Chapter 26

DC GENERATORS

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Working Principle

An **electrical generator** is a machine which converts mechanical energy into electrical energy. The energy conversion is based on the principle of the production of dynamically induced emf, where a conductor cuts magnetic flux, dynamically induced emf is produced in it according to Faraday's Laws of electromagnetic Induction. This emf causes a current to flow if the conductor circuit is closed. Hence, two basic essential parts of an electrical generator are (*i*) **a magnetic field** and (*ii*) **a conductor or conductors** which can so move as to cut the flux.

The following figure shows a single-turn rectangular copper coil rotating about its own axis in a magnetic field provided by either permanent magnets or electromagnets. The two ends of the coil are joined to two **slip-rings** '*a*' and '*b*' which are insulated from each other and from the central shaft. Two collecting brushes (**of carbon or copper**) press against the slip-rings. Their function is to collect the current induced in the coil and to convey it to the external load resistance *R*. The rotating coil may be called '**armature**' and the magnets as '**field magnets**'.

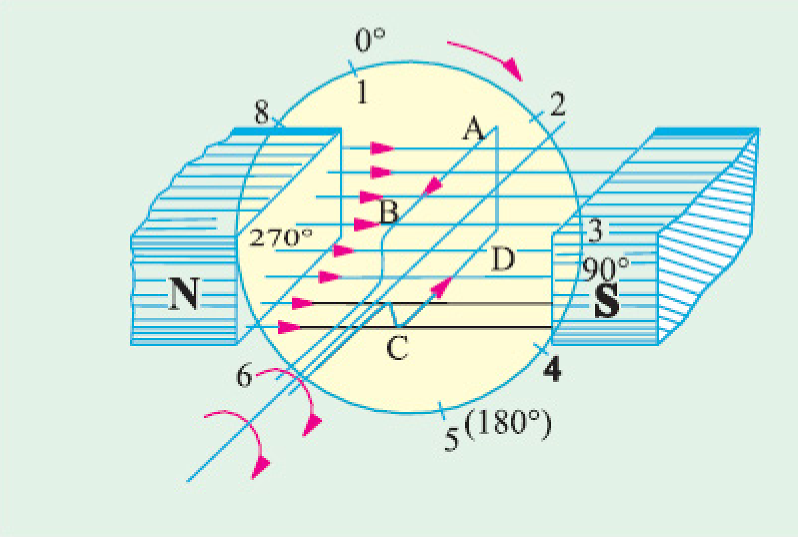


Fig. 26.2

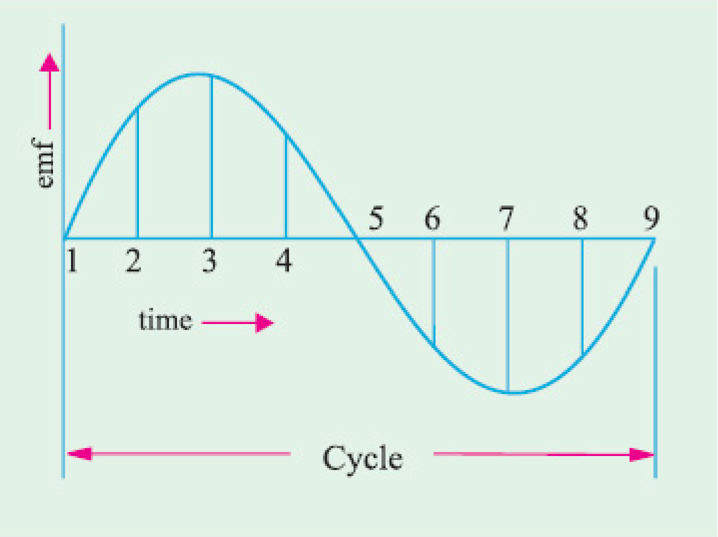


Fig. 26.3

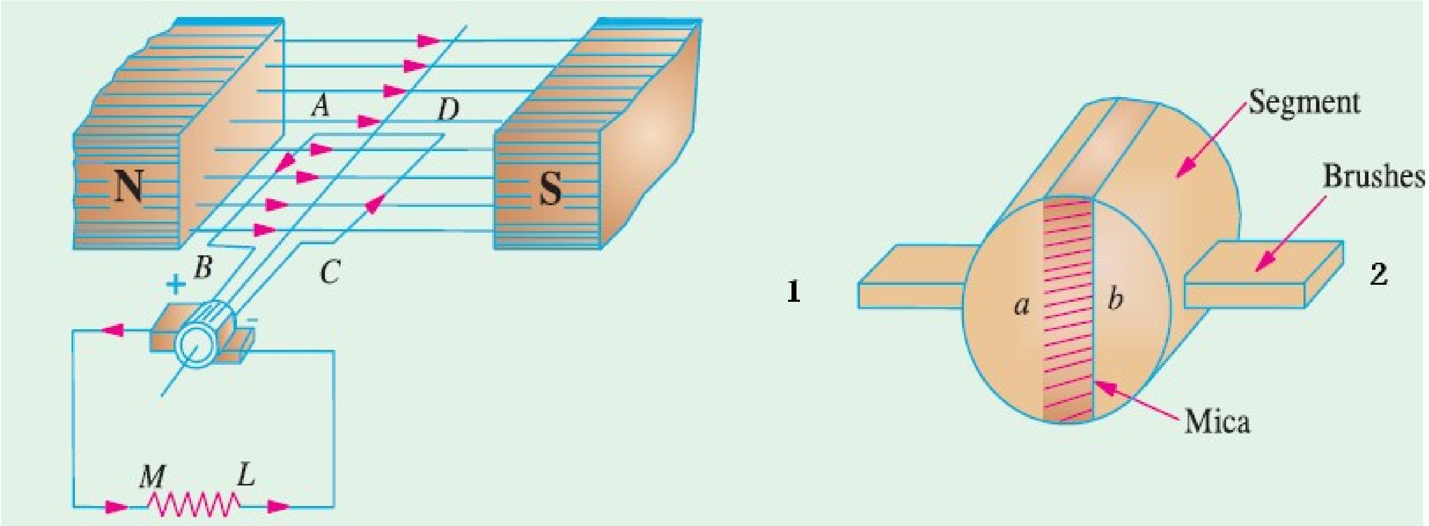
Working Principle

As the coil rotates in clock-wise direction and assumes successive positions in the field the, flux linked with it changes. Hence, an emf is induced in it which is proportional to the rate of change of flux linkages ($e = Nd\phi/dt$).

- ❖ When the plane of the coil is at right angles to lines of flux i.e. when it is in position 1, then flux linked with the coil is maximum, but rate of change of flux linkages is minimum. Hence, there is no induced emf in the coil.
- ❖ As the coil continues rotating further, the rate of change of flux linkages (and hence induced emf in it) increases, till position 3 is reached where θ = 90º, the coil plane is horizontal i.e. parallel to the lines of flux. The flux linked with the coil is minimum but rate of change of flux linkages is maximum. Hence, maximum emf is induced in the coil at this position.
- ❖ From 90º to 180º, the flux linked with the coil gradually increases but the rate of change of flux linkages decreases. Hence, the induced emf decreases gradually till in position 5 of the coil, it is reduced to zero value.
- ❖ From 180º to 360º, the variations in the magnitude of emf are similar to those in the first half revolution. Its value is maximum when coil is in position 7 and minimum when in position 1. But it will be found that the direction of the induced current is the reverse of the previous direction of flow.

Commutation

The **commutation in DC machine** or more specifically **commutation in DC generator** is the process in which generated alternating current in the armature winding of a dc machine is converted into direct current after going through the commutator and the stationary brushes. For making the flow of current **unidirectional** in the external circuit, the **slip-rings** are replaced by **split-rings**. The split-rings are made out of a conducting cylinder which is cut into two halves or segments insulated from each other by a thin sheet of mica or some other insulating material. As before, the coil ends are joined to these segments on which rest the carbon or copper brushes. It is seen that in the first half revolution current flows along (ABMLCD) i.e. the brush No.1 in contact with segment 'a' acts as the positive end of the supply and 'b' as the negative end. In the next half revolution, the direction of the induced current in the coil has reversed. But at the same time, the positions of segments 'a' and 'b' have also reversed with the result that brush No.1 comes in touch with the segment which is positive i.e. segment 'b' in this case. Hence, current in the load resistance again flows from M to L. The waveform of the current through the external circuit is as shown in below. This current is unidirectional but not continuous like pure direct current.



Commutation

- The position of brushes is so arranged that the change over of segments ‘a’ and ‘b’ from one brush to the other takes place when the plane of the rotating coil is at right angles to the plane of the lines of flux. It is so because in that position, the induced emf in the coil is zero.

- The current induced in the coil sides is alternating as before. It is only due to the rectifying action of the split-rings (also called commutator) that it becomes unidirectional in the external circuit.

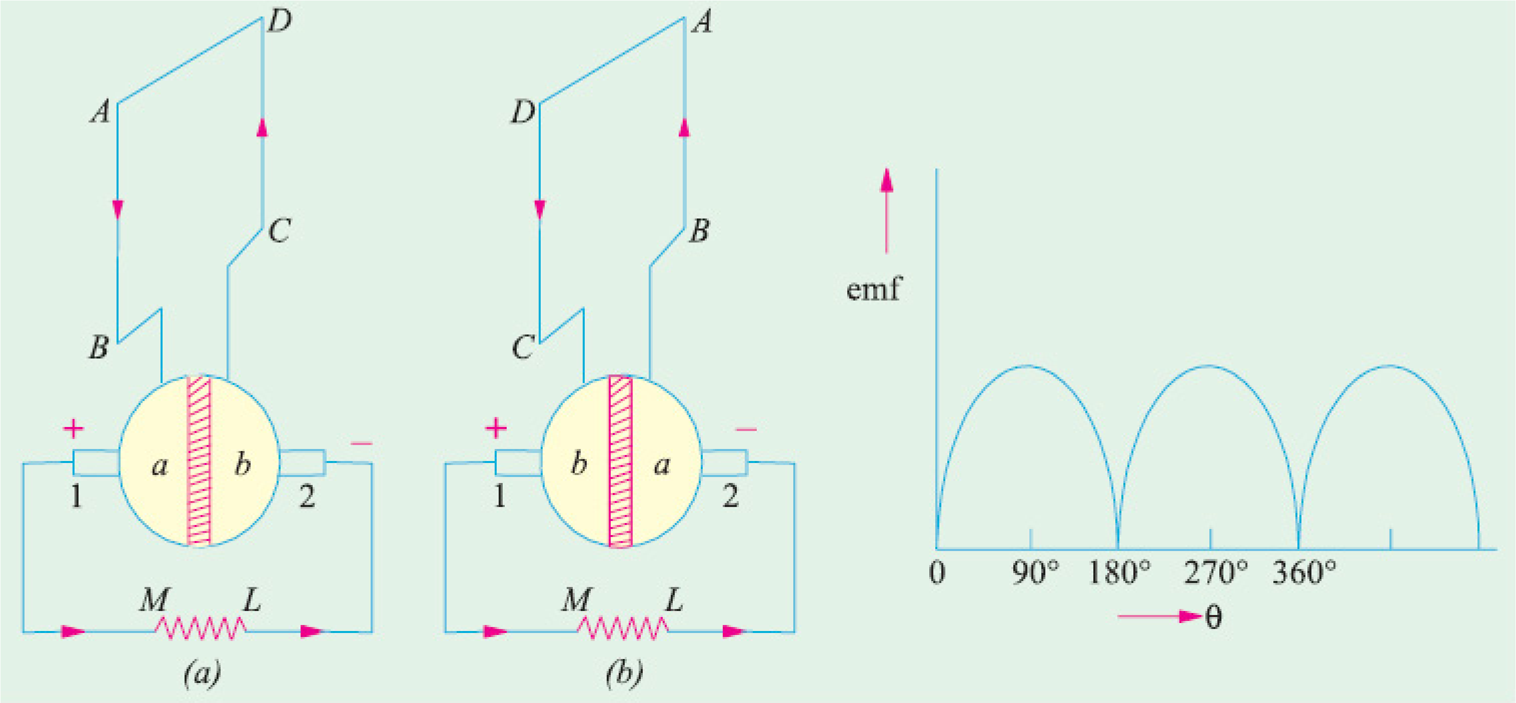
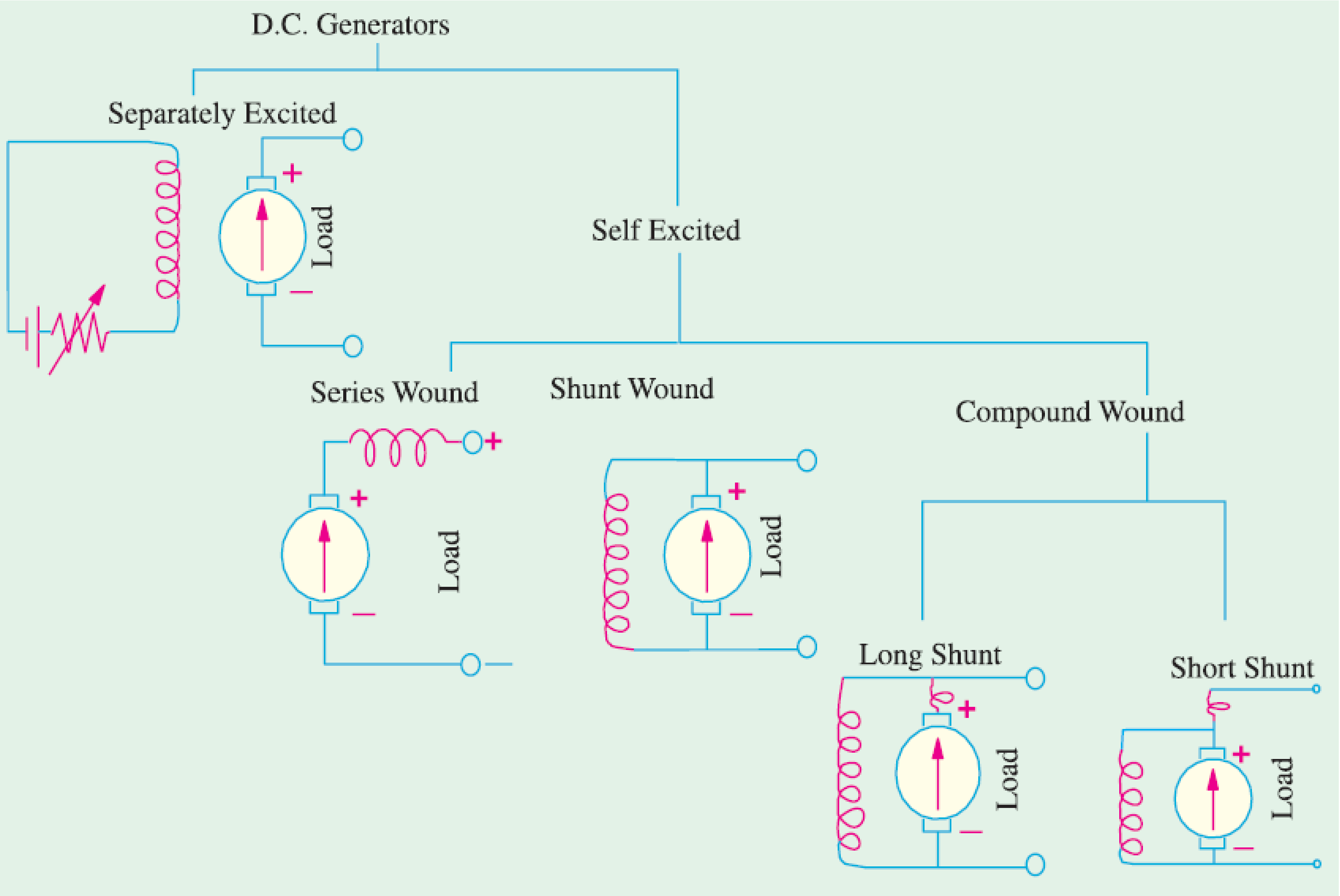


Fig. 26.6

Fig. 26.7

Types of DC Generator



E.M.F Equation

26.33. 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 $\times$ 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. E_g = e.m.f. generated in any one of the parallel paths *i.e.* E.

Average e.m.f. generated/conductor $= \dfrac{d\Phi}{dt}$ volt $\quad (\because n = 1)$

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

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

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

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

E.M.F Equation

No. of parallel paths = P

No. of conductors (in series) in one path = Z/P

$\therefore$ E.M.F. generated/path $= \dfrac{\Phi PN}{60} \times \dfrac{Z}{P} = \dfrac{\Phi ZN}{60}$ volt

In general generated e.m.f. $E_g = \dfrac{\Phi ZN}{60} \times \left(\dfrac{P}{A}\right)$ volt

where A = 2-for simplex wave-winding

= P-for simplex lap-winding

Example 26.7. *The following information is given for a 300-kW, 600-V, long-shunt compound generator : Shunt field resistance = 75 Ω, armature resistance including brush resistance = 0.03 Ω, commutating field winding resistance = 0.011 Ω, series field resistance = 0.012 Ω, divertor resistance = 0.036 Ω. When the machine is delivering full load, calculate the voltage and power generated by the armature.*

(Elect. Engg-II, Pune Univ. Nov. 1989)

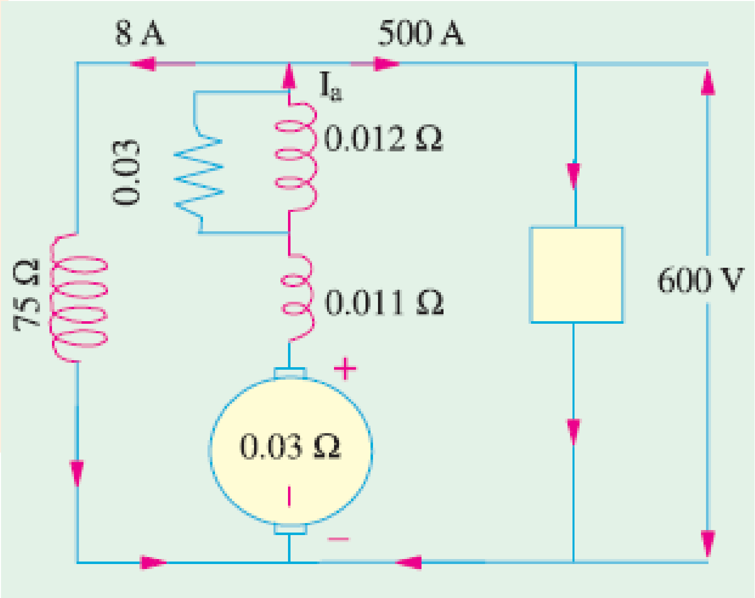


Fig. 26.50

Solution. Power output $= 300{,}000$ W

Output current $= 300{,}000/600$

$= 500$ A

$I_{sh} = 600/75 = 8$ A,

$I_a = 500 + 8 = 508$ A

Since the series field resistance and divertor resistance are in parallel (Fig. 26.50) their combined resistance is

$$= \frac{0.012 \times 0.036}{0.048} = 0.009\ \Omega$$

Total armature circuit resistance

$$= 0.03 - 0.011 + 0.009 = 0.05\ \Omega$$

Voltage drop $= 508 \times 0.05 = 25.4$ V

Voltage generated by armature

$$= 600 + 25.4 = 625.4 \text{ V}$$

Power generated $= 625.4 \times 508 = 317{,}700$

$W =$ **317.7 kW**

MATH

Example 26.11(*b*). *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

(1) Flux per pole, (2) Armature-current per parallel path. **(Nagpur University Nov. 1998)**

Solution. Geyser current = 5000/250 = 20 A

Current for Lighting = 2500/250 = 10 A

Total current = 30 A

Field Current for Generator = 1 A

Hence, Armature Current = 31 A

Armature resistance drop = 31 × 0.2 = 6.2 volts

Generated e.m.f. = 250 + 6.2 + 2 = 258.2 V,

since $E = V_t + I_a r_a$ + Total brush contact drop

For a 4-pole lap-connected armature,

Number of parallel paths = number of poles = 4

(1) The flux per pole is obtained from the emf equation

$$258.2 = [\phi\, Z\, N/60] \times (p/a)$$
$$= [\phi \times 120 \times 1000/60] \times (4/4)$$
$$= 2000\,\phi$$
$$\phi = 129.1 \text{ mWb}$$

(2) Armature current per parallel path = 31/4 = 7.75 A.

Formula

In general generated e.m.f. $E_g = \frac{\Phi Z N}{60} \times \left(\frac{P}{A}\right)$ volt

where A = 2-for simplex wave-winding

= P-for simplex lap-winding