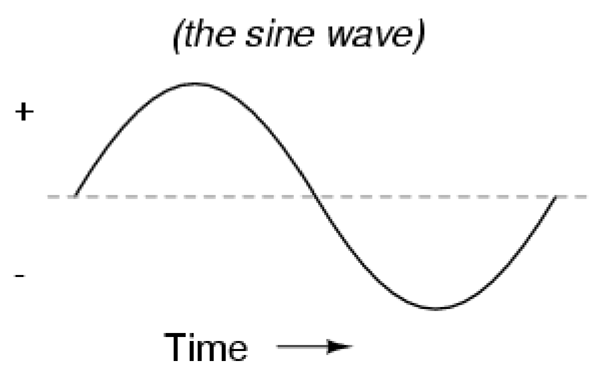
Chapter One
D.C. Generators

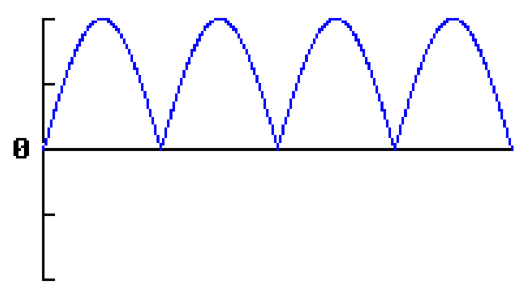
Alternating Current (AC)

In alternating current the electric charges flow changes its direction periodically. AC is the most commonly used and most preferred electric power for household equipment office and buildings Alternating current can be identified in wave form called as sine wave



Direct Current (DC)

Unlike alternating current, the flow of current in direct current do not changes periodically. The current flows in a single direction in a steady voltage. The major uses of DC is to supply power for electrical devices and also to charge batteries. For example, mobile phone batteries, flashlights, flat-screen television, hybrid and electric vehicles.



Difference Between Alternating Current and Direct Current

Alternating Current	Direct Current
AC can carry and safe to transfer longer distance even between two cities, and maintain the electric power.	DC cannot travel for very longer distance. If does, it loses electric power.
The rotating magnets cause the change in direction of electric flow.	The steady magnetism makes the DC to flow in a single direction.
The frequency of AC is depended upon the country. But, generally the frequency is 50Hz or 60Hz.	DC has no frequency of zero frequency.
In AC the flow of current changes it direction backwards periodically.	It flows in single direction steadily.
Electrons in AC keep changing its directions – backward and forward	Electrons only move in one direction – that is forward.

Generator Principle

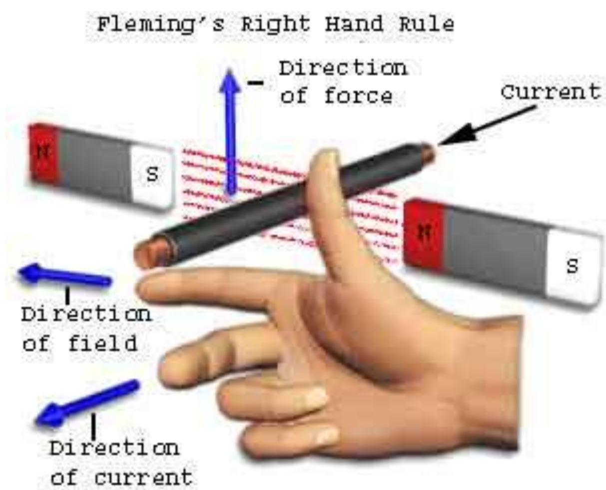
An electric generator is a machine that converts mechanical energy into electrical energy. An electric generator is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced which will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by **Fleming's right hand rule**. Therefore, the essential components of a generator are:

(a) A magnetic field

(b) Conductor or a group of conductors

(c) Motion of conductor w.r.t. magnetic field.

Fleming Right Hand Rule



As per Faraday's law of electromagnetic induction, whenever a conductor moves inside a magnetic field, there will be an induced current in it. If this conductor gets forcefully moved inside the magnetic field, there will be a relation between the direction of applied force, magnetic field and the current. This relation among these three directions is determined by **Fleming's Right Hand Rule**. This rule states "Hold out the right hand with the first finger, second finger and thumb at right angle to each other. If forefinger represents the direction of the line of force, the thumb points in the direction of motion or applied force, then second finger points in the direction of the induced current.

Simple Loop Generator

Consider a single turn loop ABCD rotating clockwise in a uniform magnetic field with a constant speed as shown below As the loop rotates, the flux linking the coil sides AB and CD changes continuously. Hence the e.m.f. induced in these coil sides also changes but the e.m.f. induced in one coil side adds to that induced in the other.

(i) When the loop is in position no.1 the generated e.m.f. is zero because the coil sides (AB and CD) are cutting no flux but are moving parallel to it.

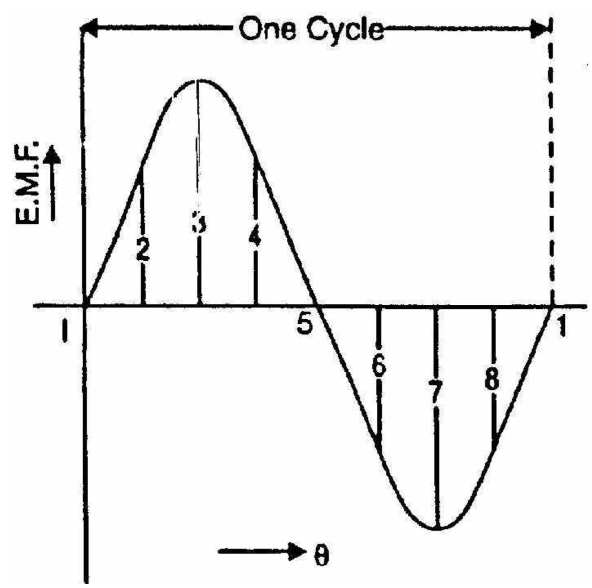
(ii) When the loop is in position no. 2, the coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated as indicated by point 2.

(iii) When the loop is in position no. 3, the coil sides (AB and CD) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate. Hence at this instant, the generated e.m.f. is maximum as indicated by point 3 in Figure

(iv) At position 4, the generated e.m.f. is less because the coil sides are cutting the flux at an angle.

(v) At position 5, no magnetic lines are cut and hence induced e.m.f. is zero as indicated by point 5 in Fig.

(vi) At position 6, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f. is reversed. The maximum e.m.f. in this direction (i.e., reverse direction) will be when the loop is at position 7 and zero when at position 1. This cycle repeats with each revolution of the coil.



Note that e.m.f. generated in the loop is alternating one. It is because any coil side, say AB has e.m.f. in one direction when under the influence of N-pole and in the other direction when under the influence of S-pole. If a load is connected across the ends of the loop, then alternating current will flow through the load. The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator. We then have the d.c. generator. In fact, a commutator is a mechanical rectifier.

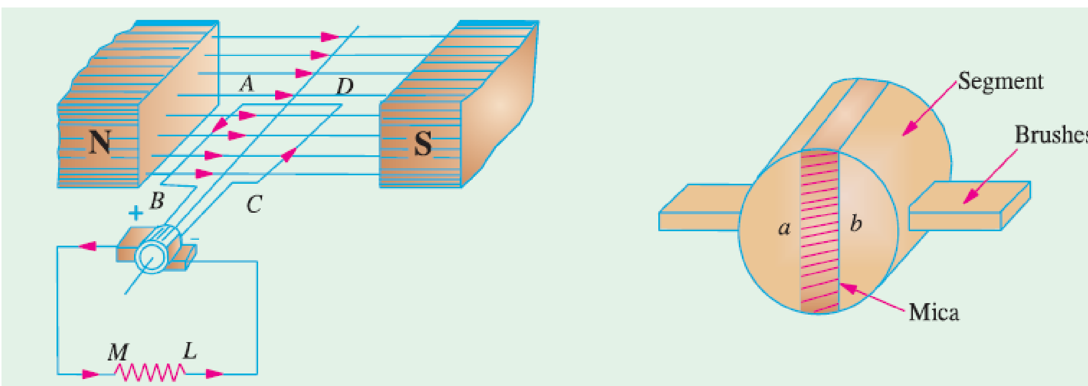
Commutator

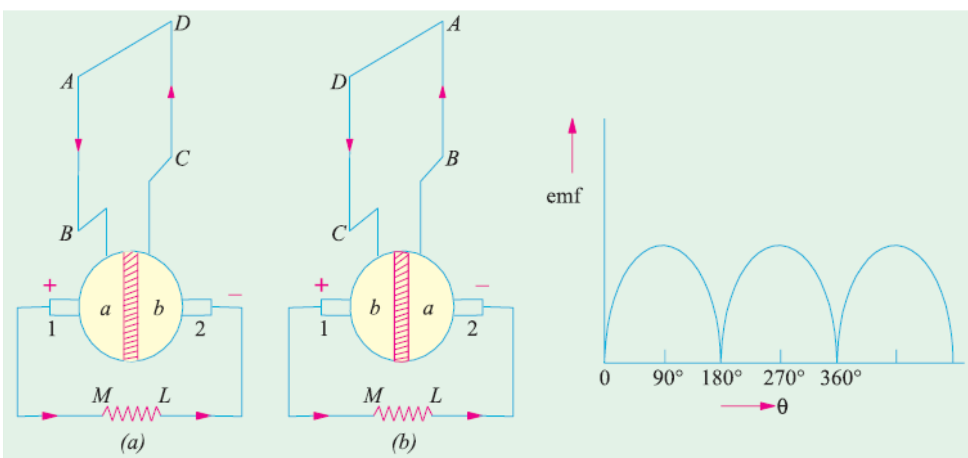
If, somehow, connection of the coil side to the external load is reversed at the same instant the current in the coil side reverses, the current through the load will be direct current. This is what a commutator does. The figure shows a commutator having two segments C_1 and C_2. It consists of a cylindrical metal ring cut into two halves or segments C_1 and C_2 respectively separated by a thin sheet of mica.

The commutator is mounted on but insulated from the rotor shaft. The ends of coil sides AB and CD are connected to the segments C_1 and C_2 respectively as shown. Two stationary carbon brushes rest on the commutator and lead current to the external load. With this arrangement, the commutator at all times connects the coil side under S-pole to the +ve brush and that under N-pole to the –ve brush.

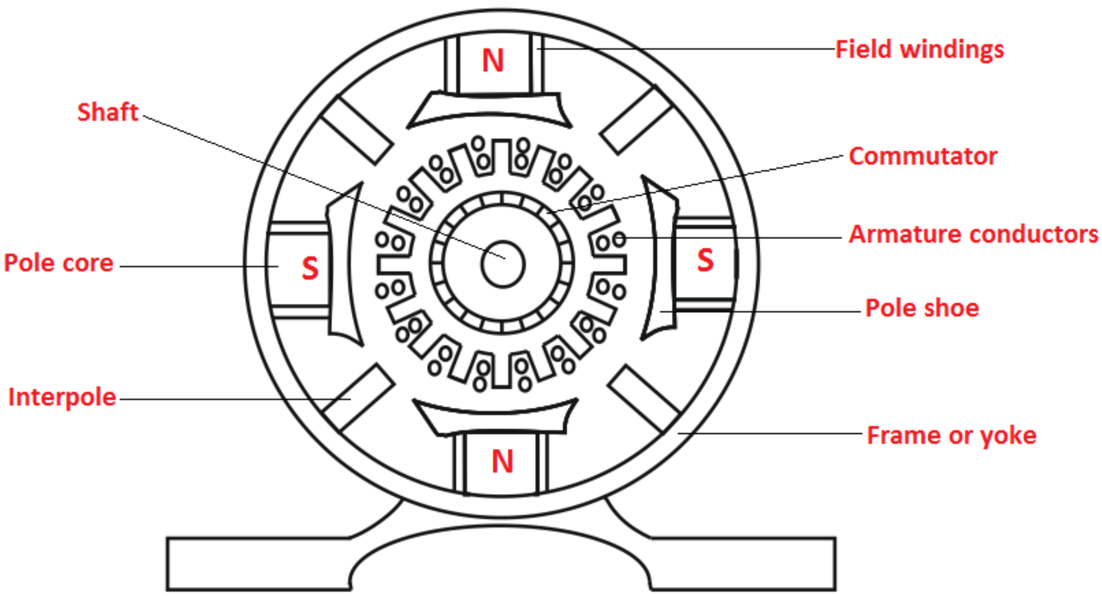
(i) In Fig below, the coil sides AB and CD are under N-pole and S-pole respectively. Note that segment C_1 connects the coil side AB to point P of the load resistance R and the segment C_2 connects the coil side CD to point Q of the load. Also note the direction of current through load. It is from Q to P.

(ii) After half a revolution of the loop (i.e., 180° rotation), the coil side AB is under S-pole and the coil side CD under N-pole as shown in Fig. (1.5). The currents in the coil sides now flow in the reverse direction but the segments C_1 and C_2 have also moved through 180° i.e., segment C_1 is now in contact with +ve brush and segment C_2 in contact with –ve brush. Note that commutator has reversed the coil connections to the load i.e., coil side AB is now connected to point Q of the load and coil side CD to the point P of the load. Also note the direction of current through the load. It is again from Q to P.



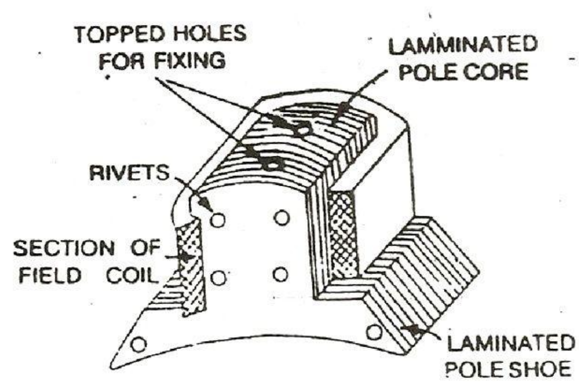


Construction of a DC Generator

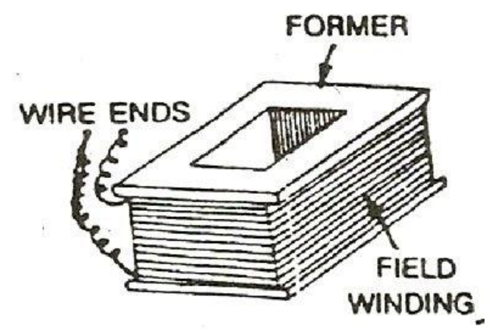


1. **Yoke:** The outer frame of a dc machine is called as yoke. It is made up of cast iron or steel. It not only provides mechanical strength to the whole assembly but also carries the magnetic flux produced by the field winding.

2. **Poles and pole shoes:** Poles are joined to the yoke with the help of bolts or welding. They carry field winding and pole shoes are fastened to them. Pole shoes serve two purposes; (i) they support field coils and (ii) spread out the flux in air gap uniformly.



3. Field winding: Each pole core has one or more field coils (windings) placed over it to produce a magnetic field. The copper wire is used for the construction of field or exciting coils. The coils are wound on the former and then placed around the pole core



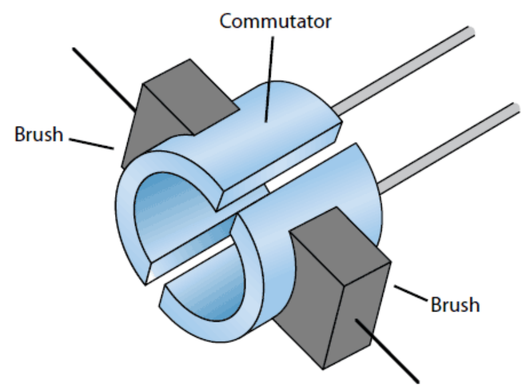
When direct current passes through the field winding, it magnetizes the poles, which in turns produces the flux. The field coils of all the poles are connected in series in such a way that when current flows through them, the adjacent poles attain opposite polarity.

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.

The armature core of a DC generator or machine serves the following purposes.

- It houses the conductors in the slots.
- It provides an easy path for the magnetic flux

5. **Commutator and brushes:** The function of a commutator, in a dc generator, is to collect the current generated in armature conductors. A commutator consists of a set of copper segments which are insulated from each other. The number of segments is equal to the number of armature coils. Each segment is connected to an armature coil and the commutator is keyed to the shaft. Brushes are usually made from carbon or graphite.



6. **Shaft**

The shaft is made of mild steel with a maximum breaking strength. The shaft is used to transfer mechanical power from or to the machine. The rotating parts like armature core, commutator, cooling fans, etc. are keyed to the shaft.

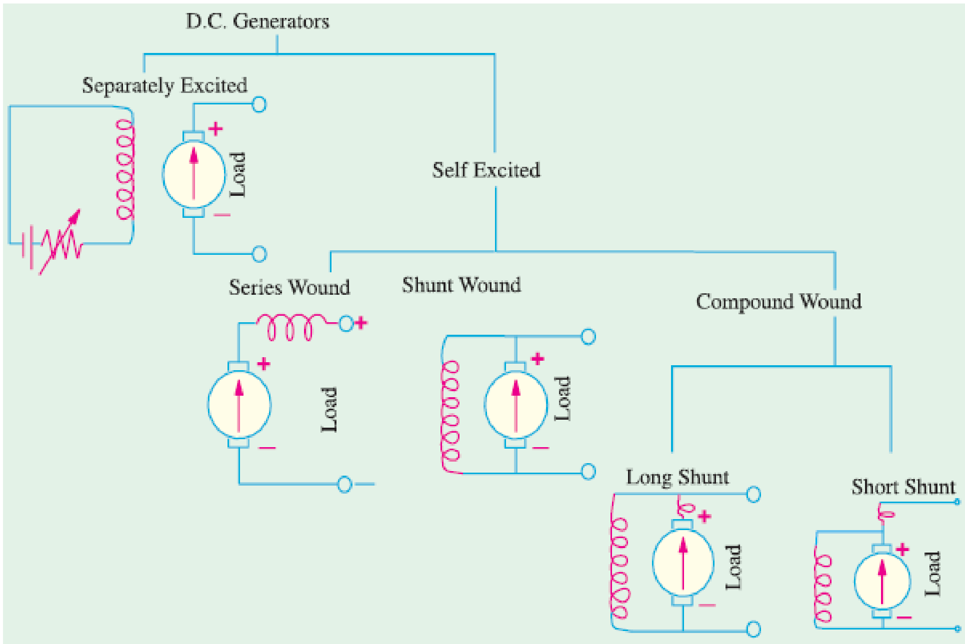
Types of D.C. Generators

The magnetic field in a d.c. generator is normally produced by electromagnets rather than permanent magnets. Generators are generally classified according to their methods of field excitation. On this basis, d.c. generators are divided into the following two classes:

(i) Separately excited d.c. generators

(ii) Self-excited d.c. generators

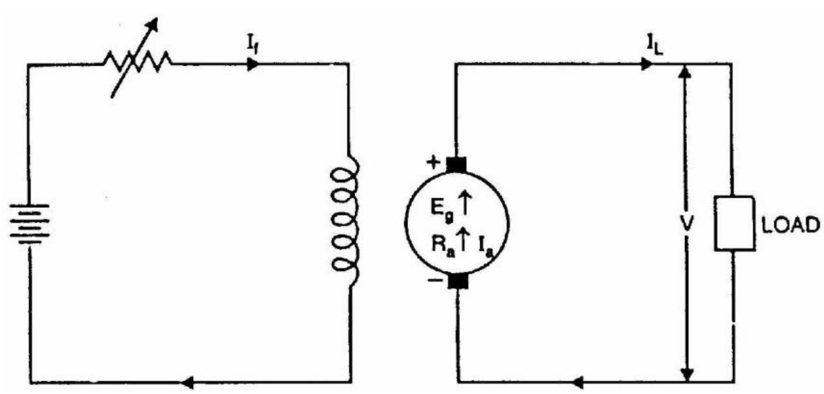
The behaviour of a d.c. generator on load depends upon the method of field excitation adopted



Separately Excited D.C. Generators

A d.c. generator whose field magnet winding is supplied from an independent external d.c. source (e.g., a battery etc.) is called a separately excited generator. Fig. below shows the connections of a separately excited generator.

The voltage output depends upon the speed of rotation of armature and the field current The greater the speed and field current, greater is the generated e.m.f. It may be noted that separately excited d.c. generators are rarely used in practice. The d.c. generators are normally of self-excited type.



Armature current, $I_a = I_L$

e.m.f generated, $E_g = V + I_aR_a$

Electric power developed = E_gI_a

Power delivered to load = VI_a

Self-Excited D.C. Generators

A d.c. generator whose field magnet winding is supplied current from the output of the generator itself is called a self-excited generator. There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature, namely;

(i) Series generator;

(ii) Shunt generator;

(iii) Compound generator

(i) Series generator

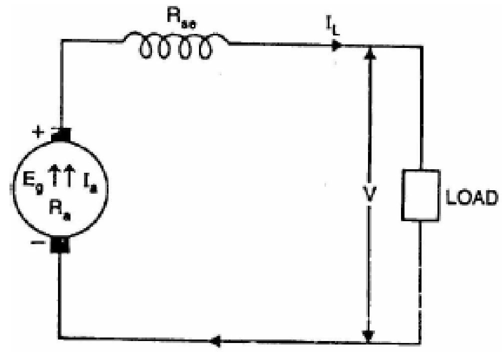
In a series wound generator, the field winding is connected in series with armature winding so that whole armature current flows through the field winding as well as the load. Figure below shows the connections of a series wound generator. Since the field winding carries the whole of load current, it has a few turns of thick wire having low resistance. Series generators are rarely used except for special purposes e.g., as boosters.

Armature current, $I_a = I_{se} = I_L = I$

e.m.f generated, $E_g = V+I(R_a + R_{se})$

Power developed in armature = E_gI_a

Power delivered to load = VI or VI_L



(ii) Shunt generator

In a shunt generator, the field winding is connected in parallel with the armature winding so that terminal voltage of the generator is applied across it. The shunt field winding has many turns of fine wire having high resistance. Therefore, only a part of armature current flows through shunt field winding and the rest flows through the load.

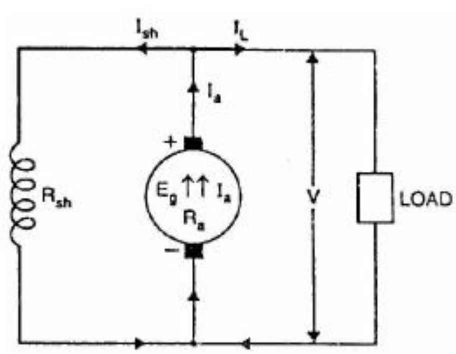
Shunt field current, $I_{sh} = V/R_{sh}$

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

e.m.f generated, $E_g = V + I_aR_a$

Power developed in armature = E_gI_a

Power delivered to load = VI_L

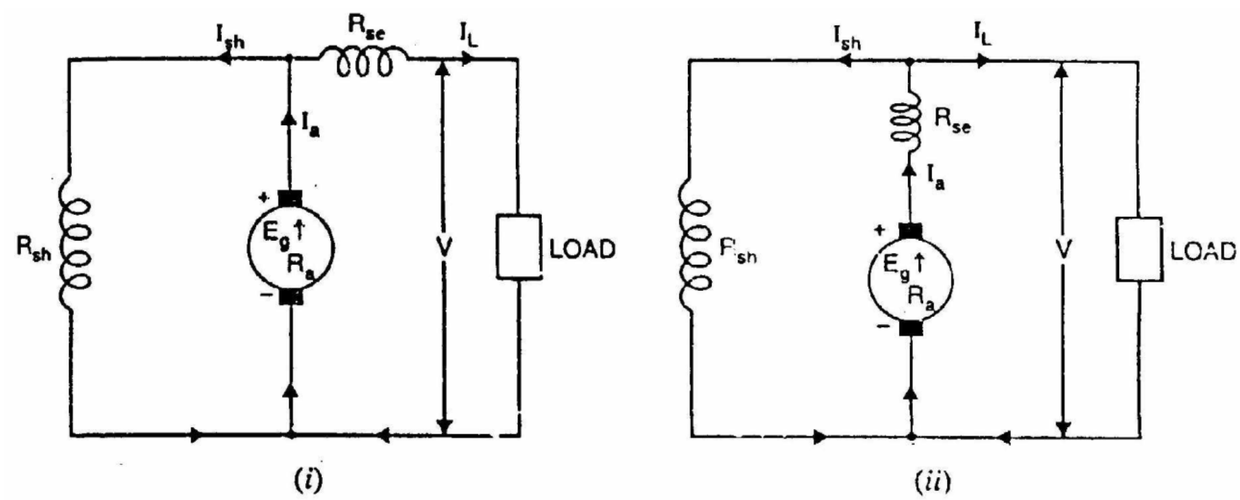


(iii) Compound generator

In a compound-wound generator, there are two sets of field windings on each pole—one is in series and the other in parallel with the armature. A compound wound generator may be:

(a) Short Shunt in which only shunt field winding is in parallel with the armature winding

(b) Long Shunt in which shunt field winding is in parallel with both series field and armature winding



Short shunt

Series field current, $I_{se} = I_L$

Shunt field current= $I_{sh} = \frac{V + I_{se}R_{se}}{R_{sh}}$

e.m.f generated, $E_g = V + I_aR_a + I_{se}R_{se}$

Power developed in armature = E_gI_a

Power delivered to load = VI_L

Long shunt

Series field current, $I_{se} = I_a = I_L + I_{sh}$

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

e.m.f generated, $E_g = V + I_a(R_a + R_{se})$

Power developed in armature = E_gI_a

Power delivered to load = VI_L

Brush Contact Drop

It is the voltage drop over the brush contact resistance when current flows.

Obviously, its value will depend upon the amount of current flowing and the value of contact resistance. This drop is generally small.

Ex1: 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.

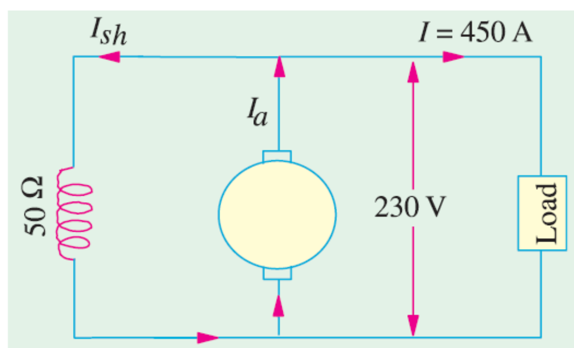
Solution:

Shunt current $I_{sh} = \frac{230}{50} = 4.6$ A

Armature current $I_a = I + I_{sh}$

$= 450 + 4.6 = 454.6$ A

Armature voltage drop $I_aR_a = 454.6 \cdot 0.03$
$= 13.6$ V

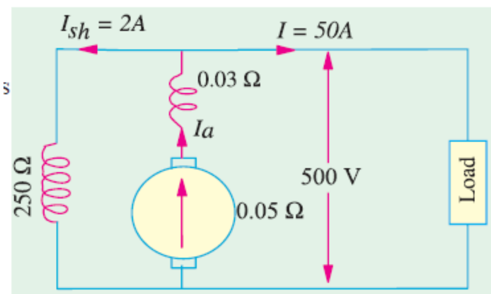


E_g = terminal voltage + armature drop
$= V + I_aR_a = 230 + 13.6 = 243.6$ V

Ex2/long-shunt compound generator delivers a load current of 50 A at 500 V and has armature, series field and shunt field resistances of 0.05 Ω, 0.03 Ω and 250 Ω respectively. Calculate the generated voltage and the armature current. Allow 1 V per brush for contact drop.

Solution:

$Ish = \frac{500}{250} = 2\ A$



Current through armature and series winding is

$= 50 + 2 = 52\ A$

Voltage drop on series field winding

$= 52 \times 0.03 = 1.56\ V$

Armature voltage drop

$IaRa = 52 \times 0.05 = 2.6\ V$

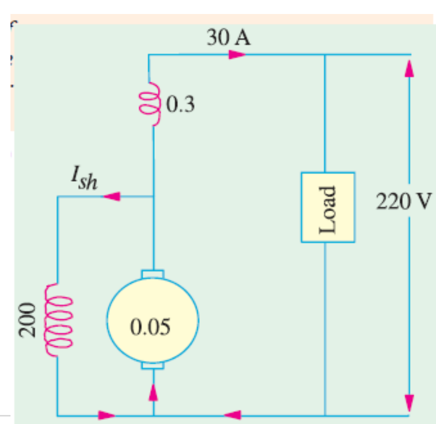
Drop at brushes = $2 \times 1 = 2\ V$

Now, *Eg* = *V* + *IaRa* + series drop + brush drop

$= 500 + 2.6 + 1.56 + 2 = 506.16\ V$

Ex3: A short-shunt compound generator delivers a load current of 30 A at 220 V, and has armature, series-field and shunt-field resistances of0.05 Ω, 0.30 Ω and 200 Ω respectively. Calculate the induced e.m.f. and the armature current. Allow 1.0 V per brush for contact drop.

Solution:



drop in series winding $= 30 \times 0.3 = 9\ V$

Voltage across shunt winding $= 220 + 9 = 229\ V$

$Ish = 229/200 = 1.145\ A$

$Ia = 30 + 1.145 = 31.145\ A$

$IaRa = 31.145 . 0.05 = 1.56\ V$

Brush drop = 2 . 1 = 2 V

Eg = V + series drop + brush drop + IaRa

= 220 + 9 + 2 + 1.56 = 232.56 V

Ex4: In a long-shunt compound generator, the terminal voltage is 230 V when generator delivers 150 A. Determine (i) induced e.m.f. (ii) total power generated and . Given that shunt field, series field, divertor and armature resistance are 92 Ω, 0.015 Ω, 0.03 Ω and 0.032 Ω respectively.

Solution:

$Ish = 230/92 = 2.5$ A

Ia = 150 + 2.5 = 152.5 A

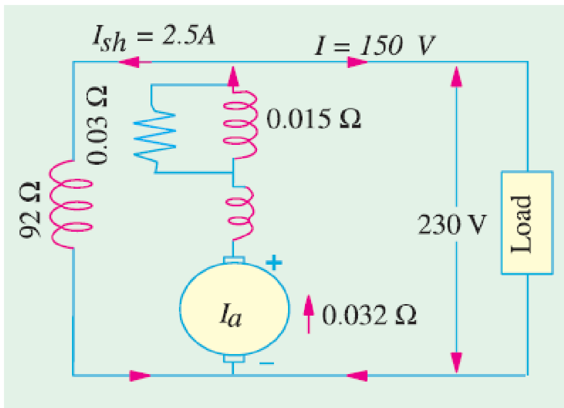
Since series field resistance and divertor resistances are in parallel (thei r combined resistance is

= 0.03 × 0.015/0.045 = 0.01 Ω

Total armature circuit resistance is

= 0.032 + 0.01 = 0.042 Ω

Voltage drop = 152.5 × 0.042 = 6.4 V



(**i**) Voltage generated by armature

Eg = 230 + 6.4 = 236.4 V

(**ii**) Total power generated in armature

EgIa = 236.4 × 152.5 = 36,051 W

Generated E.M.F. or E.M.F. Equation of a Generator

Let Φ = flux/pole in weber

Z = total number of armature conductors

= No. of slots . No. of conductors/slot

P = No. of generator poles

A = No. of parallel paths in armature

N = armature rotation in revolutions per minute (r.p.m.)

E = e.m.f. induced in any parallel path in armature

Generated e.m.f. Eg = e.m.f. generated in any one of the parallel paths *i.e.* E.

Average e.m.f. generated/conductor $= d\Phi/dt$ v ($\because n = 1$)

Now, flux cut/conductor in one revolution $d\Phi = \Phi P$ Wb

No. of revolutions/second = $N/60$ ∴ Time for one revolution, $dt = 60/N$ second

Hence, according to Faraday's Laws of Electromagnetic Induction,

E.M.F. generated/conductor $= \frac{d\Phi}{dt} = \frac{\Phi\ P\ N}{60}$ volt

$$\mathbf{Eg = \frac{\Phi\ P\ N}{60} \cdot \frac{Z}{A}}$$

Where, A=2 for a simplex wave-wound generator

A=P for a simplex lap-wound generator

Ex5: An 8-pole d.c. generator has 500 armature conductors, and a useful flux of 0.05 Wb per pole. What will be the e.m.f. generated if it is lap-connected and runs at 1200 rpm ? What must be the speed at which it is to be driven produce the same e.m.f. if it is wave-wound?

Solution:

$$Eg = \frac{\Phi\, P\, N}{60} . \frac{Z}{A}$$

$$\Phi = 0.05\ \text{Wb}\ , Z = 500, A = p, N = 1200\ \text{rpm}$$

Thus, E_g= 500 V

$$\Phi = 0.05\ \text{Wb}\ , Z = 500, A = 2, p = 8\ , N = 1200\ \text{rpm}$$

Thus, N= 300 rpm

Ex6: An 8-pole d.c. shunt generator with 778 wave-connected armature conductors and running at 500 r.p.m. supplies a load of 12.5 Ω resistance at terminal voltage of 250 V. The armature resistance is 0.24 Ω and the field resistance is 250 Ω. Find the armature current, the induced e.m.f. and the flux per pole.

Solution:

$\text{Load current} = V/R = 250/12.5 = 20\ \text{A}$

$\text{Shunt current} = 250/250 = 1\ \text{A}$

$\text{Armature current} = 20 + 1 = 21\ \text{A}$

$\text{Induced e.m.f.} = 250 + (21 \times 0.24) = 255.04\ \text{V}$

$$Eg = \frac{\Phi\, P\, N}{60} . \frac{Z}{A}$$

$$255.04 = \frac{\Phi \times 8 \times 500}{60} . \frac{778}{2}$$

$$\Phi = 9.83\ \text{mWb}$$

Ex7: A 4-pole lap-connected armature of a d.c. shunt generator is required to supply the loads connected in parallel:

(1) 5 kW Geyser at 250 V, and

(2) 2.5 kW Lighting load also at 250 V.

The Generator has an armature resistance of 0.2 ohm and a field resistance of 250 ohms. The armature has 120 conductors in the slots and runs at 1000 rpm. Allowing 1 V per brush for contact drops and neglecting friction, find Flux per pole.

Solution:

$\text{Geyser current} = 5000/250 = 20\ \text{A}$

$\text{Current for Lighting} = 2500/250 = 10\ \text{A}$

$\text{Total current} = 30\ \text{A}$

$\text{Field Current for Generator} = 1\ \text{A}\ (250\text{v}\backslash 250\text{ohm})$

$\text{Hence, Armature Current} = 31\ \text{A}$

$\text{Armature resistance drop} = 31 \times 0.2 = 6.2\ \text{volts}$

$\text{Generated e.m.f.} = 250 + 6.2 + 2(2\ \text{brushes}) = 258.2\ \text{V},$

$$\text{Eg} = \frac{\Phi\ \text{P}\ \text{N}}{60} . \frac{\text{Z}}{\text{A}}$$

$$258.2 = \frac{\Phi \times 1000 \times 120}{60}$$

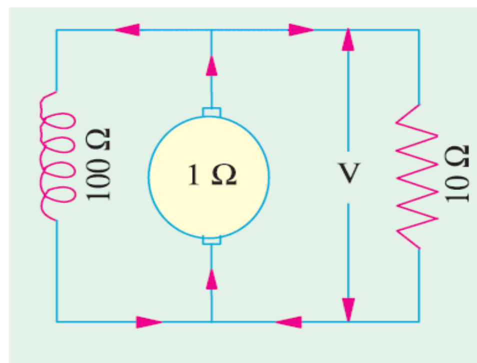
$$\Phi = 129.1\ \text{mWb}$$

Ex8: A 4-pole, d.c. shunt generator with a shunt field resistance of 100 Ω and an armature resistance of 1 Ω has 378 wave-connected conductors in its armature. The flux per pole is 0.02 Wb. If a load resistance of 10 Ω is connected across the armature terminals and the generator is driven at 1000 r.p.m., calculate the power absorbed by the load.

Solution:

Induced e.m.f. in the generator is

$$Eg = \frac{\Phi \, P \, N}{60} . \frac{Z}{A}$$



$$Eg = \frac{0.02 \times 4 \times 1000}{60} . \frac{378}{2} = 252\,V$$

Load current =V/10

Shunt current= V/100

$$\text{Armature current} = \frac{V}{10} + \frac{V}{100} = \frac{11V}{100}$$

$$V = Eg - \text{armature drop}$$

$$V = 252 - 1 \times \frac{11V}{100}$$

$$V = 227\ V$$

$$\text{Load current} = 227/10 = 22.7\ A$$

$$\text{Power absorbed} = 227 \times 22.7 = 5135\ W$$

Losses in a D.C. Machine

The losses in a d.c. machine (generator or motor) may be divided into three classes

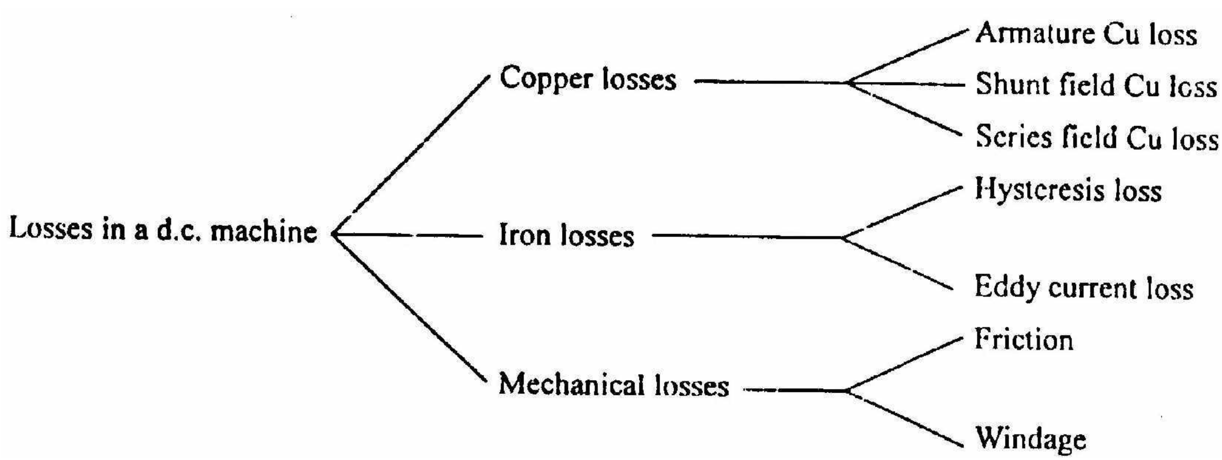
(i) copper losses

(ii) (ii) iron or core losses and

(iii) (iii) mechanical losses.

All these losses appear as heat and thus raise the temperature of the machine.

They also lower the efficiency of the machine.



Copper losses

These losses occur due to currents in the various windings of the machine.

(i) Armature copper loss $=I_a^2 \; R_a$

(ii) (ii) Shunt field copper loss$=I_{sh}^2 \; R_{sh}$

(iii) Series field copper loss$=I_{se}^2 \; R_{se}$

Iron or Core losses

These losses occur in the armature of a d.c. machine and are due to the rotation of armature in the magnetic field of the poles. They are of two types viz., (i) hysteresis loss (ii) eddy current loss.

(i) **Hysteresis loss**

Hysteresis loss occurs in the armature of the d.c. machine since any given part of the armature is subjected to magnetic field reversals as it passes under successive poles. Fig. below shows an armature rotating in two-pole machine.

Consider a small piece ab of the armature. When the piece ab is under N-pole, the magnetic lines pass from a to b. Half a revolution later, the same piece of iron is under S-pole and magnetic lines pass from b to a so that magnetism in the iron is reversed. In order to reverse continuously the molecular magnets in the armature core, some amount of power has to be spent which is called hysteresis loss. It is given by Steinmetz formula. This formula is:

$$\text{Hysteresis loss, } P_h = \eta\, B_{max}^{16}\, f\, V \quad \text{watts}$$

Where

B_{max} = Maximum flux density in armature

f = Frequency of magnetic reversals

= NP/120 where N is in r.p.m.

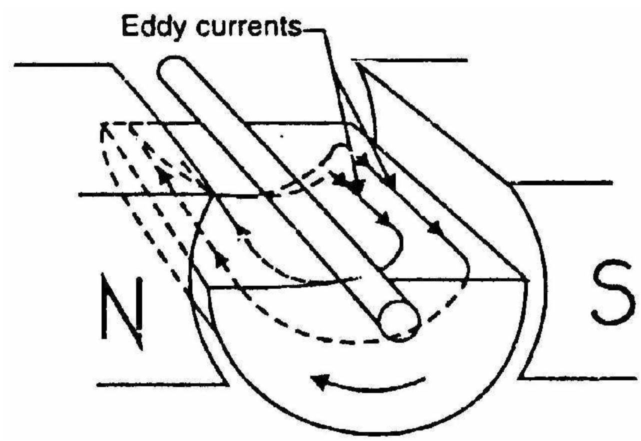
V = Volume of armature in m^3

η = Steinmetz hysteresis co-efficient

In order to reduce this loss in a d.c. machine, armature core is made of such materials which have a low value of Steinmetz hysteresis co-efficient e.g., silicon steel.

(ii) **Eddy current loss**

In addition to the voltages induced in the armature conductors, there are also voltages induced in the armature core. These voltages produce circulating currents in the armature core as shown in Figure below These are called eddy currents and power loss due to their flow is called eddy current loss. The eddy current loss appears as heat which raises the temperature of the machine and lowers its efficiency



Mechanical losses

These losses are due to friction and windage.

(i) friction loss e.g., bearing friction, brush friction etc.

(ii) windage loss i.e., air friction of rotating armature.

These losses depend upon the speed of the machine. But for a given speed, they are practically constant.

Note. Iron losses and mechanical losses together are called stray losses.

(i) **Constant losses**

Those losses in a d.c. generator which remain constant at all loads are known as constant losses. The constant losses in a d.c. generator are:

(a) iron losses

(b) mechanical losses

(c) shunt field losses

(ii) Variable losses

Those losses in a d.c. generator which vary with load are called variable losses.

The variable losses in a d.c. generator are

(a) Copper loss in armature winding, $I_a^2\ R_a$

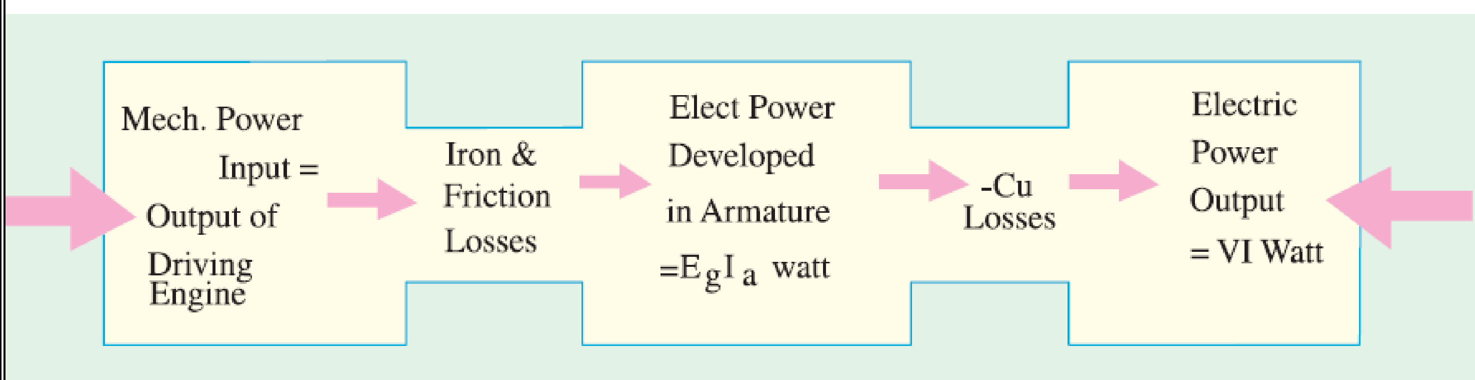
(b) Copper loss in series field winding, $I_{se}^2\ R_{se}$

Total losses = Constant losses + Variable losses

Note. Field Cu loss is constant for shunt and compound generators

Power Stages

The various power stages in a d.c. generator are represented diagrammatically in the following figure.



Mechanical efficiency

$$\eta_m = \frac{B}{A} = \frac{E_g\ I_a}{Mechanical\ power\ input}$$

Electrical efficiency

$$\eta_e = \frac{C}{B} = \frac{V\ I_L}{E_g\ I_a}$$

Commercial or overall efficiency

$$\eta_c = \frac{C}{A} = \frac{V\ I_L}{Mechanical\ power\ input}$$

$$\eta_c = \eta_e\ .\eta_m$$

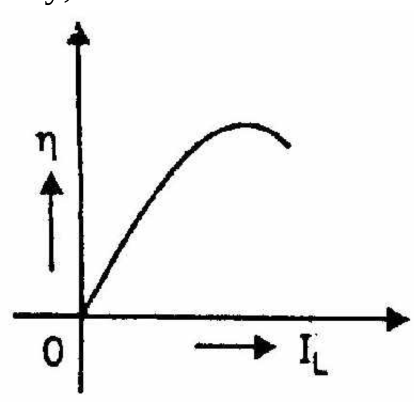
Condition for Maximum Efficiency

The efficiency of a d.c. generator is not constant but varies with load. Consider a shunt generator delivering a load current I_L at a terminal voltage V.

Variable loss = Constant loss

The load current corresponding to maximum efficiency is given by;

$$I_L = \sqrt{\frac{W_C}{R_a}}$$



Ex9: A 10 kW, 250 V, d.c., 6-pole shunt generator runs at 1000 r.p.m. when delivering full-load. The armature has 534 lap-connected conductors. Full-load Cu loss is 0.64 kW. The total brush drop is 1 volt. Determine the flux per pole. Neglect shunt current.

Solution:

Since shunt current is negligible, there is no shunt Cu loss. The copper loss occurs in armature only.

$I = Ia = 10{,}000/250 = 40\,A$

Armature Cu loss $= I_a^2 . R_a$

$640 = 40^2 . R_a \qquad R_a = 0.4\Omega$

$I_a R_a\ drop = 0.4 \times 40 = 16\,V$

Generated e.m.f $= 250 + 16 + 1 = 267$ V

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

$$267 = \frac{\Phi \times 6 \times 1000}{60} . \frac{534}{6} \quad , \quad \Phi = 30 \text{ mWb}$$

Ex10: A shunt generator delivers 195 A at terminal p.d. of 250 V. The armature resistance and shunt field resistance are 0.02 Ω and 50 Ω respectively. The iron and friction losses equal 950 W. Find **(a)** E.M.F. generated **(b)** Cu losses **(c)** output of the prime motor

(d) Commercial, mechanical and electrical efficiencies.

Solution:

$I_{sh} = \frac{250}{50} = 5\,A; \qquad I_a = 195 + 5 = 200\,A$

Armature voltage drop $= I_a R_a = 200 \times 0.02 = 4$ V

$\therefore$ Generated e.m.f. $= 250 + 4 = 254$ V

Armature Cu loss $= I_a^2 Ra = 2002 \times 0.02 = 800$ W

$Shunt\ Cu\ loss = V.I_{sh} = 250 \times 5 = 1250\ W$

Total Cu loss $= 1250 + 800 = 2050$ W

Total losses $= 2050 + 950 = 3000$ W

Output $= 250 \times 195 = 48{,}750$ W

Input $= 48{,}750 + 3000 = 51750$ W Output of prime motor

Electrical power produced in armature $= 51{,}750 - 950 = 50{,}800$ W

$$\eta_m = \left(\frac{50{,}800}{51{,}750}\right) \times 100 = 98.2\%$$

$$\eta_e = \left(\frac{48750}{48750 + 2050}\right) \times 100 = 95.9\%$$

$$\eta_c = \left(\frac{48750}{51750}\right) \times 100 = 94.2\%$$

Find the load current corresponding to maximum efficiency?

Ex11: long-shunt dynamo running at 1000 r.p.m. supplies 22 kW at a terminal voltage of 220 V. The resistances of armature, shunt field, and the series field are 0.05, 110 and 0.06 Ω respectively. The overall efficiency at the above load is 88%. Find **(a)** Cu losses **(b)** iron and friction losses **(c)** the torque exerted by the prime mover

Solution:

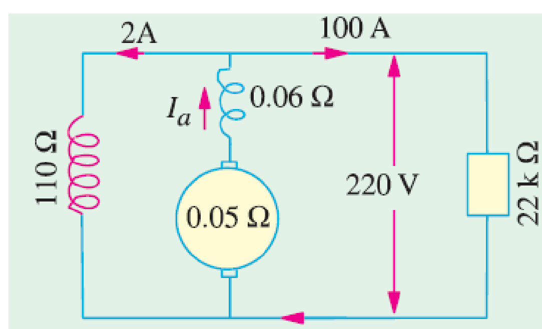
$I_{sh} = 220/110 = 2$ A

$I = 22{,}000/220 = 100$ A,

$I_a = 102$ A

Drop in series field winding $= 102 \times 0.06 = 6.12$ V

$I_a^2 Ra = 1022 \times 0.05 = 520.2$ W



Series field loss $= 102^2 \times 0.06 = 624.3$ W

Shunt field loss $= 4 \times 110 = 440$ W

Total Cu losses $= 520.2 + 624.3 + 440 = 1584.5$ W

$$\text{Input} = \frac{22{,}000}{0.88} = 25{,}000 \text{ W}$$

$\therefore$ Total losses $= 25{,}000 - 22{,}000 = 3{,}000$ W

$\therefore$ Iron and friction losses $= 3{,}000 - 1{,}584.5 = 1{,}415.5$ W

$$\text{Power} = T\frac{2\pi N}{60} \qquad T = 238.74 \text{ N.m}$$

Parallel Operation of Shunt Generators

Power plants, whether in d.c. or a.c. stations, will be generally found to have several smaller generators running in parallel rather than large single units capable of supplying the maximum peak load. These smaller units can be run single or in various parallel combinations to suit the actual load demand. Such practice is considered extremely desirable for the following reasons

(i) Continuity of Service

Continuity of service is one of the most important requirements of any electrical apparatus. This would be impossible if the power plant consisted only of a single unit, because in the event of breakdown of the prime mover or the generator itself, the entire station will be shut down.

(ii) Efficiency

Usually, the load on the electrical power plant fluctuates between its peak value sometimes during the day and its minimum value during the late night hours. Since generators operate most efficiently when delivering full load, it is economical to use a single small unit when the load is light. Then, as the load demand increases, a larger generator can be substituted for the smaller one or another smaller unit can be connected to run in parallel with the one already in operation.

(iii) Maintenance and Repair

It is considered a good practice to inspect generators carefully and periodically to forestall any possibility of failure or breakdown. This is possible only when the generator is at rest which means that there must be other generators to take care of the load

(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.

Connecting Shunt Generators in Parallel

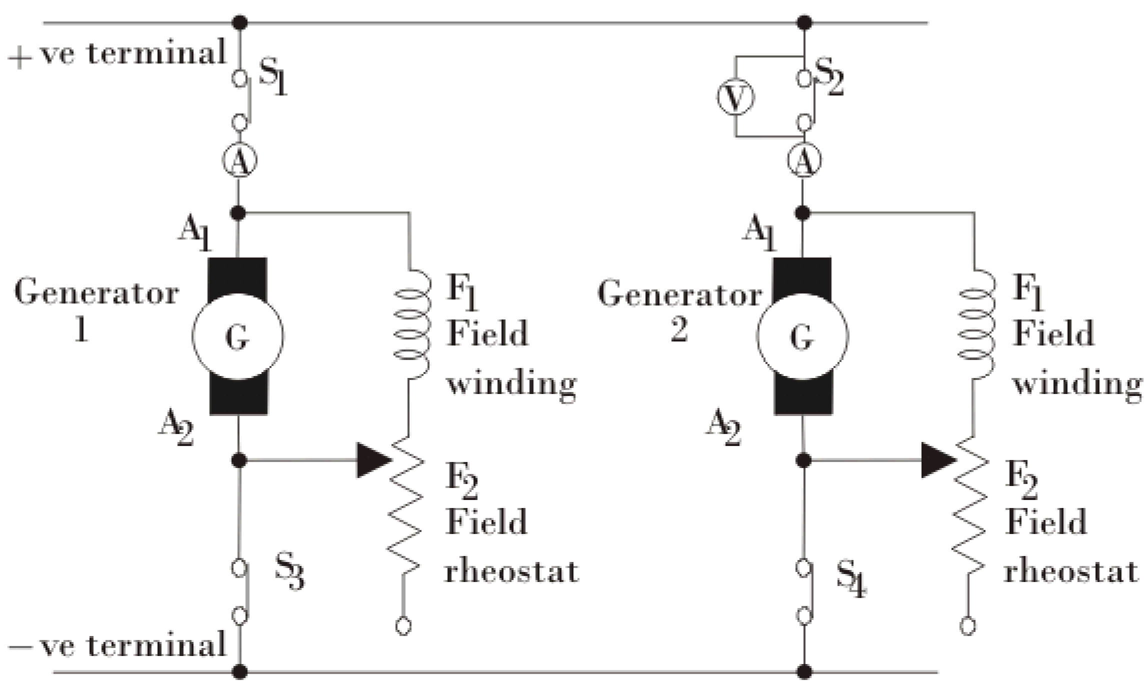
the generators in a power plant, connected by heavy thick copper bars, called bus-bars which act as positive and negative terminals. To connect the generators in parallel, Positive terminal of the generators are connected to the positive terminal of the bus-bars and negative terminals of generators are connected to negative terminal of the bus-bars, as shown in the figure.

1. To connect the 2 generators with the 1 existing working generators, first we have to bring the speed of the prime mover of the 2nd generator to the rated speed. At this point switch S_4 is closed.

2. The circuit breaker V_2 (voltmeter) connected across the open switch S_2 is closed to complete the circuit. The excitation of the generator 2 is increased with the help of field rheostat till it generates voltage equal to the voltage of bus-bars.

3. The main switch S_2 is then closed and the generator 2 is ready to be paralleled with existing generator. But at this point of time generator 2 is not taking any load as its induced e.m.f. is equal to bus-bar voltage. The present condition is called floating, that means ready for supply but not supplying current to the load.

4. The main switch S_2 is then closed and the generator 2 is ready to be paralleled with existing generator. But at this point of time generator 2 is not taking any load as its induced e.m.f. is equal to bus-bar voltage. The present condition is called floating, that means ready for supply but not supplying current to the load.



$$I_1 = \frac{E_1 - V}{R_1}$$

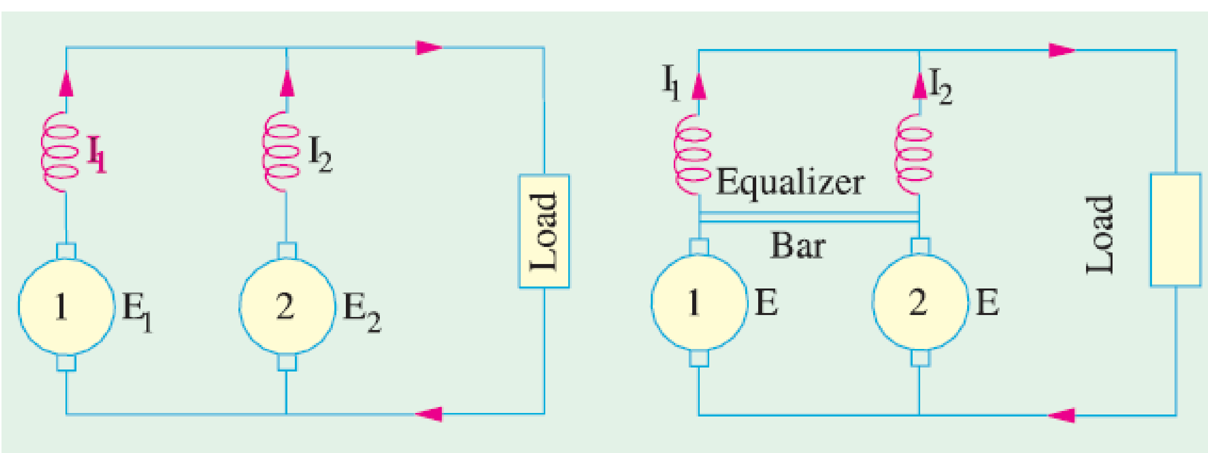
$$I_2 = \frac{E_2 - V}{R_2}$$

Series Generators in Parallel

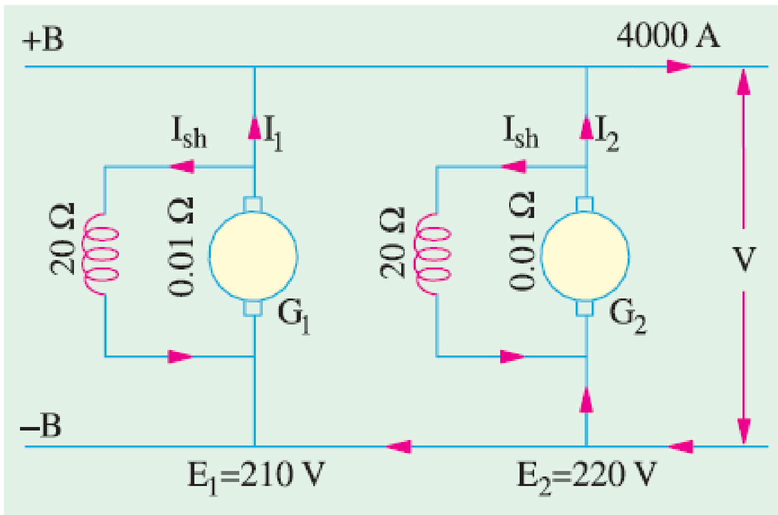
Suppose E_1 and E_2 are initially equal, generators supply equal currents and have equal shunt resistances. Suppose E1 increases slightly so that $E_1 > E_2$. In that case, I_1 becomes greater than I_2. Consequently, field of machine 1 is strengthened thus increasing E1 further whilst the field of machine 2 is weakened thus decreasing E2 further.

A final stage is reached when machine 1 supplies not only the whole load but also supplies power to machine 2 which starts running as a motor.

This condition can be prevented by using equalizing bar because of which two similar machines pass approximately equal currents to the load, the slight difference between the two currents being confined to the loop made by the armatures and the equalizer bar.



Ex12/ Two shunt generators each with an armature resistance of 0.01 ohm and field resistance of 20 ohm run in parallel and supply a total load of 4000 A. The e.m.f.s are respectively 210 V and 220 V. Calculate the bus-bar voltage and output of each machine.



V = bus-bar voltage

I_1 = output current of G1

I_2 = output current of G2

$I_1 + I_2 = 4000$ A, $\qquad$ $Ish = V/20.$

$$I_{a1} = \left(I_1 + \frac{V}{20}\right);\ I_{a2} = \left(I_2 + \frac{V}{20}\right)$$

In each machine,

V + armature drop = induced e.m.f.

$$V + Ia1\,Ra = E1$$

or $V + \left(I_1 + \frac{V}{20}\right) \times 0.01$

= 210 ...1st machine

Also $V + I_{a2}\,Ra = E2$

or $V + \left(I_2 + \frac{V}{20}\right) \times 0.01 = 220$ ... 2nd machine

Subtracting, we have $0.01\,(I1 - I2) = 10$ or $I1 - I2 = 1000$

Also, $I_1 + I_2 = 4000\text{ A} \therefore I_1 = 2500\text{ A} ; I_2 = 1500\text{ A}$

Substituting the value of I1 above, we get

$V + (2500 + V/20) \times 0.01 = 210 \therefore V = 184.9\text{ V}$

Output of Ist generator $= 184.9 \times 2500/1000 = 462.25\text{ kW}$

Output of 2nd generator $= 184.49 \times 1500/1000 = 277.35\text{ kW}$

Ex13/ Two d.c. generators A and B are connected to a common load. A had a constant e.m.f. of 400 V and internal resistance of 0.25 Ω while B has a constant e.m.f. of 410 V and an internal resistance of 0.4 Ω. Calculate the current and power output from each generator if the load voltage is 390 V. What would be the current and power from each and the terminal voltage if the load was open-circuited.

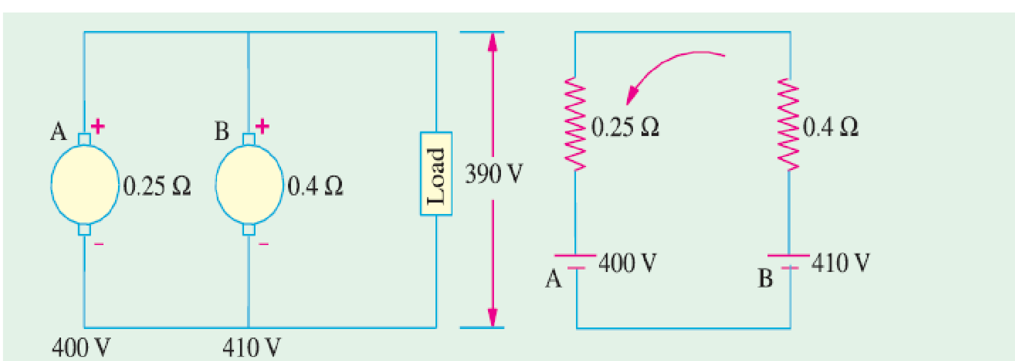


Fig. 27.30

Solution:

Since the terminal or output voltage is 390 V, hence

Load supplied by A $= (400 - 390)/0.25 = 40$ A

Load supplied by B $= (410 - 390)/0.4 = 50$A

$\therefore$ Power output from A $= 40 \times 390 = 15.6$ kW

Power output from B $= 50 \times 390 = 19.5$ kW

If the load is open-circuited as shown in figure above, then the two generators are put in series with each other and a circulatory current is set up between them.

Net voltage in the circuit $= 410 - 400 = 10$ V

Total resistance $= 0.4 + 0.25 = 0.65\ \Omega$

$\therefore$ circulatory current $= 10/0.65 = 15.4$ A

The terminal voltage $= 400 + (15.4 \times 0.25) = 403.8$ V

Obviously, machine B with a higher e.m.f. acts as a generator and drives machine A as a motor.

Power taken by A from B $= 403.8 \times 15.4 = 6{,}219$ W

Part of this appears as mechanical output and the rest is dissipated as armature Cu loss.