# DC Generator Induced EMF and Classification



***Acknowledgement:*** *The materials presented in this lecture has been taken from open source, reference books etc. This can be used only for student welfare and academic purpose.*

# Recap

- Constructional details of DC Machines
- Fleming's Right Hand Rule
- Operation of the generator and motor
- Induced EMF
- Armature Winding

# Lecture-13 Objectives

- Induced EMF
- Generating mode and motoring mode
- Methods of excitation
- Classification of DC machines

# EMF Equation of DC Generator

- Whether a DC machine working as generator or a motor, its armature rotates in the magnetic field in the air-gap.
- Armature conductors cut the magnetic flux and therefore EMF is induced in them.
- In case of generator, this emf supplies the load.
- In case of motor, this emf opposes the applied voltage.
- The expression for induced emf is same for both motor and generator.

# EMF Equation of DC Generator

- Let ϕ – flux available under each pole.

  Z – total no. of conductors in the armature

  P – No. of poles

  A – No. of parallel paths

  N – Speed of armature in rpm

  $E_g$ – Generated or Induced emf

# EMF Equation of DC Generator

- As per Faraday's law, EMF induced in a coil is,

$$E = N\frac{d\phi}{dt}$$

- Flux cut by one conductor in one revolution of the armature,

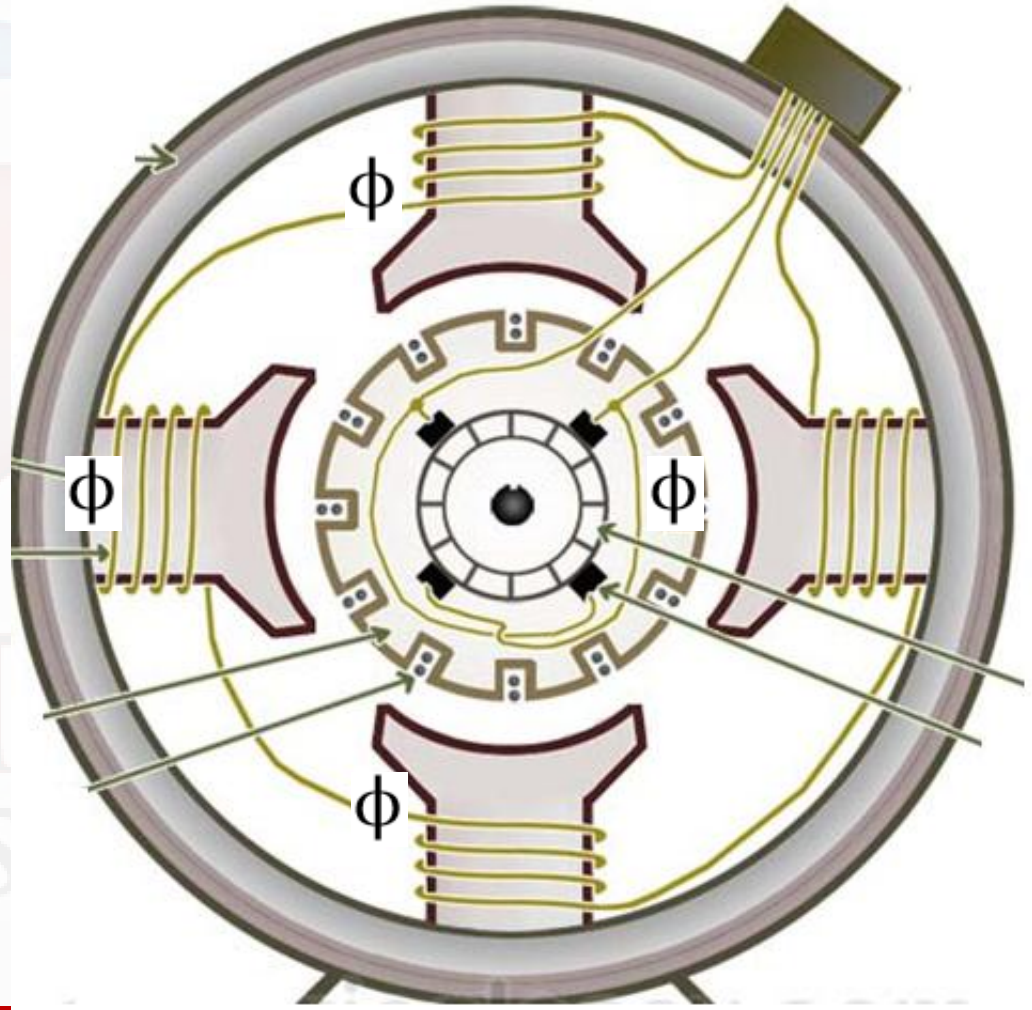
$$d\phi = P\phi \text{ webers}$$

- Time taken to complete one revolution,

$$dt = \frac{60}{N} \text{ seconds}$$

- EMF induced in one conductor is,

$$E_g = \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60} \text{ volts}$$



# EMF Equation of DC Generator

- EMF generated in whole armature is,

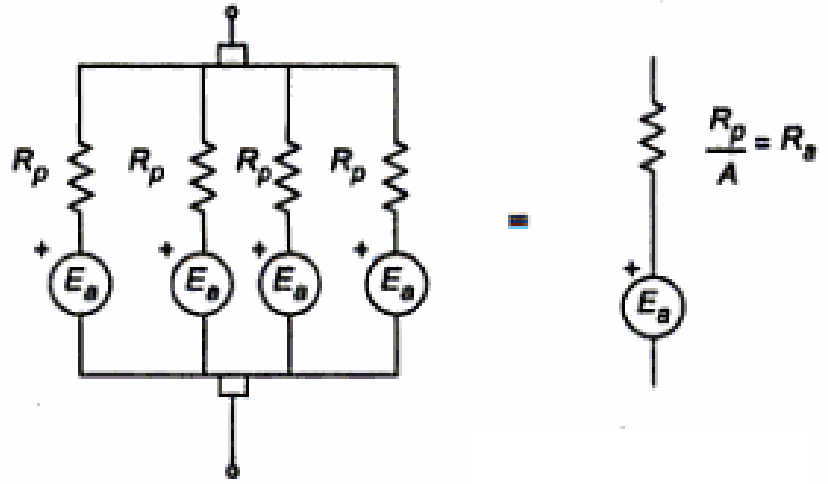
$$E_g = \frac{P\phi N}{60} \times Z \text{ volts}$$

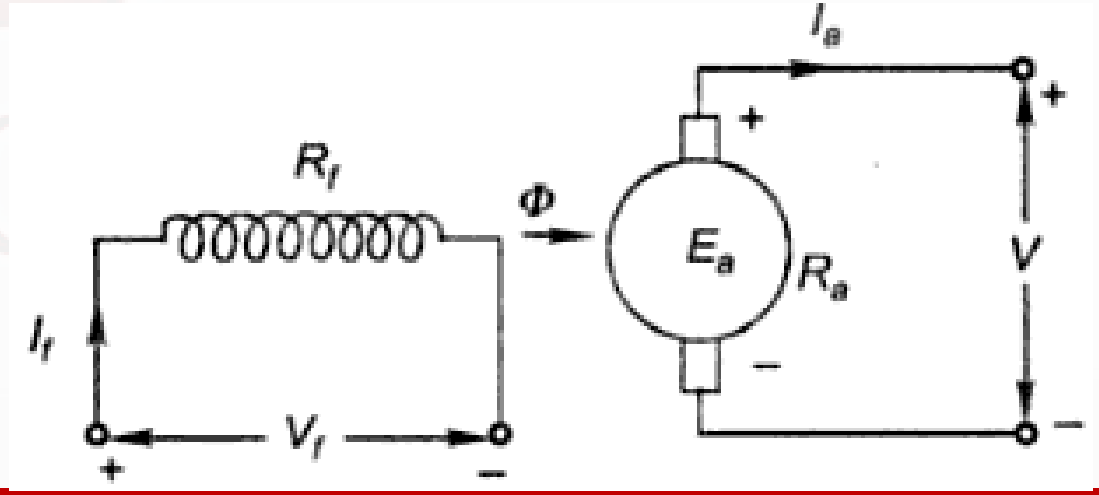
- EMF per parallel path,

$$E_g = \frac{P\phi NZ}{60\,A} = \frac{\phi ZN}{60} \times \frac{P}{A}$$

# Circuit Model of a DC Machine

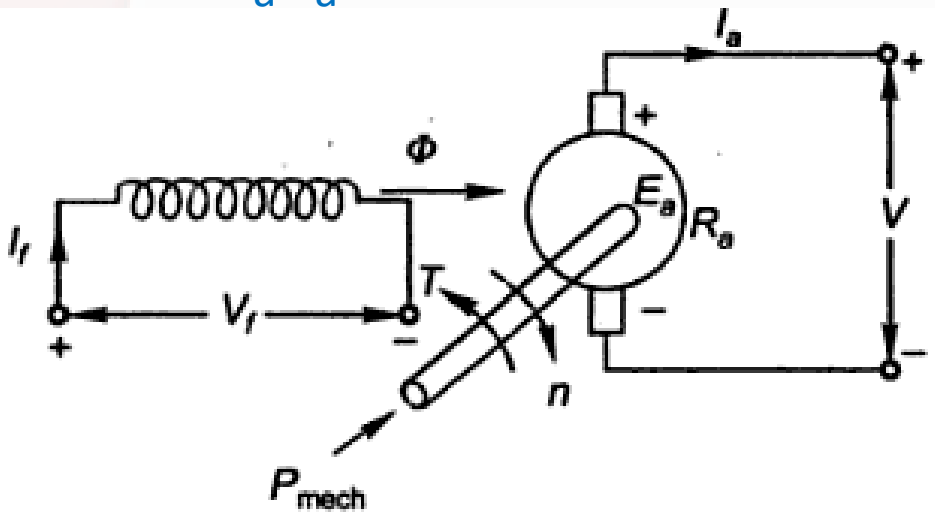
- Each parallel path of a DC machine has an induced voltage of Eg & resistance of $R_p$.
- Hence the equivalent armature resistance is ($R_p$/A) which is very small to limit copper loss to a low value.
- The voltage drop at brush – commutator contact is fixed (1 – 2V) and this effect is included with $R_a$ itself.



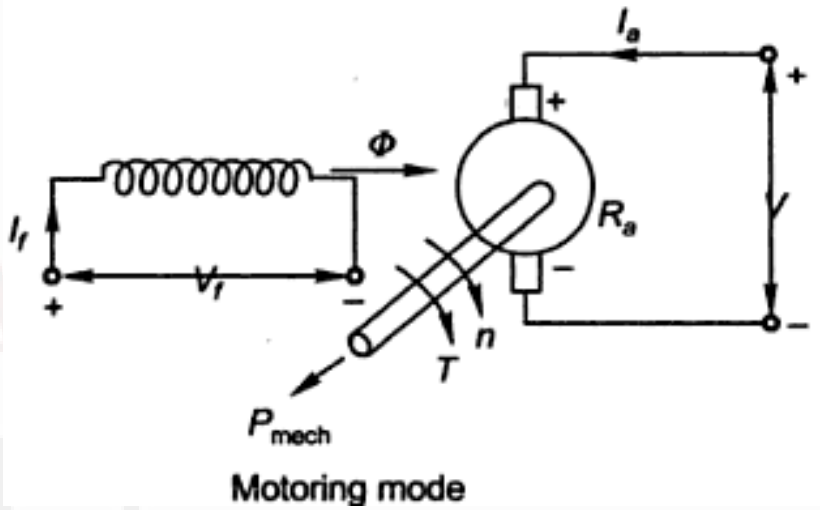
# Generating Mode

- The m/c operates in generating mode when the $I_a$ in the direction of Eg.
- For the armature circuit, $V_t = E_g - I_a.R_a$;  $E_g > V_t$
- The electrical power generated from mech power is, $E_a.I_a$
- The net electrical power output is, $P_O = V_t.I_a$
- $E_a.I_a - V_t.I_a = I_a^2.R_a$ = Armature copper loss.



# Motoring Mode

- Here $I_a$ flows in opposite to back emf $E_b$. This $E_b$ opposes the supply voltage.
- Hence for the armature circuit, $V_t = E_b + I_a.R_a$;  $E_b < V_t$
- The electrical power input is, $P_i = V_t.I_a$
- Hence $V_t.I_a - E_a.I_a = I_a^2.R_a$ = Armature copper loss



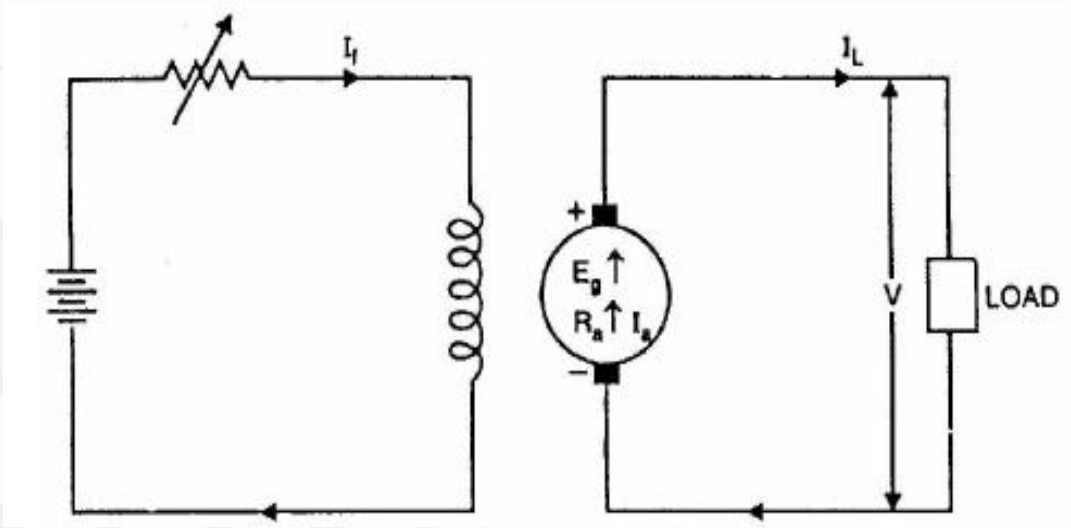
Motoring mode

# Methods of Excitation

- 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.
    - Separately excited d.c. generators
    - Self-excited d.c. generators
- The behaviour of a d.c. generator on load depends upon the method of field excitation adopted.

# Separately Excited DC generator

- Here the field is excited from a separate source independent of armature circuit.



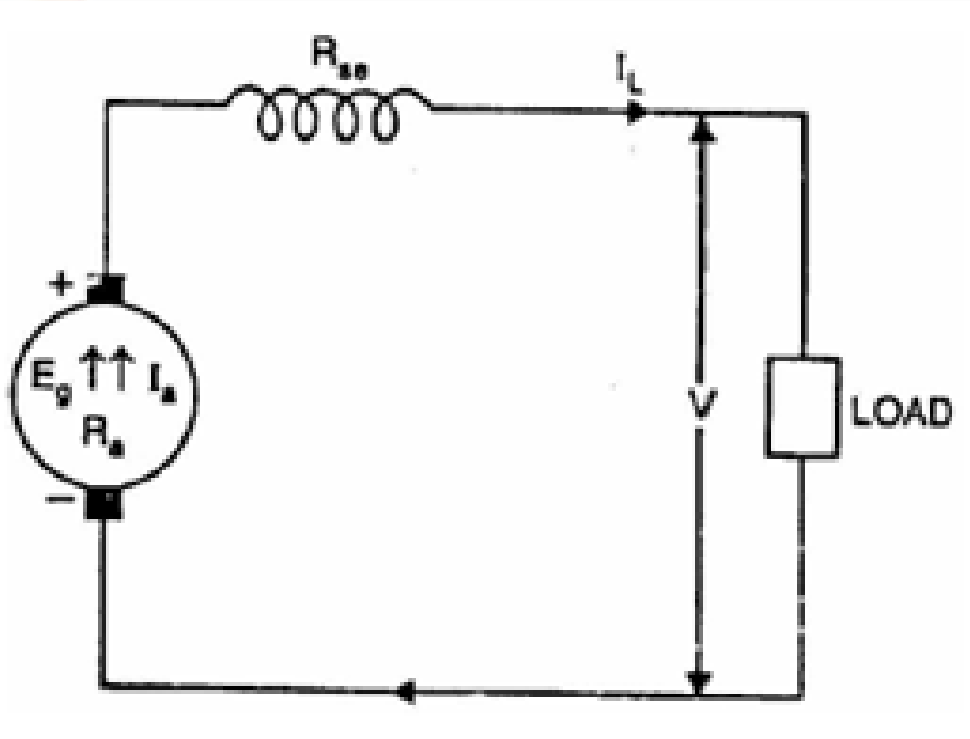

- Armature current, $I_a = I_L$
- Terminal voltage, $V_t = E_g - I_a R_a$
- Electric power developed $= E_g I_a$
- Power delivered to load $= E_g I_a - I_a^2 R_a = I_a(E_g - I_a R_a)$

# Self Excited DC Generators

- A d.c. generator whose field 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

# Series Generator

- Armature current, $I_a = I_{se} = I_L$
- Terminal voltage, $V = E_g - I_a(R_a + R_{se})$
- Power developed in armature $= E_g I_a$

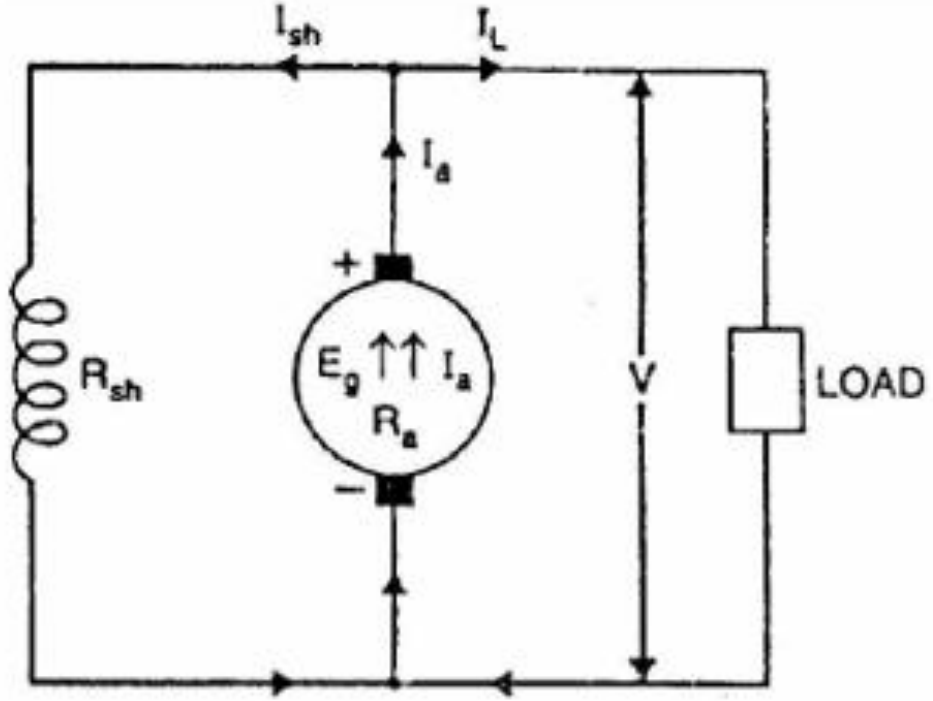



- Power delivered to load $= E_g I_a - I_a^2 R_a - I_a^2 R_{se}$

$= I_a[E_g - I_a(R_a + R_{se})] = V.I_a = V.I_L$

# Shunt Generator

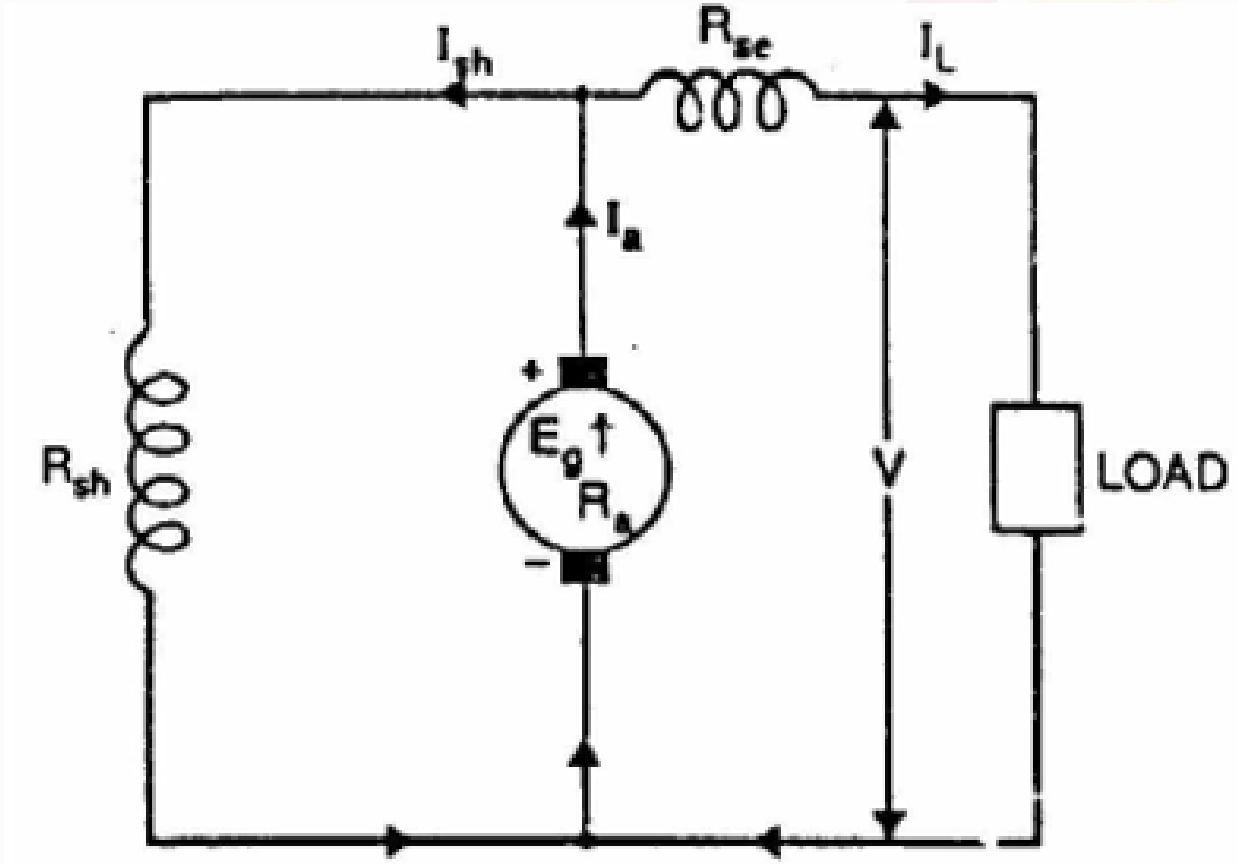
- Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$
- Armature current, $I_a = I_L + I_{sh}$
- Terminal voltage, $V = E_g - I_a R_a$
- Power developed in armature $= E_g I_a$
- Power delivered to load $= V.I_L$

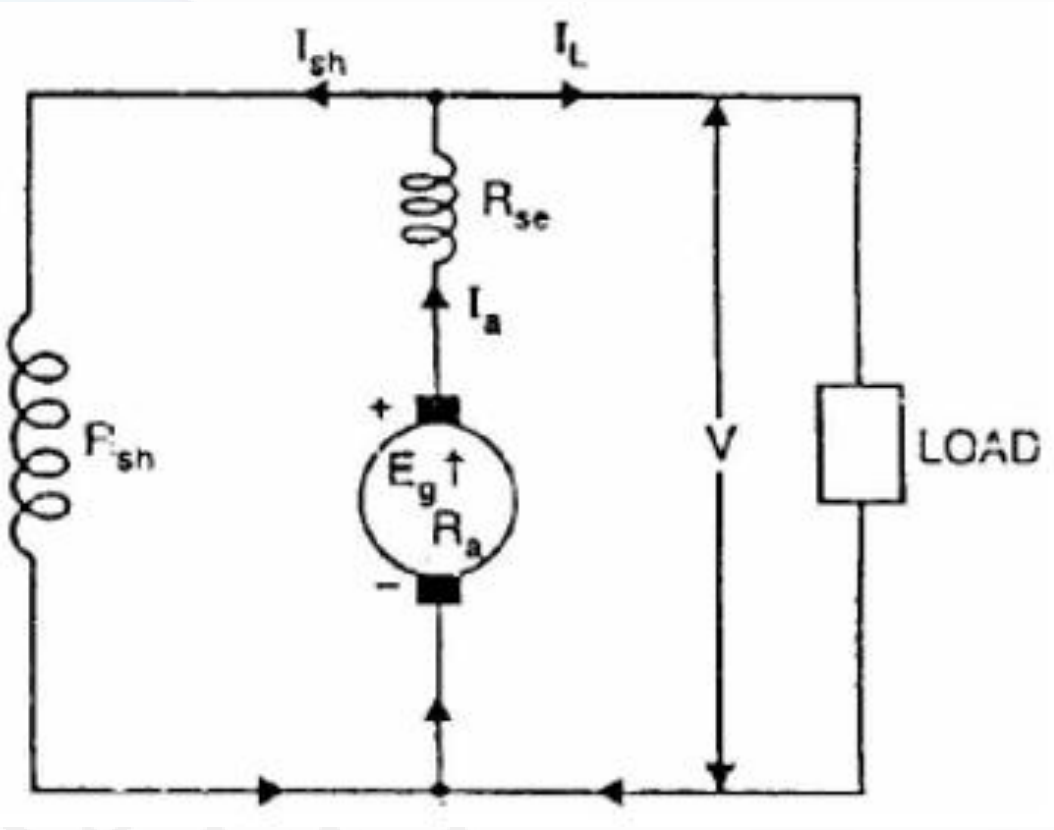


# Compound Generator

- In a compound-wound generator, there are two sets of field windings on each pole—one is in series and the other in parallel with the armature.
- Short Shunt CG – Shunt field winding alone is in parallel with the armature winding.
- Long Shunt CG – series field and armature winding are connected in series. Shunt field winding is connected in parallel with them.

# Compound Generator



# Short Shunt Compound Generator

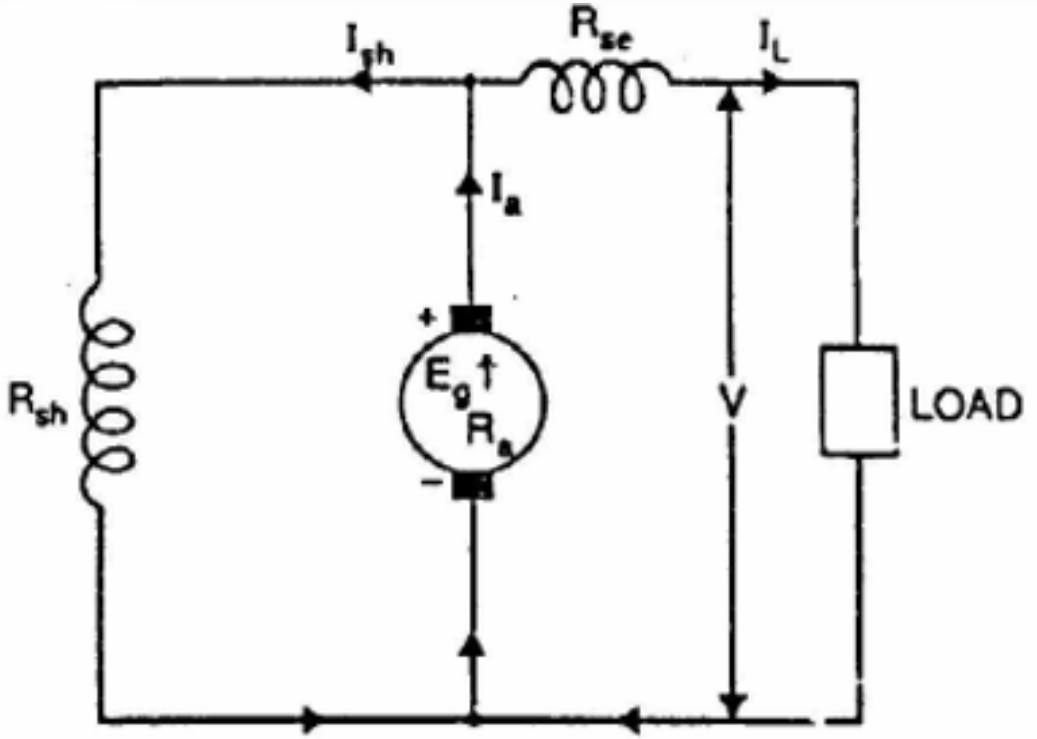
Series field current, $I_{se} = I_L$

Shunt field current, $I_{sh} = \dfrac{V + I_{se}R_{se}}{R_{sh}}$

Terminal voltage, $V = E_g - I_aR_a - I_{se}R_{se}$

Power developed in armature $= E_gI_a$

Power delivered to load $= V.I_L$



# Long Shunt Compound Generator

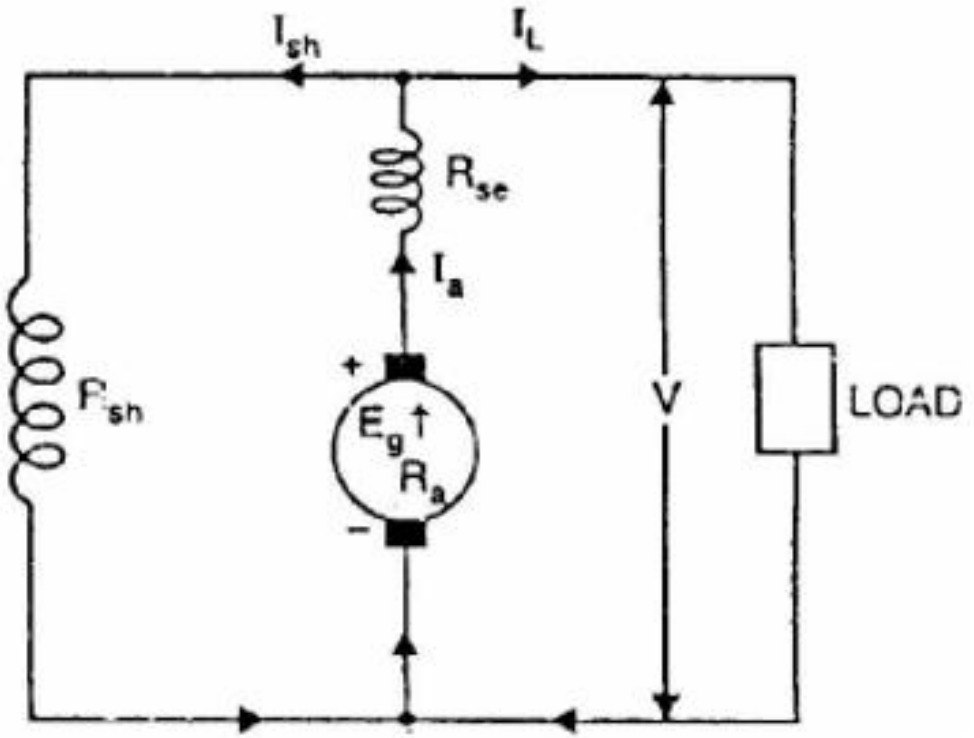
Series field current, $I_{se} = I_a = I_L + I_{sh}$

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

Terminal voltage, $V = E_g - I_a(R_a + R_{se})$

Power developed in armature $= E_g I_a$

Power delivered to load $= V.I_L$

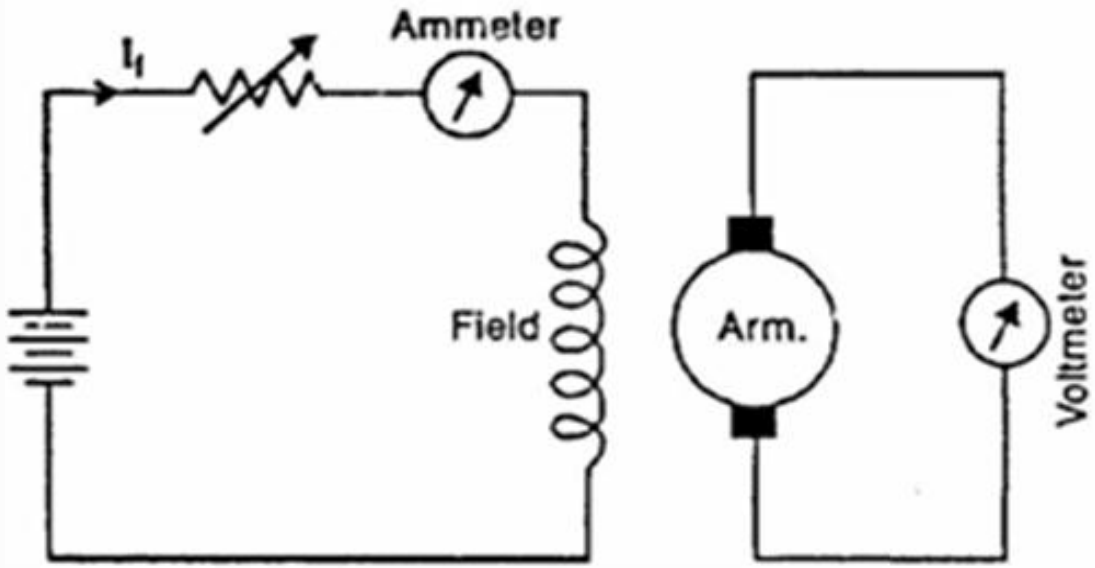


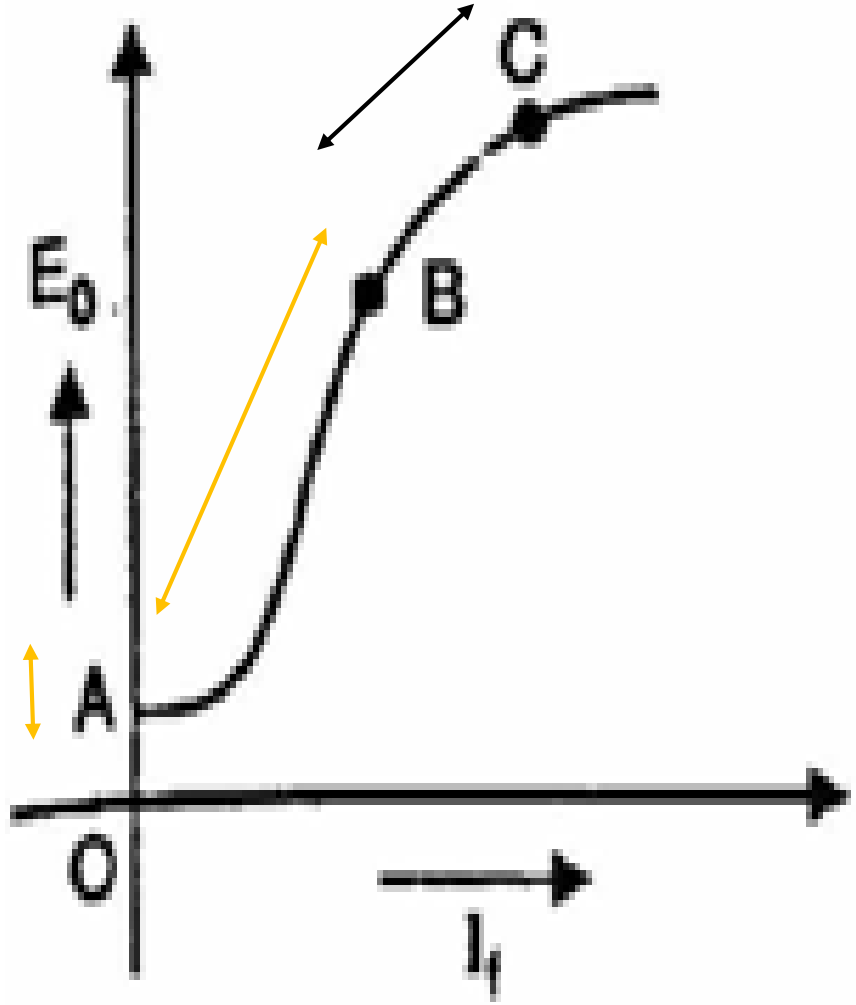
# D.C. Generator Characteristics

- The relation between excitation, terminal voltage and load can be understood graphically.
- These characteristics show the behaviour of the generator under different load conditions.
- The following are the three most important characteristics of a d.c. generator:
    - Open Circuit Characteristic (O.C.C.) – $E_g$ $V_s$ $I_f$
    - Internal characteristics – $E_g$ $V_s$ $I_a$
    - External characteristics – $V_t$ $V_s$ $I_L$

# Characteristics of a Separately Excited D.C. Generator

- **Open Circuit Characteristics**



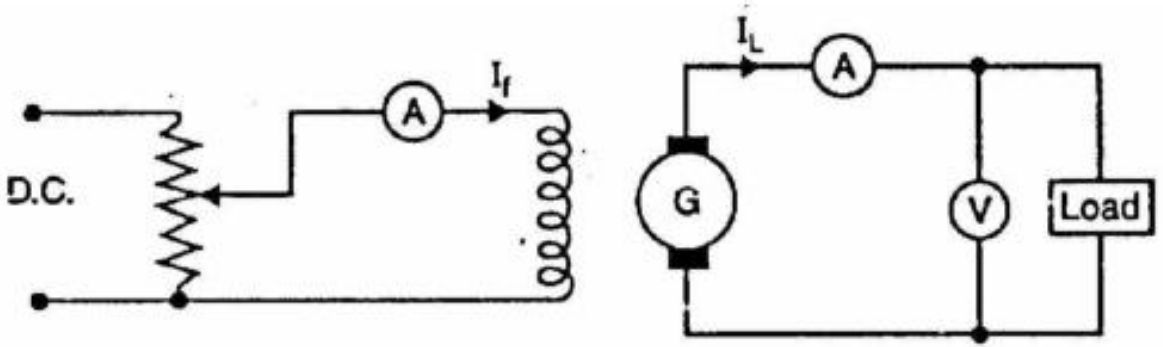

**OA – Due to residual magnetism**

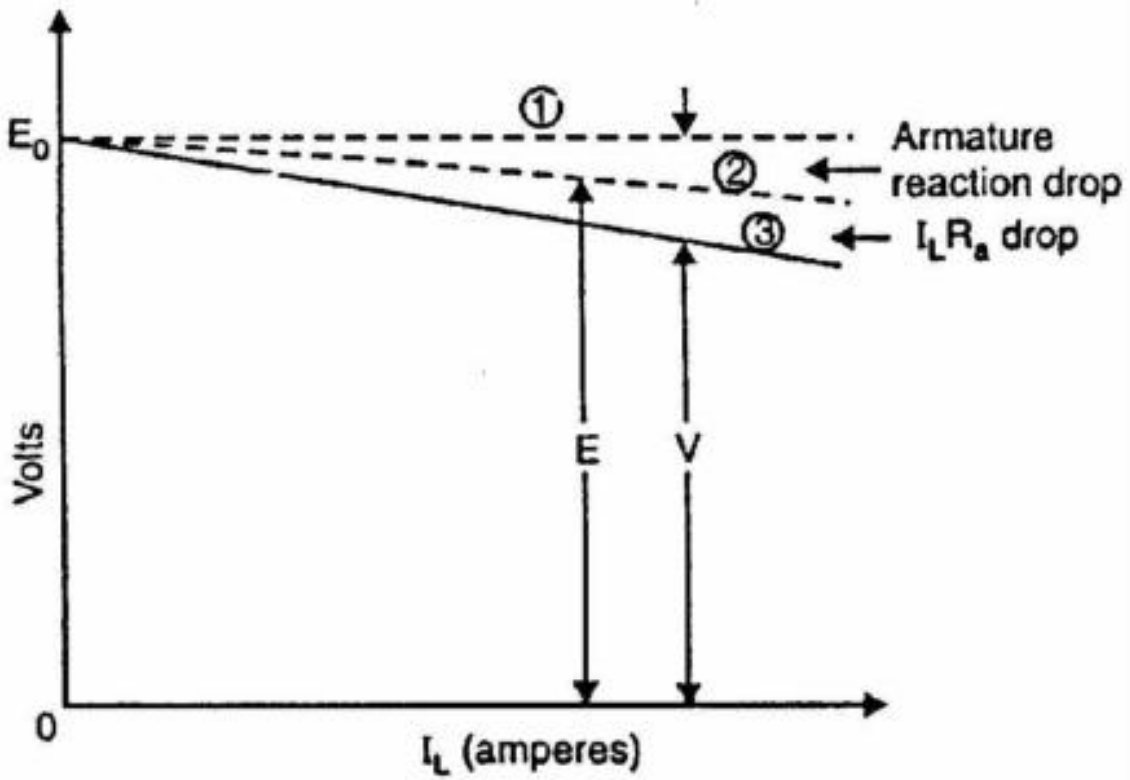
**AB – $R_i$ is negligible and $R_g$ is constant**

**BC – B is high. Hence $R_i$ increases**

# Characteristics of a Separately Excited D.C. Generator

## Internal and External Characteristics



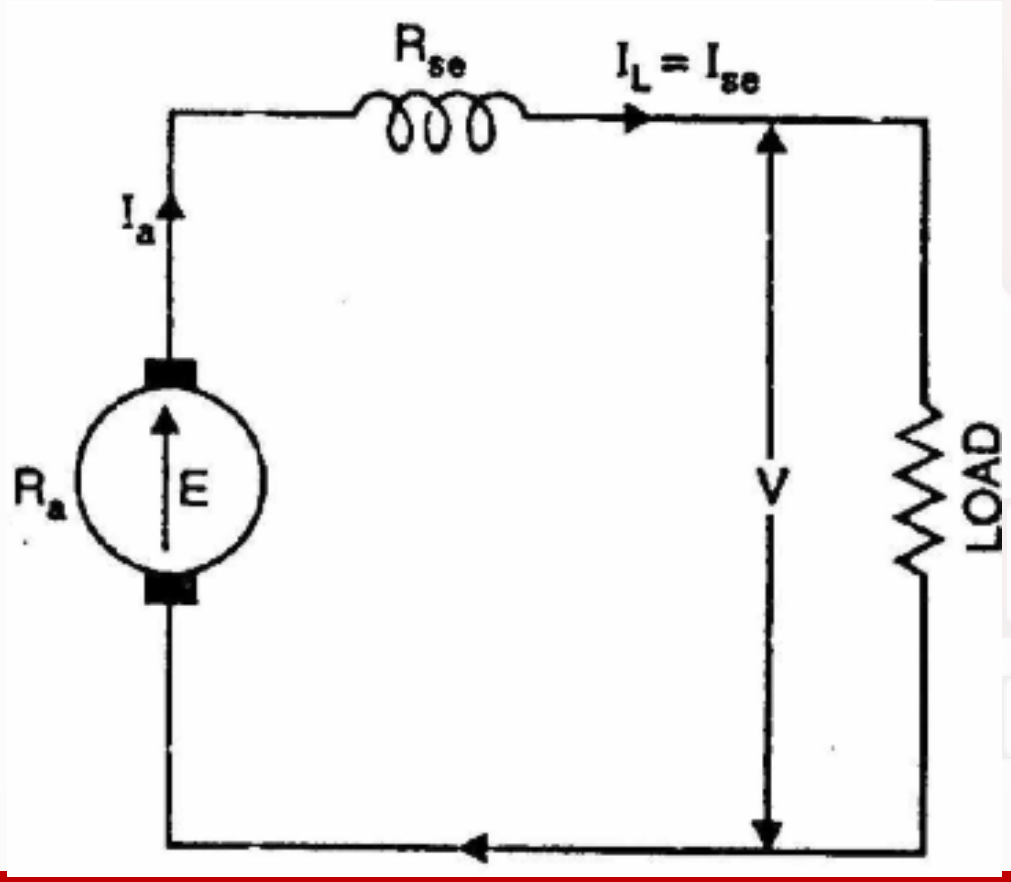



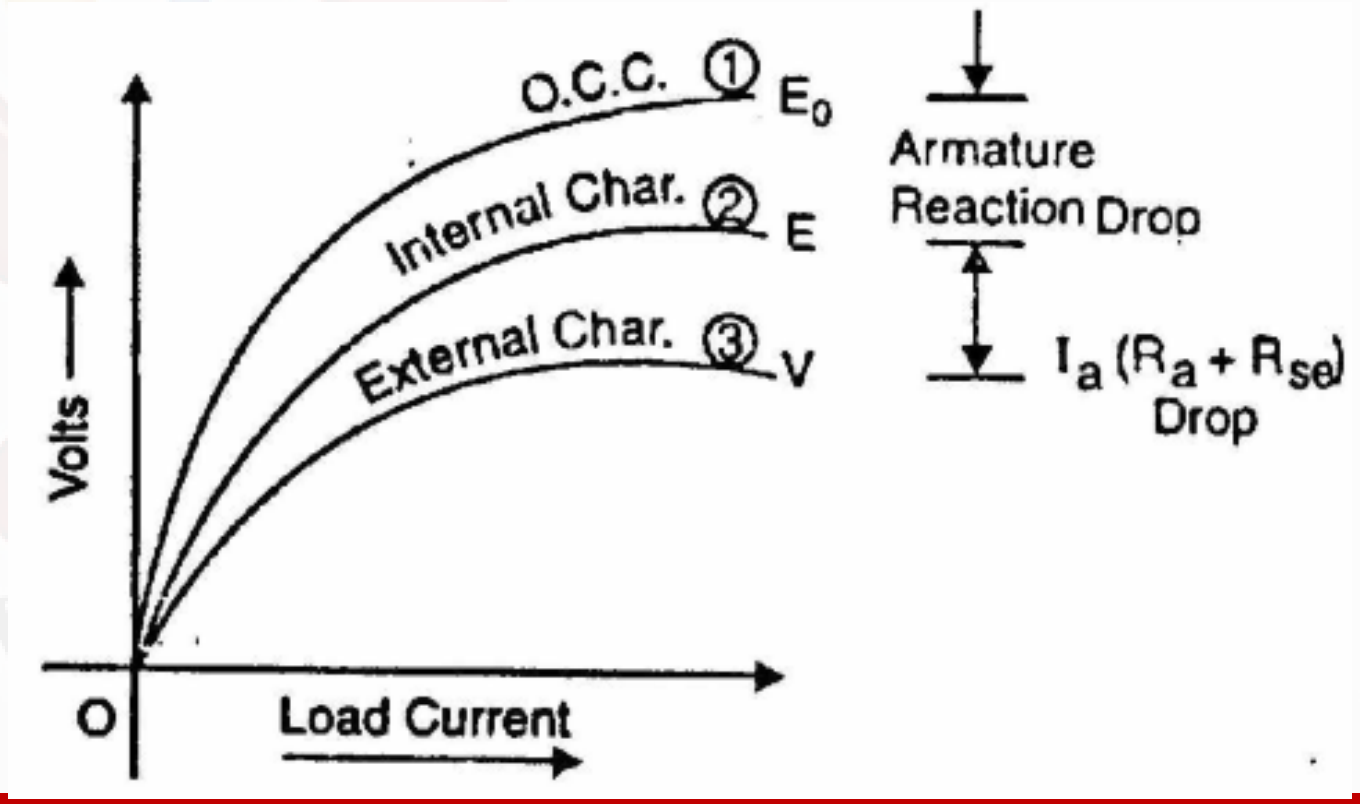

**Terminal voltage falls due to**

- ✓ **Armature reaction**
- ✓ **Voltage drop in armature resistance**

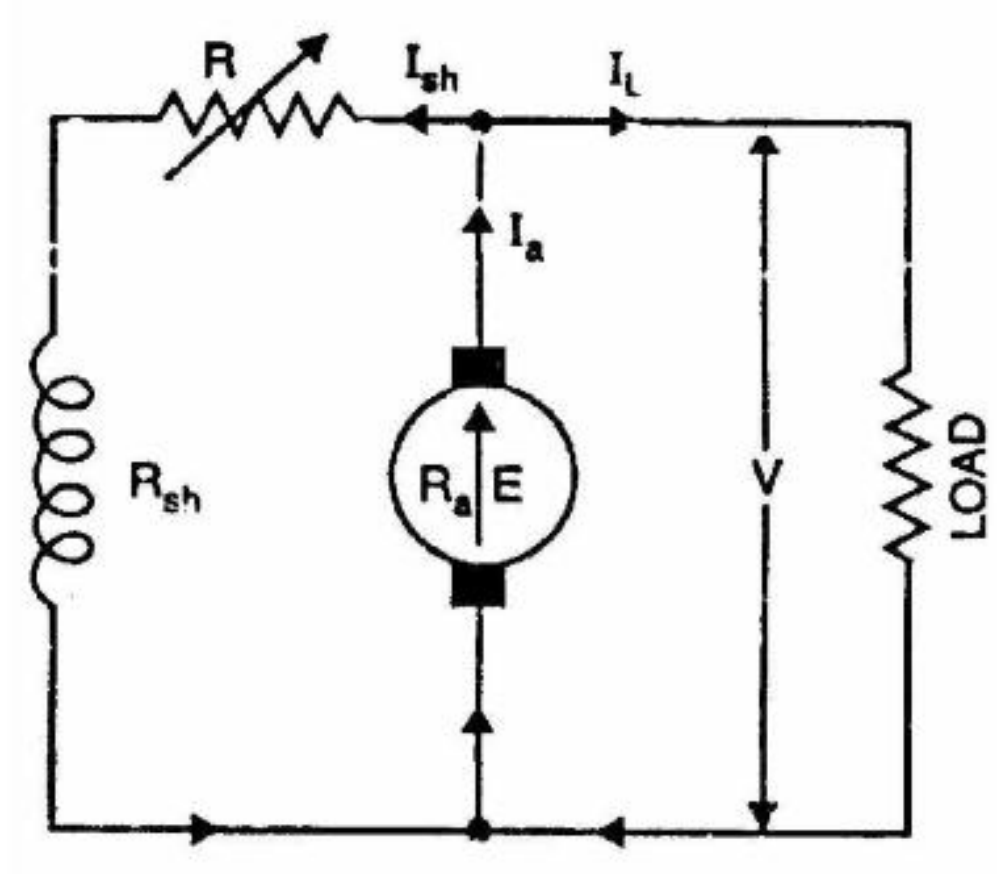
**Hence drooping curve**

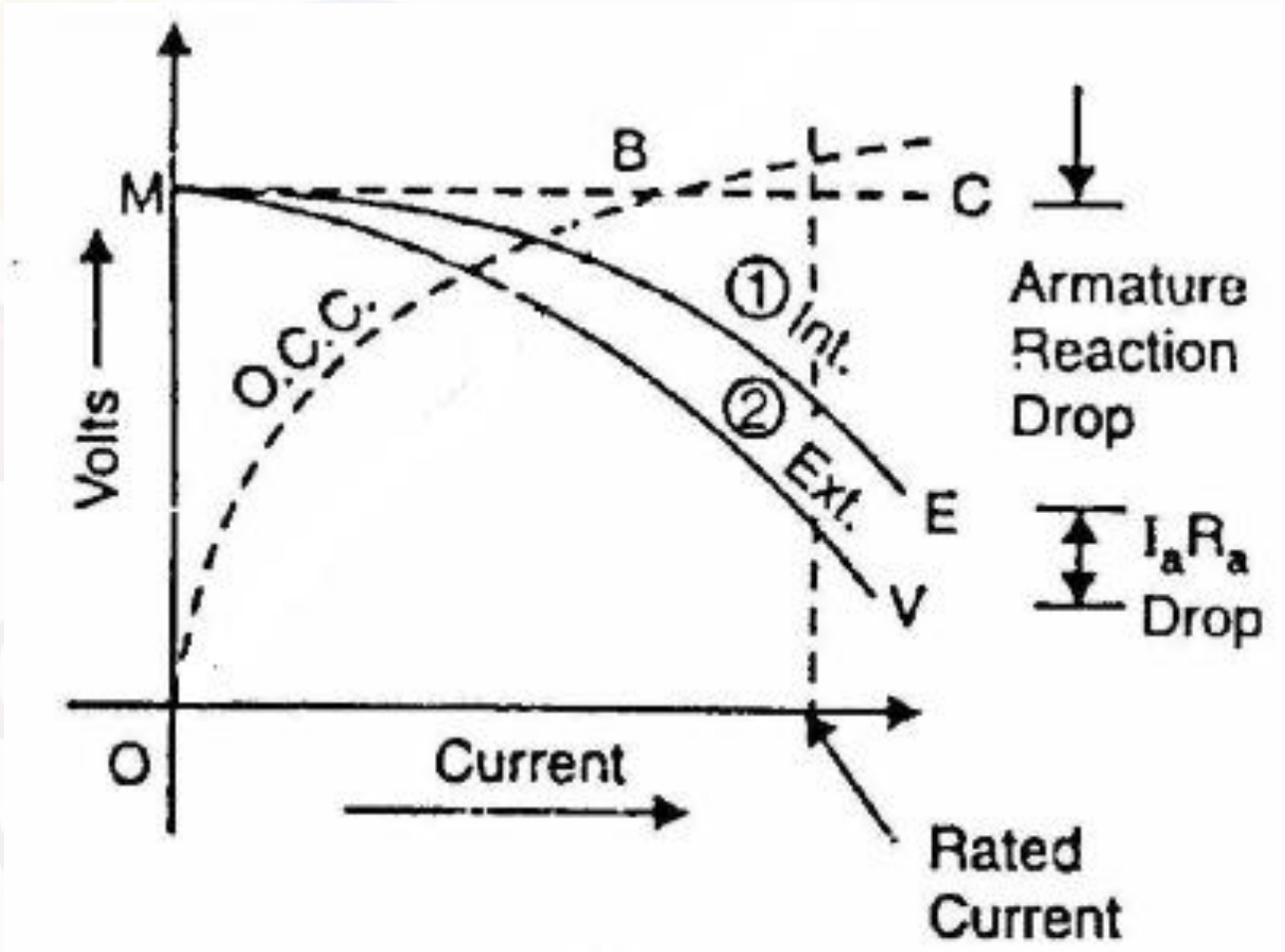
# Characteristics of Series Generator



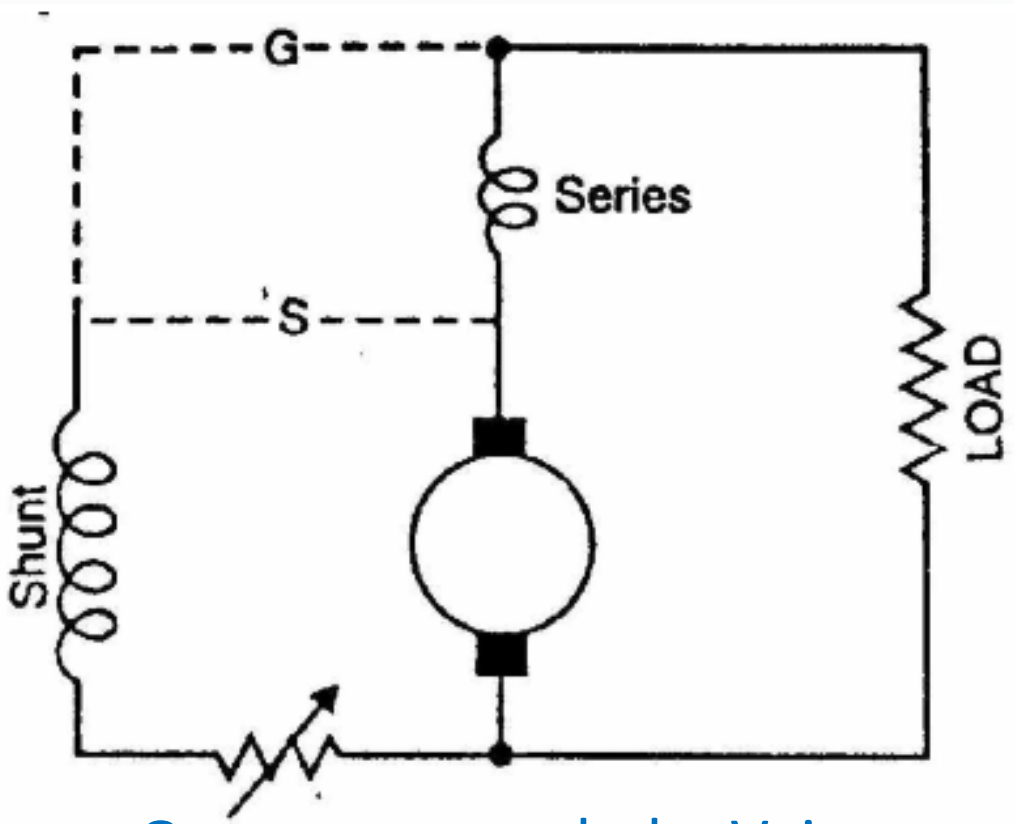



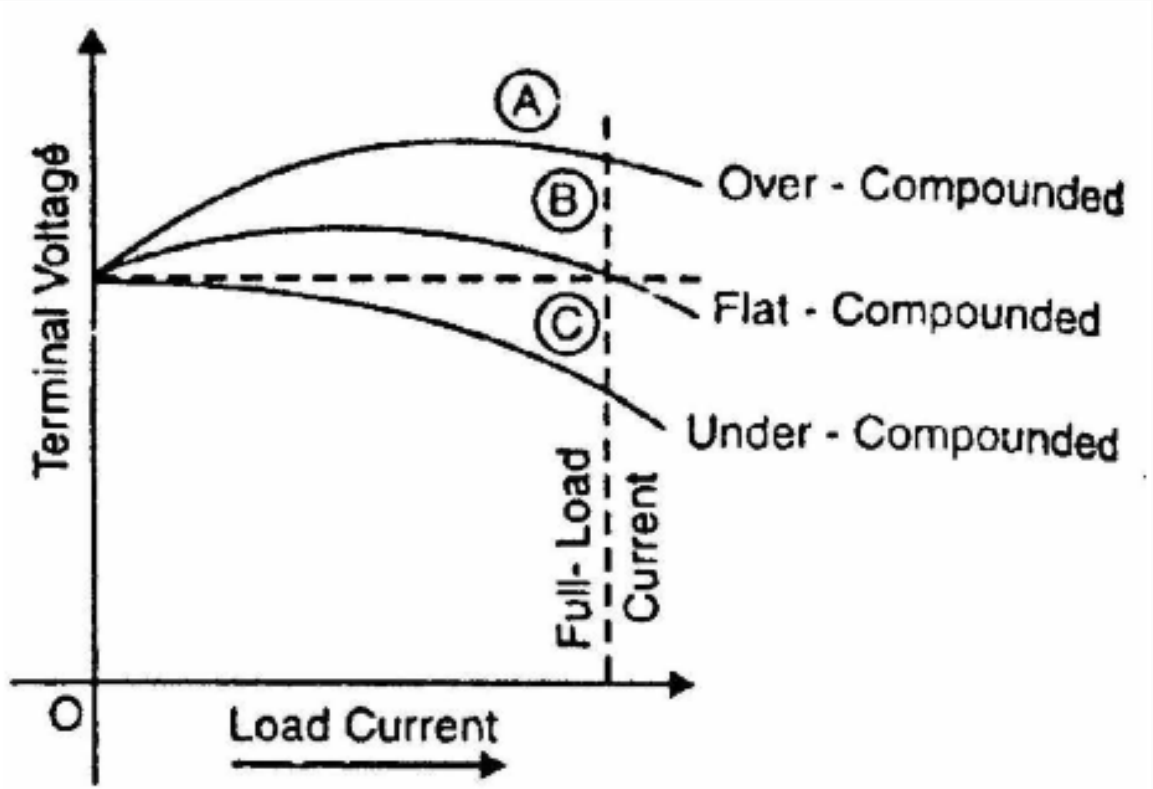
# Characteristics of Shunt Generator



# Characteristics of Compound Generator

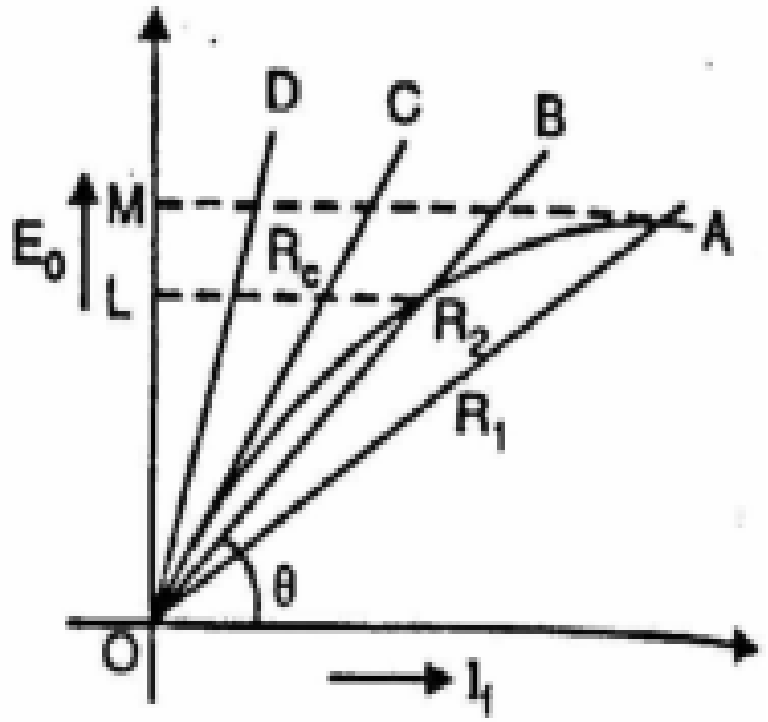



- Over compounded - $V_t$ increases with increase in $I_L$.
- Flat compounded - $V_t$ remains constant with increase in $I_L$.
- Under compounded - $V_t$ decreases with increase in $I_L$.

# Critical Field Resistance of Generator

- The maximum field circuit resistance with which the shunt generator would just excite is known as its critical field resistance.
- It should be noted that shunt generator will build up voltage only if field circuit resistance is less than critical field resistance.
- $R_f$ should be less than $R_C$.



# Critical Speed of Generator

- The minimum speed below which the generator fails to excite.
- It is the speed for which the given shunt field resistance represents the critical resistance.

## Summary

- Induced EMF
- Generating mode and motoring mode
- Methods of excitation
- Classification of DC machines