UNIT - II

D.C MACHINES

* ElectroMechanical Energy Conversion :

* An Electrical Machine, deals with the Energy transfer Either from Mechanical to Electrical form or from Electrical to Mechanical form.

* this process is called ElectroMechanical Energy Conversion.

* Introduction to D.C Machines :-

* An Electrical Machine which converts Mechanical Energy into an Electrical Energy is called an Electric generator.

* While an Electrical Machine which converts an Electrical Energy into Mechanical Energy is called an Electrical Motor.

* Such Electrical Machines May be related to an Electrical Energy of an alternating type called a.c. Machines. or May be related to an Electrical Energy direct type called D.C. Machines.

* The D.C. Machines are classified as D.C. generator & D.C Motor.

* the construction of a d.c Machine is same whether it is a generator or Motor.

* D.C. generator:

* Basic conversion principle:-

An Electrical Machine which converts Mechanical Energy into Electrical Energy is called an Electric generator.

* Operating principle of D.C generator:-

When a rotating conductor is placed in a Magnetic field, when the conductor cut's the Magnetic flux a dynamically induced EMF will be produced in the conductor.

* All the generators works on a principle of dynamically induced Emf.

* this principle is nothing but the faraday's law of ElectroMagnetic induction.

* It states that, "when ever the number of Magnetic lines of force i.e, flux linking with a conductor or a coil changes, an Electromotive force is set up in that conductor or coil."

* The Change in flux associated with the Conductor can Exist only when there Exists a relative Motion between a Conductor & the flux.

* the relative Motion can be achieved by rotating Conductor with respect to flux, or by rotating flux with respect to a Conductor.

* So a Voltage gets generated in a Conductor, as long as there Exists a relative motion between Conductor and the flux.

* Such an induced Emf which is due to Physical movement of coil or Conductor with respect to flux or movement of flux with respect to coil or Conductor is Called dynamically induced Emf.

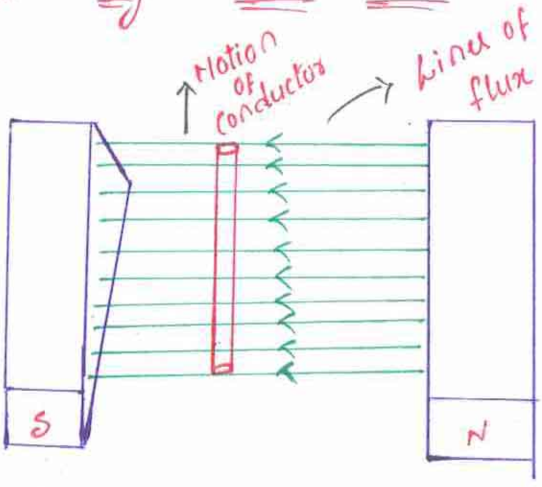
* In a practical generator, the Conductors are rotated to Cut the Magnetic flux, Keeping flux Stationary.

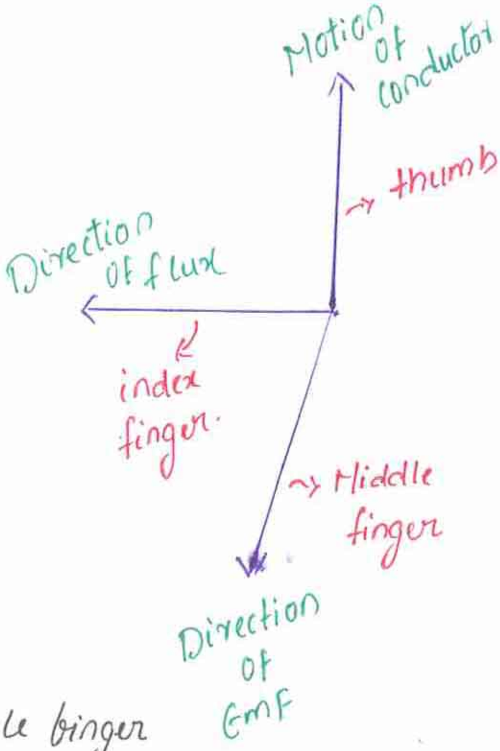
* To have a large Voltage as the Output, the number of Conductors are Connected together in a Specific Manner, to form a winding.

* this winding is Called Armature winding of a D.C. Machine. the part on which this winding is kept is Called Armature of D.C. Machine.

* The part on which this winding kept is Armature.
* to have the rotation of the conductor, the conductors placed on the Armature are rotated with the help of some External device. Such External device is called a prime mover.
* the necessary magnetic flux is produced by current carrying winding which is called field winding.
* The direction of the induced E.M.F can be obtained by using fleming's right hand rule.

* **Fleming's Right hand Rule :-**



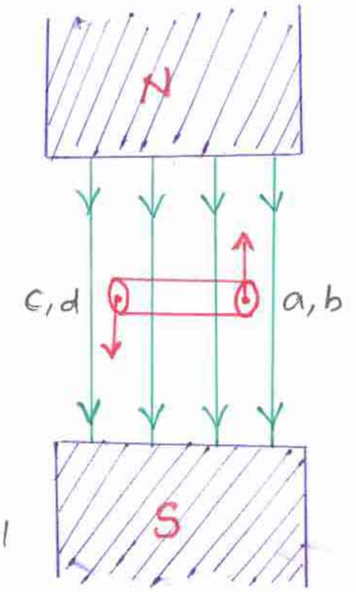


* if three fingers of a right hand, namely thumb, index finger & middle finger are outstretched so that every one of them is at right angles with the remaining two, then index finger shows the direction of lines of flux. thumb indicates the direction of Motion of the Conductor. Middle finger gives the direction of induced EMF in the Conductor.

* Magnitude of induced EMF At Various positions of Coil :

Consider different instants and positions of conductor.

* Instant - I :

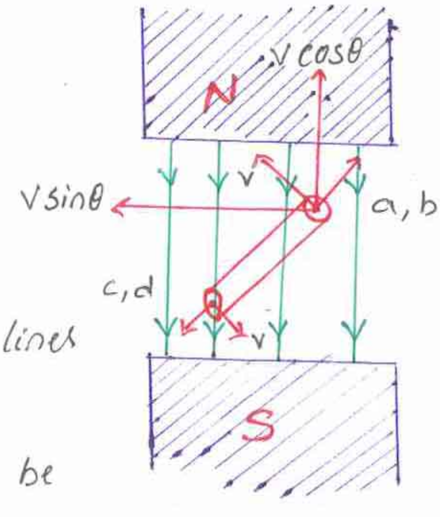


$\theta = 0^\circ$

EMF is zero

* let the intial position of the coil be shown in the big:
* the plane of the coil is perpendicular to the direction of Magnetic field.
* the instantaneous components of velocity of conductors "a, b" & "c, d" is in parallel to the Magnetic field & there cannot be the cutting of the flux lines by the conductors.
* Hence no E.m.f will be generated in the conductor.

* Instant - II

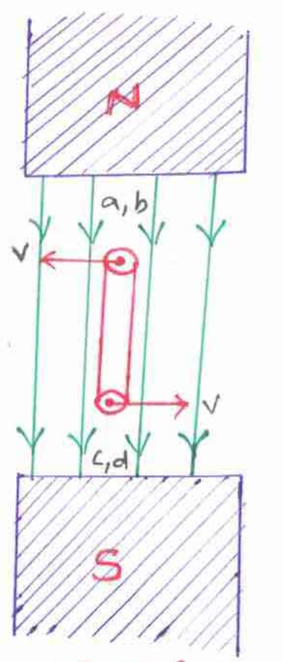


$0^\circ < \theta < 90^\circ$

* when the coil is rotated in anticlockwise direction through some angle "θ", the velocity will have two components "Vsinθ" perpendicular to flux lines & "Vsinθ" parallel to the flux lines.
* Due to Vsinθ component, there will be cutting of the flux & proportionally there will be an induced E.m.f in the conductor a,b & c,d.

Instant - III

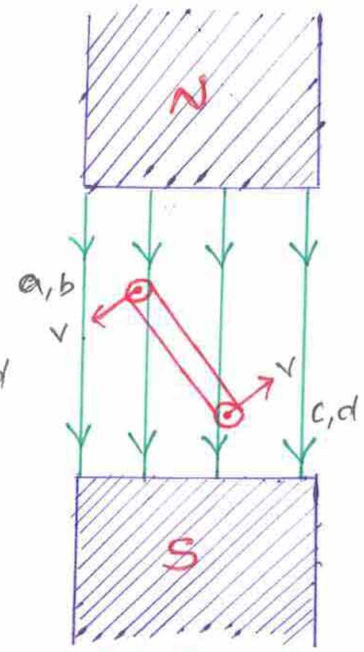
* As angle "θ" increases, the components of velocity acting perpendicular to flux lines increases, hence induced Emf also increases
* At θ = 90°, the plane of the coil is parallel to the plane of the Magnetic field while the component of velocity cutting the lines of flux is at its Maximum.
* So, induced Emf at this position is maximum in the conductor.



θ = 90°
Maximum E.M.F

Instant - IV

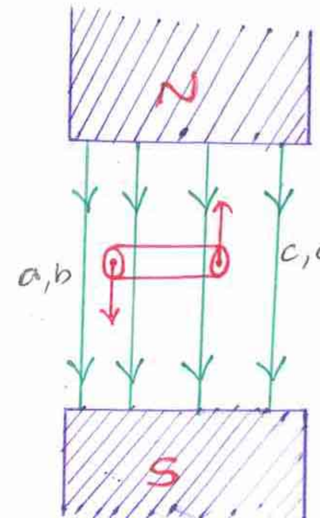
* As the coil continues to rotate further from θ = 90° to 180°, the components of velocity, perpendicular to magnetic field starts decreasing, hence gradually decreasing the magnitude of the induced Emf.
* this is shown in the fig:



90° < θ < 180°

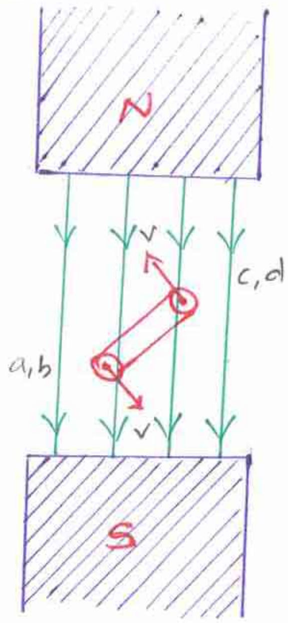
Instant - V

* In this position, the velocity component is fully parallel to the lines of flux similar to the instant - 1.
* Hence there is no cutting of flux & hence no induced E.M.F in both the conductors.



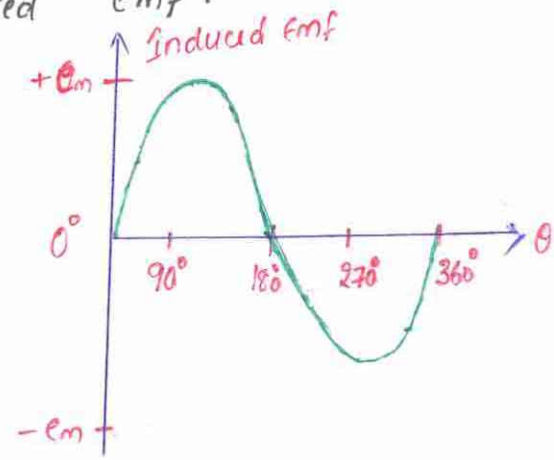
θ = 180°

Instant - 6 :-



$180^\circ < \theta < 270^\circ$
Direction of E.m.f reverses

* As the coil rotates beyond $\theta = 180^\circ$, the conductor "a, b" uptill now cutting flux lines in one particular direction reverses the direction of the cutting flux lines. Similarly for the conductor "c, d".
* the direction of the induced Emf in conductor is opposite to the direction of induced Emf in it for the rotation $\theta = 0^\circ$ to 180°.
* this is because the direction of rotation of conductors reverses with respect to field as "θ" varies from 180° to 360°.
* this process continues as coil rotates further.
* At $\theta = 270^\circ$ again again the induced Emf achieves its maximum value but the direction of this Emf in both the conductors is opposite to the previous max:- position i.e, $\theta = 90^\circ$.
* from $\theta = 270^\circ$ to 360°, induced Emf decreases without change in direction & at $\theta = 360^\circ$, coil achieves the starting position with zero induced Emf.
* the alternating Emf induced in the conductor is shown in the fig:-



* In D.C generator, such alternating induced Emf is rectified to get unidirectional D.C. Emf with the help of commutators.

* E.M.F Equation Of D.C. Generator :-

Let

P = Number of poles of the generator

ϕ = flux produced by each pole in webers

N = Speed of armature in r.p.m.

Z = Total number of armature Conductors

A : Number of parallel path's in which "Z" number of Conductors are divided.

$\therefore$ $A = P$ for lap type of winding

$A = 2$ for wave type of winding.

Now e.m.f get's induced in the Conductor according to faraday's law of Electromagnetic induction.

Hence average value of E.m.f induced in each armature Conductor is,

$$e = \text{Rate of cutting the flux} = \frac{d\phi}{dt}$$

Now consider one revolution of Conductor. In, one revolution conductor will cut total flux produced by all the poles i.e, $\phi \times P$.

$$\Rightarrow d\phi = \phi \times P$$

time required to Complete one revolution is $\frac{60}{N}$ sec as speed is "N" rpm.

$$\therefore \quad e = \frac{d\phi}{dt} = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}$$

$$\therefore \quad e = \phi P \frac{N}{60}$$

this is the Emf induced in one conductor.

Now the conductors in parallel path's are always in series.

Since there are total "Z" conductors with "A" parallel paths, hence "$\frac{Z}{A}$" number of conductors are always in series and E.m.f remains same across all the parallel paths.

$\therefore$ Total E.m.f can be Expressed as

$$E = \phi P \frac{N}{60} \times \frac{Z}{A} \text{ volts.}$$

$$\therefore \quad E = \frac{\phi P N Z}{60A}$$

the above Equation is E.m.f of a d.c. generator

for lap type generator $A = P$

$$\therefore \quad E = \frac{\phi N Z}{60}$$

for wave type generator $A = 2$

$$\therefore \quad E = \frac{\phi P N Z}{120}$$

* **Example :- 1** An 8-pole, dc generator has a lap-wound Armature. when driven at a Constant Speed of 440 r.p.m. it generates 220V. The armature has 50 slots. the flux/pole is 15 mWb. Find the number of Conductors per Slot.

Sol:- given

poles $P = 8$

speed $N = 440$ r.p.m

$E = 220$ V

$S = 50$

$\phi = 15$ mWb $= 15 \times 10^{-3}$ Wb

generated Emf $E = \dfrac{\phi Z N P}{60A}$

$$\Rightarrow 220 = \frac{15 \times 10^{-3} \times Z \times 440 \times 8}{60 \times 8} = 0.11 Z$$

for lap winding, Number of Armature $\|^{le}$ paths $= A = P = 8$

$\therefore$ Total Number of Armature conductors

$$Z = \frac{220}{0.11} = 2000$$

$\therefore$ Number of conductors per slot $= \dfrac{Z}{S} = \dfrac{2000}{50}$

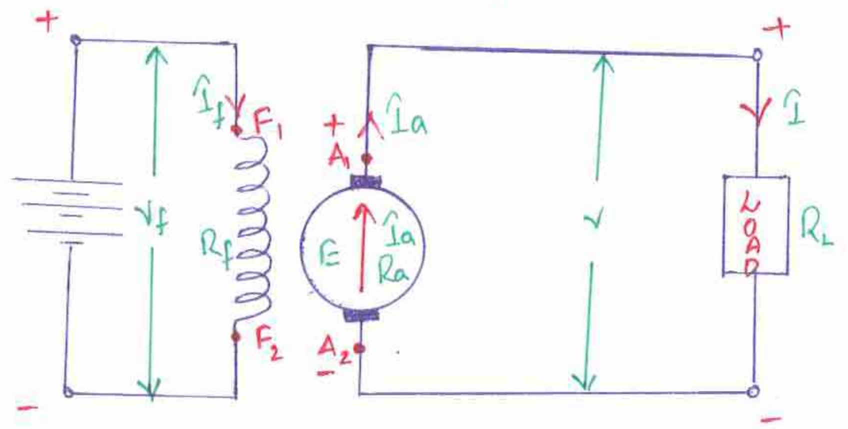
$= 40$

* Classification of D.C generators :-

Depending upon the type of field Excitation D.C. Machines are Classified into two types

① Seperately Excited generator ② Self Excited generator

* Seperately Excited DC generator :-



* In this type of generators, its field winding is Excited by a Seperate D.C Source.
* So the D.C Source is connected across the field terminals "F_1" & "F_2" as shown in the fig.
* there is no Electrical Connection between the field & Armature winding "A".
* An Electrical Load is Connected across the Armature "A_1" & "A_2".
* the D.C Supply generated by the generator is not used to Excite it's winding. the Seperated dc Supply passes the field current "I_f" through the field winding to produce the flux.
* this is known as Seperate - Excitation.

* Voltage and Current Relations for Seperately Excitied DC generator are :

from the fig: for the field ckt

field Current $I_f = \frac{V_f}{R_f}$

* V_f : field winding Voltage
* R_f : field Resistance

from the Armature & Load ckt

Emf induced in Armature = E

Voltage drop in Armature resistance = $I_a R_a$

Voltage drop in Brush contacts = V_b

Terminal Voltage (or) Load Voltage

$$V = E - I_a R_a - V_b$$

* I_a : Armature Current
* R_a : Armature resistance

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

for Load Branch $V = I R_L$

$\therefore$ Load Current $I = \frac{V}{R_L}$

* I_L : Load Current
* R_L : Load Resistance

but $I_a = I$

$\therefore$ Armature Current $I_a = I = \frac{V}{R_L}$

* power developed in the Armature

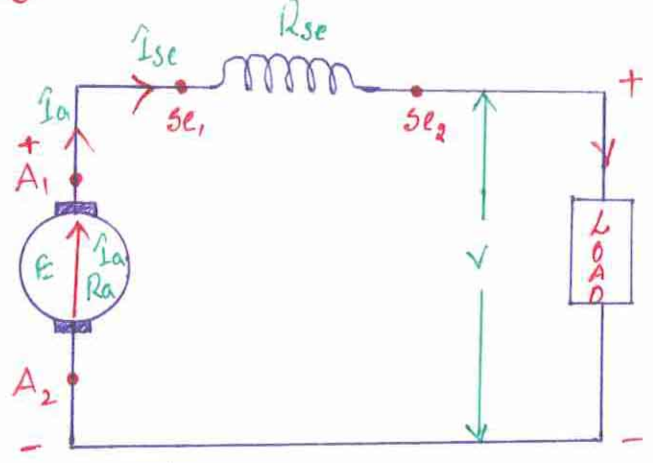
$$P_g = E I_a$$

* power Output = VI $\Rightarrow P_{o/p} = V I_a$

* Self - Excited D.C. generator :-

* In these generators, there is an Electrical Connection between the field & Armature windings.
* field winding is Excited by the Emf generated in the generator itself. this is known as Self - Excitation.
* the Emf induced in the Armature winding delivers Current to the field winding to produce the flux.
* there are different types of D.C. generators of Self - Excitation.

* DC Series generator :



* In this generator the field winding is Connected in Series with the Armature winding. so the Series field winding carries large Armature Current.
* the Series field winding is characterised by the few turns of the thick wire to produce require field M.M.F.
* its resistance "Rse" is very small.

Voltage & Current relation :-

* Armature Current $I_a = I_{se} = I = \frac{V}{R_L}$

* Terminal Voltage : $V = E - I_a R_a - I_{se} R_{se} - V_b$

$$\therefore \quad V = E - I_a [R_a + R_{se}] - V_b$$

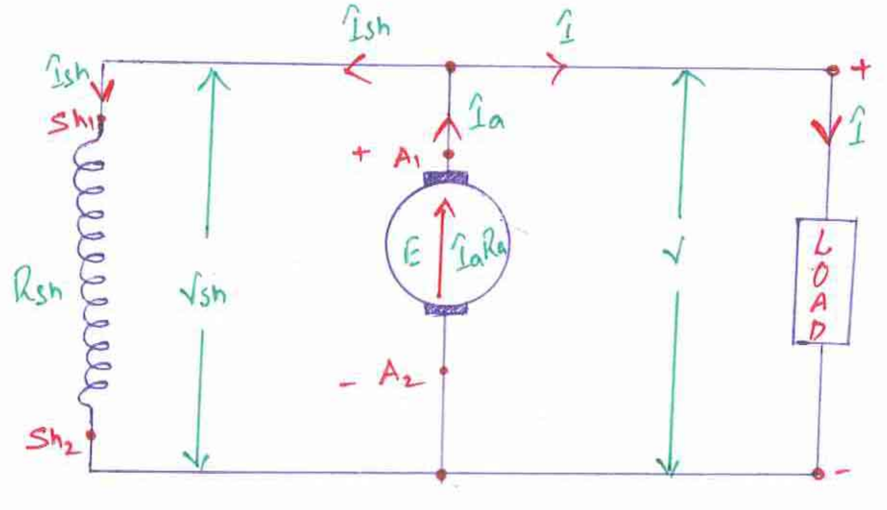
where R_a = Armarature resistance

R_{se} = Series field resistance

* power developed in Armature $P_g = E \cdot i_a$

* power output = $VI = VI_a$

* D.C Shunt generator :-



* In this generator, the field winding is Connected in parallel with the Armature winding as shown in fig:
* so the Shunt field Carries relatively Small Current. Hence it is Characterised by Large Number of turns of thin wire to produce the Necessary field m.m.f.
* it Resistance "Rsh" is large Compare to Series field resistance

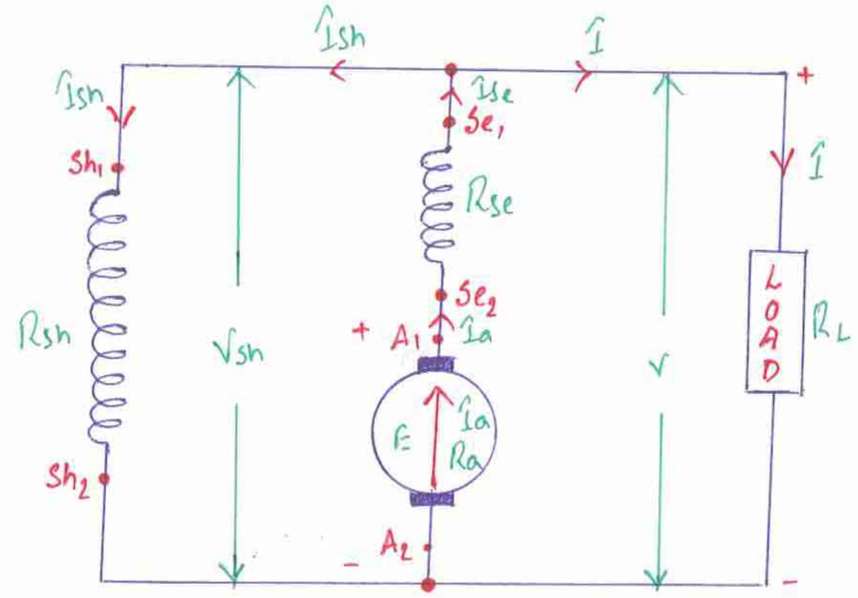
* Voltage & Current relation:-

* Terminal Voltage : $V = I R_L$
* Load Current $I = \frac{V}{R_L}$
* $V_{sh} = V$
* Shunt field Current $I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V}{R_{sh}}$
* Armature Current $I_a = I + I_{sh}$
* $V = V_{sh} = E - I_a R_a - V_b$
* power developed = $E \cdot I_a$
* power Output = $V \cdot I$

* D.C. Compound generator:-

* this type of generator has both the types of field windings. i.e, both Series & Shunt field windings wound on the Same magnetic poles.
* the Series field winding is recognised by a thick wire & few turns. So its resistance is Small & it Caries high Current.
* the Shunt field winding is Characterised by a thin wire and large Number of turns. So its resistance is large & it Carries Small Current.
* the two field windings are connected in two ways & accordingly the Compound generators are Classified into two types.

* Long Shunt Compound generator:-



* In this type of generator, the Shunt field winding is Connected in parallel with the Series Circuit of the Armature winding & Series field winding as Shown in the fig:-

Voltage & Current Relations:-

$$V_{sh} = V - I R_L$$

$$I = \frac{V}{R_L} \quad ; \quad I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V}{R_{sh}}$$

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

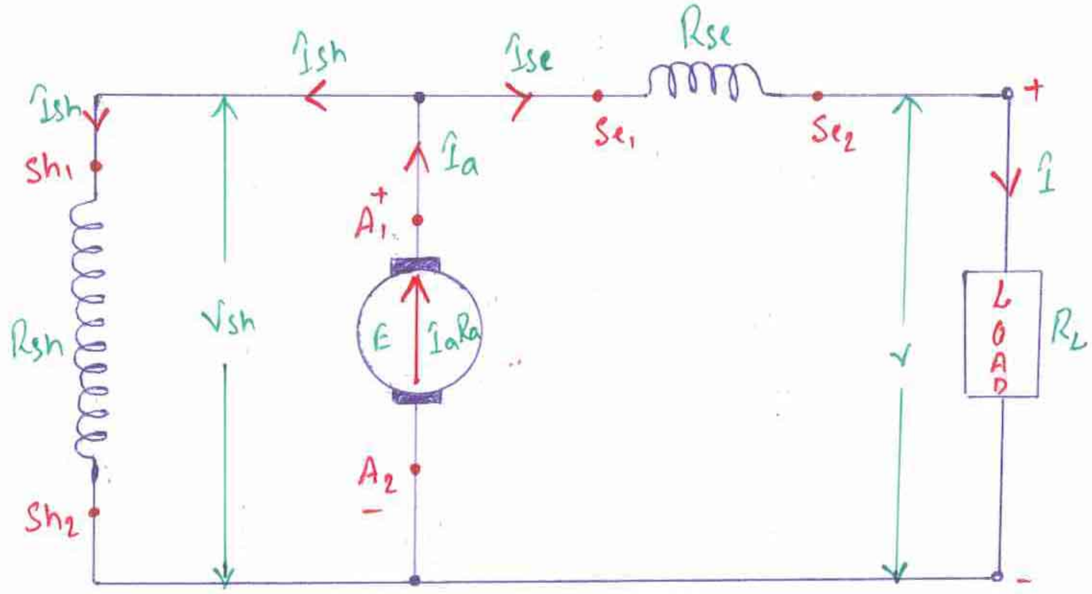
$$V = V_{sh} = E - I_a R_a - I_{se} R_{se} - V_b$$

$$\therefore \quad V = E - I_a [R_a + R_{se}] - V_b$$

power developed $= E \cdot I_a$

power Output $= V \cdot I$

* Short Shunt Compound generator:



* In this type of compound generator, the series field wingding is connected in series with the ‖le ckt of the Armature winding & Shunt field winding.

Voltage & Current relation:

$V = I.R_L$ (or) $I = \frac{V}{R_L}$

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

$I = I_{se}$

$I_a = I + I_{sh}$

$V_{sh} = E - I_a R_a$

$V = V_{sh} - I_{se} R_{se}$

$V = V_{sh} - I R_{se}$

$V = E - I_a R_a - I R_{se}$

* power developed $= E.I_a$
* power Output $= V.I$

* Applications of D.C generators:-

Sl. NO	Type of generator	features	Applications.
1	Seperately Excited generator.	* Costly due to Sperate Excitation. * Quick & precise response to the change in field resistance.	* Ward - Leonard system of Speed Control. * Electro - plating. * Electro - refining of materials.
2.	Series generator	* Rising Load Characteristic. * higher voltage for higher current.	* Supply field current for regenerative braking in D.C Locomotives. * Series boosters & line voltage drop Compensators for feeder lines of tram- cars, trolley buses.
3	Shunt generator	* Constant terminal voltage * Adjustable voltage with field regulator.	* Best suited for Battery Charging. * Lighting Supplies * power Supplies.
4	over Compound gen:	* Rising Load Characteristic.	* Lighting & power supplied as it can compensate voltage drop in distribution lines.
5	flat or level compound generator	* fairy constant voltage from no load to full load conditions.	* frequently ON - OFF, intermittent & variable loads.
6	under Compound generator.	* Drooping load Characteristics * Approximately constant voltage	* Lighting & power Supplies.
7	Differentially compound generator	* Rapidly falling voltages * Heavely drooping Char: * frequent Short ckt on Load.	* As an Arc welding generator where it is short - circuited frequently when the Electrode touches the metallic plates to be welded.

* D.C. Motor introduction:

* A D.C. Motor is defined as the Electromagnetic Rotating Machine which converts a D.C. Electrical Energy into the rotary mechanical Energy.

* the construction of D.C. Motor is Same as D.C. generator.

* Operating principle of D.C. Motor:

> when a current carrying conductor is placed in the magnetic field, the conductor Experiences a mechanical force which tends to move the conductor in its own direction with respect to magnetic field.

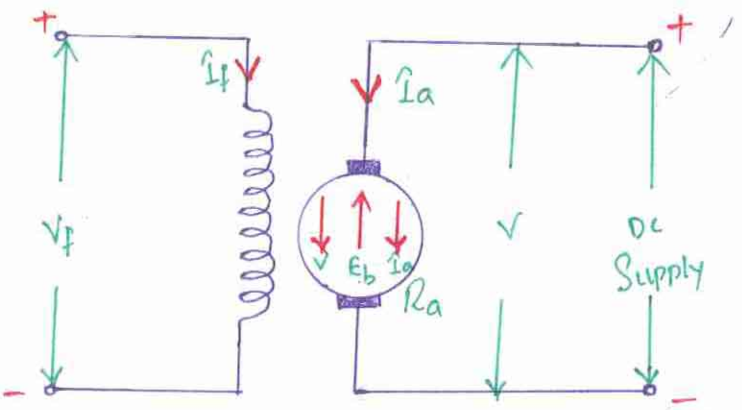
* the direction of rotation of conductor is given by flemings left hand rule.

* let a conductor of length "l" meters carrying current of "I" Amperes. when it is placed in the magnetic field of uniform flux density "B" teslas (wb/m^2) A mechanical force of "F" Newtons is developed on it.

* the force is given by

$$F = BIl$$

* Back EMF in D.C. Motor:



* Motoring Action :

* The working of the D.C Motor may be briefly Summarised as follows.
* A D.C Supply "V_f" is given to the field winding to produce the field Current "I_f" in it. it produces the main flux "ϕ".
* A D.C Supply is given to the Armature winding to produce the Armature Current "I_a" in it.
* then the Current Carrying Armature Conductors placed in the main - flux Expreance forces & the Armature Starts due to the resultant unidirectional torque developed by these forces.

* Generating Action [production of Back EMF] :

* just Similar to the principle of working of a D.C. generator, there is a motoring Action is associated in D.C. Motor like generating Action.

* During the rotation of Armature the main flux is cut by the Armature winding & an Emf is induced in it according to the faraday's law of Electromagnetic induction.

* the Magnitude of this Emf is given by the rate of change of flux.

* the direction of this induced Emf is given by the lenz's law which states that the Emf induced must oppose the Cause of its production.

* the E.M.F is Caused by the rotation which is Caused by the torque.

* But the torque is Caused by the Armature Current which is Caused by Supply voltage "V".

* thus the real Cause of the production of this Emf is Supply voltage. So this Emf opposes the Supply voltage according to lenz's law.

* hence the Emf is Called back Emf (or) Counter Emf due to its backward direction.

* EMF Equation of Motor:

let

ϕ : flux per pole in wb

Z : No. of Armature Conductors.

N : Speed of Armature in rpm

P : No. of poles.

A : No. of parallel path in Armature winding

During the rotation of the Armature

Total flux cut by each conductor in one revolution

= flux per pole × No. of poles

= ϕP webers.

Time required for one revolution = $\frac{1}{N}$ minute = $\frac{60}{N}$ sec

According to faraday's law of Electromagnetic induction,

Average induced emf in each conductor

E = Average rate of cutting the flux = $\frac{\text{flux}}{\text{time}}$

$$E = \frac{\phi P}{\frac{60}{N}} = \frac{\phi P N}{60} \text{ volts}$$

∴ Total emf generated in the dc Armature

E_b = emf / conductor × No of Conductor / parallel path

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

A = 2 for wave

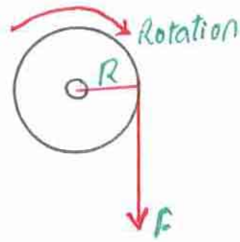
A = P for lap

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

$E_b \propto \phi N$

* Toraue Eauation of D.C. Motor:

Deff: of Toraue: The turning or twisting force about an axis is called toraue.



Consider a wheel of radius "R" meters acted upon by a circumferential froce "F" Newtons as shown in the big:

The wheel is rotated at a speed of "N" rpm.

Then the Angular Speed of the wheel is

$$\omega = \frac{2\pi N}{60} \text{ rad/sec.}$$

So work done in one revolution is

$$W = F \times \text{Distance travelled in one revolution}$$

$$= F \times 2\pi R \text{ Joules}$$

Power developed $P = \frac{\text{work done}}{\text{time}}$

$$= \frac{F \times 2\pi R}{\text{time for 1 rev}} = \frac{F \times 2\pi R}{\frac{60}{N}}$$

$$P = [F \times R] \times \left[\frac{2\pi N}{60}\right]$$

$$\therefore P = T \times \omega \text{ watts}$$

where T = toraue in N-M

ω = Angular speed in rad/sec.

Let "τ_a" be the gross torque developed by the Armature of the Motor. it is also called Armature torque.

the gross mechanical power developed in the Armature is $E_b I_a$ from the power Equation.

if Speed of the Motor is "N" rpm then

power in Armature = Armature torque × ω

$$\therefore \quad E_b I_a = \tau_a \times \frac{2\pi N}{60}$$

But E_b in a Motor is given by

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

$$\therefore \quad \frac{\phi P N Z}{60 A} \times I_a = \tau_a \times \frac{2\pi N}{60}$$

$$\therefore \quad \tau_a = \frac{1}{2\pi} \phi I_a \times \frac{P Z}{A}$$

$$\boxed{\tau_a = 0.159 \phi I_a \cdot \frac{P Z}{A}} \quad N\text{-}M$$

this is the torque Equation of a d.c. Motor.

* Power Equation of D.C. Motor:-

The voltage Equation of D.C Motor is given by

$$V = E_b + I_a R_a$$

Multiplying both Sides of the above Equation by "I_a"

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

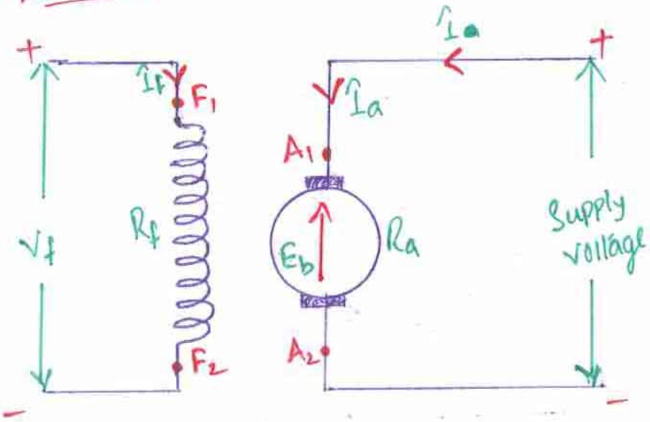
this Equation is Called power Equation of D.C. Motor.

* Types of D.C. Motors:

Like that of D.C. generators, D.C. Motors are classified into two types

* Seperately Excited D.C. Motor * Self Excited D.C. Motor

* Seperately Excited D.C. Motor:-



* in this type of Motor there is no Electrical connection between the Armature & field windings.
* Seperate independent D.C. Supplies are given to its Armature & field windings as shown in the fig:

* Voltage & Current relations:

V_f : Voltage across field winding

i_f : field Current

R_f : field resistance

$\therefore$ field Current $I_f = \frac{V_f}{R_f}$

Armature Current "I_a" = Line Current "I"

$$V = E_b + I_a R_a + V_b$$

generally "V_b" is neglected

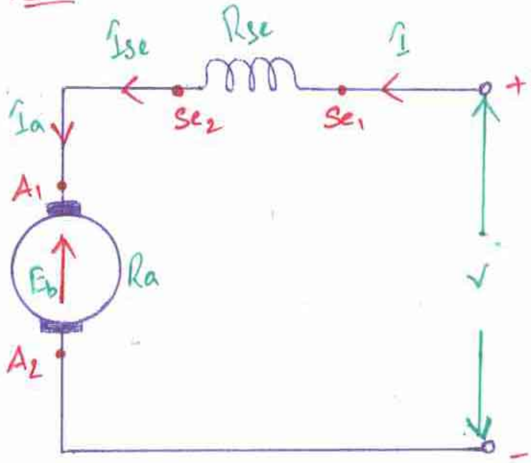
* when there is no Magnetic Saturation, the flux produced by the field winding is proportional to field Current

$$\therefore \phi \propto I_f$$

* Self Excited D.C Motor:

* In case of Self-Excited dc Motors, there is Electrical Connection between the Armature & field winding.
* the Same supply is applied to both the " to produce field current for production of flux & to produce Armature Current for the production of "E_b" and Torque.

* D.C. Series Motor:



* in this motor, field winding is connected in series with the Armature winding.

* Voltage & Current relations:

Armature Current "I_a" = Series field current "I_{se}" = Line Current "I"

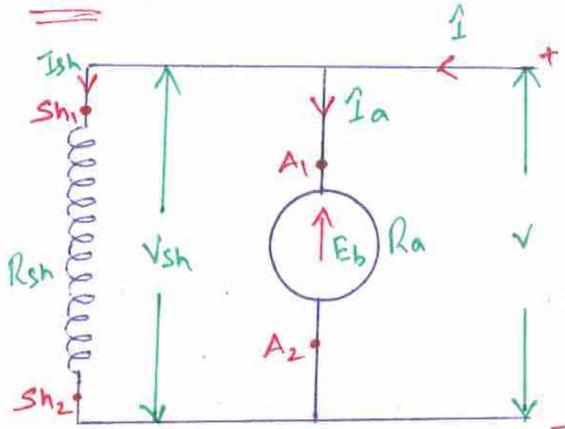
$$V = E_b + I_a R_a + I_{se} R_{se} + V_b$$

$$\therefore V = E_b + I_a [R_a + R_{se}] + V_b$$

in the absence of magnetic Saturation

$\phi \propto I_{se} \propto I_a$.

* D.C. Shunt Motor:



* In this motor, the field winding is connected in $\parallel^{le}$ with the Armature winding.

* **Voltage & Current relation:**

Shunt field voltage V_{sh} = Applied voltage "V"

Shunt field Current $I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V}{R_{sh}}$

Armature Current $I_a = I - I_{sh}$

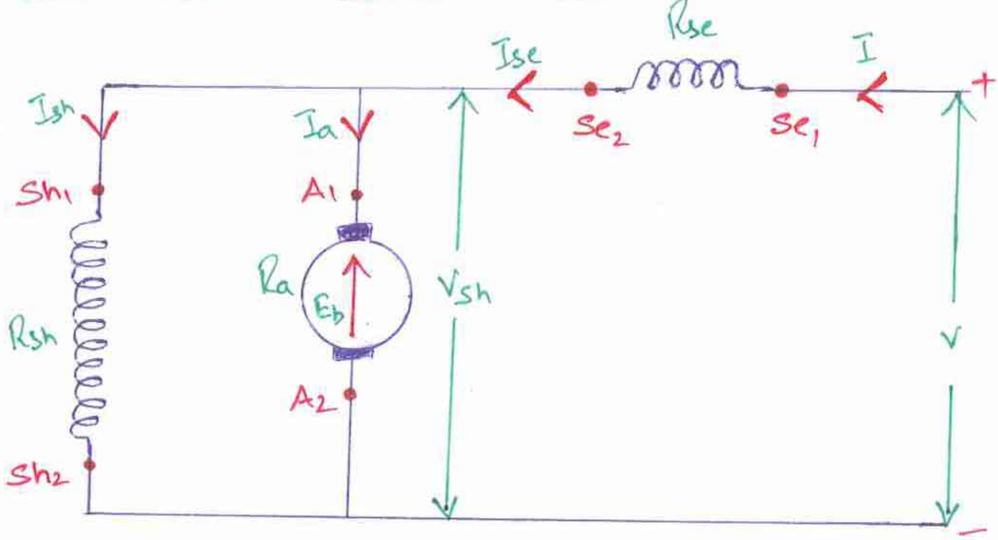
$V = E_b + I_a R_a + V_b$

In the Absence of Magnetic Saturation

flux $\phi \propto I_{sh} \propto \frac{V}{R_{sh}}$ which is Constant.

* **D.C Compound motor:-**

* **Short Shunt Compound Motor:-**



* **Voltage & Current relation:**

Series field Current I_{se} = Line Current I

Voltage across Armature = Voltage across Shunt field

$V_{sh} = V - I_{se} R_{se} = V - I R_{se}$

$V_{sh} = E_b + I_a R_a + V_b$

Applied Voltage $V = V_{sh} + I R_{se}$

$\therefore V = E_b + I_a R_a + V_b + I R_{se}$

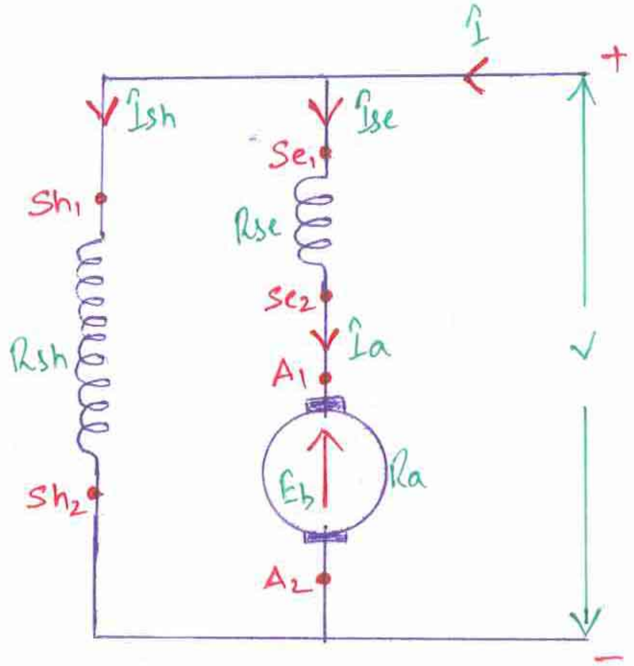
$I = I_{se} = I_a + I_{sh}$

$\because$ field Current $I_{sh} = \frac{V_{sh}}{R_{sh}}$

$\Rightarrow \frac{V - I R_{se}}{R_{sh}}$

$\Rightarrow \frac{E_b + I_a R_a + V_b}{R_{sh}}$

* Long Shunt Compound Motor:-



Voltage & Current relation:-

Armature Current $I_a = I_{se}$

Line Current $I = I_{se} + I_{sh} = I_a + I_{sh}$

$V = V_{sh}$

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

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

$$= E_b + I_a R_a + I_a R_{se} + V_b$$

$$V = E_b + I_a [R_a + R_{se}] + V_b$$

* Applications of D.C. Motors:

Sl. NO	Type of Motor	Characteristics	Applications.
1	Seperately Excited DC Motor.	* Very accurate Speeds * wide Speed variation	* Steel rolling Mills, paper Machines, diesel-Electric propulsion ships, Control Machines.
2	D.C. Series Motor.	* high Starting torque * Starting on heavy loads * Variable Speed * Adjustable Varying Speed	* Traction & hoisting systems Example: railway trains, trolley-buses, Electric locomotives, hoists, Cranes, Elevators lifts, Conveyors e.t.c.
3	D.C Shunt Motor.	* Approximately constant Speed * Adjustable Speed * Meadium Starting torque upto 1.5 F.L Torque	* Constant - Speed, line - Shafts, Machine tools, Lathes, fans, blowers, centrifugal pumps, reciprocating pumps, boring Machines e.t.c
4	D.C Cumulative Compound Motor.	* high Starting torque * Variable Speed * Adjustable Varying Speed.	* Varying & fluctuating loads, intermittent ON-OFF high torque & heavy duty loads Ex: Shears, punches, planers, Shaping Machines, compressors, ice Machines e.t.c.
5	D.C differential Compound Motor.	* May have constant or rising Speed. * poor Starting torque. * Speed instability	* Not Commonly used May be used for research & Experimental work.

THREE POINT STARTER:

The Fig. 1 shows this type of starter.

The starter is basically a variable resistance, divided into number of sections. The contact points of these sections are called studs and brought out separately shown as OFF, 1, 2, ... upto RUN. There are three main points of this starter :

1. 'L' Line terminal to be connected to positive of supply.
2. 'A' To be connected to the armature winding.
3. 'F' To be connected to the field winding.

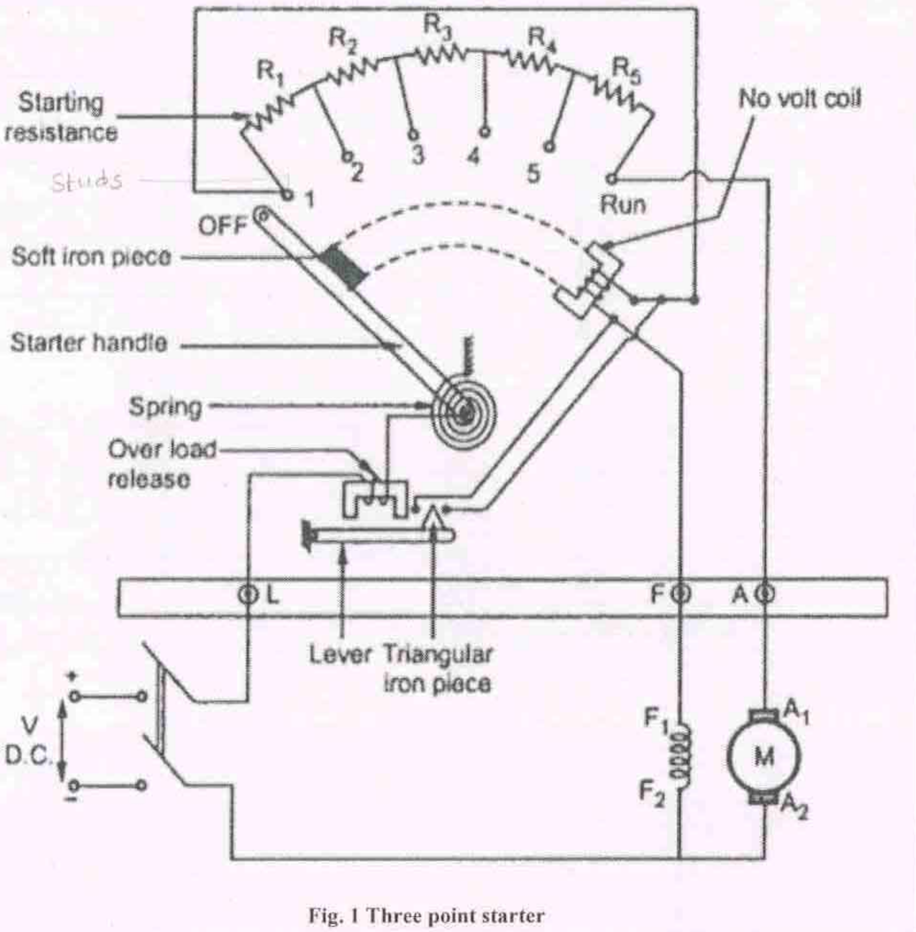


Fig. 1 Three point starter

Point 'L' is further connected to an electromagnet called overload release (OLR). The second end of 'OLR' is connected to a point where handle of the starter is provided. This handle is free to move from its other side against the force of the spring. This spring brings back the handle to the OFF position under the influence of its own force. Another parallel path is derived from the stud '1', given to the another electromagnet called No Volt Coil (NVC). The NVC is further connected to terminal 'F'. The starting resistance is entirely in series with the armature. The OLR and NVC are the two protecting devices of the starter.

Operation: Initially the handle is in the OFF position. The D.C. supply to the motor is switched on. Then handle is slowly moved against the spring force to make a contact with stud No. 1. At this point, field winding gets supply through the parallel path provided to starting resistance, through NVC. While entire starting resistance comes in series with the armature and armature current which is high at start, gets limited. As the handle is moved further, it goes on making contact with studs 2, 3, 4 etc., cutting out the starting resistance gradually from the armature circuit. Finally when the starter handle is in 'RUN' position, the entire starting resistance gets removed from the armature circuit and motor starts operating with normal speed. The handle is moved manually, and the obvious question is how handle will remain in the 'RUN' position, as long as motor is running ?

Let us see the action of NVC which will give the answer to this question along with some other functions of NVC.

1.1 Function of No Volt Coil

1. The supply to the field winding is derived through NVC. So when field current flows, it magnetises the NVC. When the handle is in the 'RUN' position, soft iron piece connected to the handle gets attracted by the magnetic force produced by NVC. Design of NVC is such that it holds the handle in 'RUN' position against the force of the spring as long as supply to the motor is proper. Thus NVC holds the handle in the 'RUN' position and hence also called hold on coil.

2. Whenever there is supply failure or if field circuit is broken, the current through NVC gets affected. It looses its magnetism and hence not in a position to keep the soft iron piece on the handle, attracted. Under the spring force, handle comes back to OFF position, switching off the motor. So due to the combination of NVC and the spring, the starter handle always comes back to OFF position whenever there is any supply problems. The entire starting resistance comes back in series with the armature when attempt is made to start the motor everytime. This prevents the damage of the motor caused due to accidental starting.

3. NVC performs the similar action under low voltage conditions and protects the motor from such dangerous supply conditions as well.

1.2 Action of Overload Release

The current through the motor is taken through the OLR, an electromagnet. Under overload condition, high current is drawn by the motor from the supply which passes through OLR. Below this magnet, there is an arm which is fixed at its fulcrum and normally resting in horizontal position. Under overloading, high current through OLR produces enough force of attraction to attract the arm upwards. Normally magnet is so designed that up to a full load value of current, the force of attraction produced is just enough to balance the gravitational force of the arm and hence not lifting it up. At the end of this arm, there is a triangular iron piece fitted. When the arm is pulled upwards the triangular piece touches the two points which are connected to the two ends of NVC. This shorts the NVC and voltage across NVC becomes zero due to which NVC looses its magnetism. So under the spring force, handle comes back to the OFF position, disconnecting the motor from the supply. Thus motor gets saved from the overload conditions.

In this starter, it can be observed that as handle is moved from different studs one by one, the part of the starting resistance which gets removed from the armature circuit, gets added to the field circuit. As the value of starting resistance is very small as compared to the field winding resistance, this hardly affects the field winding performance. But this addition of the resistance in the field circuit can be avoided by providing a brass are or copper are connected just below the stud, the end of which is connected to NVC, as shown in the Fig. 2.

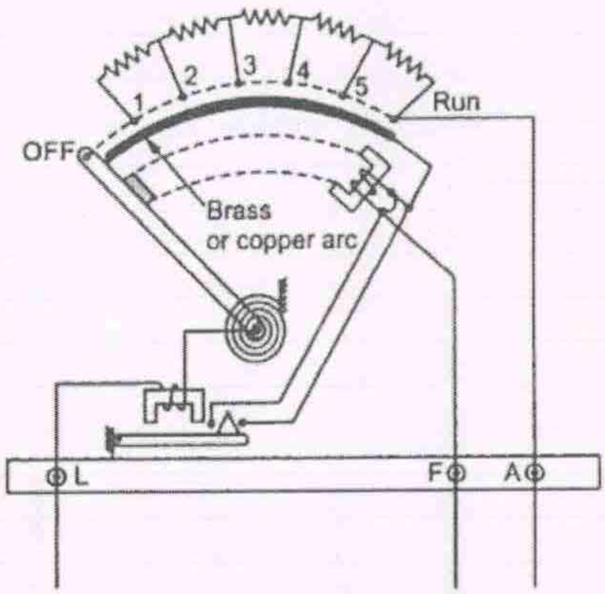


Fig. 2 Three point starter with brass arc

The handle moves over this arc, supplying the field current directly bypassing the starting resistance. When such an arc is provided, the connection used earlier to supply field winding, is removed.

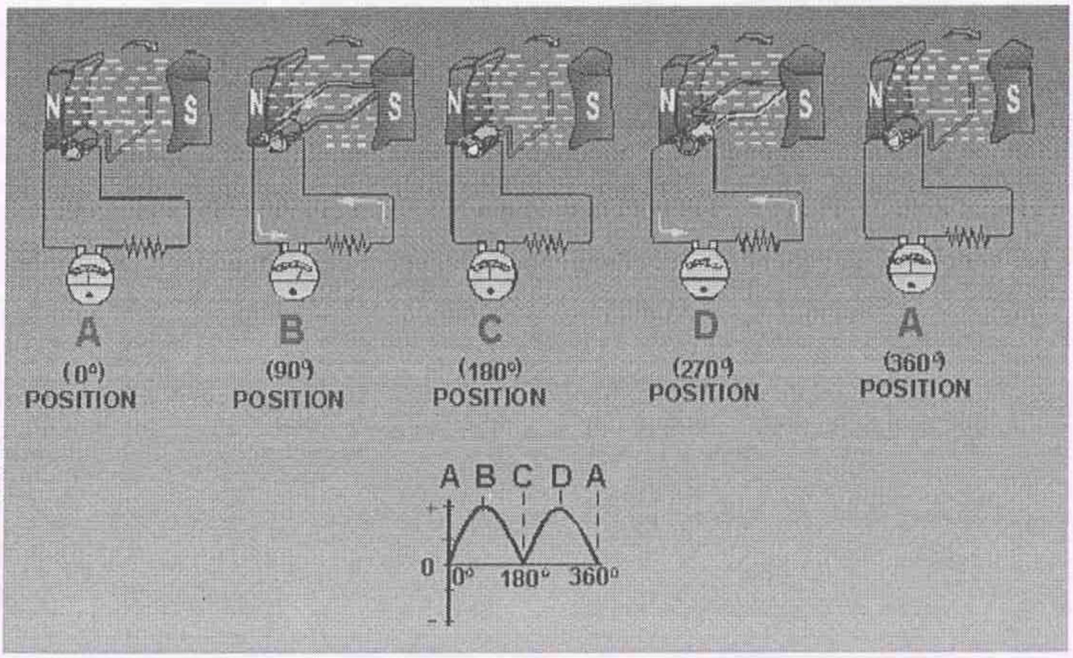
1.3 Disadvantage

In this starter, the NVC and the field winding are in series. So while controlling the speed of the motor above rated, field current is reduced by adding an extra resistance in series with the field winding. Due to this, the current through NVC also reduced. Due to this, magnetism produced by NVC also reduces. This may release the handle from its RUN position switching off the motor. To avoid the dependency of NVC and the field winding, four point starter is used, in which NVC and the field winding are connected parallel.

THE ELEMENTARY DC GENERATOR

A single-loop generator with each terminal connected to a segment of a two-segment metal ring is shown in figure 1-4. The two segments of the split metal ring are insulated from each other. This forms a simple **COMMUTATOR**. The commutator in a dc generator replaces the slip rings of the ac generator. This is the main difference in their construction. The commutator mechanically reverses the armature loop connections to the external circuit. This occurs at the same instant that the polarity of the voltage in the armature loop reverses. Through this process the commutator changes the generated ac voltage to a pulsating dc voltage as shown in the graph of figure 1-4. This action is known as commutation. Commutation is described in detail later in this chapter.

Figure 1-4. - Effects of commutation.



For the remainder of this discussion, refer to figure 1-4,parts A through D. This will help you in following the step-by-step description of the operation of a dc generator. When the armature loop rotates clockwise from position A to position B, a voltage is induced in the armature loop which causes a current in a direction that deflects the meter to the right. Current flows through loop, out of the negative brush, through the meter and the load, and back through the positive brush to the loop. Voltage reaches its maximum value at point B on the graph for reasons explained earlier. The generated voltage and the current fall to zero at position C. At this instant each brush makes contact with both segments of the commutator. As the armature loop rotates to position D, a voltage is again induced in the loop. In this case, however, the voltage is of opposite polarity.

The voltages induced in the two sides of the coil at position D are in the reverse direction to that of the voltages shown at position B. Note that the current is flowing from the black side to the white side in position B and from the white side to the black side in position D. However, because the segments of the commutator have rotated with the loop and are contacted by opposite brushes, the direction of current flow through the brushes and the meter remains the same as at position B. The voltage developed across the brushes is pulsating and unidirectional (in one direction only). It varies twice during each revolution between zero and maximum. This variation is called **RIPPLE**.

A pulsating voltage, such as that produced in the preceding description, is unsuitable for most applications. Therefore, in practical generators more armature loops (coils) and more commutator segments are used to produce an output voltage waveform with less ripple.

If a body is capable of rotating about an axis, then force applied properly on this body will rotate it about the axis (axis of rotating). This turning effect of the force about the axis of rotation is called torque.
Torque is the physical quantity which produces angular acceleration in the body.