UNIT 2.1 DC GENERATOR

OBJECTIVES

After completing this unit, you will be able to:

- understand the working principle of DC generator
- appreciate the construction of DC generator
- define the EMF equation of a generator
- define and appreciate commutation of DC machine
- identify types of DC generators and their characteristics

STRUCTURE

1. INTRODUCTION

A machine, which converts mechanical energy into electrical energy, is called a Generator. This energy conversion is based on the dynamically induced emf. According to the Faraday's law of electromagnetic Induction, an induced emf is produced in the conductor which cuts the magnetic flux. This emf causes a current to flow in the conductor if its circuit is closed.
Hence the basic essentials for an electrical generator are: -
(i) Magnetic field;
(ii) Conductor or conductors and;
(iii) Relative motion between magnetic field and conductors.

2. CONSTRUCTIONAL DETAILS OF A DC GENERATOR

Here we are dealing with a DC generator. But there is a good similarity with a DC motor also as far as construction is concerned.
The following are the main parts of a DC generator:

- Yoke
- Pole core or pole shoes
- Field coils
- Armature core
- Armature winding
- Commutator
- Brushes and bearings

2.1 YOKE OR MAGNET FRAME

This is the outer part of the DC generator. It provides the mechanical supports for the poles and acts as a protecting cover for the whole machine. It carries the magnetic flux produced by the poles. Yokes are made out of cast iron or cast steel. The modern process of forming the yoke consists of rolling a steel slab round a cylindrical mandrel and then welding it at the bottom. The feet and the terminal box etc. are welded to the frame afterwards. Such yokes possess sufficient mechanical strength and have high permeability.

2.2 POLE CORE OR POLE SHOES

The field magnet consists of pole cores and pole shoes. The pole shoes serve two purposes.
(i) They spread out the flux in the air gap and also being the larger cross section reduced the reluctance of the magnetic path.
(ii) They support the exciting coils.

2.3 FIELD COILS

The field coils or pole coils, which consist of copper wire, are former-wound for the current dimension. Then the former is removed and the wound coil is put into place over the core.

2.4 THE ARMATURE CORE

It houses the armature conductors or coils and causes them to rotate and hence cut the magnetic flux of the field magnets. Its most important function is to provide a path of very low reluctance to the flux through the armature from North Pole to South Pole. It is laminated to reduce the loss due to eddy currents. Thinner the lamination, greater will be resistance offered to the induced emf and hence smaller the current. And thus the loss is also small.

2.5 ARMATURE WINDINGS

It is generally former wound. These are first wound in the form of flat rectangular coils and then are pulled into their proper shape in a coil puller.
Two types of windings are mainly used - namely lap winding & Wave winding.

2.5.1 Lap winding

In lap winding finish end of one coil is connected to a commutator segment and to the start end of the adjacent coil situated under the same pole and similarly all coils are connected. Since the successive coils overlap each other and hence the name (Ref. fig.1).

2.5.2 Wave winding

It is also called as series winding. In this winding, the coil side is not connected back but progresses forward to another coil sides. In this way the winding progresses, passing successively every N pole and S pole till it returns to coil side from where it was started. As the winding shape is wavy, the winding is, therefore, called wave winding (Ref. fig.2).

2.6 COMMUTATOR

The commutator, whose function is to facilitate the collection of current from the armature, is cylindrical in structure, built up of segments of high conductivity, hard drawn copper insulated from one another by mica sheets. It also converts alternating current into unidirectional current (DC).

2.7 BRUSHES&BEARINGS

The function of brushes is to collect current from the commutator. These are rectangular in shape, made of carbon normally. These brushes are housed in brush holder usually of the box type variety.

Generally ball bearings are employed due to their reliability but for heavy duty, roller bearings are also used. The balls and rollers are generally packed in hard oil for quieter operation. Sleeve bearings are also used where low wear is required.

3. E.M.F. EQUATION OF A GENERATOR

Generated E.M.F, E = $P\phi ZN/60A$ Volts
Where, P = No. of poles.
ϕ = Flux per pole in Wb (Weber)
Z =Total nos. of conductors.
N = r.p.m.
A = nos. of parallel paths in Armature.
(A = 2 for wave winding & A = P for lap winding)

4. PRINCIPLE OF OPERATION

The principle of electro-magnetic induction, discovered by Faraday, states that when a conductor is moved across a magnetic field so as to cut the lines of force, electro-motive force or E.M.F. measured in volts, is generated across the conductor. Thus, if an open loop or wire is made to rotate between the poles of a permanent magnet, as shown in fig.3 and fig.4, there will be a tendency for electricity to flow through the wire. The magnitude of this EMF or voltage, depends on the speed of rotation, and on the strength of the magnet, i.e. "the magnetic flux".

The direction of voltage generated in a conductor depends on the direction of the motion of the conductor across a magnetic field and the direction of the field itself. Since the magnet has two poles, two conductors can be connected together in series to form a loop and their voltages will be additive. Several loops can be joined together to form a coil having a number of turns, all the voltages being added together. For each half revolution, embracing one complete pole, the voltage will start from zero, rise to a maximum and fall to zero again. For the remaining half revolution a similar series of events will occur, but the direction of the voltage is reversed. This very simple form of alternating current (A.C.) generator is shown in fig.3.

To change this primitive machine into a direct current (D.C. generator) fig.4, it is necessary to introduce a commutator. In order to attain constancy of direction, the ends of the loop, instead of being connected to slip rings, are connected to a split metal ring, the two halves being insulated from each other. By placing the collecting brushes (C & D) on the commutator in such a position that the voltage induced in the loop is zero when the brushes change from one segment to the other voltage at the brushes will be uniform in direction, although it will still be alternating, commutator simply alters the connection of the loop to the external circuit at the instant when the induced electromotive force changes in direction.

If the loop of wire is closed by connecting the brushes (C&D) to an external resistance(R), which represents the 'load' imposed on the machine, electric current will flow through the loop and the resistance (R). In practice, the amount of current, which flows, is measured in amperes (amps). The magnitude of the current, which will flow through the circuit, depends on the voltage generated and on the value of the joint resistance of the loop of wire and the external resistance. Voltage, which the machine is capable of developing at the certain speed and with a magnet of the given strength, the current flow, measured in volts, divided by the total resistance of the circuit, measured in ohms.

If the loop of wire be rotated in one direction, the current will flow in the wire under the south pole (S), in the direction of the arrow, that is, away from the brush (C), and then in the wire under the north pole (N) towards the brush (D). From the brush (D), it will go to the external circuit and then back to the brush (C); thus completing the electric circuit. After rotating such that the position of the segments is reversed, it will be noticed that the picture remains identical and therefore the current flow will be in the same direction.

Although the primitive direct current generator, so far described, produces a uni-directional current flow, it is obvious that for each revolution of the coil the induced current will start from zero value, rise to a maximum value, fall to zero then rise to a maximum value again and finish at the zero point from which it started. However, by increasing the number of coils and spreading them out evenly, the flow of current can be made very nearly constant. This also means that there would be an increased number of segments in the commutator in proportion to the increased number of coils. In practice, a direct current generator has many coils consisting of insulated copper wire or strip, and in order to concentrate the magnetic flux where it is required, they are embedded in slots in a soft-iron laminated cylinder. This assembly is called the armature.

The permanent magnet of the original example is replaced by an Electro-magnet having many poles wound with insulated copper wire; these are field coils and are referred to as the field system. The field strength, or excitation, depends upon the number of turns of wire on each pole and on the magnitude of current flowing through the wire.

From this it can be seen that there are two ready means of regulating the output of the generator; one by varying the speed of rotation of the armature and the other by altering the magnetic strength of the field system. The variation of speed of rotation is readily obtained by varying the governor setting on the diesel engine, which drives the armature, and by inserting variable resistance in the field system, the amount of current flowing through the coils of the Electro-magnets can be varied.

In a diesel locomotive, the driver of the locomotive makes these adjustments, as required, by moving his control handle, thereby simultaneously affecting engine speed and generator excitation. The main generator frame is coupled directly to the diesel engine flywheel casing. The armature is of the single bearing type, that is to say, one end of the shaft is coupled to the engine flywheel, and the other end is supported in a roller bearing, housed in an end plate bolted to the generator frame. The main generator is self ventilated, having its own fan which draws air through the machine so as to cool the windings and maintain them at a safe working temperature.

5. COMMUTATION

We have seen that current induced in the armature conductors of a DC generator is alternating and to make it unidirectional in the external circuit we use commutator. Also the flow of direction of current in the conductor envisages as the conductor's position changes from one pole to another i.e. as conductors pass out of the influence of a `N' pole and other that of a `S' pole the current in them is reversed. This reversal of current takes place along the Magnetic Neutral Axis (MNA).

Thus, commutation is a group of phenomena related to current reversal in the conductors of an armature winding when they place through the M.N.A. where they are short-circuited by the brushes placed on the commutator.

Commutation is said to be good if there is no sparking between the brushes and commutator when current reversal in the coil section takes place. Contrary to that, it is said to be poor if there is sparking at the brushes during current reversal in the coil section.

6. TYPES OF GENERATORS

In accordance with the method of excitation D.C. generators are divided into two categories -

1. Separately excited Generator
2. Self excited generators.

Since the separately excited generators have limited application we look forward for self-excited generators.
Generators with self-excitation can be divided according to the way of the field winding connection into following categories-

1. Shunt-excited generators
2. Series excited generators and,
3. Compound-wound generators

7. CHARACTERISTICS OF GENERATOR

There are 3 important characteristics of a DC generator.

1. Open circuit characteristic (O.C.C.)
2. External characteristic or load characteristics
3. Internal characteristic or total characteristic

7.1. O.C.C. or NOLOAD CHARACTERISTIC

It represents the relation between generated E.M.F. and field current. I_f. It is practically the same for all types of generator whether they are self-excited or separately excited.

7.2. EXTERNAL OR LOAD CHARACTERISTIC

It is a curve representing the relation between the terminal voltage V and the load current I_L.

7.3. INTERNAL OR TOTAL CHARACTERISTIC

It is a curve, which represents the relation between the generated EMF.(Eg.) and armature current I_a.

7.4. CRITICAL RESISTANCE

The value of that resistance due to which field resistance line becomes tangent to the O.C.C. curve is called critical resistance.

8. SUMMARY

Necessary informations regarding operating principle, constructions, characteristic of DC generators have been given in this unit. These informations will help in maintaining the machines to ensure reliability and their trouble free functioning. Some informations have been given about commutation of DC machines, which would prove to be important to understand behaviour of DC machines. Sketches and diagrams have been included in this unit to understand the block with more practical and systematic approach.

9. SELF-ASSESSMENT EXERCISES

1. Name different components of a dc generator and describe their functions.
2. State the EMF equation of a generator and mention detail names of different symbols.
3. Explain the commutation process of a dc machine with necessary diagrams.

UNIT 2.2 DC MOTORS

OBJECTIVES

After completion of this unit, you should be able to:

- understand the working principle of DC motor
- appreciate the construction of DC motor
- define the speed equation
- understand characteristics of DC motors
- appreciate brush grades and their selection criteria

STRUCTURE

1. Introduction
2. DC motor and its principle of operation
3. Back emf.
4. Types of DC motors
5. Speed equation
6. Speed control
7. Characteristic of DC motors
8. Constructional details of DC motor
9. Heating and cooling
10. Rating of DC motor
11. Summary
12. Self-assessment exercises

1. INTRODUCTION

A motor is a mechanism by which electrical energy is converted into mechanical energy. Its operating principle is the reverse of a DC generator. When a coil, carrying current, is placed in a magnetic field, it experiences forces, which turn it about in a direction perpendicular to both the field and current. Thus the motor armature placed inside the magnetic field gets motion, converting electrical energy to mechanical.

2. DC MOTORS – Principle of operation

A motor is a mechanism by which electrical energy is converted into mechanical energy. Both in principle and design, a DC motor is the reverse of a DC generator.

A steady current is passed through the armature coil from the commutator and the brushes are so arranged as to reverse the current every half revolution. When a coil, carrying a current, is placed in a magnetic field, it experiences forces, which turn it about in a direction perpendicular to both the field and the current. Due to the rotating torque the motion of rotation will not be continuous, unless the direction of the current is reversed each half revolution with the help of a split ring commutator (in a 2-pole machine).

The electric motor is fundamentally similar to the primitive form of D.C. generator described earlier and is based on the fact that, if a "loop of wire". If it is supplied, through its commutator, with electric current from a battery or any other source of direct current (D.C.) supply, the loop will rotate.

If the brushes of the machine were connected to the terminals of a primary cell, instead of being connected to load R, the "loop of wire "would rotate. A greatly enhanced performance would be obtained by having an iron core on this loop, a further improvement would be to have many loops, another to have increased pole area, and a still further improvement would be obtained by having electromagnets instead of permanent magnets.

When used for traction, the direct current electric motor is usually of the series wound type, that is, the current, which passes through the armature also, passes through the field coils. The reason for this is that a motor having this particular type of winding has characteristics eminently desirable for traction work, its torque being proportional to the current flow, multiplied by the magnetic strength of the field system. The series wound motor is capable; therefore, of producing a high torque when the vehicle is started, and also has the advantage that as the load increases its speed drops.

The direct current traction motor can be considered as having the following major parts;

1. The Electro-magnetic system consisting of the frame with pole pieces, the field windings and brush gear.
2. The reduction gears between the armature shaft and the road wheels, together with the

gear case, which protects the gear wheels and holds the gear lubricant.
3. The axle bearing where the traction motor frame rests on the axle of the vehicle, this arrangement maintains a constant.
4. The nose suspension arrangement prevents the frame of the motor from rotating round the axle of the vehicle, The nose is spring borne on a bogie cross member.

3. BACK EMF

Due to the rotation of the armature coil (i.e. a conductor) in the magnetic field, the motor works as a DC generator and induced e.m.f acts in the circuit, which opposes the current. This induced e.m.f is called back e.m.f.

4. TYPES OF D.C.MOTORS

Like DC generators, DC motors are also of 3 types-
(i) Series wound motor,
(ii) Shunt wound motor and
(iii) Compound wound motor.

5. SPEED EQUATION

We know that back e.m.f. is produced by the generator action of the motor
Hence back e.m.f. E = $P\phi ZN / 60A$, where symbols have their usual meanings.
Let V be the applied voltage and I_a and R_a is the armature circuit current and resistance respectively.
Then E $= V - I_a R_a$

$$P\phi ZN / 60A = V - I_a R_a$$

Or N = $(V - I_a R_a) \times 60A / P\phi Z$

Or N $\propto (V - I_a R_a) / \phi$ since P Z & A are constants. for a particular motor.

Or N $\propto V / \phi$, Since I_a R_a drop is very small as compared to the applied voltage V.

Or N $\propto 1/\phi$, if applied voltage V is constant.
Hence speed is inversely proportional to flux / per pole if the applied voltage is constant.

6. SPEED CONTROL OF DC MOTOR

We know that, N = $(V - I_a R_a)/\phi$
From this formula it follows that the speed of a D.C. motor can be regulated by:
(i) varying the supply mains voltage V
(ii) Varying the voltage drop in the armature circuit I_a R_a
(iii) Varying the field flux

Methods

(ii) & (iii) are possible in any installation with constant supply voltage. But the first method is possible only in special installation; that permits the control of the supply voltage.

7. CHARACTERISICS OF D.C.MOTORS

There are three important characteristics of a D.C motor, which are given below: -
(Ref. Attached figures)

(i) Torque - Armature current characteristics

This shows the relation between mechanical torque developed and armature current.

(ii) Speed- Armature current characteristics

As the name indicates, it relates speed with armature current.

(iii) Speed - Torque characteristics

The characteristics curve gives the relation between speed and torque of a DC motor.

8. CONSTRUCTIONAL DETAILS OF DC MOTOR

8.1 INTER POLES

In addition to the main field coils of a motor being in series with the armature, there are also the coils of a smaller system of field magnets known as inter-poles. On generators with separately excited main fields, the inter-pole coils are in series with the armature.

The inter-poles are smaller than the main poles of either a generator or motor, but are the same length and positioned alternatively with the main poles. In a generator the polarity of an inter-pole is the same as the main pole ahead of it according to the rotational direction of the armature. The polarity of an inter-pole in a motor is the same as the main pole proceeding it. An electrical machine with no inter-poles would have some magnetically neutral regions between its pole-pieces. When a coil of the armature reaches a position during its rotation in the neutral region, its connections are short-circuited with the connection of the armature coil in advance, because in this position the commutator brushes will be in contact with both of their corresponding commutator segments. The purpose of the inter-poles, being situated in the neutral regions, is to induce a current in the short-circuited armature windings, which flows in the same direction as the current, which will flow when it has left the neutral region.
The use of inter-poles also serves to prevent the distortion of the main field of the generator by the reaction of the armature field, and thereby prevents the induction of Electro-motive forces into coil sides, which are being short- circuited by the brushes.

In small machines the need for inter-poles is not important but on large generators and motors the net effect of the inter-poles is to improve the commutation. Ideally there should be no sparking of the brushes on the commutator surface, although this is often difficult to achieve in practice.

9. HEATING AND COOLING

Every electrical machine is a power (or energy) conversion device. During these power conversion some of the energy is wasted. In electrical machines the loss in energy occurs in electrical circuits and in portions of magnetic circuits also. There are also frictional losses in the dynamic parts of the machines. These losses are converted in the form of heat energy, which increases, or tends to increase the temperature of iron and copper above that of the ambient temperature, which in turn effects the winding insulation. In addition to the effect it has on the insulation, an excessive temperature rise may also adversely influence the mechanical operating conditions of a given machine part. Thus, for example the original dimension of the commutator may change. Solder between the commutator and windings may get washed out. So to avoid all these, it is very essential to provide a cooling system on machines.

In most cases, the cooling is done by air currents. The cooling of machines by air streams is called ventilation. The ventilation employed depends on the environmental conditions of the place where the machine is to operate.

According to the method of ventilation employed, the following types of machines are distinguished: -

(i) Machines with natural ventilation.
(ii) Machines with internal self-ventilation.
(iii) Machines with external self-ventilation.
(iv) Machines with independent ventilation.

Enclosures have got the direct bearing with the ventilation. The following are the main types of enclosures: -

(i) Open pedestal
Rotor and stator windings are in free contact with the surroundings.
(ii) Open end Bracket
Rotors and stator windings are in contact with surrounding through openings.
(iii) Protected (formerly called semi-enclosed)
Openings in the frame are protected with wire, perforated covers etc.
(iv) Drip proof
Opening so constructed that no solid or liquid particles falling at an angle greater than 15*0* will enter the machine.
(v) Splash proof
Similar to drip proof but the angle of approach is 100^{O} from vertical.

(vi) Duct or pipe ventilated
Air for ventilation enters and emerges through a pipe through the openings.
(vii) Totally enclosed
Exchange of air throughout side and inside of the machine is prohibited.
(viii) Water proof
The machine is totally enclosed so as to exclude water applied as a stream as specified.
(ix) Flame proof
It is designed normally for mines.
(x) Resistant
Machine is so constructed, that it will not be harmed easily by moisture fume, alkali etc.
(XI) Submersible
So constructed that it will work when submerged in water under specified condition of pressure and time.

10. RATINGS

There are three types of ratings as specified.
(i) Continuous Rating: This is an output, which a machine delivers continuously without exceeding the permissible temperature. It can deliver 25% overload for two hours.
(ii)Continuous maximum Rating: This is similar to continuous rating but not allowing overload.
(iii) Short time ratings: This is an output which a machine can deliver for a specified period (say 1 hr 1/2 hr, 1/4 hr etc) without exceeding the maximum temperature rise limit.

11. SUMMARY

Informations regarding operating principle, construction, characteristic and selection of carbon brushes for DC motors have been given in this unit. These informations will help in maintaining the motors to ensure reliability and their trouble free functioning. Sketches and diagrams have been included in this unit to understand the unit with more practical and systematic approach.

13. SELF-ASSESSMENT EXERCISES

1. Describe and mention the speed equation of a dc motor.
2. What are the different types of cooling arrangements of DC motors?
3. What do you mean by rating of a motor? What are the types of ratings?