Introduction to Electrical Circuits

Final Term
Lecture - 07

Reference Book:

[1] A Textbook of Electrical Technology , Volume- II, - B.L. Theraja, A.K. Theraja

[2] Principles of Electrical Machines -V.K. Mehta, Rohit Mehta

CONTENT

Week No.	Class No.	Chapter No.	Article No., Name and Contents	Example No.
W11	FC7		**Electromagnetism and fundamental laws:** Magnet; Magnetic materials, poles, field, flux; Faraday's law, Len's law, Fleming's left hand and right-hand rules. **DC Generator:** Definition, Basic working principle and construction of DC generator; classification, emf equation, power stages, losses, efficiency and applications of DC generators; **DC Motor**: Definition, Basic working principle and construction of DC motor; classification, voltage equation, power stages, losses, efficiency; back emf and its significance; condition for maximum power; applications of DC motors.	26.8, 26.28, 29.1, 29.2

Electromagnetism and Fundamental Laws

Magnets

- A magnet is a material or object that produces a magnetic field.
- This magnetic field is invisible but is responsible for the most notable property of a magnet: a force that pulls on other ferromagnetic materials, such as iron, and attracts or repels other magnets.
- A permanent magnet is an object made from a material that is magnetized and creates its own persistent magnetic field. An everyday example is a refrigerator magnet used to hold notes on a refrigerator door.

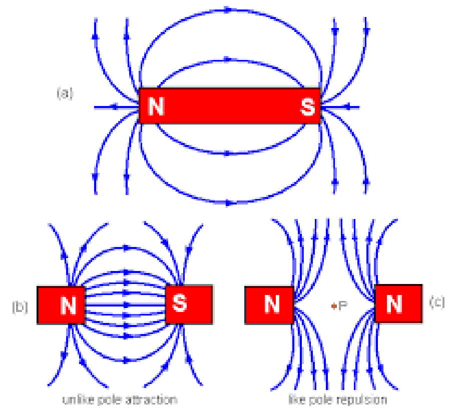
Classification of Magnetic Materials:

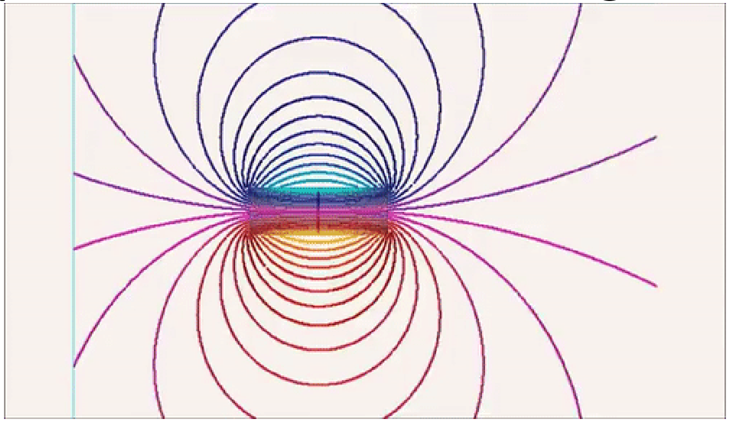
Most materials are classified either as

- ferromagnetic,
- diamagnetic or
- paramagnetic.

Magnetic Field

The area around the magnetic field where the poles experience the force of attraction and repulsion is known as magnetic field





Most magnets have magnetic fields and electromagnets create such fields from electric current moving through coils.

The alternative name of magnetic field is magnetic flux density that is represented by

Magnetic Flux density, $B = \phi/A$

The unit of magnetic flux density is Wb/m2 or T (Tesla).

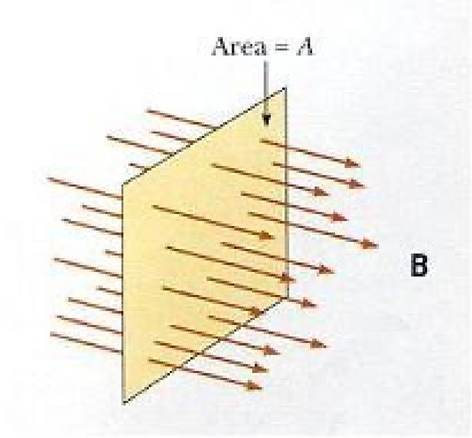
Magnetic Flux

Magnetic flux is a measurement of the total magnetic field which passes through a given area.

Magnetic flux is commonly denoted by ϕ.

The SI unit of magnetic flux is Wb (Weber).

Magnetic Flux, $\phi = AB$

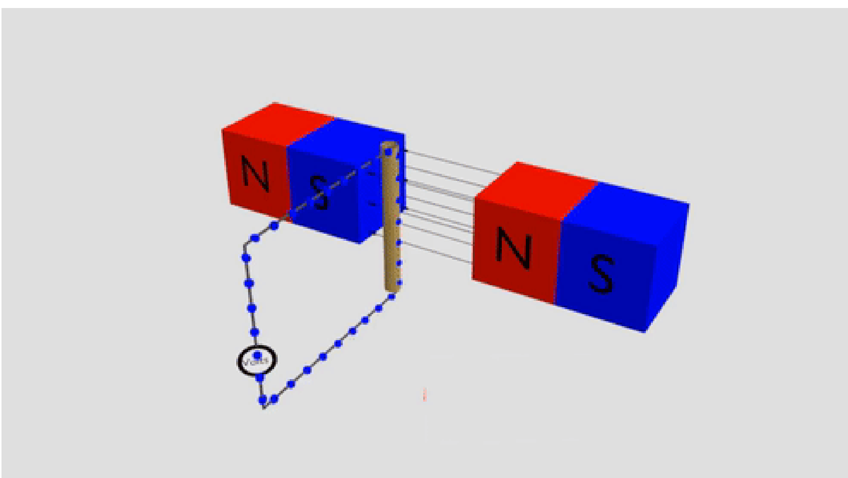


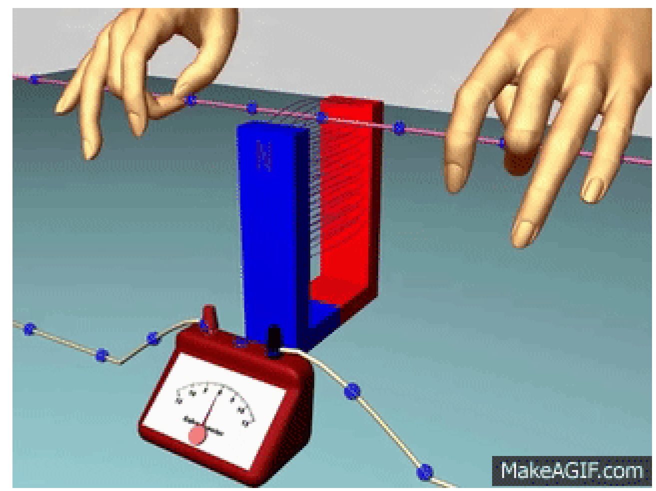
$\Phi = BA$

Faraday's Laws of Electromagnetic Induction

Faraday's First Law

Any change in the magnetic field of a coil of wire will cause an EMF to be induced in the coil. This EMF induced is called induced EMF and if the conductor circuit is closed, a current will also circulate through the circuit and this current is called induced current.





Faraday's Second Law

It states that the magnitude of emf induced in the coil is equal to the rate of change of flux that linkages with the coil. The flux linkage of the coil is the product of number of turns in the coil and flux associated with the coil.

It can be represented mathematically by the following equation:

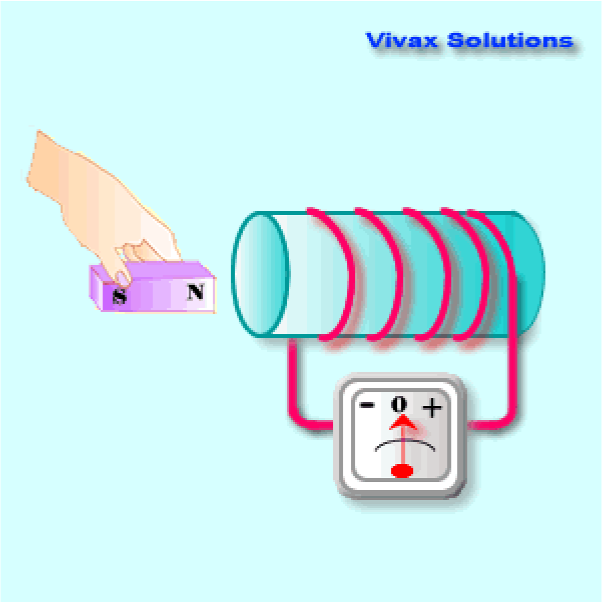
$$\varepsilon = N\frac{d\Phi}{dt}$$

Where,

ε = Induced emf

$d\Phi$ = Change in magnetic flux

N = Number of turns in coil



Lenz's Law

Lenz's law states that when an emf is generated by a change in magnetic flux according to Faraday's Law, the polarity of the induced emf is such, that it produces a current that's magnetic field opposes change which produces it. The negative sign used in Lenz's law, indicates that the induced emf (ε) and the change in magnetic flux (dΦ) have opposite signs.

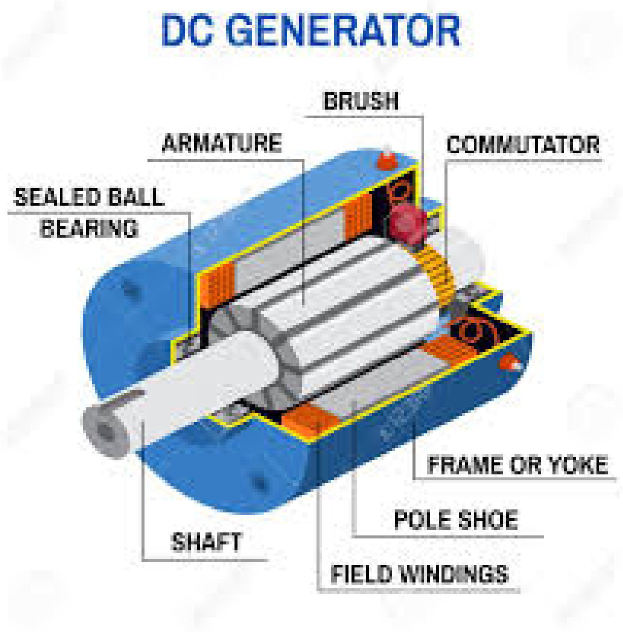
Its mathematical notation is given below.

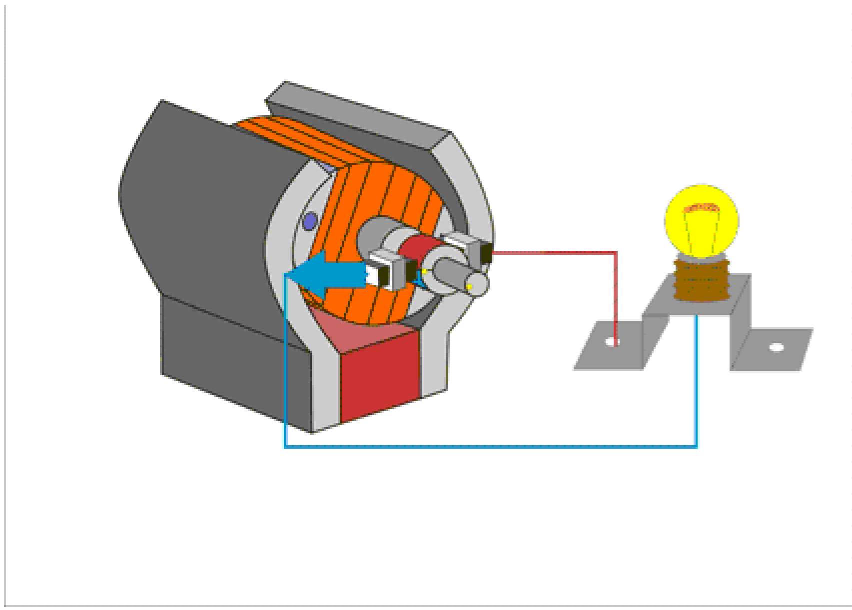
$$\varepsilon = -N \frac{d\Phi}{dt}$$

Video: https://www.youtube.com/watch?v=2_M83gNOOEg

DC Generator

An electrical generator is a machine which converts mechanical energy (or power) intoelectrical energy(or power). Whenever a conductor cuts magnetic flux dynamically induced e.m.f is produced in it according to Faraday’s law of electromagnetic induction. This e.m.f. causes a current to flow if the conductor circuit is closed.





Basic Working Principle of a Single Loop DC Generator

- When a conductor is rotated in a magnetic field **EMF** is generated in that conductor according to the Faraday's law of electromagnetic induction.
- When the conductor portion **A-B** is at position 1, it produces zero **EMF** because the rate of change in flux is zero though the flux linkage is maximum. As it moves in the clockwise direction, the rate of change in flux increases so does the **EMF**.
- When the conductor portion is at position 2, it produces maximum **EMF** because at that position the flux linkage is minimum but the rate of change in flux is maximum.
- At position 3, the **EMF** is zero, at position 4 negative maximum and at position 5 zero again.
- The wave shape of the generated **EMF** is given alongside the construction of the simple loop generator.

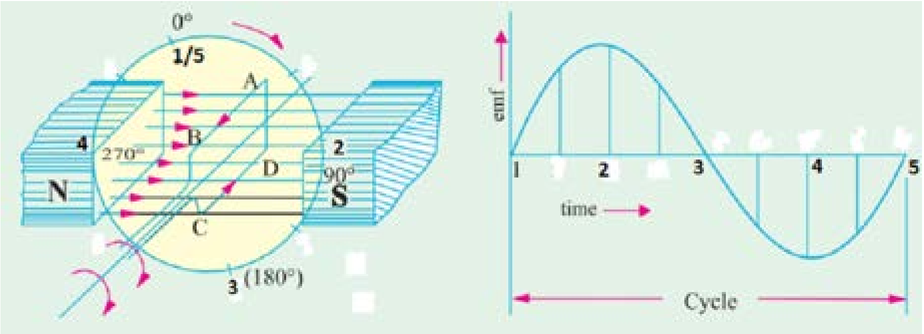
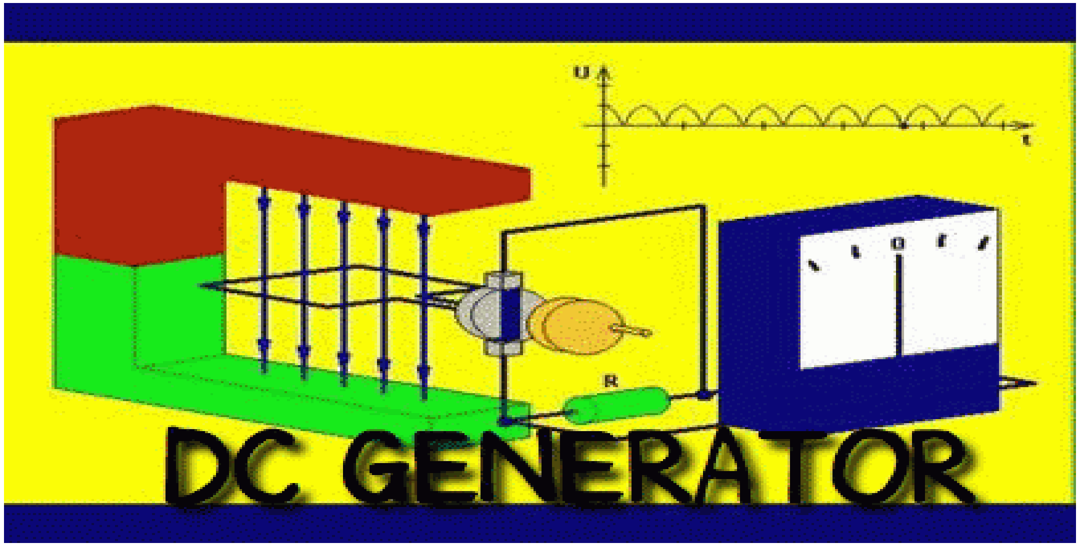
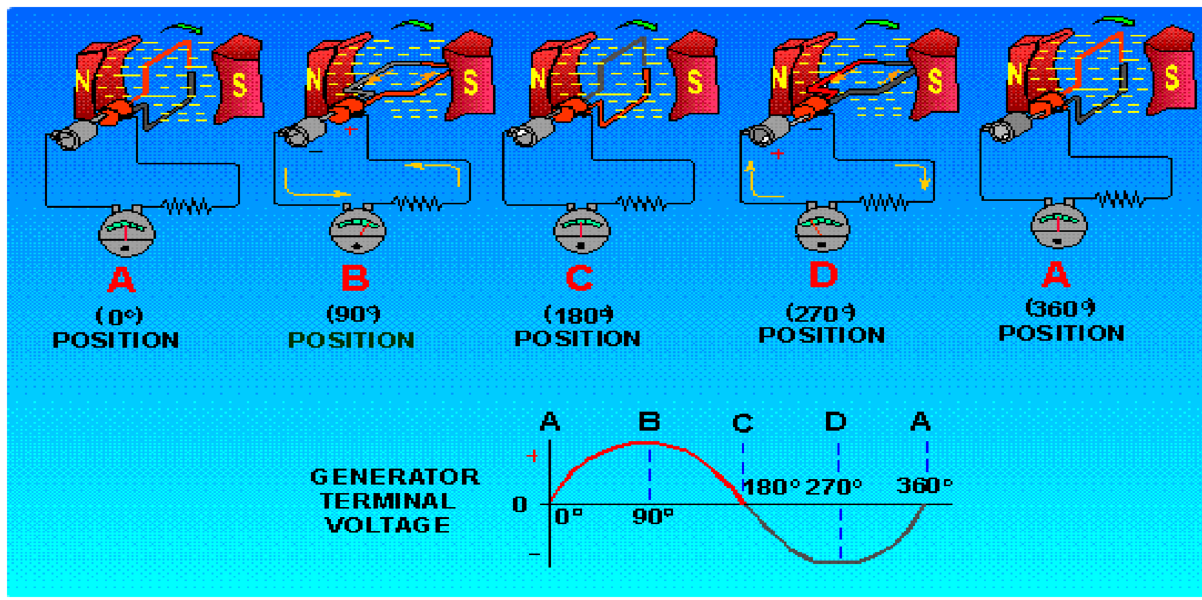


Fig. 1: Construction and Basic Working Principle of a DC Generator


U
R
DC GENERATOR


N
S
A
(0°)
POSITION
B
(90°)
POSITION
C
(180°)
POSITION
D
(270°)
POSITION
A
(360°)
POSITION
GENERATOR
TERMINAL
VOLTAGE
A B C D A
+
0
−
0°
90°
180°
270°
360°

EMF Equation of DC Generator

Let, Φ= flux/pole in weber (Wb)

Z= total number of armature conductors

= Number of slots × Number of conductors/slot

P= number of Generator poles

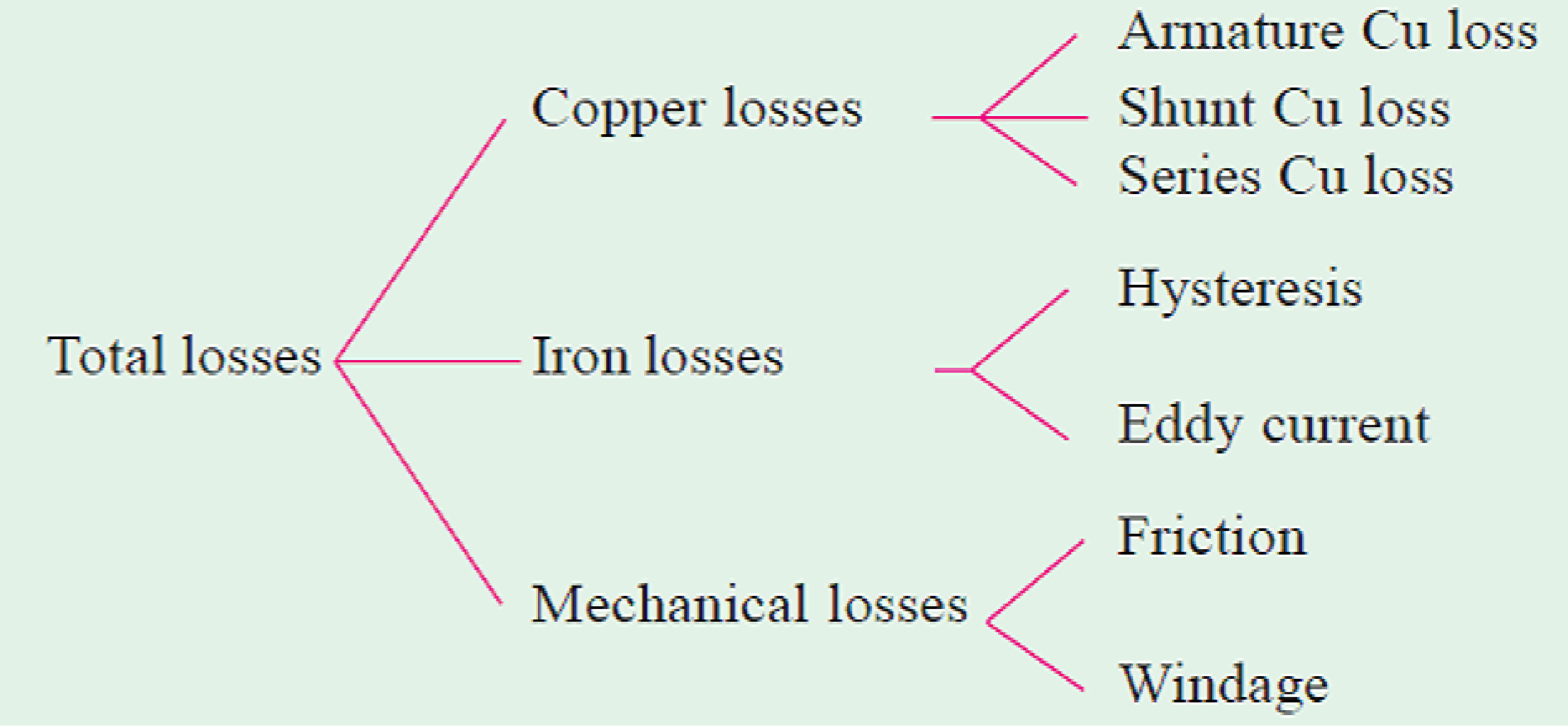
A= number of Parallel paths in armature

N= armature rotation in revolution per minute (rpm)

Eg= emf induced in any parallel path in armature

$$E_g = \frac{P\Phi N}{60} \times \frac{Z}{A} = \frac{P\Phi ZN}{60A}$$

Total Losses In a Generator



Loss and Efficiency Equations

Generator output = VI_L

Generator input = Output + Losses

Loss

$= VI_L +$ Variable losses + Constant losses

$$= VI_L + I_a^2 R_a + CL \text{; where CL= Constant Loss}$$

$$= VI_L + (I_{L+} I_{sh})^2 R_a + CL; \qquad \because I_a = I_L + I_{sh}$$

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

Input

$$\eta = \frac{output}{input} = \frac{VI_L}{VI_L + I_L{}^2 R_a + CL} = \frac{1}{1 + \left(\frac{I_L R_a}{V} + \frac{CL}{VI_L} \right)}$$

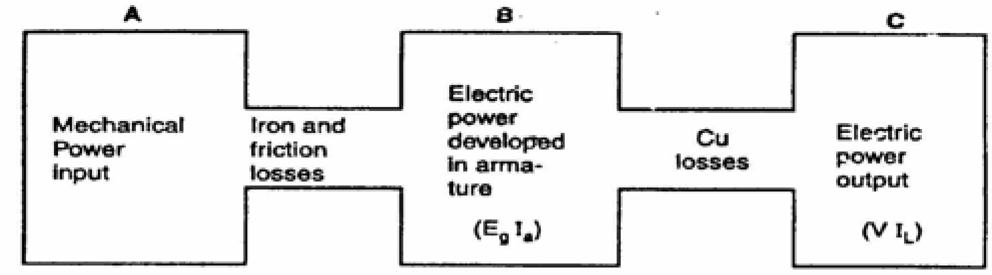
Efficiency

Power Stages of a DC Generator

The various power stages in a DC generator are represented diagrammatically in Figure below.

A - B = Iron and friction losses

B - C = Copper losses



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

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

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

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

Applications of DC Generator

Separately Excited DC Generators	Shunt wound Generators	Series Wound Generators
Separately excited DC Generators are used in laboratories for testing as they have a wide range of voltage output. Used as a supply source of DC motors.	DC shunt wound generators are used for lighting purposes. Used to charge the battery. Providing excitation to the alternators.	Used as a booster in distribution networks. Over compounded cumulative generators are used in lighting and heavy power supply. Flat compounded generators are used in offices, hotels, homes, schools, etc.

Example 26.8. *A four-pole generator, having wave-wound armature winding has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine when driven at 1500 rpm assuming the flux per pole to be 7.0 mWb ?* **(Elect. Machines-I, Allahabad Univ. 1993)**

Solution. $E_g = \frac{\Phi Z N}{60}\left(\frac{P}{A}\right)$ volts

Here, $\Phi = 7 \times 10^{-3}$ Wb, $Z = 51 \times 20 = 1020$, $A = P = 4$, $N = 1500$ r.p.m.

$\therefore \quad E_g = \frac{7 \times 10^{-3} \times 1020 \times 1500}{60}\left(\frac{4}{2}\right) = \mathbf{178.5\ V}$

Example 26.28. *A long-shunt compound-wound generator gives 240 volts at F.L. output of 100 A. The resistances of various windings of the machine are : armature (including brush contact) 0.1 Ω, series field 0.02 Ω, interpole field 0.025 Ω, shunt field (including regulating resistance) 100 Ω. The iron loss at F.L. is 1000 W ; windage and friction losses total 500 W. Calculate F.L. efficiency of the machine.* **(Electrical Machinery-I, Indore Univ. 1989)**

Solution. Output $= 240 \times 100 = 24{,}000$ W

Total armature circuit resistance $= 0.1 + 0.02 + 0.025 = 0.145\ \Omega$

$I_{sh} = 240/100 = 2.4$ A $\quad \therefore I_a = 100 + 2.4 = 102.4$ A

$\therefore$ Armature circuit copper loss $= 102.4^2 \times 0.145 = 1{,}521$ W

Shunt field copper loss $= 2.4 \times 240 = 576$ W

Iron loss $= 1000$ W ; Friction loss $= 500$ W

Total loss $= 1{,}521 + 1{,}500 + 576 = 3{,}597$ W ; $\eta = \frac{24{,}000}{24{,}000 + 3{,}597} = 0.87 = \mathbf{87\%}$

DC Motor

An electrical motor is a machine which converts electrical energy into mechanical energy.

Working Principle of a DC Motor:

An electrical motor is a machine which converts electrical energy into mechanical energy. Its action is based on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's Left-hand Rule.

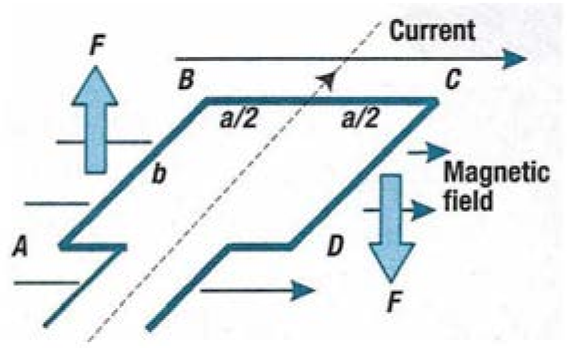
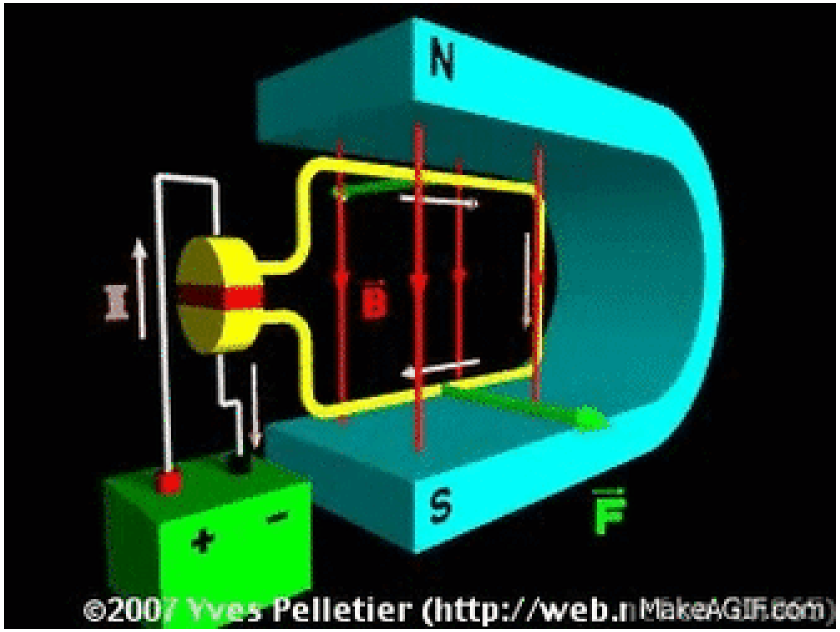
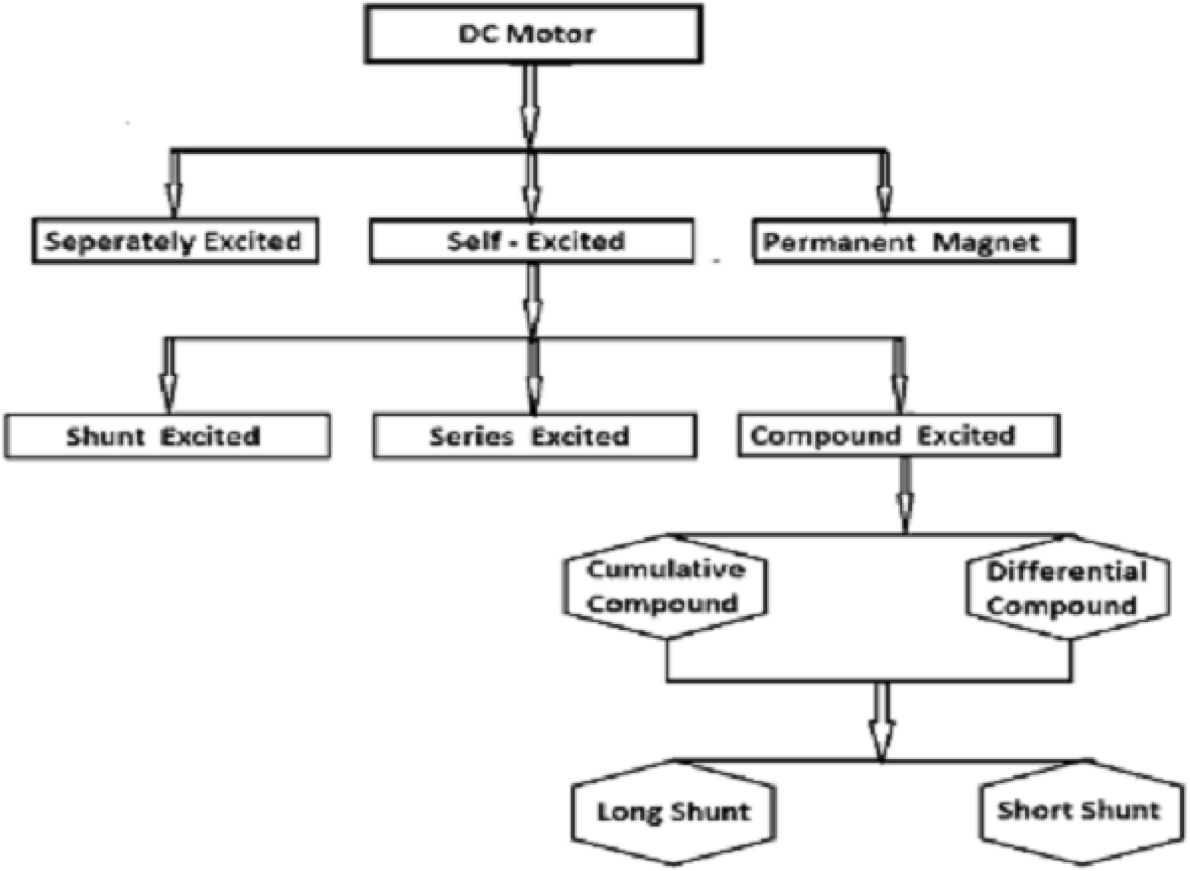


Figure 1: Demonstration of DC Motor Working Principle

- ✓ When the field magnets are excited and its armature conductors are supplied with the current, they experience a force tending to rotate the armature.
- ✓ Each conductor experiences a force which tends to rotate the armature in one direction only.
- ✓ These forces collectively produces a driving torque which sets the armature rotating.



Classification of DC Motor



Back EMF

- *When the motor armature rotates, the conductors also rotate and hence cut the flux.*
- *In accordance with the laws of electromagnetic induction, emf is induced in them whose direction, as found by Fleming's Right-hand Rule, is in opposition to the applied voltage.*
- *Because of its opposing direction, it is referred to as counter emf or back emf (V_b).*

Significance of back EMF:

- ✓ *The armature current will be established by the resultant voltage (algebraic sum of applied voltage and back EMF) and armature resistance as follows*

$$I_a = \frac{Net\ Voltage}{Armature\ \text{Resistance}} = \frac{V - V_b}{R_a}$$

Back EMF depends on several factors.

- ✓ *It is directly related to the armature speed. If speed is high, V_b is large, hence armature current I_a, seen from the above equation, is small.*
- ✓ *If the speed is less, then V_b is less, hence more current flows which develops more torque. So, it is observed that V_b acts like a governor i.e, it makes a motor self-regulating so that it draws as much current as is just necessary.*

Equations

Voltage Equation of D.C. Motor:

$$V = E_b + I_a R_a$$

Example 29.1. *A 220-V d.c. machine has an armature resistance of 0.5 Ω. If the full-load armature current is 20 A, find the induced e.m.f. when the machine acts as (i) generator (ii) motor.*

(Electrical Technology-I, Bombay Univ. 1987)

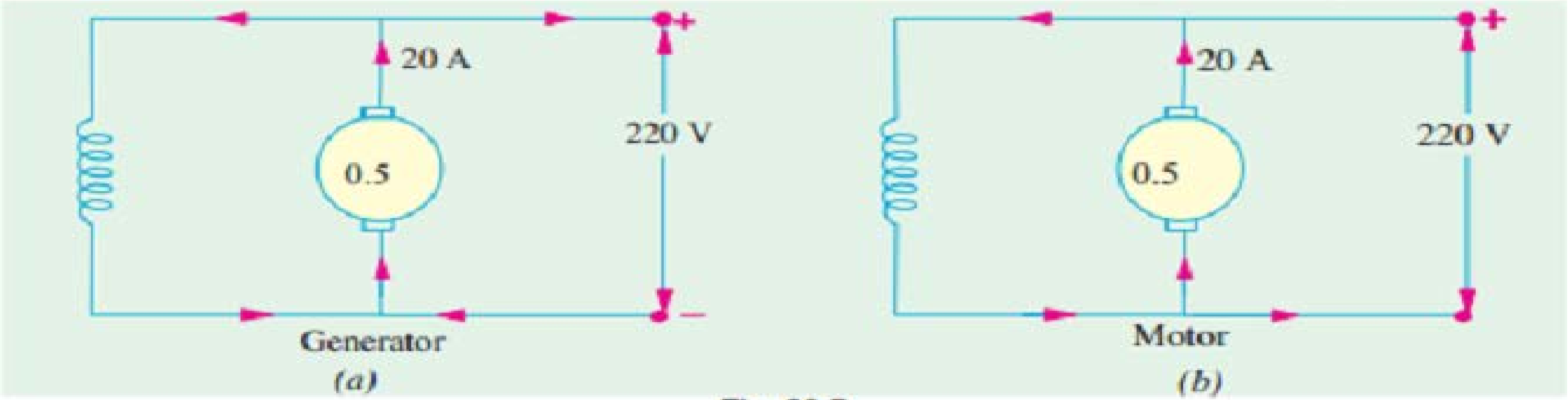


Fig. 29.7

Solution. As shown in Fig. 29.7, the d.c. machine is assumed to be shunt-connected. In each case, shunt current is considered negligible because its value is not given.

(*a*) As Generator [Fig. 29.7(*a*)] $E_g = V + I_a R_a = 220 + 0.5 \times 20 =$ **230 V**

(*b*) As Motor [Fig 29.7 (*b*)] $E_b = V - I_a R_a = 220 - 0.5 \times 20 =$ **210 V**

Example 29.2. *A separately excited D.C. generator has armature circuit resistance of 0.1 ohm and the total brush-drop is 2 V. When running at 1000 r.p.m., it delivers a current of 100 A at 250 V to a load of constant resistance. If the generator speed drop to 700 r.p.m., with field-current unaltered, find the current delivered to load.* **(AMIE, Electrical Machines, 2001)**

Solution. $R_L = 250/100 = 2.5$ ohms.

$E_{g1} = 250 + (100 \times 0.1) + 2 = 262$ V.

At 700 r.p.m., $E_{g2} = 262 \times 700/1000 = 183.4$ V

If I_a is the new current, $E_{g2} - 2 - (I_a \times 0.1) = 2.5\ I_a$

This gives $I_a = 96.77$ amp.

Applications

Type of motor	Characteristics	Applications
Shunt	Approximately constant speed Adjustable speed Medium starting torque	For driving constant speed line shafting Lathes Centrifugal pumps Machine tools Blowers and fans Reciprocating pumps
Series	Variable speed Adjustable variying speed High Starting torque	For traction work *i.e.* Electric locomotives Rapid transit systems Trolley, cars etc. Cranes and hoists Conveyors
Comulative Compound	Variable speed Adjustable varying speed High starting torque	For intermittent high torque loads For shears and punches Elevators Conveyors Heavy planers Heavy planers Rolling mills; Ice machines; Printing presses; Air compressors


THE END