of turns provided in the tapings. Generally taps are provided or used in the HV side of the transformer.



Off-Line Tap Changing Transformer:

This is one of the very cheapest & useful method .In this method, the tap changing is done by disconnecting the load from the transformer. The simple off load tap changer transformer is shown in the fig 3.68 below. It has 8 studs marked 1 to 8 .The winding is also tapped at eight points & connected with these studs. The movable contact arm (A) may be rotated by means of hand wheel mounted externally on the transformer tank. So according to the tapping position, we can get the output voltage.



On-Line Tap Changing Transformer:

This is one of the useful method .In this method, the tap changing is done by holding the load on the transformer.

An on-line tap changing Transformer (OLTC) consists of an open load tap changer. It is also known as On- Circuit Tap Changer (OCTC).In this transformer, the turns ratio can be changed without breaking the circuit. Generally it consists of 33 taps. 1 tap is centre rated tap , another 16 taps meant for increasing the ratio of windings and remaining 16 taps are meant for decreasing the ration of windings. The OLTC may of Resistor type or Reactor type to limit the short circuit current. But in modern design, the current limiting is almost carried out by a pair of resistors.

Basically this transformer is used where there is frequent interruption of power supply. Now days in all power transformers this OLTC is used.

POSSIBLE SHORT TYPE QUESTIONS WITH ANSWER:

Q1: Write important advantages of an auto transformer over the ordinary transformer

Ans: An auto transformer has a great advantage that it consists of only a single winding from where we can also get secondary winding. Another advantage is that we can save copper for the same rating of ordinary transformer.

Q2. What is use of an auto transformer? [S-14, S-15, S-19]

Ans: An auto transformer is used

i) In Electric locomotives to control equipments

ii) In Transmission lines as 1:1 transformer

iii) As starter in 3-phase induction motor

iv) As furnace transformer

Q3. What are the uses of an auto-transformer? [S-19, 22, 24]

Ans- Autotransformers are used for various applications, including motor starting, voltage regulation, adjusting AC supply voltage, and testing equipment after repairs. They are also beneficial in applications where space is limited or portability is important due to their compact size.

POSSIBLE LONG TYPE QUESTIONS

Q1.What is an auto transformer, explain with a neat diagram? [S-17]

Q2.How can you save the copper in an auto transformer over the two winding transformer, derive it? [S-19]

Q3.Expalin in brief, the On-Line Tap changing Transformer?

Q4. Explain in brief, the Off-Line Tap changing Transformer?

Q5. Explain the operation of on-load tap changer in T/F using resister transition.[S-24]

Q6. Explain the constructional features of auto-transformer and working principle of auto-transformer.[S-17, 23, 24]

CHAPTER NO.-05
INSTRUMENT TRANSFORMER

Learning objectives:

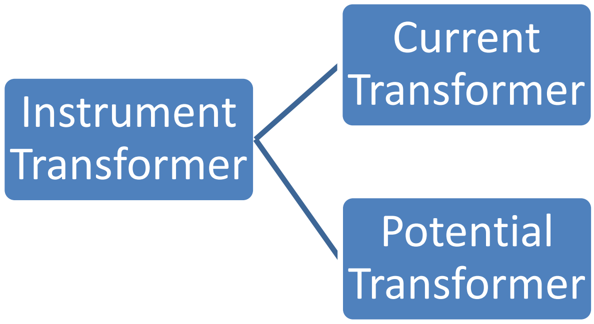
5.1 Explain Current Transformer and Potential Transformer
5.2 Define Ratio error, Phase angle error, Burden.
5.3 Uses of C.T. and P.T.

5.1 Explain Current Transformer and Potential Transformer:

Definition:

It is defined as a transformer which is used to measure electrical quantities like Current, Voltage, Power, Frequency and Power factor etc. These transformers are used in Relays to protect the power system.

Types of Instrument Transformer:



Current Transformer (CT) :

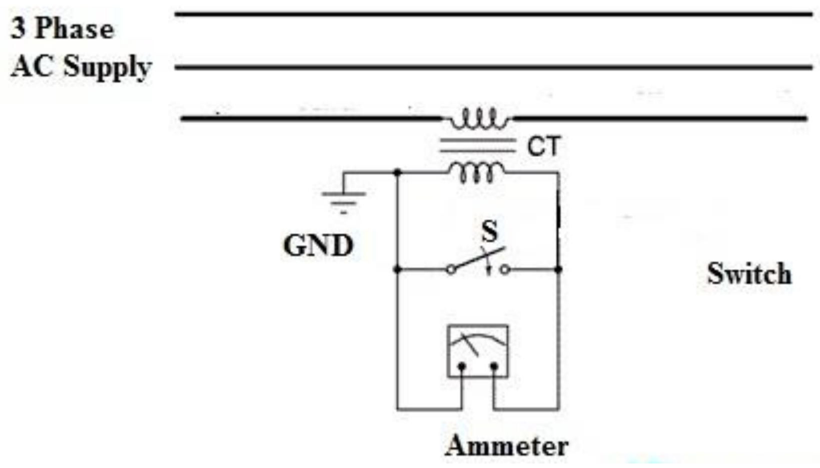
Definition:

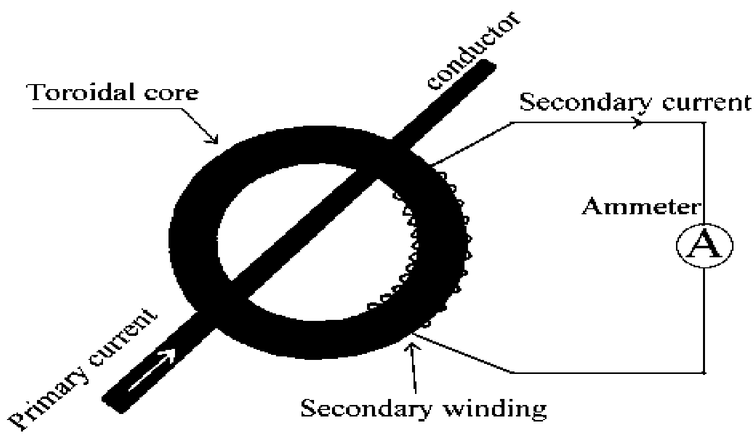
It is defined as an instrument transformer which measures electric current

Explanation:

This type of transformer has two windings like Primary and secondary winding. The primary winding consists of few numbers of turns and connected to the supply main in series. Sometimes it is also called as series transformer. Similarly the secondary winding has comparatively more no of turns and connected with an ammeter having low resistance. Hence we say the secondary winding works with full short circuit condition. The turns ratio from primary to secondary is 100:5.one terminal of the secondary winding is also grounded to avoid huge leakage current. Before disconnecting the ammeter, the secondary winding is to be disconnected by putting on the switch as shown in the fig bellow.

This type of transformer is used in power systems to step down the voltage from high level to a low level with the help of 5A ammeter. Since the current in secondary is proportional to the current in primary, so while connecting with supply main for measurement of current then proportionate current can be recorded from the ammeter.





Current Transformer

Potential Transformer:

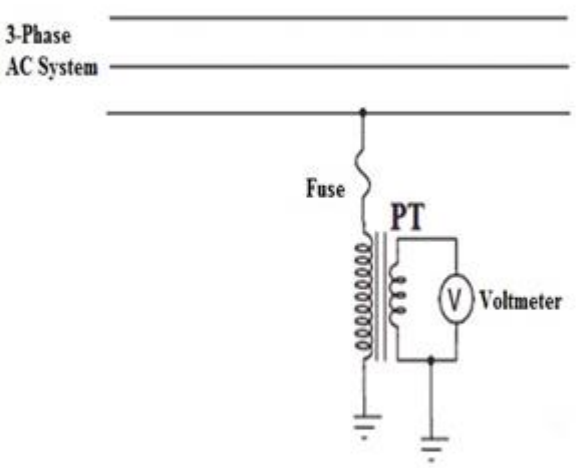
Definition:

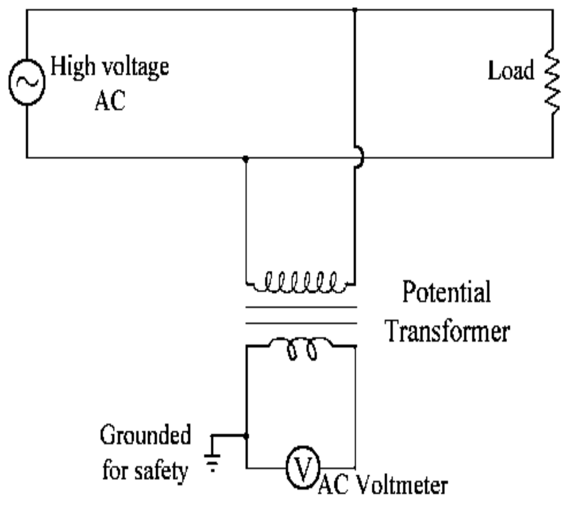
It is defined as an instrument transformer which measures electric potential.

Explanation:

This type of transformer has two windings like Primary and secondary winding. The primary winding consists of comparatively more no of turns and connected to the supply main in parallel. Sometimes it is also called as parallel transformer. Similarly the secondary winding has few no. of turns and connected with a voltmeter having high resistance. Hence we say the secondary winding works with open circuit condition. The turns ration from primary to secondary is 600:120.one terminal of the secondary winding is also grounded to protect an operator from high voltage hazard.

This type of transformer is used in power systems to step down the voltage from high level to a low level with the help of small rating voltmeter ranging from 110 V to 120 V. The diagram of a potential transformer is shown below. Since the current in secondary is proportional to the current in primary, so while connecting with supply main for measurement of current then proportionate current can be recorded from the ammeter.





5.2 Define Ratio error, Phase angle error, Burden:

Ratio error in current transformer:

In the current transformer, the primary current I_p should be exactly equal to the secondary current multiplied by turns ratio.
But there is a difference between primary current I_p should be exactly equal to the secondary current multiplied by the turns ratio.
This difference is contributed by the core excitation or magnetizing component of no-load current.
The error in the current transformer introduced due to this difference is called current error or ratio error.

Phase angle error:

Ideally the angle between the primary current and secondary current should be 180 degree. But there is some deviation from 180 degree. This deviation is called phase angle error.

Burden:

The burden of CT is the maximum load (in VA) that can be applied to the CT secondary. The burden can be expressed as the total impedance in ohms of the circuit or the total volt-amperes (VA) and power factor at a specified value of current or voltage and frequency.

The burden of PT is the total external volt-amp load on the secondary at rated secondary voltage.

5.3 Uses of C.T. and P.T :

CT and PT both are measuring devices used to measure currents and voltages. They are used where large quantities of currents and voltages are used. The role of CT and PT is to reduce high current and high voltage to a parameter.
Current transformers are the current-sensing units of the power system and are used at generating stations, electrical substations, and in industrial and commercial electric power distribution.
A potential transformer (P.T.) is an instrument transformer which is used for the protection and measurement purposes in the power systems. A potential transformer is mainly used to measure high alternating voltage in a power system.

POSSIBLE SHORT TYPES QUESTIONS WITH ANSWER:

Q1. What is instrument transformer? What are their types?

Ans: It is defined as a transformer which is used to measure electrical quantities like Current, Voltage, Power, Frequency and Power factor etc. These transformers are used in Relays to protect the power system.

It is of two types such as Current Transformer (CT) & Potential Transformer (PT).

Q2.What is the physical concept of primary winding of a CT?

Ans: The primary winding of a CT consists of few numbers of turns & is connected in series with the supply main.

Q3. State two uses of CT.[S-23]

Ans- Current transformers (CTs) are primarily used for measuring high currents in power systems and for providing overcurrent and fault protection.

Q4. Define ratio error in PT.[S-24]

Ans- In the context of a Potential Transformer (PT), ratio error refers to the deviation between the actual voltage transformation ratio (R) and the nominal or expected ratio (Kn).

POSSIBLE LONG TYPES QUESTIONS

Q1.Expalin the construction and working of a CT ?

Q2. Explain the construction and working of a PT.

Q3. Write short note on PT.[S-22]

Q4. Write short note on CT.[S-24]