DC GENERATOR

An electric generator is a device that converts mechanical energy to electrical energy, usually via electromagnetic induction.

The generator is based on the principle of electromagnetic induction discovered in 1831 by Michael Faraday. Faraday discovered that if an electric conductor, like a copper wire, is moved through a magnetic field, electric current will flow in the conductor. So the mechanical energy of the moving wire is converted into the electric energy of the current that flows in the wire.

Faraday's law of electromagnetic induction:

Electromagnetic induction is the process by which a current can be induced to flow due to a changing magnetic field.

In 1831, Michael Faraday, an English physicist gave one of the most basic laws of electromagnetism called Faraday's law of electromagnetic induction. This law explains the working principle of most of the electrical motors, generators, electrical transformers and inductors. This law shows the relationship between electric circuit and magnetic field. Faraday performs an experiment with a magnet and a coil.

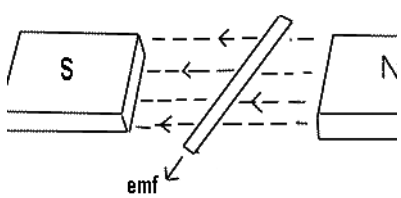
From his experiment, Faraday concluded that whenever there is relative motion between conductor and a magnetic field, the flux linkage with a coil changes and this change in flux induces a voltage across a coil. Michael Faraday formulated two laws on the basis of the experiments. These laws are called Faraday's laws of electromagnetic induction.

Faraday's first law: It states as follows:

Any change in the magnetic field of a coil of wire will cause an emf to be induced in the coil or wire. This emf induced is called induced emf and if the conductor circuit is closed, the current will also circulate through the circuit and this current is called induced current.

We can state the law as following simpler way,

Whenever a conductor cuts magnetic flux, an e.m.f induced in that conductor.



Faraday's second law: It states as follows:

It states that the magnitude of the induced emf in the coil is equal to the rate of change of flux that linkages with the coil. The flux linkage of the coil is the product of number of turns in the coil and flux associated with the coil.

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Mathematically, $e = -N\frac{d\emptyset}{dt}$ volts

Where, e = induced e.m.f

$\frac{d\emptyset}{dt}$ = rate of change of flux, and

N = number of turns of the coil

[Usually, a minus sign is given to the right-hand side expression to signify the fact that the induced e.m.f sets up current in such a direction that magnetic effect produced by it opposes the very cause producing it.]

Voltage induced in a conductor:

According to Faraday's law in order to have a voltage induced in a conductor we must have

1. A conductor
2. Line of magnetic flux
3. Motion that produces cutting of the magnetic lines.

Remember, this three condition is must for voltage generation.

With an increase in flux density and the conductor is moving at the same velocity, it then follows that the induced voltage is also increased.

If the length of the conductor is short, the number of lines of flux cut by the conductor will be small, and therefore the induced voltage will be small. If the conductor is made longer, the number of lines of flux cut will be greater. Hence the induced voltage depends directly upon both the flux density and the length of the conductor.

The speed at which the conductor cuts the lines of a stationary magnetic field also determines the magnitude of the induced voltage. If the conductor is stationary, it is obvious that no lines of flux are cut regardless of the length of the conductor or the strength of the magnetic field. If the conductor moves very slowly, the number of lines of flux cut per unit of time will be very small, and therefore the voltage induced will be very low. If the conductor moves very fast, it will cut lines of flux at a much greater speed, and the induced voltage will be greater. The same relative voltages would be induced if the conductors were stationary and the magnetic fields were to move.

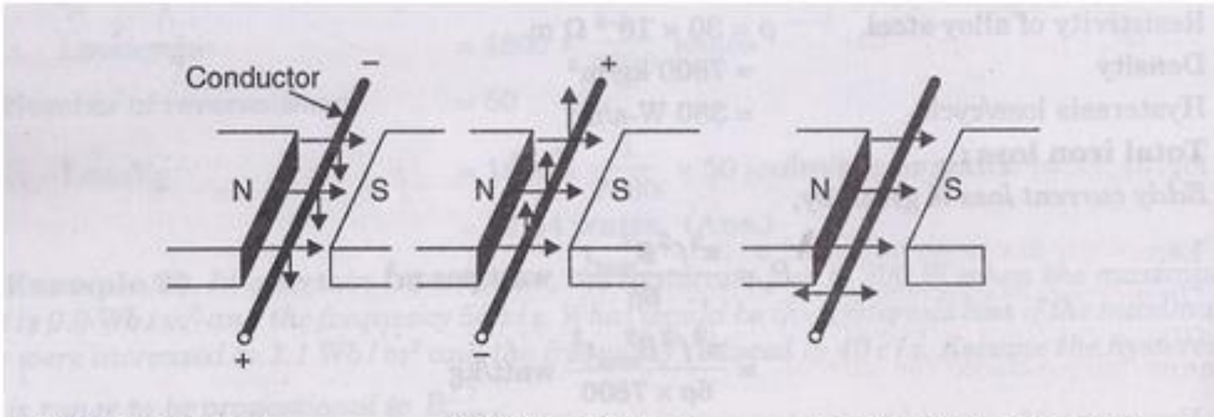
In terms of a formula the above information is:

$$E = Blv$$

Where, B = flux density, lines per sq in

l = length of that part of conductor that actually cuts flux

v = speed of conductor



(a) Voltage induced across a wire moving downward.
(b) Voltage induced across a wire moving upward.
(c) No voltage is induced in a wire moving parallel to the field.

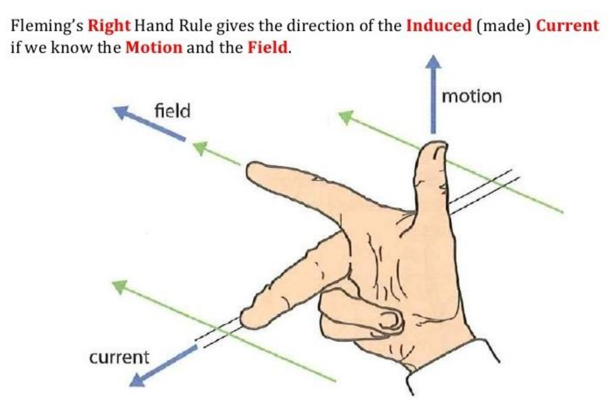
Fig. 30. When a conductor is moved across a magnetic field a voltage is induced in the conductor.

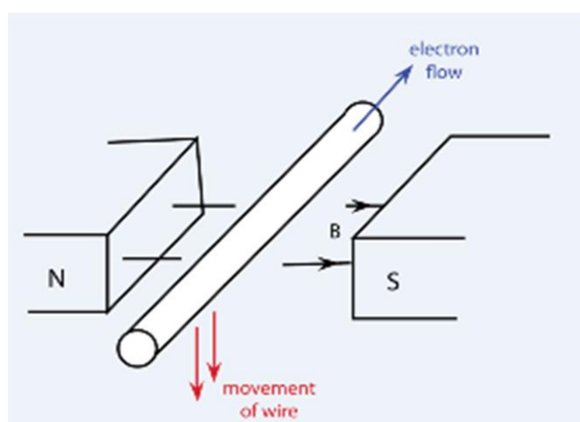
From figure we see that, if a conductor moves parallel to the lines of flux, no voltage will be induced in the conductor. If the conductor moves at right angles to the lines of flux, a voltage will be induced in the conductor in accordance with the formula E = Blv volts. However, suppose the conductor moves in a direction that is neither at right angle nor parallel to the lines, but instead moves at some angle θ, the value of voltage is given by the formula

$$E = Blv \sin \theta$$

Direction of the induced voltage:

The polarity of the induced voltage depends upon the direction in which the conductor is moving. The polarity, however, also depends upon the direction of lines of flux. Taking these two factors into consideration, the polarity of the induced voltage may be determined in the following manner. Extend the thumb, index finger, and middle finger of the right hand so they are at right angles to each other. With the index finger pointing in the direction of the lines of flux (from north to south) and the thumb pointing in the direction of motion of the conductor, the middle finger will point the direction that current will flow in the conductor. This is known as Fleming's right-hand rule.





The Direct Current Generator (DC Generator):

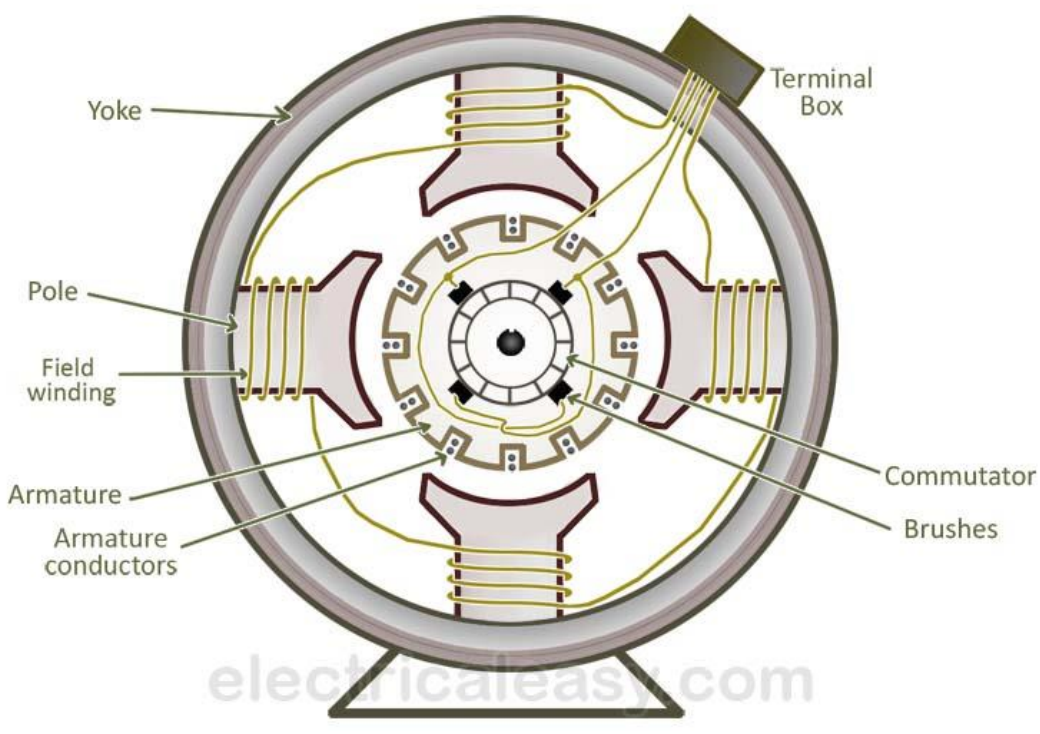
A Generator is an electrical device which converts mechanical energy into electrical energy. A DC generator is a type of generator that produces DC power. It uses the principle of electromagnetic induction to do the conversion process.

According to this law, when a conductor moves in a magnetic field it cuts magnetic lines of force, due to which an emf is induced in the conductor. The magnitude of this induced emf depends upon the rate of change of flux (magnetic line force) linkage with the conductor. This emf will cause a current to flow if the conductor circuit is closed.

Hence the most basic tow essential parts of a generator are:

1. Magnetic field system
2. Conductor coil moving inside a magnetic field called armature

Basic constructional parts of a DC machine are described below:



1. **Yoke:** The outer frame of a dc machine is called as yoke. It is made up of cast iron or steel.
2. **Poles and pole shoes:** Poles are joined to the yoke with the help of bolts or welding. They carry and support field winding or field coils.
3. **Field winding:** They are usually made of copper. Field coils are former wound and placed on each pole and are connected in series. They are wound in such a way that, when energized, they form alternate North and South poles.

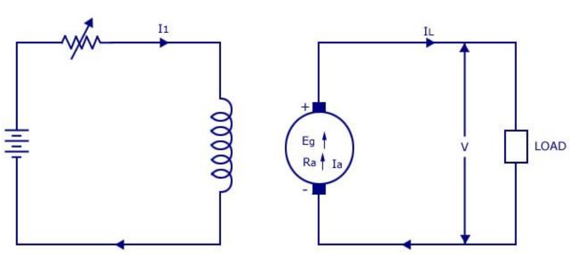
4. **Armature core:** Armature core is the rotor of the machine. It is cylindrical in shape with slots to carry armature winding. The armature is built up of thin laminated circular steel disks for reducing eddy current losses. Armature is keyed to the shaft.
5. **Armature winding:** It is usually a former wound copper coil which rests in armature slots. The armature conductors are insulated from each other and also from the armature core. Armature winding can be wound by one of the two methods; lap winding or wave winding.
6. **Commutator and brushes:** Physical connection to the armature winding to load is made through a commutator-brush arrangement. Commutator acts as a **rectifier** converting AC voltage in the armature winding to the DC voltage across the brushes. It is made of segments of Cu. Each Cu segment is insulated from each other using sheets of mica and is placed on the shaft of the machine. **Brushes** ensures electrical connections between the commutator and the external load circuit.

Types of D.C. Generators:

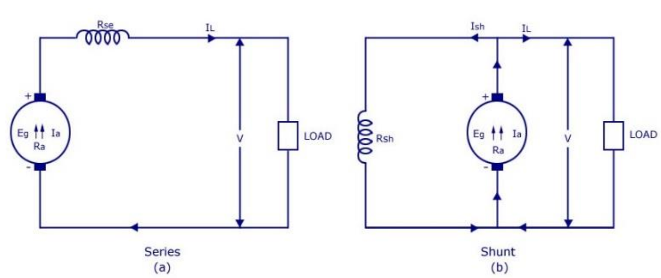
According to the way in which their fields are excited, generators are classified into (a) Separately excited generator and, (b) Self excited generator.

1. **Separately excited D.C. Generator:** Separately excited D.C. Generator are those whose field magnets are energized from an independent source of D.C. Current.
2. Self-excited D.C. Generators are those whose field magnets are energized by the currents produced by the generators themselves. There are 3 types of self-excited D.C. Generators named according to the manner in which their field coils are connected to the armature.
   These are:

   i. Shunt D.C. Generator: Shunt wound D.C. Generators have field windings and armature windings connected in parallel (shunt).
   ii. Series D.C. Generator: Series wound D.C. Generator have field windings and armature windings connected in series.
   iii. Compound D.C. Generator: Compound wound D.C. Generator have both series field windings and shunt field windings.



Separately excited generator



Self-excited generator

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Example: *A shunt generator delivers 450 A at 230 V and the resistance of the shunt field and armature are 50 Ω and 0.03 Ω respectively. Calculate the generated e.m.f.*

Solution. Generator circuit is shown in right figure:

Current through shunt field winding is

$I_{sh} = 230/50 = 4.6$ A

Load current $I = 450$ A

∴ Armature current $I_a = I + I_{sh}$

$= 450 + 4.6 = 454.6$ A

Armature voltage drop

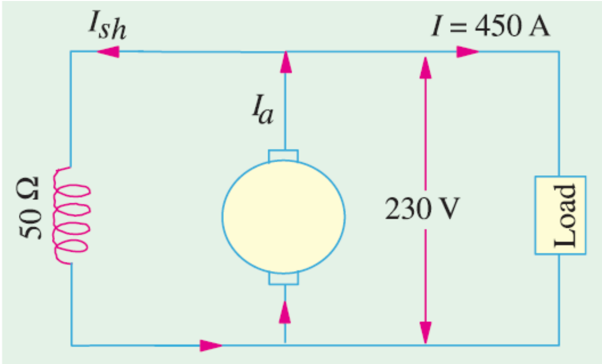
$I_a R_a = 454.6 \,.\, 0.03 = 13.6$ V

Now, E_g = terminal voltage + armature drop

$= V + I_a R_a$

∴ e.m.f. generated in the armature

$E_g = 230 + 13.6 = 243.6$ V



Losses in a DC Machine (DC Generator & DC Motor)

A dc generator converts mechanical power into electrical power and a dc motor converts electrical power into mechanical power. Thus, for a dc generator, input power is in the form of mechanical and the output power is in the form of electrical. On the other hand, for a dc motor, input power is in the form of electrical and output power is in the form of mechanical. In a practical machine, whole of the input power cannot be converted into output power as some power is lost in the process. This causes the efficiency of the machine to be reduced. Efficiency is the ratio of output power to the input power. Thus, in order to design rotating dc machines with higher efficiency, it is important to study the losses occurring in them.

Various losses in a rotating DC machine (DC generator or DC motor) can be characterized as follows:

- Copper losses
  - Armature Cu loss
  - Field Cu loss
  - Loss due to brush contact resistance

- Iron Losses
  - Hysteresis loss
  - Eddy current loss

- Mechanical losses
  - Friction loss
  - Windage loss or air friction loss

Copper Losses or Winding Losses or Electrical Losses in DC Machine

The copper losses are the winding losses taking place during the current flowing through the winding. These losses occur due to the resistance in the winding. In DC machine, there are only two winding, armature and field winding. Thus copper losses categories in three parts; armature winding loss, field winding loss, and brush contact resistance loss. The copper losses are proportional to square of the current flowing through the winding.

Armature Copper Loss in DC Machine

Armature copper loss = $I_a^2R_a$

Where, I_a is armature current and R_a is armature resistance. These losses are about 30% of the total full load losses.

Field Winding Copper Loss in DC Machine

Field winding copper loss = $I_f^2R_f$

Where, I_f is field current and R_f is field resistance. These losses are about 25% theoretically, but practically it is constant.

Brush contact loss attributes to resistance between the surface of brush and commutator. Generally, this loss is included into armature copper loss.

Iron Losses or Core Losses or Magnetic Losses in DC Machine

Hysteresis loss

Hysteresis loss is due to the reversal of magnetization of the armature core. When the core of the armature exposed to magnetic field, it undergoes one complete rotation of magnetic reversal. The portion of armature which is under S-pole, after completing half electrical revolution, the same piece will be under the N-pole, and the magnetic lines are reversed in order to overturn the magnetism within the core. The constant process of magnetic reversal in the armature, consume some amount of energy which is called hysteresis loss. The percentage of loss depends upon the quality and volume of the iron.

For reducing this loss in a d.c. machine, armature core is created of such materials that have an lesser value of Steinmetz hysteresis co-efficient e.g., silicon steel.

Eddy Current Loss in DC Machine

When the armature core rotates in the magnetic field, an emf is also induced in the core (just like it induces in armature conductors), according to the Faraday's law of electromagnetic induction. Though this induced emf is small, it causes a large current to flow in the body due to the low resistance of the core. This current is known as eddy current. The power loss due to this current is known as eddy current loss.

Eddy current loss can be reduced by using laminated core instead of solid core.

Core losses are constant for shunt and compound generators, as their field currents are approximately constant. Core loss is about 20 % to 30 % of full-load losses.

Mechanical Loss

- Friction loss at commutator and bearings, which are about 10 % to 20 % of full load losses.
- Windage loss or Air friction loss of rotating armature is called as Mechanical loss.

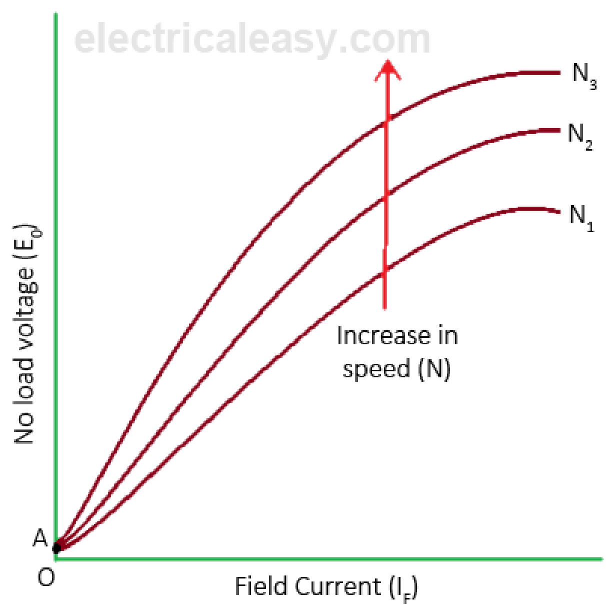
Two most important characteristic of dc shunt generators

Open Circuit Characteristic

Open circuit characteristic is also known as magnetic characteristic or no-load saturation characteristic. This characteristic shows the relation between generated emf at no load (E_g) and the field current (I_f) at a given fixed speed. The O.C.C. curve is just the magnetization curve and it is practically similar for all type of generators. The data for O.C.C. 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.

For a given excitation current or field current, the emf generated at no load E0 varies in proportionally with the rotational speed of the armature. Here in the diagram the magnetic characteristic curve for various speeds are drawn.

Due to residual magnetism the curves start from a point A slightly up from the origin O. The upper portions of the curves are bend due to saturation.

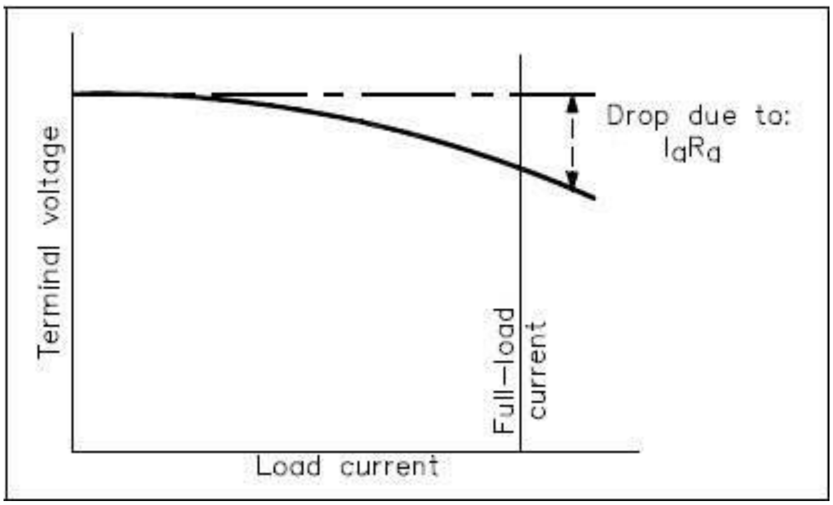


Open Circuit Characteristic (O.C.C.)

External Characteristic or Load Characteristic

An external characteristic curve shows the relation between terminal voltage (V) and the load current (I_L). Terminal voltage V is less than the generated emf E_g due to ohmic voltage drop in the armature circuit. Therefore, external characteristic curve lies below the internal characteristic curve. External characteristics are very important to determine the suitability of a generator for a given purpose. Therefore, this type of characteristic is sometimes also called as performance characteristic or load characteristic.

$$Terminal\ voltage\ V = (E_g - I_a R_a) = E_g - (I_{sh} + I_L) R_a$$



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DC MOTOR

An Electric DC motor is a machine which converts electric energy into mechanical energy. The working of DC motor is based on the principle that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force which is called Lorentz Force.

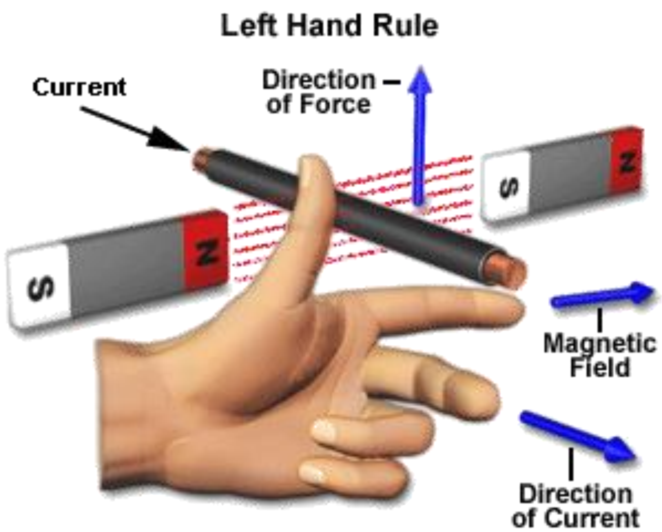
The direction of mechanical force is given by Fleming's Left-hand Rule and its magnitude is given by:

$$F = BIl \text{ Newton.}$$

Where, B = flux density of the field flux

I = current flowing through the conductor

l = effective length of the conductor



If a coil is placed in the field instead of a single conductor than a torque is produce and coil starts to rotate in the field. The torque can be express by the formula

$$\tau = BIl_w \cos\alpha$$

Where, α (alpha) is the angle between the plane of the armature turn and the plane of reference or the initial position of the armature which is here along the direction of magnetic field.

There is no basic difference in the construction of a DC generator and a DC motor. In fact, the same d.c. machine can be used interchangeably as a generator or as a motor. Like generators DC motors are also classified in to shunt-wound, series-wound and compound-wound.

DC motors are seldom used in ordinary applications because all electric supply companies furnish alternating current.

However, for special applications such as in steel mills, mines and electric trains, it is advantageous to convert alternating current into direct current in order to use dc motors. The reason is that speed/torque characteristics of d.c. motors are much more superior to that of a.c. motors.

The speed of a DC motor to which armature rotates can be expressed by the following formula:

$$N = \frac{PZ}{60a} \emptyset I_a$$

Back EMF

When the armature of the 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. The direction of this induced emf is such that it opposes the armature current (I_a) and for this reason it is called back emf or counter emf. Magnitude of Back emf can be given by the emf equation of DC generator.

Considering the back emf the speed equation can also be written as,

$$N = (V - I_a R_a) / k\emptyset$$

Where, $V - I_a R_a = E_b$

The equation implies three things:

i. Speed of the motor is directly proportional to supply voltage.
ii. Speed of the motor is inversely proportional to armature voltage drop.
iii. Speed of the motor is inversely proportional to the flux due to the field findings

Thus, the speed of a DC motor can be controlled in three ways:

i. By varying the supply voltage
ii. By varying the flux, and by varying the current through field winding
iii. By varying the armature voltage, and by varying the armature resistance

Starting Methods of A DC Motor

Basic operational voltage equation of a DC motor is given as,

$$V = E_b + I_a R_a \quad \text{and hence,} \quad I_a = (V - E_b) / R_a$$

Now, when the motor is at rest, obviously, the back emf $E_b = 0$. Hence, armature current at the moment of starting can be given as $I_a = V / R_a$. In practical DC machines, armature resistance is basically very low. Therefore, a large current flows through the armature during starting. This current is large enough to damage the armature circuit. To avoid this, a suitable DC motor starter must be used.

The main principal of the starter is the addition of external electrical resistance R_{ext} to the armature winding, so as to increase the effective resistance to $R_a + R_{ext}$, thus limiting the armature current to the rated value.

As the motor continues to run and gather speed, the back emf successively develops and increases, countering the supply voltage, resulting in the decrease of the net working voltage. At this moment to maintain the armature current to its rated value, R_{ext} is progressively decreased unless its made zero, when the motor is at rated speed and back emf produced is at its maximum. This regulation of the external electrical resistance in case of the starting of DC motor is facilitated by means of the a starter.