Introduction to direct current (dc) machines fundamentals

•DC machines are generators that convert mechanical energy to DC electric energy and motors that convert DC electric energy to mechanical energy. ***Generator action***: An emf (voltage) is induced in a conductor if it moves through a magnetic field.

• DC motors are used in a wide variety of industrial drives such as robots, machine tools, paper and steel mills. ***Motor action***: A force is induced in a conductor that has a current going through it and placed in a magnetic field

• DC generators are quite rare in modern power systems. They are being replaced by solid-state devices that convert available AC power to DC power for DC drive systems and other DC applications.

•Any DC machine can act either as a generator or as a motor.

DC Machine Working Principle

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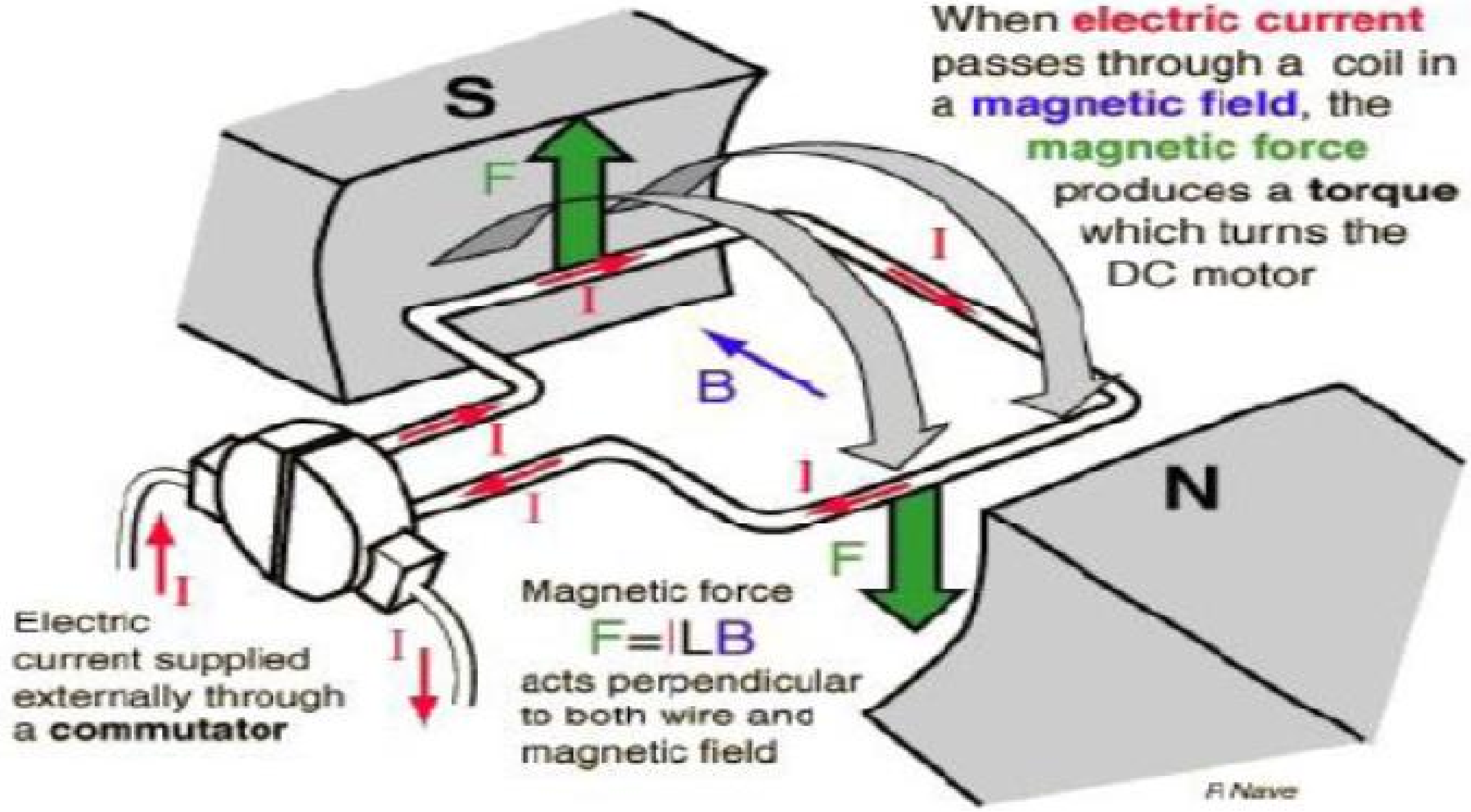


DC Generator Fundamentals

When a conductor of length *l* is moving at a velocity ***v*** to the right in a magnetic field of density **B** , according to Faraday's Law of Electromagnetic Induction, an emf $\mathbf{e_{ind}}$ will be induced.

$$e_{ind} = (B \times v) . l$$

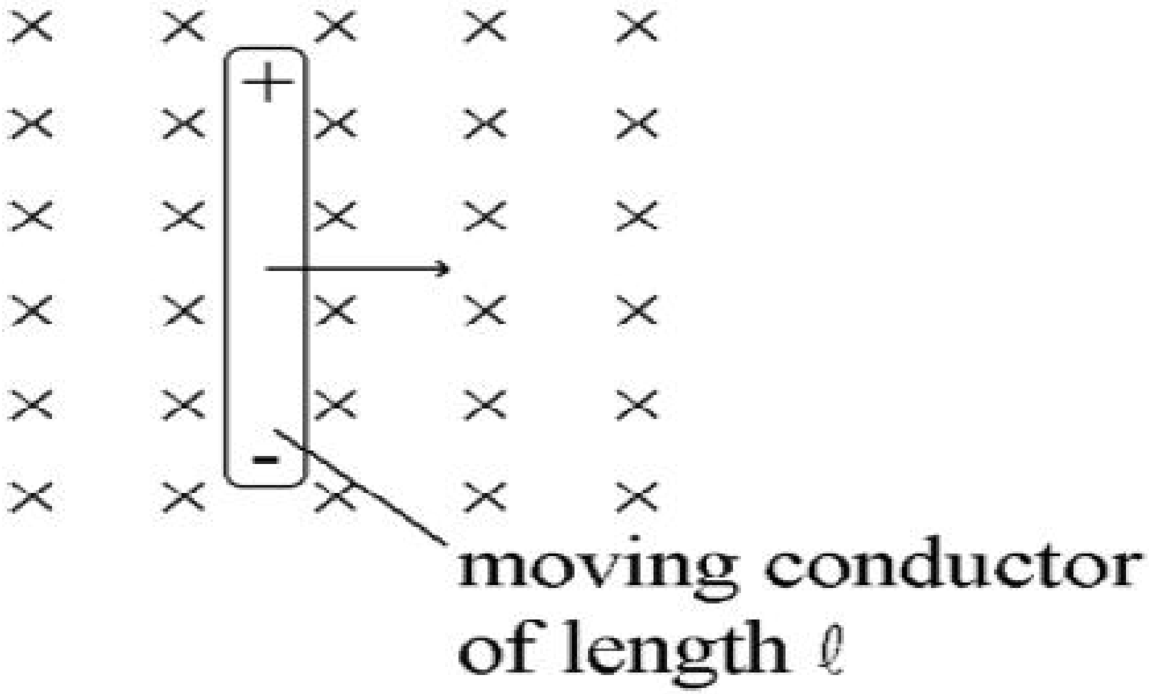
e = induced voltage, ***v*** = velocity of the conductor, **B** = flux density and ***l*** is the length of the conductor.

$$e = Bvl \sin\alpha \cos\beta$$

α - angle between the direction in which the conductor is moving and the flux is acting.

β - smallest possible angle the conductor makes with the direction of, the vector product, $(v \times B)$ and for maximum induction, $\beta = 0$. Hence, $e = Blv$ for most cases.

$(v \times B)$ indicates the direction of the current flow in the conductor, or the polarity of the emf.



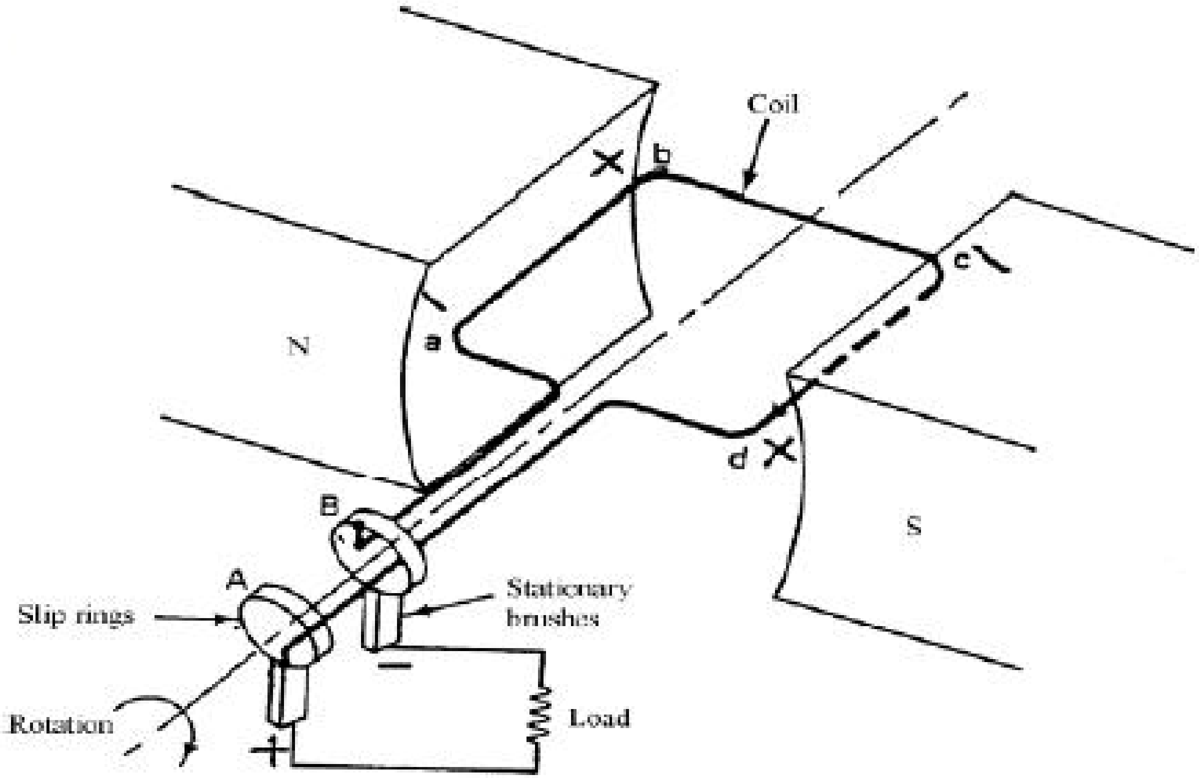
Generated Voltage in a Loop (a coil of one turn)

For emf to be induced, the conductors must cut the flux lines as they move. Otherwise, $(v \times B) = 0$.

$$e_{loop} = e_{ab} + e_{bc} + e_{cd} + e_{da}$$

$$e_{loop} = Blv + 0 + Blv + 0$$

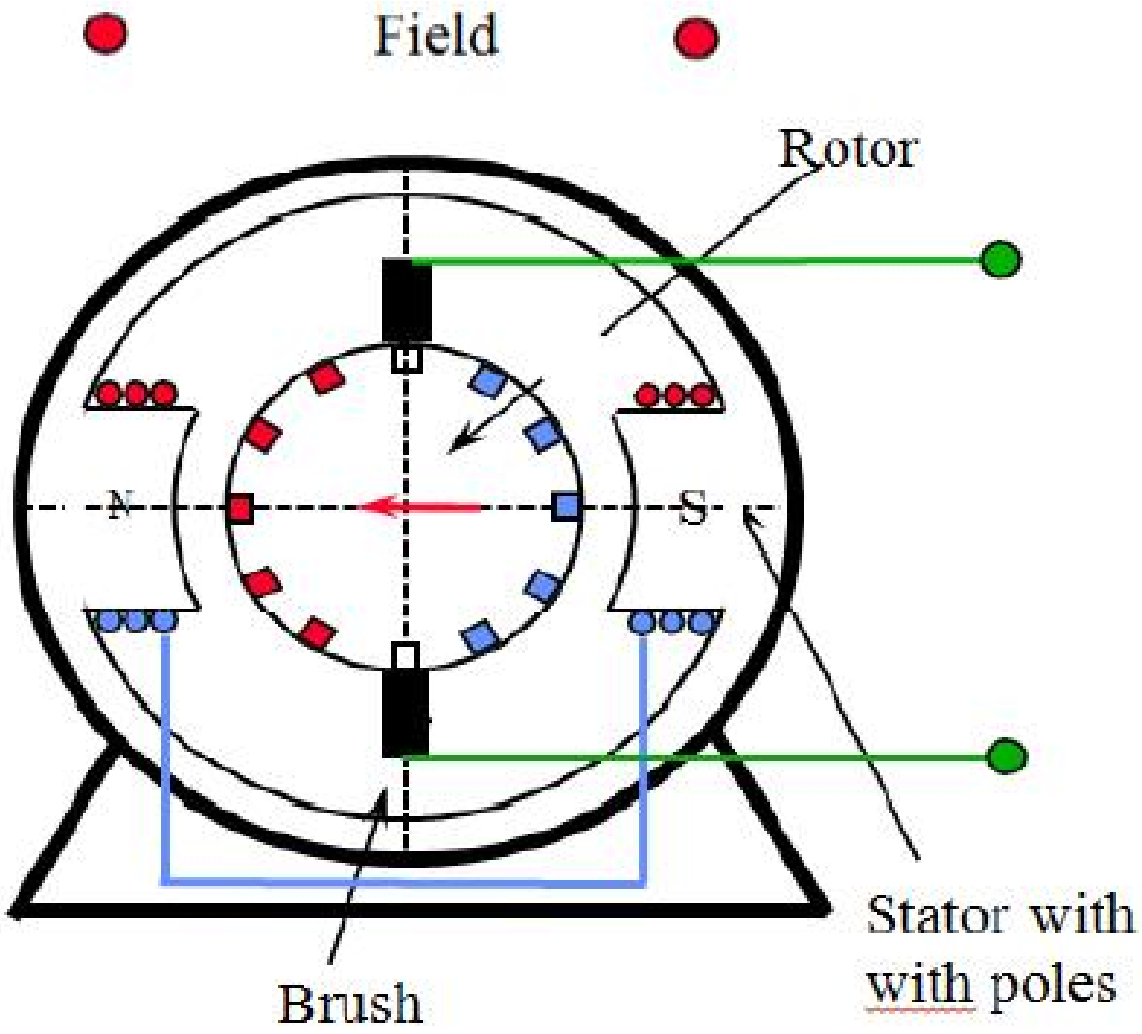
$$e_{loop} = 2\,B\,l\,v$$



Real DC machine Construction

Stator: Stationary part of the machine. The stator carries a field winding that is used to produce the required magnetic field by DC excitation. Often know as the field.

Rotor: The rotor is the rotating part of the machine. The rotor carries a distributed winding, and is the winding where the emf is induced. Also known as the armature.



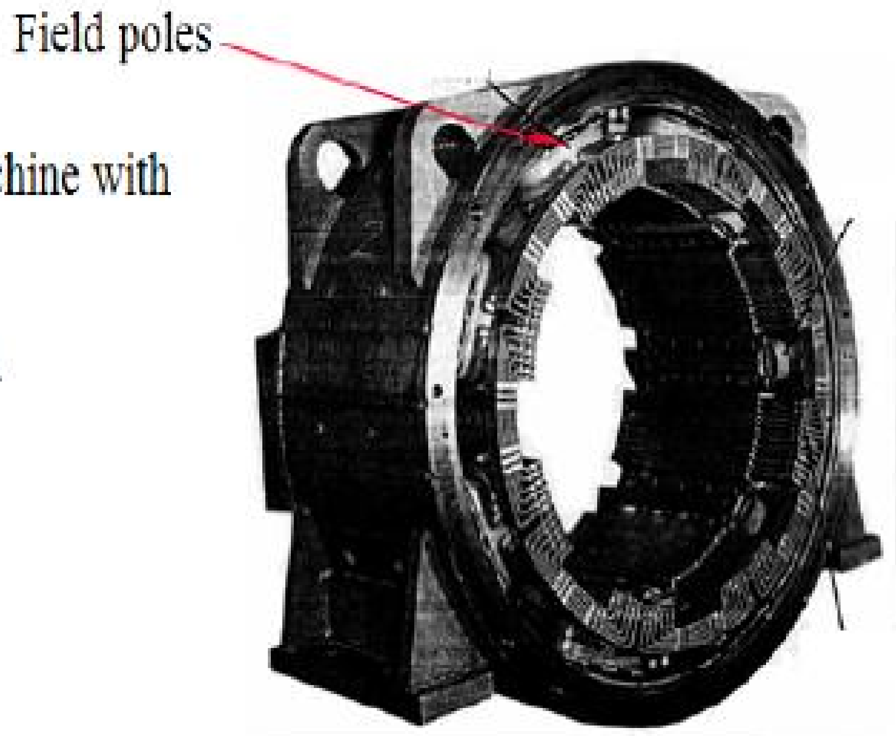
Field
Rotor
N
S
Brush
Stator with
with poles

DC machine Construction

The picture shows the stator of a large DC machine with several poles.

The iron core is supported by a cast iron frame.

Dc motor stator construction



Generated EMF in a Real DC Machine

$$E_G = \frac{ZP}{60a}\phi n = k_g \phi n = \frac{ZP}{2\Pi a}\phi\omega = k_m \phi\omega$$

Where

Z = total number of conductors, P = total number of poles.

a = P for lap winding, a = 2 for wave winding, ϕ = flux,

ω= speed in rad/s and n = speed in rpm.

DC Motor Fundamentals

$$F = (l \times B)\, i$$

F = induced force, ***B*** = flux density, ***I*** is the current passing in the conductor and ***l*** is the length of the conductor.

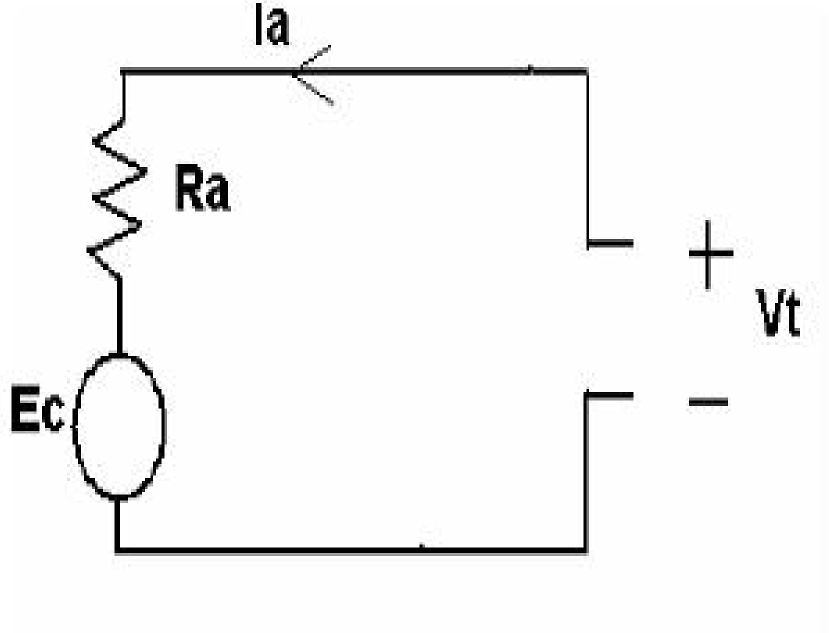
l is a vector in the direction of the flow of the current.

(l x B) Direction indicates the direction of force

Counter EMF

When the motor is running, internally generated emf, ($\mathbf{E_G} = \mathbf{E_C}$) opposes the applied voltage, thus:

$$I_A = \frac{V_T - E_C}{R_A}$$



Where: V_T = terminal voltage,
E_c = counter EMF, R_A is the armature resistance and I_A is the armature current

The relationship between the induced EMF and torque

$$E_{conductor} = B\ell v$$

$$T_{conductor} = B\ell i r$$

therefore,

$$\frac{E}{T} = \frac{B\ell v}{B\ell i r} = \frac{v}{ir}, \; v = \omega r$$

$$\frac{E}{T} = \frac{\omega}{i}$$

$$\underbrace{Ei}_{\substack{electric\\power}} = \underbrace{T\omega}_{\substack{mechanical\\power}}$$

$$T = \frac{EI}{\omega} = \frac{ZP}{2\pi a}\phi I_A$$

$$T = k_m \phi I_A$$

Where: T is the torque,

Example:

A six-pole DC machine has a flux per pole of 30 mWb. The armature has 536 conductors connected as a lap winding. The DC machine runs at 1050 rpm and it delivers a rated armature current of 225 A to a load connected to its terminals, calculate:

(a) Machine constant, K_m (b) Generated voltage, E_G (c) Conductor current
(d) Electromagnetic torque. (e) Power delivered by the machine.

$$a)\ k_m = \frac{ZP}{2\pi a} = \frac{6 * 536}{2\pi * 6} = 85.31$$

$$b)\ \omega = \frac{2\pi n}{60} = \frac{2\pi * 1050}{60} = 109.96 \text{ rad/s}$$

$$E_G = k_m \phi \omega = 85.31 * 0.03 * 109.96 = 281.4 \text{ V}$$

$$c)\ \text{Since it is lap winding :}$$

$$I(conductor) = \frac{I_a}{a} = \frac{225}{6} = 37.5 A$$

$$d)\ T = k_m \phi I_a = 85.31 * 0.03 * 225 = 575.84\ N.m$$

$$e)\ P = T\omega = E_G I_a = 63.32 \text{ kW}$$