EEE/ETI: 3105
ELECTRICAL MACHINES I

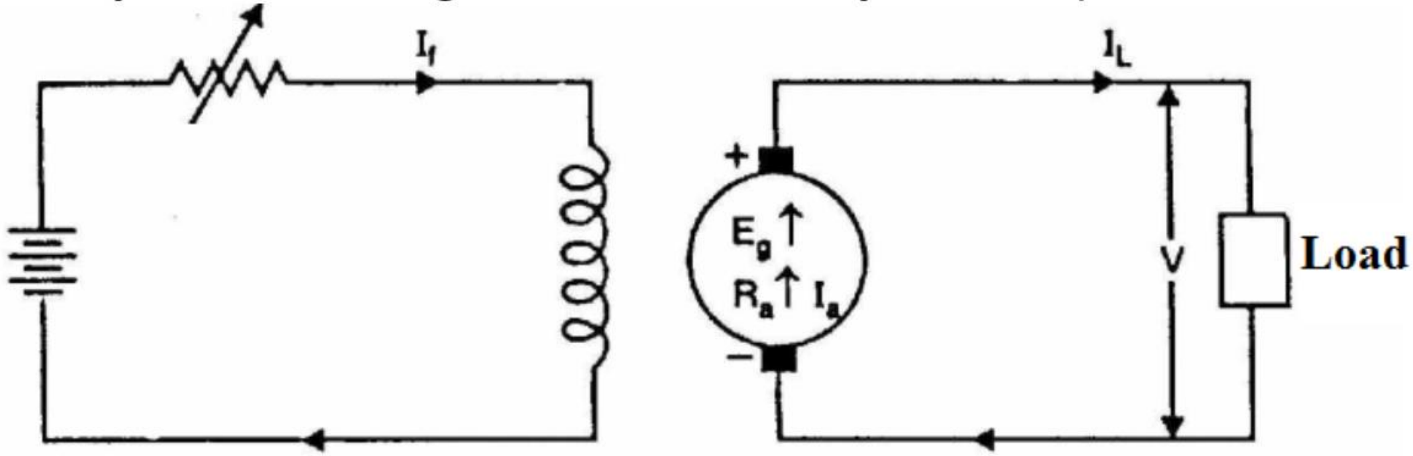
LECTURE 7: DC GENERATORS

Types of D.C. Generators

- The magnetic field in a d.c. generator is normally produced by electromagnets rather than permanent magnets.
- Generators are generally classified according to their methods of field excitation.
- On this basis, d.c. generators are divided into the following two classes:
  a) **Separately excited d.c. generators**
  b) **Self-excited d.c. generators**
- The behaviour of a d.c. generator on load depends upon the method of field excitation adopted.

Separately Excited D.C. Generators

- Its field magnet winding is supplied from an independent external d.c. source (e.g., a battery etc.)
- The voltage output depends upon the speed of rotation of armature and the field current ($E_g = P\Phi ZN/60A$).
- The greater the speed and field current, greater is the generated e.m.f.
- Separately excited d.c. generators are rarely used in practice.



Armature current, $I_a = I_L$

Terminal voltage, $V = E_g - I_a R_a$

Electric power developed $= E_g I_a$

Power delivered to load $= E_g I_a - I_a^2 R_a = I_a(E_g - I_a R_a) = VI_a$

Self-excited D.C. Generators

- A d.c. generator whose field magnet winding is supplied current from the output of the generator itself is called a self-excited generator.
- There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature, namely;
  - ✓ Series generator;
  - ✓ Shunt generator;
  - ✓ Compound generator
    - Short Shunt
    - Long shunt

Necessary conditions for voltage build-up in a self excited generators:

- ➢ There must be some residual magnetism in generator poles.
- ➢ The connections of the field winding should be such that the field current strengthens the residual magnetism.
- ➢ The resistance of the field circuit should be less than the critical resistance (for shunt generators).
- In other words, the speed of the generator should be higher than the critical speed.

Requirements of self-excited DC machine

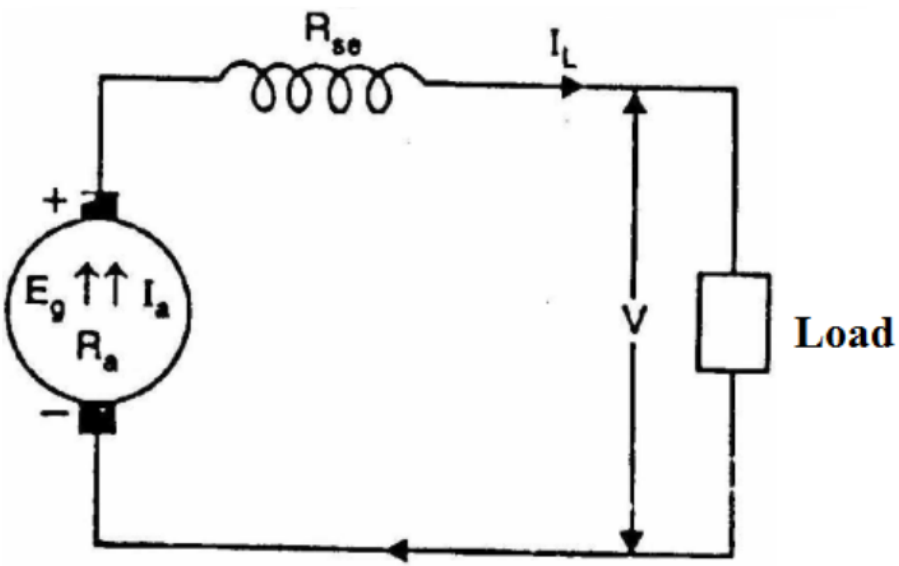
- Following are the requirements of a self-excited DC machine:

1. Its poles must have residual magnetism.
2. The field winding must be connected in such a way that field produced by the field winding must add to the residual magnetism. It should never be connected in reverse direction.
3. The field resistance should not be more than critical resistance.
4. The armature should not be rotated in reverse direction.
5. The resistance of the load circuit must not be below the critical resistance.

Critical resistance of a DC shunt generator. The maximum value of a shunt field winding resistance required to build-up voltage in a DC generator is called critical resistance. If the value of field winding resistance is more than this value, the generator will not be in position to built-up the voltage

Series D.C. Generators

- In a series wound generator, the field winding is connected in series with armature winding so that whole armature current flows through the field winding as well as the load.
- Since the field winding carries the whole of load current, it has a few turns of thick wire having low resistance.
- They are rarely used except for special purposes e.g., as boosters.



- Armature current,

$$I_a = I_{se} = I_L = I \text{ (say)}$$

- Terminal voltage,

$$V = E_g - I(R_a + R_{se})$$

- Power developed in armature

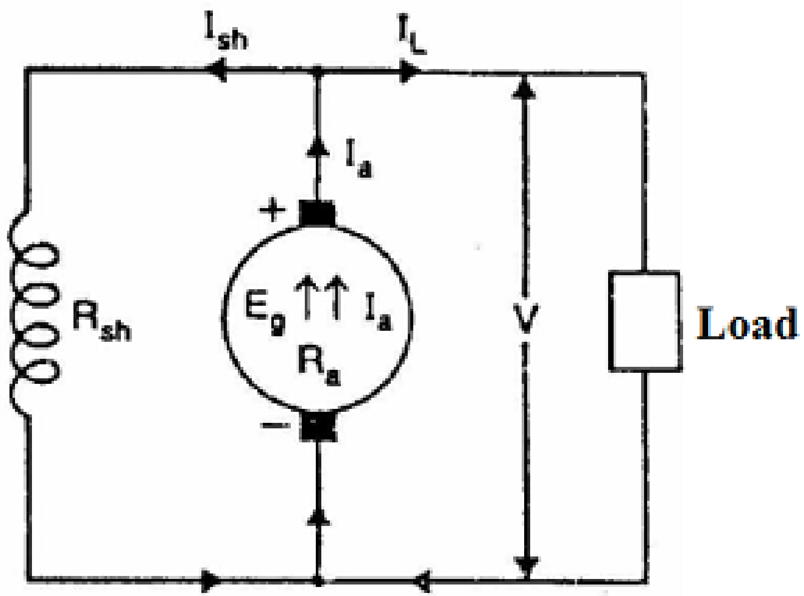
$$= E_g I_a$$

- Power delivered to load $= E_g I_a - I_a^2(R_a + R_{se})$

$$= I_a\left[E_g - I_a(R_a - R_{se})\right] = VI_a \text{ or } VI_L$$

Shunt Generators

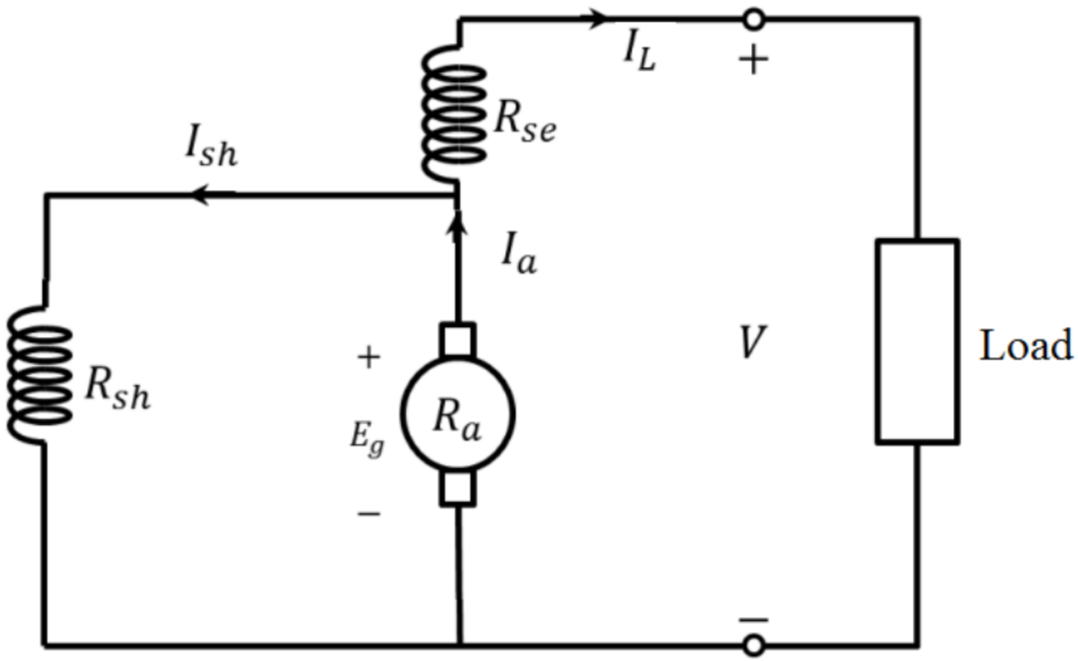
- In a shunt generator, the field winding is connected in parallel with the armature winding so that terminal voltage of the generator is applied across it.
- The shunt field winding has many turns of fine wire having high resistance.
- Therefore, only a part of armature current flows through shunt field winding and the rest flows through the load.



- Shunt field current, $I_{sh} = V/R_{sh}$
- Armature current, $I_a = I_L + I_{sh}$
- Terminal voltage, $V = E_g - I_a R_a$
- Power developed in armature $= E_g I_a$
- Power delivered to load $= VI_L$

Compound Generators - Short Shunt

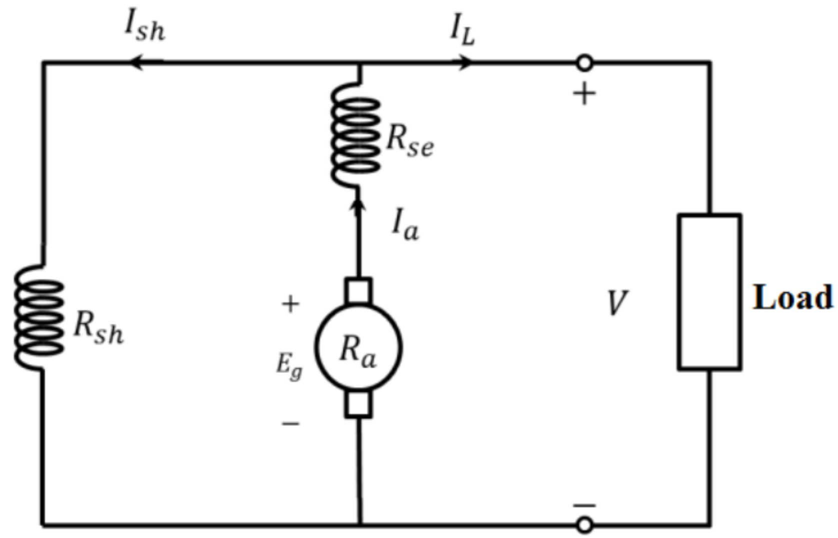
- Here only shunt field winding is in parallel with the armature winding



- Series field current, $I_{se} = I_L$
- Shunt field current, $I_{sh} = \dfrac{V + I_{se} R_{se}}{R_{sh}}$
- Terminal voltage, $V = E_g - I_a R_a - I_{se} R_{se}$
- Power developed in armature $= E_g I_a$
- Power delivered to load $= V I_L$

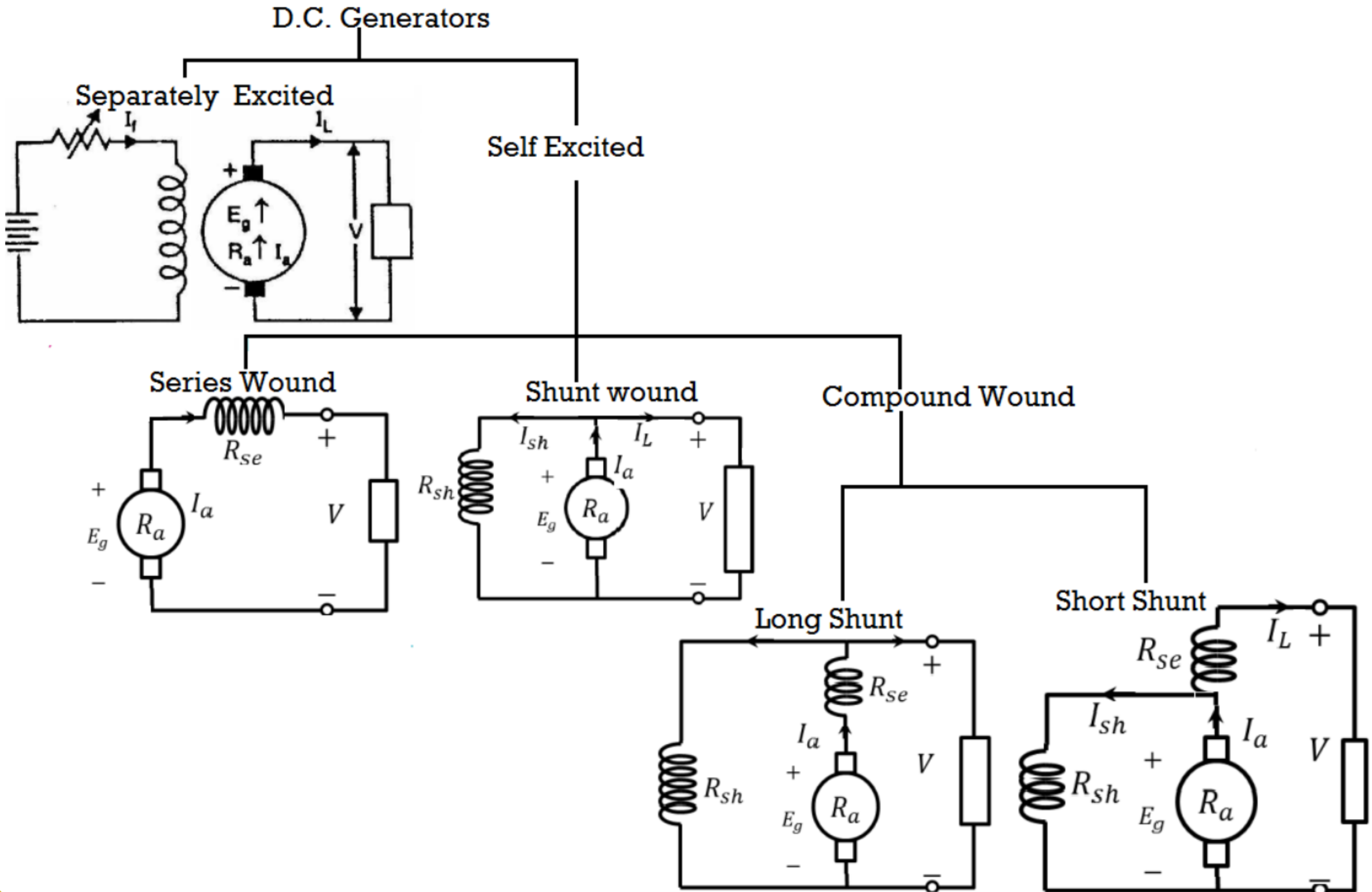
Compound Generators - Long Shunt

- Here shunt field winding is in parallel with both series field and armature winding



- Series field current, $I_{se} = I_a = I_L + I_{sh}$
- Shunt field current, $I_{sh} = \dfrac{V}{R_{sh}}$
- Terminal voltage, $V = E_g - I(R_a + R_{se})$
- Power developed in armature $= E_g I_a$
- Power delivered to load $= VI_L$

Summary- Types of D.C. Generators

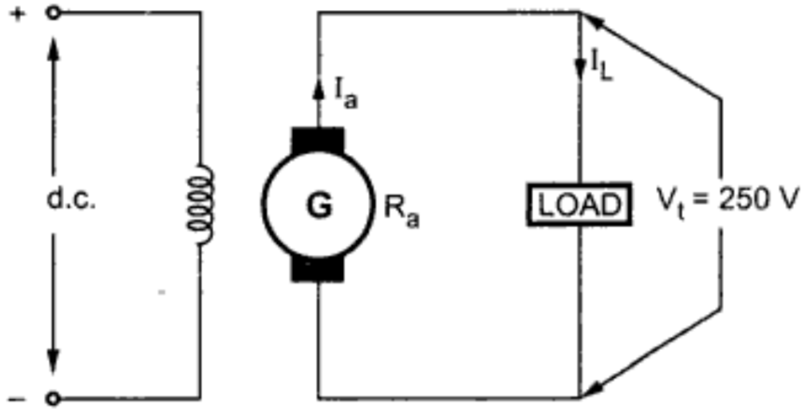


Practice Questions

- **Qn 1:** A 250 V, 10kW, separately excited generator has an induced e.m.f. of 255V at full load. If the brush drop is 2V per brush, calculate the armature resistance of the generator.
- **Qn 2:** A d.c series generator has armature resistance of 0.5 Ω and series field resistance of 0.03 Ω. It drives a load of 50 A. If it has 6 turn/coil and total 540 coils on the armature and is driven at 1500 r.p.m., calculate the terminal voltage at the load. Assume 4 poles, lap type winding, flux per pole as 2 mWb and total brush drop as 2V.
- **Qn 3:** A short shunt compound d.c generator supplies a current of 75A at a voltage of 225 V. Calculate the generated voltage if the resistance of armature, shunt field and series field windings are 0.04 Ω, 90Ω and 0.02Ω respectively.

Solution Q1

Consider separately excited generator as shown in the Fig.



$$I_a = I_L$$

$$V_t = 250 \text{ V and } P = 10 \text{ kW}$$

$$P = V_t \times I_L$$

$$I_L = \frac{10 \times 10^3}{250} = 40 \text{ A}$$

$$\therefore \quad I_a = I_L = 40 \text{ A} \quad \text{... as separately excited}$$

Now $\quad E = V_t + I_a R_a + V_{brush}$

Now there are two brushes and brush drop is 2 V/brush.

$\therefore \quad V_{brush} = 2 \times 2 = 4$ V

$\therefore \quad E = 250 + 40 \times R_a + 4$

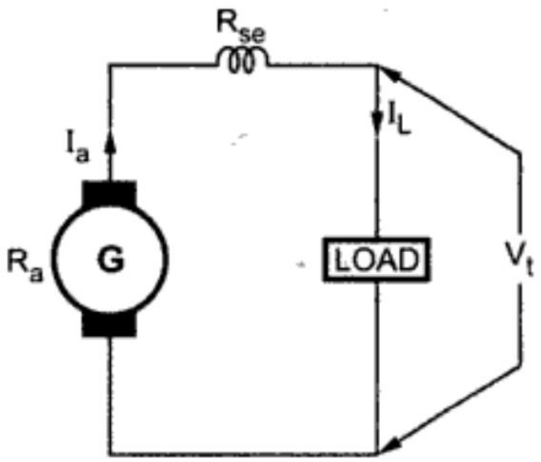
But $\quad E = 255$ V on full load.

$\therefore \quad 255 = 250 + 40 R_a + 4$

$\therefore \quad R_a =$ **0.025 Ω**

Solution Q2

Consider the series generator as shown in Fig.



$$R_a = 0.5\ \Omega, \quad R_{se} = 0.03\ \Omega$$

$$V_{brush} = 2\ V \qquad N = 1500\ \text{r.p.m.}$$

Total coils are 540 with 6 turns/coil.

$$\therefore \text{Total turns} = 540 \times 6 = 3240$$

$$\therefore \text{Total conductors } Z = 2 \times \text{turns}$$

$$= 2 \times 3240 = 6480$$

$$\therefore \quad E = \frac{\phi P N Z}{60\ A}$$

For lap type, $A = P$

and $\phi = 2\ \text{mWb} = 2 \times 10^{-3}$ Wb

$$\therefore \quad E = \frac{2 \times 10^{-3} \times 1500 \times 6480}{60} = 324\ V$$

$$E = V_t + I_a (R_a + R_{se}) + V_{brush}$$ ... total V_{brush} given

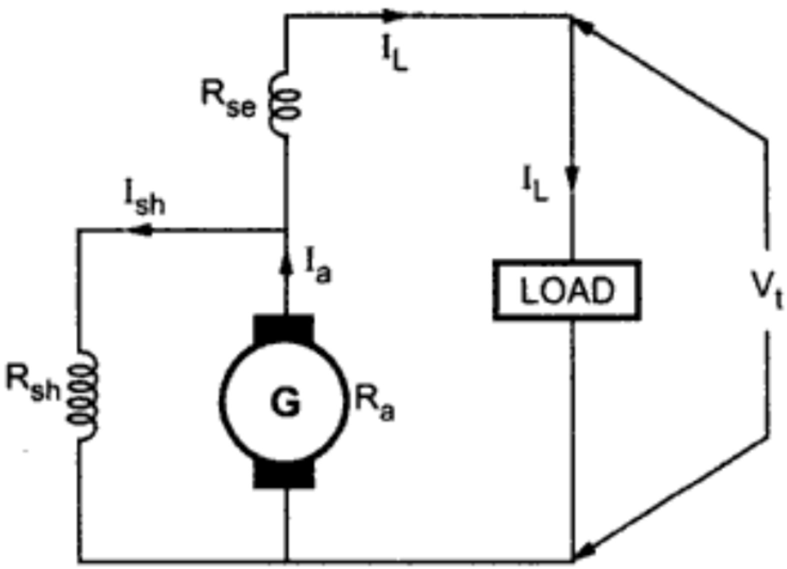
where $I_a = I_L = 50$ A

$$\therefore \quad 324 = V_t + 50\,(0.5 + 0.03) + 2$$

$$\therefore \quad V_t = 295.5\ V$$

Solution Q3

Consider a short shunt generator as shown in the Fig.



$R_a = 0.04\ \Omega, \quad R_{sh} = 90\ \Omega, \quad R_{se} = 0.02\ \Omega$

$V_t = 225$ V

$I_L = 75$ A

$I_a = I_L + I_{sh}$

Now $E = V_t + I_a R_a + I_L R_{se}$

and drop across armature terminals is,

$$E - I_a R_a = V_t + I_L R_{se}$$

$$= 225 + 75 \times 0.02 = 226.5 \text{ V}$$

$$I_{sh} = \frac{E - I_a R_a}{R_{sh}} = \frac{V_t + I_L R_{se}}{R_{sh}} = \frac{226.5}{90} = 2.5167 \text{ A}$$

$$I_a = I_L + I_{sh} = 75 + 2.5167 = 77.5167 \text{ A}$$

$$\therefore \quad E = V_t + I_a R_a + I_L R_{se}$$

$$= 225 + 77.5167 \times 0.04 + 75 \times 0.02 = \mathbf{229.6\ V}$$

Practice Questions

- **Qn 5:** A 12-pole DC shunt generator has 50 slots on its armature with 12 conductors per slot with wave winding. The armature and field winding resistance is 0.5 ohm and 60 ohm respectively. The generator is supplying a resistive load of 15 ohm at terminal voltage of 300 V when running at a speed of 625rpm. Find the armature current, the generated emf and the flux per pole.
- **Qn 6:** A load of 20 kW at 230 V is supplied by a compound DC generator. If the series, shunt field and armature resistances are 0.05, 115 and 0.1 ohm respectively. Calculate the generated emf when the generator is connected as long shunt

Solution Q5

The conventional diagram is shown in Fig.

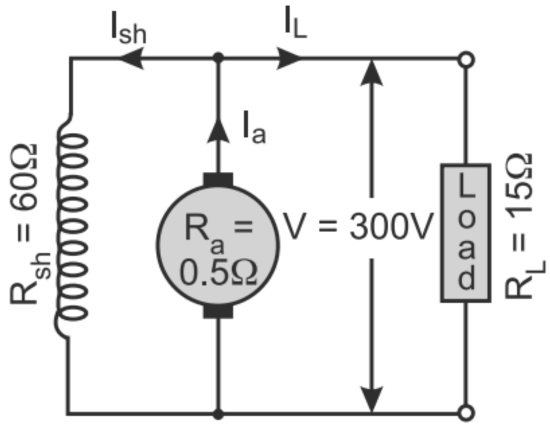
$$I_L = \frac{V}{R_L} = \frac{300}{15} = 20A;$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{300}{60} = 5\text{ A}$$

Armature current, $I_a = I_L + I_{sh} = 20 + 5 = \mathbf{25\ A}$ (*Ans.*)

Generated emf, $E_g = V + I_a R_a$

$$= 300 + 25 \times 0{\cdot}5 = \mathbf{312{\cdot}5\ V}\ (\textit{Ans.})$$



Circuit diagram

$$E_g = \frac{\phi ZNP}{60A}$$

where, $Z = 50 \times 12 = 600$; $N = 625$ rpm; P = 12; A = 2;

$$\therefore \quad 312{\cdot}5 = \frac{f \times 600 \times 625 \times 12}{60 \times 2}$$

$$\phi = \mathbf{8{\cdot}33\ m\ Wb}\ (\textit{Ans.})$$

Solution Q6

$$\text{Load} = 20\text{ kW} = 20 \times 10^3\text{ W}$$

$$V = 230\text{ V};\ R_a = 0{\cdot}1\ \Omega;\ R_{se} = 0{\cdot}05\ \Omega;\ R_{sh} = 115\ \Omega$$

Line current, $$I_L = \frac{20 \times 10^3}{230} = 86 \cdot 96\ \text{A}$$

Shunt field current, $$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{115} = 2\text{A}$$

Armature current, $$I_a = I_L + I_{sh} = 86{\cdot}96 + 2 = 88{\cdot}96\ \text{A}$$

Generated emf, $$E_g = V + I_a R_a + I_a R_{se}$$

$$= 230 + 88{\cdot}96 \times 0{\cdot}1 + 88{\cdot}96 \times 0{\cdot}05$$

$$= \mathbf{243{\cdot}3\ V}\ (\textit{Ans.})$$

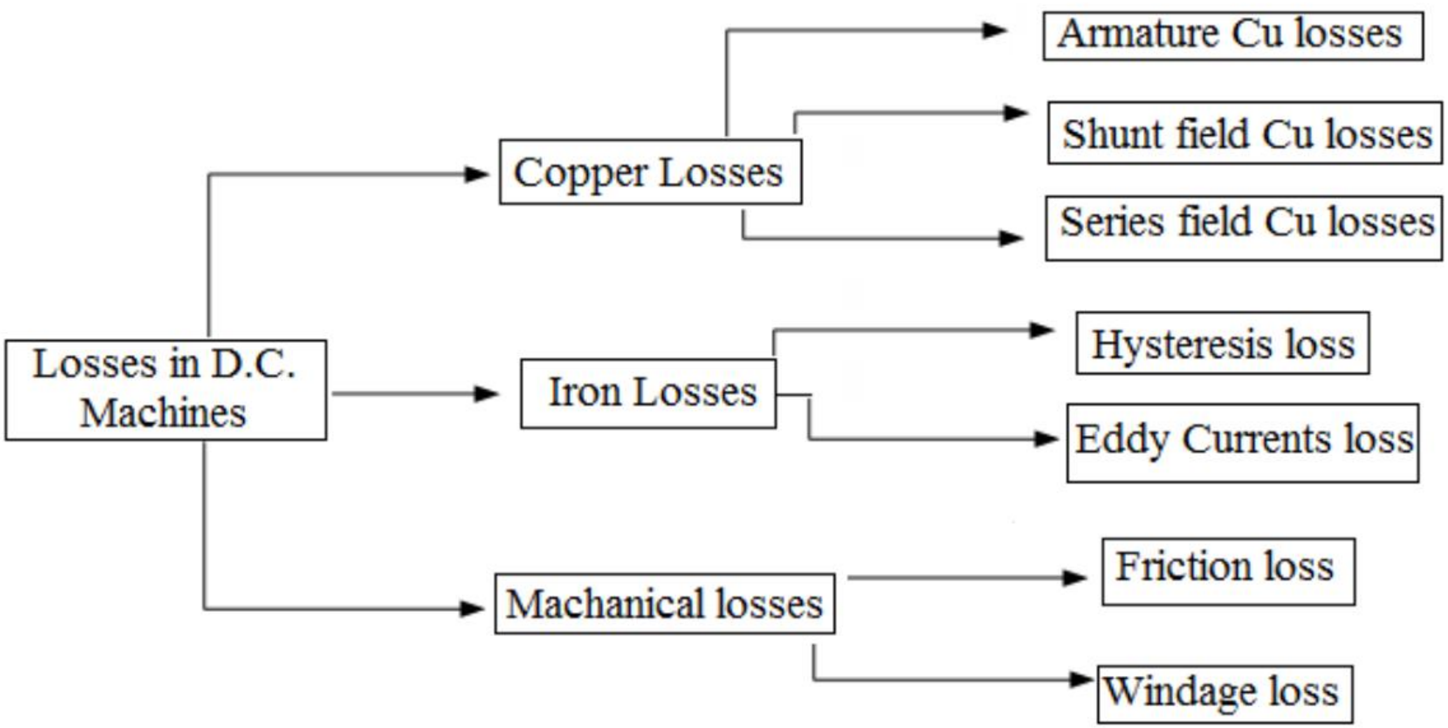
Practice Questions

Qn.1 In a 120V compound generator, the resistance of the armature, shunt and series are 0.06 Ω, 25 Ω and 0.04 Ω respectively. The load currents is 100 A at 120 V. Find the induced emf and the armature current when the machine is connected as (i) long-shunt and as (ii) short shunt.

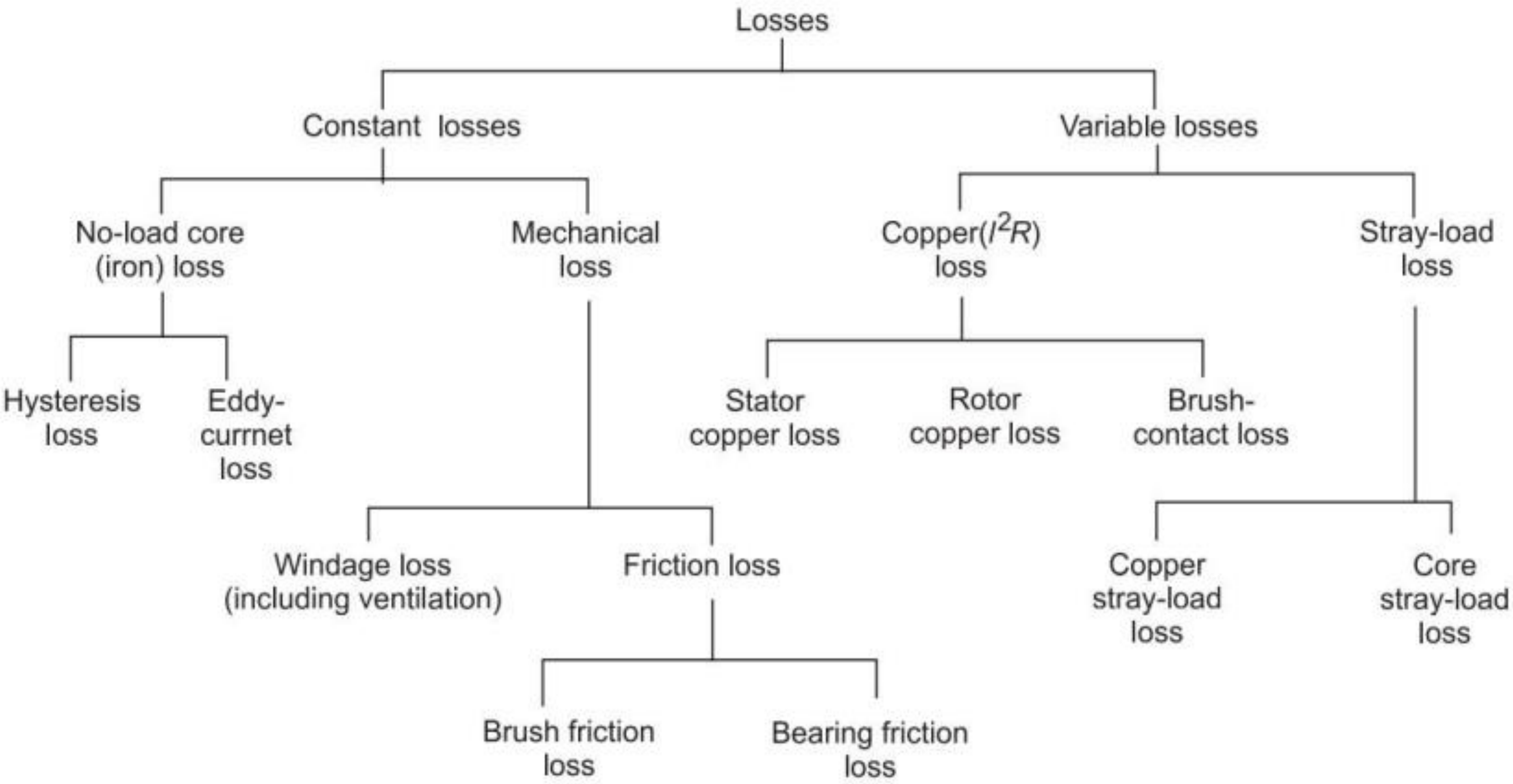
Qn. 2. An 8 pole d.c. shunt generator with 778 wave-connected armature conductors and running at 500 rpm supplies a load of 12.5 Ω resistance at terminal voltage of 50 V. The armature resistance is 0.24 Ω and the field resistance is 250 Ω. Find the armature current, the induced e.m.f. and the flux per pole.

Losses in DC Machines

- The losses in a d.c. machine (generator or motor) may be divided into three classes :
  - ✓ copper losses
  - ✓ iron or core losses and
  - ✓ mechanical losses.
- All these losses appear as heat and thus raise the temperature of the machine.
- They also lower the efficiency of the machine.



Classification of losses for Rotating Machines



Losses in a D.C. Machine

1. **Copper Losses:**
   These losses occur due to currents in the various windings of the machine, i.e;
   (i) Armature copper loss $= I_a^2 R_a$
   (ii) Shunt field copper loss $= I_{sh}^2 R_{sh}$
   (iii) Series field copper loss $= I_{se}^2 R_{se}$

   Note. The brush contact loss is included in armature copper loss.
2. **Iron / Core Losses:**
   They armature of and are due to the rotation of armature in the magnetic field of the poles. They are of two types i.e.,
   (i) hysteresis loss
   (ii) eddy current loss.
3. **Mechanical losses:**
   (i) friction loss e.g., bearing friction, brush friction etc.
   (ii) windage loss i.e., air friction of rotating armature.

   These losses depend upon the speed of the machine. But for a given speed, they are practically constant.

   Note: Iron and mechanical losses together are called **stray losses**

Constant and Variable Losses

1. **Constant Losses:**

✓ Those losses in a d.c. generator which remain constant at all loads are known as constant losses.

✓ The constant losses in a d.c. generator are:

(i) iron losses
(ii) mechanical losses
(iii) shunt field losses ($I_{sh}^2 R_{sh}$)

2. **Variable Losses:**

✓ Those losses in a d.c. generator which vary with load are called variable losses.

✓ The variable losses in a d.c. generator are:

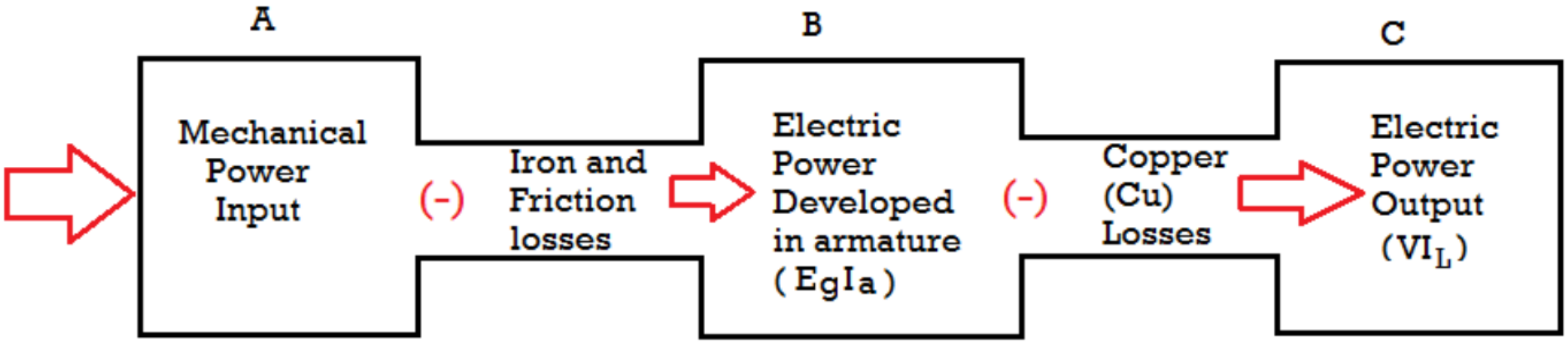
(i) Armature copper loss ($I_a^2 R_a$)
(ii) Series field copper loss ($I_{se}^2 R_{se}$)

Total losses = Constant losses + Variable losses

Note. Field Cu loss is constant for shunt and compound generators.

Power Stages in DC Generator

- The various power stages in a d.c. generator are represented below.



(i) Mechanical efficiency, $\eta_m = \dfrac{B}{A} = \dfrac{E_g I_a}{\text{Mechanical Power Input}}$

(ii) Electrical efficiency, $\eta_e = \dfrac{C}{B} = \dfrac{VI_L}{E_g I_a}$

(iii) Commercial or overall efficiency, $\eta_c = \dfrac{C}{A} = \dfrac{VI_L}{\text{Mechanical Power Input}}$

Clearly, $\eta_c = \eta_m \times \eta_e$

For good generators, its value may be as high as 95%.

Note. Unless specified otherwise, commercial efficiency is always to be understood.

Efficiency of a DC Generator

The ratio of output power to the input power of a DC generator is called its *efficiency*.

$$\text{Efficiency, } \eta = \frac{\text{output}}{\text{Input}} \text{; where, Power output} = VI_L \text{ watt}$$

$$\text{Power input} = \text{Power output} + \text{Variable losses} + \text{Constant losses}$$

Since the shunt field current I_{sh} is very small as compared to line current,

therefore, $\qquad I_L \cong I_a$ (neglecting I_{sh})

$\therefore \qquad$ Variable losses $= I_L^2 \; R_a$

Constant losses $= P_c$ (say)

Then, power output $= VI_L + I_L^2 R_a + P_c$

$$\therefore \qquad \boxed{\eta = \frac{VI_L}{VI_L + I_L^2 R_a + P_c}}$$

Condition for Maximum Efficiency

- Generator input = Output + Losses

$$
\begin{aligned}
&= VI_L + \text{Variable losses} + \text{Constant losses} \\
&= VI_L + I_a^2 R_a + W_C \\
&= VI_L + (I_L + I_{sh})^2 R_a + W_C \qquad [\because I_a = I_L + I_{sh}]
\end{aligned}
$$

- The shunt field current I_{sh} is generally small as compared to I_L and, therefore, can be neglected.

$$\therefore \ \text{Generator input} = VI_L + I_L^2 R_a + W_C$$

$$\text{Now efficiency } \eta = \frac{VI_L}{VI_L + I_L^2 R_a + W_C}$$

$$= \frac{1}{1 + \left(\frac{I_L^2 R_a}{VI_L} + \frac{W_C}{VI_L} \right)}$$

Condition for Maximum Efficiency

- The efficiency will be maximum when the denominator of the above equation is minimum i.e

$$\frac{d}{dI_L}\left(\frac{I_L^2 R_a}{VI_L}+\frac{W_C}{VI_L}\right)=0 \implies \frac{R_a}{V}-\frac{W_C}{VI_L^2}$$

$$\therefore W_C = I_L^2 R_a \text{ Variable loss} = \text{Constant loss}$$

- Hence, the efficiency of a d.c. generator will be maximum when the load current is such that variable loss is equal to the constant loss.
- The load current corresponding to maximum efficiency is given by;

$$I_L=\sqrt{\frac{W_C}{R_a}}$$

Causes of Failure to Build-up Voltage in a Generator

- There may be one or more of the following reasons due to which a generator fails to build-up voltage:
- 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: it may be due to faulty contact between brushes and commutator or commutator surface may be greasy or dirty and making no contact with the brushes.

(ii) the load circuit may have high resistance.

- ***Rectification:*** *If the generator is not building up because of absence of residual magnetism due to any reason, the field coils should be connected to a DC source for a small period in order to magnetize the poles.*

Practice Questions

- **Qn.1** A shunt generator supplies 195 A at 220 V. Armature resistance is 0.02 ohm, shunt field resistance is 44 ohm. If the iron and friction losses amount to 1600 watt, find

  (i) emf generated;

  (ii) copper losses;

  (iii) power of the engine driving the generator.

- **Qn.2** A shunt generator supplies 96 A at a terminal voltage of 200 V. The armature and shunt field resistances are 0.1 Ω and 50 Ω respectively. The iron and frictional losses are 2500 W. Find:

  (i) e.m.f. generated

  (ii) copper losses

  (iii) commercial efficiency

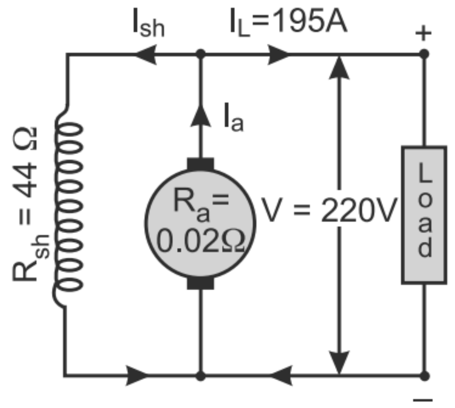
Solution Qn1

The conventional circuit is shown in Fig.

Shunt field current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{44} = 5\text{A}$$

Armature current, $I_a = I_L + I_{sh} = 195 + 5 = 200$ A



Generated or induced emf,

$$E_g = V + I_a R_a = 220 + 200 \times 0.02 = \mathbf{224\ V}\ (Ans.)$$

Armature copper loss;

$$= I_a^2 R_a = (200)^2 \times 0.02 = 800 \text{ W}$$

$$\text{Shunt field copper loss} = I_{sh}^2 R_{sh} = (5)^2 \times 44 = 1100 \text{ W}$$

$$\text{Total copper losses} = 800 + 1100 = \mathbf{1900\ W}\ (Ans.)$$

$$\text{Output power} = VI_L = 220 \times 195 = 42900 \text{ W}$$

$$\text{Input power} = 42900 + 1600 + 1900 = 46400 \text{ W}\ (Ans.)$$

Practice Questions

- **Qn.1** A shunt generator delivers 195A at terminal p.d. of 250V. The armature resistance and shunt field resistance are 0.02Ω and 50Ω respectively. The iron and friction losses equal 950 W. Find, (a) E.M.F generated (b) Cu losses (c) output of the prime mover (d) commercial, mechanical and electrical efficiencies

- **Qn.2** A short shunt compound dc generator supplies a current of 100 A at 220 V. The resistances of the armature, shunt field and series field are 0.05 Ω, 50 Ω , and 0.025 Ω respectively. Iron and friction losses amount to 1 kW. Find:

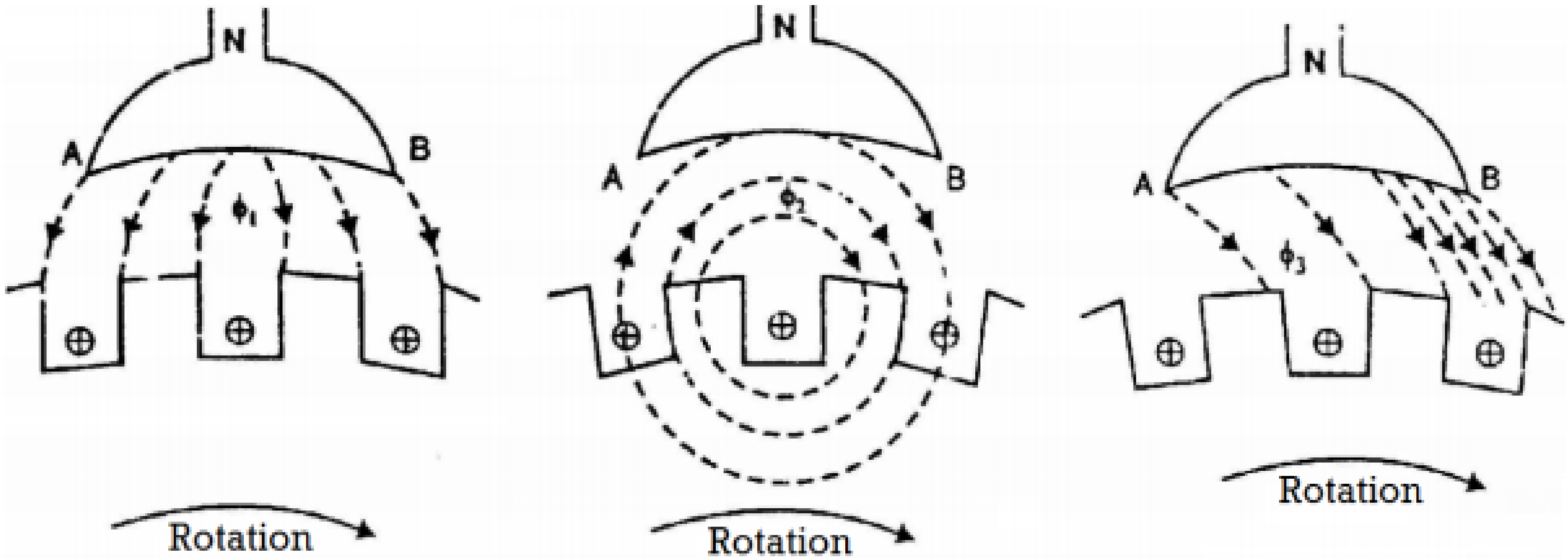
(i) The e.m.f. generated **[227.72 V]**

(ii) The copper losses **[1790 W]**

(iii) commercial efficiency **[88.74 %]**

Armature Reaction in D.C. Machines

- There are two kinds of magnetic fluxes acting in DC Generator
- The first one is because of the stator poles called **main flux**, while the second one is because of the current flowing in the armature called **armature flux**.
- This armature flux weakens and distort the main flux, thus the overall effective flux in DC Generator decrease.
- This mutual action of armature flux on the main field flux is known as **armature reaction**.



(i) Main Flux (ii) Armature Flux (iii) Effective distorted flux

Geometrical and Magnetic Neutral Axes

- EMF is induced in the armature conductors when they cut the magnetic field lines.
- But, there is an axis along which armature conductors move parallel to the flux lines and, hence, they do not cut the flux lines at the moment.
- This is defined as Magnetic Neutral Axis (M.N.A.) and no emf is generated in the conductors as they move parallel to the flux lines.
- Brushes are always placed along MNA otherwise, it will lead to sparking at the surface of brushes.
- Geometrical Neutral Axis (GNA) may be defined as the axis which is perpendicular to the stator field axis

The adverse effects of armature reaction.

- Armature reaction weakens the main flux. In case of a dc generator, weakening of the main flux reduces the generated voltage.
- Armature reaction distorts the main flux, hence it is hard to determine the exact position of M.N.A.

Reducing Armature Reaction in D.C. Machines

- Usually, no special efforts are taken for small machines (up to few kW) to reduce the armature reaction.
- For large DC machines, compensating winding and interpoles are used,

1. **Using Compensating Winding**
   - Now, if we place another winding in close proximity of the armature winding and if it carries the same current but in the opposite direction as that of the armature current then this will nullify the armature field.
   - Such an additional winding is called as **compensating winding** and it is placed on the pole faces.
   - Compensating winding is connected in series with the armature winding in such a way that it carries the current in opposite direction.
2. **Using Interpoles**
   - They are small poles placed in between the main poles.
   - These are connected in series with armature, so that they carry armature current.
   - The e.m.f induced by the interpoles neutralizes the effect of armature m.m.f in the intelpolar region, thus making commutation sparkless.

D.C. Generator Characteristics

- The speed of a d.c. machine operated as a generator is fixed by the prime mover.
- For general-purpose operation, the prime mover is equipped with a speed governor so that the speed of the generator is practically constant.
- Under such condition, the generator performance deals primarily with the relation between excitation, terminal voltage and load.
- These relations can be best exhibited graphically by means of curves known as generator characteristics.
- These characteristics show at a glance the behaviour of the generator under different load conditions.

- The most important characteristics of a d.c. generator are:

Open Circuit Characteristic (O.C.C.)

- This curve shows the relation between the generated e.m.f. at no-load (E_0) and the field current (I_f) at constant speed.
- It is also known as **magnetic characteristic** or **no-load saturation curve**.
- Its shape is practically the same for all generators whether separately or self-excited.
- The data for O.C.C. curve are obtained experimentally by operating the generator at no load and constant speed and recording the change in terminal voltage as the field current is varied.

Internal or Total characteristic (E/I_a)

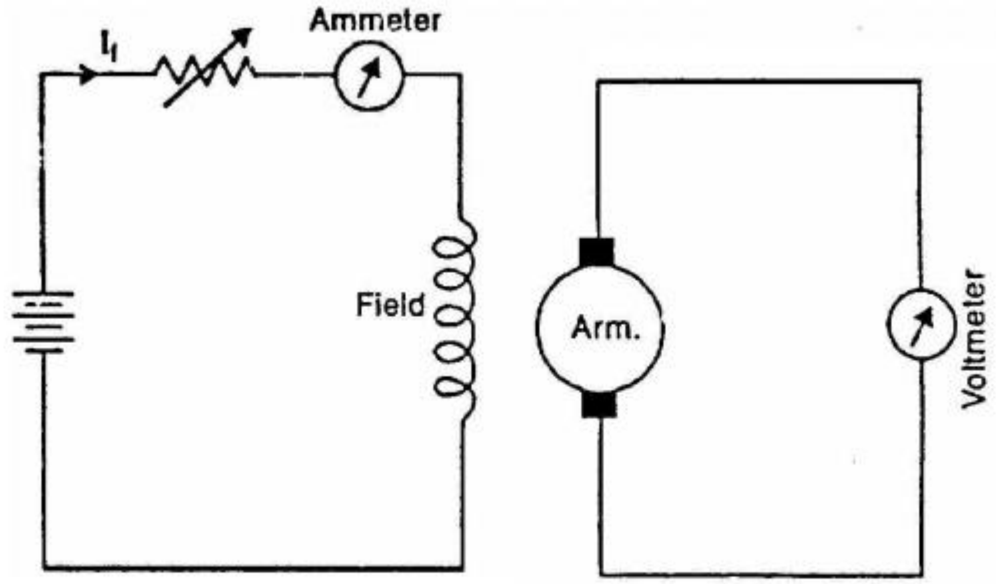
- This curve shows the relation between the generated e.m.f. on load (E) and the armature current (I_a).
- The e.m.f. E is less than E_0 due to the demagnetizing effect of armature reaction.
- Therefore, this curve will lie below the open circuit characteristic (O.C.C.).
- It cannot be obtained directly by experiment. It is because a voltmeter cannot read the e.m.f. generated on load due to the voltage drop in armature resistance.

External characteristic (V/I_L)

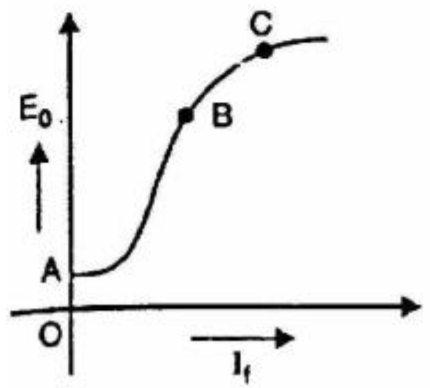
- This curve shows the relation between the terminal voltage (V) and load current (I_L).
- The terminal voltage V will be less than E due to voltage drop in the armature circuit.
- Therefore, this curve will lie below the internal characteristic.

Open Circuit Characteristic of a D.C. Generator

- The O.C.C. for a d.c. generator is determined as follows. The field winding of the d.c. generator (series or shunt) is disconnected from the machine and is separately excited from an external d.c. source as shown in Fig.(i).
- The generator is run at fixed speed (i.e., normal speed).
- The field current (I_f) is increased from zero in steps and the corresponding values of generated e.m.f. (E_0) read off on a voltmeter connected across the armature terminals. On plotting the relation between E_0 and I_f, we get the open circuit characteristic as shown in Fig. (ii).



(i)



(ii)

The following points may be noted from O.C.C.:

- When the field current is zero, there is some generated e.m.f. OA. This is due to the residual magnetism in the field poles.

- Over a fairly wide range of field current (up to point B in the curve), the curve is linear. It is because in this range, reluctance of iron is negligible as compared with that of air gap. The air gap reluctance is constant and hence linear relationship.

- After point B on the curve, the reluctance of iron also comes into picture. It is because at higher flux densities, μ_r for iron decreases and reluctance of iron is no longer negligible. Consequently, the curve deviates from linear relationship.

- After point C on the curve, the magnetic saturation of poles begins and E_0 tends to level off.

- The O.C.C. of even self-excited generator is obtained by running it as a separately excited generator.

Characteristics of a Separately Excited D.C. Generator

Open circuit characteristic.

- Fig.(i) shows the variation of generated e.m f. on no load with field current for various fixed speeds.
- Note that if the value of constant speed is increased, the steepness of the curve also increases.
- When the field current is zero, the residual magnetism in the poles will give rise to the small initial e.m.f. as shown.

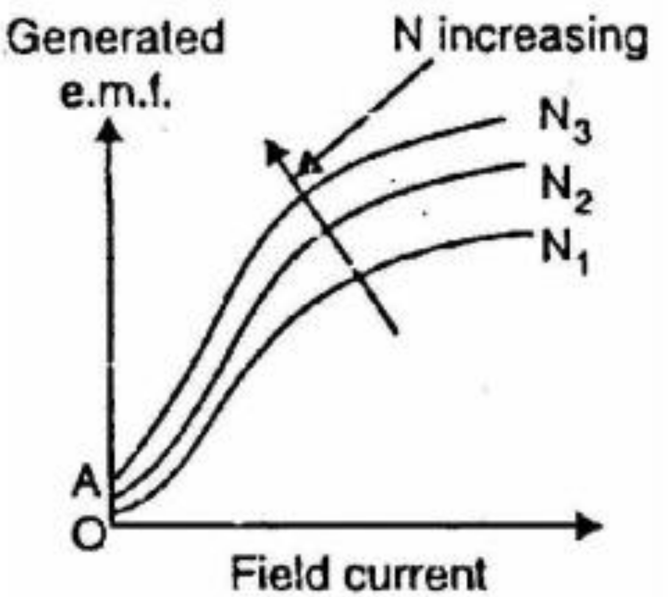
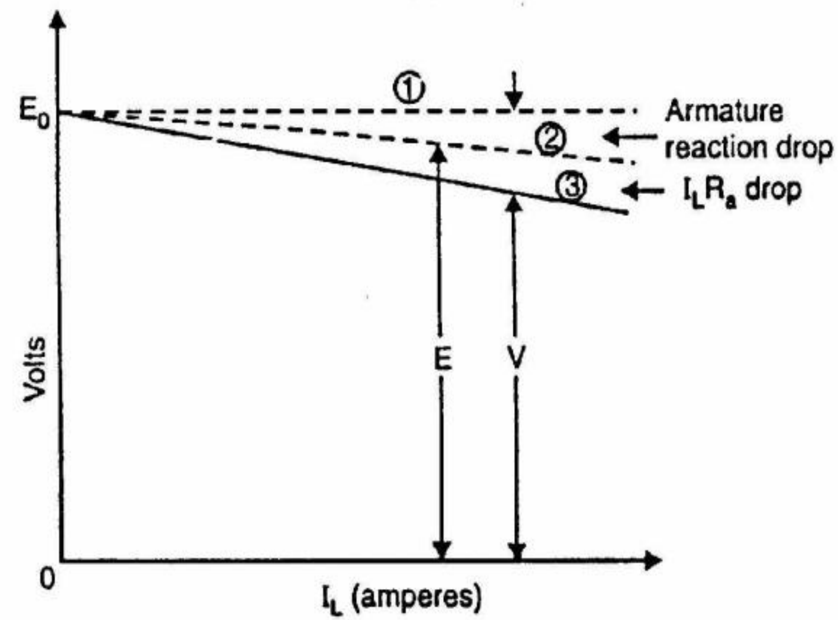


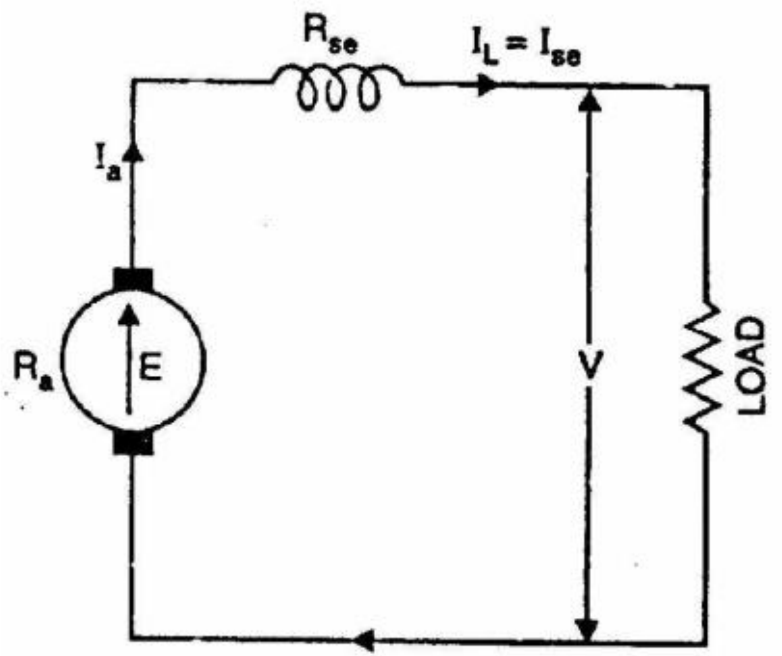
Fig (i)

Internal and External Characteristics

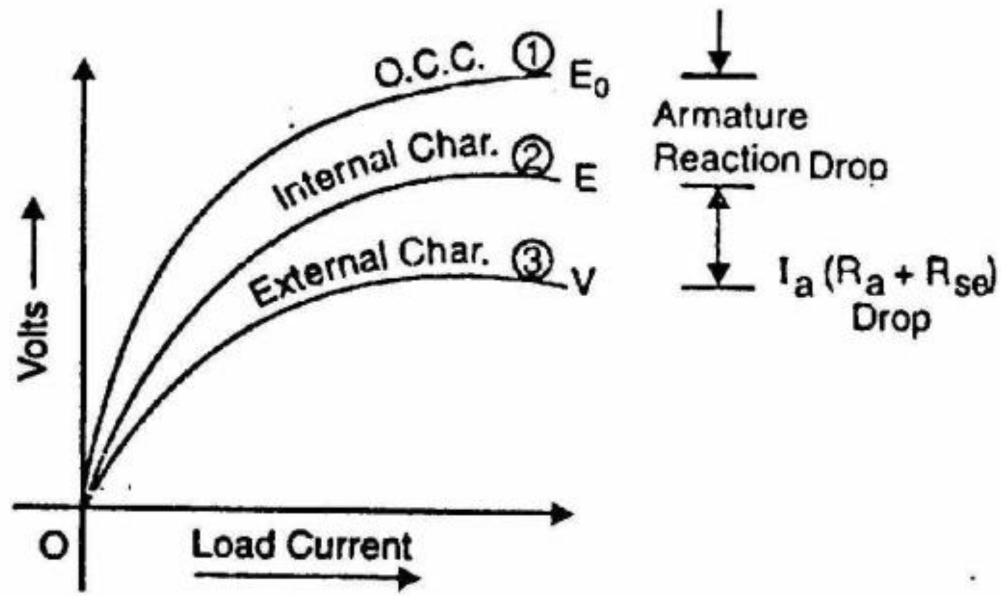
- The external characteristic of a separately excited generator is the curve between the terminal voltage (V) and the load current I_L
- As the load current increases, the terminal voltage falls due to two reasons:
  - ✓ The armature reaction weakens the main flux so that actual e.m.f. generated E on load is less than that generated (E_0) on no load.
  - ✓ There is voltage drop across armature resistance (= I_L*R_a = I_a*R_a).
- Due to these reasons, the external characteristic is a drooping curve [curve 3].
- Note that in the absence of armature reaction and armature drop, the generated e.m.f. would have been E_0 (curve 1).
- The internal characteristic can be determined from external characteristic by adding I_L*R_a drop to the external characteristic. It is because armature reaction drop is included in the external characteristic.
- Curve 2 is the internal characteristic of the generator and should obviously lie above the external characteristic.



Characteristics of Series Generator



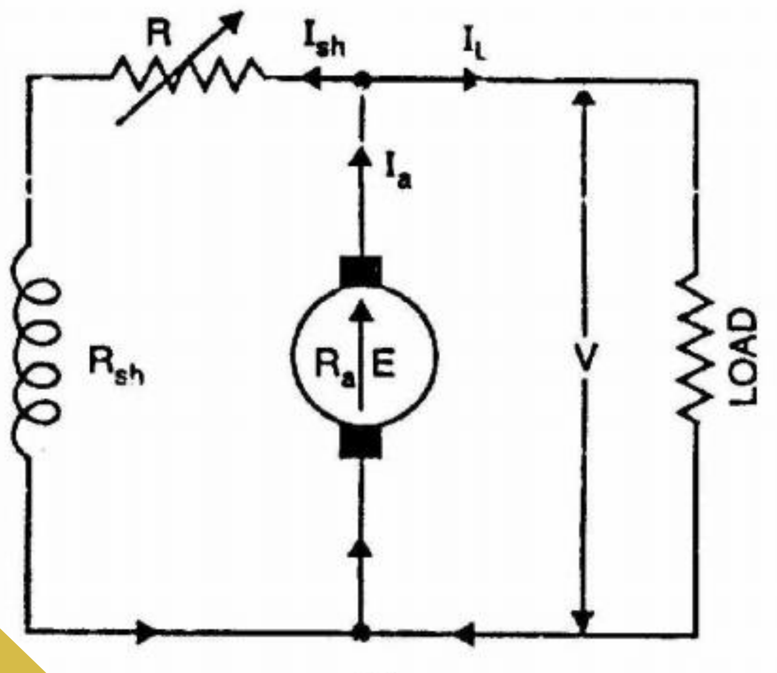
(i)



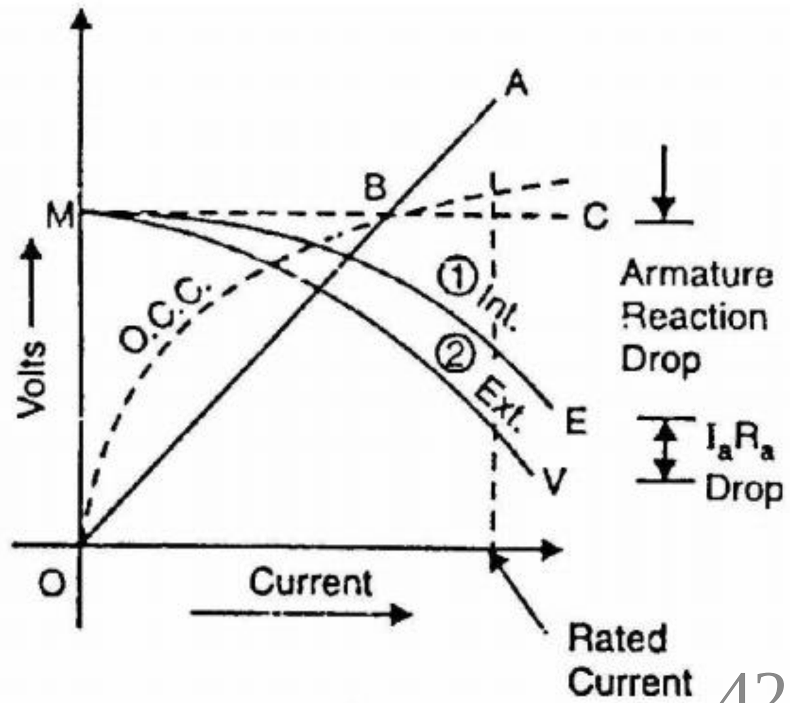
(ii)

Characteristics of a Shunt Generator

- The O.C.C. of a shunt generator is similar in shape to that of a series generator as shown in Fig. (ii). The line OA represents the shunt field circuit resistance. When the generator is run at normal speed, it will build up a voltage OM. At no-load, the terminal voltage of the generator will be constant (= OM) represented by the horizontal dotted line MC



(i)



(ii)

Internal characteristic

- When the generator is loaded, flux per pole is reduced due to armature reaction.
- Therefore, e.m.f. E generated on load is less than the e.m.f. generated at no load.
- As a result, the internal characteristic (E/I_a) drops down slightly as shown in Fig.(ii).

- **External characteristic**
- Curve 2 shows the external characteristic of a shunt generator. It gives the
- relation between terminal voltage V and load current I_L.

$$V = E - I_a R_a = E - \left(I_L + I_{sh}\right) R_a$$

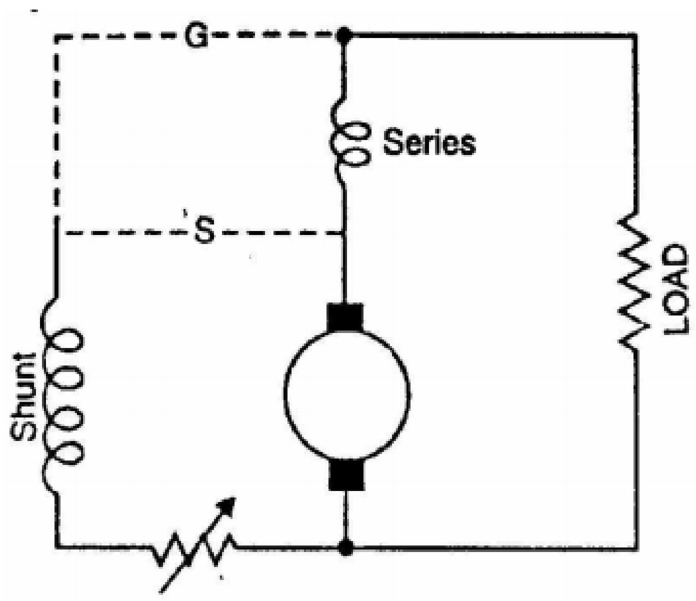
- Therefore, external characteristic curve will lie below the internal characteristic curve by an amount equal to drop in the armature circuit [i.e., $(I_L + I_{sh})R_a$] as shown in Fig.(ii).

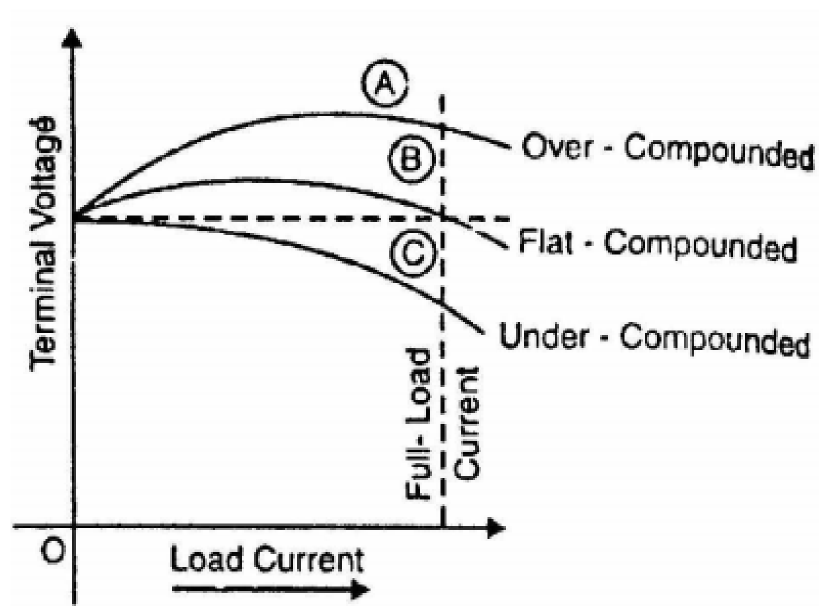
- **Note.** It may be seen from the external characteristic that change in terminal voltage from no-load to full load is small. The terminal voltage can always be maintained constant by adjusting the field rheostat R automatically

Compound Generator Characteristics

External characteristic

- Fig. shows the external characteristics of a cumulatively compounded generator
- The series excitation aids the shunt excitation.
- The degree of compounding depends upon the increase in series excitation with the increase in load current.





- If series winding turns are so adjusted that with the increase in load current the terminal voltage increases, it is called over-compounded generator. In such a case, as the load current increases, the series field m.m.f. increases and tends to increase the flux and hence the generated voltage. The increase in generated voltage is greater than the (I_aR_a) drop so that instead of decreasing, the terminal voltage increases as shown by curve A.
- If series winding turns are so adjusted that with the increase in load current, the terminal voltage substantially remains constant, it is called flat-compounded generator. The series winding of such a machine has lesser number of turns than the one in over-compounded machine and, therefore, does not increase the flux as much for a given load current. Consequently, the full-load voltage is nearly equal to the no-load voltage as indicated by curve B.
- If series field winding has lesser number of turns than for a flat compounded machine, the terminal voltage falls with increase in load current as indicated by curve C. Such a machine is called under-compounded generator.

Voltage Regulation in DC Generator

- The change in terminal voltage of a generator between full and no load (at constant speed) is called the **voltage regulation**.
- It usually expressed as a percentage of the voltage at full-load.

$$\% \text{ Voltage Regulation } = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

where V_{NL} = Terminal voltage of generator at no load

V_{FL} = Terminal voltage of generator at full load

- Note that voltage regulation of a generator is determined with field circuit and speed held constant.
- If the voltage regulation of a generator is 10%, it means that terminal voltage increases 10% as the load is changed from full load to no load.

Parallel Operation of D.C. Generators

- In a d.c. power plant, power is usually supplied from several generators of small ratings connected in parallel instead of from one large generator. This is due to the following reasons:

Continuity of service

- If a single large generator is used in the power plant, then in case of its breakdown, the whole plant will be shut down.
- However, if power is supplied from a number of small units operating in parallel, then in case of failure of one unit, the continuity of supply can be maintained by other healthy units.

Efficiency

- Generators run most efficiently when loaded to their rated capacity.
- Electric power costs less per kWh when the generator producing it is efficiently loaded.
- Therefore, when load demand on power plant decreases, one or more generators can be shut down and the remaining units can be efficiently loaded

Maintenance and repair

- Generators generally require routine-maintenance and repair.
- Therefore, if generators are operated in parallel, the routine or emergency operations can be performed by isolating the affected generator while load is being supplied by other units.
- This leads to both safety and economy.

Increasing plant capacity

- In the modern world of increasing population, the use of electricity is continuously increasing.
- When added capacity is required, the new unit can be simply paralleled with the old units.

Non-availability of single large unit

- In many situations, a single unit of desired large capacity may not be available.
- In that case a number of smaller units can be operated in parallel to meet the load requirement.
- Generally a single large unit is more expensive.

Self Assessment

- What are the requirements of self-excited DC machine? Or What are the conditions to be fulfilled for a DC shunt generator to build-up emf?
- With aid of diagrams differentiate a short compound generator from a long compound generator.
- Define critical resistance of DC shunt generator.
- Name the various parts of a DC machine and give their function.
- Derive emf equation of a DC generator (or DC machine).
- A 1500kW, 600V, 16 pole, separately excited d.c generator runs at 200rpm. It has 2500 lap connected conductors and full load copper losses are 25kW. Find the useful flux per pole. If average flux density is 0.85Wb/m^2 , find area of pole shoe. [0.0723Wb, 0.0861 m^2]