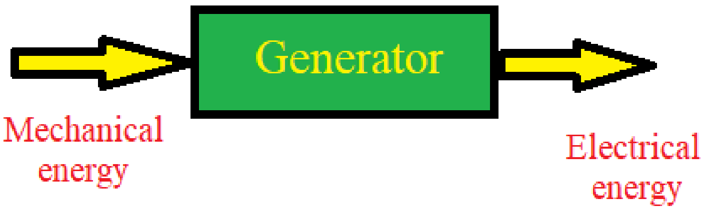
Basic Electrical Engineering

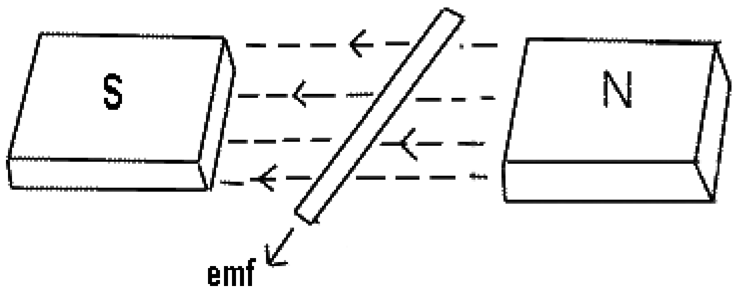
Unit-1: Principal of operation of dc generator, EMF equations, types of dc machines, torque equation of dc motor, applications, three point stators, losses and efficiency, Swinburne's test, speed control methods, occ of dc generators, break test on dc shunt motor, numerical problems.

Generator: generator is a device which converts mechanical energy in to electrical energy.



Generator works on the principle of faradays laws of electro magnetic induction.

Farady's first law: whenever a conductor cuts the magnitc field then an EMF/VOLTAGE to be induced in that conductor.



Faraday's second law: it states that the induced EMF in the conductor is directly proportional to the rate of change in flux (ϕ) cut by the conductor.

$$\text{EMF } \alpha \ \frac{d\phi}{dt}$$

$$\text{Emf} = N\frac{d\phi}{dt}$$

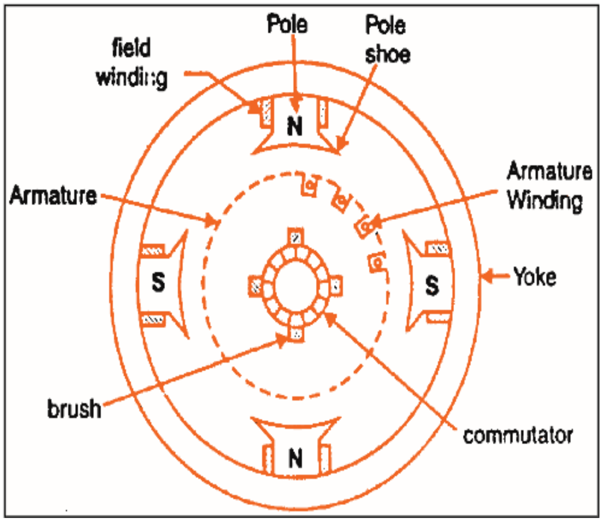
Where N is constant (no. of turns in the conductor)

So the important thing to produce EMF is change in flux $\frac{d\phi}{dt}$ (relative motion between conductor and flux ϕ), it can be produced in two ways.

1. Moving the conductors in a stationary field flux ϕ

2. Moving the field flux ϕ by keeping conductors as stationary.

Construction of dc generator:



Dc generators and dc motors are same construction. A machine can works as generator as well as a motor depending on type of input.

The two important parts in dc machine are stator and rotor

The stator having

1. Yoke
2. Pole core & pole shoe
3. Field wining

And the rotor having

4. Armature
5. Armature winding
6. Commutator and brush arrangement

YOKE: Also called as Frame. Main function of the Yoke is to protect the internal parts of machine from any mechanical injury, dust or moisture. It provides mechanical support to the machine. It also provides the passage for magnetic flux produced by the poles. For small machines, yoke is made up of Cast Iron and for large machines it is made up of fabricated steel.

POLE AND POLE SHOE: Pole of a DC machine is like an Electromagnet. Field windings are placed on it and produces the magnetic flux. Poles are made up of thin cast iron lamination riveted together. Purpose of the pole shoe is to enlarge the cross section area so that the reluctance of the magnetic path is reduced. It spreads the magnetic flux in the air gap more uniformly.

FIELD WINDING: Purpose of the field winding is to produce the magnetic flux when an electric current is passed through it. It is placed on pole and a small DC source is connected to it. Material used for Field Winding is Enameled Copper Wire.

ARMATURE : Armature is the rotating part of the machine and is cylindrical in shape. It is made up of thin silicon steel lamination, which are circular in shape and are riveted together. Thin laminations are used to reduce Eddy Current Loss. On the outer periphery/circumference of the armature, slots are provided to accommodate the Armature winding.

ARMATURE WINDING: They are placed in the slots provided on Armature. Made up of enameled copper wire and have multi-turns. When the Armature rotates, it will also rotate and an emf is induced in these winding. The armature winding of dc generator having two types

1. Wave winding (no. of parallel paths A=2)   2. lap winding (no.of parallel paths A = P).

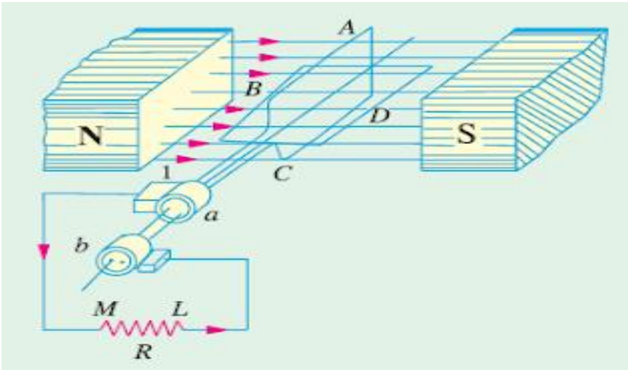
COMMUTATOR: It is mounted on the same shaft as the Armature. Its function is to connect the rotating Armature winding to the stationary external circuit using brushes. It also provide uni-directional torque in case of DCmotor. Commutator is cylindrical in shape and is made up of hard drawn copper segments. These segments are insulated from each other by a thin sheet of mica.

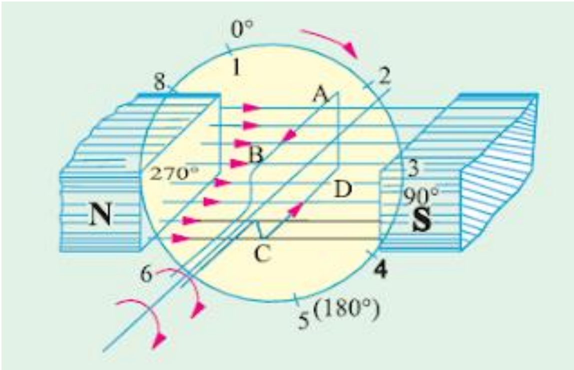
BRUSHES: Brushes are placed and pressed upon the commutator and makes a connecting link between the armature winding and the external circuit. Brushes are made up of high grade carbon and it is placed in a particular position around commutator by brush holder.

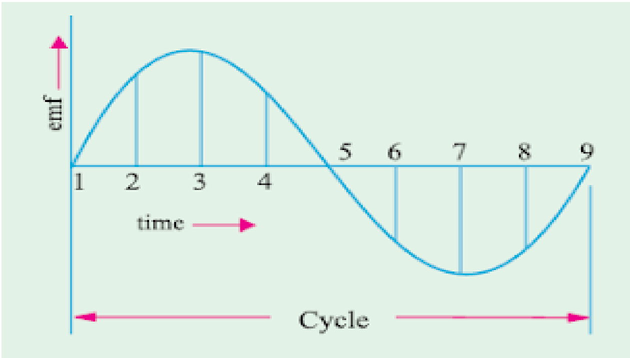
Working of dc generator: (single loop generator)

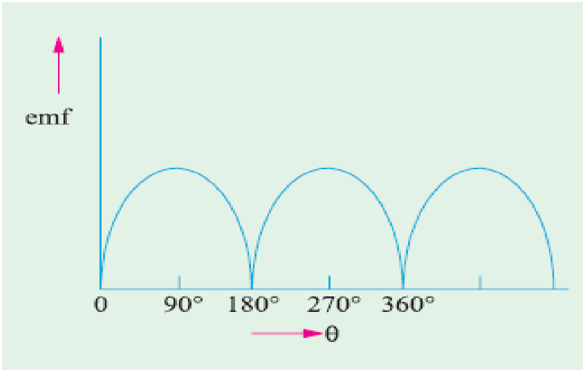
An electrical generator is a machine which converts mechanical energy into electrical energy. The energy conversion is based on the principle of the production of dynamically induced e.m.f. whenever a conductor cuts magnetic flux, dynamically induced e.m.f is produced in it according to Faraday's Laws of Electromagnetic Induction. This e.m.f. causes a current to flow if the conductor circuit is closed. Hence, two basic *essential parts of an electrical dc generator are (i) a magnetic field and*

(ii) a conductor or conductors which can so move as to cut the flux.









Construction

A single-turn rectangular copper coil ABCD rotating about its own axis in a magnetic field provided by either permanent magnet is or electromagnets. The two ends of the coil are joined to two slip-rings 'a' and 'b' which are insulated from each other and from the central shaft. Two collecting brushes (of carbon or copper) press against the slip-rings. Their function is to collect the current induced in the coil and to convey it to the external load resistance R. The rotating coil may be called 'armature' and the magnets as 'field magnets'.

Working

Imagine the coil to be rotating in clock-wise direction . As the coil assumes successive positions in the field, the flux linked with it changes. Hence, an e.m.f. is induced in it , D.C. Generators EMF proportional to the rate of change of flux linkages (e = N $\frac{d\phi}{dt}$). When the plane of the coil is at right angles to lines of flux i.e. when it is in position, 1, then flux linked with the coil is maximum but rate of change of flux linkages is minimum. It is so because in this position, the coil sides AB and CD do not cut or shear the flux, rather they slide along them i.e. they move parallel to them. Hence, there is no induced e.m.f. in the coil. Let us take this no-e.m.f. or vertical position of the coil as the starting position. The angle of rotation or time will be measured from this position.

As the coil continues rotating further, the rate of change of flux linkages (and hence induced e.m.f. in it) increases, till position 3 is reached where θ = 90º. Here, the coil plane is horizontal i.e. parallel to the lines of flux. As seen, the flux linked with the coil is minimum but rate of change of flux linkages is maximum. Hence, maximum e.m.f. is induced in the coil when in this position. In the next quarter revolution i.e. from 90º to 180º, the flux linked with the coil gradually increases but the rate of change of flux linkages decreases. Hence, the induced e.m.f. decreases gradually till in position 5 of the coil, it is reduced to zero value.

So, we find that in the first half revolution of the coil, no (or minimum) e.m.f. is induced in it when in position 1, maximum when in position 3 and no e.m.f. when in position 5. The direction of this induced e.m.f. can be found by applying Fleming's Right-hand rule which gives its direction from A to B and C to D. Hence, the direction of current flow is ABMLCD . The current through the load resistance R flows from M to L during the first half revolution of the coil. In the next half revolution i.e. from 180º to 360º, the variations in the magnitude of e.m.f. are similar to those in the first half revolution. Its value is maximum when coil is in position 7 and minimum when in position 1. But it will be found that the direction of the induced current is from D to C and B to A as shown in Fig. 26.1 (b). Hence, the path of current flow is along DCLMBA which is just the reverse of the previous direction of flow.

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

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

EMF Equation of dc generator:

We know that the working principle of dc generator, that when conductors begin to cut the magnetic lines of force and therefore, the e.m.f. induces in the conductors according to 'Faraday's Law of Electromagnetic Induction'. The value of induced e.m.f. depends upon the lengths of the conductor, the magnetic field strength, and the speed at which the coil rotates. Let us see the equation for induced e.m.f.

Let,

ϕ = Flux per pole in Weber.

Z = Total number of armature conductors.

N = Armature rotation in revolution per minute (r.p.m).

P = Number of poles.

A = Number of parallel paths in armature.

E = e.m.f induced in any parallel path or generated e.m.f.

According to Faraday's law of Electromagnetic induction Average e.m.f generated per conductors is

$$\text{EMF} = \frac{d\phi}{dt} = \frac{Flux\ cut}{time\ taken} \text{ in volts}$$

Flux cut per Conductors in one revolution, $d\phi = \phi P$ wb

Number of revolutions per minute = *N / 60*

Time taken for one revolution dt = 60 / N

E.m.f generated per conductor $= \frac{d\phi}{dt} = \frac{\phi P}{\frac{60}{N}} = \frac{\phi P N}{60}$

Therefore, the total emf (Eg) generated between the terminals if given as,

*Eg = Average e.m.f generated per conductor * Number of conductor in each parallel path*

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

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

Where A is no.of parallel paths in the armature winding

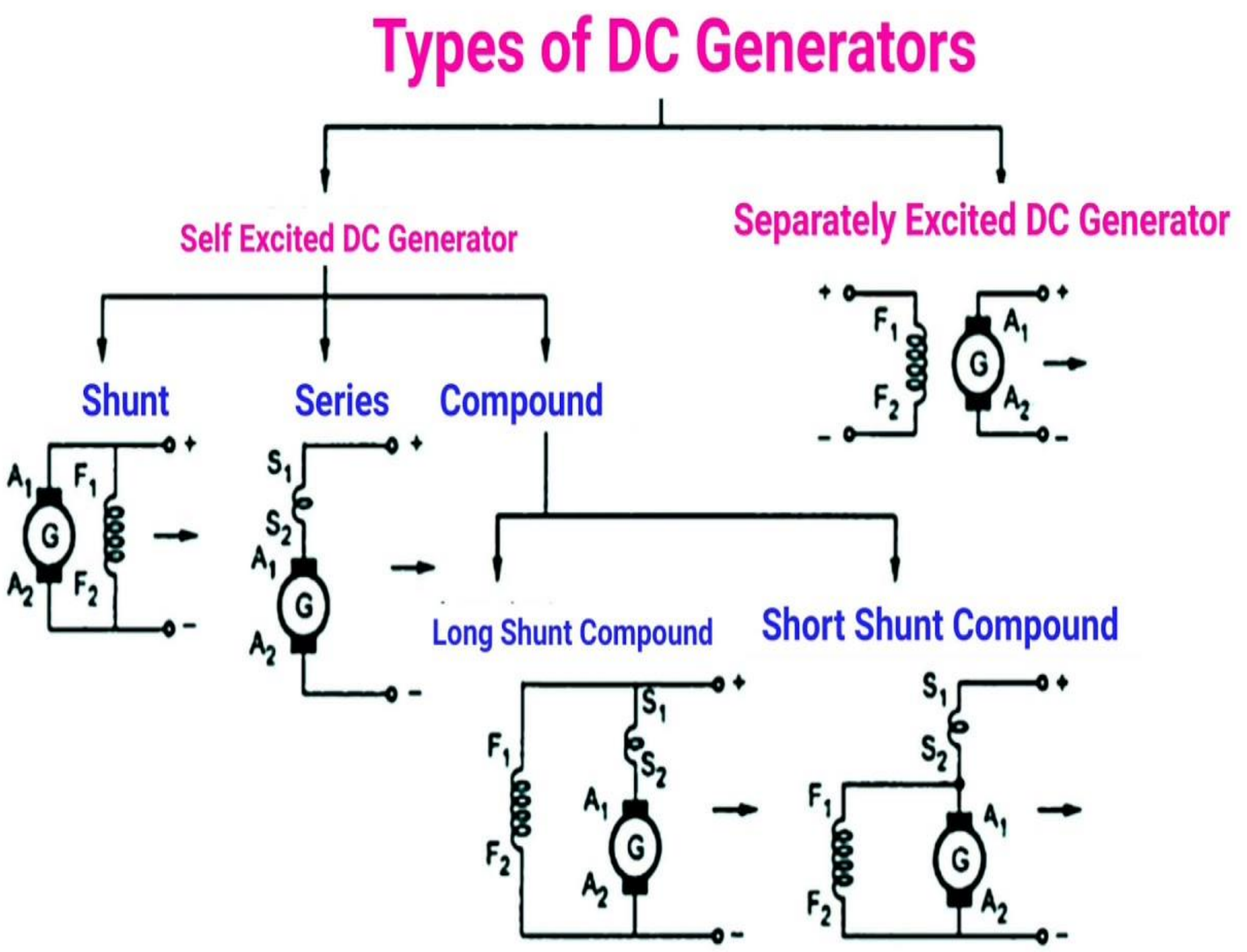
A=2 for wave winding

A=P For lap winding

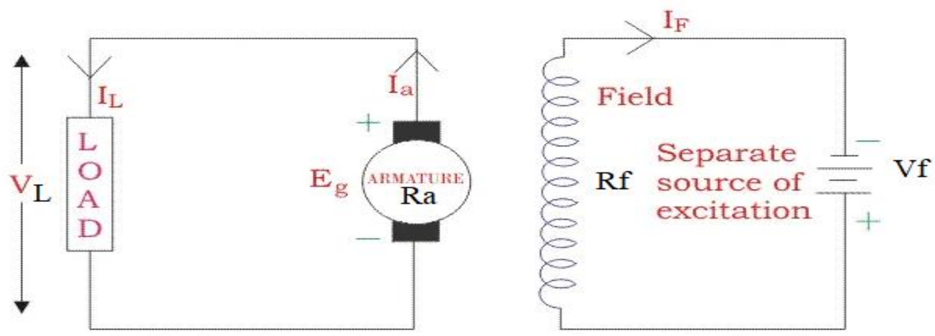
Types of dc generators:

1. Permanent magnet generators
2. Electromagnetic generators
   - I. Separately excited generators
   - II. Self excited generators
     - i. Series generator
     - ii. Shunt generators
     - iii. Compound generators (cumulative , differential)
       1. Long shunt compound generator
       2. Short shunt compound generator

DC Generator is classified according to the methods of their field excitation. By excitation, the DC Generators are classified as **Separately excited** DC Generators and **Self-excited** DC Generators. The self-excited DC Generators are further classified as **Series** generators, **Shunt** generators and **Compound** generators. The Compound generators are further divided as long shunt generators, and short shunt generators.



Separately Excited DC Generator: A DC generator whose field winding is energised by a separate or external DC source is called a separately excited DC Generator. The flux produced by the poles depends upon the field current of the poles. i.e. flux is directly proportional to the field current. But in the saturated region, the flux remains constant. The figure of separately excited generator is shown in bellow.



Separately Excited DC Generator

Vf is the field voltage

I_f is field current

I_a is armature current

I_L is load current

E_g is generated voltage

R_a is the armature resistance

V_L is load voltage

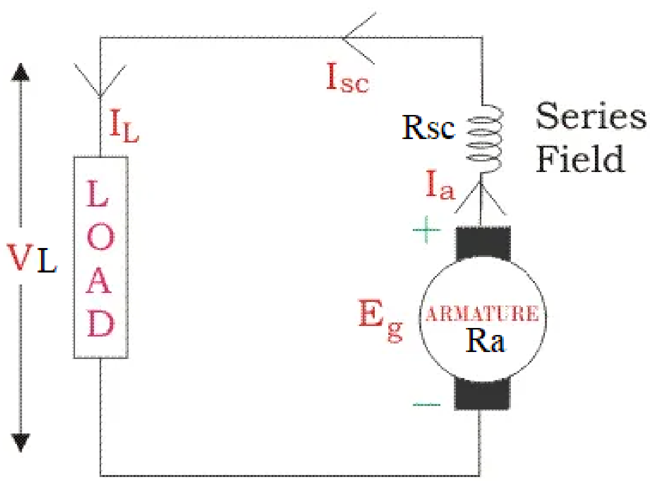
From the figure If = $\frac{Vf}{Rf}$ and I_a=I_L,

Eg = V_L + Ia Ra

VL = Eg – IaRa

Self excited generators: Self-excited DC generators are generators whose field magnets are energized by the current supplied by themselves. In these type of machines, field coils are internally connected with the armature.

Series generator: In these type of generators, the field windings are connected in series with armature conductors, as shown in the figure below.



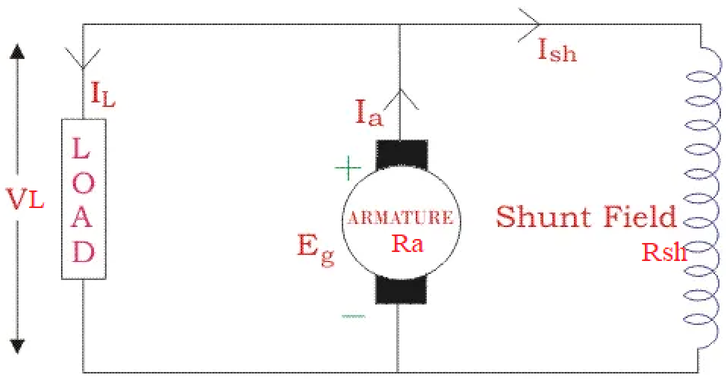
- R_{sc} = Series winding resistance
- I_{sc} = Current flowing through the series field
- R_a = Armature resistance
- I_a = Armature current
- I_L = Load current
- VL= Load voltage
- E_g = Generated EMF

Then from the above fig, **Ia = IL = Isc**

Eg = VL + Ia Ra + Isc Rsc

Eg = VL + Ia (Ra + Rsc)

Shunt generator: In these type of DC generators, the field windings are connected in parallel with armature, as shown in the figure below. In shunt wound generators the voltage in the field winding is same as the voltage across armature.



- R_{sh} = Shunt winding resistance
- I_{sh} = Current flowing through the shunt field
- R_a = Armature resistance
- I_a = Armature current
- I_L = Load current
- VL = Terminal voltage
- E_g = Generated EMF

From the above fig; $\mathbf{Ia = I_L + I_{sh}}$

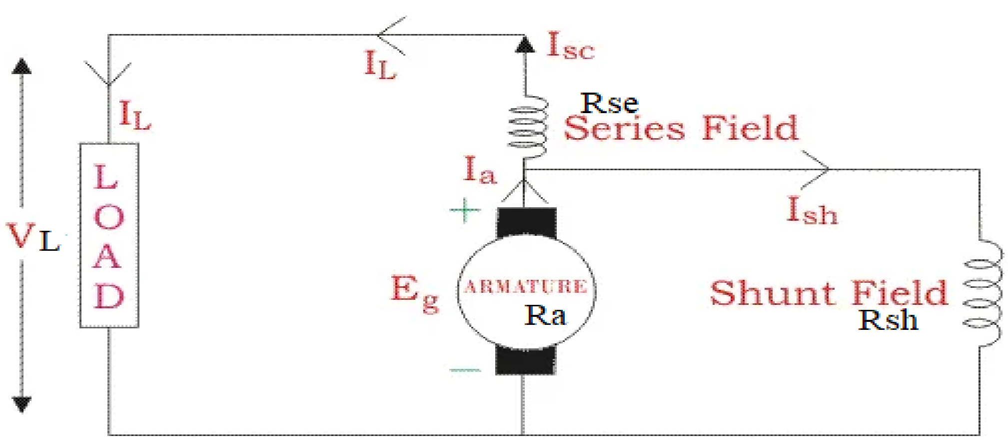
$$I_{sh} = \frac{VL}{Rsh}$$

$$Eg = VL + Ia\,Ra$$

Compound generators: Compound wound generators have both series field winding and shunt field winding. One winding is placed in series with the armature, and the other is placed in parallel with the armature. This type of DC generators may be of two types- short shunt compound-wound generator and long shunt compound-wound generator.

Short shunt compound generator:

Short Shunt Compound Wound DC Generators are generators where only the shunt field winding is in parallel with the armature, as shown in the figure below

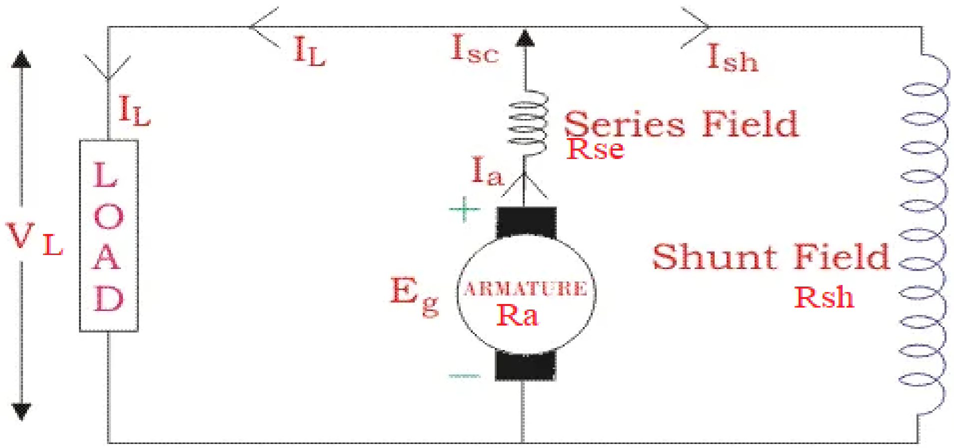


From the fig $\mathbf{Ia = I_{sh} + I_L}$; $\mathbf{Ish = (V_L + I_L R_{se}) / Rsh}$

$$Eg = V_L + Ia\,Ra + I_L\,Rse$$

Long shunt compound generator:

Long Shunt Compound Wound DC Generator is generator where the shunt field winding is in parallel with both series field and armature, as shown in the figure below.



From the fig, $Ia = I_L + I_{sh}$

Ish = VL/ Rsh

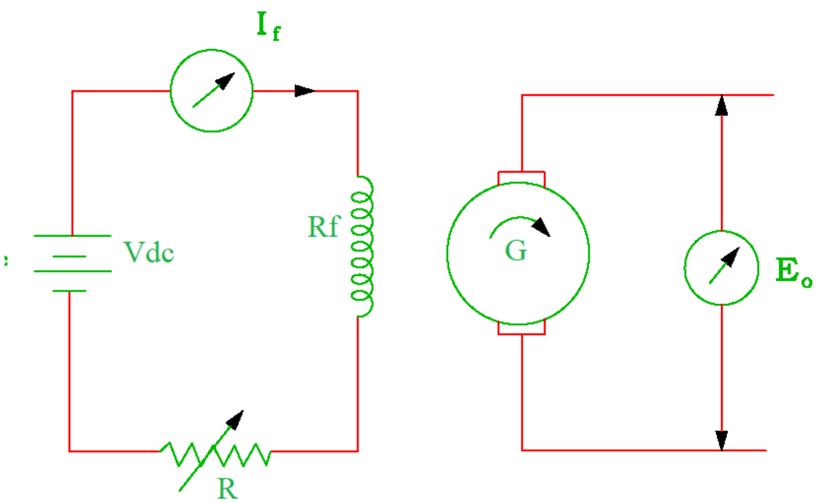
Isc = Ia

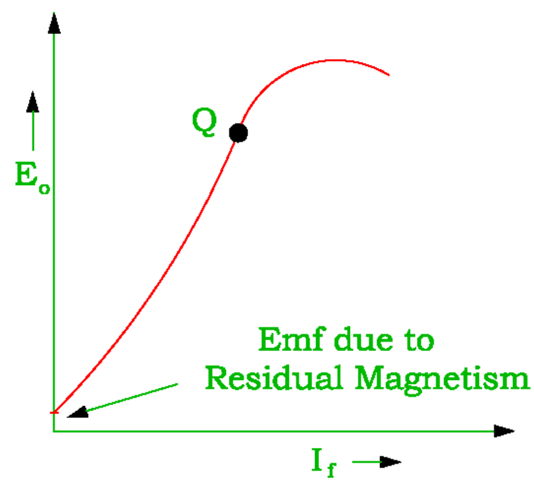
Eg = VL + Ia Ra + Isc Rse

Eg = VL + Ia (Ra + Rse)

Open circuit characteristics (O.C.C) / magnetization characteristics of dc Generator:

The curve which gives the relation between field current (I_f) and the generated voltage (E_0) in the armature on no load at a constant speed is called **magnetization or open circuit characteristic of a DC generator**. The plot of this curve is practically same for all types of generators, whether they are separately excited or self-excited. This curve is also known as no load saturation characteristic curve of DC generator.





Circuit diagram **magnetization characteristics**

To find magnetization characteristics of a dc generator the field winding is excited separately with help of an external source as shown in the circuit diagram.

Vdc is the external dc voltage source

Rf is the resistance of the field winding,

R is the variable resistance (by varying R we can vary the field current If)

If is the field current and If = Vdc / (Rf + R), it can be measured by using an ammeter as shown in fig.

E0 is the no load voltage of the generator it can be measured by using an voltmeter as shown in the fig.

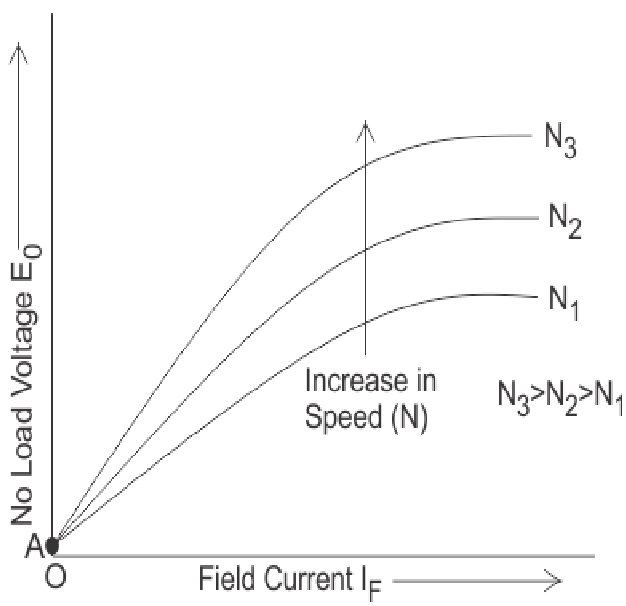
Procedure: rotate the rotor of a generator with a constant speed and vary the field current of the generator from zero value to maximum value in a step by step process and note the emf E_0 of the generator in all steps, plot the graph between I_f and E_0 we get magnetization characteristics as shown in the fig.

But if you observe the graph at zero field current we get a small EMF which is called residual voltage due to residual flux in the pole of the generator. Residual flux is nothing but flux in the poles at zero field current. Up to the point "Q" the EMF is increased linearly with respect to the increasing field current I_f, because of If α ϕ if I_f increases which increases the flux ϕ from the poles.

And we know EMF α ϕ N,   N is speed of generator it is also constant

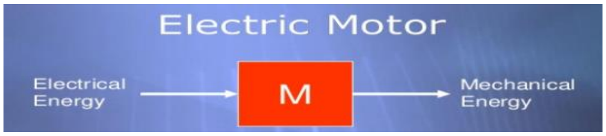
EMF α ϕ and it is proportional to filed current If up to point Q, offer point Q the field flux from the poles is saturated and we get a rated(maximum) voltage, so we didn't get more than rated voltage by increasing field current If.

Here in this figure below we can see the variation of generated emf on no load with field current for different fixed speeds of the armature. For higher value of constant speed, the steepness of the curve is more.

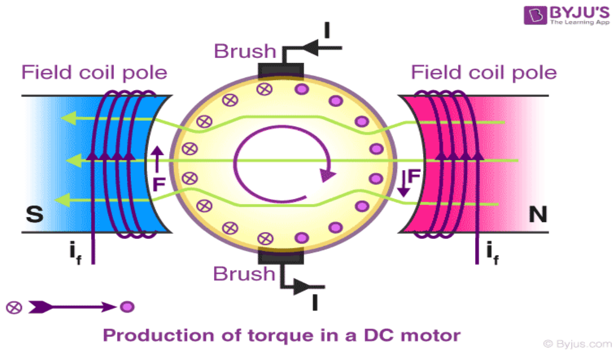


Magnetic or Open Circuit Characteristic

Dc motor: a dc motor is a device which converts dc electrical energy in to mechanical energy

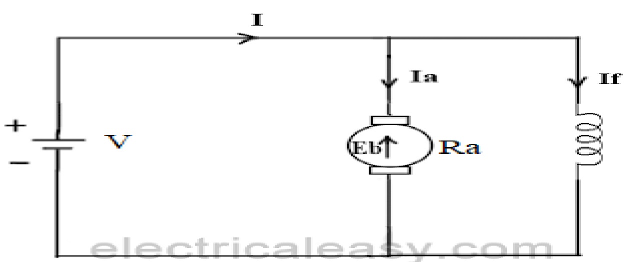


The basic **working** principle of a **DC motor** is: "whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force".



When armature winding is connected to a DC supply, an electric current sets up in the winding. Magnetic field may be provided by field winding (electromagnetism). In this case, current carrying armature conductors experience a force due to the magnetic field, according to the principle stated above.

According to fundamental laws of nature, no energy conversion is possible until there is something to oppose the conversion. In case of generators this opposition is provided by magnetic drag, but in case of dc motors there is back emf. When the armature of a motor is rotating, the conductors are also cutting the magnetic flux lines and hence according to the Faraday's law of electromagnetic induction, an emf induces in the armature conductors is called back emf (Eb) . The direction of this back emf (Eb) is such that it opposes the armature current (Ia). The circuit diagram below illustrates the direction of the back emf and armature current. Magnitude of the Back emf can be given by emf equation of a DC generator.



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

$V = Eb + Ia\ Ra$ and

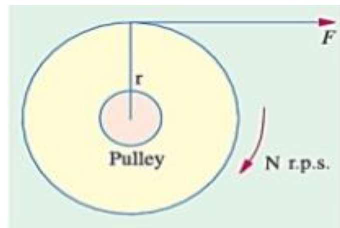
$I = I_a + I_f$

Significance of back EMF (Eb): Magnitude of back emf is directly proportional to speed of the motor. if a dc motor is suddenly loaded, the load will cause decrease in the speed. Due to decrease in speed, back emf will also decrease allowing more armature current. Increased armature current will increase the torque to satisfy the load requirement. Hence, presence of the **back emf makes a dc motor 'self-regulating.**

Torque equation of dc motor: When the current-carrying current is placed in the magnetic field, a force is exerted or it which exerts turning moment or torque F x r. This torque is produced due to the electromagnetic effect, hence is called Electromagnetic torque**.**

Electrical power in the armature of the dc motor is Pe= Eb * Ia

the mechanical power that rotates the armature can be given regarding torque T and speed N so the mechanical power in the armature Is Pm= T * ω



Mechanical power = electrical power

T* ω = Eb * Ia

Where $\omega = \frac{2\pi N}{60}$ **and** $Eb = \frac{\phi Z N}{60} * \frac{P}{A}$, sub ω and E_b in above eqn, we get

$$T * \frac{2\pi N}{60} = \frac{\phi Z N}{60} * \frac{P}{A} * Ia$$

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

$$T = 0.519 \phi Z Ia \left(\frac{P}{A}\right)$$

Speed Control Methods Of Dc Motor:Before discussing the **speed control of dc shunt motor**, we have to find the factors affecting the speed of a DC motor. We know back emf $Eb = \frac{\phi Z N}{60} * \frac{P}{A}$

$$Eb \, \alpha \, \phi \, N$$

$$N \, \alpha \, \frac{Eb}{\phi}$$

$$N \, \alpha \, \frac{V - Ia\,Ra}{\phi}$$

From the above expression The speed is

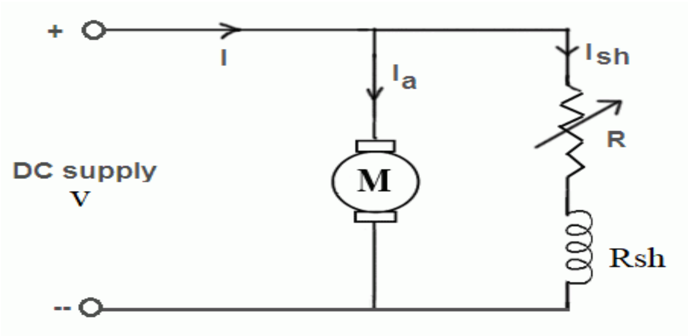
inversely proportional to flux φ.

It is directly proportional to armature voltage drop ($I_a R_a$).

It is directly proportional to applied Voltage V. so the speed control methods of dc motor are

1. Field flux control method
2. Armature resistance control method
3. Supply voltage control method

Field flux control method:

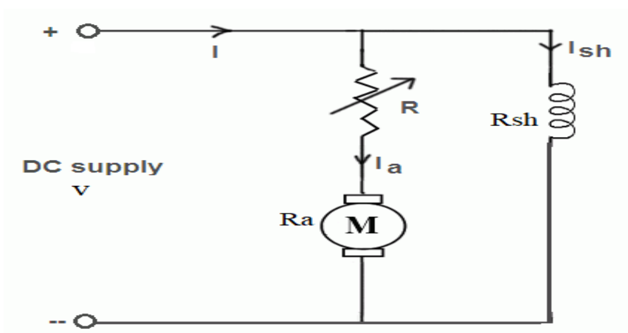


$N \alpha \frac{1}{\phi}$, $\phi \alpha Ish$, $Ish = \frac{V}{Rsh+R}$

The set up for speed control of DC shunt motor using flux control technique is shown in the figure. In order to change the speed, we have to change flux. This can be achieved by changing the field current. The field current can be changed by changing the rheostat R connected in series with the field. At the time of starting the motor, we need to run the motor slowly, therefore, the flux should be maximum, because, N α 1 / φ

To obtain maximum flux at the start, the field current should be maximum at the time of starting. To obtain this, the value of rheostat (R) should be minimum. The speed of DC shunt motor can be varied by varying the field current. As we increase the resistance R of the rheostat, the field current I_{sh} decreases. So the flux φ decreases. This results in increasing the speed of the motor. As the R is increased, the speed increases. We can use this technique to control motor speed above its rated value.

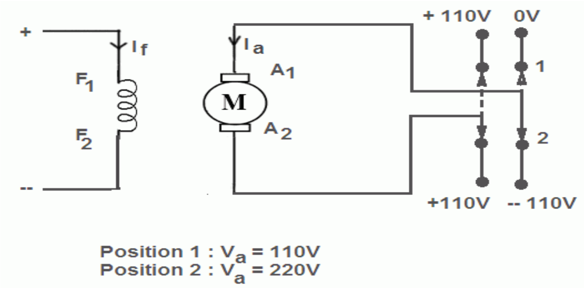
Armature resistance control method:



N α Eb and Eb = V – Ia (Ra + R)

The set up for speed control of DC shunt motor by armature voltage control method is shown in the figure. A rheostat is connected in series with armature winding. By varying the value of R we can vary the voltage across the armature. Because speed N is directly proportional to armature voltage, it is possible to change the speed by changing the value of rheostat R. We can use this technique to control motor speed below its rated value. But it is neither efficient nor economical method because, in this method, speed is reduced at the cost of power loss in rheostat (I_a^2R).

Supply voltage control method:



In this method, the field winding of the motor is connected to a constant DC voltage. But armature is supplied with different voltages with the help of suitable switch gear as shown in the figure. By changing the input voltage the speed of the motor is changed because of N α V.