Lecture Notes On

ELECTRICAL MACHINE - I

4TH SEM ELECTRICAL & ETC ENGINEERING

Topics = **D.C Generator**
D.C Motor
Transformer

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BIT

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TRANSFORMER

It is a Static device, which transfor electric power from input to output without changing its frequency.

→ It has two winding known as LV & H.V.

→ According to The Connection it divided in two types. The winding is Connected Supply is Called primary winding. The winding Connected to load is Called Secondary winding.

WORKING PRINCIPLE

It works on the principle of Faraday's laws of electromagnetic induction. basically Mutual induction.

→ It Consist of two windings, which are mounted Core of laminated Silicon Steel Material. The lamination is of the order of 0.35MM to 0.5MM.

→ The two winding are wound on Separate limb of transformer.

→ When Supply is given to the one winding known as primary winding it produces flux in nature of alternating. which links through Silicon Core and Current will flow Through The Core. This Current again produces flux in the Secondary and emf is induced in Secondary winding. This process is known as mutual induction.

→ According to Mutual induction as well as Self induction

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

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

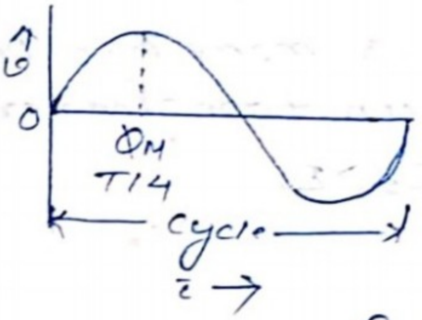
where, E_1 = primary voltage
E_2 = Secondary voltage.
N_1 = primary Turn.
N_2 = Secondary Turn.

Dividing Eq(II) to Eq(I) we get.

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

Where, K is turn ratio of transformer.

EMF EQUATION OF TRANSFORMER



Let, N_1 = number of turns in primary winding
N_2 = number of turns in secondary winding
ϕ_M = Maximum flux in weber
B_m = Maximum flux density wb/m^2
F = Frequency in hertz.

Avarage emf induced in primary winding

$$e = N_1 \frac{d\phi_m}{dt} = N_1 \frac{\phi_m}{t/4} = N_1 4\phi_m f \quad (\because F = \frac{1}{T})$$

From factor = $\frac{\text{R.m.s value}}{\text{Avarage value.}}$

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IDEAL TRANSFORMER

If number of turns of Secondary is equal to number turn of primary Turn.

$$V_2 = V_1$$
$$N_2 = N_1$$

In this transformer is no losses according to the Theoriticary efficiency is 100%

i.e input power = out put power

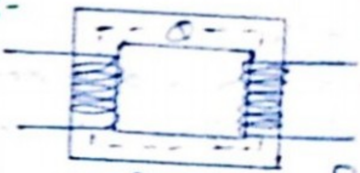
$$V_1 I_1 = V_2 I_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{I_1}{I_2} = K$$

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

ACCORDING TO CONSTRUCTION IT DIVIDED THREE TYPES :-

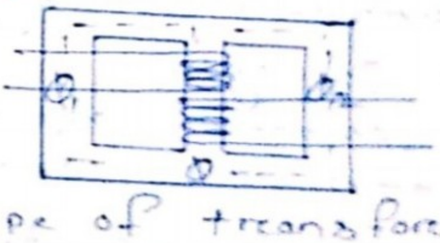
CORE TYPE :-



In this type of transformer. winding are Surrounding are Core.

→ The number of magnetic path is only one

SHELL TYPE



In this type of transformer, Core are Surrounded in the windings.

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$$E_{1rms} = 1.11 \times \text{average Value}$$
$$= 1.11 \times 4 N_1 \phi_m f$$
$$= 4.44 \phi_m N_1 f$$
$$= 4.44 B_m A N_1 f \quad (\because B_m = \frac{\phi}{A})$$

$$E_{2rms} = 4.44 B_m A f N_2$$

CLASSIFICATION

According to use it is up to three types.

- Step up Transformer
- Step down Transformer.
- Ideal Transformer.

STEP UP TRANSFORMER

If Secondary voltage is more than primary voltage then it is called step up transformer.

$V_2 > V_1$, $E_2 > E_1$

$N_2 > N_1$

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

Hence, $K > 1$ for step up Transformer.

STEP DOWN TRANSFORMER

If Secondary voltage is less than primary voltage then it is called Step down transformer.

$V_2 < V_1$, $N_2 < N_1$

Hence, $K < 1$ for Step down transformer.

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IDEAL TRANSFORMER

If number of turns of secondary is equal to number turn of primary Turn.

$$V_2 = V_1$$
$$N_2 = N_1$$

In this transformer is no losses according to the Theoritically efficiency is 100%.

i.e input power = output power

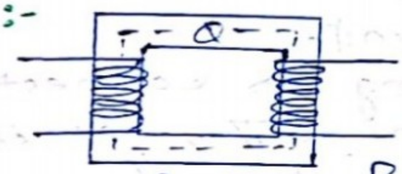
$$V_1 I_1 = V_2 I_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{I_1}{I_2} = K$$

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

ACCORDING TO CONSTRUCTION IT DIVIDED THREE TYPES :-

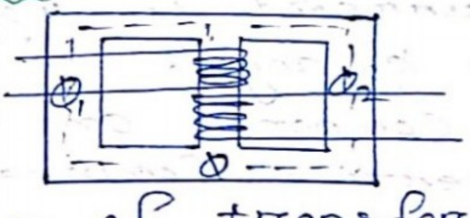
CORE TYPE :-



In this type of transformer, winding are surrounding are core.

→ The number of magnetic path is only one.

SHELL TYPE



In this type of transformer, core are surrounded in the windings.

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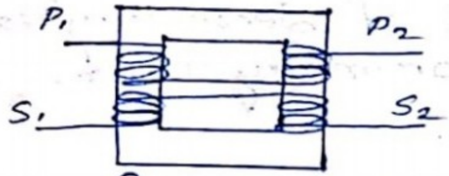
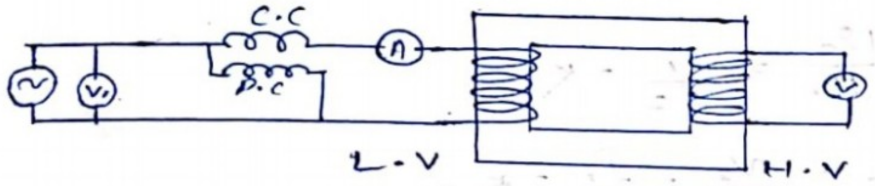
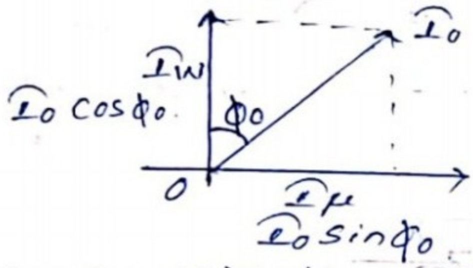
BERRY TYPES



A part of both primary and Secondary winding wound on the Common limb. it is the latest model of transformer.

TRANSFORMER NO-LOAD CONDITION





→ If primary winding is Connected Supply and Secondary is kept open, Then it is known as no-load Condition of transformer.

→ The ammeter Connected the primary side to measurement at Current at no-load Condition i.e I_0 which is 1 to 3% of full load current.

→ The no-load Current I_0 laggs behind the Supply voltage by ϕ_0 angle.

→ The I_0 has two Componet one is horizontal and another is vertical Component.

→ Vertical Componet $I_\mu = I_0 \sin\phi_0$ is known as magnetising componet of no-load Current which is quadrature to supply voltage. V_1

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-> Horizental Componet I_w i.e working Componet $I_w = I_o \cos\phi_o$

which is Supply voltage V_1

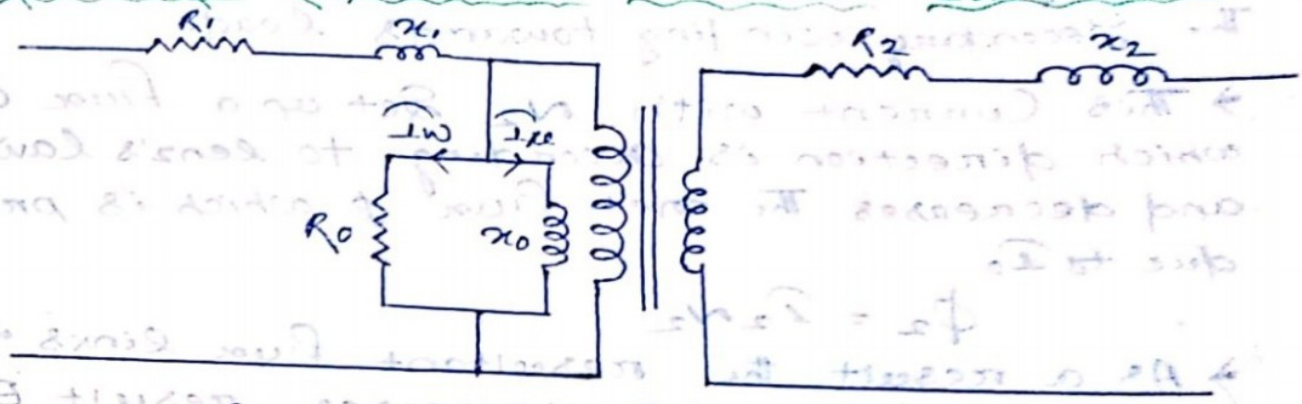
-> $I_o = \sqrt{I_w^2 + I_\mu^2}$

-> The wattmeter reads the value of $w_o = V_1 I_o \cos\phi_o$

i.e loss in transformer.

-> This loss is known as Iron loss of Transformer.

TRANSFORMER NO LOAD CONDITION EQUIVALANT CKT



Ro = exciting Coil resistance
xo = exciting Coil Reactance.

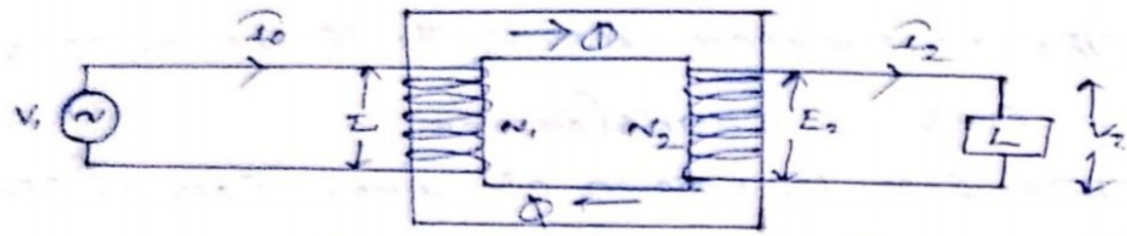
TRANSFORMER ON LOAD CONDITION

The primary is Connected to Supply and Secondary is Connected across load is known as transformer on load Condition.

->When load increases in Secondary then the Current of Secondary increases but at every instant in order to meet load Current. The Secondary emf E_2 and flux ϕ increases.

-> According to Lenz's law every changes is opposed at every instant. So it is not possible to change to flux when load increase transformer increases or decreases from source (primary).

OR



When load is connected across secondary winding a load current I_2 will flow through the secondary winding towards load.

→ This current with N_2 set up a flux ϕ_2 which direction is according to Lenz's law, and decreases the net flux ϕ which is produce due to I_0.

$$\phi_2 = I_2 N_2$$

→ As a result the resultant flux links with primary winding get decreases, result E_1 is decreases.

→ There is a potential difference is created between source voltage and primary winding emf as a result I_2' flow towards the primary winding to full fill the flux amount.

So, flux induced in primary = flux induced in secondary.

i.e $\phi_2 = \phi_2'$

So, $\phi_2' = N_1 I_2'$

i.e $N_2 I_2 = N_1 I_2'$

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

$= K I_2$

$$\boxed{\Rightarrow I_2' = K I_2}$$

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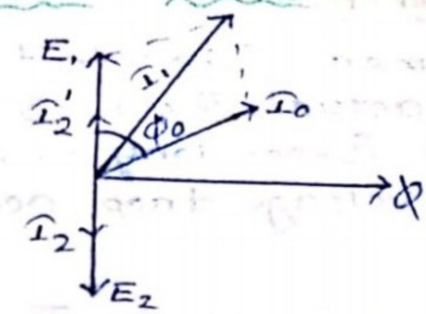
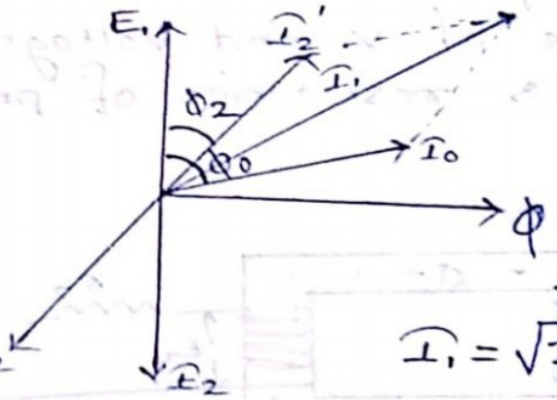
For Resistive Load



By the parallalogram law

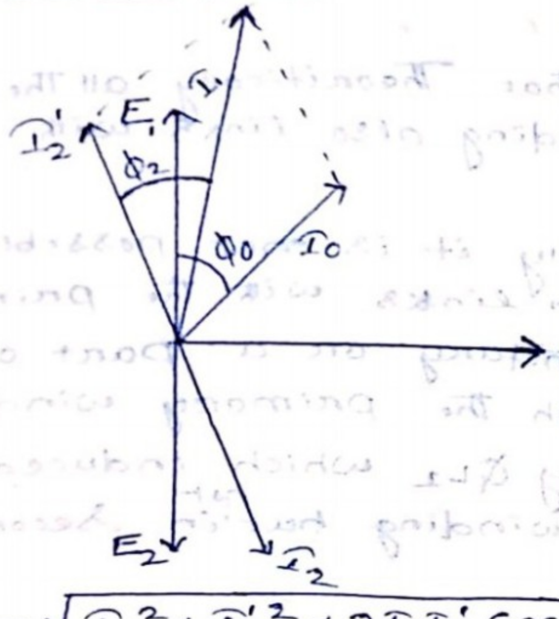
$$I_1 = \sqrt{I_2'^2 + I_0^2 + 2 I_0 I_2' \cos\phi_0}$$

For Inductive Load



$$I_1 = \sqrt{I_0^2 + I_2'^2 + 2 I_0 I_2' \cos(\phi_0 - \phi_2)}$$

For Capacitive Load



$$I_1 = \sqrt{I_0^2 + I_2'^2 + 2 I_0 I_2' \cos(\phi_0 + \phi_2)}$$

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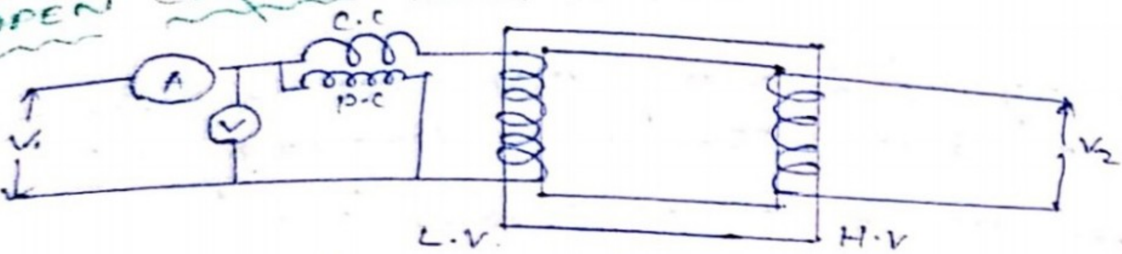
TEST ON TRANSFORMER

OPEN CIRCUIT TEST



→ In case of no-load test. the L.V winding is connected to supply of rated voltage and frequency.

→ The H.V side open circuited or a voltmeter is connected i.e V_2.

→ The voltage should be adjusted such that it shows rated voltage at secondary.

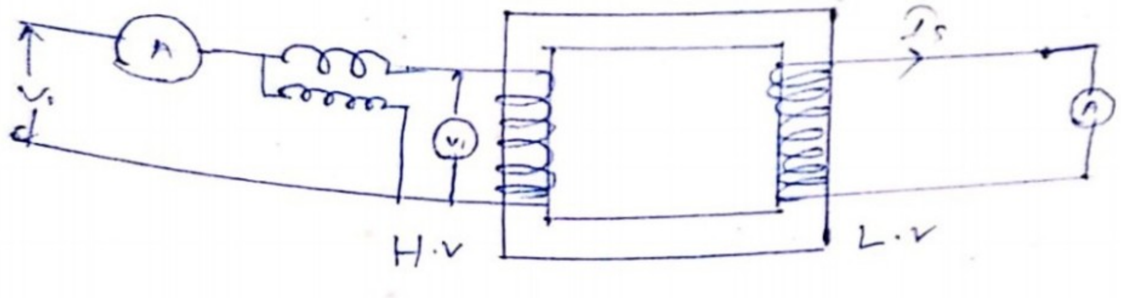
→ In this condition, the wattmeter shows deflection and reading will be (W_0), which indicate no-load loss or Iron loss or Core loss.

$$\text{So. } W_0 = I_0 V_1 \cos\phi_0$$

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

$$I_\mu = I_0 \sin\phi_0 = \sqrt{I_0^2 + I_\omega^2}$$

SHORT CIRCUIT TEST



→ In the Short Circuit test H.V winding is Connected to supply of rated voltage and frequency.

→ All the Measuring instrument is Connected in H.V winding Side of transformer.

→ The L.V Side winding Short Circuited by Copper Thick wire or a ammeter Connected across it.

→ A Small voltage is applied on the H.V Side and the voltage is adjusted Such that the Secondary Side Carries full load Current

→ At the time, the wattmeter Shows Copper Loss i.e W_c.

→ As no-load Current is very Small than full load Current. So iron loss is neglezible

$$W = I_2^2 \times R_{02}$$

$$R_{02} = \frac{W}{I_2^2}$$

Let, Z_{02} = total impedance of transformer voltage applied at the primary is 5 to 10% of rated voltage, so it is known as Short Circuit voltage. (V_{sc})

$$Z_{02} = \frac{V_{sc}}{I_2}$$

Where, I_2 = full load Current at Secondary

V_{sc} = Reduce voltage applied to H.V Side

$$X_{02} = \sqrt{Z_{02}^2 - R_{02}^2}$$

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VOLTAGE REGULATION

It is defind as the change in secondary terminal voltage from no-load to full load w.r.t to full load terminal voltage or no-load terminal voltage.

Let, E_2 is the no-load terminal voltage
V_2 is the full-load terminal voltage.

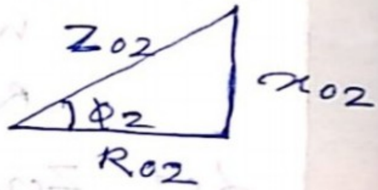
$$(V.R\%)_{UP} = \frac{E_2 - V_2}{V_2} \times 100$$

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

$$E_2 - V_2 = I_2 Z_{02}$$

Z_{02} = total impedance of transformer at secondary side.

I_2 = Secondary Current.



$$Z_{02} = R_{02} \cos\phi_2 \pm x_{02} \sin\phi_2$$

$$V.R\% = \frac{I_2 (R_{02} \cos\phi_2 \pm R_{02} \sin\phi_2)}{E_2/V_2}$$

+ Sign for Lagging Load.
− Sign for Leading Load.

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EQUIVALANT CIRCUIT DIAGRAM OF TRANSFORMER

Let R_0 is Resistance of exciting Coil

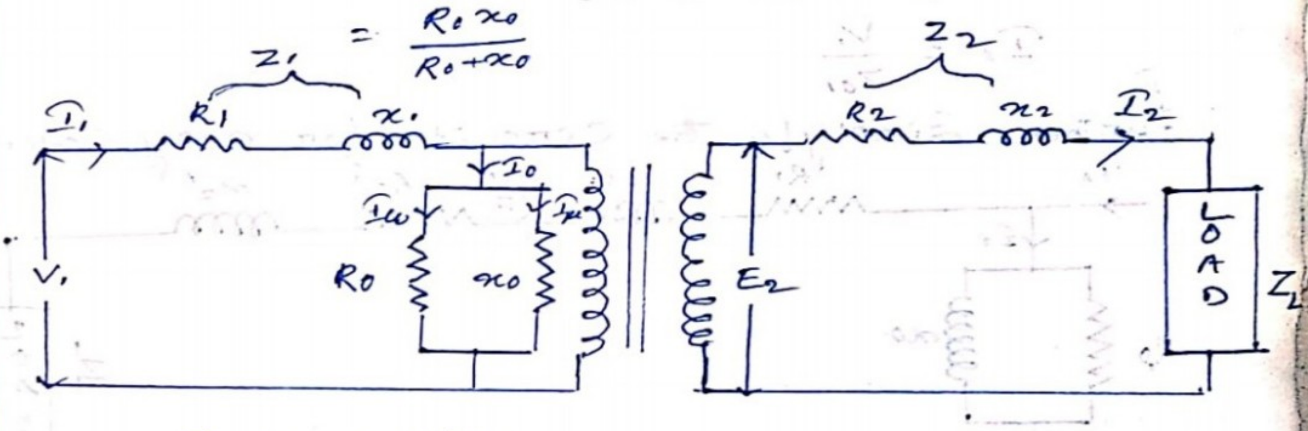
x_0 is Reactance of exciting Coil

$$R_0 = \frac{V_1}{I_w}, \quad x_0 = \frac{V_1}{I_\mu}$$

In exciting Coil R_0 is parallel to x_0

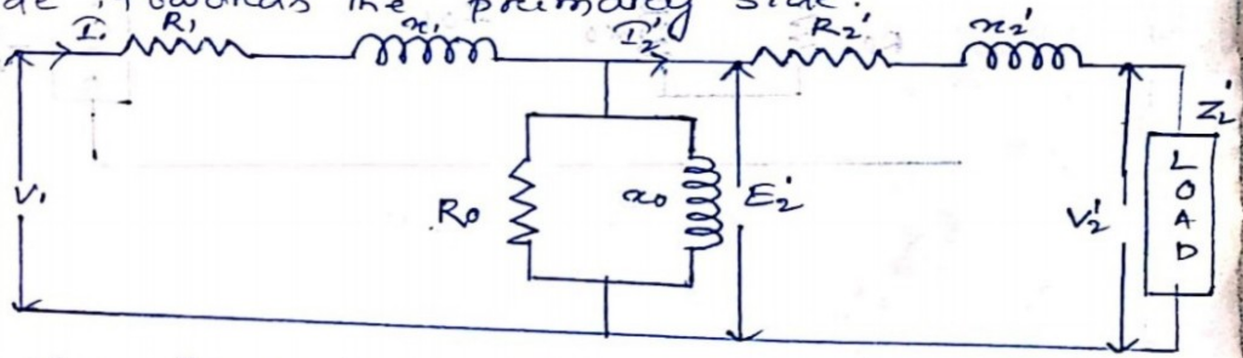
Let, Z_M = impedance of exciting coil

$$= \frac{R_0 x_0}{R_0 + x_0}$$



$$Z_1 = R_1 + jx_1$$
$$Z_2 = R_2 + jx_2$$
$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Let Now transforing Secondary primary Side towards the primary side.



Now, the primary equivalant of Secondary induced emf $E_2' = \frac{E_2}{K} = E_1$

Similarly, primary equivalant of Secondary terminal voltage $V_2' = \frac{V_2}{K} = V_1$

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Primary equivalant of Secondary Current: (64)

$I_2' = K I_2 = I_1$

Transforing Secondary impedance in primary Side

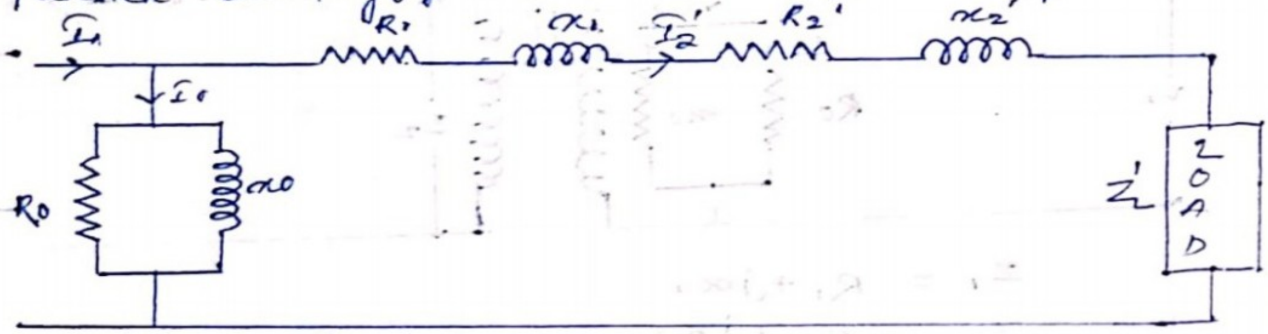
$R_2' = \frac{R_2}{K^2}$, $x_2' = \frac{x_2}{K^2}$

$Z_2' = \frac{Z_2}{K^2}$, $Z_L' = \frac{Z_L}{K^2}$

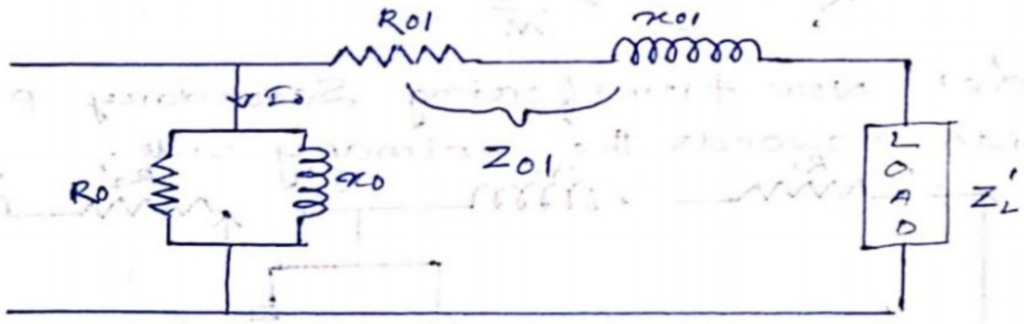
$Z_{01} = Z_1 + (Z_m \| Z_2' + Z_L')$

$I_1 = \frac{V_1}{Z_{01}}$

further Simplyfy the circuit for easy Calculation



Again Simplify



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LOSSES IN A TRANSFORMER

As. Since, transformer is a static device, hence Their is no mechanical or frictional loss, hence two type loss are their

→ Constant loss (Iron loss)
→ Variable loss (Copper loss)

Iron loss divided into two types.

→ Hysterisis loss
→ Eddy current loss

HYSTERSIS LOSS

It is occur due to reversal of magnetism.

EDDY CURRENT LOSS

When transformer is connect to supply, alternating current primary winding and a flux is produced.

→ This flux links the core of the transformer. Since core is transfomer is low resistance closed path hence a current circulate across the core known as eddy current loss.

COPPER LOSS

It is the loss occurrs across the resistance of primary winding and secondary winding.

→ Copper loss at primary winding = $I_1^2 R_1$

Copper loss at secondary winding = $I_2^2 R_2$

So, total copper loss $= I_1^2 R_1 + I_2^2 R_2$

$= I_1^2 R_{01}$

$= I_2^2 R_{02}$

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MECHANICAL LOSS :-

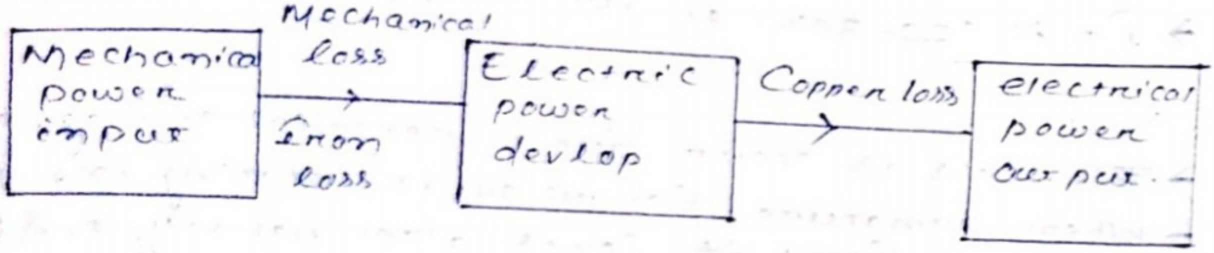
→ It is two types → Friction losses
→ Windage Losses.

→ It is about (10-20%) of full load loss.

FRICTIONAL LOSSES :-

→ In this type of loss is occur due to ball & bearing. where windage loss due to air friction over rotating armature.

POWER STAGE :-

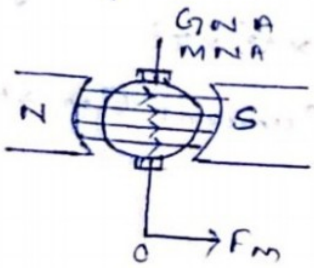


ARMATURE REACTION

→ As we Know that main magnetic field flux which is N pole to S' pole, when armature is rotated inside that magnetic field it cuts magnetic lines of force and emf is induced and Currents flows through the armature Conductor.

→ Due to flowing of this Current in the armature Conductor Set up an another magnetic field

→ So, armature reaction is defind as the effect of armature magnetic field on main magnetic field.



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In this figure the lines of forces arrving from N pole to moves towards 'S' pole and they moves parallely.

> The flux distributed Symetrical between Center of N and S

> In this Case MNA and GNA are Concite with each other

MNA →

Magnetic Neutral axis is this axis which no emf is generare because they then become move parallel to lines of force.

GNA :→

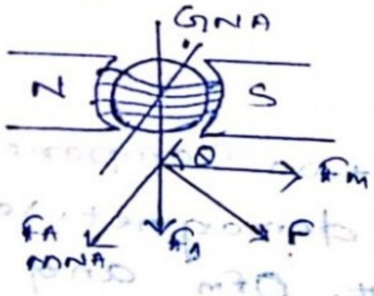
Geometrical Neutral axis is the axis which is divided geometrical the armature to equal half.

→ O→Fm which indicates main magnetic field direction.

→ During the rotation armature magnetic field is set up.

→ It is the lines of force due to armature field parallel to MNA

→ So, O-F_A represent direction of armature field flux force direction.



→ By Combining two magnetic field effect the flux through the armature is no longer uniform about the pole rether it has been destreot-

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→ Due to flux are gethered at tralling pole trip and wearness Lead pole trip.

LPT

The pole trip which is first meet during rotation by armature Conductor.

TPT

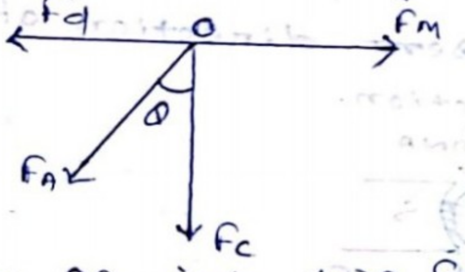
The pole trip which lift by armature Conductor.

→ During Combining two effect new field O-F generated.

→ Due to this MNA occupied a new positions, it shift angle θ and perpendicular to OF.

→ Due to Shifting of MNA, redistrubition of armature Conductor occur that means which moves or Comes under N pole now Corner Under S pole and vice-versa.

→ As OFA Conside with MNA, So OFA Shifts and occupied new position along the MNA



→ By resolving OFA into two Componet O.Fd and OFc. OFd is known as demagnetised Component which is direct oppose the OFm and OFc is Cross magnetising Componet which is perpendi-Cular oppeses to OFm by producing destorition of magnetic field.

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→ ① Shifting of MNA forwardly in case of generator & Shifting of MNA backwardly in case of motor.

COMMUTATION

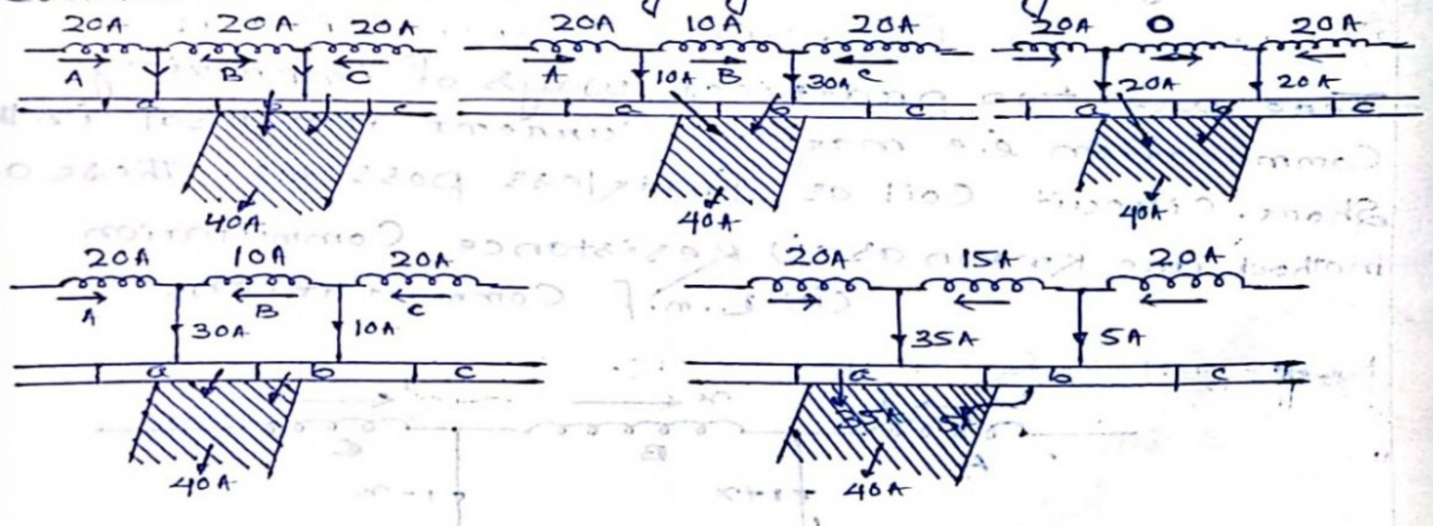
> MNA is the axis with reference to which the current direction is changed.

> When conductor moves under 'N' pole the current in flow in one direction where as it comes 'S' pole the current direction is reversed. with the reference of MNA, where brush are placed.

> The process by which, the current direction is reversed in armature conductor while crossing MNA is called commutation.

> If current reversal i.e change from +i to 0 to -i is complied by end of commutation period then it is known as ideal commutation.

> If current reversal not completed that time then sparking is produce between brush and commutator which may get damaged.



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→ Here, the brush width is equal to commutator segment width in first figure, the brush is short circuit 'b' completely so, coil connected to 'b' (B & C) carry equal current i.e 20A.

→ In second case brush just enter to segment 'a' and cover 1/3 period so, current comming from resultant of A & B and C equal to 40A.

→ In third case figure coil 'B' is in middle, the current through 'b' is reduced to zero and it is full fill by the coil A & C by drawing current 20A each.

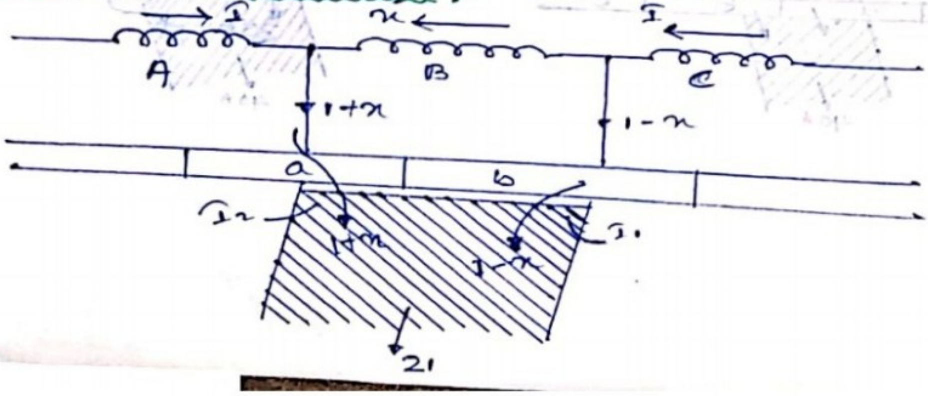
→ In fourth figure, the brush occupies more area segment then 'b' segment result more current will be come from segment a, then b.

→ But in fifth case, the coil 'B' end of commutation so, at that time current it coil 'B' is reversed but it is carrying 15A in place of 20A due to poor commutation so, the result current come from segment 'b' 5A as spark to brushes.

METHODS OF IMPROVING COMMUTATION

There are two practical ways of improving commutation i.e making current reversal in the short circuit coil as sparkless possible. These are method are known as (i) Resistance Commutation
(ii) E.m.f Commutation.

RESISTANCE COMMUTATION :-



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> In this Case the Coil 'c' current is Comes to brush VIA eigther Segment 'a' or Segment 'b' as both the Segments are touch to brush. If it is Copper.

> If Copper brush is replaced by high resistance Carbon brush, the the Current of Coil 'C' is follow only path 'a' to brush but it doesn't follow 'b' brush due to high resistance path.

> Due to this at the end of the Commutation period the Current doesn't go through to air midium to brush and Sparking will be get reduced.

E.M.F COMMUTATION

> In this method a voltage which is cancell the reactance voltage is used for good Commutation.

$$\text{Reactance voltage} = \text{Self inductance of armature coil} \times \frac{di}{dt}$$

> The reactance voltage Causes the reversal of Current i.e there should be Sparking at the brush due to failure of current in Short circuit Coil to reach is full value.

> The emf induced in the Coil opposes the reactance voltage and froces the reversal of Current in the Coil.

INTERPOLES

> By using interpole, it also reduces the Sparking in the Commutator. These are Small pole fix to the yoke placed between two main pole.

> It has been thick wire, few turns which is Connected Series with the armature Circuit. result it ~~as~~ automatic neutralized the reactance voltage.

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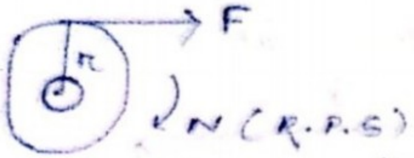
TORQUE EQUATION OF DC MOTOR



Torque means twisting or turning moment of armature about an axis is known as torque.

We know, T = Force × perpendicular distance.

$= F \times r$

So, $T_a = F \times r$

Work done by the force in one revolution

$W = \text{Force} \times \text{distance}$

$= F \times 2\pi r$

$\text{power develop} = \frac{\text{work done}}{\text{Time}}$

$= \frac{F \times 2\pi r}{T}$

$= F \times 2\pi r \times N \quad (\because \frac{1}{T} = N)$

$\omega = \text{angular velocity} = \frac{\text{angular displacement}}{\text{Time}}$

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

$= 2\pi N$

So. $\text{power} = T \times \omega$

Where, $\omega = 2\pi N$ (radian / minute)

$\frac{2\pi N}{60}$ radian / sec

$\therefore \text{power} = T \times \omega$

$= T \times \frac{2\pi N}{60}$

$= \frac{NT}{9.55}$

The electrical power will be converted mechanical power in armature $= E_b I_a$

Here, Armature power $= T_a \times 2\pi N$

So, $T_a \times 2\pi N = E_b I_a$

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

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$\Rightarrow T_a \times \frac{2\pi N}{60} = \frac{P\phi ZN}{60 \times A} \times I_a$

$\Rightarrow T_a = \frac{P\phi ZN}{60 \times A} \times I_a \times \frac{60}{2\pi N}$

$= 0.159\, \phi I_a \frac{ZP}{A}$

SPEED REGULATION :-

It is defind as the change in speed when the load in motor reduce from rated value to zero. and expressed in percentage.

So. percentage of Speed Regulation

$$= \frac{\text{No load speed} - \text{Full load speed}}{\text{Full load Speed}} \times 100$$

NECESSITY OF STARTER

We know that $V = E_b + I_a R_a$

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

at the time of starting $E_b = 0$ ($\because N = 0$)

Let. $V = 230V$.

$R_a = 0.5\Omega$

$I_a = \frac{230 - 0}{0.5} = 460A$.

i.e the Current drawn is very high at the starting as backemf is zero and armature resistance is very low.

→ Due to excessive Current. the motor may burn So, in order to save motor from no-load to full load and also limit the Starting Current, Starter are necessary.

→ Starter are the device which limit the Starting Current also provide to protection by introducing resistance in armature circuit.

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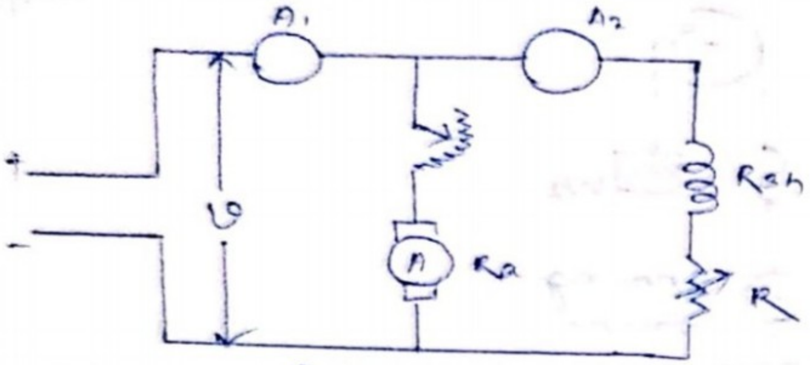
SWINBURNE'S TEST OR NO-LOAD TEST



It is suitable for shunt motor. it is applicable to the machine whose field flux practically constant.

→ In this method, we have to calculate measurement losses separately and efficiency at any desired load calculated.

AT NO-LOAD

At no-load the current measured by ammeter is let I_0 and shunt field current is measured by ammeter A_2.

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

$$I_{a0} = (I_0 - I_{sh})$$

motor input $= V \times I_0$

input = loss at no-load.

= Constant loss + Variable loss

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

$$\Rightarrow W_c = VI_0 - I_{a0}^2 R_a.$$

AT-LOAD

V = Supply Voltage.

I = load current (A.)

input $= V \times I$

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Now, Armature Current $I_a = (I - I_{sh})$

Armature Copper loss $I_a^2 R_a$

Total loss = Constant loss + Variable loss

$= W_c + I_a^2 R_a$

$= VI_0 - I_{a0}^2 R_a + I_a^2 R_a$

$$\text{efficiency} = \frac{O/P}{I/P} = \frac{I/P - \text{loss}}{I/P}$$

$$= \frac{VI - VI_0 - I_{a0}^2 R_a + I_a^2 R_a}{VI}$$

$$= \frac{VI - W_c + I_a^2 R_a}{VI}$$

SHAFT TORQUE

Motor output $= T \times \omega$

$$T = \frac{O/P}{\omega} = \frac{O/P}{2\pi N} = \frac{O/P}{\frac{2\pi N}{60}} \text{ (where N in RPS)}$$

$$\text{where } T = \frac{60 \times O/P}{2\pi N} = 9.55 \frac{O/P}{N}$$

$$= 9.55 \frac{E_b I_a}{N}$$

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4th SEM, ELECTRICAL & ELECTRONICS ENGINEERING

Sub :- ELECTRICAL MACHINE

F.M - 80

Answer any five questions including Q.No. 1 & 2.

Answer all questions

2×10 = 20

(a) what is resultant pitch of armature winding.
(b) what is commutator.
(c) what is the function of Brushes in D.C Motor?
(d) state faraday's Laws of Electromagnetic Induction.
(e) State the losses in D.C machine.
(f) what is M.N.A.?
(g) write down any one use of D.C motor?
(h) write down the emf equation of Transformer and state the parameters in it.
(i) write down one advantage of Parallel operation of 1-φ Transformer.
(j) what do you understand by voltage regulation.

2. Answer any five

6×5 = 30

(a) make a comparison between auto Transformer and 2-winding Transformer.
(b) state the causes of failure of development of emf in D.C shunt Generator and justify.
(c) Draw the various performance characteristics of D.C shunt & series motor.
(d) Draw the equivalent circuit of a Transformer and explain the various parameter in it.
(e) A 250V. lap wound D.C shunt motor draws an armature current of 50A at a given load. If the armature resistance is 0.275 Ω by how much the main flux be changed to raised the speed by 50% assuming a constant Torque operation.
(f) state any one method of speed control of D.C motor & explain.
(g) what is back emf? Explain condition for maximum power.

3. A D.C series motor develops a torque of 20 N-M at 3A of line current. If the current is increase to 6A. what will be the Torque develop? 10

4. Explain about the Principle of operation of D.C Generator. 10

5. what is the Principle of Transformer, Deduce emf equation of Transformer. 10

6. with a neat diagram Explain the working of a 4-point starter. 10

7. what are different types of D.C motor, Deduce the torque equation of D.C motor. 10

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