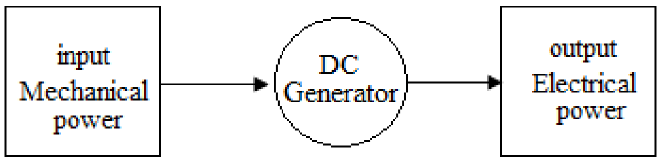
DC GENERATORS

DC Machine: DC machine is an electro mechanical converting device, which converts electrical energy into mechanical energy or mechanical energy into electrical energy.

DC Generator: DC Generator is a machine, which converts mechanical energy into electrical energy.



Operating principle of DC Generator:

The DC Generator works on Faraday's laws of electromagnetic induction principle i.e. '*Whenever a rotating conductor is placed in magnetic field, an emf will induced across the conductors*'.

Let us consider a single turn conductor running with a constant speed is placed in a magnetic field as shown in Fig.(1). The working of the DC Generator is explained as

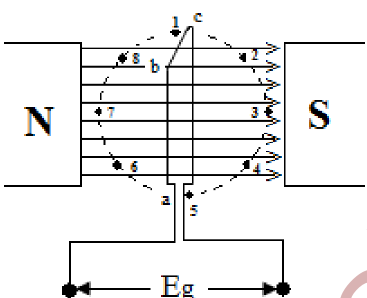


Figure. (1)

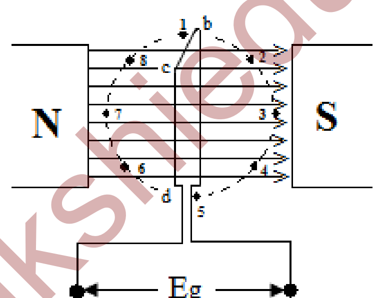


Figure. (2)

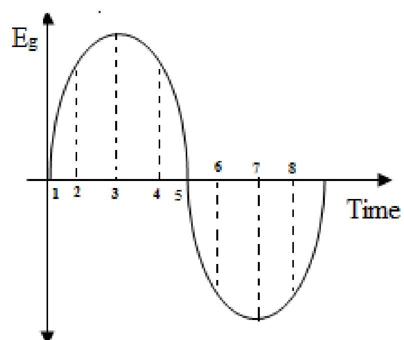


Figure. (3)

follows:

When the conductor is in position-1, the flux linking with the conductor is maximum and the change in flux (dΦ/dt) is minimum, so the *emf* induced across the conductor is zero.

At position-2, the flux linking with the conductor is decreasing and the change in flux (dΦ/dt) is increasing from zero, hence the *emf* induced across the conductor is increasing from zero as shown in fig.(3).

At position-3, the flux linking with the conductor is minimum and the change in flux (dΦ/dt) is maximum. So the emf induced across the conductor is maximum.

At position-4, the flux linking with the conductor is increasing from minimum and the change in flux (dΦ/dt) is decreasing from maximum value, hence the *emf* induced across the conductor is decreasing from maximum as shown in fig.(3).

At position-5, the flux linking with the conductor is maximum and the change in flux (dΦ/dt) is minimum, so the emf induced across the conductor is minimum.

At position-6, the flux linking with the conductor is decreasing and the change in flux (dΦ/dt) is increasing from zero, hence the *emf* induced across the conductor is increasing from zero as shown in fig.(3) but the direction of induced *emf* is negative from conductor position 5 to 1.

Differences between lap and wave windings:

Lap Winding	Wave Winding
1. In Lap winding the finishing end of the one coil is connected to starting end of the adjacent coil.	1. The wave winding is designed like a wave
2. EMF generation is low because no. of conductors in parallel path is less.	2. EMF generation is more because no. of conductors in parallel path is more.
3. No. of parallel paths = No. of poles	3. No. of parallel paths = 2
4. It is suitable for low voltage and high current applications.	4. It is suitable for high voltage and low current applications.

E.M.F. Equation of a D.C. Generator

Let

ϕ = flux/pole in Wb   P = number of poles

Z = No. of armature conductors = No. of slots * conductors/slot

A = No. of parallel paths = P ... for Lap winding

= 2 ... for Wave winding

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

E_g = Generated EMF or EMF/parallel path

According to faraday's laws of electromagnetic induction principle, average induced EMF (E_g) = $d\phi/dt$

Where $d\phi$ = Flux cut by a conductor in one revolution = $P\phi$ wb dt = Time taken to complete one revolution

Since N no. of revolutions are made by the generator per minute, no. of revolutions are made by the generator per sec = N / 60

$\therefore$ Time taken to complete one revolution (dt) = $\frac{1}{(Ns/60)}$ = 60/N

Average value of induced EMF /conductor = $\frac{P\Phi}{(60/N)} = \frac{P\Phi N}{60}$

The DC generator has Z no. of armature conductors and are divided into A no. of parallel paths, then no. of conductors per each parallel path is Z/A.

$\therefore$ Induced EMF per each parallel path = $\frac{P\Phi N}{60} * \frac{Z}{A}$

Induced EMF (or) Generated EMF (E_g) = $\frac{\Phi ZN}{60} * \frac{P}{A}$

Where A = No. of parallel paths = P for lap winding

= 2 for wave winding

Types of D.C. Generators

DC Generators are generally classified into two, according to their field excitation. Those are

(i) Separately excited d.c. generators

(ii) Self-excited d.c. generators

(i) Separately Excited D.C. Generator:

The d.c. generator whose field winding is excited from an independent external d.c. source (battery) is called a separately excited generator. Fig.4 shows the connections of a separately excited generator. The separately excited d.c. generators are rarely used in practice.

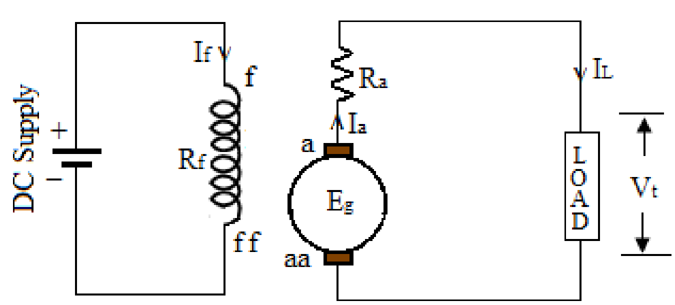


Figure 4

From the diagram $I_a = I_L$ and $E_g = V_t + I_a R_a + B.D$

Electrical power developed = $E_g I_a$ and Power delivered to load = $V_t I_L = V_t I_a$

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

And B.D = Brush contact drop

(ii) Self excited D.C. Generator

The d.c. generator whose field winding is excited by itself is called a self-excited generator. There are three types of self-excited generators, namely;

(i) DC Shunt generator (ii) DC Series generator (iii) DC Compound generator

DC Shunt generator

In a DC Shunt Generator, the field windings are connected in parallel with the armature winding as shown in fig (5). The shunt field winding has *many turns* of *thin* wire having high resistance, therefore, a part of the armature current flows through shunt field winding and the remaining current flows through the load.

From the diagram,

Shunt field current $I_{sh} = V_t / R_{sh}$

Armature current $I_a = I_L + I_{sh}$ (or) $I_L = I_a - I_{sh}$

Generated EMF $E_g = V_t + I_a R_a + B.D$

Terminal voltage $V_t = E_g - I_a R_a - B.D$

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t (I_a - I_{sh})$

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

And B.D = Brush contact drop

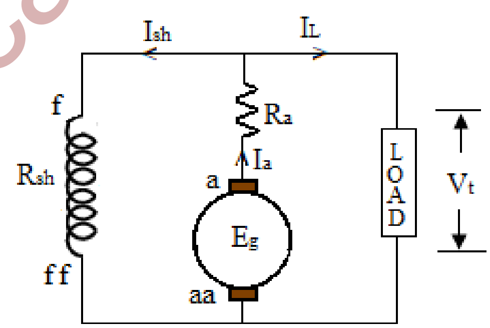


Figure.(5)

DC Series generator

If the field winding is connected in series with armature winding as shown in fig.(6) is called DC Series Generator. The series field winding has a *few turns* of *thick* having low resistance. The DC Series generators are rarely used except for special purposes e.g., as boosters.

From the circuit,

Armature current = Series field current = Load current

i.e $I_a = I_{se} = I_L$

Generated EMF $E_g = V_t + I_a R_a + I_{se} R_{se} + B.D$

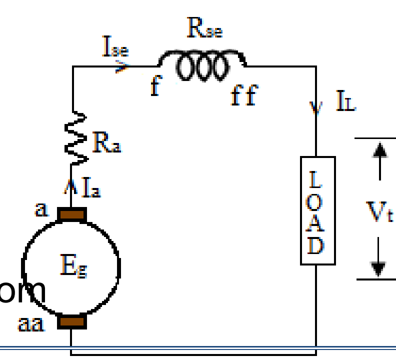


Figure. (6)

$= V_t + I_a (R_a + R_{se}) + B. D$

$\therefore$ Terminal voltage, $V_t = E_g - I_a (R_a + R_{se})$ - B. D

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t I_a$ (since $I_a = I_L$)

Where,

I_a = Armature current,

R_a = Armature Resistance,

V_t = Terminal voltage,

I_L = Load current and

B.D = Brush contact drop

DC Compound generator:

In a DC compound generator, there are two sets of field windings on each pole, one is in series with the armature and the other in parallel with the armature. Based on these field winding connections, the DC compound generators are classified into

(i) Long shunt compound generator
(ii) Short shunt compound generator

Long shunt compound generator

In a Long Shunt Compound generator, the shunt field winding is in parallel with the both series field and the armature winding as shown in fig. (7).

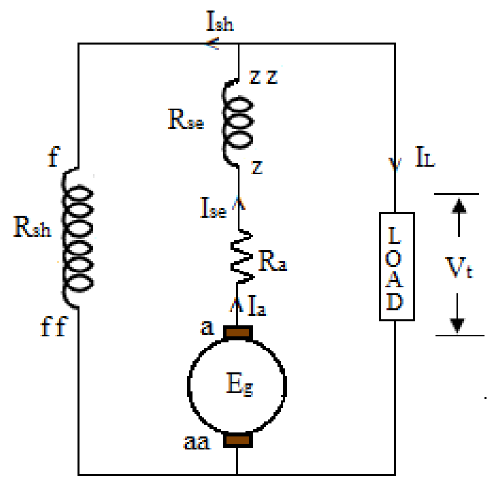


Figure. (7)

From the diagram,

Shunt field current $I_{sh} = V_t / R_{sh}$

Armature current $I_a = I_{se} = I_L + I_{sh}$ (or) $I_L = I_a - I_{sh}$

Generated EMF $E_g = V_t + I_a R_a + I_{se} R_{se} + B. D$

$= V_t + I_a (R_a + R_{se}) + B. D$

Terminal voltage $V_t = E_g - I_a (R_a + R_{se})$ - B. D

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t (I_a - I_{sh})$

Where,

I_a = Armature current,

R_a = Armature Resistance,

V_t = Terminal voltage,

I_L = Load current and

B.D = Brush contact drop

Short shunt compound generator

In a Short Shunt Compound generator, the shunt field winding is connected in parallel with armature winding only, as shown in fig. (8).

From the diagram

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

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

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

Generated EMF $E_g = V_t + I_a R_a + I_{se} R_{se}$ + B. D

Terminal voltage $V_t = E_g - I_a R_a - I_{se} R_{se})$ - B. D

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t (I_a - I_{sh})$

Where

I_a = Armature current,

R_a = Armature Resistance,

V_t = Terminal voltage,

I_L = Load current and

B.D = Brush contact drop

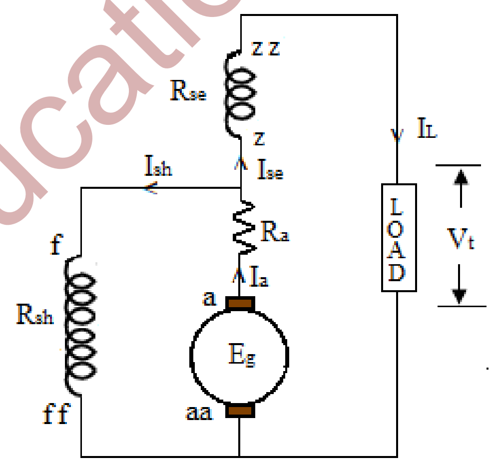


Figure (8)

Magnetization or Open Circuit Characteristic (O.C.C.)

This curve shows the relation between the generated e.m.f. at no-load (E_0) and the field current (I_f) at constant speed. It is also known as magnetic characteristic or no-load

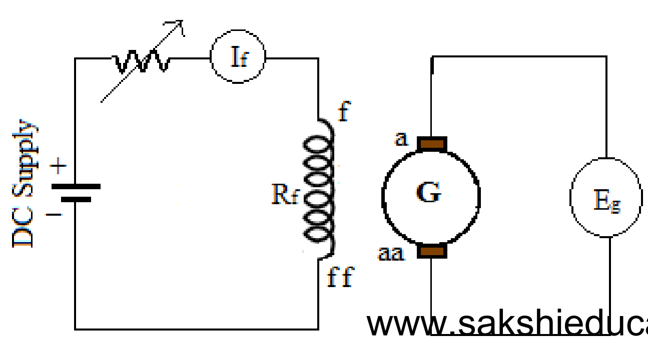


Figure (9)

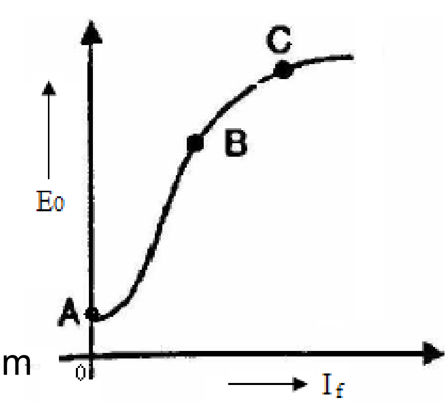


Figure (10)

saturation curve. Its shape is practically the same for all generators whether separately or self excited. The data for O.C.C. curve are obtained experimentally by operating the generator at no load and constant speed and recording the change in terminal voltage as the field current is varied.

The O.C.C. for a d.c. generator is determined as follows:

The field winding of the d.c. generator (series or shunt) is separately excited from an external d.c. source as shown in Fig. (9). Now the field current (I_f) is increased from zero in steps and the corresponding values of generated e.m.f. (E_0) are noted. Now plot the graph between E_0 and I_f to get the open circuit characteristic as shown in Fig.(10).

The following points may be noted from O.C.C:

(i) When the field current is zero, there is some generated e.m.f. OA. This is due to *the residual magnetism* in the field poles.

(ii) Upto certain range of field current (upto point B in the curve), the curve is linear, because reluctance of iron is negligible as compared with that of air gap. The air gap reluctance is constant and hence linear relationship.

(iii) After point C on the curve, the poles get saturated and hence the magnetic flux varies slowly with field current.

Characteristics of Shunt Generator

Open Circuit Characteristic (O.C.C.):

This curve shows the relation between the generated e.m.f. at no-load (E_0) and the field current (I_f) at constant speed. It is also known as magnetic characteristic or no-load saturation curve. Its shape is practically the same for all generators whether separately or self-excited. The data for O.C.C. curve are obtained experimentally by operating the generator at no load and constant speed and recording the change in terminal voltage as the field current is varied.

The O.C.C. for a d.c. shunt generator is determined as follows.

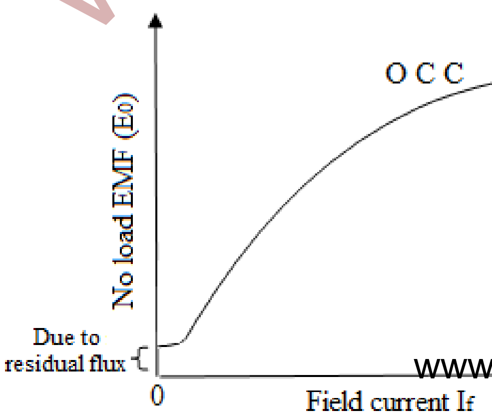


Figure (11)

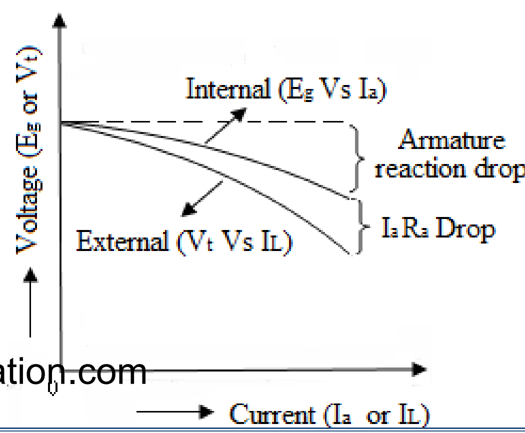


Figure (12)

The field winding of the d.c. shunt generator is separately excited from an external d.c. source. Now the field current (I_f) is increased from zero in steps and the corresponding values of generated e.m.f. (E_0) are noted. On plotting the graph between E_0 and I_f, we get the open circuit characteristic as shown in Fig.(11).

Load Characteristic

The load characteristics of DC shunt generator are classified as Internal characteristics and External characteristics.

Internal characteristics

Internal characteristics are drawn between the generated e.m.f. on load (E_g) and the armature current (Ia). When the generator is loaded, the flux per pole is reduced due to armature reaction. Therefore, e.m.f. generated (E_g) on load is less than the e.m.f. generated (E_0) at no load. As a result, the internal characteristic (E_g Vs Ia) falls down slightly as shown in Fig.(12).

External characteristics

The External characteristics are drawn between terminal voltage V_t and load current I_L. We know that terminal voltage $V_t = E_g - I_a R_a$. As the load on the generator increases, the armature voltage drop ($I_a R_a$) increases, this result in decrease in terminal voltage (V_t) from rated value as shown in fig. (12). The External characteristic always lies below the Internal characteristics. The load characteristics of a DC Shunt Generator are called ***Drooping characteristics***.

Characteristics of Series Generator

Open Circuit Characteristic (O.C.C.)

The open circuit characteristics are drawn between the generated e.m.f. at no-load (E_0) and the field current (I_f) at constant speed. It is also known as magnetic characteristic or no-load saturation curve. The data for O.C.C. curve are obtained experimentally by operating the generator at no load and constant speed and recording the change in terminal voltage as the field current is varied.

The O.C.C. for a d.c. series generator is determined as follows. The field winding of the d.c. series generator is separately excited from an external d.c. source. Now the field current (I_f) is increased from zero in steps and the corresponding values of generated e.m.f. (E_0) are noted. On plotting the graph between E_0 and I_f, we get the open circuit characteristic as shown in Fig.(13).

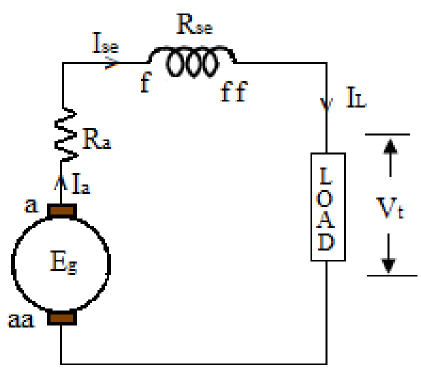


Figure (13)

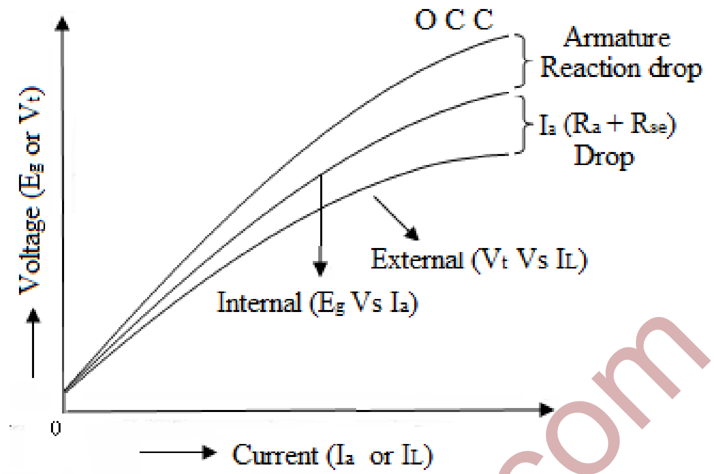


Figure (14)

Load Characteristic

The load characteristics of DC series generator are classified as Internal characteristics and External characteristics.

Internal characteristics

Internal characteristics are drawn between the generated e.m.f. on load (E_g) and the armature current (Ia). When the generator is loaded, the flux per pole is reduced due to armature reaction. Therefore, e.m.f. generated (E_g) on load is less than the e.m.f. generated (E_0) at no load. Consequently, internal characteristic curve lies below the O.C.C. curve as shown in fig. (14).

External characteristics

The External characteristics are drawn between terminal voltage V_t and load current I_L or I_a or I_{se}. We know that terminal voltage $V_t = E_g - I_a (R_a + R_{se})$. As the load on the generator increases, the armature voltage drop I_a (R_a + R_{se}) increases, this result in decrease in terminal voltage (V_t). Therefore the External characteristic always lies below the Internal characteristics. The load characteristics of a DC Series Generator are called *Rising characteristics.*