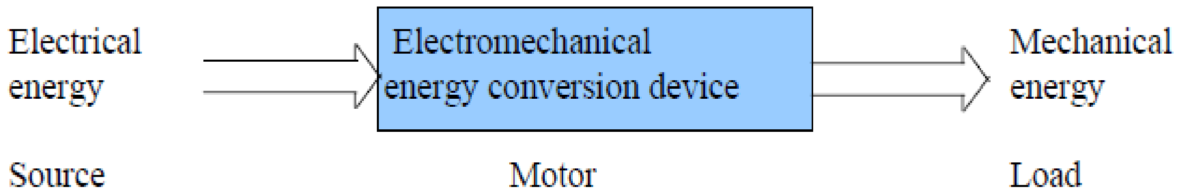
DC MOTOR

Almost every mechanical movement that we see around us is accomplished by an electric motor. Electric machines are a means of converting energy. Motors take electrical energy and produce mechanical energy. Electric motors are used to power hundreds of devices we use in everyday life. Motors come in various sizes.
Huge motors that can take loads of 1000's of Horsepower are typically used in the industry. Some examples of large motor applications include elevators, electric trains, hoists, and heavy metal rolling mills. Examples of small motor applications include motors used in automobiles, robots, hand power tools and food blenders.

Electric motors are broadly classified into two different categories: DC (Direct Current) and AC (Alternating Current). Within these categories are numerous types, each offering unique abilities that suit them well for specific applications. In most cases, regardless of type, electric motors consist of a stator (stationary field) and a rotor (the rotating field or armature) and operate through the interaction of magnetic flux and electric current to produce rotational speed and torque. DC motors are distinguished by their ability to operate from direct current.

Electromechanical Energy Conversion
An electromechanical energy conversion device is essentially a medium of transfer between an input side and an output side. Three electrical machines (DC, induction and synchronous) are used extensively for electromechanical energy conversion. Electromechanical energy conversion occurs when there is a change in magnetic flux linking a coil, associated with mechanical motion.

Electric Motor



Construction
DC motors consist of one set of coils, called armature winding, inside another set of coils or a set of permanent magnets, called the stator. Applying a voltage to the coils produces a torque in the armature, resulting in motion.

Stator

- The *stator* is the stationary outside part of a motor.
- The stator of a permanent magnet dc motor is composed of two or more permanent magnet pole pieces.
- The magnetic field can alternatively be created by an *electromagnet*. In this case, a DC coil (field
winding) is wound around a magnetic material that forms part of the stator.

Rotor

- The *rotor* is the inner part which rotates.
- The rotor is composed of windings (called armature windings) which are connected to the external circuit through a mechanical commutator.
- Both stator and rotor are made of ferromagnetic materials. The two are separated by air-gap.

Winding

A winding is made up of series or parallel connection of coils.

- Armature winding - The winding through which the voltage is applied or induced.
- Field winding - The winding through which a current is passed to produce flux (for the electromagnet)
- Windings are usually made of copper.

Principle of operation

Consider a coil in a magnetic field of flux density **B** (figure 4). When the two ends of the coil are connected across a DC voltage source, current I flows through it. A force is exerted on the coil as a result of the interaction of magnetic field and electric current. The force on the two sides of the coil is such that the coil starts to move in the direction of force.

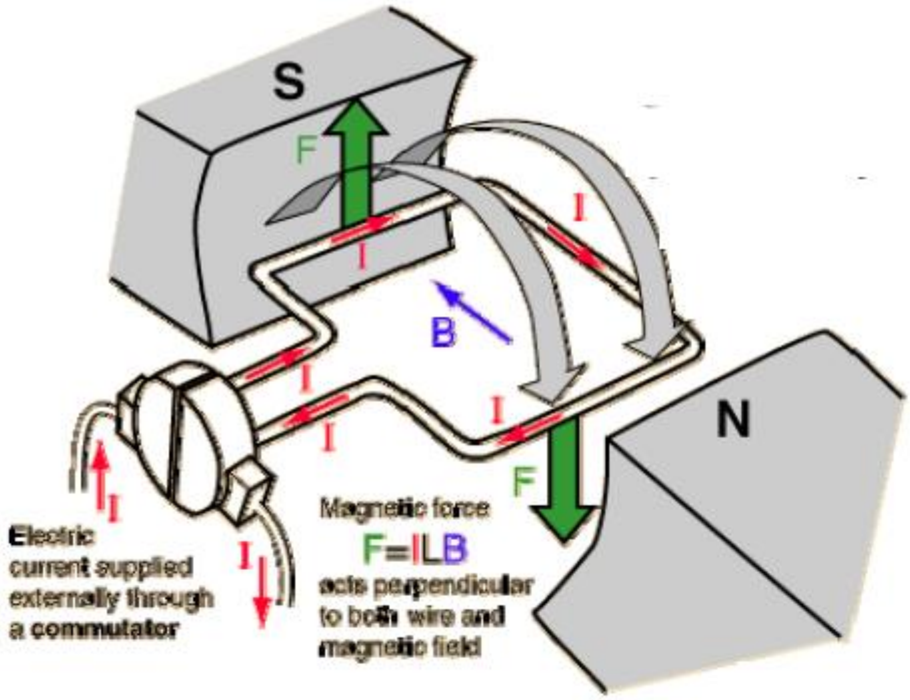


Figure 4: Torque production in a DC motor

In an actual DC motor, several such coils are wound on the rotor, all of which experience force, resulting in rotation. The greater the current in the wire, or the greater the magnetic field, the faster the wire moves because of the greater force created. At the same time this torque is being produced, the conductors are moving in a magnetic field. At different positions, the flux linked with it changes, which causes an *emf* to be induced ($e = d\phi/dt$) as shown in figure 5. This voltage is in opposition to the voltage that causes current flow through the conductor and is referred to as a *counter-voltage* or *back emf*.

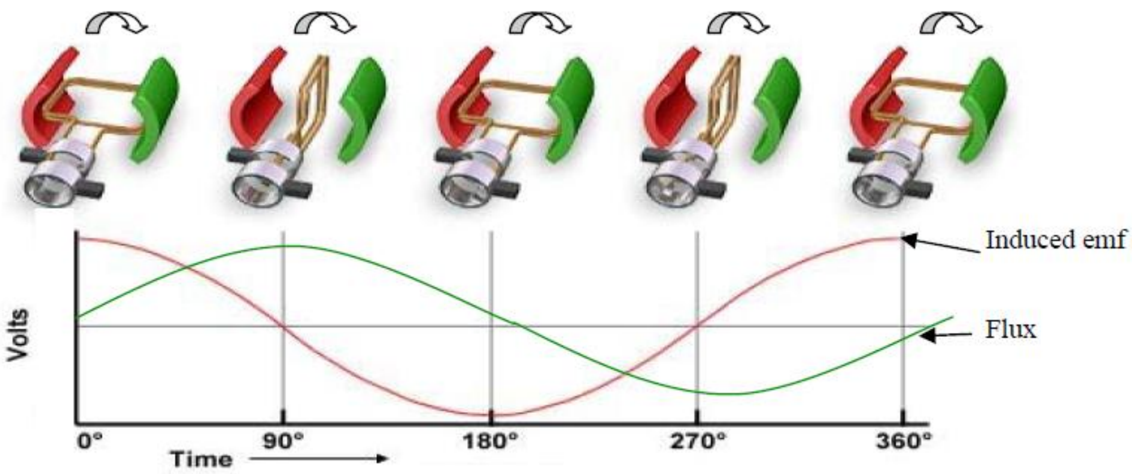


Figure 5: Induced voltage in the armature winding of DC motor

The value of current flowing through the armature is dependent upon the difference between the applied voltage and this counter-voltage. The current due to this counter-voltage tends to oppose the very cause for its production according to Lenz's law. It results in the rotor slowing down. Eventually, the rotor slows just enough so that the force created by the magnetic field (*F* = *Bil*) equals the load force applied on the shaft. Then the system moves at constant velocity.

Torque Developed

The force on one coil of wire ***F*** =*i* ***l*** x ***B*** Newton
Note that ***l*** and ***B*** are vector quantities
Since $B = \phi/A$ where A is the area of the coil, Therefore the **torque** for a **multi turn coil** with an armature current of *Ia*:

$$T = K \phi Ia$$

Where ϕ is the flux/pole in weber, *K* is a constant depending on coil geometry, and *Ia* is the current flowing in the armature winding.

The mechanical power generated is the product of the machine torque and the mechanical speed of rotation, ω_m

Or, $Pm = \omega_m T$
$= \omega_m K \phi Ia$

It is interesting to note that the same DC machine can be used either as a motor or as a generator, by reversing the terminal connections.

Induced Counter-voltage (Back emf):

Due to the rotation of this coil in the magnetic field, the flux linked with it changes at different positions, which causes an *emf* to be induced

The induced emf in a single coil, $e = d\phi_c/dt$

Since the flux linking the coil, $\phi_c = \phi Sin\ \omega t$

Induced voltage : $e = \omega \phi Cos\ \omega t$

Note that above equation gives the emf induced in one coil. As there are several coils wound all around the rotor, each with a different emf depending on the amount of flux change through it, the total emf can be obtained by summing up the individual emfs.
The total emf induced in the motor by several such coils wound on the rotor can be obtained by integrating above equation and expressed as:

$$Eb = K \phi \omega_m$$

where K is an armature constant, and is related to the geometry and magnetic properties of the motor, and ω_m is the speed of rotation.

The electrical power generated by the machine is given by:

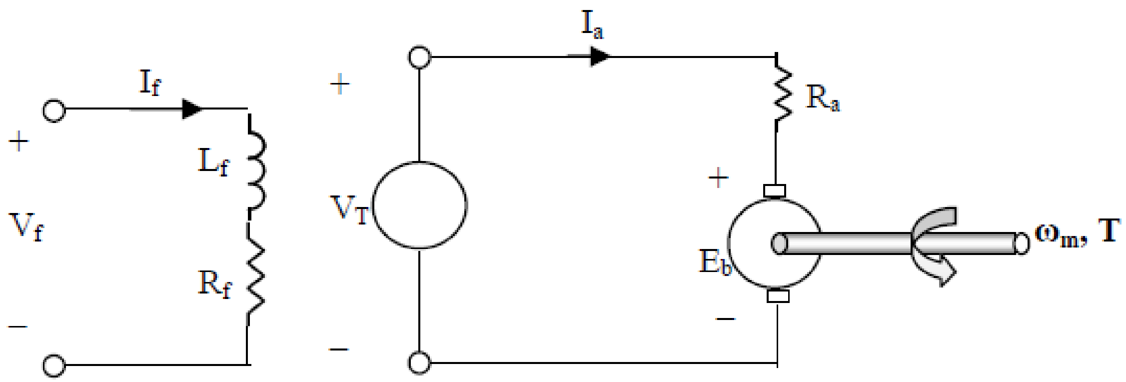
$$P_{dev} = E_b I_a = K \phi \omega_m I_a$$

DC Machine Classification

DC Machines can be classified according to the electrical connections of the armature winding and the field windings. The different ways in which these windings are connected lead to machines operating with different characteristics. The field winding can be either self-excited or separately-excited, that is, the terminals of the winding can be connected across the input voltage terminals or fed from a separate voltage source, in self-excited motors, the field winding can be connected either in series or in parallel with the armature winding. These different types of connections give rise to very different types of machines,

Separately excited machines

- The armature and field winding are electrically separate from each other.
- The field winding is excited by a separate DC source.



The voltage and power equations for this machine are same as those derived in the previous section.

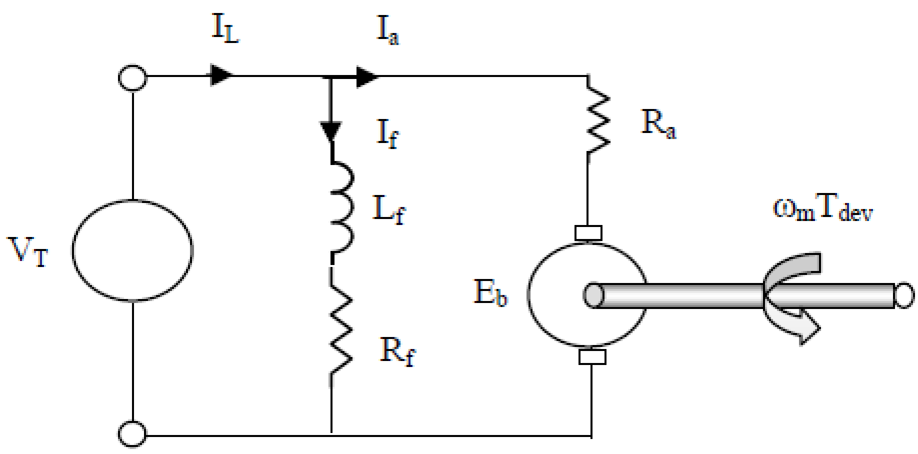
Note that the total input power = $V_f I_f + V_T I_a$

Self excited machines

In these machines, instead of a separate voltage source, the field winding is connected across the main voltage terminals.

Shunt machine

- The armature and field winding are connected in parallel.
- The armature voltage and field voltage are the same.



Total current drawn from the supply, $I_L = I_f + I_a$

Total input power = $V_T I_L$

The voltage and power equations

$V_T = E_b + I_a R_a$

$V_f = R_f I_f$

$E_b I_a$ (electrical power) = $\omega_m T_{dev}$ (mechanical power developed)

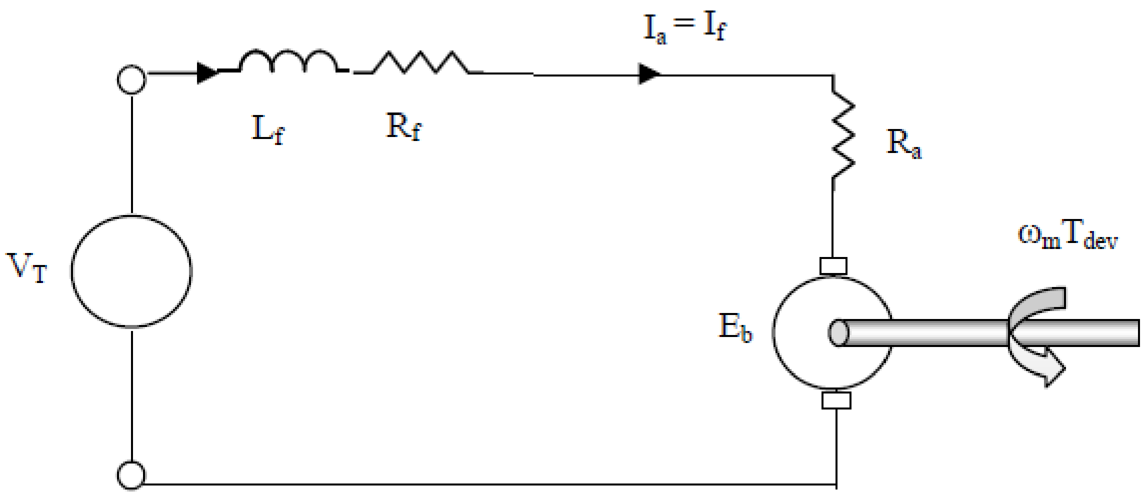
Note: The speed in revolutions per minute, N, is related to the angular speed ω_m (in radians per second) by

$$\omega = \frac{2\pi N}{60}$$

Series DC machine

- The field winding and armature winding are connected in series.
- The field winding carries the same current as the armature winding.

A series wound motor is also called a *universal* motor. It is universal in the sense that it will run equally well using either an ac or a dc voltage source. Reversing the polarity of both the stator and the rotor cancel out. Thus the motor will always rotate the same direction regardless of the voltage polarity.



Compound DC machine

If both series and shunt field windings are used, the motor is said to be compounded.

In a compound machine, the series field winding is connected in series with the armature, and the shunt field winding is connected in parallel.

Two types of arrangements are possible in compound motors:
Cumulative compounding - If the magnetic fluxes produced by both series and shunt field windings are in the same direction (i.e., additive), the machine is called cumulative compound.
Differential compounding - If the two fluxes are in opposition, the machine is differential compound.
In both these types, the connection can be either *short shunt* or *long shunt*.