SAMPLE STUDY MATERIAL

Electrical Engineering

EE / EEE

Postal Correspondence Course

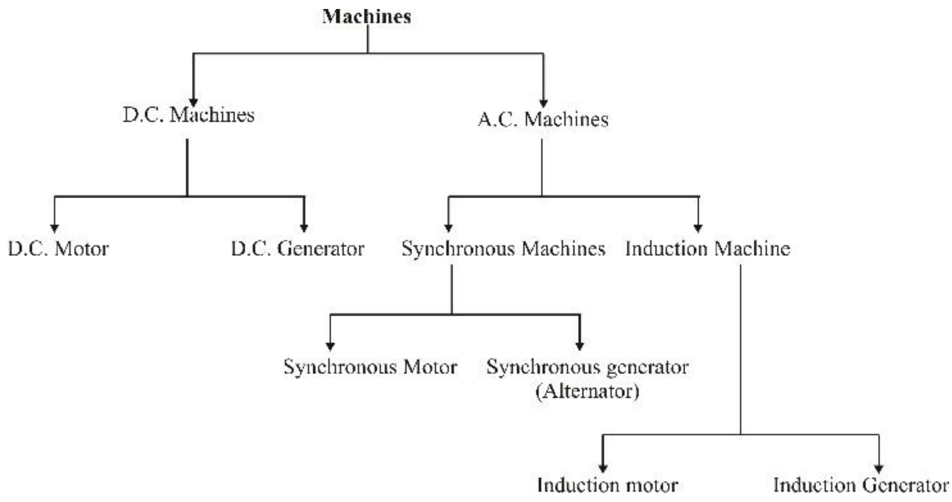
Electrical Machine

GATE, IES & PSUs

CONTENT

INTRODUCTION

Transformer is not a machine. It is a coupled device. Machines are classified as



DC Machines

1. In case of DC Machine armature is placed on rotor.
2. Armature produces A.C. voltage. The slip Brushes convert it to D.C.
3. For a DC Motor, i/p is D.C. voltage, fed through brushes by commutation process when reaches armature becomes A.C. Its o/p is mechanical power.
4. For D.C. generator, i/p is mechanical power fed by a prime mover's, armature produces a.c. which is converted to DC by brushes.
5. DC Machine always works at unity p.f.
6. For D.C. motor Fleming's Left hand rule is used.
7. For DC generator Fleming's right hand rule is used.
8. The DC Machines has problem of commutation. Hence it is seldom used.
9. Separately excited DC machine is a doubly excited M/C.

Synchronous Machines

1. They always rotate at synchronous speed.
2. They are doubly excited machine.
3. The field windings are placed on rotor and supplied by DC voltage source.
4. The induced e.m.f. in armature conductor (*for both motor & generator*) is AC.
5. However for some cases, field is placed on stator & armature is placed on rotor.
6. They are used at large scale like generating power stations.
7. They are not self starting machines.
8. They can work at leading, lagging or at unity p.f.

Induction machines (3 – ¤)

1. They are used predominantly as Induction Motor.
2. They are self starting.
3. They always work at lagging p.f.

4. They are single excited machine.
5. They never rotate at synchronous speed. An Induction motor rotates at a speed less than synchronous speed $(n_r < n_s)$ and for induction generator $(n_r > n_s)$
6. If they are rotated at synchronous speed, the net torque produced will be zero.
7. In Induction motor, armature is placed on rotor and stator has field winding which is stationary.
8. For induction generator, a prime mover is used to rotate the rotor at a speed greater than n_s. Under this condition it acts as induction generator.

CHAPTER-1

DC MACHINES

A. PRINCIPLE OF ELECTROMECHANICAL ENERGY CONVERSION:

- *The meaning of the words electromechanical energy conversion is conversion of electrical energy into mechanical energy or mechanical energy to electrical energy.*
- *The conversion of electrical energy to mechanical energy is achieved by using some type of a motor. An electric energy is applied to a motor. The motor rotates and converts electrical energy to mechanical energy at the shaft as shown in Figur-1(a).*

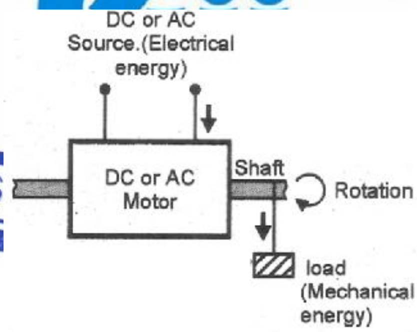


Figure-1(a) : Electrical to mechanical energy conversion

- *Depending on the type of source of electrical energy, the motor can be an AC motor or a DC motor.*
- *Various types of motors available are listed in Figure-1(b).*

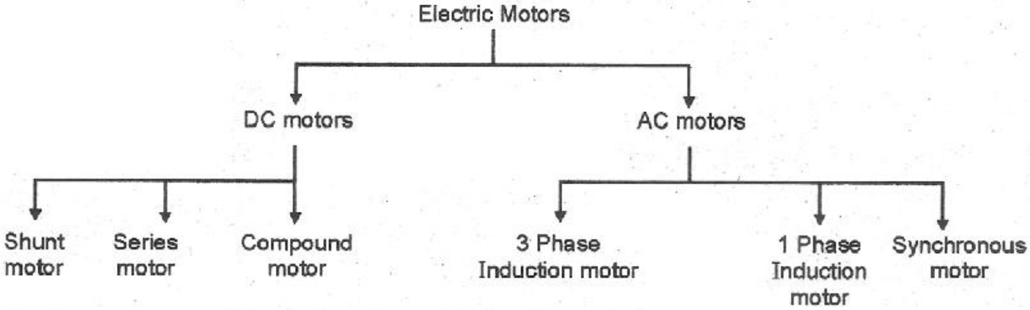


Figure-1(b) : Types of motors

- The motors continuously convert the electrical energy into mechanical energy. But some other devices *are used to produce translational forces. The examples of such devices are solenoids, relays, electromagnets etc.*
- *An electric generator converts the mechanical energy applied at its input to an electrical energy as shown in Figure-1(c).*
- *A prime mover machine is required to be used to rotate the generator mechanically.*

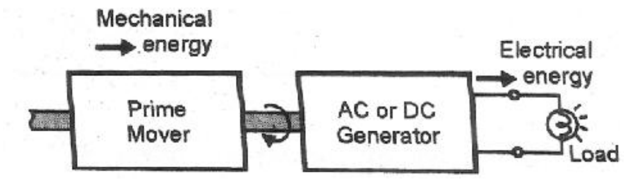


Figure-1(c) : Mechanical to Electrical energy conversion

- *The generators can be AC generators or DC generators. The AC generators are called as alternators.*
- *The block diagram of a general electromechanical conversion system is shown in Figure-2.*

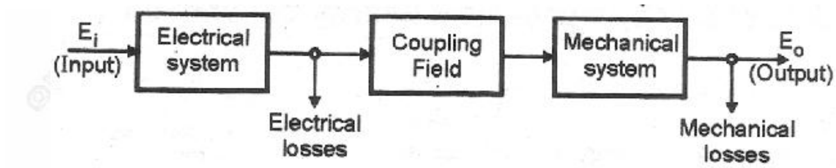


Figure-2 : Electromechanical Energy Conversion

- *The three parts of electromechanical energy conversion devices are:*
  1. *Electrical system*
  2. *Coupling field*
  3. *Mechanical system*
- *The process of electromechanical conversion is a reversible process.*

B. TYPES OF DC MACHINES:

- *DC machines are basically of two types:*
  1. *D.C. generator* 2. *D.C. motor.*
- *A dc generator is rotated by a prime mover and produces a dc voltage. So it converts mechanics energy into electrical energy.*
- *A dc motor receives energy from a d.c. voltage source and rotates at a speed proportional to the applied voltage. So a dc motor converts the electrical energy into a mechanical energy.*

C. WINDINGS IN A DC MACHINE:

- *In any dc machine, (motor or generator) there are two windings:*
  1. *Field winding* 2. *Armature winding*
- *Out of these, the field winding is stationary which does not move at all and the armature winding is a movable winding.*
- *The armature winding is mounted on a shaft. So it can rotate freely.*

- *The construction of a dc generator and dc motor is the same. That means we can use the same dc machine either as a generator or as a motor.*

Connection of windings for operation as generator:

- *The field winding is connected across the dc power supply.*
- *The field winding then produces a magnetic field in the air gap between the armature and field windings.*
- *The armature winding is a rotating winding which is mounted on the shaft. The shaft is mechanically coupled to another machine called prime mover as shown in Figure-3(a).*
- *And the connections of the armature winding are brought out. A load such as electric lamp is connected across the armature winding.*

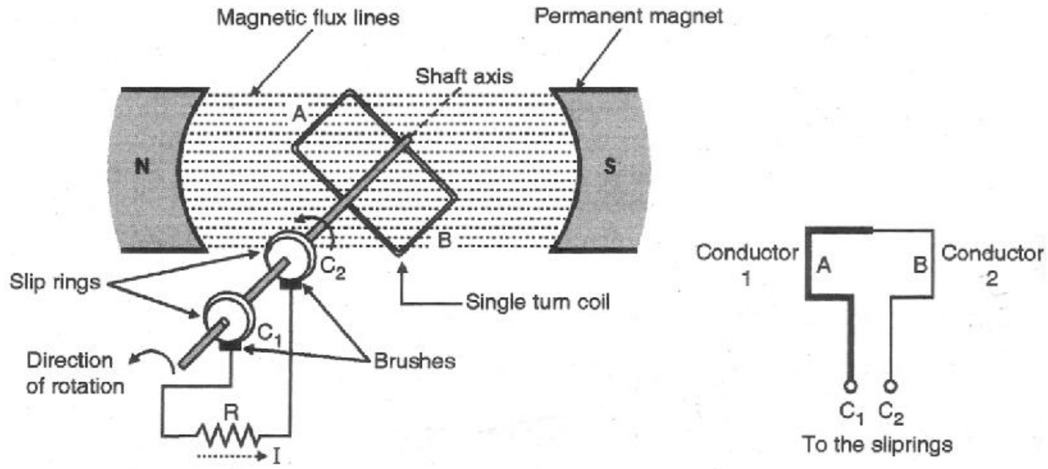
Principle of Operation of a DC Generator:

- *The DC generator operates on the principle of dynamically induced emf in a conductor.*
- *According to this principle, if the flux linked with a conductor is changed, then an emf is induced into the conductor.*
- *In case of a DC generator, when armature winding is rotated by the prime mover, the flux linked with it changes and an emf is dynamically induced into the armature winding.*
- *This is the principle of operation of a generator.*
- *The prime mover can be a water turbine, steam engine, steam turbine or diesel engine etc.*
- *The direction of induced voltage in the armature winding is given by the Fleming's Right hand rule.*

D. SINGLE TURN ALTERNATOR:

Construction:

- *The construction of single turn alternator is shown in Figure-4(a). This alternator consists of a permanent magnet with two poles N and S, and a single turn rectangular coil made up of some conducting material (aluminium or copper).*
- *As shown in Figure-4(b) the single turn coil is made from two conductors A and B. These conductors are connected to each other on one end whereas their other ends (C_1 and C_2) are connected to the slip rings mounted on the shaft.*



(a) A single turn alternator **(b) A single turn coil**

Figure-4

- *The coil can rotate around its own axis in clockwise or anticlockwise directions. The slip rings C_1 and C_2 are connected to the coil.*
- *The slip rings rotate along with the shaft. The brushes do not rotate.*
- *Electrical connections are made to the brushes. As shown in Figure-4(a) a resistance R is connected between the two brushes.*

GENERATION OF AC VOLTAGE:

- *Refer Figure-4(b). This single turn coil is rotated in the anticlockwise direction in the flux produced by the permanent magnet.*
- *Due to rotation, the conductors A and B cut the magnetic lines of flux produced by the permanent magnet.*
- *According to the Faraday's law of electromagnetic induction, an emf is induced into the rotating conductors.*
- *Due to this induced emf, current flows through the external resistance R.*
- *The induced emf in the single turn coil is given by,*

$$e = Blv \sin$$ ¯

- *Hence the shape of the induced voltage and the corresponding positions of the single turn coil are shown in Figure-5.*
- *Thus the single turn alternator produces a sinusoidal voltage.*

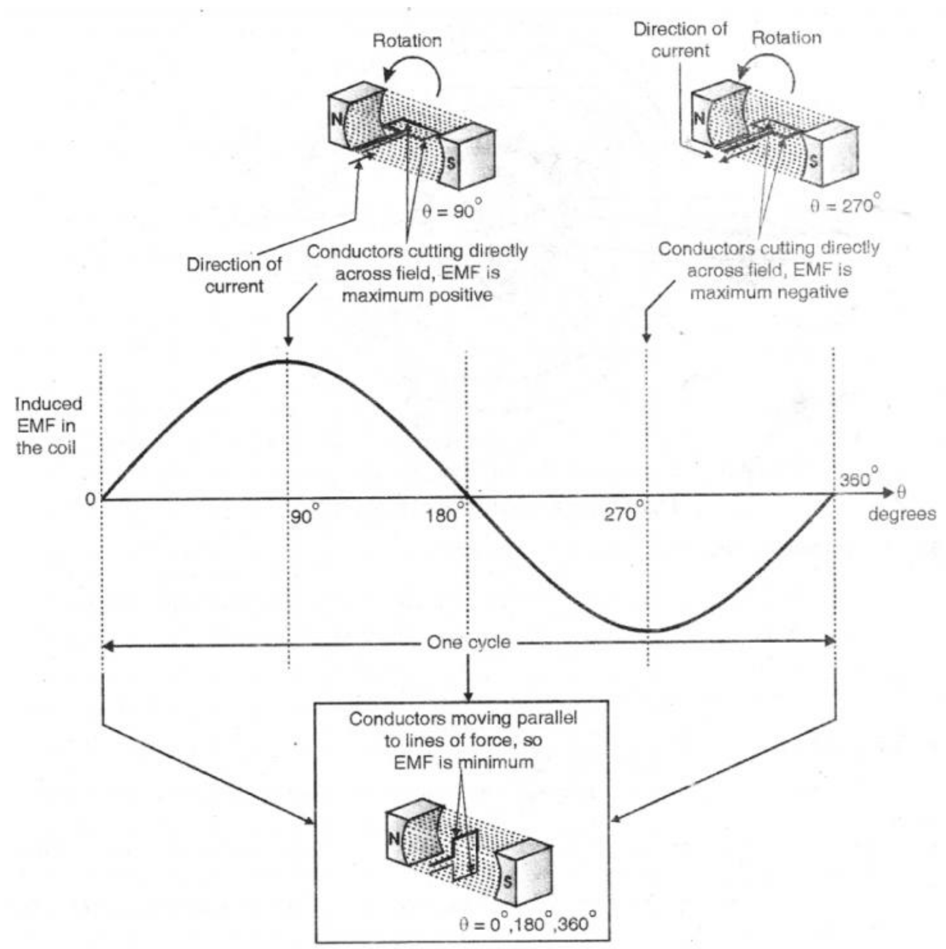


Figure-5: Shape of induced emf and corresponding positions of single turn coil

- **In the practical dc generator also, the alternating waveform is generated internally. It is then rectified to produce the unidirectional DC voltage. This is achieved by replacing** the **slip-rings by a** *commutator*.

E. CONSTRUCTION OF A DC MACHINES:

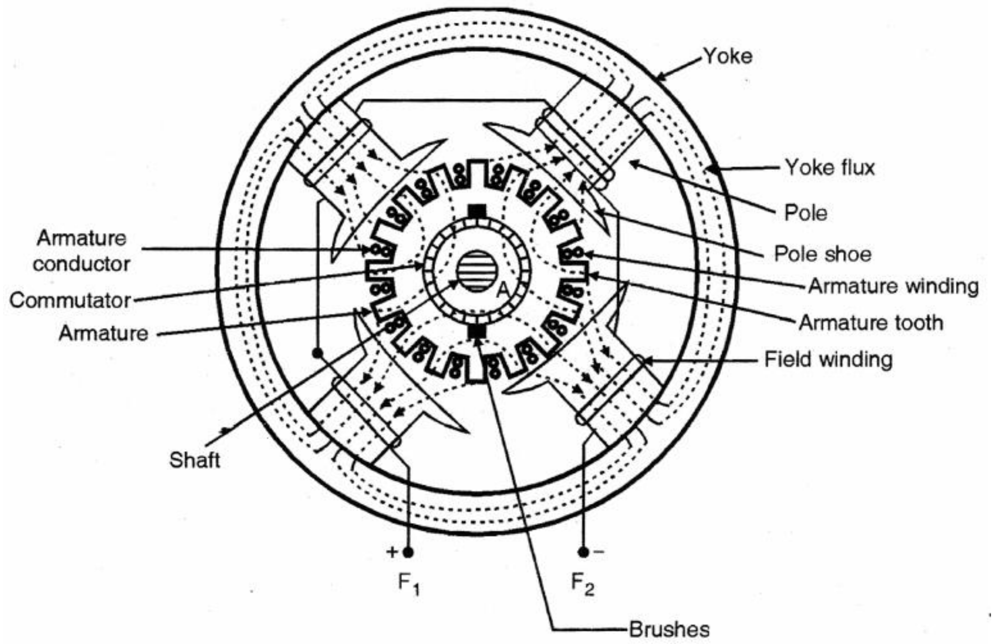


Figure-6 : Construction of a dc generator

1. Important Parts of a DC Generator:

The cross-section of a DC generator reveals that it consists of the following important parts:

- Yoke
- Field winding
- Poles
- Armature
- Commutator, brushes and gear
- Bearings.

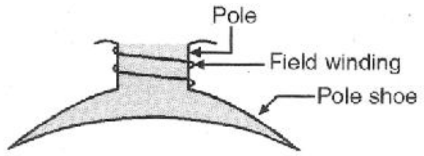
2. Yoke:

The important information about the yoke which acts as the outer cover of a DC machine are as given below:

- Yoke is also called as frame. It provides protection to the rotating and other parts of the machine from moisture, dust etc.
- Yoke is an iron body which provides the path for the flux. This is essential to complete the magnetic circuit.
- It provides the mechanical support for the poles.
- Materials used for yoke are basically the low reluctance materials such as cast iron, silicon steel, rolled steel, cast steel etc.

3. Poles, Pole Shoe and Pole Core:

The important points about the poles are as follows:



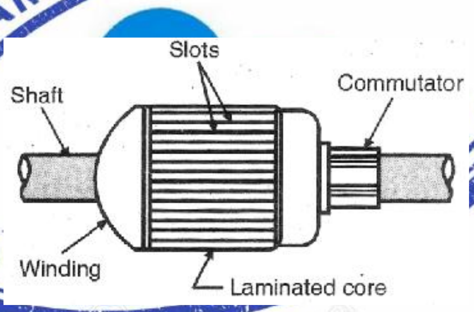
- A pole of a generator is an electromagnet. The field winding is wound over the poles.

- Poles produce the magnetic flux when the field winding is excited.
- Pole shoe is an extended part of a pole. Due to its typical shape, it enlarges the area of the pole.
- Due to this enlarged area, more flux can pass through the air gap to armature.
- A low reluctance magnetic material such as cast steel or cast iron is used for the construction of a pole or pole shoe.

4. Field Winding ($F_1 - F_2$):

- The coils wound around the pole cores are called field coils.
- The field coils are connected in series to form the field winding.
- Current is passed through the field winding in a specific direction, to magnetize the poles and pole shoes. The magnetic flux ¤ is thus produced in the air gap between the pole shoes and armature.
- The field winding is also called as exciting winding.
- The material used for the field conductor is copper.
- Due to the current flowing through the field winding alternate N and S poles are produced which pole is produced at a particular core is decided by the right hand thumb rule for a current carrying circular conductor.

5. Armature Core:



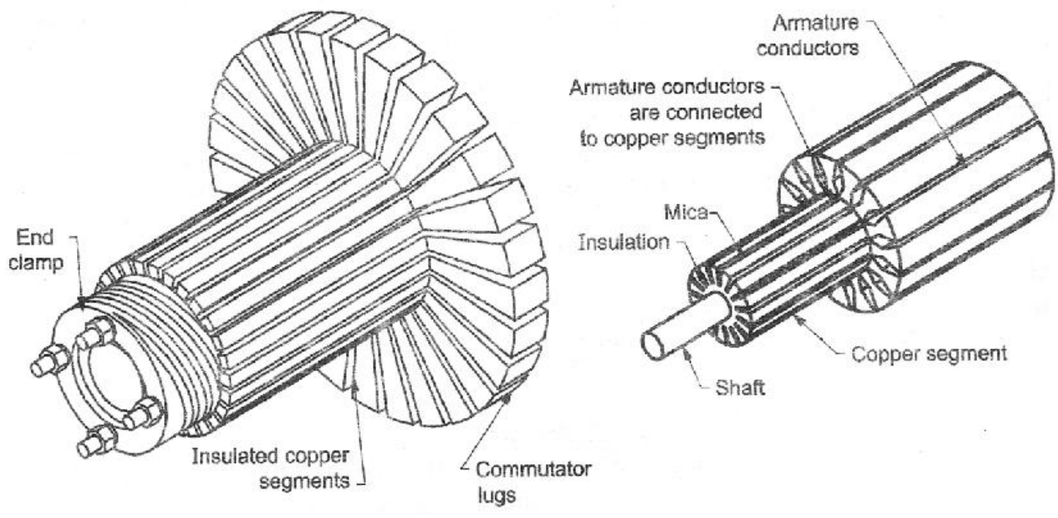
- Armature core is a cylindrical drum mounted on the shaft.
- Armature core provides a low reluctance path to the flux produced by the field winding.
- High permeability, low reluctance materials such as cast steel or cast iron are used for the armature core.
- The air holes are provided for the air circulation which helps in cooling the armature core.
- The laminated construction is used to produce the armature core to minimize the Eddy current losses.

6. Armature Winding:

- The armature conductors made of copper are placed in the armature slots present on the periphery of armature core.
- Armature conductors are interconnected to form the armature winding.
- Armature winding is connected to the external circuit (load) through the commutator and brushes.
- Armature winding made up of copper.

7. Commutator:

The construction of a commutator is as shown in Figure-7.



(a) Commutators (b) Rotor of a DC Machine

Figure-7 : Construction of a Commutator

- **A commutator is a cylindrical drum mounted on the shaft along with the armature core.**
- **It is made of a large number of wedge-shaped segments of hard-drawn copper.**
- **The segments are insulated from each other by thin layers of mica.**
- **The armature winding is tapped at various points and these tappings are successively connected to various segments of the commutator.**

Functions of a commutator:

1. **It converts the alternating emf generated internally in a d.c. voltage. So it basically works** *like a* **rectifier.**
2. **It collects the current from the armature conductors and passes it to the external load via-**brushes.
3. **For dc motors, it helps to produce a unidirectional torque.**

8. Brushes:

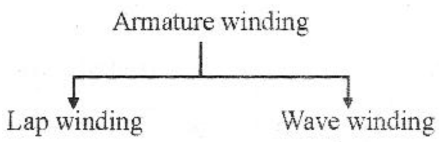
- **Current is conducted from the armature to the external load by the carbon brushes which are held against the surface of commutator by springs.**
- **Brushes wear with time. Hence they should be inspected regularly and replaced occasionally.**

Function of brushes:

To collect current from the commutator and apply it to the external load.

F. **TYPES OF ARMATURE WINDINGS:**

- **Armature conductors are connected together in a specific manner to construct the armature winding. The manner in which the armature conductors are connected depends on the requirements of an application.**



1. Lap Winding:

For lap winding the number of parallel paths is exactly equal to the number of poles P.

$$A = P$$

The lap winding is useful for low voltage high current machines:

- **Due to the existence of a large number of parallel paths, the lap wound armature winding is capable of supplying larger load currents.**
- **But these generators are capable of generating low voltages.**

In lap winding the armature conductors are divided into P groups. All the conductors in a group are connected in series and all such groups are connected in parallel.

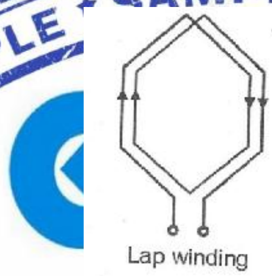


Figure-8(a) : Simplified diagram of Lap winding

2. Wave Winding:

This type of winding will create only two parallel paths irrespective of the number of poles.

∴ Number of parallel paths (A) = 2

Wave winding is useful for high voltage low current machines:

- **Note that the number of parallel paths for wave winding will be less than that for lap winding.**
- **Hence this winding does not have the capability of supplying larger load currents. So the generators with wave winding are of low current ratings. But these generators are capable of producing high voltage.**
- **Thus in wave winding, all the conductors are connected in series to form a single closed circuit.**

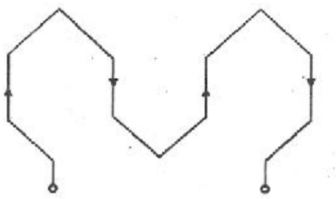
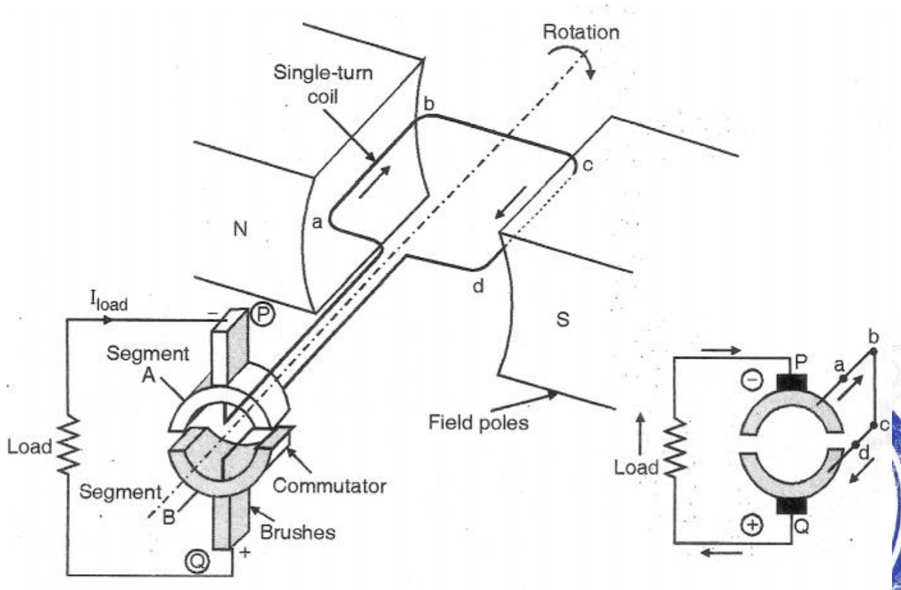


Figure-8(b): Simplified diagram of wave winding

G. ACTION AND ROLE OF COMMUTATOR:

1. Action of Commutator:



(a) DC generator with simplified commutator (b) Simplified construction

Figure-9

- We know that the emf induced into the rotating conductor is always sinusoidal. The commutator is used to convert it into a unidirectional (dc) emf.
- The action of commutator is as follows:
  - Refer Figure-9(a) which shows a single turn dc generator, with the commutator in its simplest form.
  - We assume that the commutator has been divided only into two segments namely segments A and B.
  - The simplified construction is shown in Figure-9. The commutator segments A and B are connected to the brushes P and Q respectively.
  - Commutator segments, A and B are connected to conductors "ab" and "cd" respectively and rotate together.

Operation:

- Refer Figure-9(a). According to Fleming's right hand rule, the induced current in coil "ab" and "cd" is as shown.
- Hence brush P becomes negative and Q becomes positive as shown in Figure-9(b).
- The current I_{load} through external load resistance R_L flows from bottom to top as shown in Figure 9(b).

After half rotation

- **After half the rotation, the segments A and B of the commutator will change their positions as shown in Figure-10(b). So brush P is in contact with segment B and Q is in contact with segment A.**
- **The directions of currents induced in conductors "ab" and "cd" are reversed as shown in Figure-10(b)**
- **Hence brush P continues to be negative and Q continues to be positive.**
- **Hence the current through the external load continues to flow from bottom to top as shown in Figure-10(a).**
- **Thus the load current and load voltage has become unidirectional.**

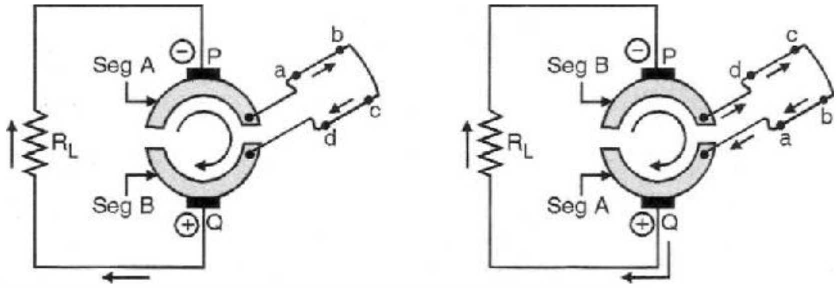


Figure-10 : (a) Initial equivalent circuit (b) Equivalent circuit after half rotation

2. Role of Commutator:

- **As discussed in the previous section, the load voltage (voltage across R_L) is unidirectional.**
- **Thus the commutator converts the alternating voltage produced by the single turn alternator into a DC voltage.**
- **Thus a commutator operates as a rectifier which converts the ac voltage to DC voltage.**
- **For DC motors, it helps to produce a unidirectional torque.**

H. E.M.F. EQUATION OF A DC GENERATOR:

- **When a mechanical device, such as a diesel engine drives the armature drum, armature winding cuts the magnetic flux produced by the pole. An equation for e.m.f. induced can be obtained as under.**

  Let P = number of poles of the generator.

  ¤ = flux produced by each pole, Wb.

  N = speed in r.p.m. at which the generator is driven.

  Z = number of conductors of armature winding.

  A = number of parallel paths of armature winding.

- **Then according to Faraday's law of induction, magnitude of e.m.f. induced in a conductor is,**

$$E = \frac{d¤}{dt} \qquad ......(1)$$

- **For one complete revolution of a conductor, the flux cut by the conductor is ($P¤$)Wb and time required to complete one revolution is (60/N) seconds. Therefore, Equation(1) may be written as,**

$$E = \frac{P¤}{(60/N)} = \frac{P¤N}{60} \qquad \ldots\ldots(2)$$

- **As Z conductors are divided in A parallel groups, there are $\frac{Z}{A}$ conductors in series in each group. Therefore e.m.f. induced in the total armature winding is,**

$$\boxed{E = \frac{P¤N}{(60)} \cdot \frac{Z}{A}} \qquad \ldots\ldots(3)$$

- **Equation (3) is the e.m.f. equation of a dc generator.**

Solved Examples:

Example : The armature of a 6 pole generator has 120 slots, each slot carrying 30 conductors. The armature winding is lap wound and flux developed by each pole is 0.02 Wb. The generator is driven at 1000 r.p.m. Calculate e.m.f. induced in the generator.

Sol. **Number of conductors Z = (120 × 30) = 3600, Due to lap winding A = P = *6***

$$\therefore\ E = \frac{¤ZNP}{60A} = \frac{0.02\times(120\times30)\times1000\times6}{60\times6} = 1200V \quad \textbf{Ans.}$$

Example : A 480 V dc generator has **4** poles and armature drum has **96** slots, each carrying **10** conductors. When flux per pole is 25.2 mWb, e.m.f. induced in the wave connected armature winding is 484 V. Determine the speed at which the generator is driven. If current carrying capacity of armature conductors is 1.3 A, what is the kW rating of the generator?

Sol. : *Given:* **Number of slots = 96, Number of conductors/slot =10.**

$$\therefore\ Z = 96\times10 = 960, \qquad A = 2(\text{Due to wave winding})$$

$$¤ = 25.2\,mWb, \qquad E = 484V,\ P = 4$$

Speed of the generator (N):

$$N = \frac{60AE}{¤ZP}$$, where, A = 2, being wave connected.

$$= \frac{60\times2\times484}{0.0252\times960\times4} = 600\,r.p.m \qquad \ldots\ldots\textbf{Ans}$$

kW rating :

The 960 conductors of armature winding are divided into two parallel paths. Obviously, current
carrying capacity of each path is 1.3 A i.e. current rating of the generator is (1.3 + 1.3) = 2.6 A

$$\therefore\ \textbf{kW rating of the generator} = \frac{480\times2.6}{1000} = 1.25\,kW \qquad \ldots\ldots Ans$$

Ex. : Determine the flux per pole of a six pole generator required to generate 240 V at 500 **r.p**.m. The armature winding has 1080 conductors and are lap connected.

Sol. :

Given; **E = 240 V, P = 6, N = 500 rpm, Z = 1080, lap winding, so A = P = 6.**

We know that, $E = \dfrac{P\phi NZ}{60A}$

$$\therefore \phi = \frac{60AE}{ZNP} = \frac{60 \times 6 \times 240}{1080 \times 500 \times 6} = 26.27\,mWb \qquad ......Ans$$