UNIT – 1

DC MACHINES

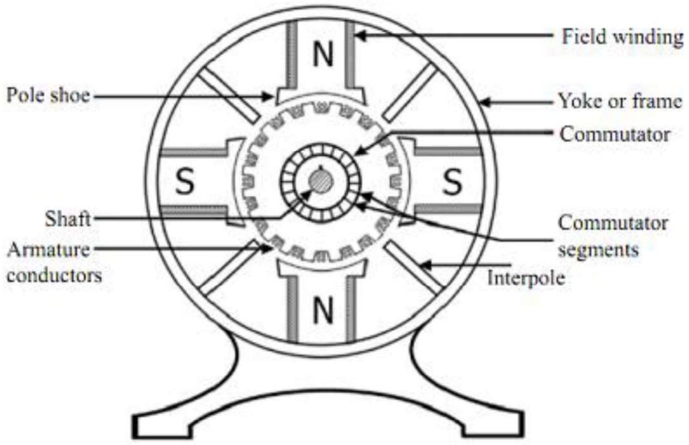
1.1 DC GENERATOR - INTRODUCTION

An electrical generator is a rotating machine which converts mechanical energy into electrical energy. This energy conversion is based on the principle of electromagnetic induction. According to Faraday's law of electromagnetic induction, whenever a conductor is moved in a magnetic field, dynamically induced emf is produced in the conductor. When an external load is connected to the conductor the induced emf causes a current to flow in the load.

1.2 CONSTRUCTION OF DC GENERATOR

Major parts of a dc generator are,

1. Magnetic frame or yoke
2. Poles
3. Interpoles
4. Armature
5. Commutator
6. Brushes
7. Bearings
8. Shaft



1.2.1 Magnetic frame or yoke

In smaller machines where cheapness is the main consideration and weight is not a critical factor, the yoke is made up of cast iron. But for large machines where weight is the main consideration, cast steel or rolled steel is used.

Purpose of yoke

1. It acts as a protecting cover for the whole machine
2. It provides a mechanical support for the poles.
3. It carries the magnetic flux produced by the poles.

1.2.2 Poles

For very small machines the poles are made up of cast iron. For larger machines cast steel is used. To minimize eddy current losses, the pole is laminated. Sheet steel laminations are used for this.

Parts of poles

1. Pole core
2. Pole shoes
3. Pole coils

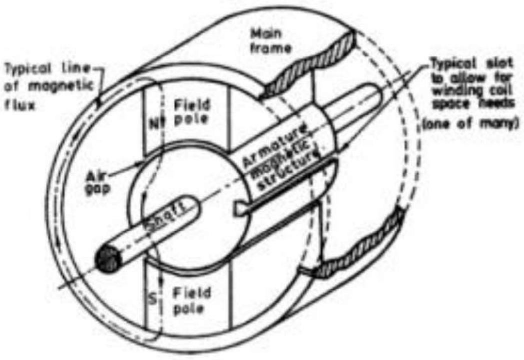
Pole cores and pole shoes form the field magnet. The end of the pole core towards the armature is often expanded in the form of shoe to reduce the reluctance of the air gap. Since the poles are electromagnets a field winding is wound over the pole core. The pole coils are made up of copper wire. When current is passed through these coils the pole becomes an electromagnet and starts establishing a magnetic field in the machine.

1.2.3. Interpoles

In modern DC machines commutating poles or interpoles are provided to improve commutation. Just like the field winding, the commutating poles also have exciting coils which are connected in series with the armature. Since they carry full armature current, the coils are made up of fewer turns of thicker conductor to reduce the resistance.

1.2.4. Armature

The armature consists of an armature core and armature windings. The armature core houses the armature conductors and coils. When the conductors rotate, they alternatively come under the influence of north and south poles. This causes high hysteresis losses in the armature cor. To reduce losses, low hysteresis steel containing a few percentage of silicon is used in the armature.



When the armature core rotates in the pole flux, eddy current are also produced in it. If a solid iron armature is used, an emf is induced in an axial direction and iron being a conductor would result in large circulating current called eddy current to flow in the core. This produces unnecessary heat which results in heavy power loss. To minimize the eddy current losses the armature core is laminated. In between laminations insulation is provided.

The eddy current losses and hysteresis losses produce considerable heat in the armature, and spacers. Ventilating ducts may be necessary to remove this heat. Sometimes a fan is provided at one end of the armature for good ventilation. The armature conductors are usually made up of copper and are housed in the slot provided in the armature. The slots are rectangular in shape for larger machines in circular for small machines: the conductors are housed in slots in two layers. The slots are closed by fiber or wood wedges t prevent the conductors from flying out due to centrifugal force, when the armature rotates.

1.2.5 Commutator

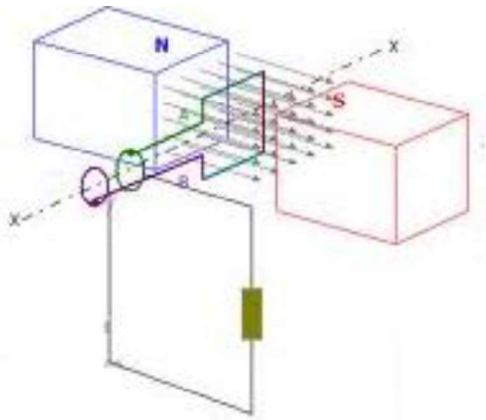
The commutator converts the alternating emf into unidirectional or direct emf. It is made up of wedge shaped segments or hard drawn or drop forged copper, insulated from each other by thin layers of built- up mica.

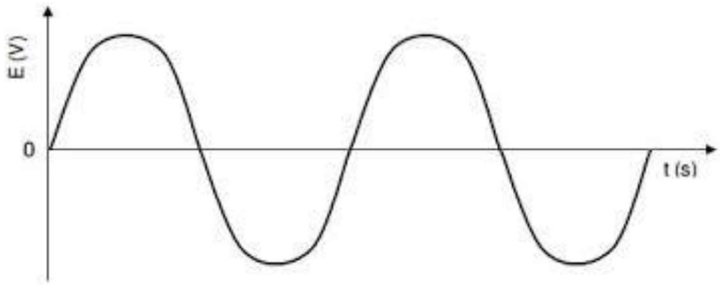
1.2.6 Brushes and bearings

The brushes, which are made up of carbon or graphite, collect the current from the commutator. They are rectangular in shape. These brushes are holders and mounted over brush holder studs. The brush holder studs are mounted on a brush yoke or, rocker arm. The brush holder studs are insulated from the brush yoke by insulation sleeves. Ball bearings are usually employed as they are reliable for light machines. For heavy duty machines roller bearings are used. The bearings are packed in hard oil for quieter operation.

1.3 PRINCIPLE OF OPERATION OF DC GENERATOR

Let us consider a single turn coil ABCD rotated on a shaft within a uniform magnetic field of flux density. It is rotated in an anticlockwise direction.





Let'l' be the length and 'b' be the breath of the coil in metes. When the coil sides AB and CD are moving parallel to the magnetic field, the flux lines are not being cut and no emf is induced in the coil. At this position, we assume the angle of rotation 'ϴ' as zero.

This vertical position of the coil is the starting position. According to Faraday's law II, the emf induced is proportional to the rate of change of flux linkages.

$$e = -N \frac{d\phi}{dt}$$

where,

N is the number of turns

Φ is the flux

t is the time

As N = 1, $e = -\frac{d\phi}{dt}$ volts

Initially, when the coil is moving parallel to the flux lines, no flux line is cut and hence

$$\frac{d\phi}{dt} = 0 \text{ and } e = 0$$

After time t secs, the coil would have rotated through an angle ωt radians in the anti-clockwise direction. the flux then linking with the coil is Blbcosθ.

Therefore, $e = -\frac{d}{dt}(Blb\cos\omega t) = E_m \sin\omega t$

Where, Em = Blbω, Em is the maximum value of induced emf

B is the flux density

When $\theta = 90^o$, the coil sides are moving at right angles to the flux lines. The flux lines are cut at the maximum rate and the emf induced is maximum.

When $\theta = 180^o$, the coil sides are again moving parallel to the flux lines and the emf induced is zero once again.

When $\theta = 270^o$, the coil sides again move at right angles to the flux lines but with their position reversed when compared with $\theta = 90^o$. Hence the emf induced is maximum in the opposite direction .

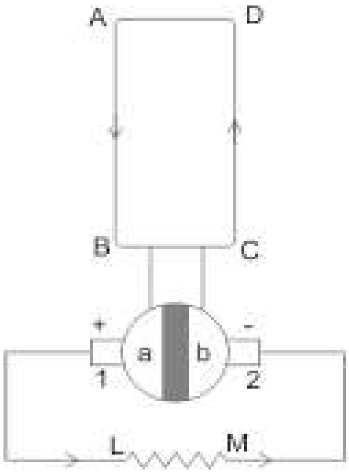
When $\theta = 360^o$, the coil sides are once again move parallel to the flux lines and the emf induced is zero again. The coil has now come back to the starting point.

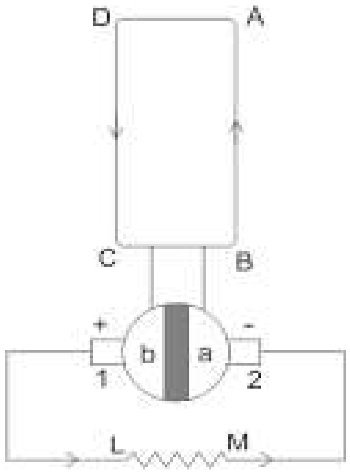
The emf induced in the coil can be increased by,

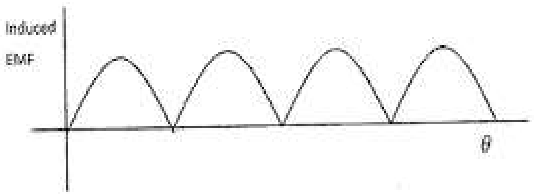
1) increasing the flux density, B

2) increasing the angular velocity, ω

The current flowing in the external resistance to a DC generator is made unidirectional by replacing the slip rings by a split rings. The ring is split into two equal segments a and b and the segments are insulated from each other and also from the shaft. In a DC generator, split rings are called commutator. The coil side AB is always attached to the segment a and likewise CD and b. The brushes 1 and 2 touch these segments and are meant to collect the current.







During the first half revolution, current flows along ABLMCD through brush 1 which is positive and into 2 (negative brush).

After half a cycle AB and CD have exchanged positions along with the segments a and b and current now flows through DCLMBA. B1 is now in contact with b.

1.4 EMF EQUATION OF DC GENERATOR

Let Φ be the flux per pole in webers

Let p be the number of poles

Let z be the total number of conductors in the armature

Let A be the number of parallel paths

So each parallel path will have Z/A conductors in series.

Let N be the speed of rotation in revolutions per minute (rpm)

Consider one conductor on the periphery of the armature. As this conductor makes one complete revolution, it cuts pΦ webers. As the speed is rpm, the time taken for one revolution is 60/N secs.

According to Faraday's law,

$$e \ \alpha \ \frac{d\phi}{dt} = \frac{p\phi}{60/N}$$

$$e = \frac{p\phi N}{60} \text{ volts}$$

Since there are Z/A conductors in series in each parallel path, the emf induced is,

$$Eg = \frac{p\phi N}{60} . \frac{Z}{A} = \frac{p\phi ZN}{60A} \text{ volts}$$

The armature conductors are generally connected in two different ways, viz, lap winding and wave winding. For lap wound armature, the number of parallel paths is equal to the number of poles (i.e., A = P) In wave wound machines,

A = 2 always.

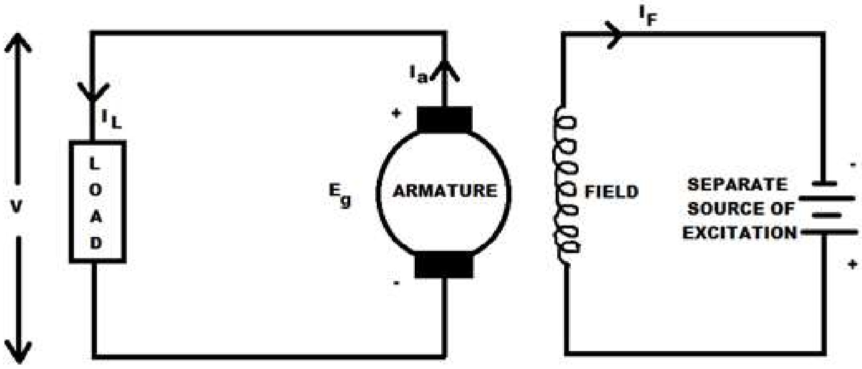
1.5 TYPES OF DC GENERATORS

There are two types of DC generators on the basis of excitation.

1. Separately excited DC generators
2. Self excited DC generators

Separately excited DC generators

If the field winding is excited by a separate DC supply, then the generator is called separately excited DC generator. The field winding has large number of turns of thin wire.



Separately excited DC generator

Armature current, Ia = Load current, I_L

Generated emf, $Eg = V + IaRa + V_{brush}$

Terminal voltage, $V = Eg - IaRa - V_{brush}$

Electric power developed = Eg Ia

power delivered to load = V I_L

Self excited DC generators

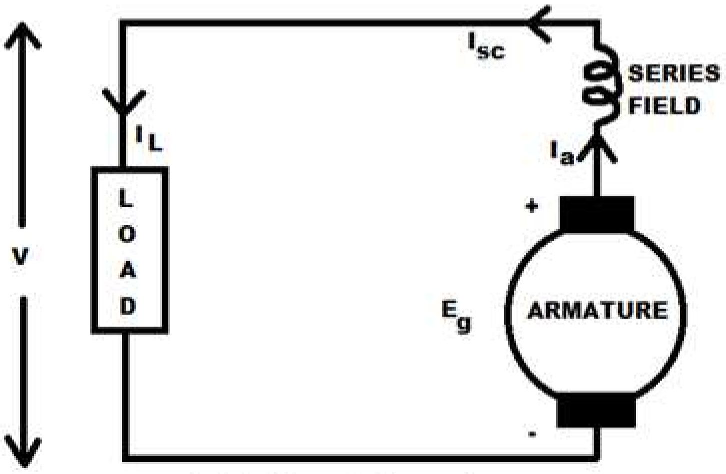
If in a DC generator field winding is supplied from the armature of the generator itself, then it is called a self excited DC generator.

Self excited DC generators can be classified depending upon how the field winding is connected to the armature. There are three types,

1. Series generator
2. Shunt generator
3. Compound generator

Series generator

If the field winding is connected in series with the armature, then it is called series generator. The field winding has less number of turns of thick wire. It has low resistance. It is denoted by Rse. Here, armature, field and load are all in series. So they carry the same current.



Series Wound Generator

Armature current, $Ia = Ise = I_L$

Generated emf, $Eg = V + IaRa + IseRse + V_{brush}$

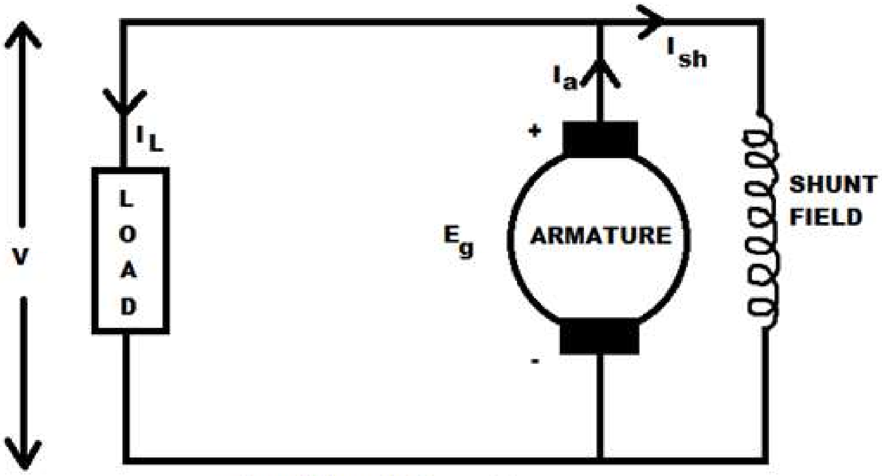
Terminal voltage, $V = Eg – IaRa – IseRse - V_{brush}$

Electric power developed = $Eg\,Ia$

power delivered to load = $V\,I_L$

Shunt generator

If the field winding is connected across the armature, then it is called shunt generator. The field winding has more number of turns of thin wire. It has high resistance.



Shunt Wound Generator

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

Shunt field current, $I_{sh} = \dfrac{V}{R_{sh}}$

Generated emf, $E_g = V + I_a R_a + V_{brush}$

Terminal voltage, $V = E_g - I_a R_a - V_{brush}$

Electric power developed = $E_g I_a$

power delivered to load = $V I_L$

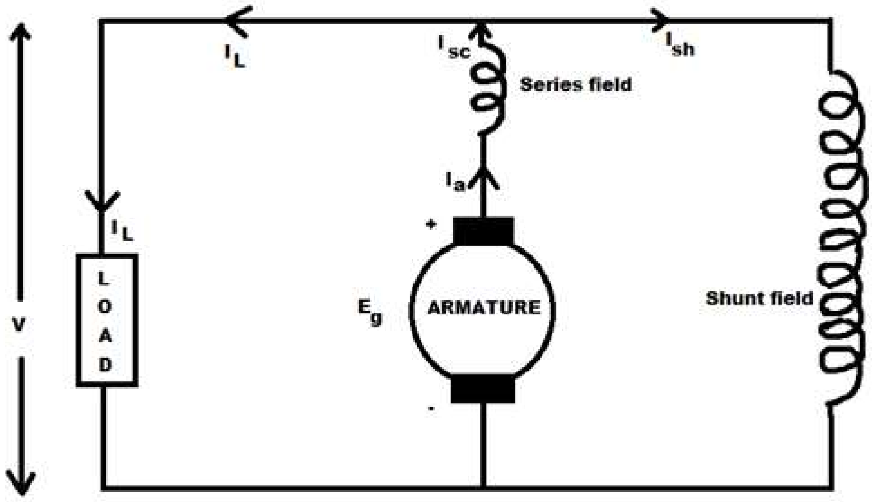
Compound generator

The compound generator consists of both shunt field and series field windings. One winding is connected in series and the other winding is in parallel with the armature. Depending upon the shunt field and series field connections, compound generator can be classified as,

1. Long shunt compound generator
2. Short shunt compound generator

Long shunt compound generator

Here, shunt field winding is connected across both series field and armature windings.



Long Shunt Compound Wound Generator

Armature current, $Ia = I_L + Ish = Ise$

Shunt field current, $Ish = \dfrac{V}{R_{sh}}$

Generated emf, $Eg = V + IaRa + IseRse + V_{brush}$

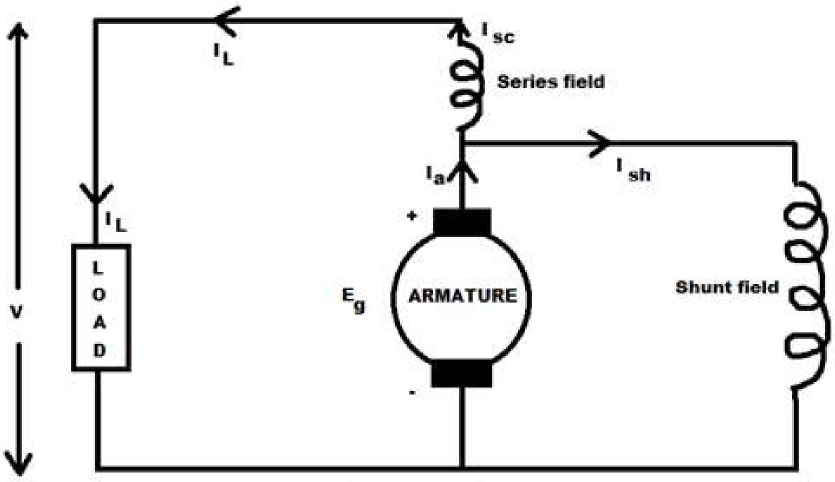
Terminal voltage, $V = Eg - IaRa - IseRse - V_{brush}$

Electric power developed = $Eg\,Ia$

power delivered to load = $V\,I_L$

Short shunt compound generator

Here, shunt field winding is connected in parallel with the armature and this combination is connected in series with series field winding.



Short Shunt Compound Wound Generator

Armature current, $Ia = I_L + Ish = Ise$

Shunt field current, $Ish = \frac{V}{R_{sh}}$

Generated emf, $Eg = V + IaRa + IseRse + V_{brush}$

Terminal voltage, $V = Eg - IaRa - IseRse - V_{brush}$

Electric power developed = Eg Ia

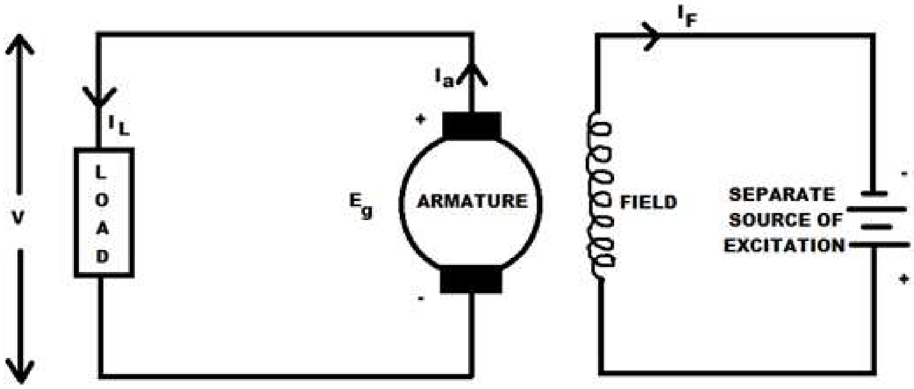
power delivered to load = $V\, I_L$

1.6 CHARACTERISTICS OF DC GENERATOR

There are three types of characteristics.

1. Open circuit characteristics (OCC) or magnetisation characteristics or no load characteristics (Eo Vs If)
2. Internal characteristics or total characteristics or load characteristics (Eg Vs Ia)
3. External characteristics or performance characteristics or voltage regulated characteristics or load characteristics (V Vs I_L)

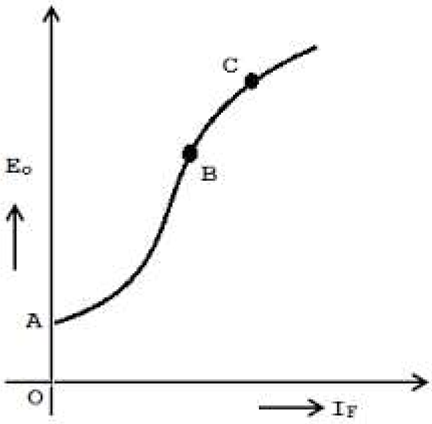
1.6.1 Separately excited DC generator characteristics



Separately excited DC generator

No load characteristics

For a given DC generator it is clear that the induced emf is proportional to the flux and the speed. If speed is kept constant, and the flux is varied, the induced emf also varies.



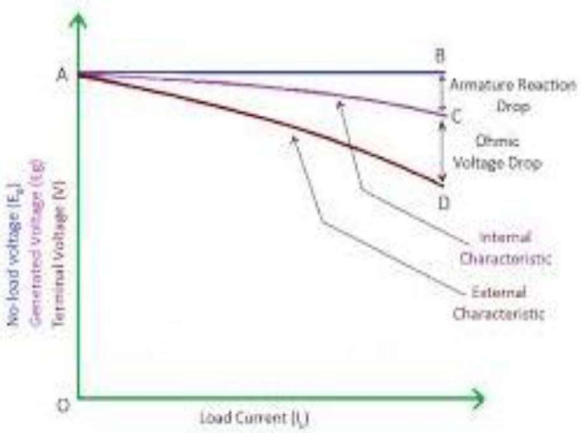
Since $E_g = \frac{p\phi ZN}{60A}$

$E_g \, \alpha \, \phi N$

When the field current is zero, there is some flux due to residual magnetism and this causes a small induced emf. It is shown in figure as OA.

As the field current is increased, the induced emf increases linearly from A to B. As the field current is further increased, the increase in flux is much smaller and hence emf also increases slowly. At point D saturation has set and any further increase in field current does not produce any increase in induced emf.

Load characteristics



Characteristics of separately excited DC generator

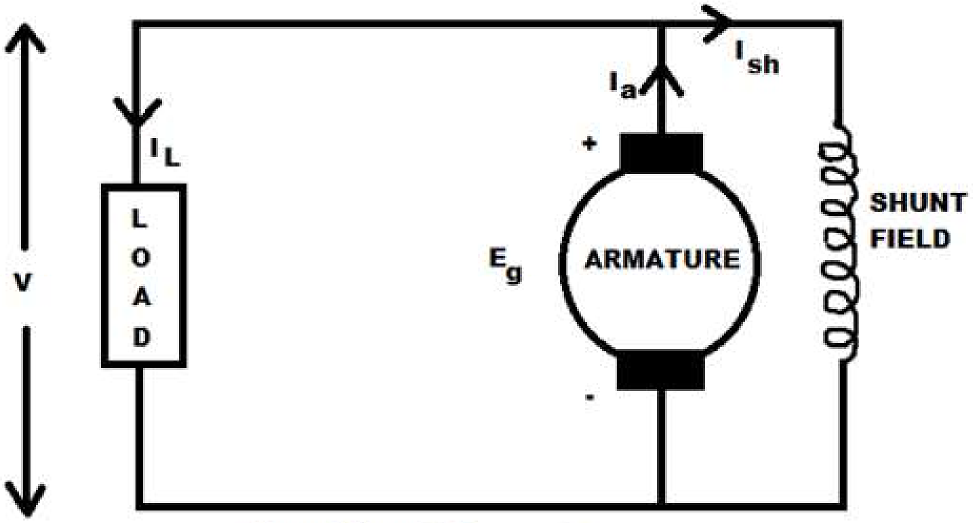
Internal characteristics

This curve is drawn between Eg and Ia. Here, by increasing the armature current induced emf will decrease due to armature reaction.

External characteristics

This curve is drawn between V and I_L. Here, by increasing the load current induced emf again decreases due to armature resistance.

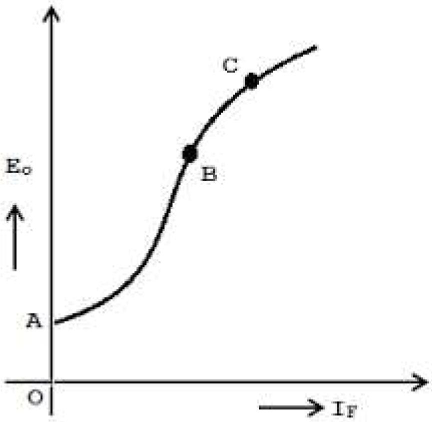
1.6.2 DC shunt generator characteristics



Shunt Wound Generator

No load characteristics

For a given DC generator it is clear that the induced emf is proportional to the flux and the speed. If speed is kept constant, and the flux is varied, the induced emf also varies.



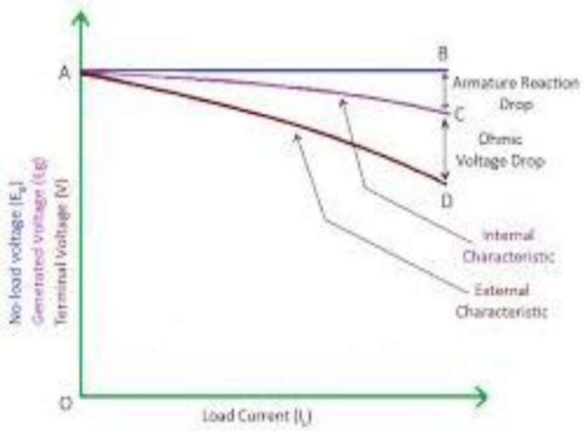
Since $$E_g = \frac{p\phi ZN}{60A}$$

$$E_g \,\alpha\, \phi N$$

When the field current is zero, there is some flux due to residual magnetism and this causes a small induced emf. It is shown in figure as OA.

As the field current is increased, the induced emf increases linearly from A to B. As the field current is further increased, the increase in flux is much smaller and hence emf also increases slowly. At point D saturation has set and any further increase in field current does not produce any increase in induced emf.

Load characteristics



Characteristics of separately excited DC generator

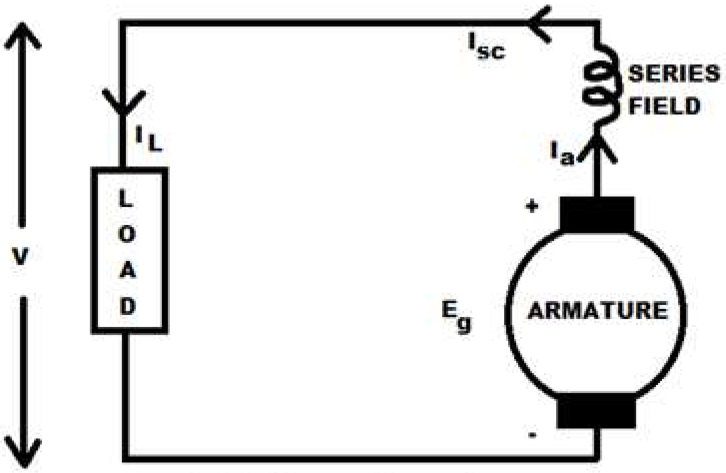
Internal characteristics

This curve is drawn between Eg and Ia. Here, by increasing the armature current induced emf will decrease due to armature reaction.

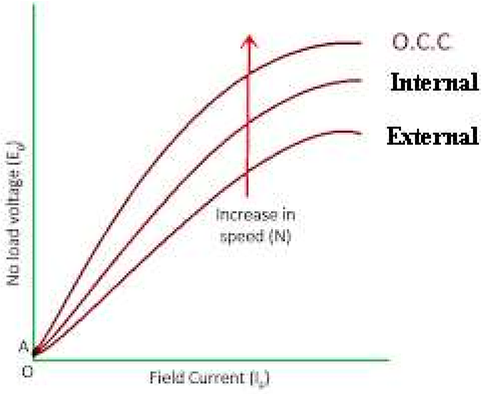
External characteristics

This curve is drawn between V and I_L. Here, by increasing the load current terminal voltage decreases due to armature resistance.

1.6.3 DC series generator characteristics



Series Wound Generator



No load characteristics

It can be obtained experimentally by disconnecting the field winding from the machine and exciting from a separate DC source.

Load characteristics

Internal characteristics

Here the drop is due to armature reaction. By increasing the armature current induced emf decreases.

External characteristics

Here the drop is due to armature resistance and series field resistance. This curve is drawn between V and I_L. Here, by increasing the load current terminal voltage decreases.

1.6.4 DC compound generator characteristics

. Depending upon the shunt field and series field connections, compound generator can be classified as,

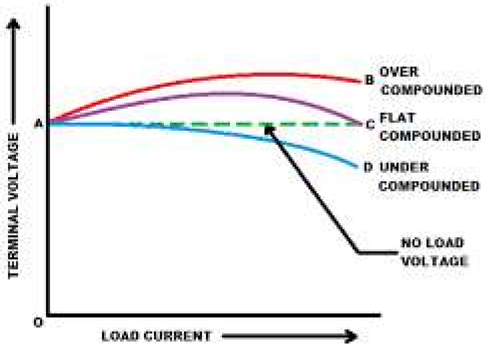
1. Long shunt compound generator
2. Short shunt compound generator

. Depending upon the flux, compound generator can be classified as,

1. Cumulative compound generator
2. Differential compound generator

The cumulative compound generator is further classified into,

1. Flat compound generator
2. Over compound generator
3. Under compound generator



Flat compound generator or Level compound generator

In shunt generator, we have seen that the terminal voltage falls on loading, when in series generator the terminal voltage increases with load. A compound generator consists of both shunt field and series field windings. So the drop in flux in shunt field is compensated by the rise in flux in series field and gives constant voltage characteristics. Here, by increasing the load current the terminal voltage is almost constant.

$$V = Eg$$

Over compound generator

Here the series field excitation is more than shunt field excitation. Here, by increasing the load current the terminal voltage will increase.

$$V > Eg$$

Under compound generator

Here the series field excitation is less than shunt field excitation. Here, by increasing the load current the terminal voltage will decrease.

$$V < Eg$$

1.7 APPLICATIONS OF DC GENERATOR

DC Shunt generator

- Battery charging
- Exciters for AC generators

DC Series generator

- Used for boosters
- Used for series incandescent lighting

DC compound generator

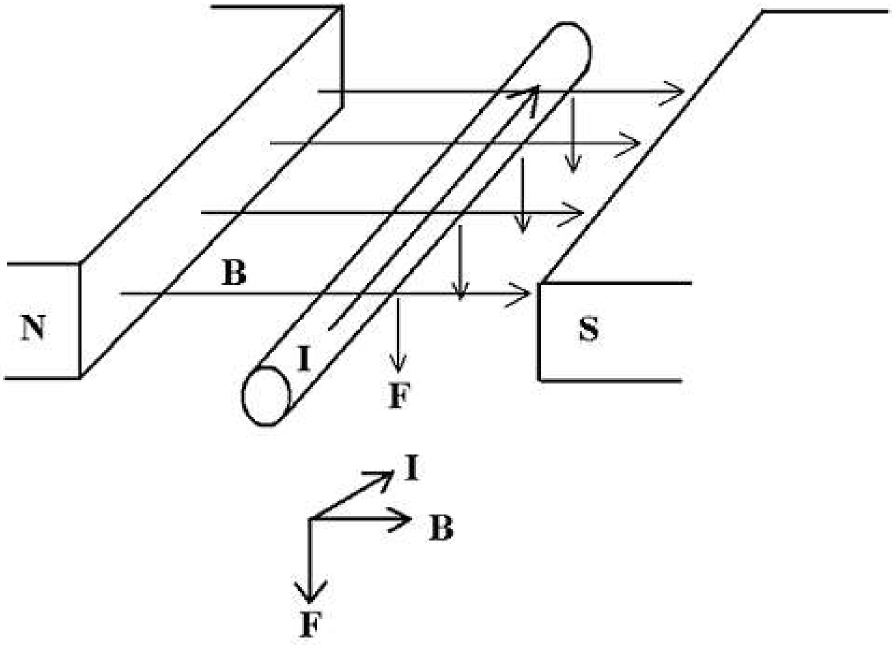
- Used for welding purpose
- Used to supply power to, railway circuits, incandescent lamps, elevator motor etc.

1.8 DC MOTOR - INTRODUCTION

DC motor converts electrical energy into mechanical energy. This energy conversion is based on the principle of electromagnetic induction.

1.9 PRINCIPLE OF OPERATION OF DC MOTOR

Whenever a current carrying conductor is placed in a magnetic field, it experiences a force tending to move it.



If a current carrying conductor is placed between two magnetic poles , both a fields will be distorted.

Above the conductor, the field is weakened and below the conductor, the field is strengthened. Therefore the conductor tends to move upwards.

Here, below the conductor, the field is weakened and above the conductor, the field is strengthened. Therefore the conductor tends to move downwards.

The magnitude of the force experienced by the conductor in a motor is given by,

$$F = BIl \quad \text{newtons}$$

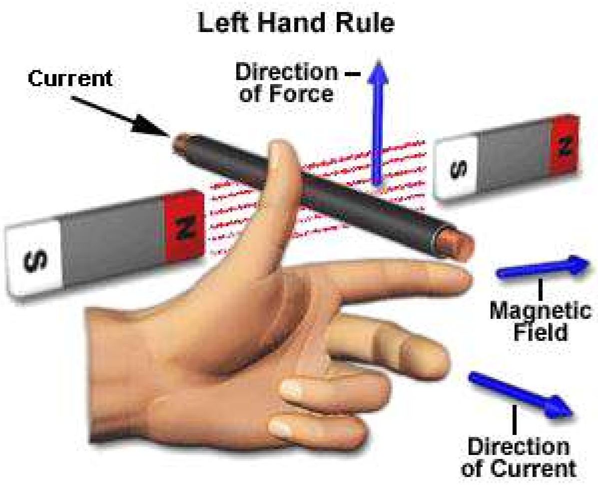
Where,

B is the magnetic field intensity in wb/m^2

I is the current in amperes

l is the length of the conductor in meters

The direction of motion is given by Fleming's left hand rule, which states that if the thumb, fore finger and middle finger of the left hand are held such that the fingers show three mutually perpendicular directions and if the fore finger indicates direction of the field and the middle finger indicates the direction of current then the thumb points the direction of motion of conductor.



1.10 BACK EMF

When a motor rotates, the conductors housed in the armature also rotate and cut the magnetic lines of force. So an emf is induced in the armature conductors and this induced emf opposes the supply voltage as per Lenz's law. This induced emf is called back emf or counter emf.

$$E_b = \frac{p\phi ZN}{60A} \text{ volts}$$

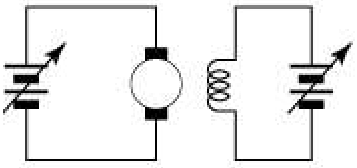
1.11 TYPES OF DC MOTORS

There are two types of DC motors on the basis of excitation.

1. Separately excited DC motors
2. Self excited DC motors

Separately excited DC generators

If the field winding is excited by a separate DC supply, then the motor is called separately excited DC motor.



Armature current, Ia = Load current, I_L

Back emf, Eb = V - IaRa - V_{brush}

Input voltage, V = Eb + IaRa + V_{brush}

Self excited DC generators

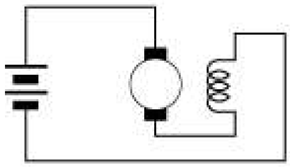
If in a DC motor field winding is supplied from the armature of the motor itself, then it is called a self excited DC motor.

Self excited DC motor can be classified depending upon how the field winding is connected to the armature. There are three types,

1. Series motor
2. Shunt motor
3. Compound motor

Series motor

If the field winding is connected in series with the armature, then it is called series motor. The field winding has less number of turns of thick wire. It has low resistance. It is denoted by Rse. Here, armature, field and load are all in series. So they carry the same current.



Armature current, $Ia = Ise = I_L$

Back emf, $Eb = V - IaRa - IseRse - V_{brush}$

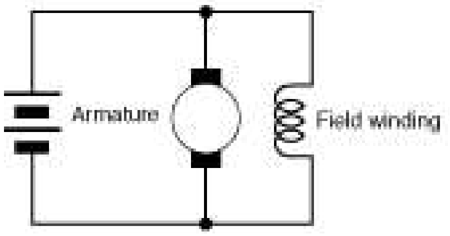
Input voltage, $V = Eb + IaRa + IseRse + V_{brush}$

In a DC series motor, full armature current flows through the series field winding. Therefore, flux produced is directly proportional to the armature current.

i.e., $\Phi \alpha Ise \alpha Ia$

Shunt motor

If the field winding is connected across the armature, then it is called shunt motor. The field winding has more number of turns of thin wire. Ra is very small and Rsh is quite large.



Line current, $I_L = I_a + Ish$

Shunt field current, $Ish = \frac{V}{R_{sh}}$

Back emf, $Eb = V - IaRa - V_{brush}$

Input voltage, $V = Eb + IaRa + V_{brush}$

In a DC shunt motor, flux produced by field winding is directly proportional to the field current.

i.e., $\Phi \alpha Ish$

Compound motor

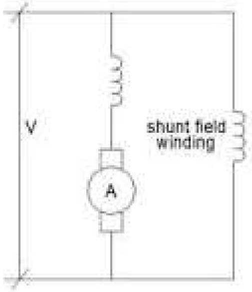
The compound motor consists of both shunt field and series field windings. One winding is connected in series and the other winding is in parallel with the armature. Depending upon the shunt field and series field connections, compound motor can be classified as,

1. Long shunt compound motor

2. Short shunt compound motor

Long shunt compound motor

Here, shunt field winding is connected across both series field and armature windings.



Line current, $I_L = I_a + Ish$

Armature current, Ia = Ise

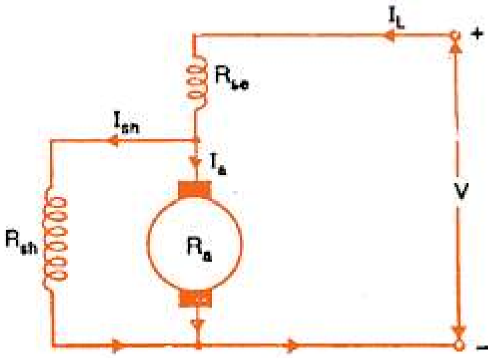
Shunt field current, Ish = $\frac{V}{R_{sh}}$

Back emf, Eb = V - IaRa - IseRse - V_{brush}

Input voltage, V = Eb + IaRa + IseRse + V_{brush}

Short shunt compound motor

Here, shunt field winding is connected in parallel with the armature and this combination is connected in series with series field winding.



Short-shunt connection

Line current, $I_L = I_a + Ish$

$I_L = Ise$

Shunt field current, $Ish = \dfrac{V}{R_{sh}}$

Back emf, $Eb = V - IaRa - IseRse - V_{brush}$

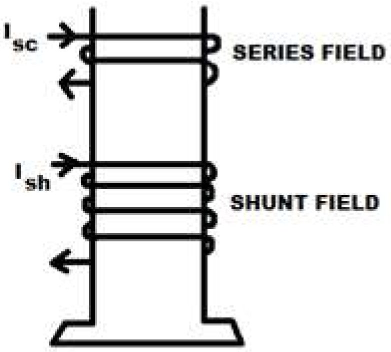
Input voltage, $V = Eb + IaRa + IseRse + V_{brush}$

The compound motor again can be classified into two types.

1. Cumulative compound motor
2. Differential compound motor

Cumulative compound motor

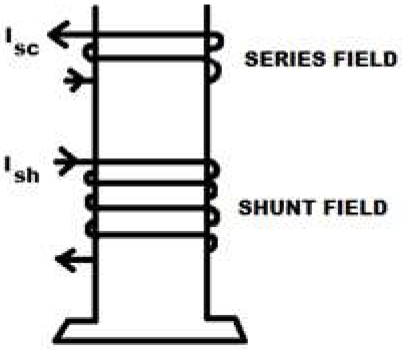
In this type of motor, the two field winding fluxes aid each other i.e., flux due to the series field winding strengthens the flux due to the shunt field winding.



CUMULATIVE COMPOUNDING

Differential compound motor

In this type of motor, the two field winding fluxes oppose each other i.e., flux due to the series field winding weakens the flux due to the shunt field winding.



DIFFERENTIAL COMPOUNDING

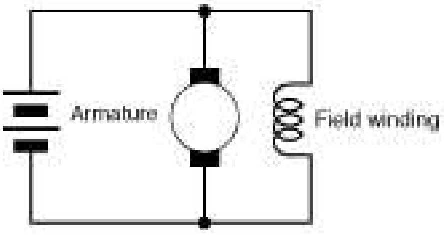
1.12 CHARACTERISTICS OF DC MOTORS

There are three types of characteristics.

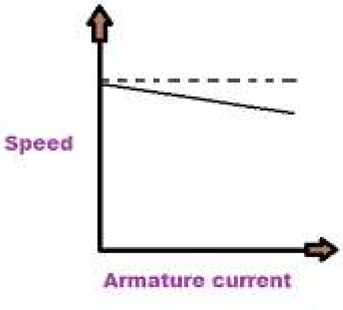
1. Speed – armature current characteristics
2. Torque – armature current characteristics
3. Speed – torque characteristics

1.12.1 Shunt motor characteristics

In this field is connected across the supply voltage. Since the supply voltage is constant, the field current and hence the flux are also constant.



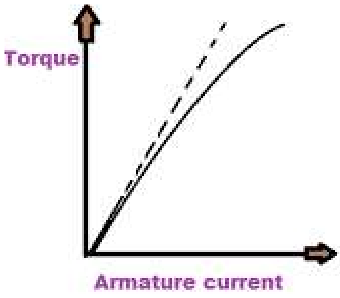
Speed– armature current characteristics



$$N \alpha \frac{E_b}{\phi}$$

Flux is constant for shunt motor. Therefore speed is nearly a constant.

Torque – armature current characteristics



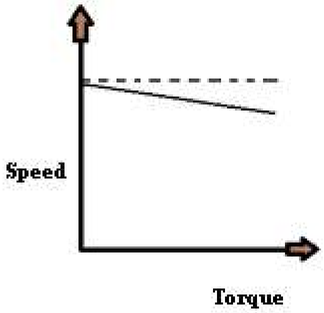
$$T \alpha \Phi Ia$$

Flux is constant for shunt motor.

Therefore, $T \alpha Ia$

So current increases, torque also increases.

Speed– torque characteristics

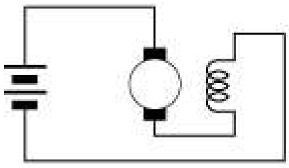


In this, torque increases speed slightly decreases.

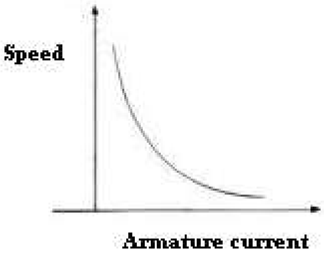
$$\omega = \frac{P}{T}$$

1.12.2 Series motor characteristics

In this field winding is connected in series with the armature winding.



Speed– armature current characteristics



$$N \alpha \frac{E_b}{\phi}$$

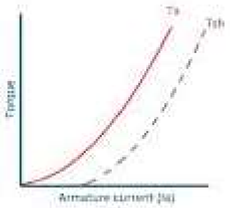
Flux is proportional to the armature current for series motor.

$$\Phi \ \alpha \ Ia$$

Therefore, $N \ \alpha \ \frac{E_b}{Ia}$

So current increases, speed will decrease.

Torque – armature current characteristics



$$T \ \alpha \ \Phi \ Ia$$

Flux is proportional to the armature current for series motor.

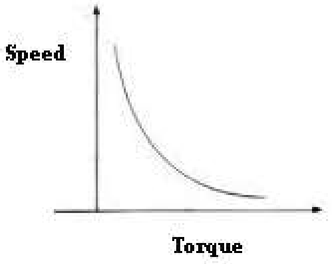
$$\Phi \ \alpha \ Ia$$

Therefore, $T \ \alpha \ Ia^2$

So current increases, torque increases as the square of the current. Hence this characteristic is a parabola.

After saturation flux becomes constant. i.e., T α Ia. So the curve becomes a straight line.

Speed – torque characteristics



Here the DC series motor speed is high, the torque is low and vice-versa.

$$N \propto \frac{1}{\sqrt{T}}$$

$$\omega = \frac{P}{T}$$

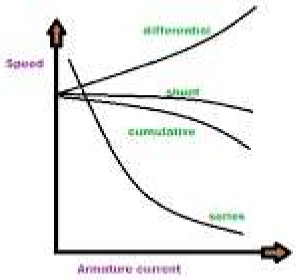
1.12.3 Compound motor characteristics

The characteristics of a compound motor will depend whether the series and shunt field windings are assisting each other (cumulative) or opposing each other (differential).

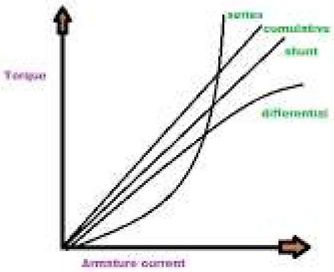
In the cumulative connections, the characteristics will be between those of shunt and series motors characteristics.

In the differential connections, the characteristic curve lying over the shunt motor characteristics.

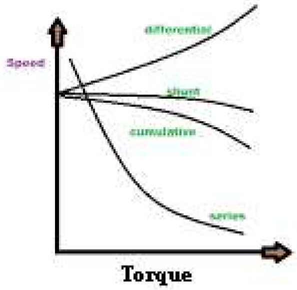
Speed– armature current characteristics



Torque – armature current characteristics



Speed– torque characteristics



1.13 SPEED CONTROL OF DC MOTORS

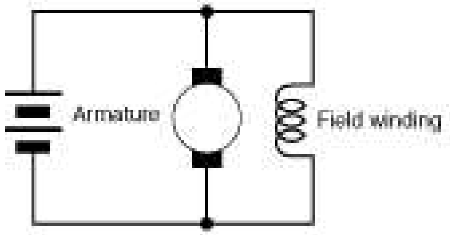
1.13.1 Speed control of dc shunt motor

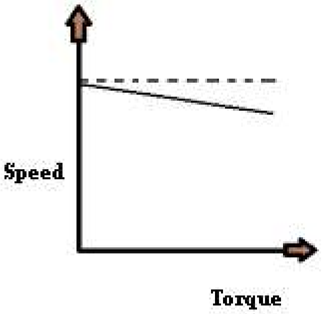
Three methods of speed control are

1. By varying the resistance in the armature circuit (Rheostatic control)
2. By varying the flux (Flux control)
3. By varying the applied voltage (Voltage control)

By varying the resistance in the armature circuit (Rheostatic control)

A variable resistance R is connected in series with armature circuit. Here the input voltage V is constant. The speed of the motor can be controlled by varying the resistor R. By increasing the controller resistance R, the potential drop across the armature is decreased. Therefore the motor speed also decreases. This method of speed control is applicable only for speed lower than no load speed (base speed).





$$N \propto \frac{E_b}{\phi}$$

Advantage

Simple method of speed control.

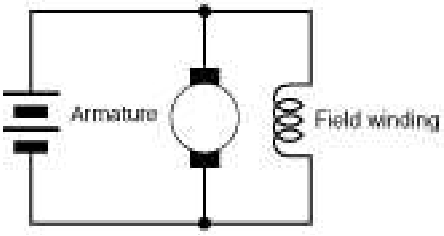
Disadvantages

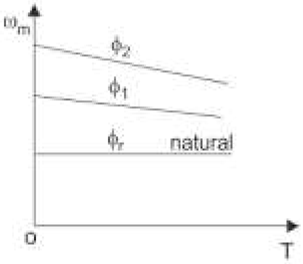
1. High power loss
2. Highly inefficient

By varying the flux (Flux control)

$$N \propto \frac{E_b}{\phi}$$

From the above equation, the speed is inversely proportional to flux. By varying the flux, the motor speed can be varied. The flux of a DC motor can be changed by changing the field current.





By varying the field resistance, the field current can be decreased. i.e., the flux will be decreased. Thus motor speed can be increased by decreasing the flux. This method of speed control can be used for increasing the speed of the motor above its rated speed.

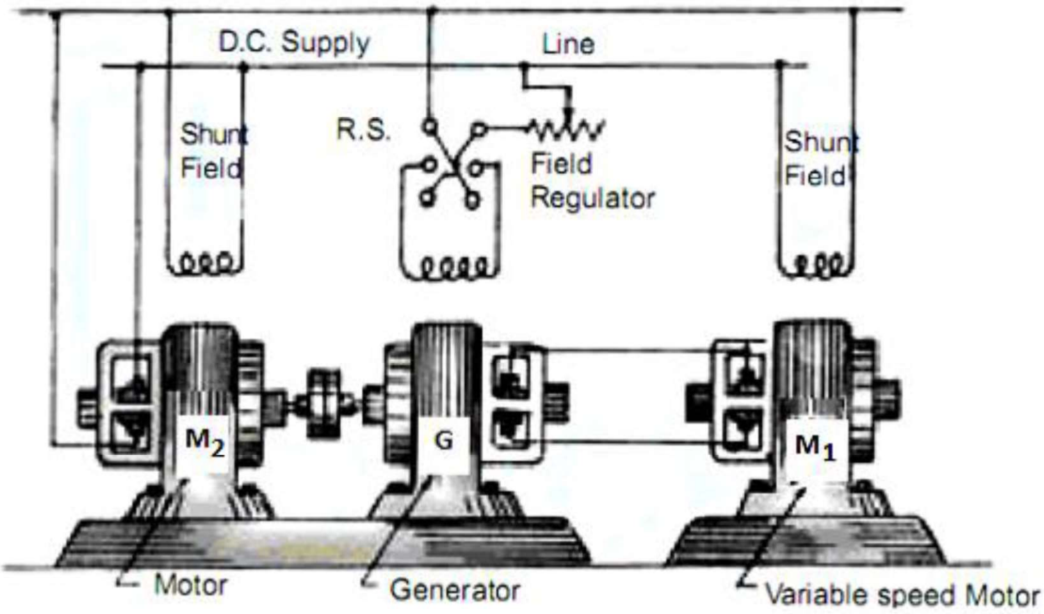
By varying the applied voltage (Voltage control)

Ward-Leonard control system

It consists of three DC machines i.e., two DC motors and one DC generator. The system uses a motor – generator (M_1–G) set. The DC drive motor M_1 is the main motor, directly coupled to the DC generator. DC supply is given to the armature terminal as well as shunt field winding.

The M – G set runs at constant speed. The voltage of the generator can be varied from zero to maximum value by means of its field regulator. The generated DC voltage is fed to the controlled DC motor (M_2).

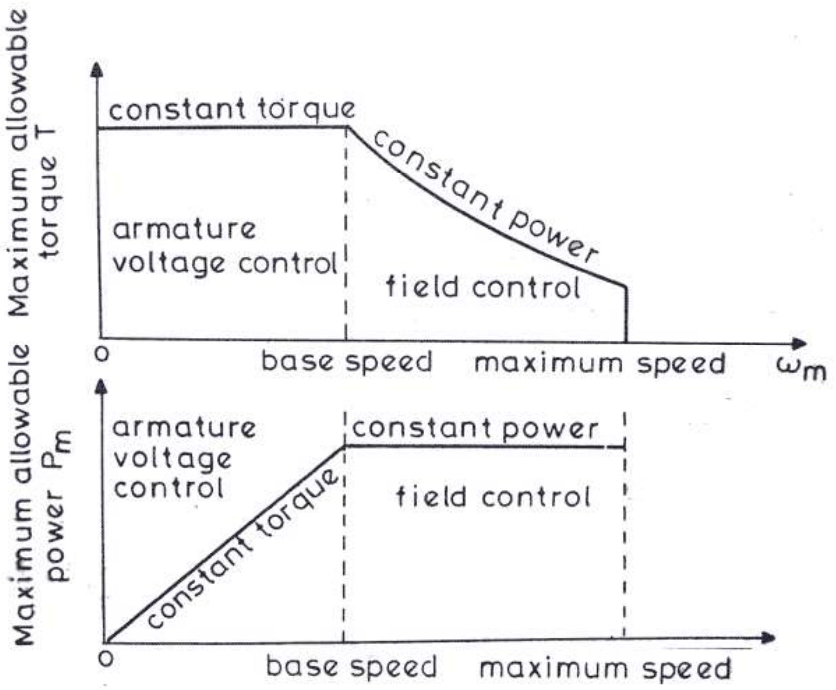
The direction of the rotation of controlled DC motor M_2 can be changed by reversing the direction of the field current of generator G. it is done by using reversing switch (RS) and the generated voltage can be reversed and the motor rotates in reverse direction. This method of speed control is the combination of armature control and flux control methods. The armature voltage control can be achieved by varying the field of the DC generator.



WARD LEONARD SYSTEM OF SPEED CONTROL

The flux control method can be achieved by varying the field of the controlled DC motor. The Ward-Leonard system provides a constant torque as well as constant horse power.

In the constant torque operating mode, the flux of the controlled DC motor is kept constant and the armature voltage is controlled. In the horse power operating mode, the armature voltage is kept constant and the field current is controlled.



Advantages

1. Full forward and reverse speed can be achieved.
2. A wide range of speed control is possible.

Disadvantages

1. High initial cost.
2. Efficiency is low
3. Large amount of space is required
4. The drive produces noise
5. It requires frequent maintenance

Applications

Used in

- Electric excavators
- Elevators

- Steel mills
- Paper mills

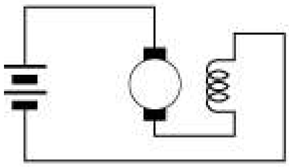
1.13.2 Speed control of dc series motor

Two methods of speed control are

1. By varying the resistance in the armature circuit (Rheostatic control)
2. By varying the flux (Flux control)

By varying the resistance in the armature circuit (Rheostatic control)

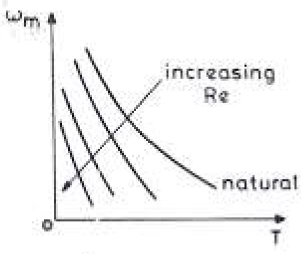
In this method, variable resistance is connected in series with armature. By increasing the resistance, the voltage applied across the armature terminal can be decreased. By reducing the voltage across the armature, the motor speed also decreases. Because the applied voltage is directly proportional to the speed.



$$N \alpha \frac{E_b}{\phi}$$

$$E_b \alpha V$$

Therefore, $N \alpha V$

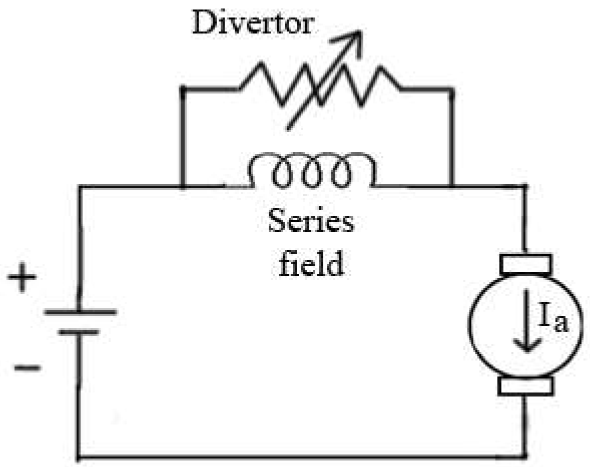


Series

By varying the flux (Flux control)

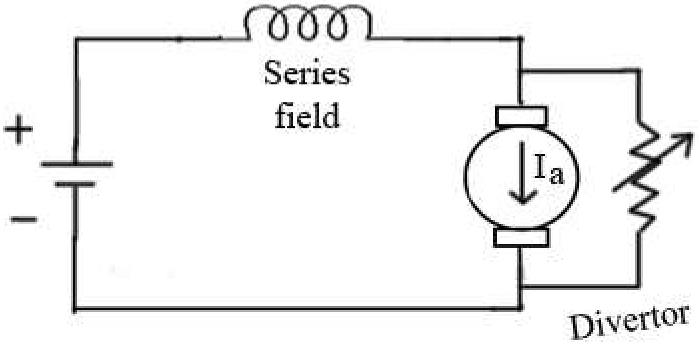
i) **Field divertor**

Field divertor means, a variable resistance is connected across the series field winding. By varying the resistance, the current flowing through the series field changes. Due to decrease in field current, the flux can be decreased and consequently, the speed also increases.



ii) **Armature divertor**

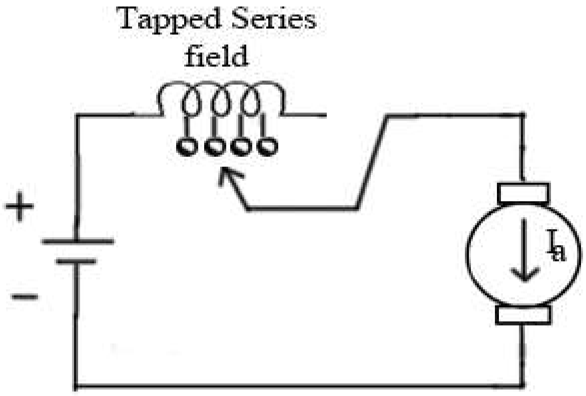
Armature divertor means, a variable resistance is connected across the armature. For a constant load torque operation, the armature current is decreased due to armature divertor and flux must increase, because the load torque is directly proportional to flux and armature current. This results in an increase in current taken from the mains. Due to current increase, series field flux also increases. Then the speed of the motor can be decreased.



$$N \alpha \frac{E_b}{\phi}$$

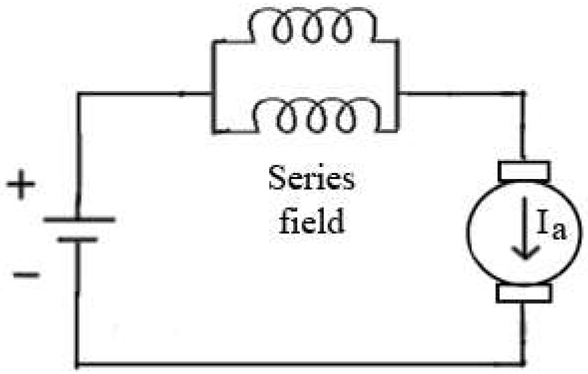
iii) Tapped field control

The speed of the motor is controlled by variation of the number of field turns. This method of speed control is applicable where the speed control required is above the base speed. Because by varying the series field turns, the flux can be decreased and motor speed can be increased. This method is mainly used in electric traction.



iv) Paralleling field coils

In this method, speed control is achieved by rearranging the field coils. This method is mainly used in fan motors. Here, we can get three speeds easily by using a 4 pole motor.



1.14 APPLICATIONS OF DC MOTORS

DC shunt motor

- Lathe machines
- Fans
- Machine tools
- Drilling machines

DC series motor

- Electric locomotives
- Cranes
- Hoists
- Elevators
- Trolleys

Cumulative compound motor

- Elevators
- Rolling mills
- Printing presses
- Air compressors

Differential compound motor

Not suitable for any practical applications

PROBLEMS

1. A 4 pole generator with wave wound armature has 51 slots each having 24 conductors. The flux per pole is 0.01 weber. At what speed must the armature rotate to give an induced emf of 250 V. what will be voltage developed, if the winding is lap connected and the armature rotates at the same speed.

Solution:

$Z = 51 \times 24 = 1224$ conductors, $E_g = 250$ V, $P = 4$

For wave wound $A = 2$, $\phi = 0.01$ wb

$$E_g = \frac{P\phi ZN}{60A}$$

$$N = \frac{E_g\ 60A}{P\phi Z} = \frac{250 \times 60 \times 2}{4 \times 0.01 \times 1224}$$

$$\boxed{N = 612.74 \text{ rpm}}$$

For lap connection, $A = P$

Speed $N = 612.74$ rpm

$$E_g = \frac{P\phi ZN}{60A} = \frac{4 \times 0.01 \times 1224 \times 612.74}{60 \times 4}$$

$$\boxed{E_g = 125 \text{ V}}$$

2. An 8-pole, wave connected armature has 600 conductors and is drives at 625 rev/men. If the flux perpole is 20 mwb, determine the generated emf.

Given data :

Number of poles P = 8, Total number of conductors Z = 600

Flux per pole ϕ = 20 wb for wave wound A = 2

Induced armature voltage $E_g = \frac{P\phi ZN}{60A} = \frac{8 \times 20 \times 10^{-3} \times 600 \times 625}{60 \times 2}$

$$\boxed{E_g = 500 \text{ V}}$$

3. A 4 pole, 500 V dc shunt motor has 700 wave connected conductors on its armature. The full load armature current is 60 A and flux per pole is 30 mwb. Calculate the full load speed if the motor armature resistance is 0.2 Ω and the brush drop is 1 volt per brush.

Given data :

Number of poles P = 4, Supply Voltage V = 500 V,

Number of conductors Z = 700, Full load armature current I_a = 60 A,

Flux per pole ϕ = 30 mwb Armature resistance R_a = 0.2 Ω

Brush drop = 1 V per brush = 2 × 1 = 2 V, for wave connection A = 2

To find:

Full load speed (N)

Solution:

Back emf $E_b = V - I_aR_a -$ brush drop

$= 500 - 60 \times 0.2 - 2 = 486$ V

$$E_b = \frac{P\phi ZN}{60A}$$

$$N=\frac{E_b\ 60A}{P\phi Z}=\frac{486\times 60\times 2}{4\times 30\times 10^{-3}\times 700}$$

$$\boxed{N = 694.28\text{rpm}}$$

4. A 4 pole DC motor takes an armature current of 50 A. the armature has 480 lap connected conductors. The flux per pole is 20 mwb. Calculate the gross torque developed by the motor.

   Given data :

   Number of poles P = 4, Armature Current $I_a = 50$ A, Flux per pole ϕ = 20 mwb

   Number of conductors Z = 480, for lap connection A = P

   To find:

   Gross Torque (T_a)

   Solution:

   Gross Torque T_a=

$$0.159\,\phi\, I_a \frac{PZ}{A} N-m = 0.159\times 20\times 10^{-3}\times \frac{50\times 4\times 480}{4} N-m$$

$$\boxed{T_a = 76.32\text{ N-m}}$$

5. Determine developed torque, shaft torque and lost torque of a 220 V, 4 pole series motor with 800 conductors wave connected supplying a load of 8.2kW by taking 45 A from the mains. The flux per pole is 25 mwb and its armature resistance is 0.6 Ω.

   Given data :

No. of poles P = 4, Supply Voltage V = 220 V,

No. of conductors Z = 800, current $I_a = 45$ A,

Flux per pole ϕ = 25mwb Armature resistance $R_a = 0.6\ \Omega$

Output power P_{out}= 8200W, wave connected ie., A = 2

To find:

i)Armaturetroque T_a ii) Shaft torque T_{sh} iii) Lost torque T_f

Solution:

i)Armaturetroque T_a

$$T_a = 0.159\,\phi\, I_a \frac{PZ}{A} = 0.159 \times 25 \times 10^{-3} \times 45 \times \frac{4 \times 800}{2}$$

$$\boxed{T_a = 286.32 \text{ N-m}}$$

ii) Shaft torque T_{sh}

$$E_b = V - I_a R_a = 220 - 45 \times 0.6 = 193 \text{ V}$$

$$N = \frac{E_b\ 60A}{P\phi Z} = \frac{193 \times 60 \times 2}{4 \times 25 \times 10^{-3} \times 800}$$

$$N = 289.5 \text{ rpm}$$

$$T_{sh} = 9.55 \frac{P_{out}}{N} = 9.55 \times \frac{8200}{289.5}$$

$$\boxed{T_{sh} = 270.5 \text{ N-m}}$$

iii) Lost torqueT_f

$$T_f = T_a - T_{sh} = 286.2 - 270.5$$

$$\boxed{T_f = 15.7 \text{ N-m}}$$