MEC 3102 – PRODUCTION ENGINEERING I AND ELECTRICITY & ELECTRONICS II

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2nd Series Lecture 4[1]

1.7 Torque Equation

when a current carrying conductor is placed in the magnetic field a force is exerted on it which exerts turning moment or torque (F × r) (see Fig. 1.11). This torque is produced due to electro-magnetic effect, hence is called **electromagnetic torque**.

Let

$\mathrm{P} =$ Number of poles of the machine.

$\emptyset =$ Flux per pole in Wb

$\mathrm{Z} =$ Total number of armature conductors.

$\mathrm{r} =$ Average radius of armature in metre

$l =$ Effective length of each conductor in metre.

$I_a =$Total armature current.

$A =$ number of parallel paths

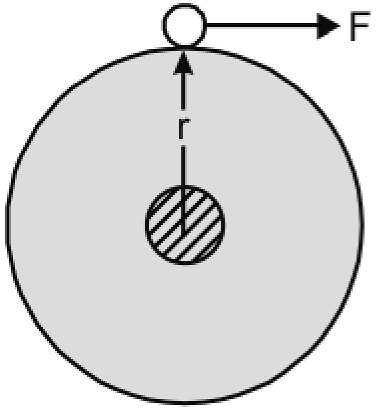

Fig. 1.11

Average force on each conductor, $F = Bli$ newton

Torque due to one conductor= $F \times r$ newton metre

Total torque developed in the armature,

$$T = ZFr \quad \text{newton metre}$$

or

$$T = ZBlir \quad \text{newton metre} \qquad (1.3)$$

Now, current in each conductor, $i = I_a/A$

Average flux density, $B = \emptyset/a$, where ‘a’ is the X- sectional area of flux path at radius r.

Obviously,

$$a = \frac{2\pi rl}{P} \quad m^2 \qquad \therefore \quad B = \frac{\emptyset P}{2\pi rl} \quad \text{tesla}$$

Substituting these values in equation (5.9), we get

$$T = Z \times \frac{\emptyset P}{2\pi rl} \times \frac{I_a}{A} \times l \times r = \frac{PZ\emptyset I_a}{2\pi A} \quad \text{Nm} \qquad (1.4)$$

Alternately; The power developed in the armature is given as

$$E_g I_a = \omega T = \frac{2\pi N}{60} \times T$$

Using equation (1.2),

$$\frac{PZ\emptyset N}{60A} \times I_a = \frac{2\pi N}{60} \times T$$

Still,

$$T = \frac{PZ\emptyset I_a}{2\pi A} \quad \mathrm{Nm}$$

For a particular machine, the number of poles (P), number of conductors per parallel path (Z/A) are constant. Hence, torque produced in the armature is directly proportional to flux per pole and armature current

Example:

1. A 50 HP, 400 V, 4 pole, 1000 rpm, DC motor has flux per pole equal to 0.027 Wb. The armature having 1600 conductors is wave connected. Calculate the gross torque when the motor takes 70 ampere.

Solution:

Given: $P = 4, N = 1000\ rpm, \emptyset = 0.027\ Wb, Z = 1600, A = 2,$ and $I_a = 70\ A$

Since,

$$T = \frac{PZ\emptyset I_a}{2\pi A} = \frac{4 \times 1600 \times 0.027 \times 70}{2 \times \pi \times 2} = \mathbf{962.57\ Nm}$$

1.8 Armature Reaction

The effect of armature field produced by the armature current carrying conductors on the main magnetic field is known as **armature reaction**

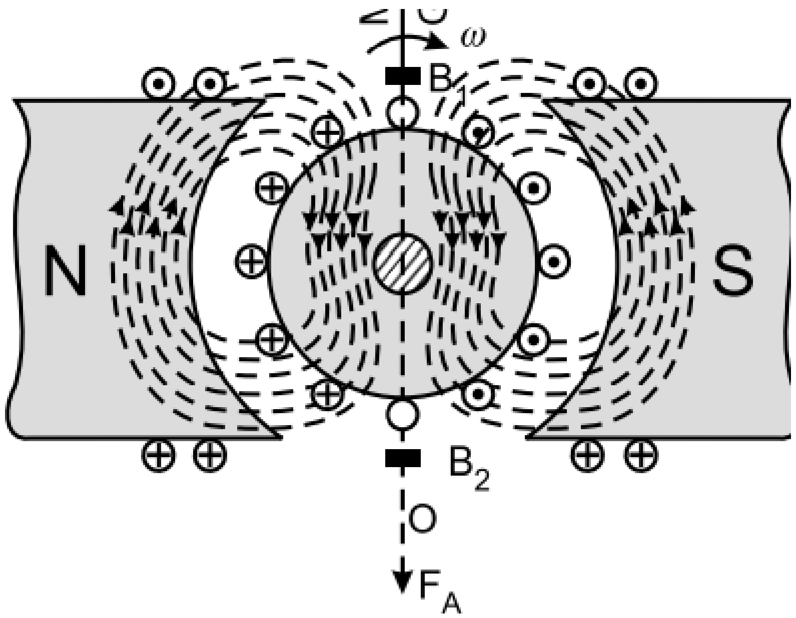

Fig. 1.12 Field produced by armature conductors

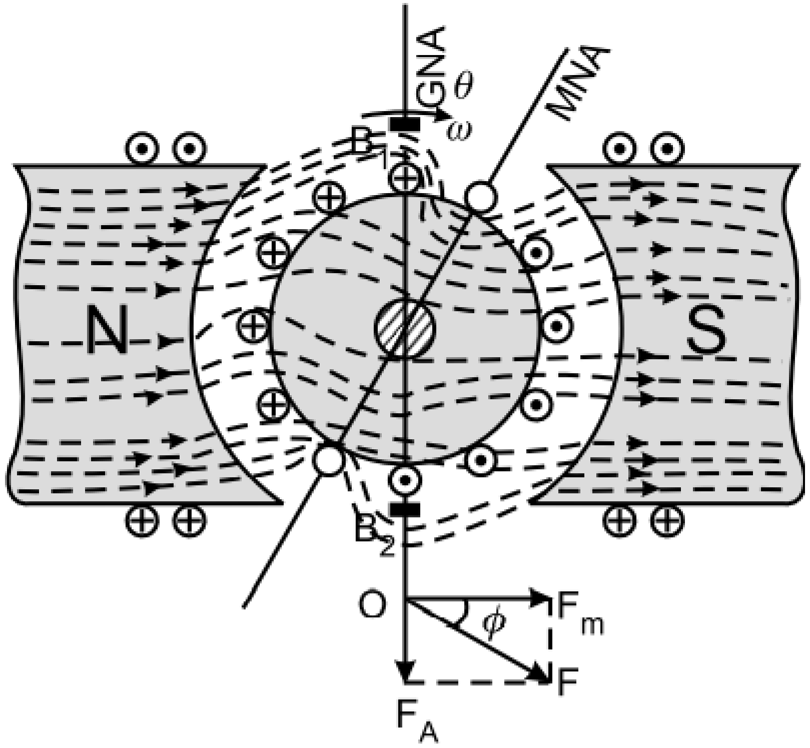

Fig. 1.13 Resultant field

Thus, the armature magnetic field produces.

(i) Cross magnetising effect which creates a magnetic field in between the two adjacent opposite poles where brushes are placed for commutation.

(ii) Demagnetising effect which weakens the main magnetic field and changes the flux distribution such that at trailing pole tips the flux is strengthened and at leading pole tips the flux is weakened

1.9 Types of DC Generators

D.C. generators are generally classified according to the methods of their field excitation, they can be classified as:

1. Separately excited d.c. generators
2. Self excited d.c. generators – these are further classified as:
    - (i) Shunt wound d.c. generators
    - (ii) Series wound d.c. generators
    - (iii) Compound wound d.c. generators.
        - (a) Long shunt compound wound generators
        - (b) Short shunt compound wound generators.

Except the above, there are also permanent magnet type d.c. generators. In these generators, no field winding is placed around the poles.

1.10 Separately-excited d.c. **Generators**

Important relations:

$$I_a = I_L$$

Where, I_a is armature current and I_L is the line current.

Terminal voltage,

$$V = E_g - I_a R_a \qquad (1.5)$$

Power developed $= E_g I_a$

Power output $= V I_L = V I_a$

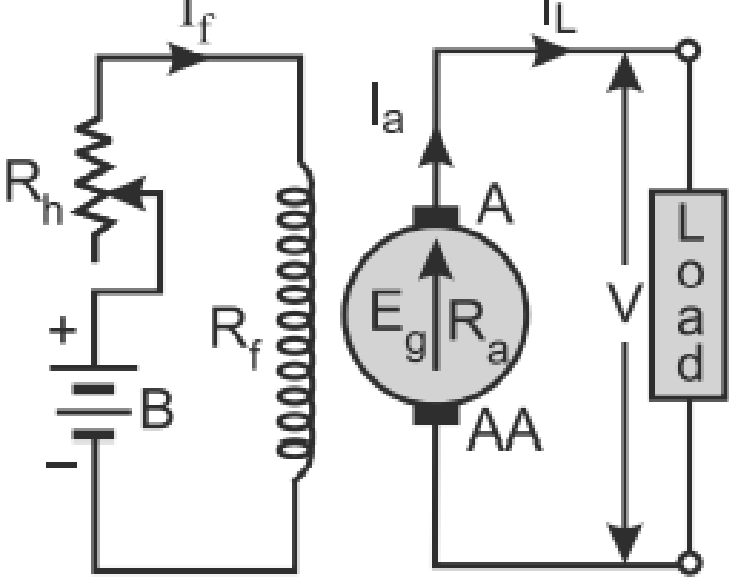

Fig. 1.14 Circuit diagram for separately excited d.c. generator

1.11 Self-excited DC Generators

A d.c. generator whose field winding is excited by the current supplied by the generator itself is called a self-excited d.c. generator.

1. Shunt Wound Generators

- In a shunt wound generator, the field winding is connected across the armature winding forming a parallel or shunt circuit. Therefore, full terminal voltage is applied across the field winding. A very small current I_{sh} flows through it because this winding has many turns of fine wire having very high resistance R_{sh} (of the order of 100 ohms).
- The field current I_{sh} is practically constant at all loads, therefore, the d.c. shunt machine is considered to be constant flux machine.

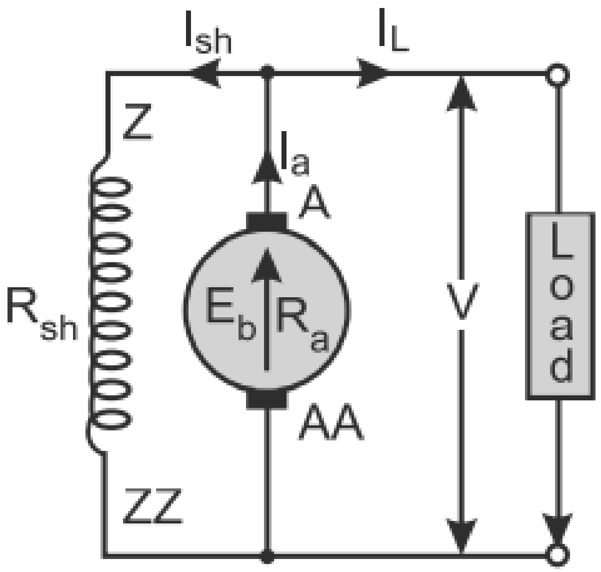

Fig.1.15 Circuit diagram for DC shunt generator

Important relations:

Shunt field current,

$$I_{sh} = V/R_{sh} \qquad (1.6)$$

Armature current,

$$I_a = I_L + I_{sh} \qquad (1.7)$$

Terminal voltage,

$$V = E_g - I_a R_a \qquad (1.8)$$

Power developed $= E_g I_a$

Power output $= V I_L$

2. Series Wound Generators

In a series wound generator, the field winding is connected in series with the armature winding forming a series circuit.

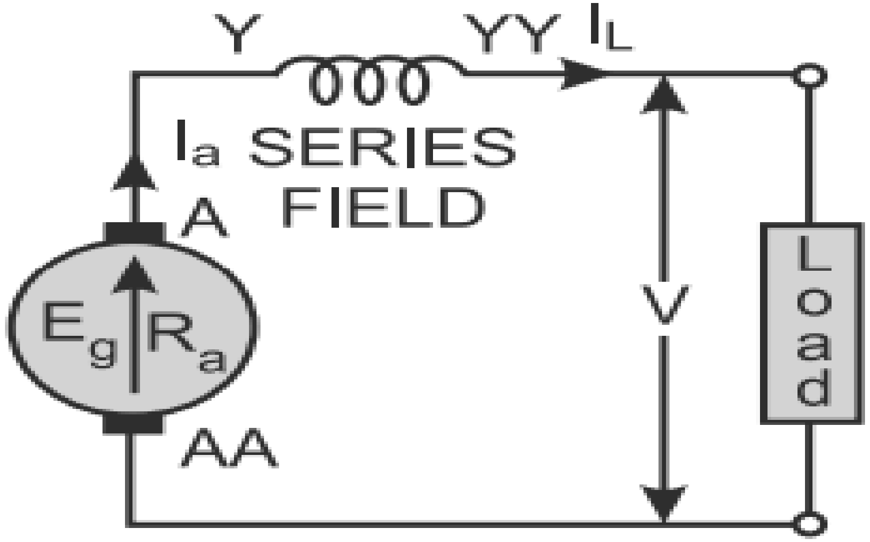

Fig. 1.16 Circuit diagram for DC series generator

Important relations:

Series field current,

$$I_{se} = I_a = I_L \qquad (1.9)$$

Series field winding resistance

$$= R_{se}$$

Terminal voltage,

$$V = E_g - I_a R_a - I_a R_{se}$$

$$V = E_g - I_a(R_a + R_{se}) \quad (1.10)$$

Power developed $= E_g I_a$

Power output $= VI_a = VI_L$

Note: The flux developed by the series field winding is directly proportional to the current flowing through it (i.e., $\emptyset \propto I_{se}$). But it is only true before magnetic saturation, after saturation flux becomes constant even if the current flowing through it is increased.

3. Compound Wound Generators

In a compound generator-wound generator, there are two sets of windings, one on each pole.

a) Long shunt in which the shunt field winding is connected in parallel with the combination of both armature and series field winding.

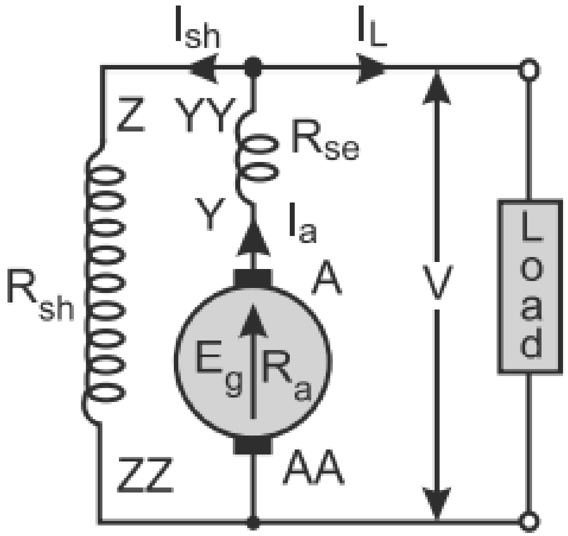

Fig. 1.17

Important relations:

Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$

Series field current,

$$I_{se} = I_a = I_{sh} + I_L \qquad (1.11)$$

Terminal voltage,

$$V = E_g - I_a R_a - I_{se} R_{se}$$

$$V = E_g - I_a(R_a + R_{se}) \quad (1.12)$$

Power developed $= E_g I_a$

Power output $= V I_L$

b) Short shunt in which the shunt field winding is connected in parallel with only armature winding.

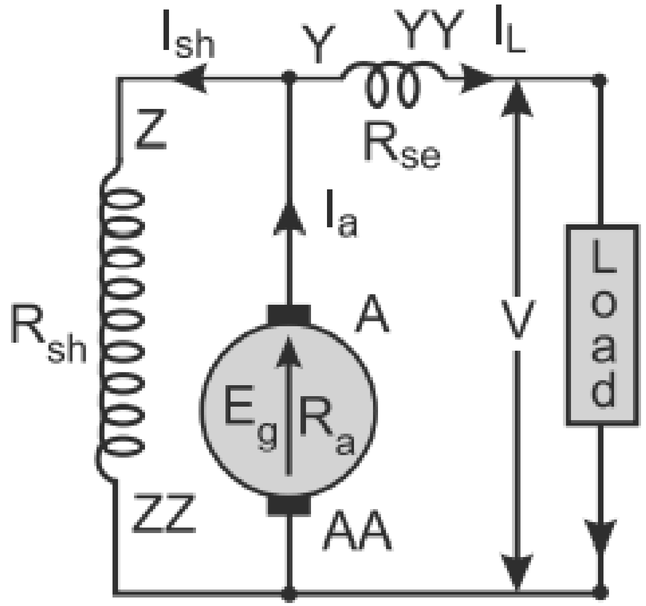

Fig. 1.18

Important relations:

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

Shunt field current,

$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$$

$$I_{sh} = \frac{E_g - I_a R_a}{R_{sh}} \qquad (1.13)$$

$$I_a = I_{sh} + I_L$$

Terminal voltage,

$$V = E_g - I_a R_a - I_L R_{se} \qquad (1.14)$$

Power developed $= E_g I_a$

Power output $= V I_L$

1.12 Characteristics of DC Generators

To determine the relation between different quantities of a DC generator, the following are the important characteristics of DC generators:

1. **No-load characteristics**. It is also known as magnetic characteristics or open-circuit characteristics (O.C.C.). It shows the relation between the no-load generated emf in the armature (E_0) and the field current (i.e., exciting current) I_f , at a specified speed.
2. **External characteristics**. It is also called the performance characteristics. It shows the relation between the terminal voltage (V) and the load current I_L.
3. **Internal Characteristics**. It is also known as total characteristics. It gives the relation between the emf induced in the armature (E_g) and the armature current I_a.

1.13 No-load Characteristics of d.c Generators

- ✓Open the field winding of the generator and connect it to a separate d.c. source through a rheostat.
- ✓Run the armature at a specified speed
- ✓the O.C.C. of even self-excited generator is obtained by running it as a separately excited generator.

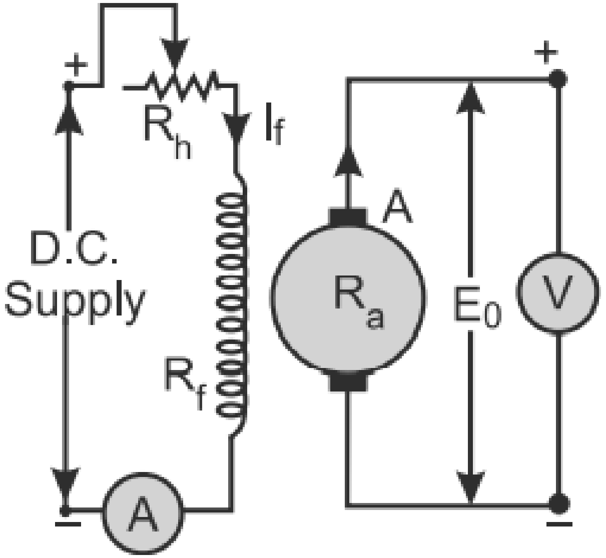

Fig. 1.19 Circuit diagram

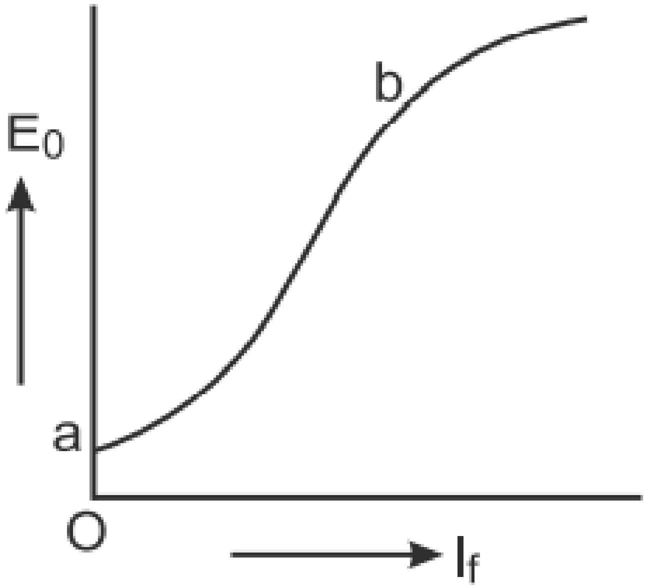

Fig. 1.20 No-load characteristics

In Fig. 1. 20:

1. The curve starts from point ‘a’ instead of ‘O’ when the field current is zero. It is because of the **residual magnetism** of the poles.
2. The initial part of the curve (ab) is almost a straight line because at this stage the magnetic material is unsaturated and it has high permeability.
3. After point ‘b’ the curve bends and the generated emf (E_0) becomes almost constant. It is because after point ‘b’, the poles (magnetic material) starts getting saturated.

1.14 Voltage Build-up in Shunt Generators

- The shunt field resistance is represented by a straight line OX.
- When armature is rotated at a constant speed of ω rad/sec, the small residual flux of the poles is cut by the armature conductors, and very small emf (oa) is induced in the armature.
- If now key (K) connected is closed, current ob flows in the field winding. This current increases the flux produced by the poles and voltage generated in the armature is increased to oc

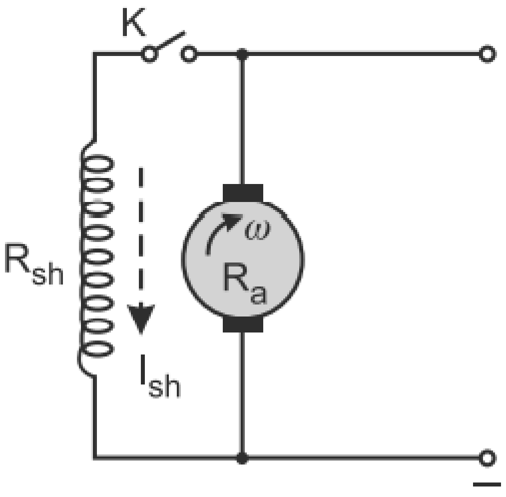

Fig. 1.21

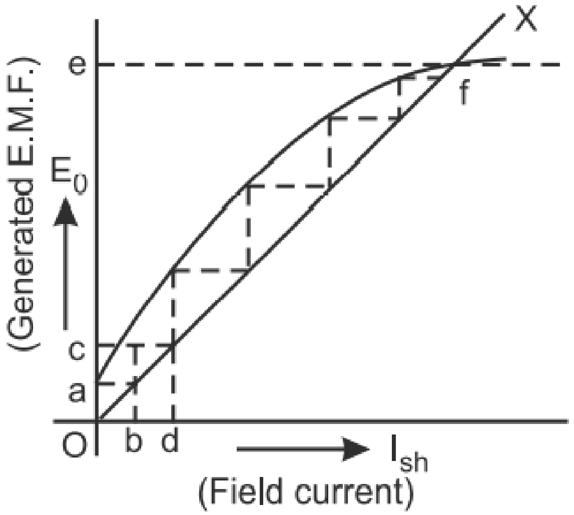

Fig. 1.22

1.15 Critical Field Resistance of a d.c. Shunt Generator

The open circuit characteristic of a d.c. shunt generator are as shown below. The line OX is drawn in such a way that its slope gives the field winding resistance, i.e.,

$$R_{sh} = \frac{OB(in\ volt)}{OC(in\ ampere)}$$

In this case, the generator can build up a maximum voltage OB with a shunt field resistance R_{sh}.

- A line OY represents a smaller resistance
- If the field resistance is increased, the slope of the resistance line increases.

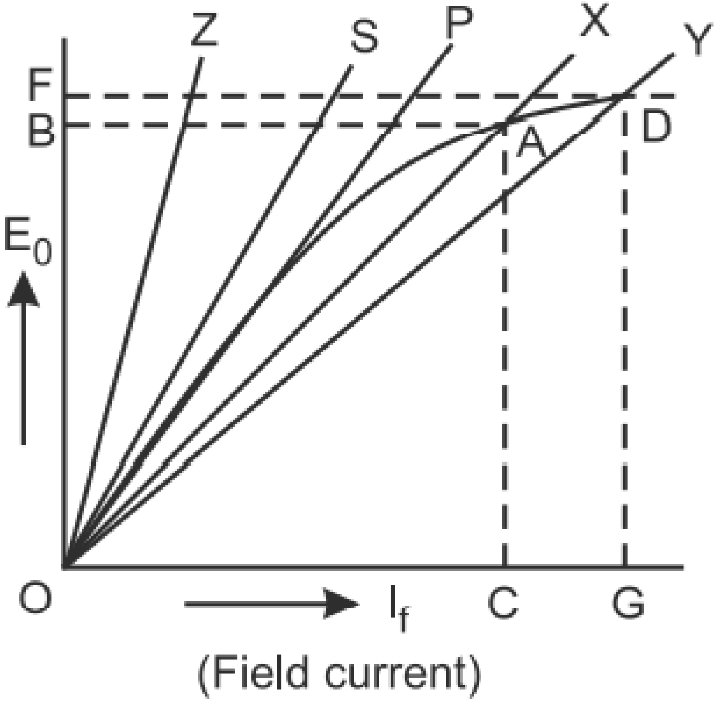

Fig. 1.23 Critical resistance

In Fig. 1.23:

- If the value of R_{sh} is increased to such an extent that the resistance line does not cut the no-load characteristics at all (OZ), then it is apparent that the voltage will not be built-up (i.e., the generator fails to excite).
- If the resistance line (OP) just coincide with the slope of the curve, at this value of field resistance, the generator will just excite. This resistance, given by the tangent to the *O.C.C.* is called the ***critical resistance*** at a specified speed

- ***Critical resistance*** of a field winding. It is that maximum value resistance of a field winding which is required to build-up voltage in a generator.
- **Critical load resistance**. The minimum value of load resistance on a DC shunt generator with which it can be in position to build-up is called its critical load resistance.
- **Critical speed** of a DC shunt generator. It is the speed of a DC shunt generator at which shunt field resistance will represent the critical field resistance.

1.16 Load Characteristics of Shunt Generator

- It is also called external or performance characteristics of shunt generator.
- At start switch off the load and run the generator at rated speed.

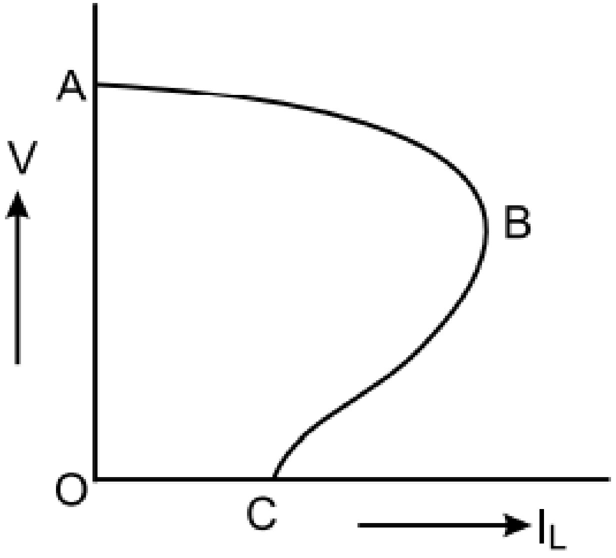

Fig. 1.25 Curve

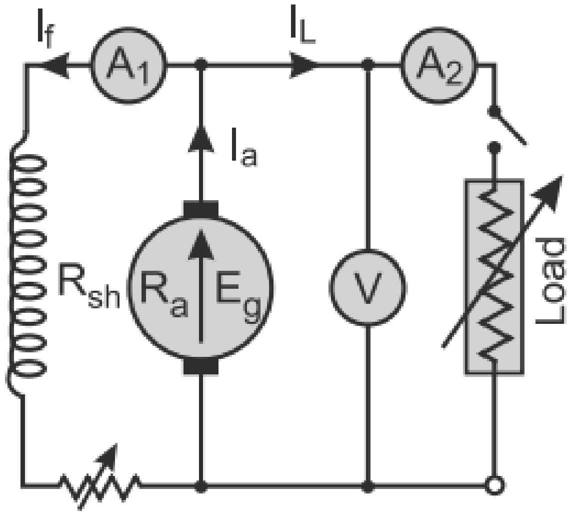

Fig. 1.24 Circuit Diagram

Analysis of the Curve:

1. At no-load, the voltage across the terminals is maximum and is considered to be equal to generated e.m.f. E_g.

2. As the load is increased gradually, the load current I_L increases but the terminal voltage decreases. The decrease in voltage is because of the following reasons:
   a. Due to increase in voltage drop in the armature resistance ($I_a R_a$)
   b. Due to armature reaction when load current or armature current I_a increases, the demagnetising effect of the armature field increases on the main field which reduces the induced e.m.f., consequently the terminal voltage decreases.
3. During initial portion of the curve AB, the tendency of the voltage drop due to armature resistance is more than armature reaction.
4. At point B these two effects neutralise each other.
5. After point B, armature reaction dominates and the curve turns back.
6. The point C at which the external characteristic cuts the current axis corresponds to a gradual short circuit.

1.17 Load Characteristics of Series Generators

- When load increases, I_a increases which increases flux and consequently generated e.m.f. is also increased.
- This, correspondingly increases the terminal voltage V.
- At higher loads, the terminal voltage begins to reduce because of the excessive demagnetising effects of armature reaction

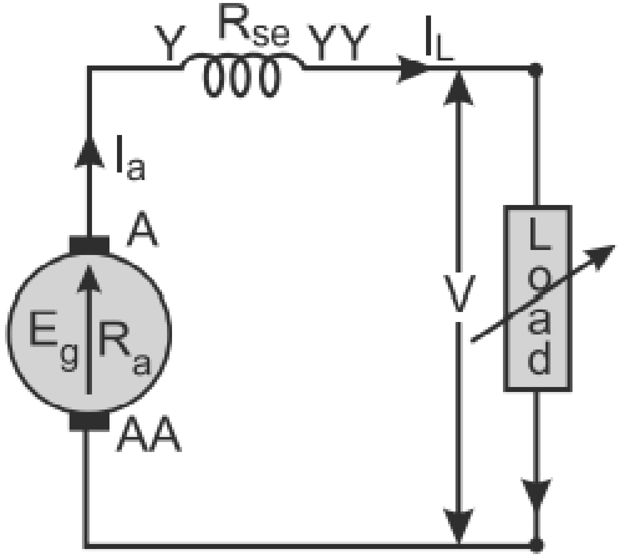

Fig. 1.26 Circuit

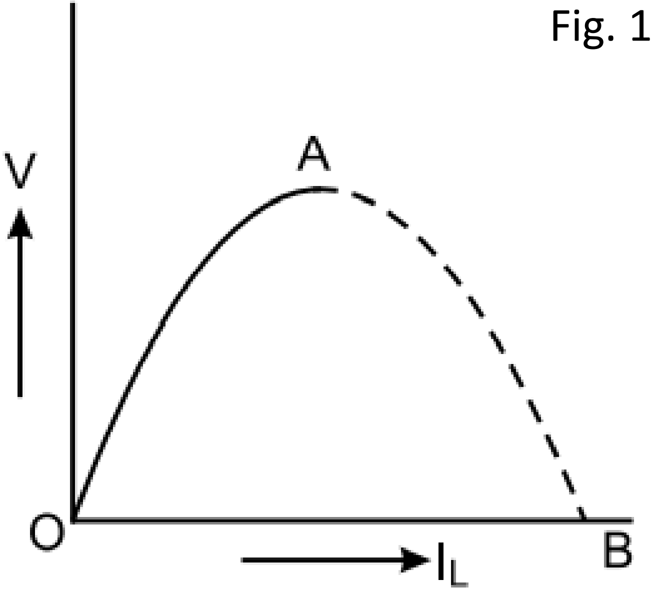

Fig. 1.27 Curve

1.18 Load Characteristics of Compound Generator

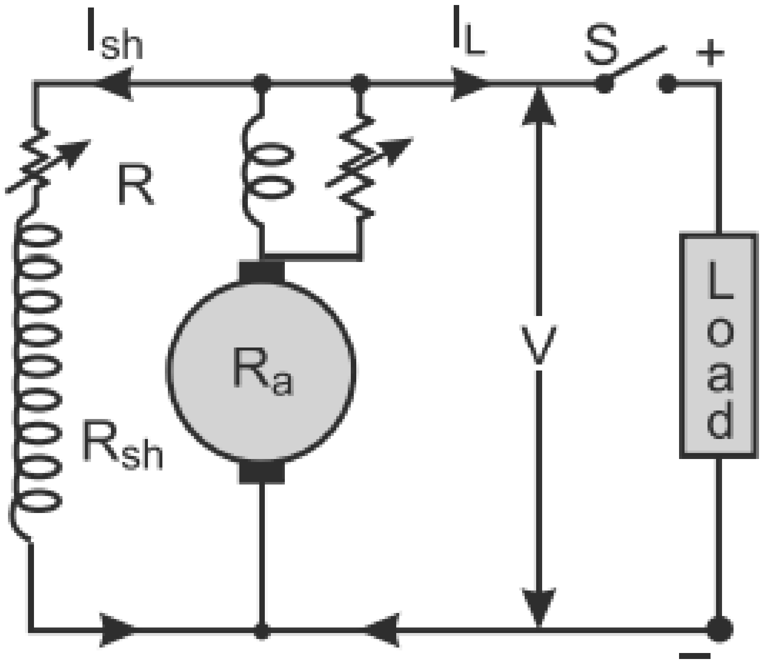

Fig. 1.28. Circuit diagram

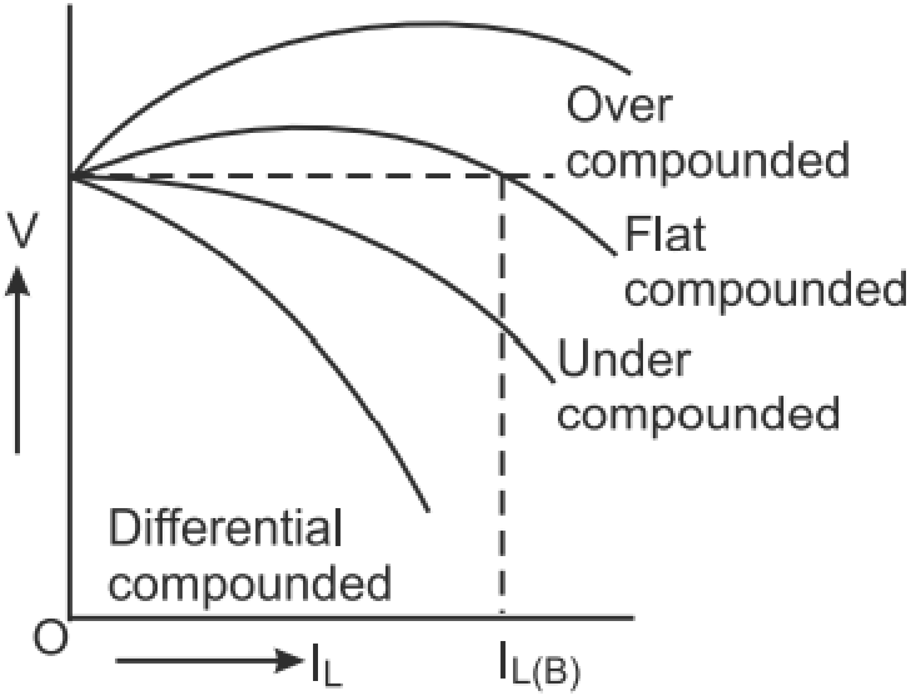

Fig. 1.29. Load characteristics of compound generator

1.18 Load Characteristics of Compound Generator

- When the field current is adjusted such that the terminal voltage V on full load remains the same as that on no-load, the generator is called to be **level or flat compounded generator.**
- When the terminal voltage on full-load is more than its terminal voltage at no-load, the generator is called to be an **over compounded generator.**
- when the terminal voltage on full-load is less than no-load voltage, the generator is called to be as **under compounded generator.**
- However, if the field produced by the series field winding acts in opposite direction to the field produced by the shunt field winding, the generator is called to be **differentially compounded.**

1.19 Causes of Failure to Build-up Voltage in a Generator

1. When the residual magnetism in the field system is destroyed.
2. When the connections of the field winding are reversed. This, in fact, destroys the residual magnetism due to which generator fails to build up voltage.
3. In case of shunt-wound generators, the other causes may be
    i. the resistance of shunt field circuit may be more than the critical resistance.
    ii. the resistance of load circuit may be less than critical resistance.
    iii. the speed of rotation may be below the rated speed.
4. In case of series-wound generators, the other causes may be
    i. the load circuit may be open.
    ii. the load circuit may have high resistance.

Applications of DC Generator:

1. **Separately excited**. Employed where quick and definite response to control is important such as Ward–Leonard System of speed control.
2. **Shunt-wound**. As they provide constant terminal voltage, they are best suited for battery charging. Along with field regulators, they are also used for light and power supply purposes.
3. **Series-wound**. DC locomotives, where they supply field current for regenerative braking, arc lighting, as series boosters for increasing DC voltage across the feeders.
4. **Compound-wound**.
    1. **Over-compounded type**. Lighting and power services
    2. **Differential-compounded type**. Welding sets.