Unit-I

Electromechanical Energy Conversion. & Introduction of D.C. MOTOR

Principle of Electromechanical Energy Conversion :-

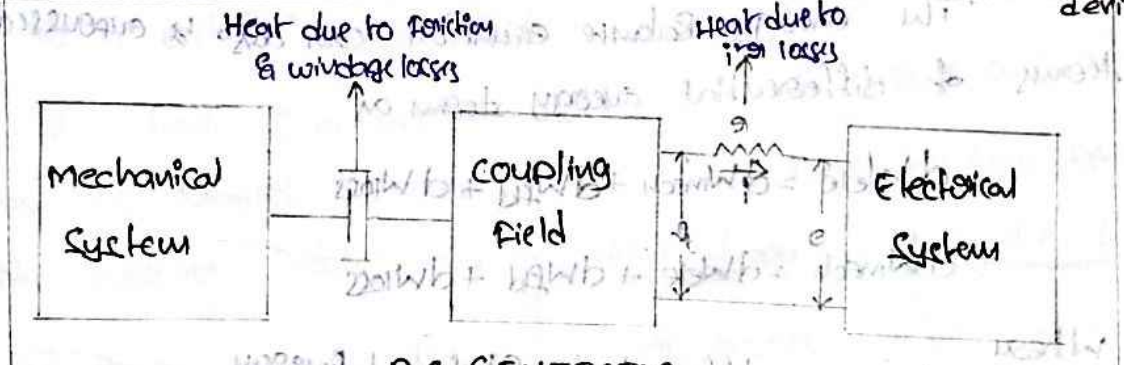
When energy is converted from one form into another form, the principle of conservation of energy can be invoked. According to the principle. energy can neither be created nor destroyed. it can merely be converted from one form to another form. for example:

"A D.C. Machine which converts mechanical energy into electrical energy is called a D.C. Generator."

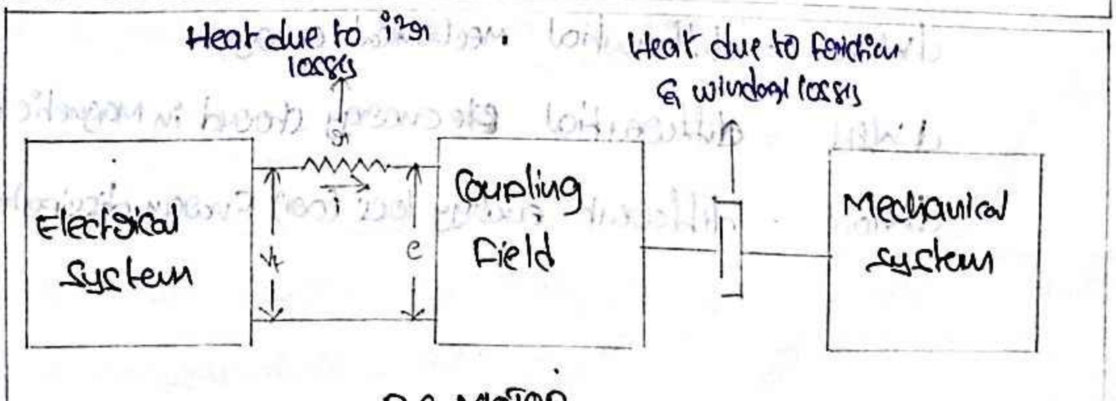
"A D.C. Machine which converts electrical energy into mechanical energy is called a D.C. Motor."

"The energy conversion is based on the production of dynamically induced e.m.f." All these conversions takes place through magnetic medium.

* Model of Electromechanical Conversion device.



D.C. GENERATOR



D.C. MOTOR.

Energy Balance Equation :-

The energy balance equation must include these four energy terms, and for a motor, it can be written as

$$\begin{bmatrix}\text{Total Electrical}\\ \text{energy input}\end{bmatrix} = \begin{bmatrix}\text{Mechanical}\\ \text{energy output}\end{bmatrix} + \begin{bmatrix}\text{Total energy}\\ \text{stored}\end{bmatrix} + \begin{bmatrix}\text{Total energy}\\ \text{dissipated}\end{bmatrix}$$

∴ It should be noted as the above equation is written as motor action, where electrical energy input and mechanical energy output are treated as positive terms.

For generator action,

$$\begin{bmatrix}\text{Total Mechanical}\\ \text{energy input}\end{bmatrix} = \begin{bmatrix}\text{Electrical}\\ \text{energy output}\end{bmatrix} + \begin{bmatrix}\text{Total energy}\\ \text{stored}\end{bmatrix} + \begin{bmatrix}\text{Total energy}\\ \text{dissipated}\end{bmatrix}$$

The various forms of energies involved in above equations for an electromechanical energy conversion device.

Due to current flowing in winding, eddy current losses, hysteresis losses, Mechanical & friction losses etc.

The energy Balance equation can also be expressed in terms of differential energy term as

$$dW_{ele} = dW_{mech} + dW_{fld} + dW_{loss}$$

$$dW_{mech} = dW_{ele} + dW_{fld} + dW_{loss}$$

Where

dW_{ele} = differential Electrical energy

dW_{mech} = differential Mechanical energy

dW_{fld} = differential energy stored in Magnetic field

dW_{loss} = different energy loss (or) Energy dissipated.

Laws of Electromagnetism :-

⇒ The laws of electromagnetism play an important role in the understanding of various electro mechanical energy conversion device. This laws are stated by the scientist "Faraday" & "Ampere". The laws are

1. Whenever the number of magnetic lines are force [Flux] linkage with a coil or circuit changes an EMF gets induced in that coil or circuit.

2. The magnitude of induced e.m.f α Rate of change of flux linkages i.e, Flux × turns of coil.

λ = Flux linkages = Flux × No. of turns of coil.

$\lambda = \phi \times N$.

$$\boxed{\text{i.e } = \frac{d\lambda}{dt}}$$ [induced e.m.f]

⇒ According to lentz law the induced e.m.f sets up a current in such a direction so as to oppose because producing it this is called "statically induced e.m.f"

3. If there is a relative motion b/w a conductor and a flux e.m.f gets induced in the conductor. This conductor (or) magnetic field such an induced e.m.f are called "dynamically induced e.m.f."

4. If the conductor is moving with a velocity "v" m/sec. at an angle θ measured with plane of the flux (φ) then the induced e.m.f conductor is given by

$$\boxed{\therefore e = Blv \sin\theta}$$

B = flux density in Wb/m²

l = length of conductor in M

⇒ If a plane of rotation of conductor perpendicular to the vertical flux $\theta = 90°$ & $e = Blv$ volts

The direction of such are an induced e.m.f is given by Flemings Right hand rule.

5. If a current carrying conductor is placed in the lines of magnetic field [flux]. Then experiences a force.

6. The magnitude of the force experienced by the conductor carrying current (I) placed in magnetic field of flux density (B) is given by.

$$\therefore F = BIl \text{ Newtons}$$

where

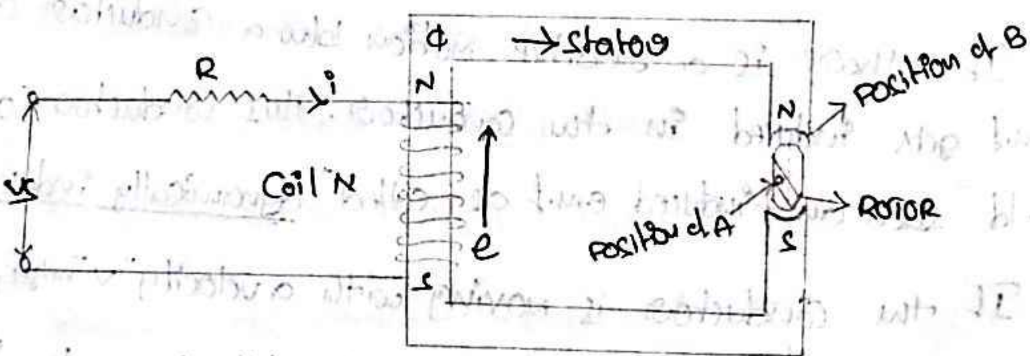
I = current in "Amperes"

l = Length of the conductor in "meters"

⇒ The direction of this force is given by Fleming left hand rule

the laws form a base of Electromechanical energy conversion process.

Single Excited Magnetic Field System:



⇒ The above figure shows the single excited rotating system. Rotor is simple iron piece let us take rotor is in position "A". When STATOR & ROTOR will also magnetised with opposite polarity by induction principle then a force of attraction takes place b/w rotor & stator poles. The rotor rotates to a position B when there is less reluctance. Thus it when there stops rotating reluctance is cause for its deflection & hence it called as reluctance torque (or) salient (projection) torque. The instantaneous voltage equation for the coil by KVL.

$$\Rightarrow \boxed{V = Ri + e}$$

$$= Ri + n\frac{d\phi}{dt} \qquad n\phi = \psi$$

$$V = Ri + \frac{d}{dt}(n\phi)$$

$$\Rightarrow V = Ri + \frac{d\psi}{dt} \rightarrow \text{voltage Relation}$$

$$\Rightarrow Vi = Ri^2 + i\frac{d\psi}{dt} \rightarrow \text{power Relation}$$

$$\Rightarrow Vidt = Ri^2dt + id\psi \rightarrow \text{Energy equation}$$

⇒ Integration on both sides

$$\begin{bmatrix}\text{Total Electrical} \\ \text{Energy input}\end{bmatrix} = \begin{bmatrix}\text{Electric} \\ \text{Energy loss}\end{bmatrix} + \begin{bmatrix}\text{Electrical Energy} \\ \text{converted into} \\ \text{magnetic energy}\end{bmatrix}$$

$$\Rightarrow \boxed{W_{ele} = W_{loss} + W_{fld}}$$

$$\Rightarrow W_{f} = \int_0^{\psi} i\,d\psi = W_{fld} + W_{mech}$$

Where W_{fld} = Energy stored in the magnetic form.

W_{mech} = Energy spend in doing mechanical work.

Steady State Equation:-

⇒ When the Rotor is the steady state.

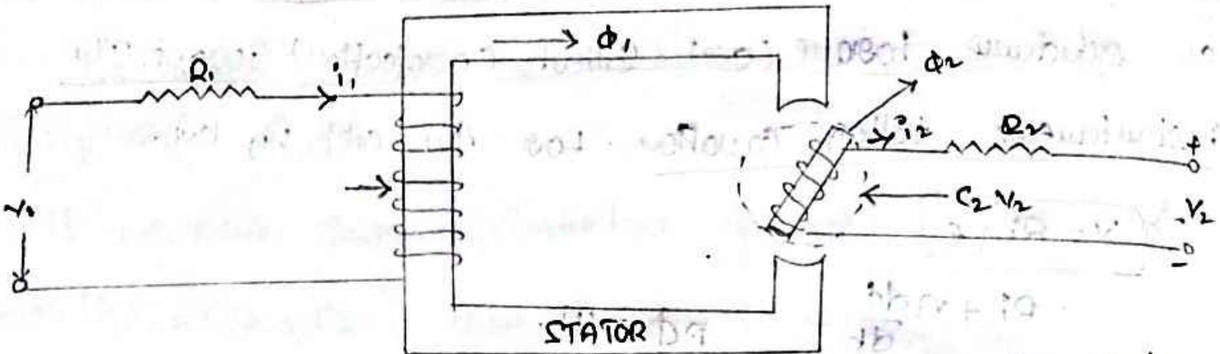
$\therefore W_{mech} = 0$

$$\Rightarrow \therefore W_{fld} = \int_0^{\psi} i\,d\psi = \int_0^{\psi} \frac{\psi}{L}d\psi = \frac{\psi^2}{2L} \qquad [\because \psi = Li]$$

$$= \frac{L^2i^2}{2L}$$

$$\boxed{W_{fld} = \frac{1}{2}Li^2} \text{ Joules}$$

Double Excited System:-



⇒ The above diagram shows the Double Excit rotating system to stator & rotor seperatly magnetising field by two seperate forces are called Double Exited system. When C_1 & C_2 coils are Excited the following are takes place

1. The flux ϕ produced by C_1 links with its own coil C_1 & secondary coil C_2

i.e, $\psi_1 = L_1 i_1 + M i_2$ → ①

2. The flux ϕ_2 produced by links with own coil C_2 and primary coil is C_1

i.e, $\psi_2 = L_2 i_2 + M i_1$ → ②

3. The voltage equation According to KVL

$$V_1 = R_1 i_1 + \frac{d\psi_1}{dt} \rightarrow ③$$

$$V_2 = R_2 i_2 + \frac{d\psi_2}{dt} \rightarrow ④$$

solving ψ value equation ③ we get

$$V_1 = R i_1 + \frac{d}{dt}(L_1 i_1 + M i_2)$$

$$V_1 = R_1 i_1 + L_1 \frac{di}{dt} + i_1 \frac{dL_1}{dt} + M \frac{di_2}{dt} + i_2 \frac{dM}{dt} \rightarrow ⑤$$

Multiplying the above equation i_1 we get

$$V i_1 = R_1 i_1^2 + L_1 i_1 \frac{di_1}{dt} + i_1^2 \frac{dL_1}{dt} + M i_1 \frac{di_2}{dt} + i_1 i_2 \frac{dM}{dt} \rightarrow ⑥$$

Similarly ⑦ equation can be written as

$$v_2 i_2 = R_2 i_2^2 + L_2 i_2 \frac{di_2}{dt} + i_2^2 \frac{dL_2}{dt} + M i_2 \frac{di_1}{dt} + i_2 i_1 \frac{dM}{dt} \rightarrow (7)$$

Integrating both the equation w.r.t. time & adding we get

$$\int(v_1 i_1 + v_2 i_2) = \int(R_1 i_1^2 + R_2 i_2^2)dt + \int(L_1 i_1 di_1 + L_2 i_2 di_2 + i_1 M i_2 + 2 i_2 i_1 dM + i_1^2 di_1 + i_2^2 di_2 + L_2 M di_1)dt \rightarrow (8)$$

$$\int(v_1 i_1 + v_2 i_2 - R_1 i_1^2 - R_2 i_2^2)dt = \int(L_1 i_1 di_1 + L_2 i_2 di_2 + i_1^2 dL_1 + i_2^2 dL_2)dt + \int(i_1 M di_2 + i_2 M di_1 + 2 i_1 i_2 dM)dt \rightarrow (9)$$

[Use Electrical Energy input] = [Field Energy Stored in Electrical System] + [Energy transferred b/w Rotor & Stator (or) Electrical to Mechanical] → (10)

Stored Magnetised energy is Double Excited state:

⇒ Under steady state i.e. when the mechanical output is zero the entire electrical energy is stored in the system in the form of magnetic. As the system is steady the terms dL_1, dL_2 & dM in equation (9)

$$\int(v_1 i_1 + v_2 i_2 - R_1 i_1^2 - R_2 i_2^2) = \int(L_1 i_1 di_1 + L_2 i_2 di_2)dt + \int(i_1 M di_2 + i_2 M di_1)dt$$

∴ Total stored magnetic Energy (W_{fld})

$$= \int(L_1 i_1 di_1 + L_2 i_2 di_2 + i_1 M di_2 + i_2 M di_1)dt$$

$$= \int_0^{i_1}(L_1 i_1 di_1) + \int_0^{i_2}(L_2 i_2 di_2) + \int_0^{i_1 i_2}(i_2 M di_1 + i_1 M di_2)$$

$$\text{Total } (W_{fld}) = \frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + M i_1 i_2 \rightarrow (11)$$

Electro Magnetic torque in Double Excited System:

⇒ Mechanical work is done from stored Energy. The mechanical work is equal to rate of change of energy stored.

∴ Mechanical Work done $\left[\frac{d}{dt}[W_{fld}]\right]$

$$= \frac{d}{dt}\left[\frac{1}{2}L_1 i_1^2 + \frac{1}{2}L_2 i_2^2 + M i_1 i_2\right]$$

$$= \frac{d}{dt}\left[\frac{1}{2}L_1 i_1^2\right] + \frac{d}{dt}\left[L_2 i_2^2\right] + \frac{d}{dt}\left[M i_1 i_2\right]$$

$$\Rightarrow \frac{L_1}{2}\frac{d}{dt}(i_1^2) + \frac{L_2}{2}\frac{d}{dt}(i_2^2) + \frac{i_1^2}{2}\frac{dL_1}{dt} + \frac{i_2^2}{2}\frac{dL_2}{2} + i_1 i_2 \frac{d(M)}{dt} + i_2 M \frac{d(i_1)}{dt} + M i_1 \frac{d(i_2)}{dt} \rightarrow (12)$$

Integrating above equation w.r.to Time,

$$\Rightarrow \int d(W_{fld}) = \int (L_1 i_1 di_1 + \frac{i_1^2}{2} dL_1 + L_2 i_2 di_2 + \frac{i_2^2}{2} dL_2 + i_1 i_2 dM + i_1 M di_2 + i_2 M i_1) \rightarrow (13)$$

Re-writing above equation

$$\Rightarrow W_{fld} = \int (L_1 i_1 di_1 + L_2 i_2 di_2 + i_1 M di_2 + i_2 M di_1) + \int (\frac{i_1^2}{2} dL_1 + \frac{i_2^2}{2} dL_2 + i_2 i_1 dM)$$

$$\Rightarrow W_{fld} = W_{stored} + W_{mechanical}$$

$$\Rightarrow W_{mech} = \int \frac{1}{2} dL_1 i_1^2 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM \longrightarrow (14)$$

By producing mechanical energy the terms $dL_1, dL_2 \& dM$ are constant.

But varies with θ_M

Differentiating equation (14) w.r.t θ_M.

$$\boxed{\frac{d}{d\theta_M}(W_{mech}) = \frac{1}{2} i_1^2 \frac{dL_1}{d\theta_M} + \frac{1}{2} i_2^2 \frac{dL_2}{d\theta_M} + i_2 i_1 \frac{dM}{d\theta_M}} \longrightarrow (15)$$

$\Rightarrow$ Torque equation for double Excited system

Torque equation for single Excited System:-

⇒ In this case of single Excited System one of the two terminal current is equal to zero.

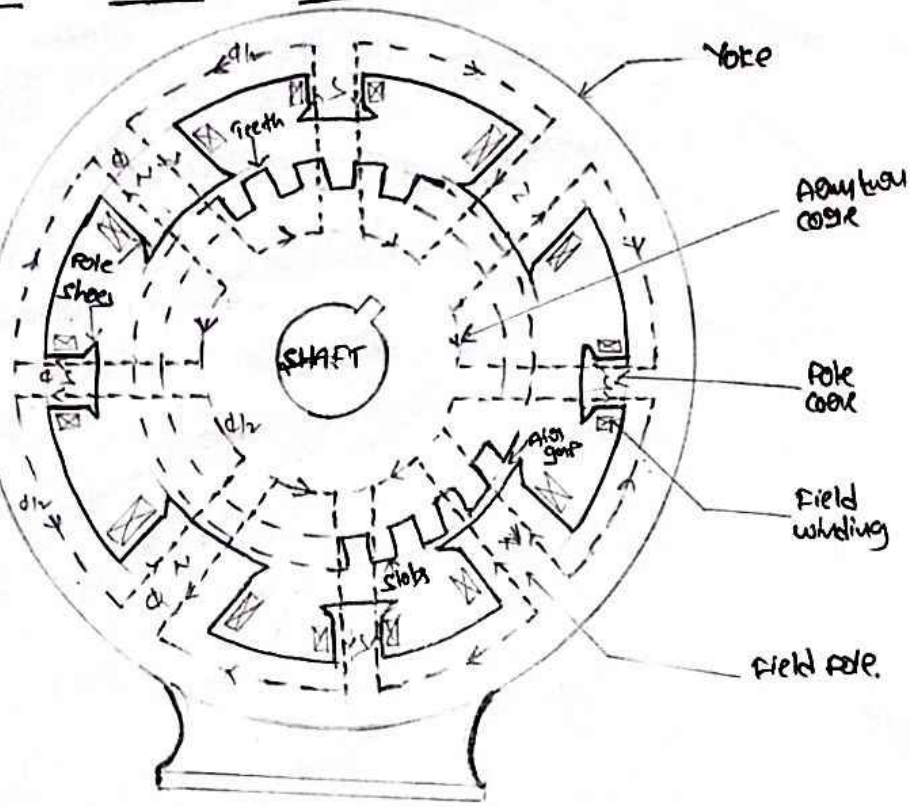
Sub $i_2 = 0$ in equation (15)

$$\therefore \frac{d}{d\theta_m}(W_{mech}) = \frac{1}{2} i_1^2 \frac{dL_1}{d\theta_m} \rightarrow (16)$$

1. The terms of $\frac{1}{2} i_1^2 \frac{dL_1}{d\theta_m}$ and $\frac{1}{2} \frac{dL_2}{d\theta_m}$,

2. The term $i_1 \& i_2 \frac{dM}{d\theta_m}$ is called co-allignment torque.

Construction of D.C. Generator :-



Essential Parts of D.C. Generator :-

* Yoke (or) Magnetic frame.
* Pole core & Pole shoes
* Field coils (or) Pole coils
* Armature core
* Armature winding
* Commutator
* Brushes
* End covers
* Bearings
* Shaft & Pulley
* Terminal Box
* Eye bolt.

1. Yoke :-

→ The outer most cylinder frame is called yoke (or) magnetic frame

→ It is made of cast iron for small machines and for large machines usally cast steel or rolled steel is employed.

*Purposes:-

→ It acts as protecting cover for a whole machine and also provide mechanical support for the magnetic poles.

→ It provides a low reluctance path for the magnetic flux.

2. Pole core and Pole shoe :-

The field magnetic magnets consists of pole core & pole shoe.

(a) Pole core it self may be a solid piece made of either cast iron (or) cast steel but the pole shoe is laminated and is fastened to the pole face by means of sunk screws.

Purposes:-

(i) They support the field coils (or)

(ii) They spread out the magnetic flux in the air gap.

(iii) They reduces the reluctance of magnetic path since pole shoes have larger cross section.

3. Field coil :-

The field coils consists of enamel coated copper or Aluminium wire. The coils are wound on the former then the former is removed and the wound coil is placed around the pole core.

4. Armature core :-

Armature core is cylindrical in shape and is made up of high permeability silicon steel stampings (or) laminations.

The thickness of each lamination is about 0.3mm. to 0.5mm Each lamination is insulated from the other by thin paper (or) varnish.

Purposes :-

i) It houses the conductors in the slots

ii) It provides path of low reluctance to magnetic flux.

5. Armature winding :-

The armature winding are usually former wound. These are first wound in the form of rectangular coils and are then pulled into their proper shape in a coil puller. The conductors of the coils are insulated from each other by varnish and placed in the armature slots which lined with through insulating material.

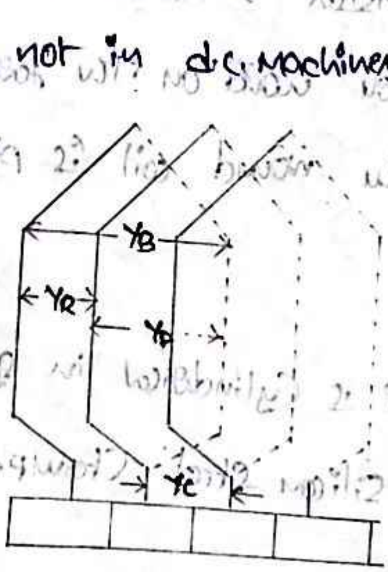
Armature windings are usually of symmetrically distributed in slots around the Armature. There are two types of windings.

1. Open coil winding (or) Lap winding

2. Closed coil winding (or) wave winding.

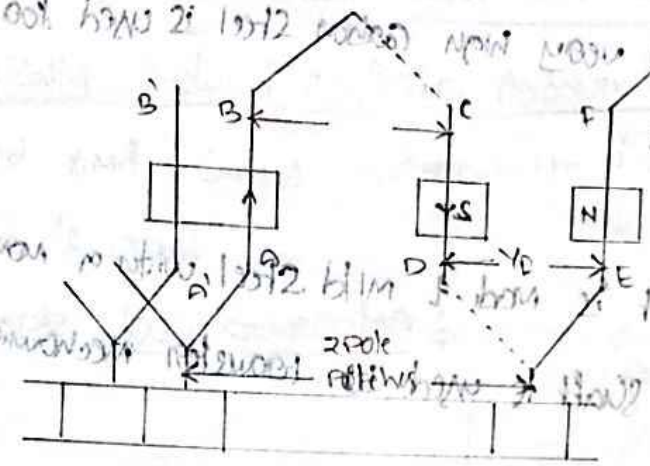
1. Open coil winding (or) Lap winding :-

Lap winding is that winding which does not close on itself. This type of winding is usually employed in a.c machines, but not in d.c machines



2. Closed coil winding (or) wave winding :

Closed coil winding is that winding which closes on itself. This a winding if one starts tracing through it, one will come back to the starting point without passing through any external connection. D.C. machines employ only closed winding



6. Commutator :

It is most important part of d.c. machine. The commutator is of cylindrical shape and it is made up of wedge-shaped segments of high conductivity hard drawn copper. It facilitates the collection of current from the armature conductor.

7. Brushes & Brush Holders :

Brushes are usually made up of high grade carbon. because carbon is conducting material.

The main function of the brush is to collect the current from the commutator & supply it to the external load circuit.

8 End Covers :

The end covers are usually made of cast iron (or) cast steel

The main function of end covers is to protect the inner parts of the machine.

9. Bearings :-

The functions of the bearings is to reduce friction b/w the rotating & stationary part of the machine.

Most commonly very high carbon steel is used for the construction of bearings

10. Shaft & Pulley :-

The shaft is made of mild steel with a maximum breaking strength. The shaft is used to transfer mechanical power from to the machine.

The pulley is made of cast iron & is fixed on the shaft by a key or stud.

11. Terminal Box :-

This is an insulated box which carries the bars nuts & bolts to which wires from the brushes & field

12. Eye Bolt :-

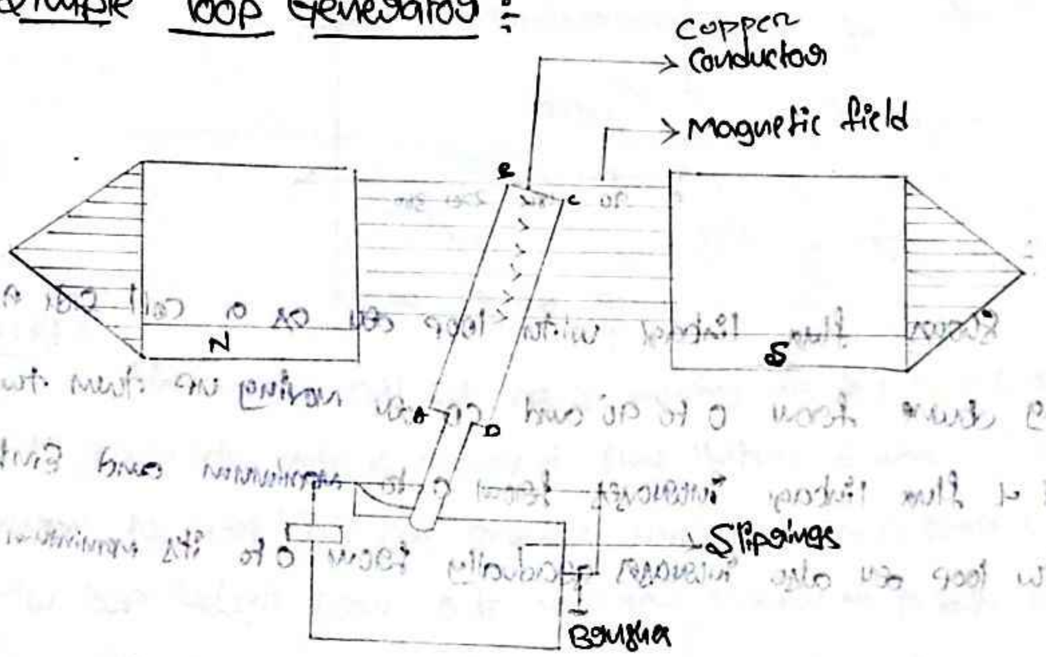
The eye bolt is provided with the body generally on the top for lifting the machine

Principle & working of D.C. Generator :-

A D.C. Generator is a machine which converts mechanical energy into electrical energy. The energy conversion based on the principle of dynamically induced e.m.f

"whenever a conductor cuts magnetic lines of flux dynamically induced e.m.f is produced in the conductor. This induced e.m.f causes a current to flow if the conductor circuit is closed"

Simple loop Generator :-



Consider a rectangular copper conductor of uniform magnetic field in the clock-wise this constitutes simple loop Generator the magnetic field is stationary and conductors are movable.

As the loop ABCD rotating in an clock-wise direction at constant speed in the magnetic field the flux linkages of coil change continuously & Emf is induced in loop

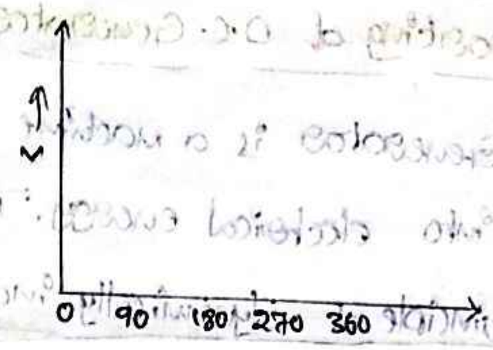
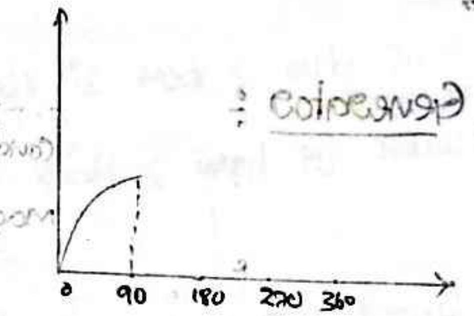


Fig.(A) :- Shows the flux linkages with the loop are maximum but rate of change of flux linkages are minimum

∴ No emf is in the loop



Fig(B) :-

Shows flux linkage with loop are as a coil side AB moving down from 0 to 90° and CD are moving up then the rate of change of flux linkage increases from 0 to maximum and Emf induced in the loop are also increases gradually from 0 to its maximum value

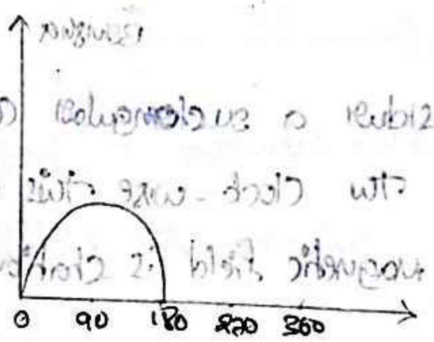


Fig (C) :-

Shows as coil side AB moving down from 90 to 180 CD moving up the rate of change of flux linkage decreases gradually from maximum to 0. Then E.M.F induced in loop also decreases from maximum value to 0.

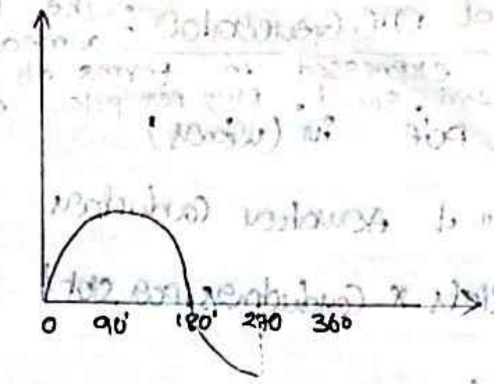


Fig (D) :- Shows as coil side AB moving up from 180 to 270 CD moving down rate of change of flux increases from 0 to maximum value during this rotation direction of motor loop changes from AB & CD reversed and hence emf also shows in the -ve direction

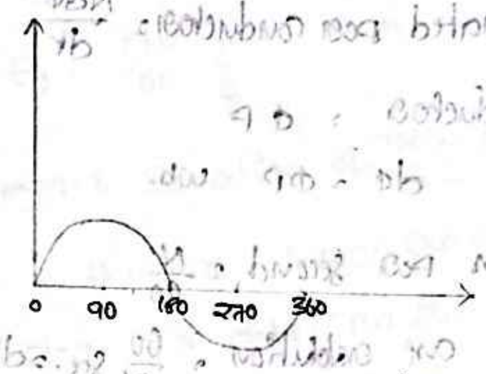


Fig (E) :- Shows as coil side AB is moving up 270 to 360 and CD moving down the rate of change of flux linkage decreases from -ve maximum to zero. This one complete revolution ABCD EMF induced in the loop induced from 0 to maximum, maximum to zero, 0 to -ve maximum & from -ve maximum to zero.

E.M.F Equation of D.C Generator: The E.M.F induced in the armeature of a D.C generator is usually expressed in terms of the number of poles, armeature, conductors, speed, flux per pole etc.

let ϕ = flux per pole in (webers)

Z = Total no. of Armature conductors

(No. of slots × conductors per slot)

N = Speed in RPM.

P = No. of Poles

A = No. of parallel paths

Eg = Emf induced in the armature.

Average emf generated per conductor = $\frac{Nd\phi}{dt}$ ($\because$ N=1) one revolution

Flux cut per conductor = ϕP

$d\phi = \phi P$ wb.

No. of revolution per second = $\frac{N}{60}$.

Time for one revolution = $\frac{60}{N}$ sec. = dt.

Rate of change of flux linkages = Flux cut per conductor/sec

$= \frac{d\phi}{dt} = \frac{\phi P}{60/N} = \frac{\phi PN}{60}$ wb/sec.

Emf generated per conductor per sec = Flux cut per conductor/sec

$= \frac{\phi PN}{60}$

EMF generated for "z" conductors = $\frac{\phi PN}{60} \times Z$ volts

No. of parallel paths available = A

Generated e.m.f $E_g = \frac{\phi PN}{60} \times \frac{Z}{A}$ V.

$$\boxed{E_g = \frac{\phi PN}{60} \times \frac{Z}{A} \text{ volts}}$$

Lap winding :

No. of Parallel Paths (A) = No. of Poles (P)

$$\boxed{E_g = \frac{\phi Z N}{60}} \text{ volts}$$

Wave winding :

No. of Parallel Paths = 2

$\therefore A = 2$

$$E_g = \frac{\phi Z N}{60} \times \frac{P}{2} \text{ V}$$

$$E_g = \frac{\phi Z N P}{120} \text{ V}$$

Generated e.m.f $\boxed{E_g = \frac{\phi Z N}{60} \times \frac{P}{2}}$ V

Problems on E.M.F. Equation of D.C. Generator :

① A 4 pole machine running at 1500 r.p.m has an armature with 90 slots and 6 conductors per slots. The flux per pole is 60mwb. determine the terminal Energy of D.C. Generator if the coils are lap connected. If the current per conductor is 100A. Determine the electrical power developed in the armature?

Sol No. of Poles [P] = 4

Speed (N) = 1500 RPM

Total no. of conductors [Z] = 90×6 = 540

flux per pole = 60×10^{-3} wb

No. of parallel paths A = 4

Total armature current for 4 parallel paths = 4×100 = 400A

Generated EMF $E_g = \frac{\phi Z N}{60} \times \frac{P}{A}$

$$= \frac{60\times10^{-3}\times540\times1500}{60}\times\frac{4}{4}$$

$E_g = 810$ V

Power developed in armature = $E_g I_a$

$= 810 \times 400$

$= 324000$ W.

$= 324$ kW

2. A 4 pole D.C. Generator having a wave wound armature conductor has 51 slots with each slot containing 20 conductors. Find the e.m.f generated when the machine is driven at 1500 RPM assuming flux per pole to be 7.0 mwb.

Sol

Given data:

Nou of poles $[P] = 4$

Nou of slots $= 51$

Total nou. of conductors/slot $= 20$

Speed $[N] = 1500$

Flux per pole $[\phi] = 7.0 \times 10^{-3}$ wb

Total nou of armature conductors $Z = 51 \times 20 = 1020$

Nou of parallel paths $= 2$ [∵ Wave wound]

Generated emf $E_g = \frac{\phi Z N}{60} \times \frac{P}{A}$

$= \frac{7.0 \times 10^{-3} \times 1020 \times 1500}{60} \times \frac{4}{2}$

$E_g = 357$ V.

③ A 6 pole D.C shunt generator with 770 wave connected armature conductors and running at 500 R.P.M, supplies a load of 12.5 Ω resistance at a terminal voltage of 250 V. The armature resistance is 0.22 Ω and field resistance 250 Ω. Find the armature current, the induced emf and flux per pole

Sol Given data:

No. of poles [P] = 6

Total No. of conductors [Z] = 770

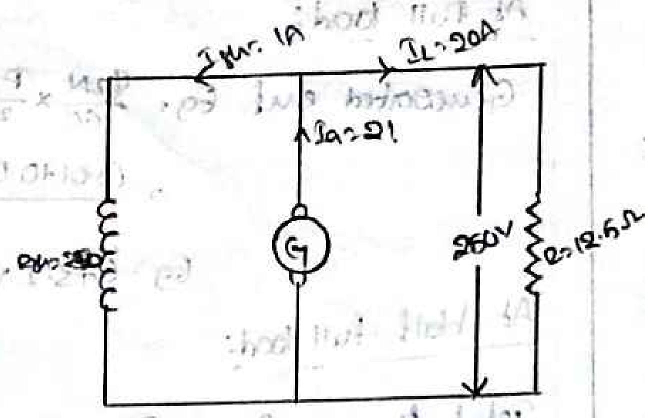
Speed [N] = 500 RPM

load Resistance [R] = 12.5 Ω

terminal voltage [V] = 250 V

Armature resistance [Ra] = 0.25 Ω

Field Resistance [Rsh] = 250 Ω



load Current $(I_L) = \frac{V}{R} = \frac{250}{12.5} = 20A$

Shunt field current $[I_{sh}] = \frac{250}{250} = 1A$

Armature current $I_a = I_L + I_{sh} = 20 + 1 = 21A$

Induced emf $E_g = V + I_a R_a = 250 + 21 \times 0.25 = 255.25\ V$

Generated emf $E_g = \frac{\phi Z N}{60} \times \frac{P}{A}$

$\phi = \frac{E_g \times 60 \times A}{PNZ} = \frac{255.25 \times 60 \times 2}{770 \times 500 \times 6}$

$\phi = 0.0132\ Wb.$

4. A wave wound short shunt cumulative compound generator has 34 slots and 18 conductors per slot. It is wound for 4 poles. The shunt field produces a constant flux of 0.01 wb, while the series field produces a flux of 0.012 wb at full load. The armature, shunt field & series field resistance are 0.03 Ω, 100 Ω & 0.02 Ω respectively. If the full load armature current is 100A. Calculate the terminal voltage at full load & half load. The shaft is rotated at 1500 r.p.m.

Sol Given data:

Total no. of conductors Z = No. of slots × Conductors per slot
$= 34 \times 18 = 612$

No. of poles [P] = 4

Speed [N] = 1500 r.p.m.

At Full load:

Generated emf $E_g = \frac{\phi Z N}{60} \times \frac{P}{2}$

$= \frac{(0.01+0.012) \times 612 \times 1500 \times 4}{120}$

$E_g = 673.2\,V$

At Half full load:

Total flux $\phi = [\phi_{sh} + \phi_{se}]$

$= [0.01 + \frac{0.012}{2}]$

$= 0.016\,Wb$

$E_g = \frac{0.016 \times 612 \times 1500 \times 4}{120}$

$E_g = 489.6\,V$

At full load:

voltage drop in armature $= I_a R_a = 100 \times 0.03 = 3V$

voltage across shunt field $= E_g - I_a R_a = 673 - 3 = 670V$

Shunt field current $I_{sh} = \frac{V}{R_{sh}} = \frac{670}{100} = 6.7\,A$

Current in series field $= I_a - I_{sh} = 100 - 6.7 = 93.3V$

Voltage drop in series field $= I_{se} R_{se} = 93.3 \times 0.02 = 1.866\,V$

Terminal voltage $V = E_g - I_a R_a - I_{se} R_{se}$

$= 673.2 - 3 - 1.866$

$V = 668.3\,V$

At Half full load:

The voltage drop at for half full load in armature

$= 50 \times 0.03 = 1.5V$

voltage drop across shunt field $= E_g - I_a R_a$

$= 489.6 - 1.5 = 488.1V$

Shunt field current $I_{sh} = \frac{488.1}{100} = 4.881\,A$

Current in series field $= I_a - I_{sh} = 50 - 4.881 = 45.119\,A$

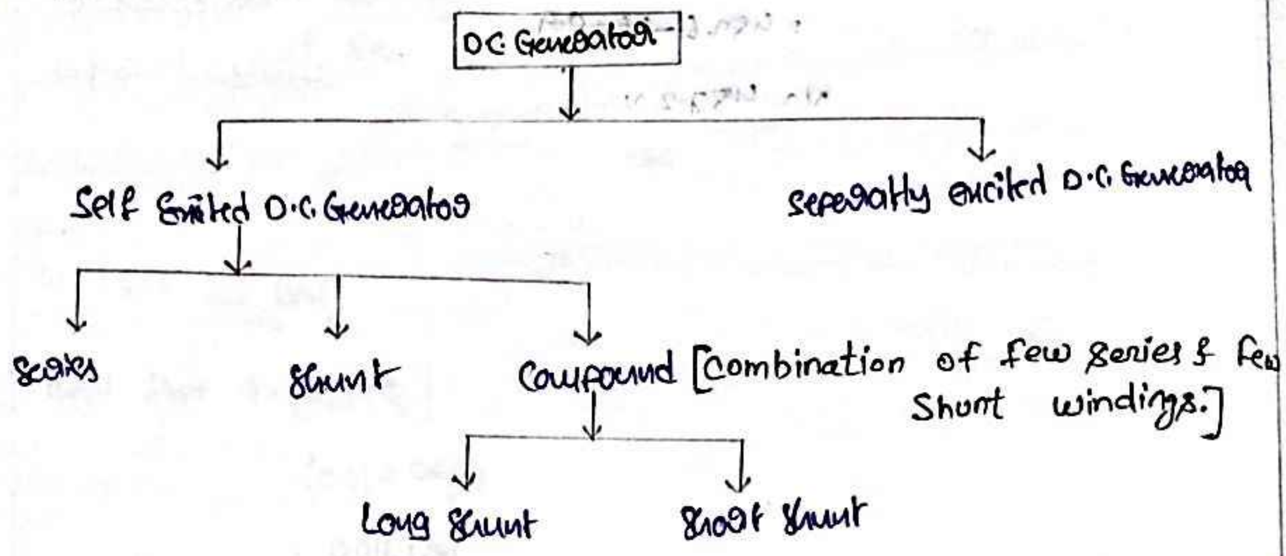
voltage drop in series field $= I_{se} R_{se} = 45.119 \times 0.02 = 0.9$

Terminal voltage $V = E_g - I_a R_a - I_L R_L$

$= 489.6 - 1.6 - 0.9$

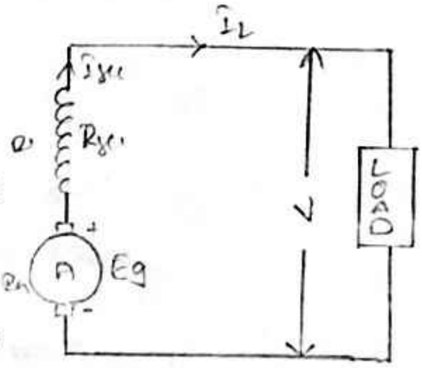
$V = 487.2\ V$

Classification of D.C. Generator :-



D.C. Series Generator :-

In this field windings are connected in series with armature. The current flowing in armature, series field and the line are same. The series field carries full armature current. The field winding consists of less no. of turns with thick wire.



$I_a = I_{se} = I_L$

Terminal voltage $V = E_g - I_a(R_a + R_{se})$

Generated EMF $(E_g) = V + I_a(R_a + R_{se})$

Where

I_L = load current

V = load voltage

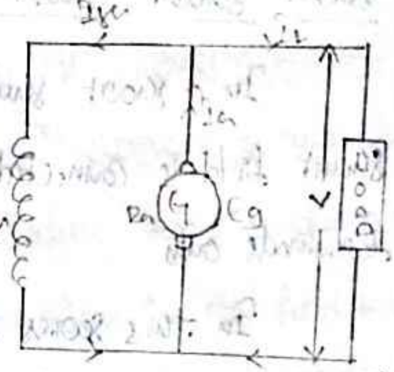
I_{se} = series field current

R_{se} = series field resistance

R_a = Armature resistance

E_g = Generated emf.

D.C. Shunt Generator :



In this field windings are connected in parallel with the armature. So the field winding carries full voltage of the generator applied across them. The shunt winding consists of many turns of thin wire.

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

$$I_{sh} = \frac{V}{R_{sh}} \qquad I_L = \frac{P}{V}$$

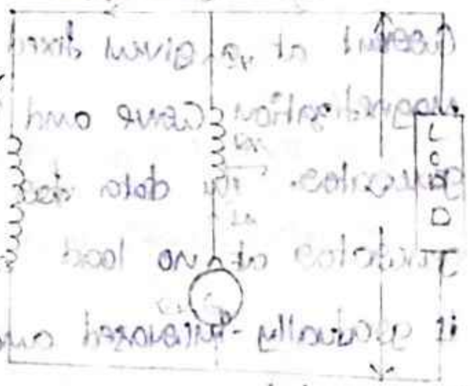
Generated e.m.f (E) $E_g = V + I_a R_a$ + Brush drop

where $E = \frac{\phi PNZ}{60}$

D.C. Compound Generator :

It is a combination of a few series & few shunt windings. This can be connected either in long shunt (or) short shunt.

Long Shunt Compound Generator :



Compound generator contains both shunt field and series field. In long shunt compound generator the shunt field is connected parallel to both armature and series field. The current distribution is again a combination of shunt generator & series generator

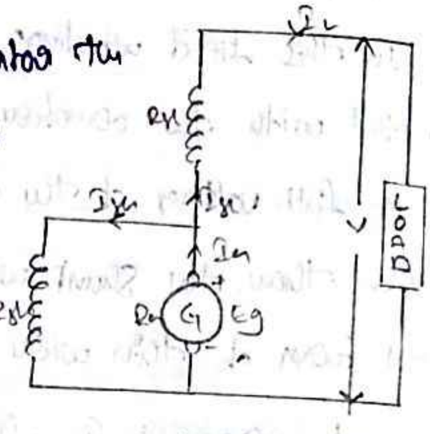
$$I_a = I_{se} = I_L + I_{sh}$$

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

Generated e.m.f $E_g = V + I_a(R_a + R_{se})$ + Brush drop.

Power $P = E_g \times I_a$

Short Shunt Compound Generator :-



In a short shunt compound generator the shunt field is connected across the armature terminals only.

In this series field takes the load current and shunt field is impressed with armature voltage.

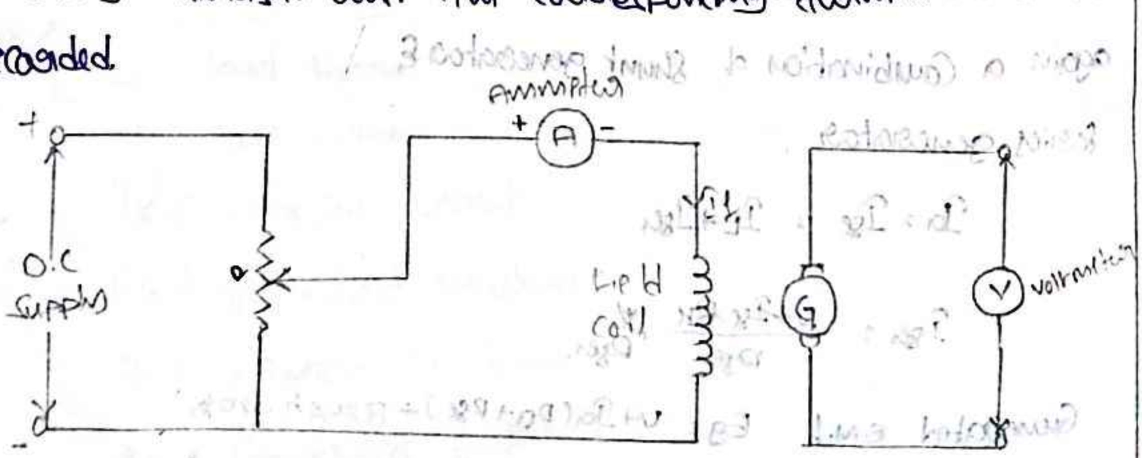
$$I_L = I_{se} = I_a - I_{sh}$$

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

Generated emf $E_g = V + I_a R_a + I_{se} R_{se}$

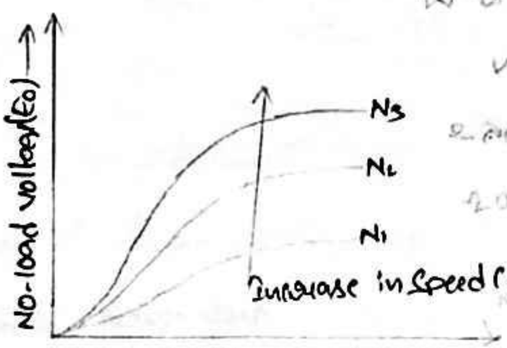
OCC of D.C. Shunt generator :-

* Open circuit characteristics is also known as magnetic characteristics (or) no-load saturation characteristics. It shows the relation b/w generated e.m.f at no-load and the shunt field current at a given fixed speed. The occ curve is just the magnetization curve and it is practically similar for all type of generator. The data for occ curve is obtained by operating the generator at no load and keeping a constant speed. Field current is gradually increased and the corresponding terminal voltage is recorded.



* From the e.m.f equation of d.c Generator, we know that $E_g = K\phi$. Hence the generated e.m.f should be directly proportional to field flux. However, even when the field current is zero, some amount of emf is generated. This initially induced e.m.f is due to the fact that there exists some residual magnetism in the field poles. Due to the residual magnetism, a small initial emf is induced in the armature. This is induced in the armature. This initially induced emf aids the existing residual flux.

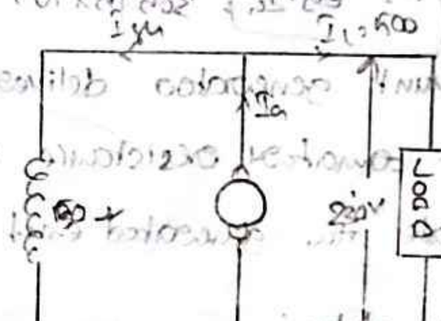
* Hence the OCC curve looks like a B-H characteristics



Problems of D.C Generators:

1. A shunt generator delivers 500A at 230V & resistance of shunt field and armature are 50Ω & 0.03Ω respectively. Calculate the generated e.m.f

Sol Given data:



$I_L = 500A$

$V = 230V$

$R_{sh} = 50\Omega$

$R_a = 0.03\Omega$

$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{50} = 4.6A$

$I_a = I_L + I_{sh} = 500 + 4.6 = 504.6A$

Armature voltage drop:

$I_a R_a = 504.3 \times 0.03 = 15.18V$

$E_g = V + I_a R_a$

$= 230 + 15.18$

$= 245.13 V$

2. A 30kW, 300V DC shunt generator has armature and field resistance of 0.05Ω & 100Ω. Calculate total load power delivered by armature when it delivers full load o/p.

Sol

Given data:-

$P = 30 \times 10^3 W$

$V = 300V$

$R_a = 0.05 \Omega$

$R_{sh} = 100 \Omega$

$I_a = I_L + I_{sh}$

$I_{sh} = \frac{V}{R_{sh}} = \frac{300}{100} = 3A$

$I_L = \frac{P}{V} = \frac{30 \times 10^3}{300} = 100A$

$I_a = I_L + I_{sh} = 100 + 3 = 103A$

$E_g = V + I_a R_a = 300 + (103 \times 3) = 305.15V$

$P = E_g \cdot I_a$ $305.15 \times 103 = 31.43 kW$

3 A shunt generator delivers 245A at terminal voltage of 250V if the armature resistance is 0.04Ω & field resistance is 50Ω. Calculate the generated e.m.f

Sol Given data:-

$I_L = 245A$

$V = 250V$

$R_a = 0.04\,\Omega$

$R_{sh} = 50\,\Omega$

$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{50} = 5A$

$I_a = I_L + I_{sh} = 5 + 245 = 250A$

Generated emf = $V + I_a R_a$ + Brush drop.

$= 250 + (250 \times 0.04)$

$E_g = 260V$

4. A shunt field generator delivers 450A at 230V and resistance of shunt field and armature are 50Ω & 0.03Ω. Calculate the generated emf.

Sol

Given data

$I = 450A$

$V = 230V$

$R_{sh} = 50\,\Omega$

$R_a = 0.03\,\Omega$

$E_g = V + I_a R_a$ + Brush drop.

$I_a = I_L + I_{sh}$

$I_L = \frac{P}{V} = 450A$

$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{50} = 4.6\,\Omega$

$I_a = 450 + 4.6 = 454.6A$

$E_g = V + I_a R_a$ BD

$E_g = 230 + (454.6 \times 0.03)$

$E_g = 243.63V$

6 A long shunt compound generator a load current of 50A at 500A and resistance of armature of shunt & series of resistance 0.04Ω & 0.08 & 250Ω at calculated the generated emf and the armature current allow 2V for brush for contact drop.

Sol Given data:

$I_L = 50A$

$V = 230V$

$R_a = 0.04\Omega$

$R_{se} = 0.08\Omega$

$R_{sh} = 250\Omega$

$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{250} = 2A$

$I_{se} = I_a + I_L + I_{sh} = 50 + 2 \quad 252A$

$E_g = V + I_a R_a + I_{se} R_{se} + \text{Brush drop}$

$E_g = 508.63V$

Key points :

Machine :- Machine is a device, it reduce the human effect

D.C. Motor :- It converts Electrical energy to mechanical energy. "Whenever a current carrying conductor placed in magnetic field, it will experience a mechanical force". This force is obtained by Fleming's left hand rule.

D.C. Generator :- A D.C Generator is a machine it converts mechanical energy to electrical energy. "Whenever a conductor cuts magnetic lines of flux dynamically induced emf is produced in the conductor". The direction of this machine is Fleming's Right hand rule

Torque :- Torque is defined as the twisting and turning of a moment of force about an axis.

T = Force x radius

EMF :- [Electro motive force],

It is defined as around closed loop of conductor as the electromagnetic work that would be done on an electrical charge if it travels once around the loop for time varying the flux linking a loop".

(or)

"It is the electrical pressure (or) force that is supplied by a voltage source, which causes current to flow in a circuit"

Lenz law :- According to this law, the induced e.m.f sets up a current in such a direction so as to oppose because producing it.

This called "statically induced emf"

If there is a relative motion b/w a conductor & flux emf gets induced in the conductor. This relative motion is due to physical movement of conductor (or) magnetic field. Such as induced emf is called "dynamically Induced emf"

Faraday's law:-

1st law:- "Whenever a conductor is placed in a magnetic field conductor cuts the magnetic flux, then an e.m.f. emf induced in the conductor"

2nd law:- The induced emf in that conductor is equal to the rate of change of flux linkages

Fleming's Right hand Rule:- This rule is particularly suitable to find the direction of induced emf, and hence current, when the current conductor moves at right angles to a stationary magnetic field

"Stretch out the fore fingers point at in the direction of magnetic field, thumb in the direction of motion of the conductor, & the middle finger will point in the direction of induced current"

Fleming's Left hand rule:- The direction of force on a c.c. conductor placed in a magnetic field can be found by Fleming left hand rule

"Stretch out the fore finger points in the direction of the magnetic field, middle finger points towards the direction of current, thumb will point in the direction of motion of the conductor"