# DC MACHINES

# Topics to be covered in this Unit



## DC Machine

### DC Generator

1. Construction
2. Types
3. Emf Equations
4. Power Flow Diagram

### DC Motor

1. Construction
2. Types
3. Concept of back emf
4. Torque equations
5. Characteristics

6 Power Flow Diagram

7. Speed Control Methods
8. Types of Starters
9. Applications

10.Numerical

### Permanent Magnet Motor

1.Constuction

2. Advantages
3. Disadvantages
4. Applications

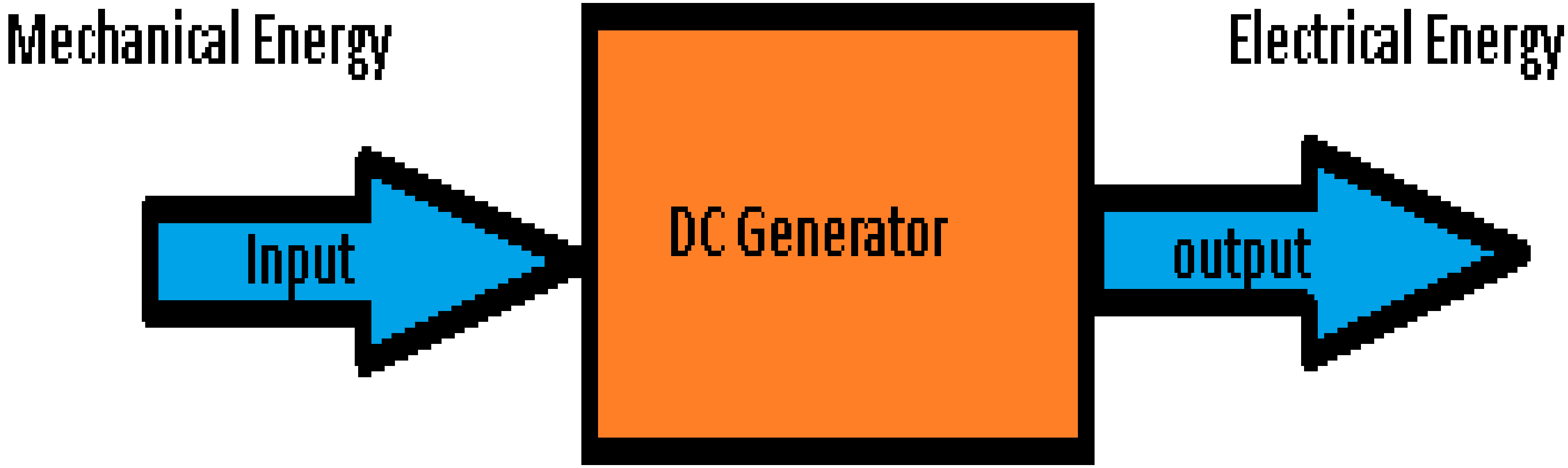
# Direct Current (DC) Machines Fundamentals



- Generating action: An emf (voltage) is induced in a conductor if it moves through a magnetic field.
- Motoring action: A force is induced in a conductor that has a current going through it and placed in a magnetic field.
- Any DC machine can act either as a generator or as a motor.

# Generating action



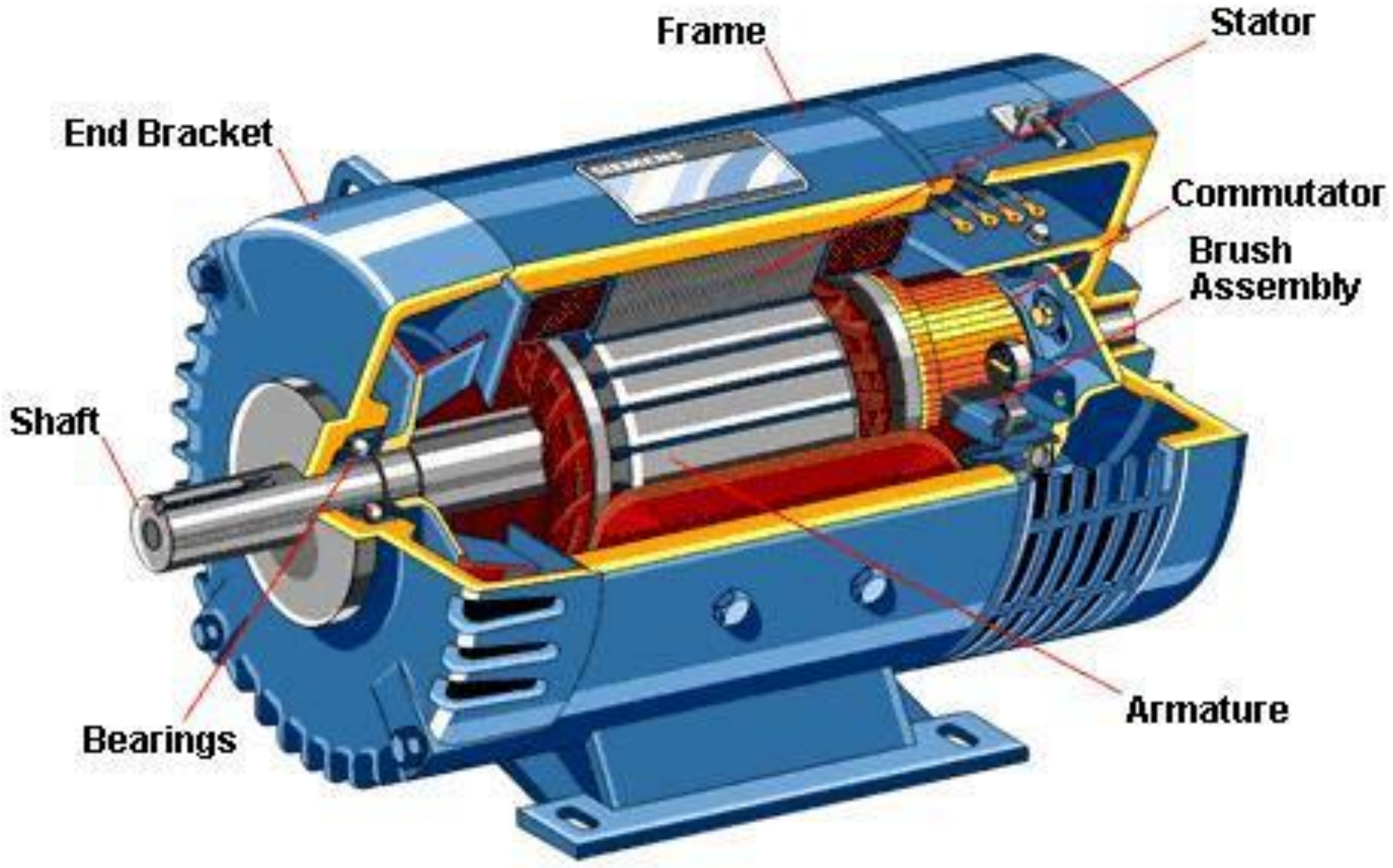


# Motoring action



# Construction of DC Machine

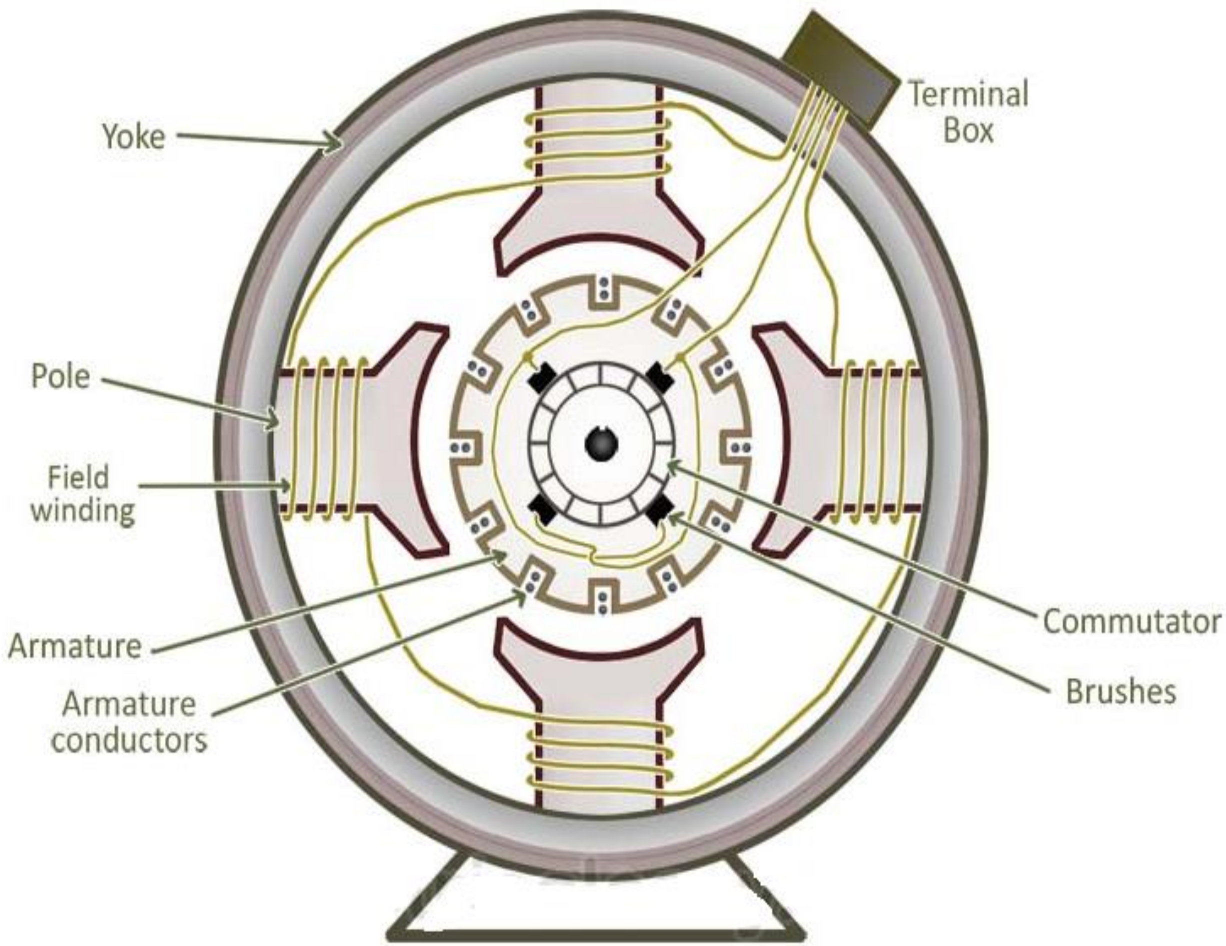




# Parts of DC Machine

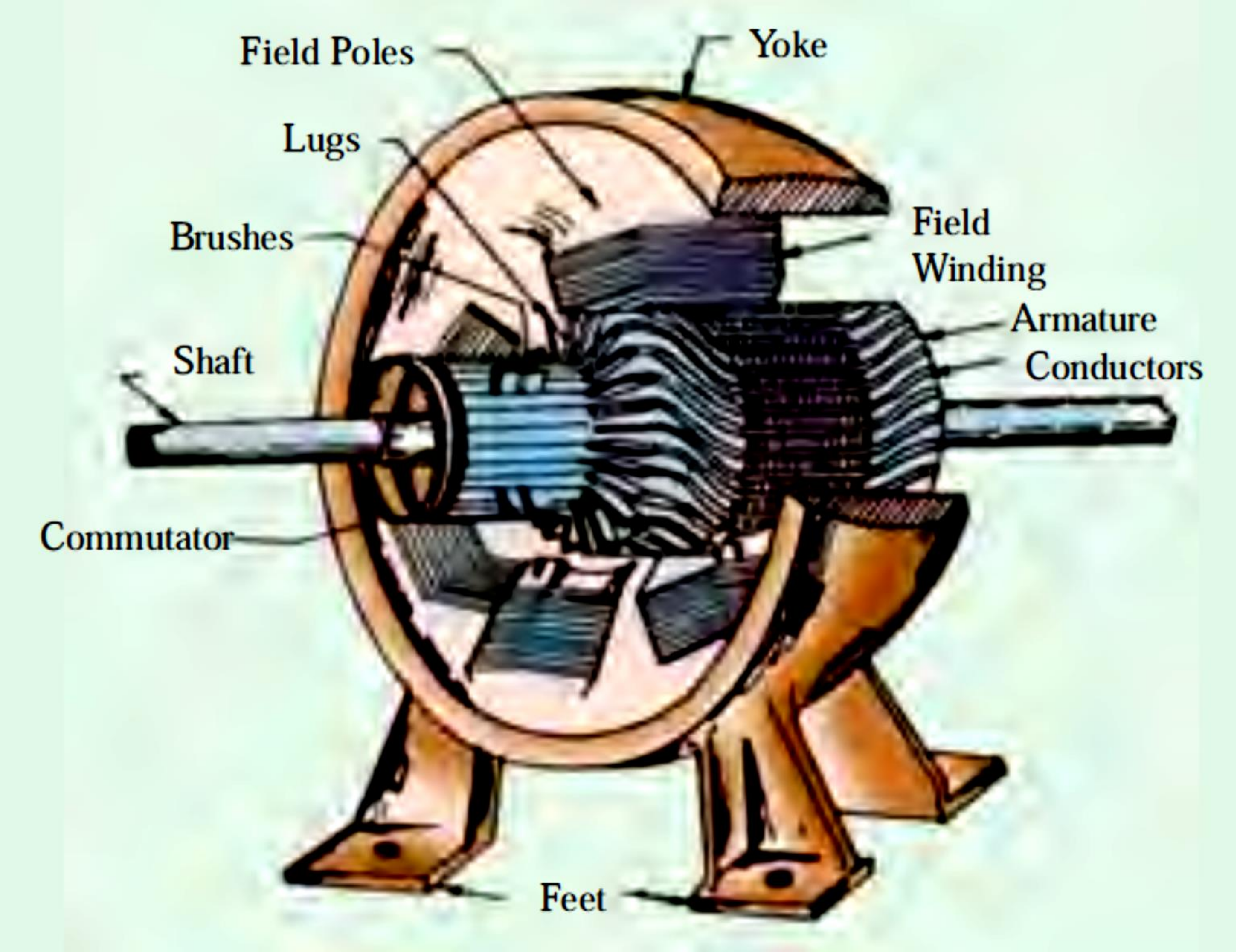


- Field system
- Armature core
- Armature winding
- Commutator
- Brushes



# Parts of DC Machine





# Parts and functions



| Parts | Function |
|---|---|
| Yoke | ✓Outer most cover to protect machine from moisture, dust and gases<br>✓Provides mechanical support<br>✓Provides low reluctance path to setting up the flux |
| Pole:<br>1. Pole Core<br><br>2. Pole Shoe | <br>✓To Carry the field winding<br>✓Directs flux through air gap to armature core<br>✓Enlarges the area of armature core to come across flux |
| Field Winding | To carry current to produce the magnetic field |
| Armature<br>1. Armature Core<br><br>2. Armature Winding | ✓For housing the armature conductors and provide low reluctance path for flux<br>✓Generation of EMF takes place in it.<br>✓To Carry current supplied in case of DC motor |

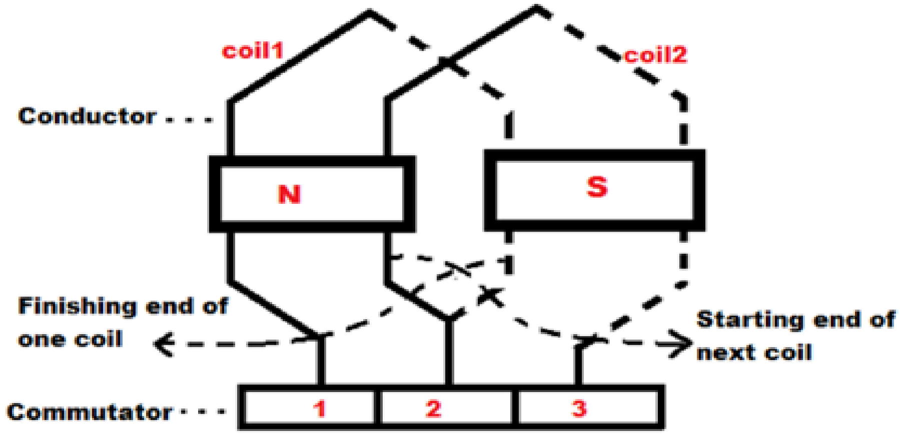
# Parts and functions



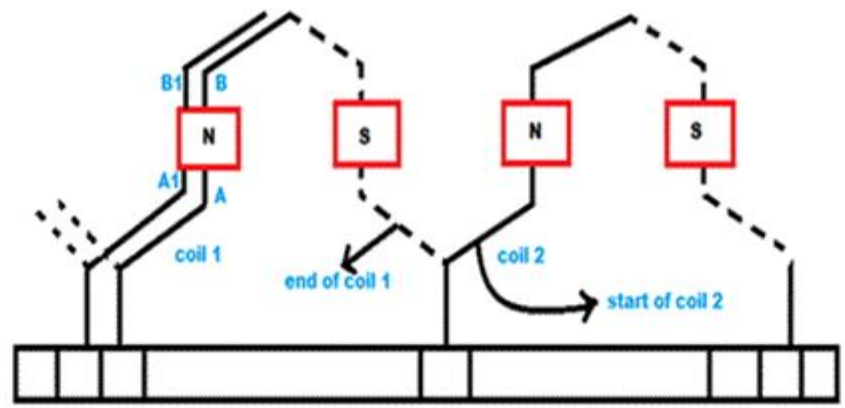
| Parts | Function |
| --- | --- |
| Commutator | ✓To facilitate the collection of current from armature<br>✓To convert AC to DC<br>✓To produce uni-diectional torque in case of DC motor |
| Brushes | ✓Collects current from commutator and make it available for external circuit.<br>✓And also avoid wear and tear of commutators |

# Armature Windings in DC Machine






Lap Winding




Wave Winding

1. A=P
2. No. of brushes = P
3. Preferable for high current and low voltage capacity generator
4. Used for generator capacity more than 500 Amp

1. A=2
2. No of brushes= 2
3. Preferable for low current and high voltage capacity generator
4. Used for generator capacity less than 500 Amp

# Armature reaction

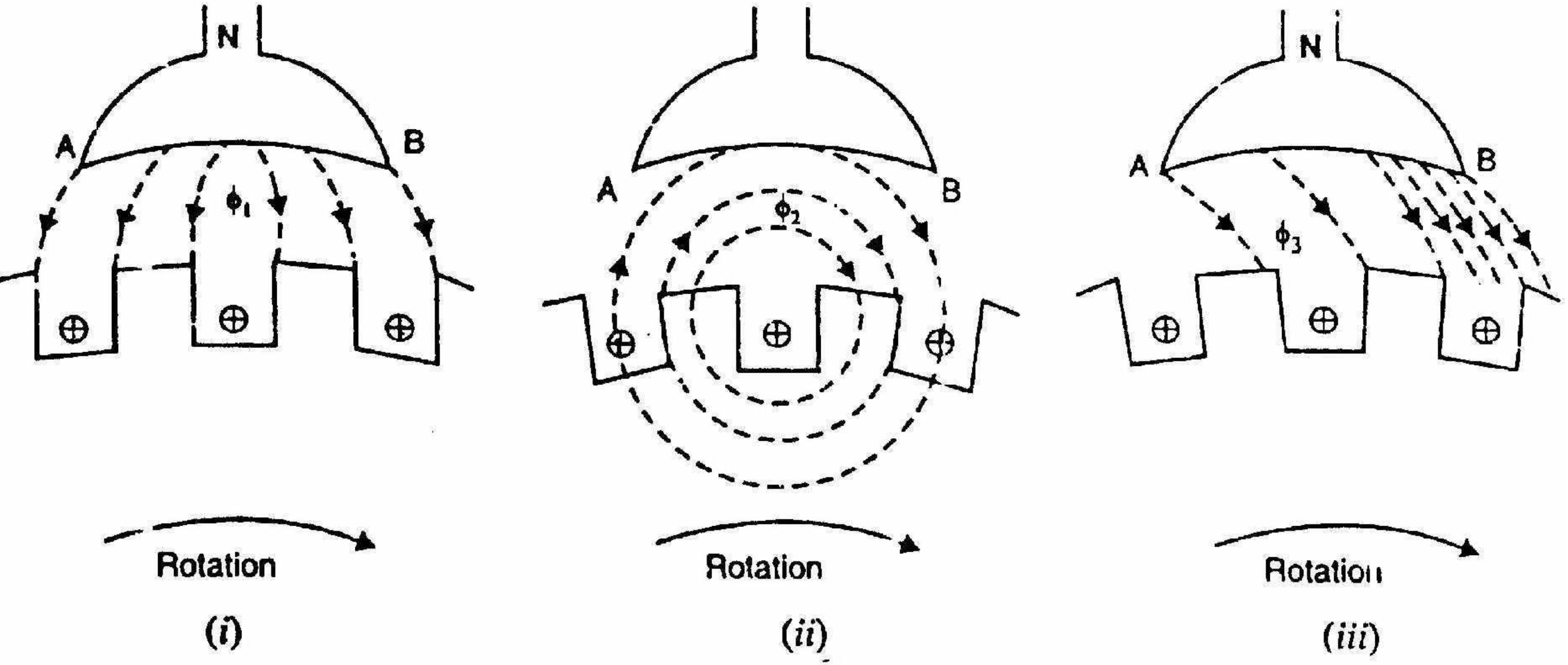


Definition: In a DC Machine, two kinds of magnetic fluxes are present; 'armature flux' and 'main field flux'. The effect of armature flux on the main field flux is called as **armature reaction**.

If a load is connected to the terminals of the dc machine, a current will flow in its armature windings. This current flow will produce a magnetic field of its own, which will distort the original magnetic field from the machine’s field poles. This distortion of the magnetic flux in a machine as the load is increased is called the armature reaction.

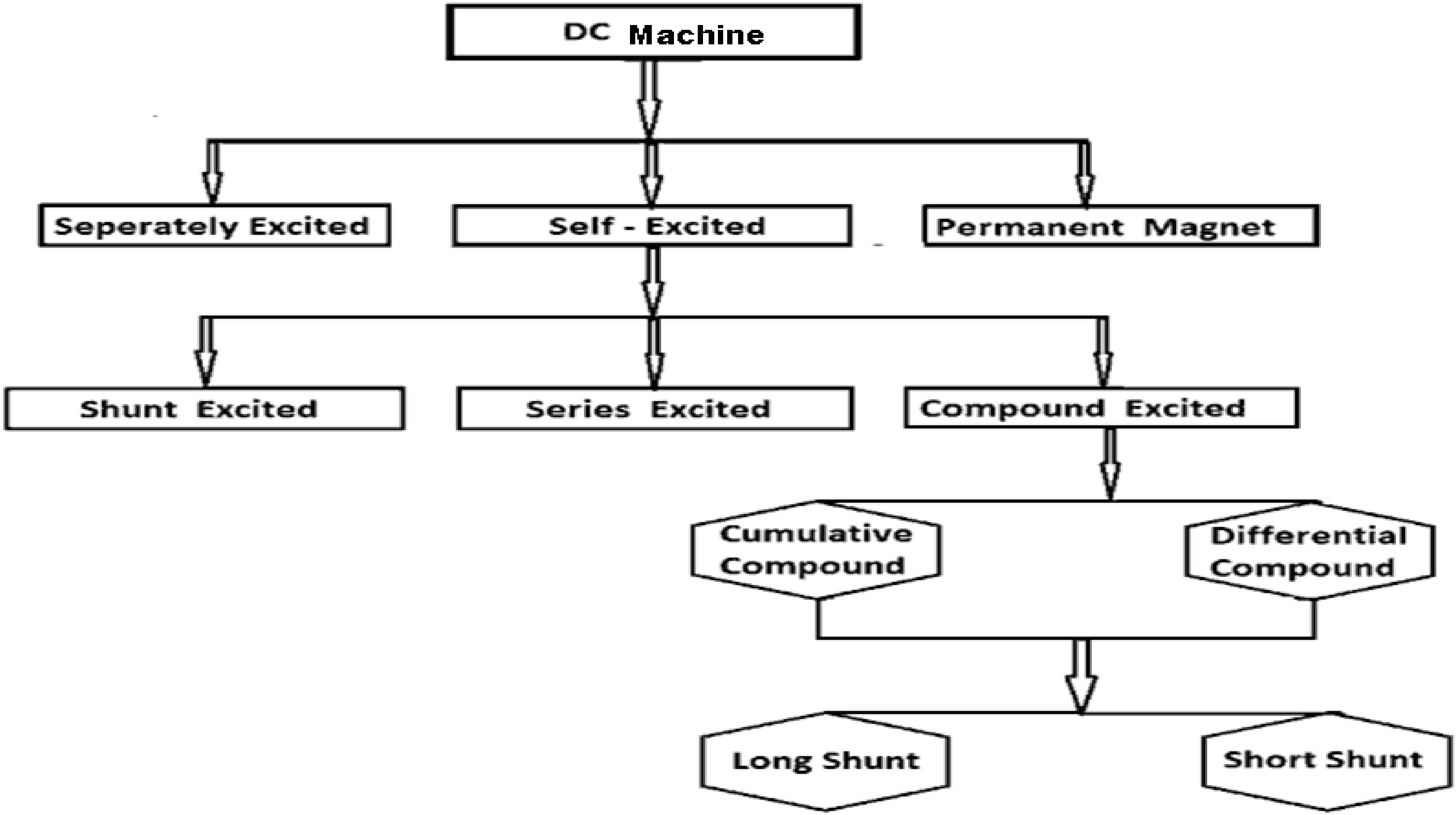
# Armature reaction





# Types of DC Machine





# Types of DC Machines



Both the armature and field circuits carry direct current in the case of a DC machine.

**Types**:

- **Separately-excited DC machine:** The field windings may be separately excited from an eternal DC source.
- **Self-excited DC machine:** when a machine supplies its own excitation of the field windings. In this machine, residual magnetism must be present in the ferromagnetic circuit of the machine in order to start the self-excitation process.
- **Shunt Machine:** armature and field circuits are connected in parallel. Shunt generator can be separately-excited or self-excited.
- **Series Machine:** armature and field circuits are connected in series.

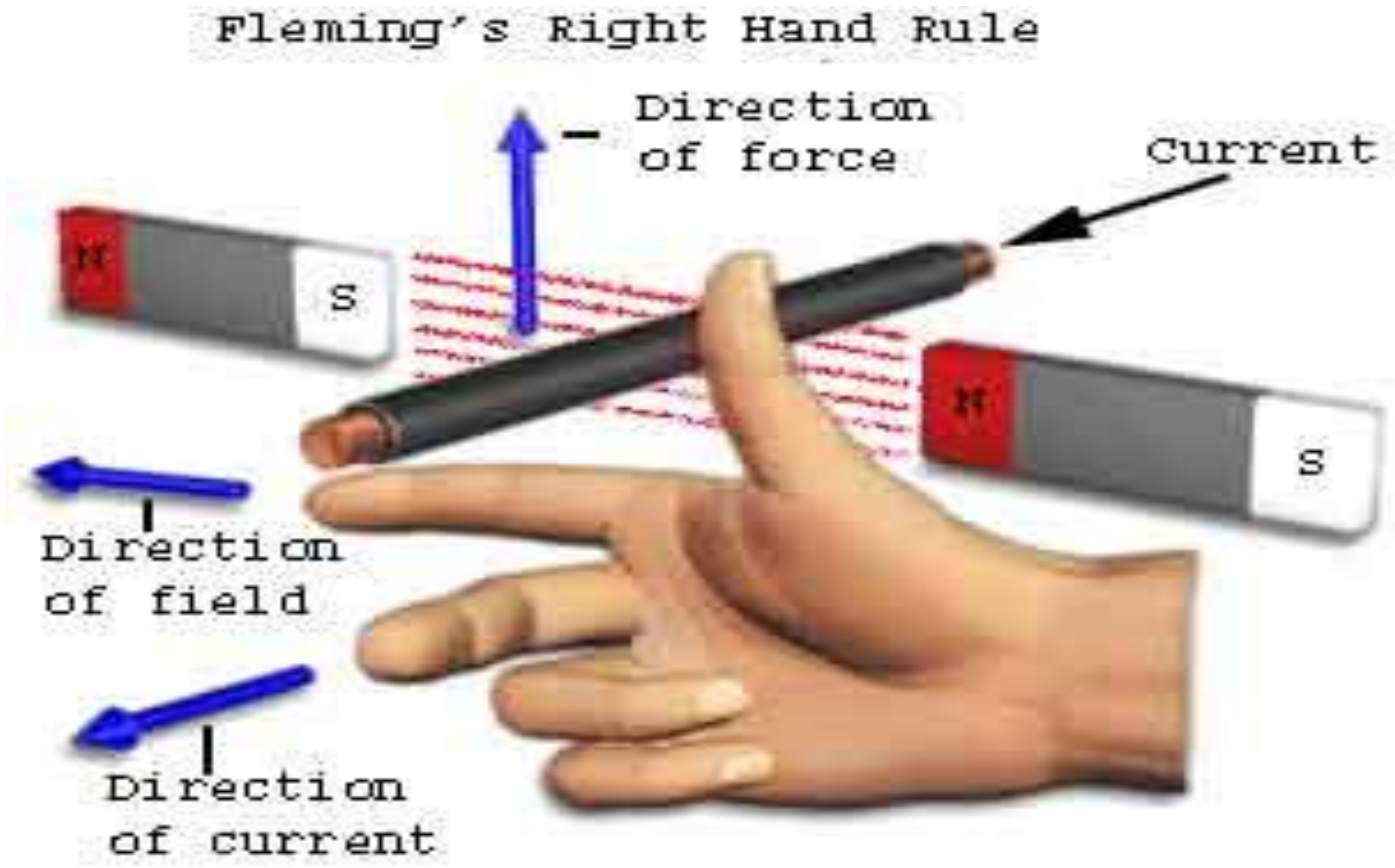
# Working Principle of DC Generator



- A generator works on the principles of Faraday's law of electromagnetic induction
- *Whenever a conductor is moved in the magnetic field , an emf is induced and the magnitude of the induced emf is directly proportional to the rate of change of flux linkage*
- This emf causes a current flow if the conductor circuit is closed

# Direction of Induced EMF





# Emf Equation of Generator



Let, $P$ = No. of poles in generator

$N$= Speed of generator in rpm

$\Phi$ = flux per pole

$Z$= No. of armature conductors

$A$ = No. of parallel paths

# Emf Equation of DC Generator



Total flux produced by all the poles $= \phi \times P$

And, Time taken to complete one revolution $= \dfrac{60}{N}$

$$e = \frac{d\phi}{dt} \quad and\ e = \frac{total\ flux}{time\ take}$$

**Induced emf of one conductor is** $e = \dfrac{\phi P}{60/N} = \dfrac{\phi P N}{60}$

**Therefore, Total Induced emf of DC generator is** $E_g = \dfrac{\phi P}{60/N} = \dfrac{\phi P N}{60} \times \dfrac{Z}{A}$ *volts*

A=2 for Wave Winding

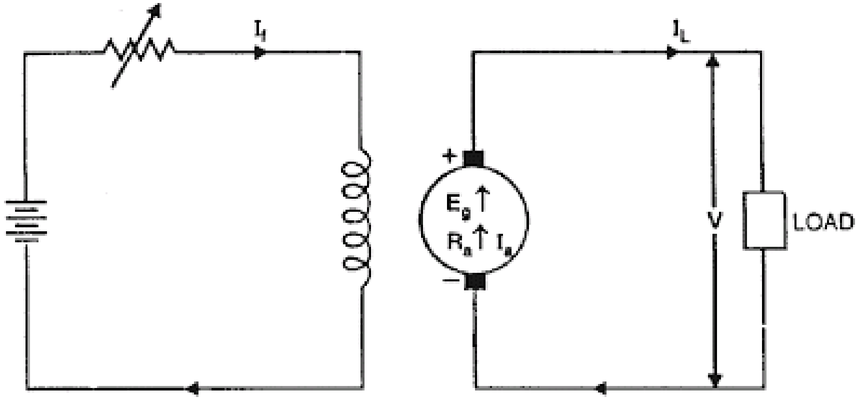
A=P for Lap Winding

# Types of DC generator



## Separately Excited DC Generator:

- Armature current, $Ia = I_L$
- Terminal voltage, $V = E_g - IaRa$
- Electric power developed = $E_g * Ia$
- Power delivered to load= $E_g * Ia$

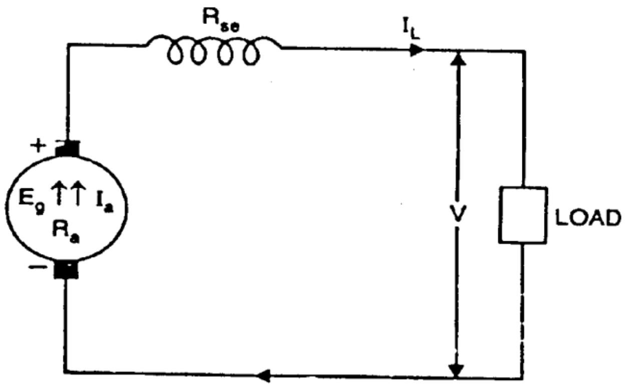


# Types of DC generator

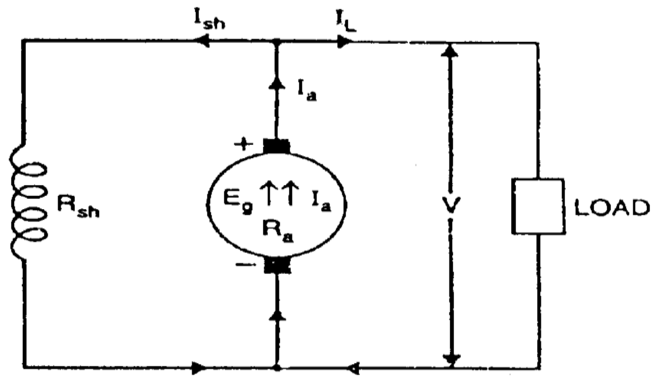


## Self Excited DC Generator:

- **Series generator**
  - Armature current, $Ia = Ise = I_L$
  - Terminal voltage, $V = E_g - I(Ra + Rse)$
  - Power developed in armature = $E_g$ *Ia



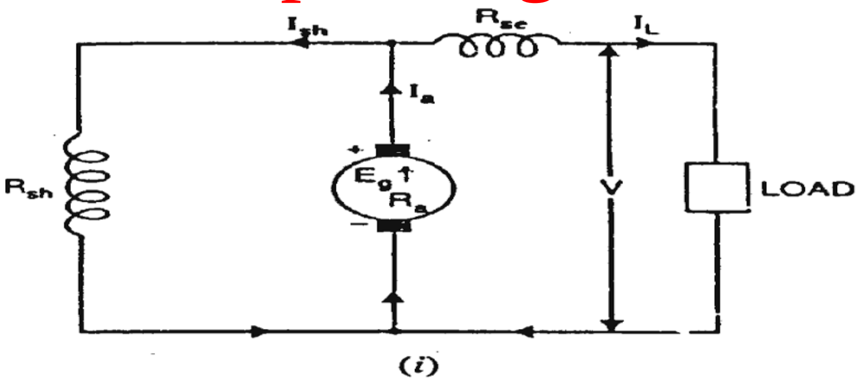

- **Shunt generator**
  - Shunt field current, Ish = V/Rsh
  - Armature current, $Ia = I_L + Ish$
  - Terminal voltage, $V = E_g - IaRa$
  - Power developed in armature = $E_g$ *Ia

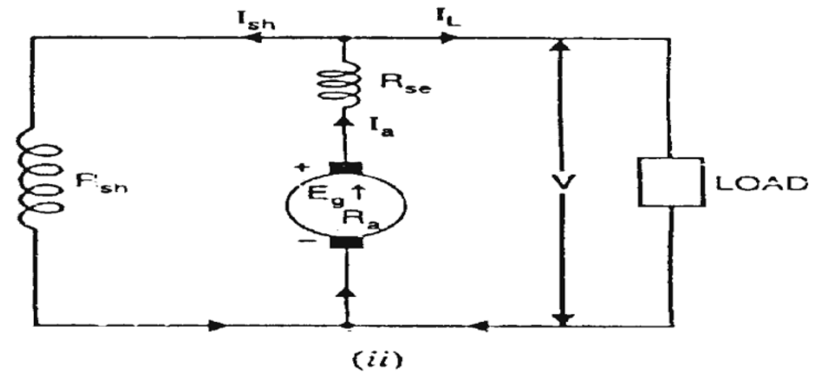


# Types of DC generator



- Compound generator




**Short shunt**

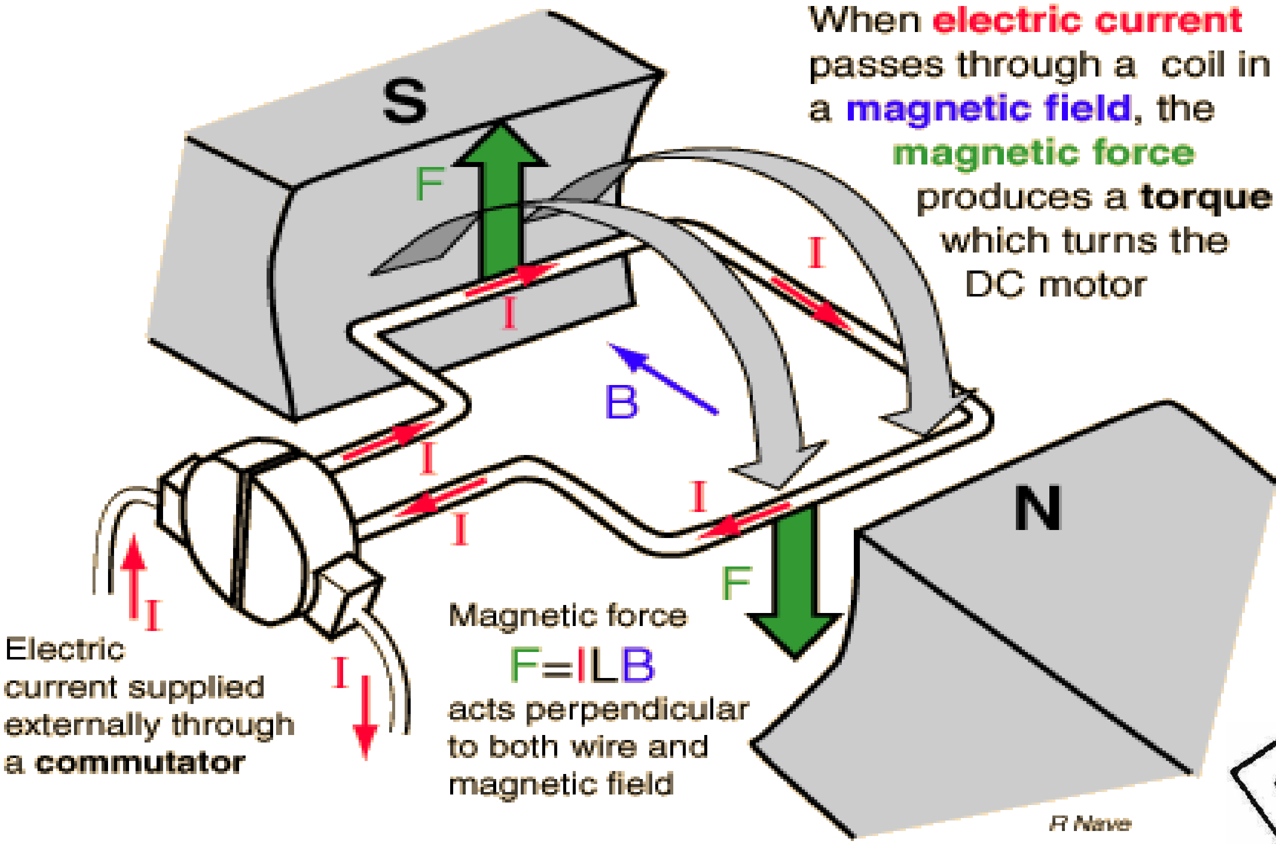
- Series field current, Ise = $I_L$
- Shunt field current,
- Terminal voltage, V = $E_g$ - IaRa - IseRse
- Power developed in armature = $E_g$ *Ia

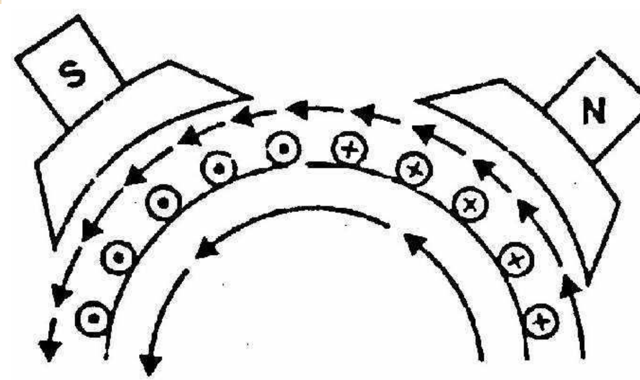
**Long shunt**

- Series field current, Ise = Ia = $I_L$ + Ish
- Shunt field current, Ish = V/Rsh
- Terminal voltage, V = $E_g$ - Ia(Ra +Rse)
- Power developed in armature = $E_g$ *Ia

# Working Principle of DC Motor

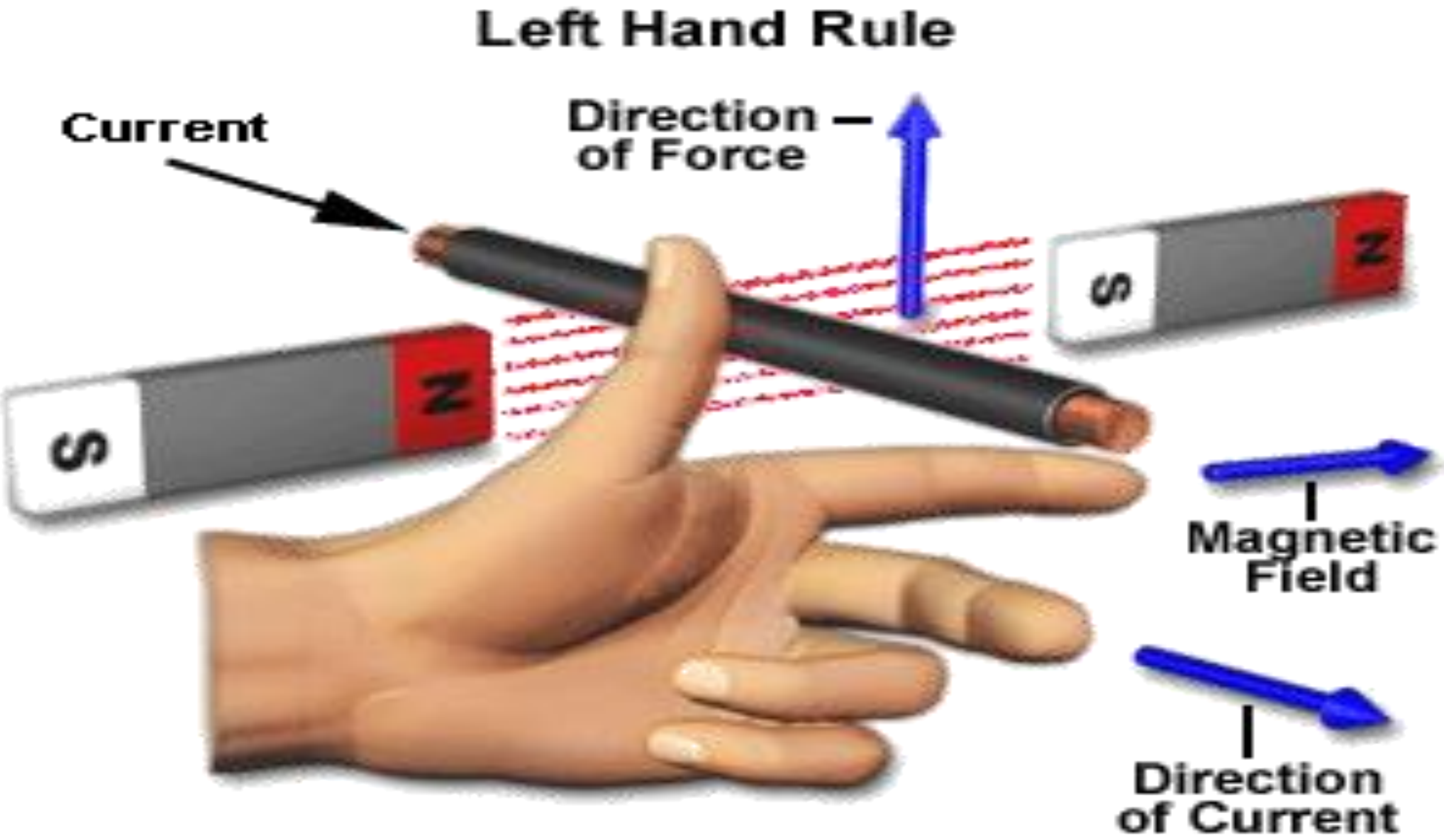




# Direction of Force in DC Motor





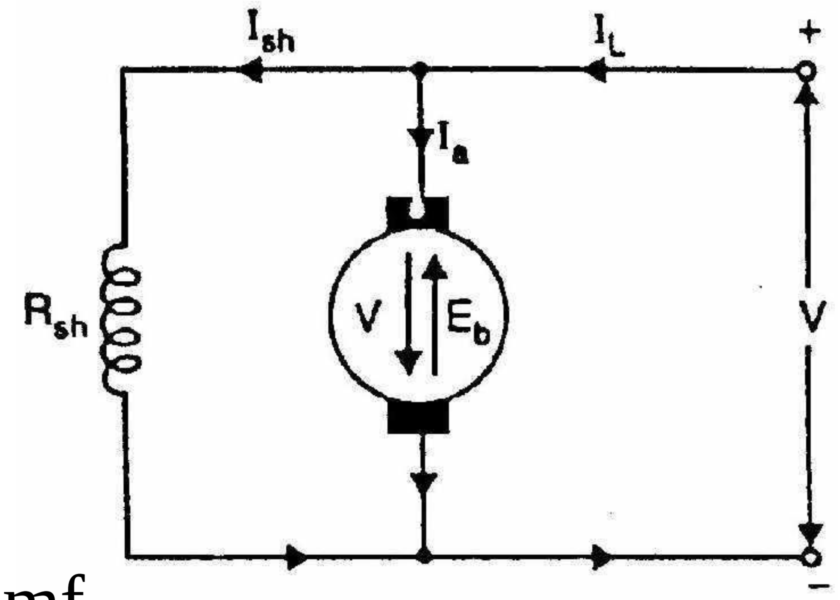
# Back EMF Equation



- Equation of Back EMF

$$I_a = \frac{V - E_b}{R_a}$$

$$E_b = V - I_a R_a$$




- Explain: Significance of Back Emf

Due to presence of back emf DC motor becomes regulating machine. That is motor adjusts itself to draw the armature current just enough to satisfy the load demand.

# Classification of DC Motor



DC motors are mainly classified into three types as listed below:

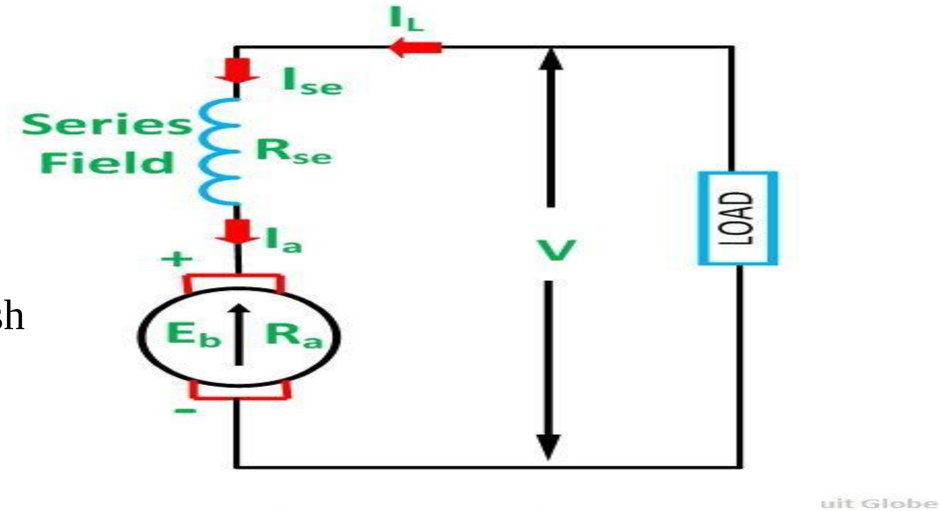
- Shunt motor
- Series motor
- Compound motor
    - Differential compound
    - Cumulative compound

# Types of DC Motor



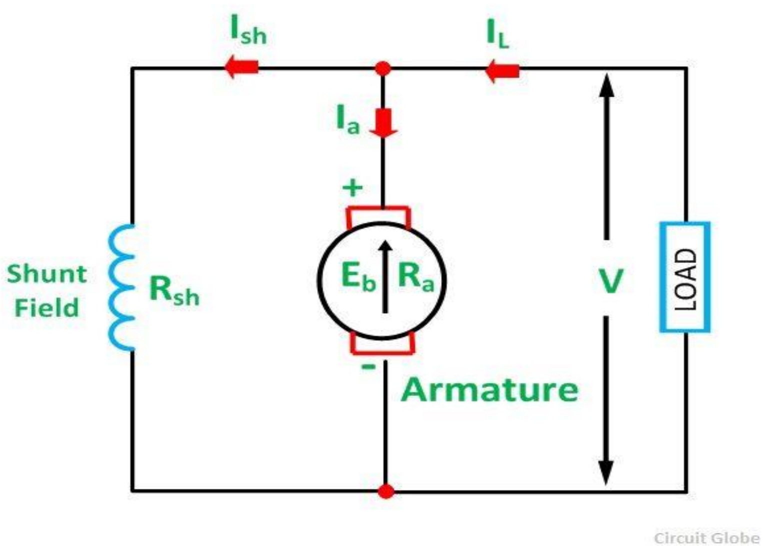
➢ DC Series Motor

- $I_L = I_{se} = I_a$
- $V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$
- $\Phi \ \alpha \ I_{se} \ \alpha \ I_a$




➢DC Shunt Motor

- $I_L = I_a + I_{sh}$
- $I_{sh} = V / R_{sh}$
- $V = E_b + I_a R_a + V_{brush}$
- $\Phi \ \alpha \ I_{sh}$

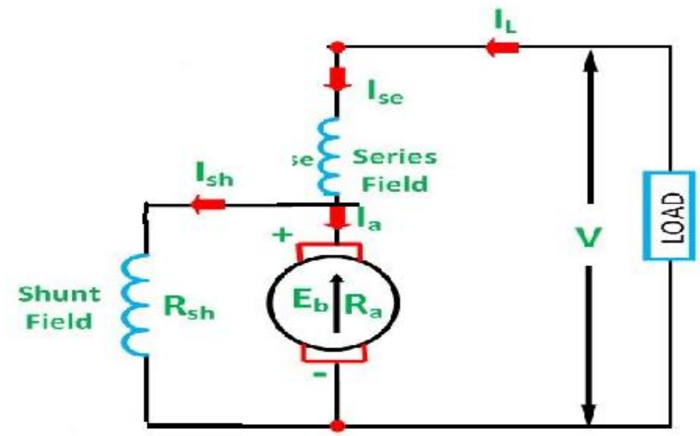


# Types of DC Motor



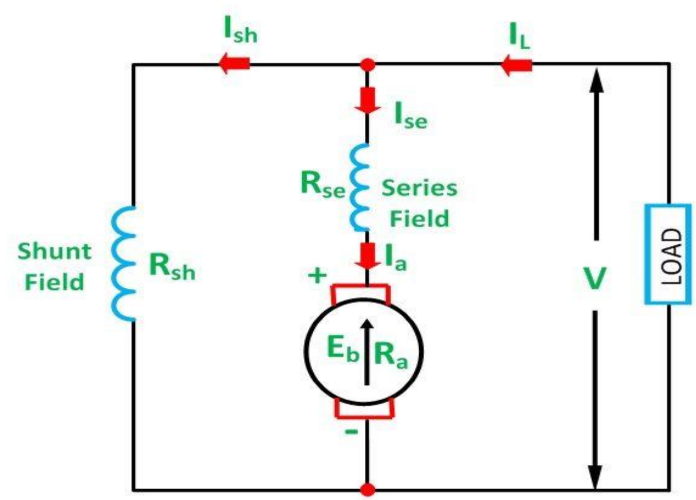
## ➢Short Shunt Compound motor

- $I_L = I_{se}$
- $I_L = I_a + I_{sh}$
- $V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$




## ➢Long Shunt Compound Motor

- $I_L = I_{se} + I_{sh}$
- $I_{se} = I_a$ i.e. $I_L = I_a + I_{sh}$
- $I_{sh=} V/ R_{sh}$
- $V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$



# Torque Equation:



Let $T_a$ = gross torque developed
P= No. of poles
N = Speed of rotor in rpm
Z = No. of armature conductors

$\varphi$= Flux per pole
A= No. of parallel path
$E_b$= Back Emf

Mechanical power developed = $T_a * \omega$
Electrical equivalent of gross mechanical power develop in armature= $E_b * I_a$

# Torque Equation:



$$\mathrm{E_b} \times \mathrm{Ia} = \mathrm{T_a} \times \frac{2\pi N}{60}$$

$$E_b = \frac{\phi PNZ}{60A}$$

$$\frac{\phi PNZ}{60A} \times \mathrm{Ia} = \mathrm{T_a} \times \frac{2\pi N}{60}$$

$$T_a = \frac{1}{2\pi}\phi I_a \frac{PZ}{A} = 0.159\phi I_a \frac{PZ}{A}$$

# Torque Equation:



## Shaft Torque ($T_{sh}$)

The torque which is available for doing useful work is known as shaft torque $T_{sh}$. It is so called because it is available at the shaft. The motor output is given by

Output = $T_{sh} \times 2\pi N$ Watt provided $T_{sh}$ is in N-m and $N$ in r.p.s.

$$\therefore \quad T_{sh} = \frac{\text{Output in watts}}{2\pi N} \text{ N- m} - N \text{ in r.p.s}$$

$$= \frac{\text{Output in watts}}{2\pi N / 60} \text{ N-m} - N \text{ in r.p.m.}$$

$$= \frac{60}{2\pi} \frac{\text{output}}{N} = 9.55 \frac{\text{Output}}{N} \text{ N-m.}$$

The difference $(T_a - T_{sh})$ is known as lost torque and is due to iron and friction losses of the motor.

**Note.** The value of back e.m.f. $E_b$ can be found from

(*i*) the equation, $E_b = V - I_a R_a$

(*ii*) the formula $E_b = \Phi ZN \times (P/A)$ volt

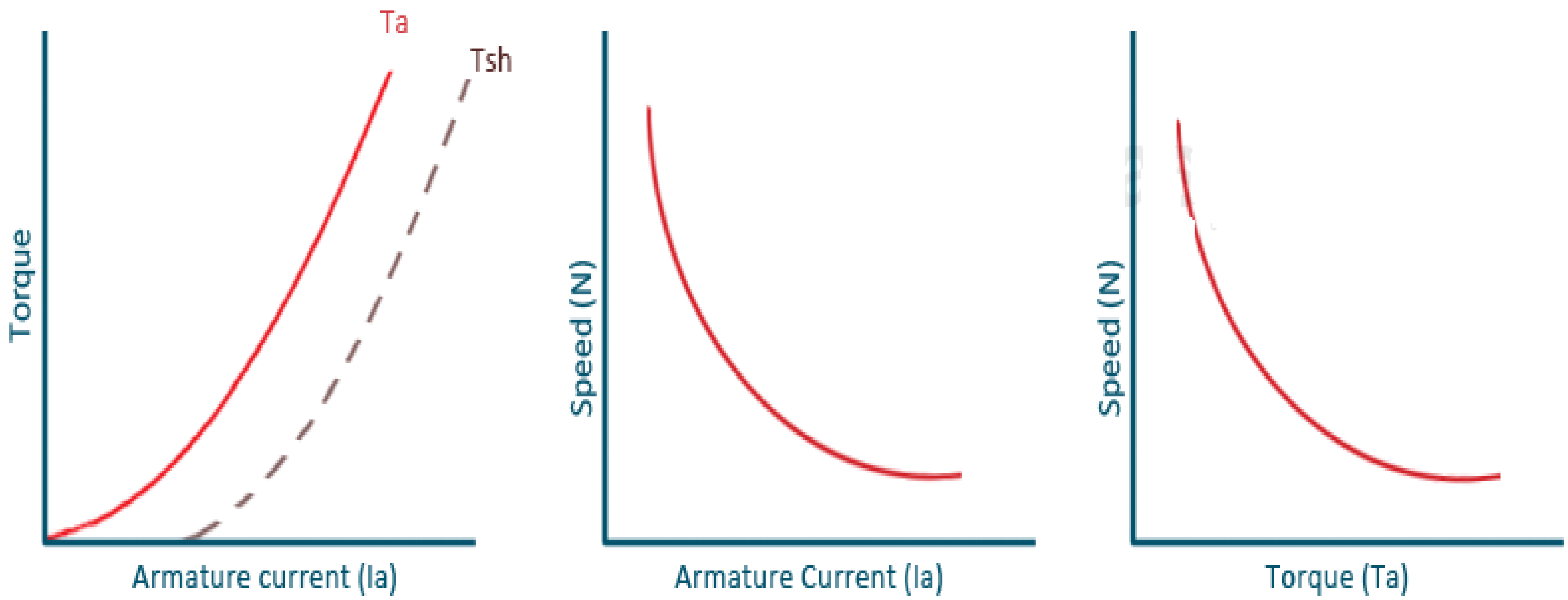
# Characteristics of DC motor



- Torque/Armature current Characteristic
- Speed/ Armature current  Characteristic
- Speed/Torque Characteristic

# DC Series Motor

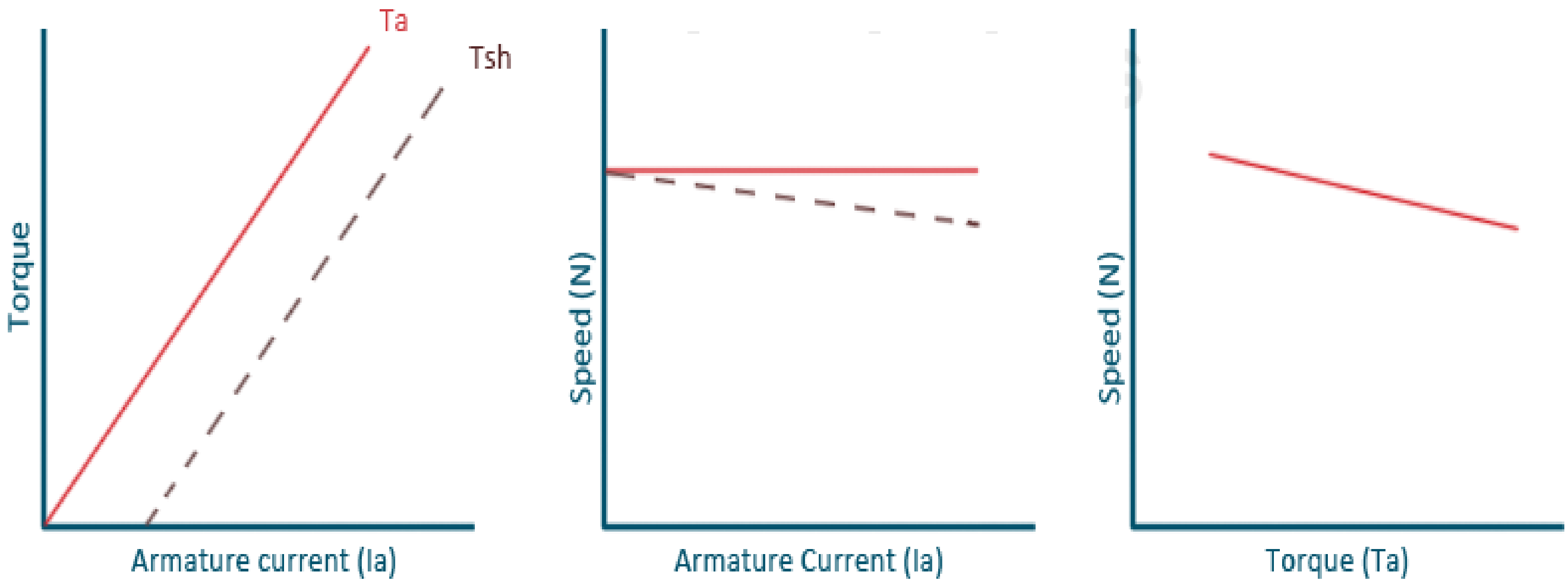





Characteristics of DC series motor

# DC Shunt Motor

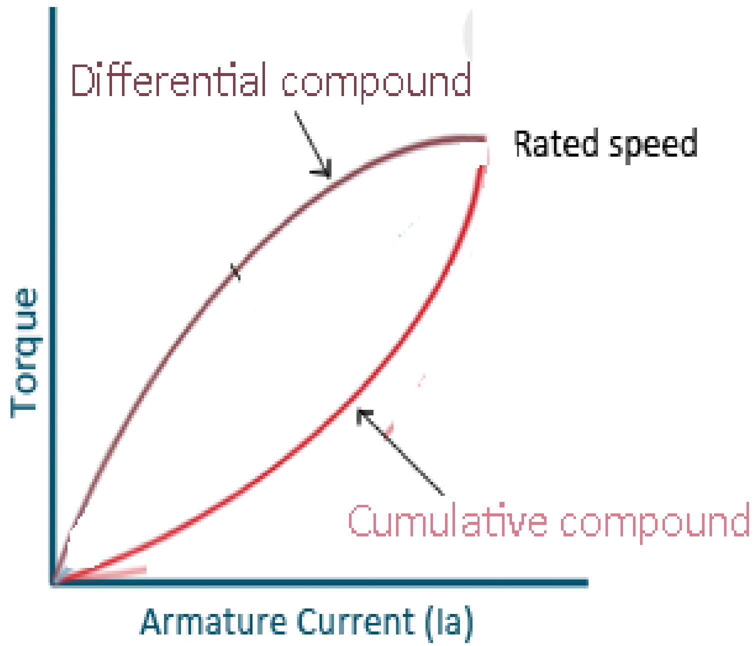


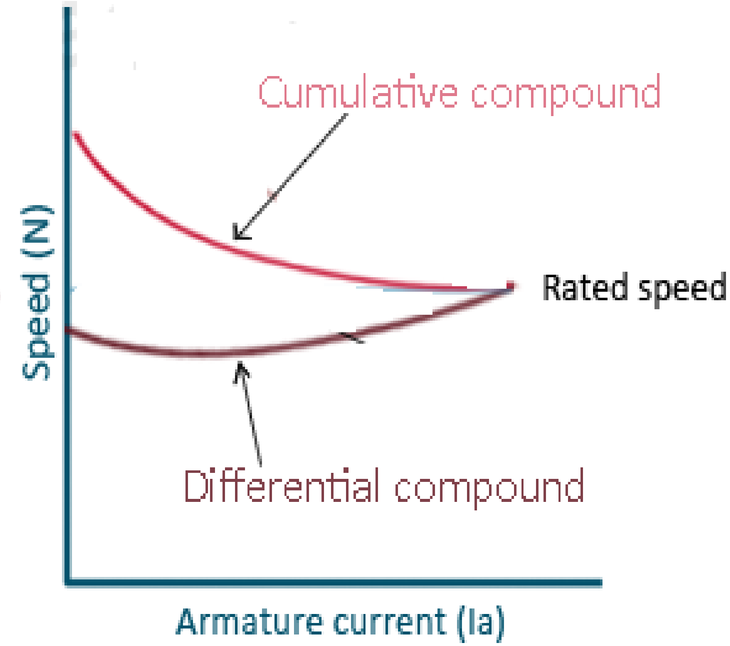



Characteristics of DC shunt motor

# DC Compound Motor



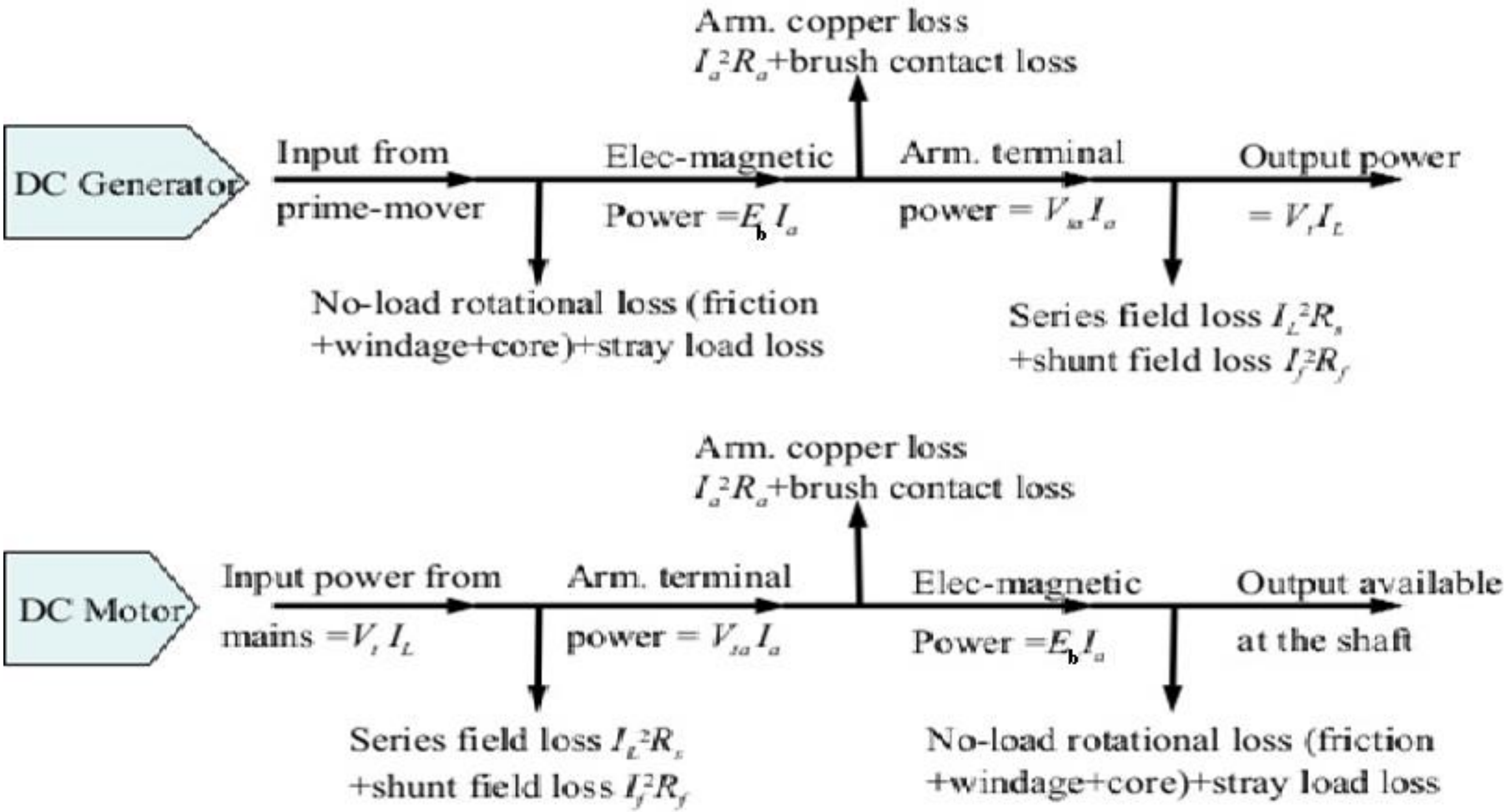



Characteristics of DC compound motor

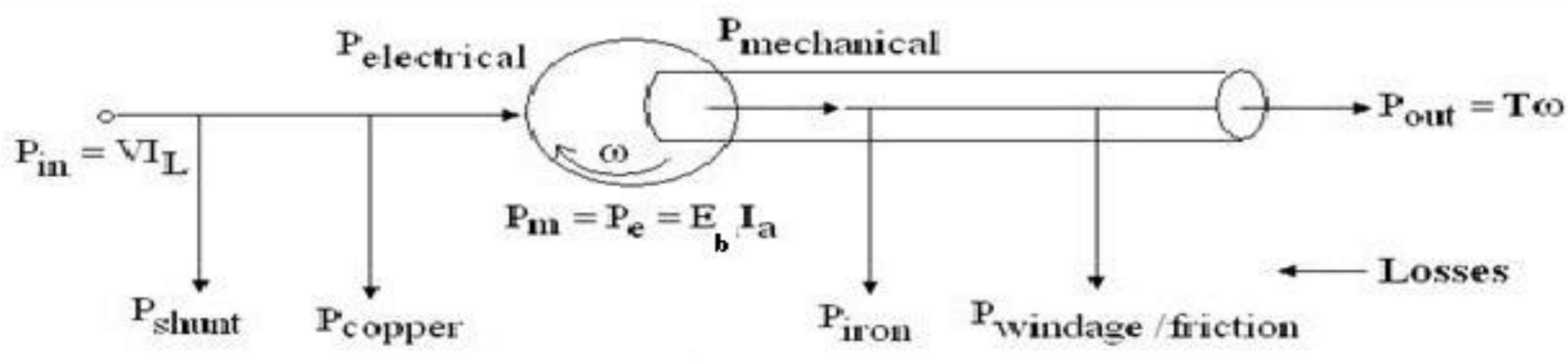
# Power Flow in DC Machine





# Power Flow in DC Motor






$$Overall\ Efficiency(\eta) = \frac{P_{out}}{P_{in}} = \frac{T\,\omega}{V\,I_L}$$

$$= \frac{P_{out}}{P_{out} + P_{losses}} = \frac{T\,\omega}{T\,\omega + losses}$$

# Numerical:



- Speed

$$N \,\alpha\, \frac{E_b}{\phi}$$

- Torque

$$T_a = \frac{1}{2\pi}\phi I_a \frac{PZ}{A} = 0.159\phi I_a \frac{PZ}{A}$$

- Losses

$$Overall\ Efficiency(\eta) = \frac{P_{out}}{P_{in}} = \frac{T\,\omega}{V\,I_L}$$

$$= \frac{P_{out}}{P_{out} + P_{losses}} = \frac{T\,\omega}{T\,\omega + losses}$$

# Speed Control of DC Motor



According to the speed equation of a dc motor

$$E_b = \frac{\phi Z N P}{60 A} \ volts$$

$$N \ \alpha \ \frac{E_b}{\phi}$$

$$N \ \alpha \ \frac{V - I_a R_a}{\phi}$$

where R = Ra for shunt motor
= Ra + Rse for series motor

Thus speed can be controlled by-

1. Flux control method
2. Armature Voltage or Rheostatic control method
3. Applied Voltage Control Method:

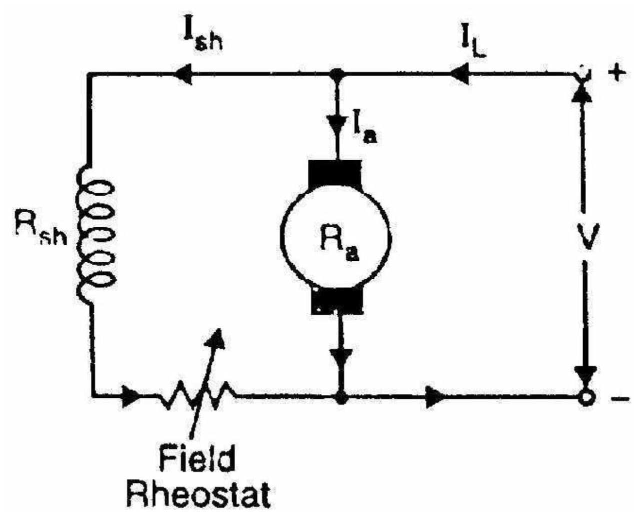
# Speed Control of Shunt Motor



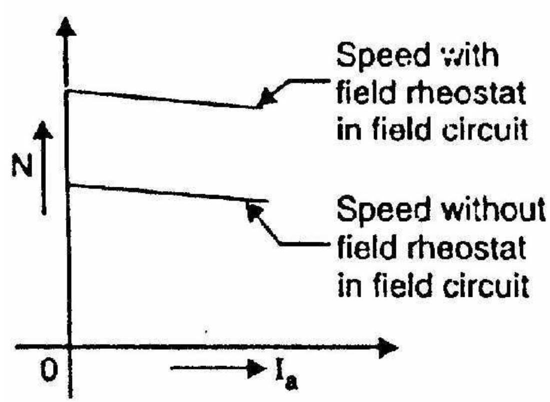
## Flux Control Method:

$$N \propto 1/\phi$$

- Variable field resistance is placed in series with the field winding → reduces the shunt field current Ish
- Speed control above rated speed is possible




**Advantages:**
Easy and convenient
Inexpensive
Independent of load



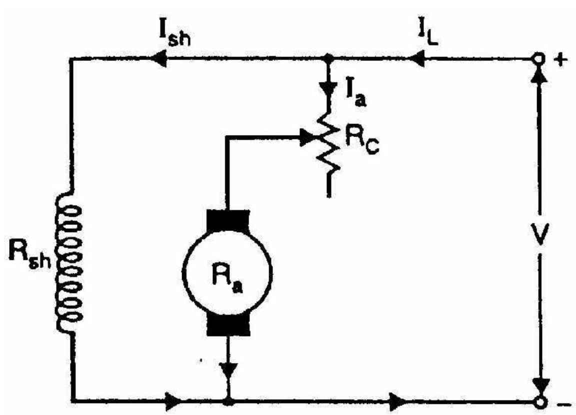

**Disdvantages:**
Only above normal
Limit to maximum
speed

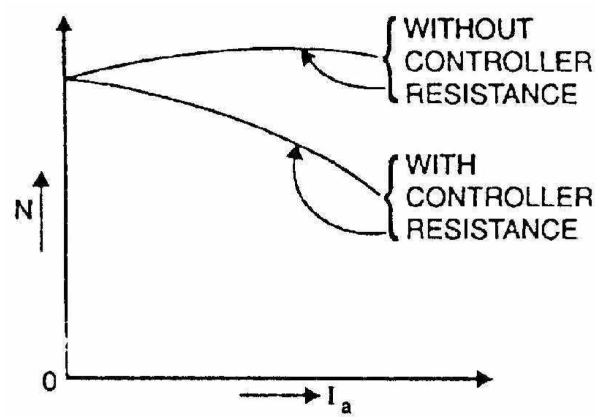
# Speed Control of Shunt Motor



## Armature / Rheostatic Control Method:

- The back emf and the speed of the motor can be changed by varying the voltage across armature V
- Eb α V−Ia (Ra+Rc) and N ∝ Eb
- Speed control below rated speed is possible




**Disdvantages:**

- Power wasted in Rc as carries full Ia
- Output and efficiency reduced
- Poor speed regulation

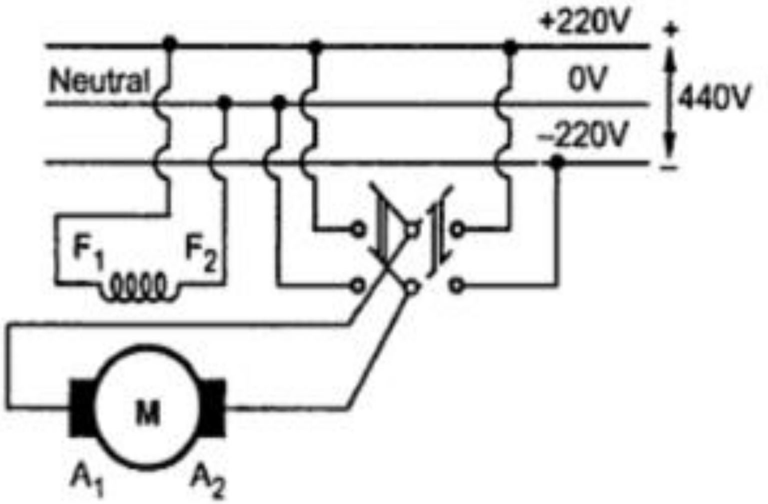
# Speed Control of Shunt Motor



## Applied Voltage Control Method:

### 1. Multiple voltage control method:

- Shunt field: connected permanently across a-fixed voltage source
- Armature: connected across several different voltages through a suitable switchgear
- Give wide range of speed control
- Speed control in both the direction

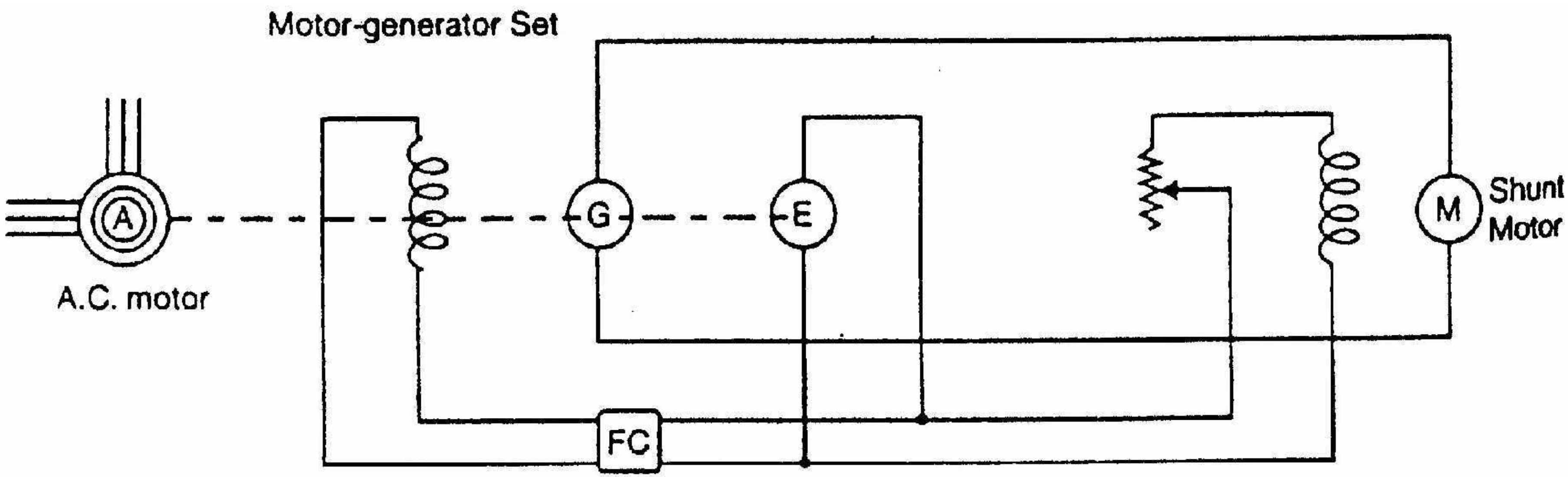


# Speed Control of Shunt Motor



## 2. Ward Leonard Method:

Wide and sensitive speed control




Ward-Leonard speed-control system.

# Speed Control of Series Motor

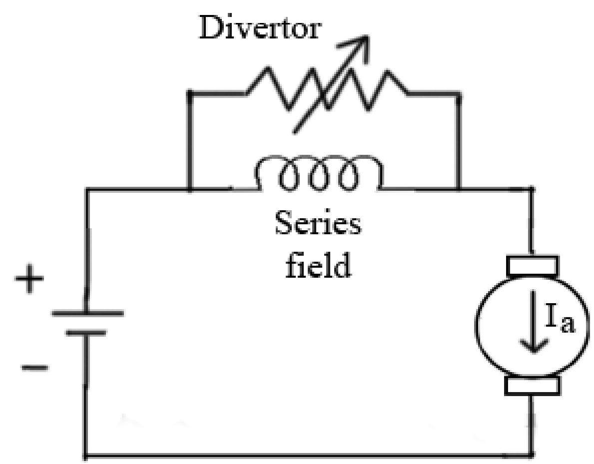


## Flux Control Method:

### 1.Field Diverter method:

- Used for controlling speed
- above rated speed
- only provide speeds above the normal speed. The series field diverter method is often employed in traction work.

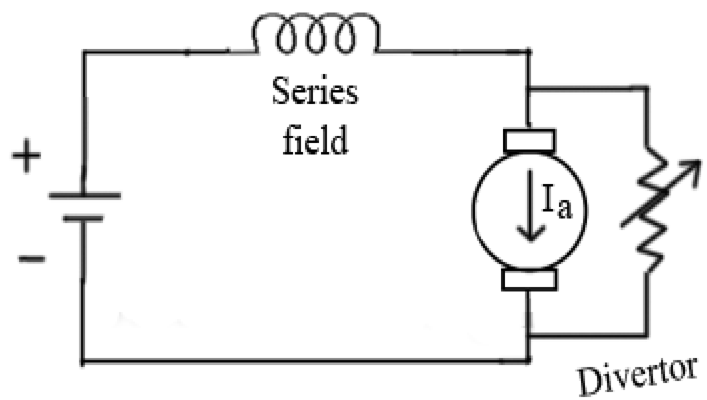
$$N \propto 1/\phi$$




Field Divertor

### 2. Armature Diverter:

- It is used for controlling speed below rated speed.



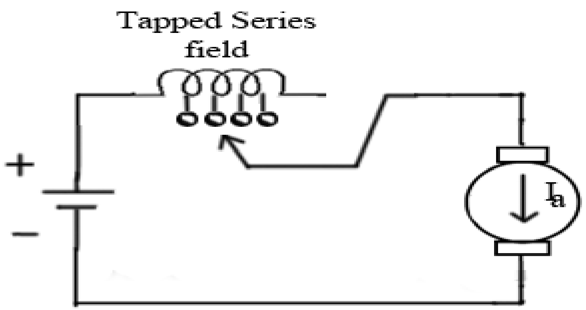

Armature Divertor

# Speed Control of Series Motor



## 3. Tapped Field Control :

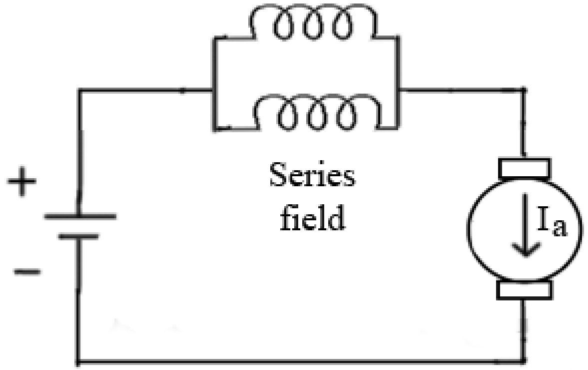
- It is used for controlling speed above rated speed.




Tapped field

## 4. Series- Parallel Control:

- Two speeds at constant torque are possible



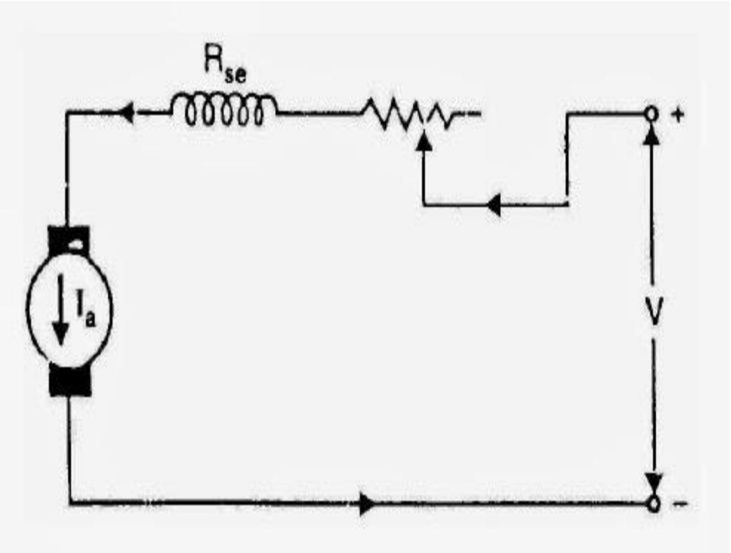

Paralleling Field coils

# Speed Control of Series Motor



- **Armature Resistance/ Rheostatic Method:**

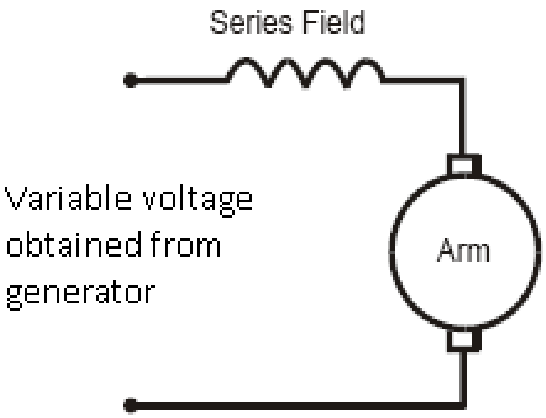
- By changing the value of variable resistance, any speed below the normal speed can be obtained.



# Speed Control of Series Motor



- **Applied Voltage Control:**




- It is used for controlling speed below rated speed.

# Necessity of Starters in DC Shunt Motor



The back emf at the starting is zero and develops as the motor gradually speed up.

Basic operational voltage equation of a DC motor,

$E = E_b + I_a R_a$ and hence, $I_a = (E - E_b) / R_a$

at rest, obviously, the back emf $E_b = 0$

Hence, armature current at the moment of starting $I_a = E / R_a$
In practical DC machines, armature resistance is basically very low, (generally about 0.5 Ω) → a large current flows through the armature during starting → large enough to damage the armature circuit

# Necessity of Starters in DC Shunt Motor



5 H.P., 220 V shunt motor has a full-load current of 20 A and an armature resistance of about 0.5 W.

If this motor is directly switched on to supply,

Ia = 220/0.5 = 440 A: 22 times the full-load current. This high starting current may result in:

(i) burning of armature due to excessive heating effect,

(ii) damaging the commutator and brushes due to heavy sparking,

(iii) excessive voltage drop in the line to which the motor is connected. The result is that the operation of other appliances connected to the line may be impaired and in particular cases, they may refuse to work.

# Necessity of Starters in DC Shunt Motor



In order to avoid excessive current at starting, a variable resistance (known as starting resistance) is inserted in series with the armature circuit

This resistance is gradually reduced as the motor gains speed (and hence Eb increases) and eventually it is cut out completely when the motor has attained full speed

The value of starting resistance is generally such that starting current is limited to 1.25 to 2 times the full-load current.

# Necessity of Starters in DC Shunt Motor



It is very important and desirable to provide the starter with protective devices to enable the starter arm to return to OFF position

(i) when the supply fails, thus preventing the armature being directly across the mains when this voltage is restored → For this purpose, ***we use no-volt release coil.***

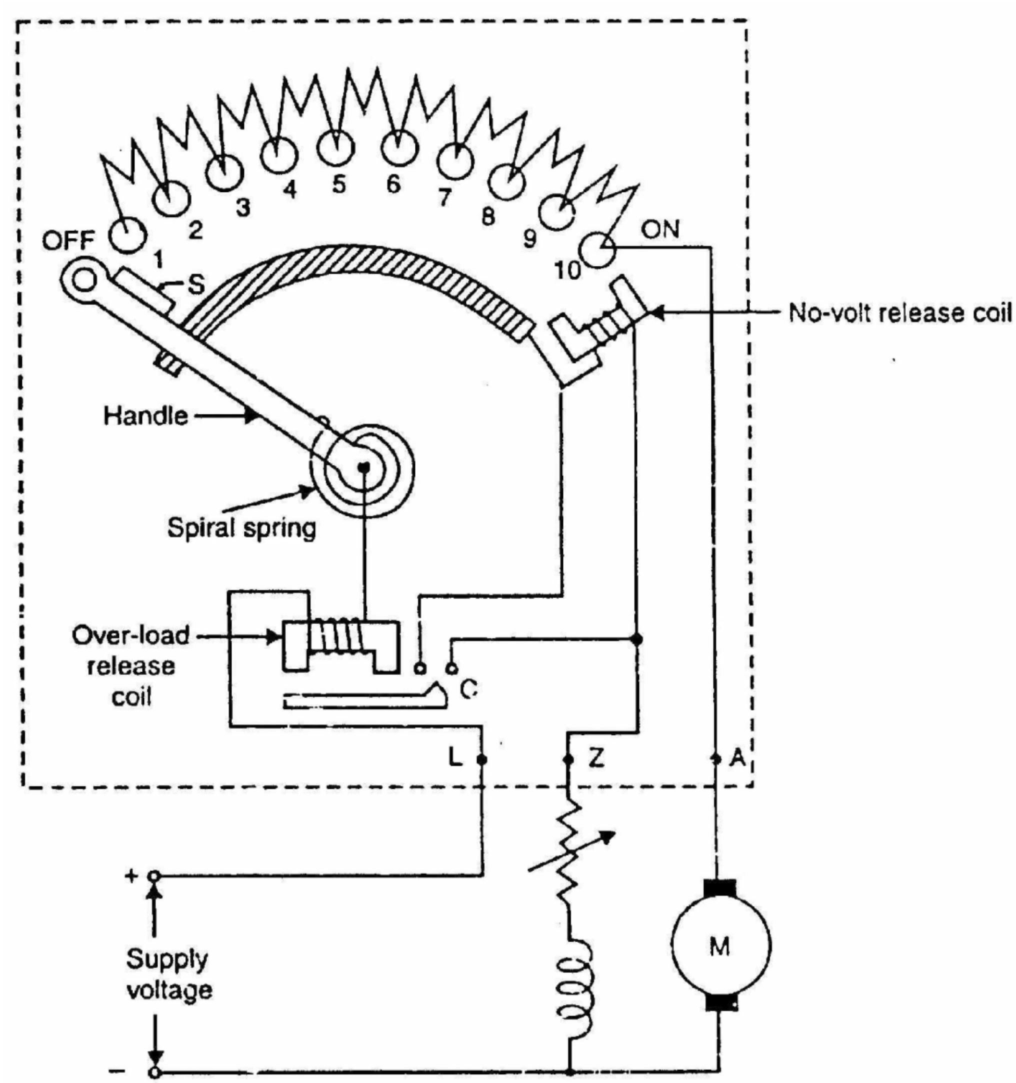
(ii) when the motor becomes overloaded or develops a fault causing the motor to take an excessive current →For this purpose, ***we use overload release coil.***

Types of Starter:

1. Three point starter 2. Four point starter

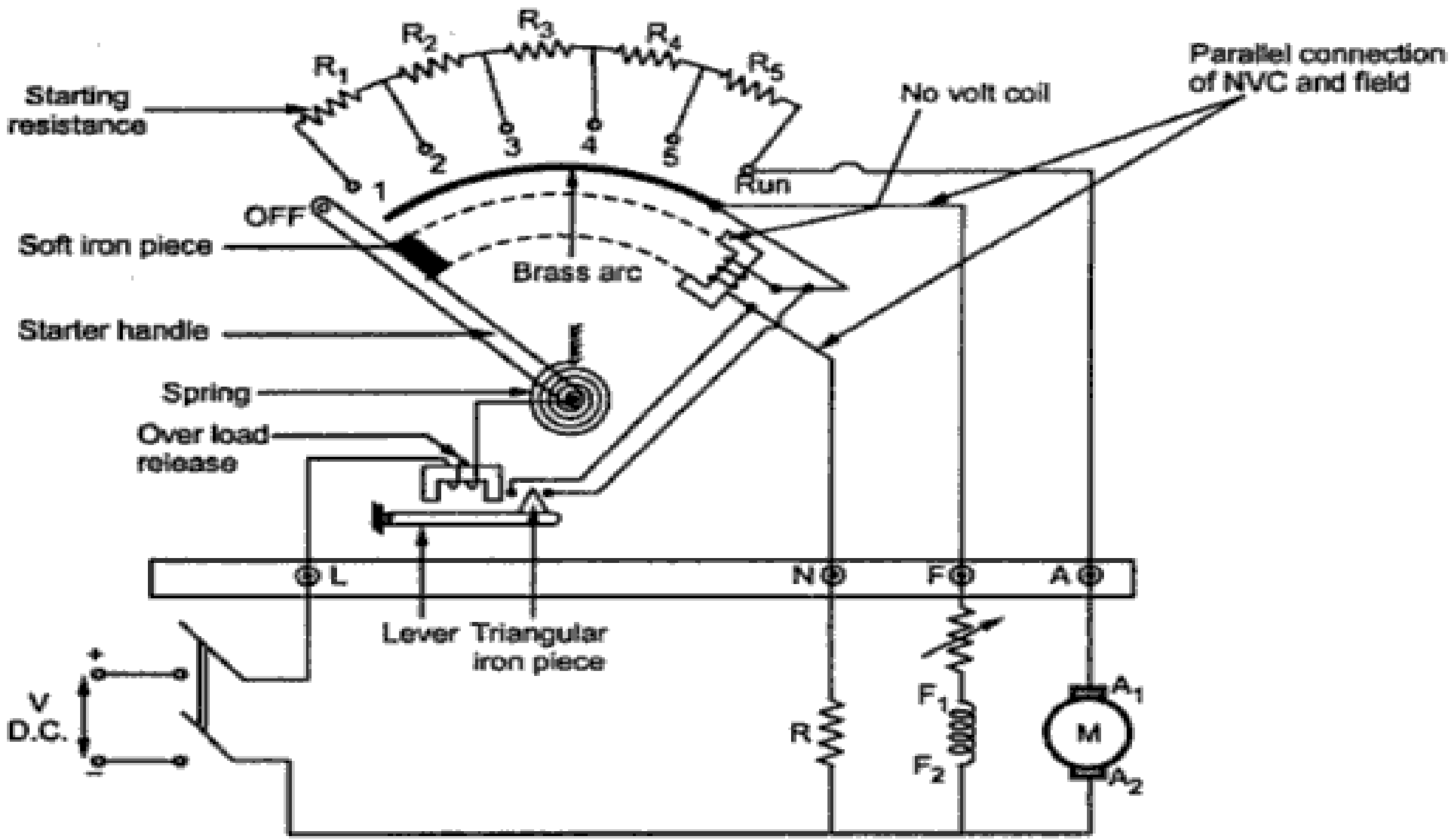
# Three point starter





# Four point starter






**4 point Starter**

# Applications



## Shunt Motor:

- Blowers and fans
- Centrifugal and reciprocating pumps
- Lathe machines
- Machine tools
- Milling machines
- Drilling machines

# Application



<u>Series Motor:</u>

- Cranes
- Hoists , Elevators
- Trolleys
- Conveyors
- Electric locomotives

# Application

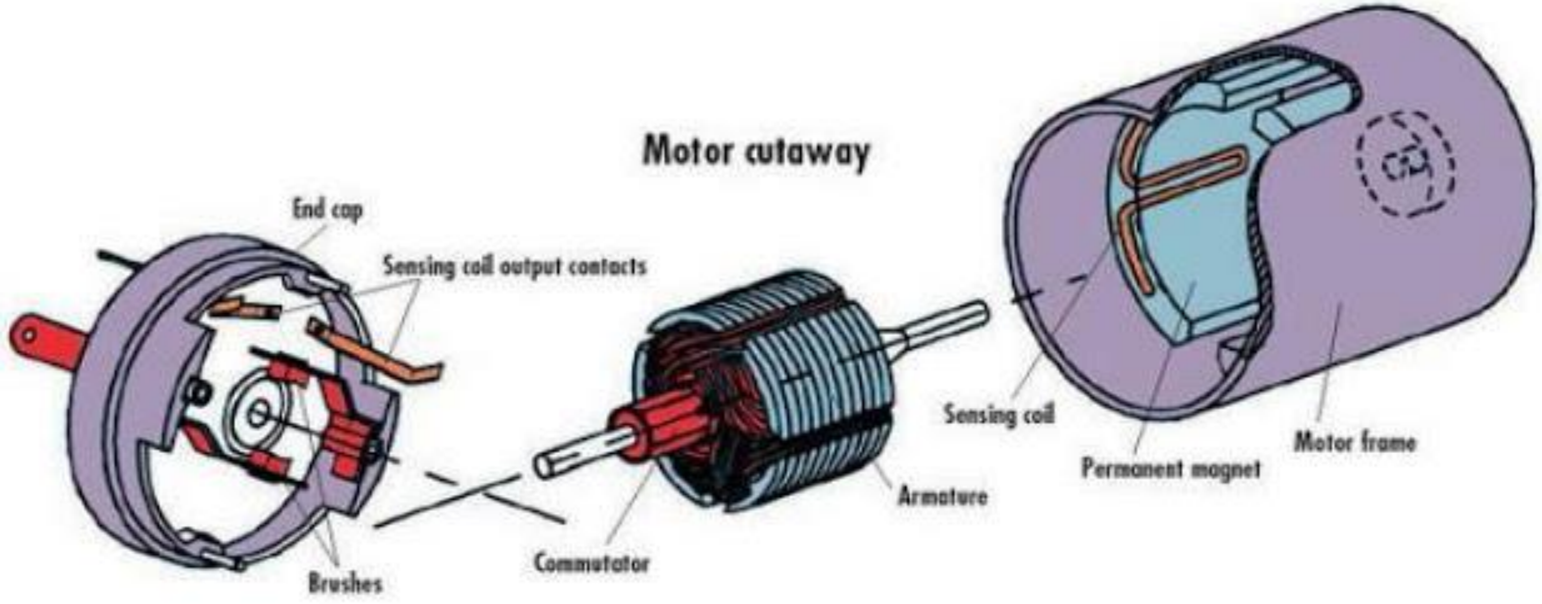


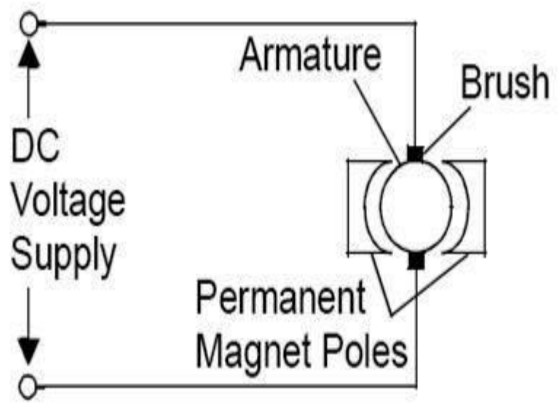
## Cumulative compound Motor:

- Rolling mills
- Punches
- Shears
- Heavy planers
- Elevators

# Permanent Magnet DC motor





# Permanent Magnet DC motor



A permanent magnet DC (PMDC) motor is a motor whose poles are made out of permanent magnets to produce the stator field.

**Advantages:**

- Since no external field circuit is needed, there are no field circuit copper losses.
- Since no field windings are needed, these motors can be considerably smaller.
- Widely used in low power application.
- Field winding is replaced by a permanent magnet (simple construction and less space).
- No requirement on external excitation.

# Permanent Magnet DC motor



**Disadvantages:**

- Since permanent magnets produces weaker flux densities then externally supported shunt fields, such motors have lower induced torque.
- There is always a risk of demagnetization from extensive heating or from armature reaction effects.

**Applications:**

- PMDC motor have been proven most suitable for position control in machine tools, robotics, Electric bike.
- PMDC motors are used in printing and coil winding, packaging, textile, welding and pharmaceutical machinery, and also conveyors and machine tools industry.

# Text and Reference Books



## Text Books

- Electrical Machines by Abhijit Chakabarti and Sudipta Devnath (Tata McGraw Hill Publication)

## Refenence Book

- Electrical Machines by A E Fitzgerald, Charles Kingsley and Jr Stephen D. Umans (Tata McGraw Hill Publication)
- Electrical Machines by I J Nagrath and D P Kothari (Tata McGraw Hill Publication)

# Experiments related to DC Machines



- Load characteristics of DC series motor
- Brake Test on DC Shunt Motor
- Speed Control of DC Motor using Armature voltage and Field Current control method

# THANK YOU