

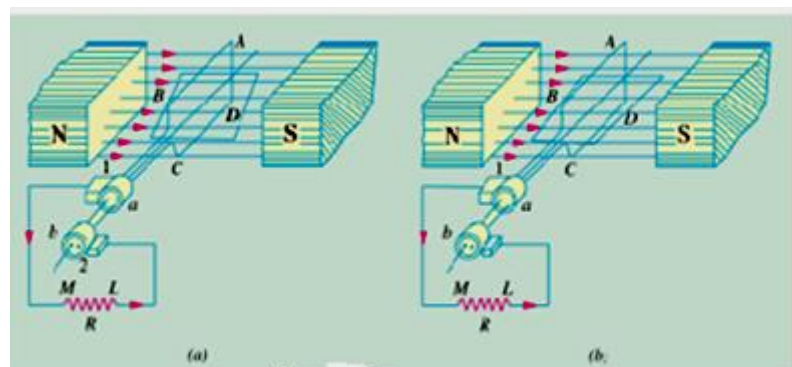
UNIT-2

DC Generators

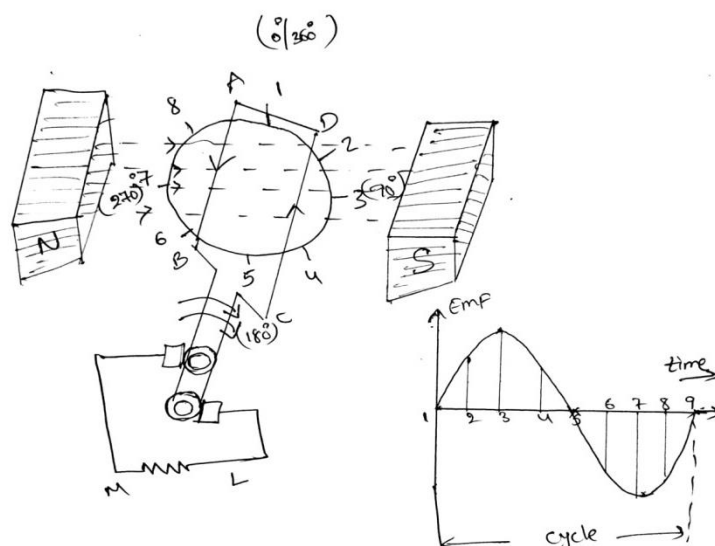
An electrical generator is a machine which converts mechanical energy into electrical energy. This energy conversion is based on the principle of the production of dynamically induced e.m.f., whenever a conductor cuts magnetic flux, dynamically induced e.m.f. is produced in it according to Faraday's laws of electromagnetic induction. This e.m.f. causes current to flow if the conductor circuit is closed. The basic parts of an electrical generator are:

- i) A magnetic field
- ii) A conductor which can so move to cut the flux

Working operation of a DC Generator



Above figure shows the single turn rectangular coil ABCD rotating about its own axis in a magnetic field provided by either permanent magnet or electromagnet. The two ends of the coil are joined to two slip rings a and b which are insulated from each other against the slip rings. The function of the brushes to collect the current induced in the coil.



Assume the coil to be rotating in clock wise direction

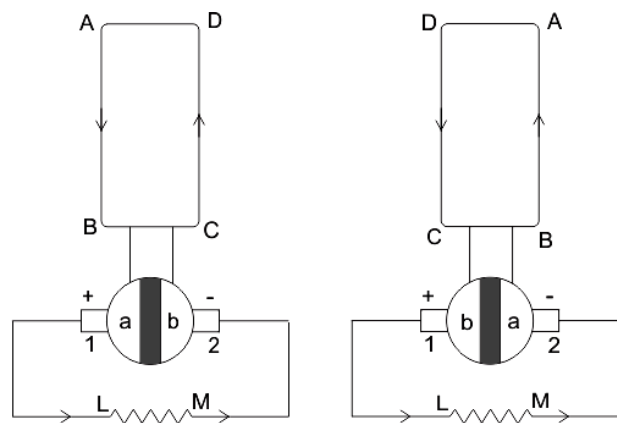
Step-1: when the coil position-1 that is right angles to lines of flux at that position the flux linked with the coil is maximum but the rate of change of flux linkages is minimum because the coil sides AB and CD links with the flux lines so there is no induced emf in the coil.

Step-2: as the coil continues rotating further, the rate of change of flux linkages increases so the emf starts increasing towards maximum value the maximum value of emf will exist when the conductor is at $\theta=90^\circ$ and parallel to the flux lines

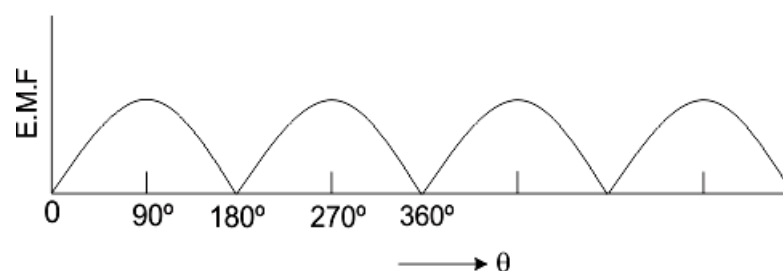
Step-3: the conductor further moving towards 180° the flux linked with the coil is gradually increases so the rate of change of flux linkages decreases so the emf will gradually come to zero value

Step-4: In the half revolution the current direction is from ABMLCD but in the next half revolution the current will pass from DCLMBA which is just reverse of the previous direction of flow so the next cycle will be in negative plane as shown in figure.

Action of commutator



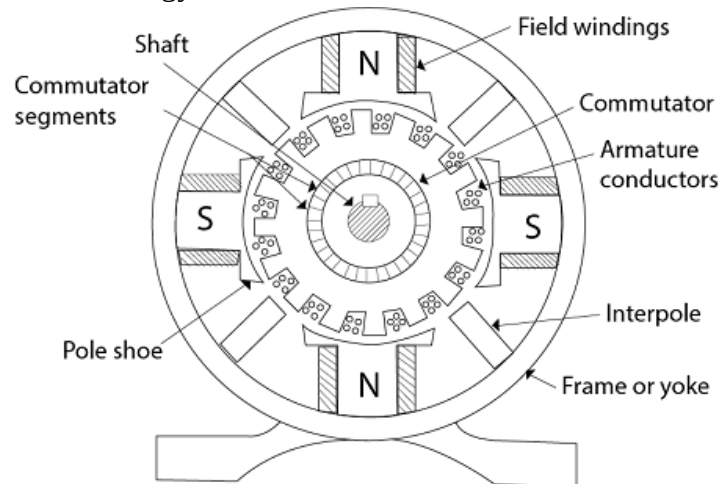
- The figure shows the commutator action of the motor AB, CD are the two sides of coil, ML is the load resistor, ab are the two split rings 1,2 are the two brushes.
- The coil ABCD is connected to the split rings ab and the brushes 1,2.
- The main function of the brushes is to collect the current from the coil or commutator.
- In the first half cycle the current will flow in the direction of “AB-a-1-LM-2-b-CD.
- The current flows here from +ve to –ve.
- In the next half revolution the current will flow in the direction of DC-b-1-LM-2-a-BA the current direction from +ve to –ve.
- For both half cycles the current will flow from +ve to –ve so the negative half cycle is also come in the +ve plane.
- This current is unidirectional like DC current.



Construction of a DC machine

A DC machine consists of two main parts:

- i) Stationary part. It is designed mainly for producing a magnetic flux
- ii) Rotating part. It is called the armature, where mechanical energy is converted into electrical or electrical energy into mechanical.



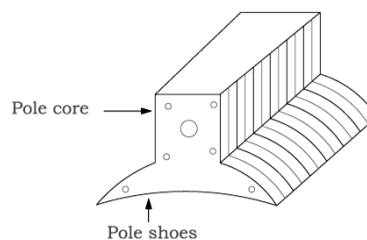
1) Magnetic Frame or Yoke:

- It provides mechanical support for the poles and acts as a protecting cover for the whole machine
- It carries the magnetic flux produced by the poles
- The material used for yoke is cast iron silicon steel

2) Pole core and pole shoes:

Pole shoe will serve two main purposes

- They spread out the flux in the air gap and also being of larger cross section, reduce the reluctance of the magnetic path
- They support the exciting coils or field coils
- Pole core itself may be a solid piece made out of either cast iron or steel and it is laminated with small pieces

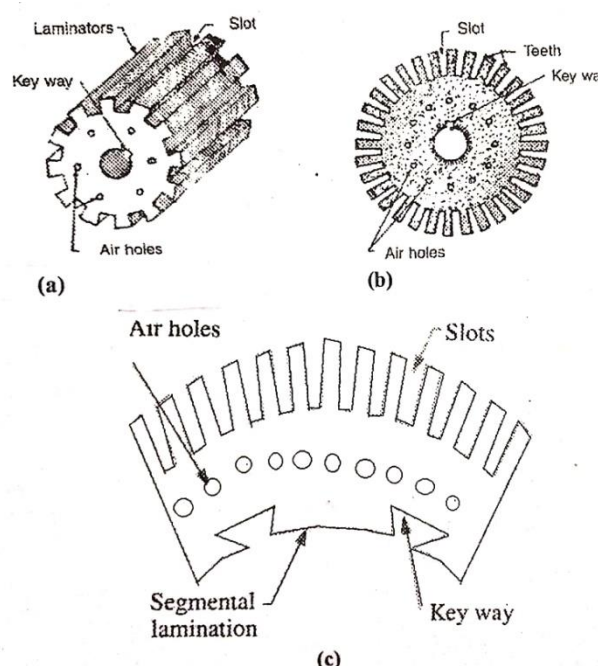


Pole coils

The field coils or pole coils which consist of copper wire called as a field winding. When current is passed through these coils they electro magnetise the poles which produce the necessary flux.

3) Armature core:

It houses the armature conductors or coils and causes them to rotate and hence cut the magnetic flux of the field magnets in addition to this its most important function is to provide a path of very low reluctance to the flux through the armature from a N pole to S pole.



The armature conductors are placed in the slots

The armature core is also a thin laminated core.

4) Brushes and bearings:

The function of the brushes to collect the current from commutator and are usually made of carbon or graphite

Bearings are used for smooth operation

5) Armature windings:

- Armature windings are made up of Copper material.
- The armature winding is housed in slots on the surface of the armature. The conductors of each coil are so spaced that when one side of the coil is under a north pole, the opposite is under a south pole.

There are two types of windings: a) lap winding b) wave winding

- For lap winding, number of parallel paths always equal to no. of poles ($A=P$). This is used for high current, low voltage applications.
- For wave winding, number of parallel paths equal to two ($A=2$). This is used for high voltage, low current applications.

EMF Equation of a DC Generator:

Let, P = Number of poles of the generator

Φ = Flux produced by each pole in webers (Wb)

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

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Z = Total Number of Armature Conductors

A = Number of parallel paths in which the ' Z ' number of conductors are divided

So $A = P$ for lap type of winding

$A = 2$ for wave type of winding

Now e.m.f. gets 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,

$$e = \text{Rate of cutting the flux} = d\Phi/dt$$

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

While time required completing one revolution is $60/N$ seconds as speed is N r.p.m.

$$e = \frac{\phi P}{\left(\frac{60}{N}\right)} = \frac{\phi P N}{60}$$

This is the e.m.f. induced in one conductor. Now the conductors in one parallel path are always in series. There are total Z conductors with A parallel paths, hence Z/A number of conductors are always in series and e.m.f. remains same across all the parallel paths.

∴ Total e.m.f. can be expressed as,

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

This is nothing but the e.m.f. equation of a d.c. generator.

$$E = \frac{\phi P N}{60} * \frac{Z}{A} \quad \text{Volts}$$

$$E = \frac{\phi N Z}{60} \quad \text{for lap type as } A = P$$

$$E = \frac{\phi P N Z}{120} \quad \text{for Wave type as } A=2$$

Ex-1: A 4 pole generator having a wave wound armature winding has 51 slots, each slot contains 20 conductors, what will be the voltage generated in the machine when driven at 1500 rpm, flux per pole 7 mwb? **[ans: 357V]**

Ex-2: An 8-pole, lap wound armature rotated at 350 rpm is required to generate 260V, the useful flux per pole is 0.05wb, if the armature has 120 slots calculate the number of conductors per slot? **[ans: 8]**

Ex-3: the armature of 60 rpm lap wound generator has 90 slots if each slot has 4 turns calculate the flux per pole required to generate an emf of 288V, $A=6$. **[ans: 0.04wb]**

Ex-4: the armature of DC generator has 81 slots and the commutator has 243 segments lap wound connected, flux per pole 30 mwb, calculate generated emf at a speed of 20 rps, $A=6$ **[291V]**

Armature Reaction in DC generator

Armature reaction means the effect of magnetic field setup by the armature current on the distribution of flux under main poles of a generator.

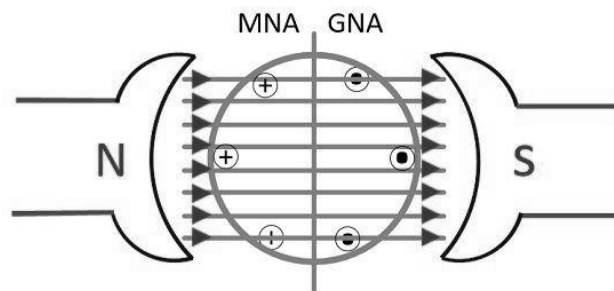
The armature mmf produces two undesirable effects on the main field flux

- 1) It demagnetises or weakens the main field flux
- 2) It cross magnetises or distorts it

The first effect will lead to reduced generated voltage.

Second one gives harmful effects, increases iron losses, poor commutation, sparking

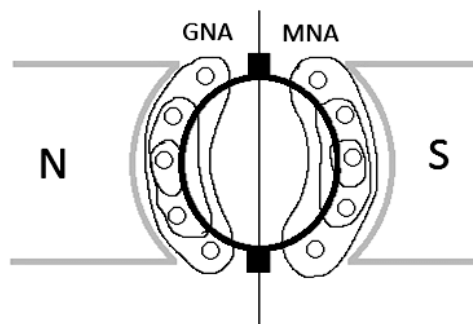
Consider a two pole machine



The above figure shows that machine at no load having no armature currents

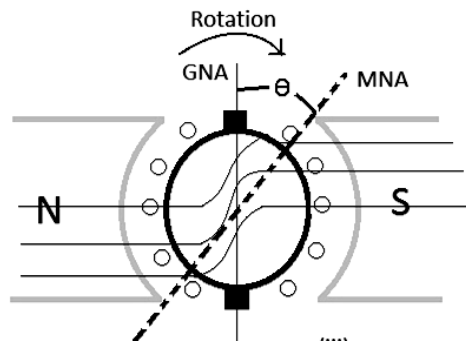
In this condition the GNA and MNA both are in phase. The main flux is at right angles to the MNA.

If the machine is loaded then the armature winding receives the current these currents setup armature flux.



ϕ_A = armature flux it will be produced due to I_a .

From the figure ϕ_A is perpendicular to the ϕ_f . that is the path of armature flux crosses the path of main field flux, this effect is known as cross magnetising.



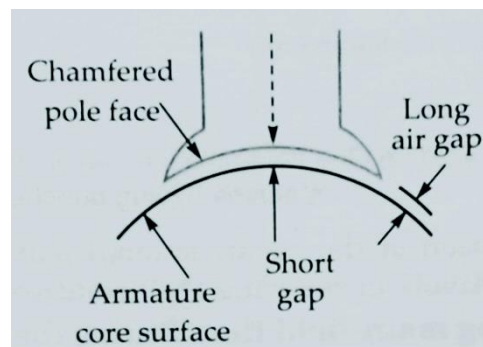
From the above figure it is clear that armature flux aids the main field flux at upper end of north pole and at lower end of south pole. This will causes the weakening of main field and the resultant flux decreases. This effect will called demagnetising effect.

The effects of armature reaction will results:

- 1) It will distorts the main field flux this is causing non uniform of flux distribution
- 2) Cross magnetising and demagnetising effect
- 3) Iron losses, poor commutation
- 4) Sparking

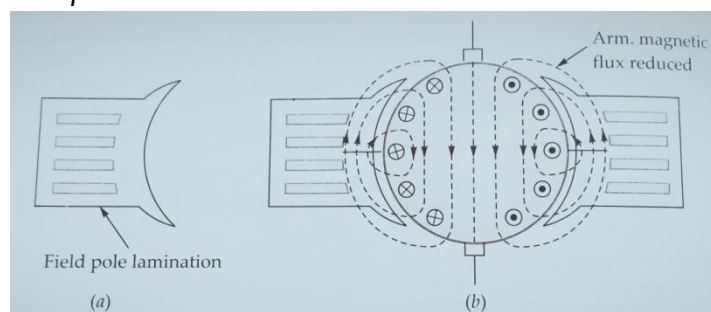
Methods of limiting the effects of armature reaction:

- 1) *High reluctance pole tips*



By flattening the pole faces slightly so that the air gap is longer at the pole tips rather than at the centre of the pole. This will results in increase in reluctance of the pole tips and the magnitude of armature cross flux is reduced.

- 2) *Reduction in armature flux*



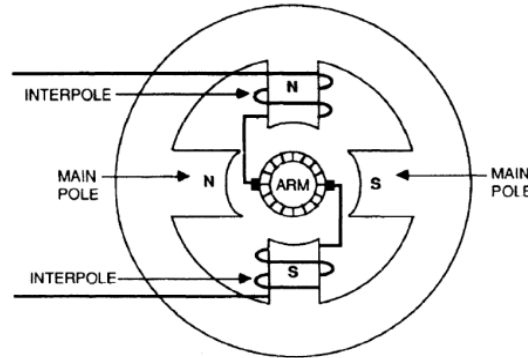
Another constructional technique of reducing the armature cross flux is to create more reluctance in the path of armature flux without reducing the main field flux. This is achieved by using field poles laminations having several rectangular holes punched in them.

From the above figure the reluctance offered to armature flux is increased due to airgap openings in the path of cross flux. As a result armature cross flux is reduced where as the main field flux remains almost un-effected.

3) *Strong main field flux*

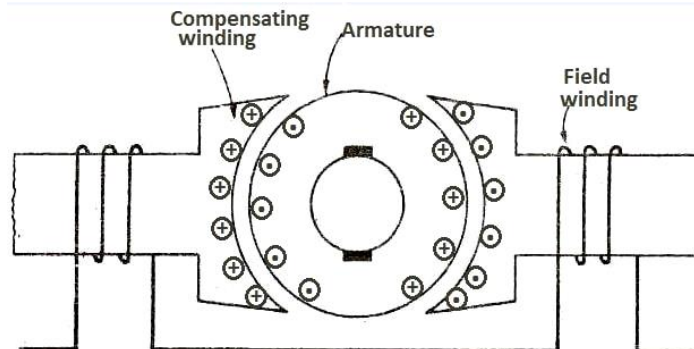
During the design of DC machine it should be ensured that main field mmf should be strong when compared to full load armature mmf the distortion.

4) *Interpoles or commutating poles*



Interpoles are small poles placed in between the main poles. These are connected in series with armature so that they carry armature current. The emf induced by the interpoles neutralizes the effect of armature mmf in the inter polar region.

5) *Compensating winding*



A compensating winding is an auxiliary winding embedded in slots located in the faces of main poles. This winding is connected in series with armature in such a manner. So that the direction of current flowing in this winding should be quite opposite to the direction of current flowing in the armature conductors. To maintain the uniform flux distribution of flux in the main poles and to neutralize the armature reaction effect compensating windings are provided but due to this winding the cost of the machine is increases. It increases the armature copper losses.

Types of DC Generators

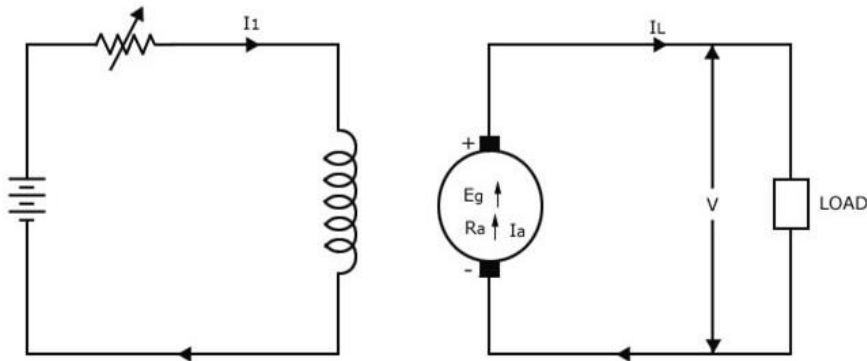
There are mainly two types

- i) Separately excited DC generator
- ii) Self-excited DC generator
 - a) Series wound DC generator
 - b) Shunt wound DC generator

- c) Compound wound DC generator
 - 1) Long shunt compound wound DC generator
 - 2) Short shunt compound wound DC generator

Generators are usually classified according to the way in which their fields are excited.

Separately excited DC generator:



In separately excited DC generators there is no connection between armature and field windings. In this machine the field winding is excited by a separate DC source. Like battery.

Self-excited DC generator:

In the field magnets there is some amount of flux will be present even the current becomes zero. This flux is called residual flux.

In this type of machine whose field magnets are energised by the current produced by the generator them due to residual magnetism there is always some flux in the poles. When the armature is rotated some emf and some current is produced which is passed through the field coils there by strengthening the pole flux.

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

$$I_a = I_L$$

$$E_g = V + I_a R_a$$

$$I_L = \frac{V}{R_L}$$

I_a – armature current

I_L – Load current

I_f – field current

R_f – field resistance

R_L – Load resistance

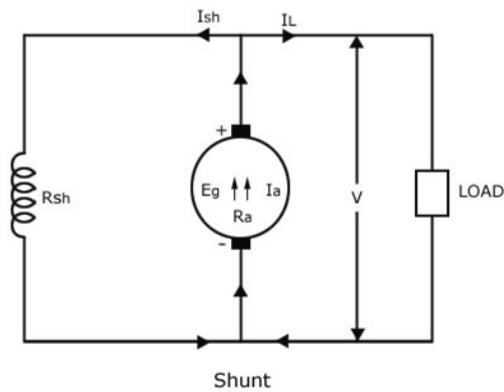
R_a – Armature resistance

There are 3 types of self-excited generators

- a) Shunt wound DC generator
- b) Series wound DC generator
- c) Compound wound DC generator

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Shunt wound DC generator:

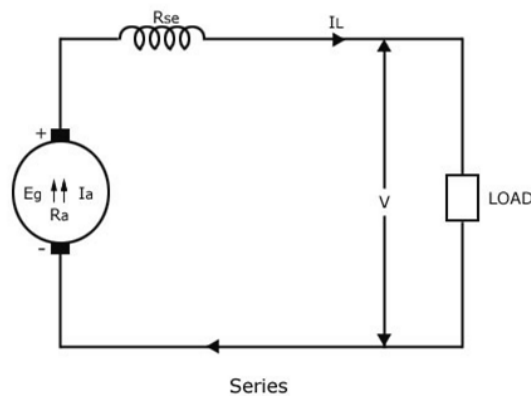
In this type of machine the field winding is connected in parallel to the armature winding then the machine is called DC shunt machine.

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

$$E_g = V + I_a R_a$$

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

$$I_L = \frac{V}{R_L}$$

Series wound DC generator:

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

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

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

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

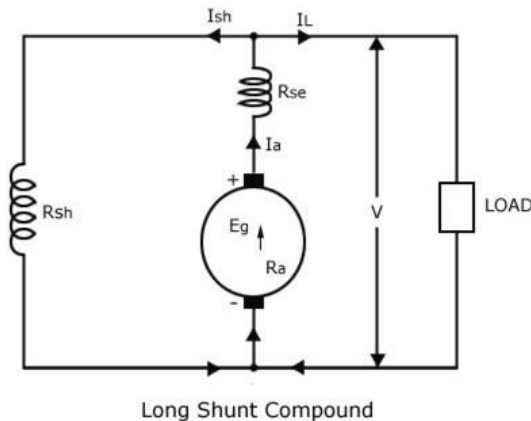
Compound DC generator:

The combination of two windings that is series winding and shunt winding is considered as compound DC generator.

Based on the type of connection of the shunt field to the armature and series field it is classified as

- 1) Long shunt DC compound generator
- 2) Short shunt DC compound generator

Long shunt DC compound generator:



In this type of machine the series current and armature current is made same and the shunt connection is made after the series connection.

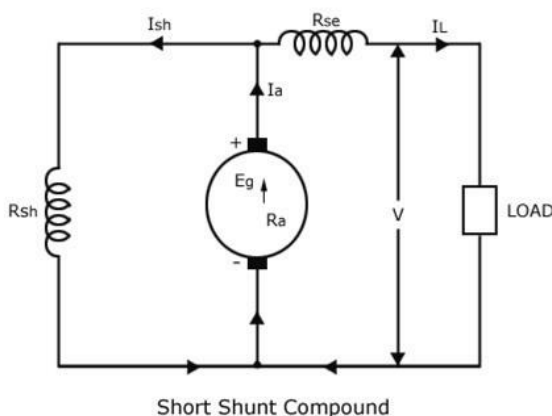
$$I_a = I_{se} = I_L + I_{sh}$$

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

$$I_L = \frac{V}{R_L}$$

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

Short shunt DC compound generator:



In this type of machine the series field current is made same to that of the load current.

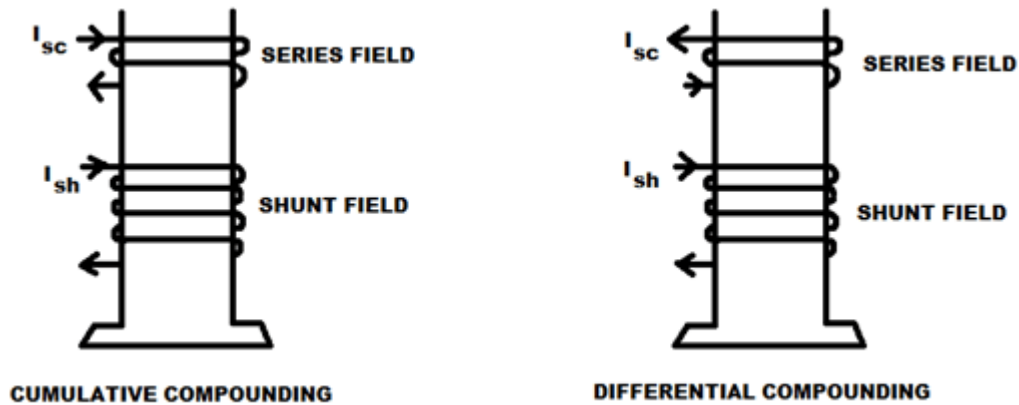
$$I_a = I_{sh} + I_L \text{ (or) } I_{sh}$$

$$I_{se} = I_L$$

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

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

Cumulative compound machine:



If the flux of series field adds with shunt field then the machine is called cumulative compound machine.

$$\phi = \phi_{sh} + \phi_{se}$$

Differential compound machine:

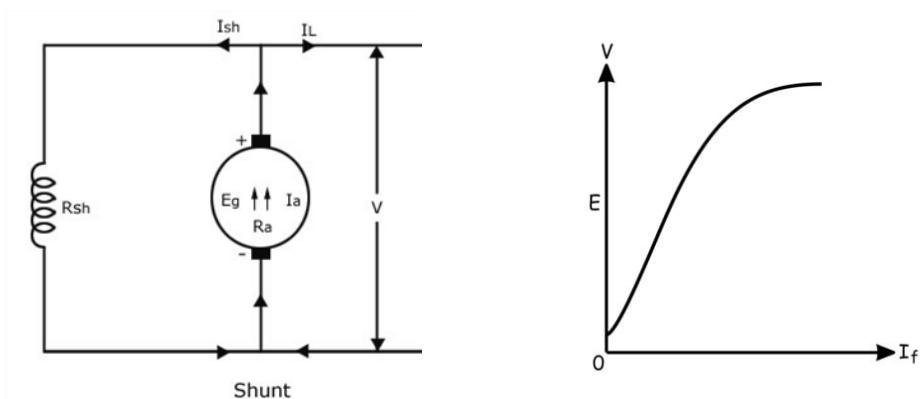
If the both shunt and series field fluxes are in opposite direction the machine is called differential compound machine.

$$\phi = \phi_{sh} - \phi_{se}$$

Generation of voltage in self-excited generators:

Residual flux is the main cause in developing voltage in self-excited generator.

Due to residual flux some voltage [10 to 20V] is induced in armature winding as the field winding is connected to armature some current passes through field. The winding produces another flux known as main flux. This flux adds with residual flux. The above cumulative process continuous until it comes saturation condition.



Conditions for build-up EMF:

- 1) There must be sufficient residual flux
- 2) Field resistance should be less than critical resistance
- 3) The flux produced by field current must be in same direction with residual flux.
- 4) The speed must be more than critical speed.

Critical field resistance:

It is the maximum resistance at which the generator fails to build up an EMF.

Critical speed:

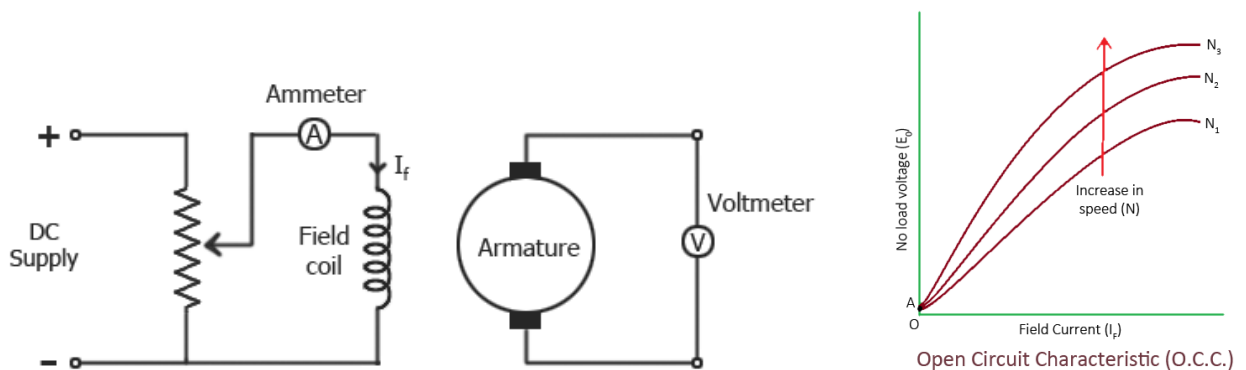
It is the speed at which the DC shunt generator just starts to build up voltage.

Characteristics of DC generators

Generally, following three characteristics of DC generators are taken into considerations: (i) Open Circuit Characteristic (O.C.C.) (or) Magnetizing Characteristic, (ii) Internal (or) Total Characteristic and (iii) External Characteristic.

1. Open Circuit Characteristic (O.C.C.) (E_0/I_f)

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_0) 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. The connection arrangement to obtain O.C.C. curve is as shown in the figure below. For shunt or series excited generators, the field winding is disconnected from the machine and connected across an external supply.



Now, from the emf equation of dc generator, we know that $E_g = k\phi$. Hence, the generated emf should be directly proportional to field flux (and hence, also directly proportional to the field current). However, even when the field current is zero, some amount of emf is generated (represented by OA in the figure below). This initially induced emf is due to the fact that there exists some residual magnetism in the field poles. Due to the residual magnetism, a small initial emf is induced in the armature. This initially induced emf aids the existing residual flux, and hence, increasing the overall field flux. This consequently increases the induced emf. Thus, O.C.C. follows a straight line. However, as the flux density increases, the poles get saturated and the ϕ

becomes practically constant. Thus, even we increase the I_f further, ϕ remains constant and hence, E_g also remains constant. Hence, the O.C.C. curve looks like the B-H characteristic.

2. Internal Or Total Characteristic (E/I_a)

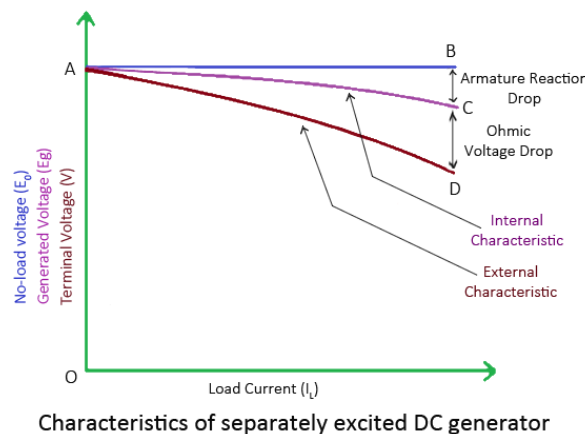
An internal characteristic curve shows the relation between the on-load generated emf (E_g) and the armature current (I_a). The on-load generated emf E_g is always less than E_0 due to the armature reaction. E_g can be determined by subtracting the drop due to demagnetizing effect of armature reaction from no-load voltage E_0 . Therefore, internal characteristic curve lies below the O.C.C. curve.

3. External Characteristic (V/I_L)

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 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.

Internal and external characteristic curves are shown below for each type of generator.

Characteristics of Separately Excited DC Generator

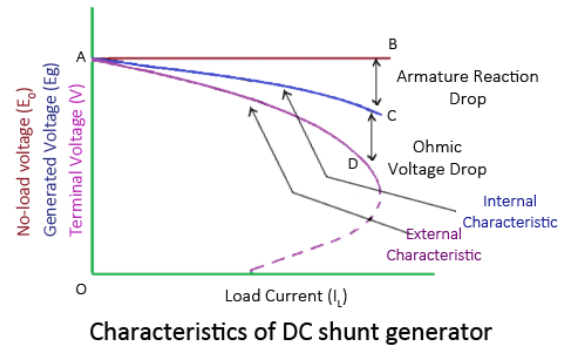
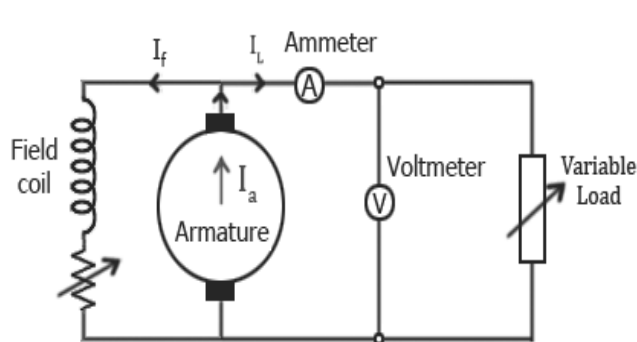


If there is no armature reaction and armature voltage drop, the voltage will remain constant for any load current. Thus, the straight line AB in above figure represents the no-load voltage vs. load current I_L . Due to the demagnetizing effect of armature reaction, the on-load generated emf is less than the no-load voltage. The curve AC represents the on-load generated emf E_g vs. load current I_L i.e. internal characteristic (as $I_a = I_L$ for a separately excited dc generator). Also, the terminal voltage is lesser due to ohmic drop occurring in the armature and brushes. The curve AD represents the terminal voltage vs. load current i.e. external characteristic.

Characteristics of DC Shunt Generator

To determine the internal and external load characteristics of a DC shunt generator the machine is allowed to build up its voltage before applying any external load. To build up voltage of a shunt generator, the generator is driven at the rated speed by a prime mover. Initial voltage is induced due to residual magnetism in the field poles. The generator builds up its voltage as explained by the O.C.C. curve. When the generator has built up the voltage, it is gradually loaded

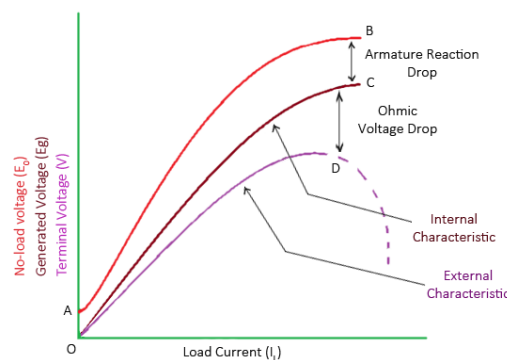
with resistive load and readings are taken at suitable intervals. Connection arrangement is as shown in the figure below.



Unlike, separately excited DC generator, here, $I_L \neq I_a$. For a shunt generator, $I_a = I_L + I_f$. Hence, the internal characteristic can be easily transmitted to E_g vs. I_L by subtracting the correct value of I_f from I_a .

During a normal running condition, when load resistance is decreased, the load current increases. But, as we go on decreasing the load resistance, terminal voltage also falls. So, load resistance can be decreased up to a certain limit, after which the terminal voltage drastically decreases due to excessive armature reaction at very high armature current and increased I^2R losses. Hence, beyond this limit any further decrease in load resistance results in decreasing load current. Consequently, the external characteristic curve turns back as shown by dotted line in the above figure.

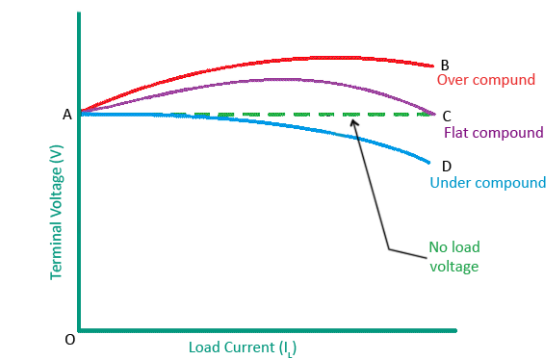
Characteristics of DC Series Generator



Characteristics of DC series generator

The curve AB in above figure identical to open circuit characteristic (O.C.C.) curve. This is because in DC series generators field winding is connected in series with armature and load. Hence, here load current is similar to field current (i.e. $I_L = I_f$). The curve OC and OD represent internal and external characteristic respectively. In a DC series generator, terminal voltage increases with the load current. This is because, as the load current increases, field current also increases. However, beyond a certain limit, terminal voltage starts decreasing with increase in load. This is due to excessive demagnetizing effects of the armature reaction.

Characteristics of DC Compound Generator



External characteristic of DC compound generator

The above figure shows the external characteristics of DC compound generators. If series winding amp-turns are adjusted so that, increase in load current causes increase in terminal voltage then the generator is called to be over compounded. The external characteristic for over compounded generator is shown by the curve AB in above figure. If series winding amp-turns are adjusted so that, the terminal voltage remains constant even the load current is increased, then the generator is called to be flat compounded. The external characteristic for a flat compounded generator is shown by the curve AC. If the series winding has lesser number of turns than that would be required to be flat compounded, then the generator is called to be under compounded. The external characteristics for an under compounded generator are shown by the curve AD.

Losses:

There are some losses taking place continuously in the core known as iron losses or core losses or magnetic losses in the iron losses

- i) Hysteresis losses
- ii) Eddy current losses

- i) *Hysteresis losses (w_h):* this losses due to the reversal of magnetisation of the armature core every portion of the rotating core passes under N and S pole alternatively there by attaining S and N polarity respectively

The losses depends upon the volume and grad of iron

$$w_h = \eta B_{max}^{1.6} f v \text{ watts}$$

V= volume of the core m^3

η = hysteresis coefficient

This loss is reduced by using the materials of which having low hysteresis coefficient.

Ex: silicon steel

- ii) *Eddy current losses (w_e):* when the armature core rotates it also cuts the magnetic flux. Hence an emf is induced in the body of the core according to the laws of electromagnetic induction. This emf through small sets up large current in the body of the core due to its small resistance. This current is known as eddy current.

$$w_e = k B_{max}^2 f^2 t^2 v^2 \text{ watts}$$

$B_{\max}$ = maximum flux density

F = frequency

T = thickness of each lamination

V = volume of armature core

In order to reduce this loss the core is made of thin laminations. These laminations are insulated from each other by the coating of varnish.

So the eddy currents is reduced to considerable amount

Copper losses:

Armature copper losses:

The losses occurs at armature winding is called armature copper losses

$$P = I^2 R$$

Field copper losses:

The losses occurs at field winding is called field copper losses

Shunt generator: $P = I_{sh}^2 R_{sh}$

Series generator: $P = I_{se}^2 R_{se}$

Mechanical Losses:

These losses are the combination of friction losses and windage losses.

- i) Friction losses are occurs at bearings of commutator brushes
- ii) Windage losses are occurs at armature against wind flow.

Parallel Operation of DC Generator - Conditions & Advantages

In a d.c power plant, power is usually supplied from several generators of small ratings connected in parallel instead of from one large generator. This is due to the following reasons:

(i) Continuity of service:

If a single large generator is used in the power plant, then in case of its breakdown, the whole plant will be shut down. However, if power is supplied from a number of small units operating in parallel, then in case of failure of one unit, the continuity of supply can be maintained by other healthy units.

(ii) Efficiency:

Generators run most efficiently when loaded to their rated capacity. Electric power costs less per kWh when the generator producing it is efficiently loaded. Therefore, when load demand on power plant decreases, one or more generators can be shut down and the remaining units can be efficiently loaded.

(iii) Maintenance and repair:

Generators generally require routine-maintenance and repair. Therefore, if generators are operated in parallel, the routine or emergency operations can be performed by isolating the affected generator while the load is being supplied by other units. This leads to both safety and economy.

(iv) Increasing plant capacity:

In the modern world of increasing population, the use of electricity is continuously increasing. When added capacity is required, the new unit can be simply paralleled with the old units. In many situations, a single unit of desired large capacity may not be available. In that case, a number of smaller units can be operated in parallel to meet the load requirement. Generally, a single large unit is more expensive.

(v) Non-availability of single large unit:

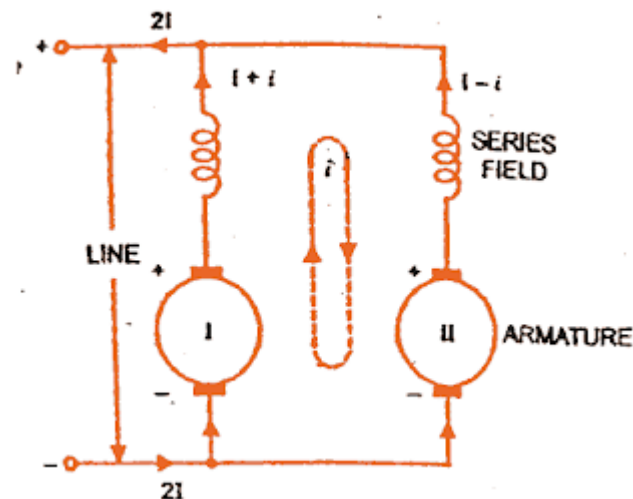
In many situations, a single unit of desired large capacity may not be available. In that case, a number of smaller units can be operated in parallel to meet the load requirement. Generally, a single large unit is more expensive.

Parallel Operation of Series Generator

For satisfactory parallel operation of dc series generators, it is necessary to connect the armatures of the two machines through a heavy copper bar, called the **equalizing bar**. It is explained below :

Parallel Operation Without Equalizing Bar

Let two DC machines (I and II) of resistance R (the armature and field resistance), induced EMFs E_1 and E_2 operate in parallel, as shown in the figure.



When the induced EMFs E_1 and E_2 are equal they will share the equal load.

There is a problem when induced EMFs are different in the two machines. When one of the induced emf becomes greater than another induced emf a circulating current will flow.

If E_1 becomes slightly greater than E_2 , then a current i will circulate in the clockwise direction, as shown by dotted lines in the first figure. The magnitude of the circulating current i will be $(E_1 - E_2) / R$.

Now total current supplied by machine I will be $(I + i)$ and of machine II $(I - i)$. So the series field current of the machine I increase, also characteristic of a DC series generator is a rising characteristic.

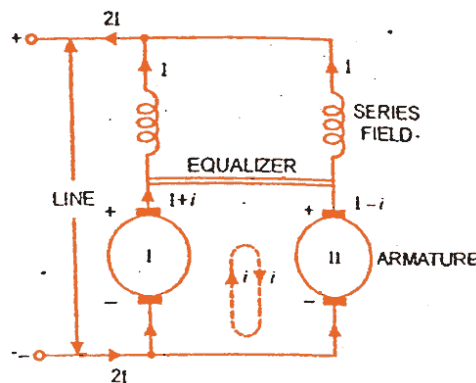
Thus the induced emf of machine I (E_1) will rise and induced emf of machine II will fall. Thus the difference of the two induced EMFs E_1 and E_2 will increase, which will cause a further increase in circulating current.

Thus the effect is cumulative and if there were no fuse or automatic switch in the circuit, the current in machine II will be reversed. This would reverse the direction of induced emf E_2 and resultant emf in the circuit would be $[E - (-E_2)]$ i.e. $(E_1 + E_2)$ and circulating current $(E_1 + E_2)/2R$.

Thus the two EMFs will then act in series around a circuit of very low resistance and conditions are virtually those of a short-circuit on the two machines resulting in damage of the machines. We have to avoid this short circuit problem for the parallel operation of DC series generators.

Parallel Operation with Equalizing Bar

Here comes the use of equalizer bars in the parallel operation of DC series generators.



The possibility of reversal of either machine can be prevented by preventing the flow of circulating current produced due to inequalities of induced EMFs of the machines through the series field winding.

This aim can be achieved by connecting a heavy copper bar of negligible resistance across the two machines as shown in the figure.

Now the circulating current does not affect the field winding, but it gets confined to the armature and the equalizing bars. Now if the armature current increases, the terminal voltage drop occurs and the original condition is restored.

Parallel Operation of Shunt DC Generator

There may be two conditions for parallel operation of shunt DC generators.

Condition 1

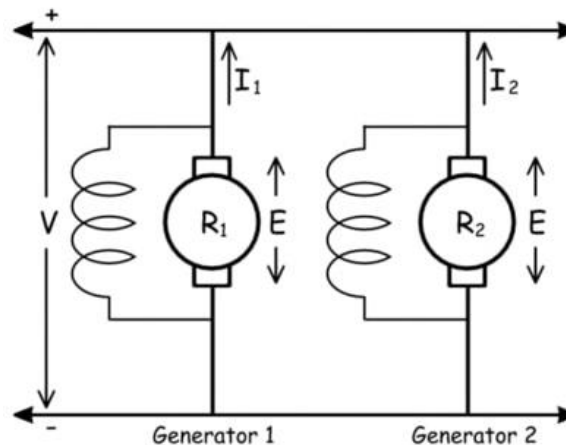
The no-load voltage of the generators to be operated in parallel is the same.

Condition 2

The no-load voltage of the generators to be operated in parallel is unequal.

No Load Voltage of Parallel Generators is the same

Let us consider E is the no-load voltage of DC generator 1 and 2 as shown in the figure below.



V is the voltage of the bus to which we will connect the DC generators. Also, we consider the armature resistance of Generator 1 and 2 are R_1 and R_2 respectively. The load delivered by generator 1 and generator 2 are,

$$I_1 R_1 = E - V \text{ and } I_2 R_2 = E - V$$

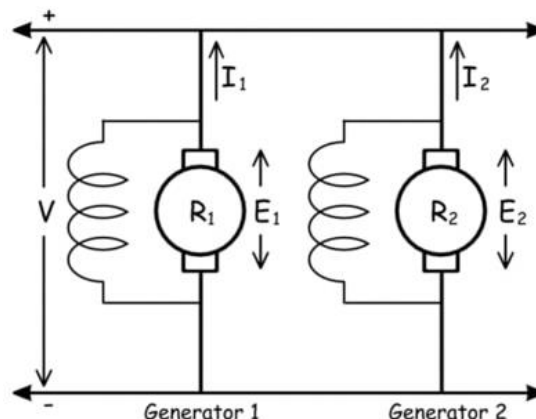
From these two equations, we can write,

$$\begin{aligned} I_1 R_1 &= I_2 R_2 \\ \Rightarrow \frac{I_1}{I_2} &= \frac{R_2}{R_1} \\ \Rightarrow I &\propto \frac{1}{R} \end{aligned}$$

Here, I_1 is the load current delivered by generator 1 and I_2 is the load current delivered by generator 2. From the above expressions it can conclude that when the no load voltage or open circuit voltage of generators in parallel is same, the current delivered by the individual generator is inversely proportional to the armature resistance of that generator.

No Load Voltage of Parallel Generators is not the same

Now, condition 2 where two generators are being operated in parallel with unequal no load voltage



In that case, let us consider E_1 and E_2 are the open circuit or no load voltage of generator 1 and 2 respectively. Now we can write,

$$\begin{aligned} E_1 - V &= R_1 I_1 \\ \Rightarrow I_1 &= \frac{E_1 - V}{R_1} \\ E_2 - V &= R_2 I_2 \\ \Rightarrow I_2 &= \frac{E_2 - V}{R_2} \end{aligned}$$

Now, by making ratio of I_1 and I_2 we get,

$$\frac{I_1}{I_2} = \frac{E_1 - V}{E_2 - V} \times \frac{R_2}{R_1}$$

Again we know that, the no load voltage of a DC generator is directly proportional to the field flux and speed of the prime mover. So, we can write,

$$E_1 \propto \phi_1 N_1$$

Where, Φ_1 and N_1 are the field flux and RPM of generator 1. Now, we can write,

$$E_1 = K_1 \phi_1 N_1$$

Where, K_1 is the proportionality constant.

Similarly, we can establish that the no load voltage of generator 2,

$$E_2 = K_2 \phi_2 N_2$$

Putting the expression of E_1 and E_2 in the expression of armature currents or load currents, we get, the ratio of load currents as

$$\frac{I_1}{I_2} = \frac{K_1 \phi_1 N_1 - V}{K_2 \phi_2 N_2 - V} \times \frac{R_2}{R_1}$$

So from the above equation it is clear to us that by controlling the field excitation (Φ) and speed of the prime mover (N), we can control the load sharing by these two generators on the system. Whatever maybe the value of field flux or RPM of the generator but it is true that during parallel operation of DC shunt generators, the voltage drop across the armature would be such that it will cause same terminal voltage for both the generators when running with loads. This online terminal voltage will be exactly equal to the voltage of the bus to which we connect the generator.

APPLICATIONS OF A DC GENERATOR:

The applications of the various types of DC Generators are as follows:-

Separately Excited DC Generators

- Separately excited DC Generators are used in laboratories for testing as they have a wide range of voltage output.
- Used as a supply source of DC motors.

Shunt wound Generators

- DC shunt wound generators are used for lighting purposes.
- Used to charge the battery.
- Providing excitation to the alternators.

Series Wound Generators

- DC series wound generators are used in DC locomotives for regenerative braking for providing field excitation current.
- Used as a booster in distribution networks.
- Over compounded cumulative generators are used in lighting and heavy power supply.
- Flat compounded generators are used in offices, hotels, homes, schools, etc.
- Differentially compounded generators are mainly used for arc welding purpose.

Exercise Problems: