DC Generator

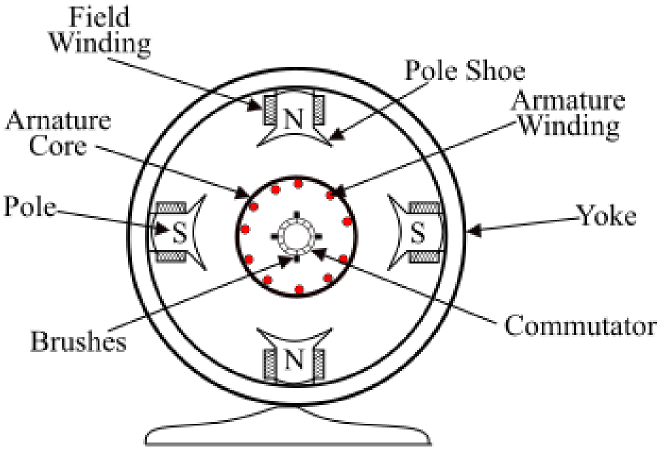
A DC generator is an electromechanical energy conversion device that converts mechanical power into DC electrical power through the process of electromagnetic induction.

Principle:

According to Faraday's laws of electromagnetic induction, whenever a conductor is placed in a varying magnetic field, an emf (electromotive force) is induced in the conductor. The magnitude of induced emf can be calculated from the emf equation of dc generator.

Construction:

A DC generator consists of the following main parts:



Yoke

The outer frame of a DC generator is a hollow cylinder made up of cast steel or rolled steel and is known as yoke. The yoke serves following two purposes

- ✓ It supports the field pole core and acts as a protecting cover to the machine.
- ✓ It provides a path for the magnetic flux produced by the field winding.

Magnetic Field System

The magnetic field system of a DC generator is the stationary part of the machine. It is also known as stator. It produces the main magnetic flux in the generator. It consists of an even number of pole cores bolted to the yoke and field winding wound around the pole core. The field system of DC generator has salient poles i.e. the poles project inwards and each pole core has a pole shoe having a curved surface. The pole shoe serves two purposes

- ✓ It provides support to the field coils.
- ✓ It reduces the reluctance of magnetic circuit by increasing the cross-sectional area of it.

Armature Core

The armature core of DC generator is mounted on the shaft and rotates between the field poles. It is the rotating part and is known as rotar. It has slots on its outer surface and the armature conductors are put in these slots. The armature core is a made up of soft iron laminations which are insulated from each other and tightly clamped together. In small machines, the laminations are keyed directly to the shaft, whereas in large machines, they are mounted on a spider. The laminated armature core is used to reduce the eddy current loss.

Armature Winding

The insulated conductors are put into the slots of the armature core. The conductors are suitably connected. This connected arrangement of conductors is known as armature winding. There are two types of armature windings are used – wave winding and lap winding.

Commutator

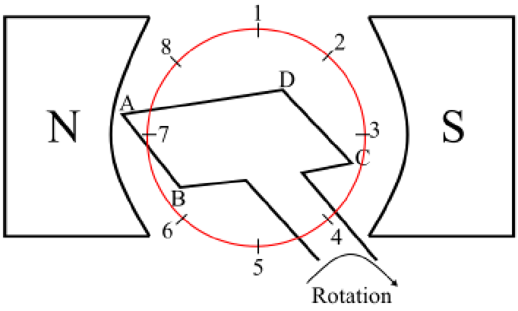
A commutator is a mechanical rectifier which converts the alternating emf generated in the armature winding into the direct voltage across the load terminals. The commutator is made of wedge-shaped copper segments insulated from each other and from the shaft by mica sheets. Each segment of commutator is connected to the ends of the armature coils.

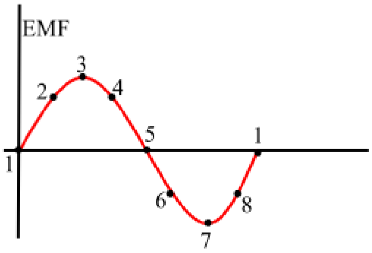
Brushes

The brushes are mounted on the commutator and are used to collect the current from the armature winding. The brushes are made of carbon and is supported by a metal box called brush holder. The pressure exerted by the brushes on the commutator is adjusted and maintained at constant value by means of springs. The current flows from the armature winding to the external circuit through the commutator and carbon brushes.

Working of a DC Generator

Consider a single loop DC generator (as shown in the figure), in this a single turn loop “ABCD‟ is rotating clockwise in a uniform magnetic field with a constant speed. When the loop rotates, the magnetic flux linking the coil sides “AB‟ and “CD‟ changes continuously. This change in flux linkage induces an EMF in coil sides and the induced EMF in one coil side adds the induced EMF in the other.





The EMF induced in a DC generator can be explained as follows

When the loop is in position-1, the generated EMF is zero because, the movement of coil sides is parallel to the magnetic flux.

- When the loop is in position-2, the coil sides are moving at an angle to the magnetic flux and hence, a small EMF is generated.
- When the loop is in position-3, the coil sides are moving at right angle to the magnetic flux, therefore the generated EMF is maximum.
- When the loop is in position-4, the coil sides are cutting the magnetic flux at an angle, thus a reduced EMF is generated in the coil sides.
- When the loop is in position-5, no flux linkage with the coil side and are moving parallel to the magnetic flux. Therefore, no EMF is generated in the coil.
- At the position-6, the coil sides move under a pole of opposite polarity and hence the polarity of generated EMF is reversed. The maximum EMF will generate in this direction at position-7 and zero when at position-1. This cycle repeats with revolution of the coil.

It is clear that the generated EMF in the loop is alternating one. It is because any coil side (say AB) has EMF in one direction when under the influence of N-pole and in the other direction when under the influence of S-pole. Hence, when a load is connected across the terminals of the generator, an alternating current will flow through it. Now, by using a commutator, this alternating emf generated in the loop can be converted into direct voltage.

EMF Equation of Generator

According to Faraday's laws of electromagnetic induction, whenever a conductor is placed in a varying magnetic field, an emf (electromotive force) is induced in the conductor. The magnitude of induced emf can be calculated from the emf equation of DC generator.

Consider a DC generator with the following parameters,

P = number of field poles
Ø = flux produced per pole in Wb (weber)
Z = total no. of armature conductors
A = no. of parallel paths in armature
N = rotational speed of armature in revolutions per min(rpm)

Now,

- Average emf generated per conductor is given by
  dΦ/dt (Volts) .. (Equation 1)
- Flux cut by one conductor in one revolution is
  dΦ = PΦ ….(Weber)
- Number of revolutions per second (speed in RPS) = N/60

Therefore, time for one revolution = dt = 60/N (Seconds)

- From Equation 1, emf generated per conductor = dΦ/dt = PΦN/60 (Volts) .. (Equation 2)
- Above Equation 2, gives the emf generated in one conductor of the generator. The conductors are connected in series per parallel path, and the emf across the generator terminals is equal to the generated emf across any parallel path.

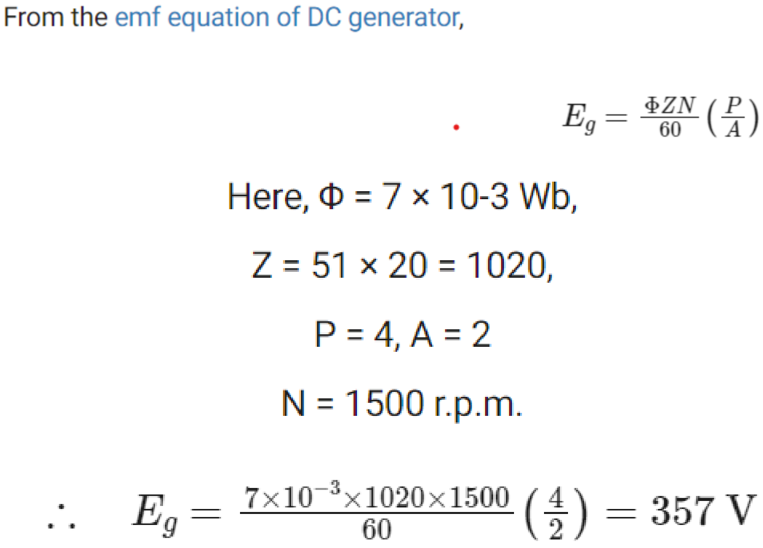
Therefore, **E_g = PΦNZ / 60A**

For simplex lap winding, number of parallel paths is equal to the number of poles (i.e. A=P),
Therefore, for simplex lap wound dc generator, **Eg = PΦNZ / 60**

For simplex wave winding, number of parallel paths is equal to 2 (i.e P=2),
Therefore, for simplex wave wound dc generator, **Eg = PΦNZ / 120**

Problems:

1. A four-pole generator, having wave-wound armature winding has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine when driven at 1500 rpm assuming the flux per pole to be 7.0 mWb ?



From the emf equation of DC generator,

$$E_g = \frac{\Phi Z N}{60}\left(\frac{P}{A}\right) \text{ volts}$$

Here, Φ = 7 × 10-3 Wb,

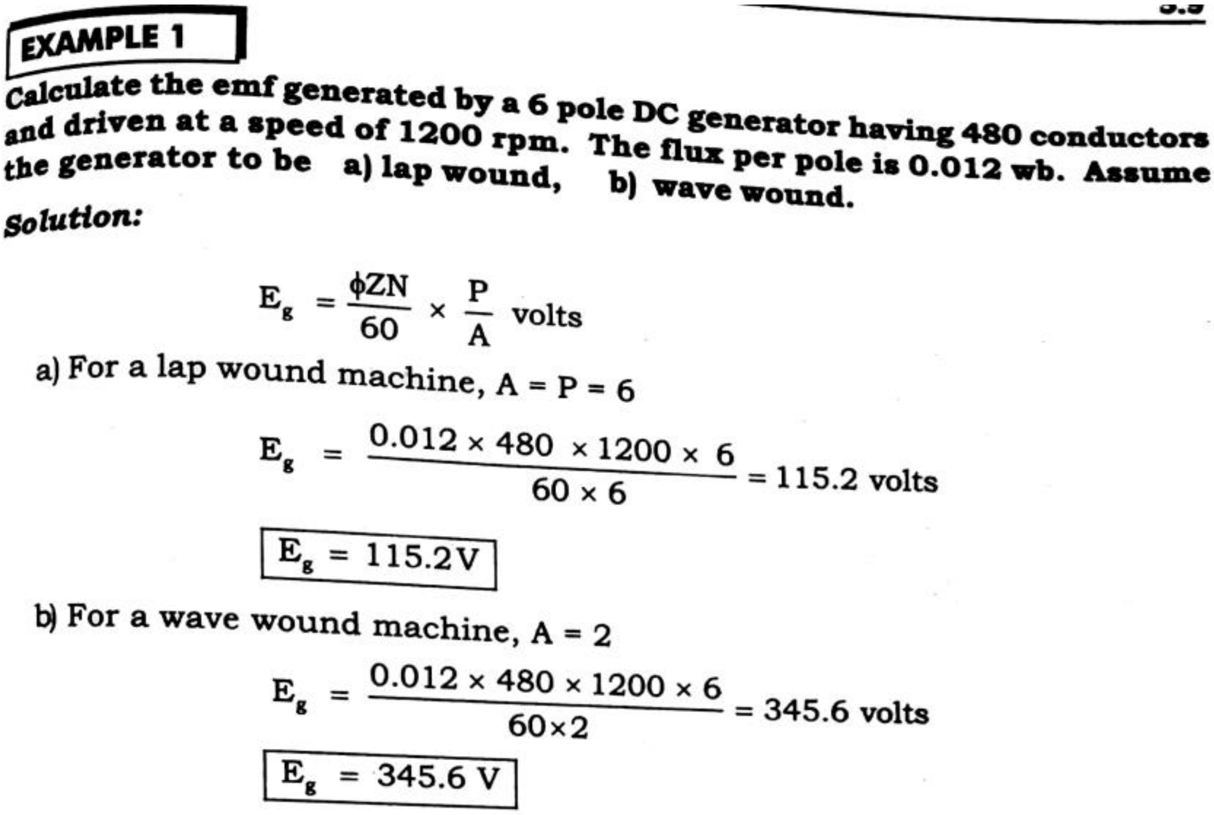
Z = 51 × 20 = 1020,

P = 4, A = 2

N = 1500 r.p.m.

$$\therefore \quad E_g = \frac{7\times10^{-3}\times1020\times1500}{60}\left(\frac{4}{2}\right) = 357 \text{ V}$$

2.



EXAMPLE 1

Calculate the emf generated by a 6 pole DC generator having 480 conductors and driven at a speed of 1200 rpm. The flux per pole is 0.012 wb. Assume the generator to be a) lap wound, b) wave wound.

Solution:

$$E_g = \frac{\phi Z N}{60} \times \frac{P}{A} \text{ volts}$$

a) For a lap wound machine, A = P = 6

$$E_g = \frac{0.012 \times 480 \times 1200 \times 6}{60 \times 6} = 115.2 \text{ volts}$$

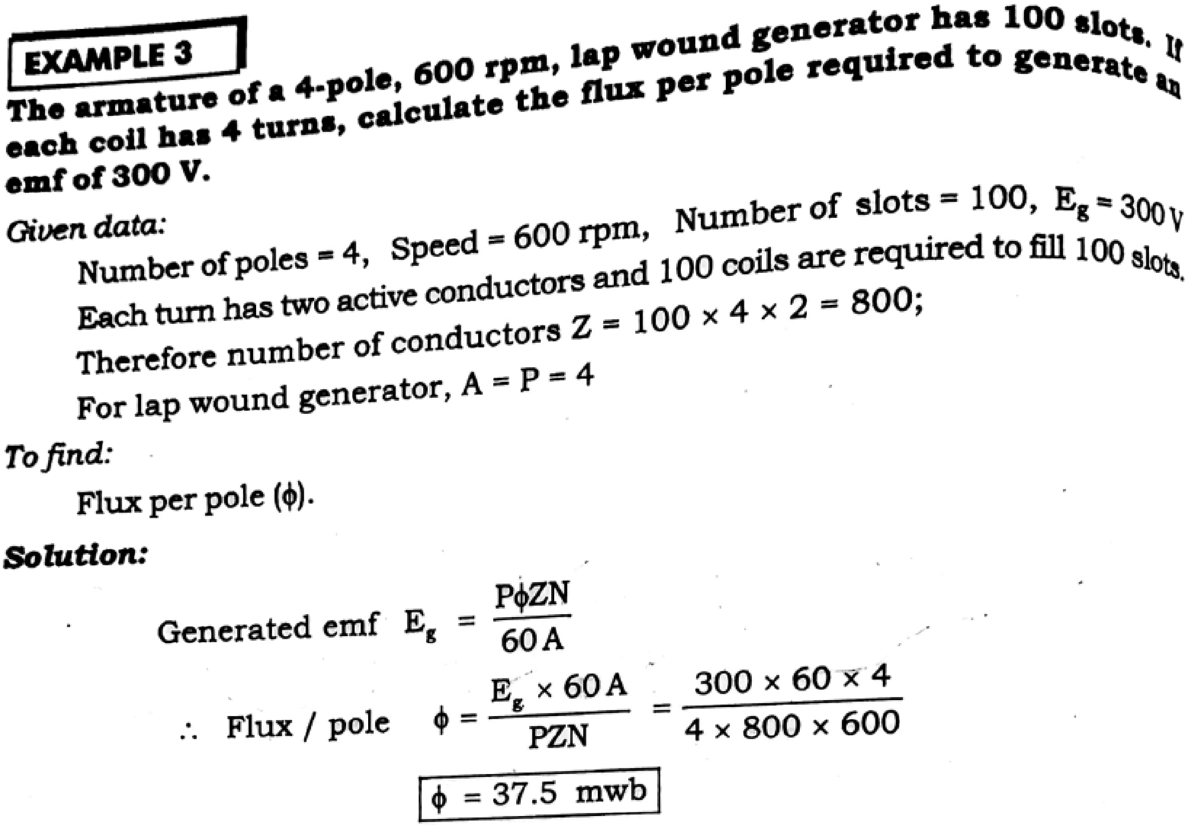
$$\boxed{E_g = 115.2\text{V}}$$

b) For a wave wound machine, A = 2

$$E_g = \frac{0.012 \times 480 \times 1200 \times 6}{60 \times 2} = 345.6 \text{ volts}$$

$$\boxed{E_g = 345.6 \text{ V}}$$

3.



EXAMPLE 3

The armature of a 4-pole, 600 rpm, lap wound generator has 100 slots. If each coil has 4 turns, calculate the flux per pole required to generate an emf of 300 V.

Given data:

Number of poles = 4, Speed = 600 rpm, Number of slots = 100, $E_g = 300$ V

Each turn has two active conductors and 100 coils are required to fill 100 slots.

Therefore number of conductors Z = 100 × 4 × 2 = 800;

For lap wound generator, A = P = 4

To find:

Flux per pole (ϕ).

Solution:

$$\text{Generated emf } E_g = \frac{P\phi Z N}{60\,A}$$

$$\therefore \text{ Flux / pole } \phi = \frac{E_g \times 60\,A}{PZN} = \frac{300 \times 60 \times 4}{4 \times 800 \times 600}$$

$$\boxed{\phi = 37.5 \text{ mwb}}$$

DC Motor

While a DC generator converts mechanical energy in the form of rotation of the conductor (armature) into electrical energy, a motor does the opposite. The input to a DC motor is electrical and the output is mechanical rotation or torque. It is shown in figure 3.25.

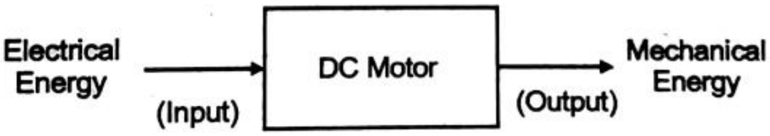


Figure 3.25

The fundamental principles and construction of the DC motors are identical with DC generators which have the same type of excitation. A DC machine that runs as a motor will also operate as a generator.

Principle

When kept in a magnetic field, a current-carrying conductor gains torque and develops a tendency to move. In short, when electric fields and magnetic fields interact, a mechanical force arises. This is the principle on which the DC motors work.

Parts of a DC Motor

Yoke

The outer frame of a DC generator is a hollow cylinder made up of cast steel or rolled steel and is known as yoke. The yoke serves following two purposes

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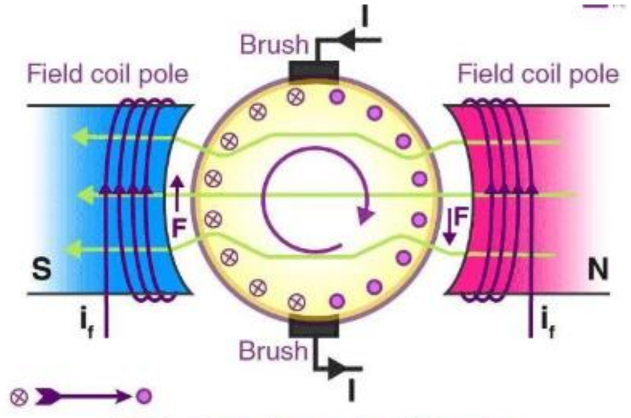
DC Motor Working

A magnetic field arises in the air gap when the field coil of the DC motor is energised. The created magnetic field is in the direction of the radii of the armature. The magnetic field enters the armature from the North pole side of the field coil and "exits" the armature from the field coil‟s South pole side.



Production of torque in a DC motor

The conductors located on the other pole are subjected to a force of the same intensity but in the opposite direction. These two opposing forces create a torque that causes the motor armature to rotate.

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

$$F = BIl \text{ Newtons}$$

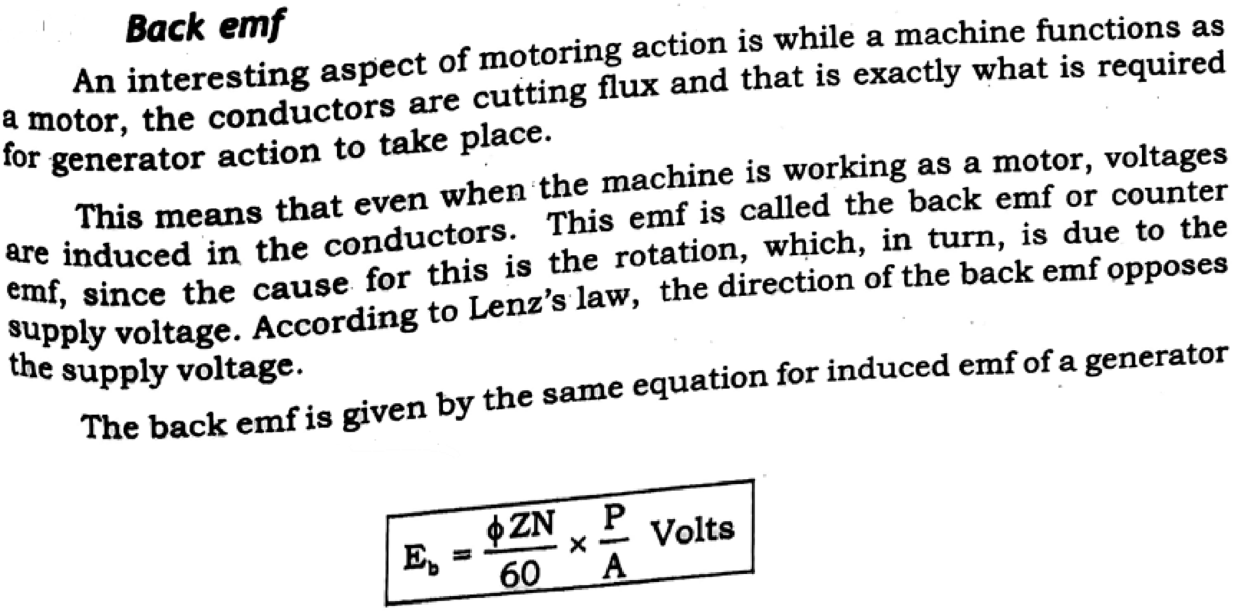
where

B = Magnetic field intensity in wb/ m^2.

I = current in ampers

l = length of the conductor in metres.

In a DC motor, a strong electromagnetic field and a large number of current carrying conductors housed in an armature, make the armature rotate.



Back emf

An interesting aspect of motoring action is while a machine functions as a motor, the conductors are cutting flux and that is exactly what is required for generator action to take place.

This means that even when the machine is working as a motor, voltages are induced in the conductors. This emf is called the back emf or counter emf, since the cause for this is the rotation, which, in turn, is due to the supply voltage. According to Lenz's law, the direction of the back emf opposes the supply voltage.

The back emf is given by the same equation for induced emf of a generator

$$\boxed{E_b = \frac{\phi ZN}{60} \times \frac{P}{A} \text{ Volts}}$$

The applications of different types of DC motors are listed below:

Shunt DC Motors
Owing to the fairly constant speed and medium starting torque of shunt DC motors, they are used in the following applications:
Centrifugal and reciprocating pumps
Lathe machines
Blowers and Fans
Drilling machines
Milling machines
Machine tools

Series DC Motors
Owing to the high starting torque and variable speed of series DC motors, they are used in the following applications:
Conveyors
Hoists, Elevators
Cranes
Electric Locomotives