

LECTURE 12

Basic Concepts of DC Machines

The material covered in this lecture will be as follows:

- 1) To understand the basic principles of energy conversions
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- 2) To learn about the components of DC machine
To learn about the components of DC machine
- (3) to classify DC machines according to their function
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At the end of this lecture you should be able to:

- ⇒ understand how energy is converted from one form to the other.
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- ⇒ understand how a DC machine works .
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1. Introduction Energy Conversion Principles

Generators convert mechanical energy into electric energy.

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Motors convert electric energy into mechanical energy.

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A generator can operate as a motor and vice versa.

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The energy or power balance is :

Generator: Mechanical power = electric power + losses

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Motor: Electric Power = Mechanical Power + losses.

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2. Energy Conversion Principles

An electric machine converts energy according to the law of conservation of energy.

Neglecting losses, the mechanical and electrical power are equal , that is

$$\omega T \Leftrightarrow VI \quad (1)$$

Where

T = mechanical torque (N-m)

V = voltage (V)

I = current (A)

ω = speed in rad/sec

$\omega T =$ Mechanical power

$v_i =$ Electrical power

Figure 1 illustrates an ideal energy converter

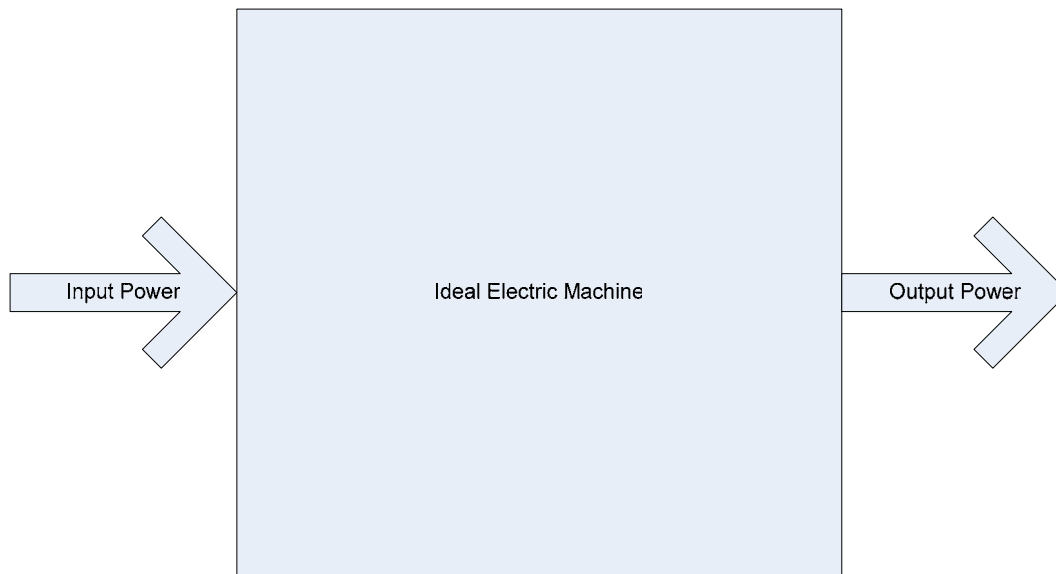


Figure 1 Ideal Electric Energy Converter

a. Voltage Generation

It is known that if a coil is rotated in a magnetic field, a voltage is induced.

Let us make the following definitions

- N is the number of turns in a coil
- L is the length of the coil
- D is the width of the coil
- B is the magnetic flux density
- f is the number of cycles per seconds. It is function of the speed rotation

Figure 2 shows such a coil in magnetic field

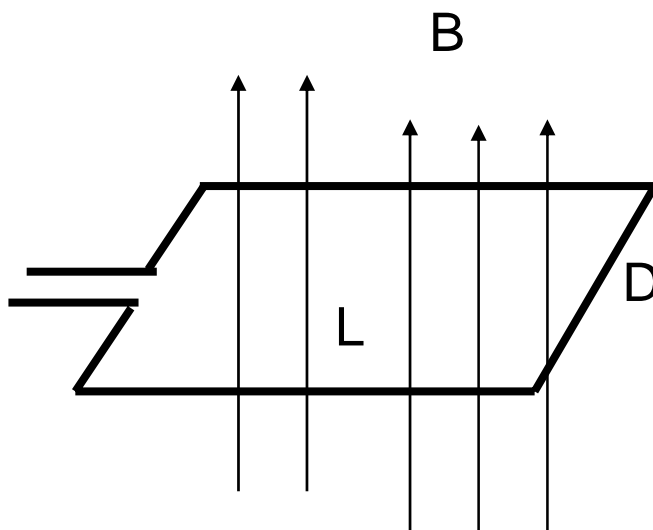


Figure 2 : A coil in a Magnetic Field

When the coil rotates, it cut the lines of flux. The flux, $\phi(t)$, appears to be changing with time according to equation 2:

$$\phi(t) = BDL \cos(\omega t) = BA \cos(\omega t) = \phi_m \cos(\omega t) \quad (2)$$

Where

$$\omega = 2\pi f$$

$$A = DL$$

$\phi_m = BA$ is the maximum value of the flux

By Faraday's law, the voltage induced in the coil is given by equation 3

$$v(t) = N \frac{d\phi(t)}{dt} = N \phi_m \omega \sin(\omega t) \quad (3)$$

The voltage induced is alternating and is sinusoidal

The rms value of the induced voltage, V_{rms} is given by

$$V_{rms} = \frac{\phi_m N \omega}{\sqrt{2}} = \frac{\phi_m N 2\pi f}{\sqrt{2}} = 4.44 \phi_m N f \quad (4)$$

Equation 4 can be written as follows

$$V = K \phi_m \omega \quad (5)$$

Equation 5 shows the voltage generated is function of the magnetic flux and the speed of rotation.

Let us now substitute equation 5 into equation 1

$$\omega T \Leftrightarrow k \phi \omega I$$

b. Torque Relationship

$$T \Leftrightarrow k \phi I \quad (6)$$

Equation 6 shows the machine torque is function of the magnetic flux and the current drawn by the machine

2. Electric Machines

Equations 5-6 form the basis of electromechanical energy conversion. However practical electric machines are quite different.

Voltages are generated in coils that consist of several turns.

Coils are rotated through a magnetic field or the field is rotated past the coils.

There must be a relative motion between the flux and the coils.

Many coils are connected to form what is known as " Armature winding".

The flux is produced either from a permanent magnet or from an electromagnet.

The electromagnet is supplied through a number of coils. Those coils are called the " field winding"

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In summary an electric machine shall have two important componets:

1. The armature winding
2. The field winding

Electric Machines are classified according to the voltage and current at their terminals

DC machines have DC voltages and currents at the terminals.

AC machines have AC voltages and currents at the terminals.

This lecture is devoted to the DC machines only.

2. Construction of DC Machines

The armature winding of DC machine is the rotating element. It is referred to as the rotor.

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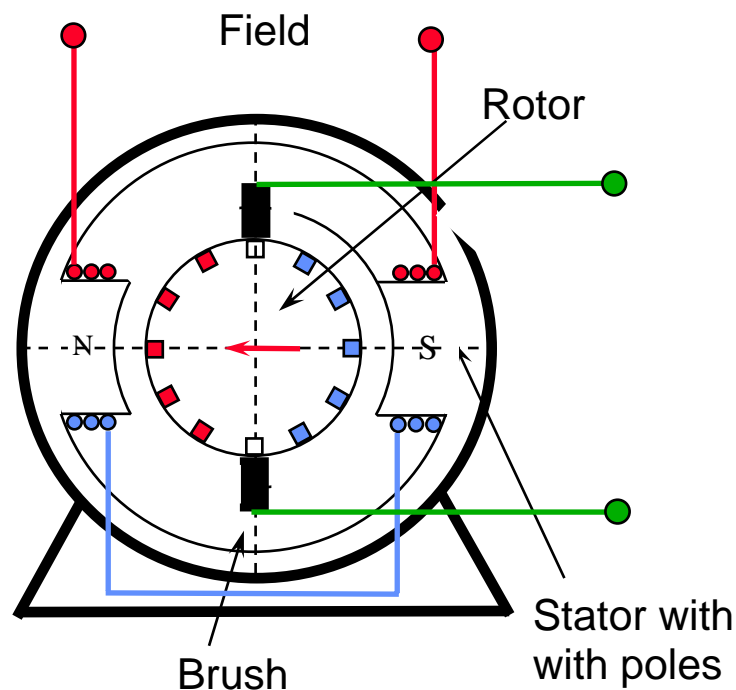
The field winding of DC machine is the stationary element. It is referred to as the stator.

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The DC machine has the following components:

1. Stator or field winding
2. Rotor or copper winding
3. Commutators
4. Brushes

Figure 3 shows the components of a DC machines



1. Field or Stator

The stator of the DC machine has poles which are bolted to the inside of the circular frame.

The iron frame is made of solid steel but the pole are made of stacked laminations.

The field winding is wound around the poles. It is The are supplied (excited) by DC currents.

The flux produced is function of this current and number of turns in the windings.

The DC current for the field winding is supplied from an external source or from the machine itself.

DC machines are classified according to the method of excitation. This will be discussed later.

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The magnetic flux can also be produced by permanent magnets. These do not require field winding.

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Figure 3 depicts a stator with two poles. However some DC machines may have 4,6,8 etc poles depending on the physical size of the machine.

2. Armature or Rotor

The armature is the rotating part of the DC machine. It consists of a number of coils.

The armature winding (coils) is firmly keyed to an iron shaft.

The iron core is made of slots, and iron laminations.

The armature coils are firmly placed into the slots and are well supported to prevent falling off during machine rotation.

The armature coils are connected in series in a variety of forms. The coils ends are terminated on the commutators.

When the armature coils are rotated inside the stator frame, they cut the field flux and a voltage is generated.

3. Commutators

The commutator is made of copper segments separated by mica sheets.

4. Brushes

Brushes are fixed elements. They slide on the commutators to ensure good contact between the rotating and stationary parts of the DC machine.

The brushes are made mostly from carbon graphite because of its low contact resistance.

Multipole machines shall have many brushes as number of poles.

For example a 4 poles machine will be equipped with 4 bushes and so on.

Figure 4 shows how the armature winding, commutators are arranged.

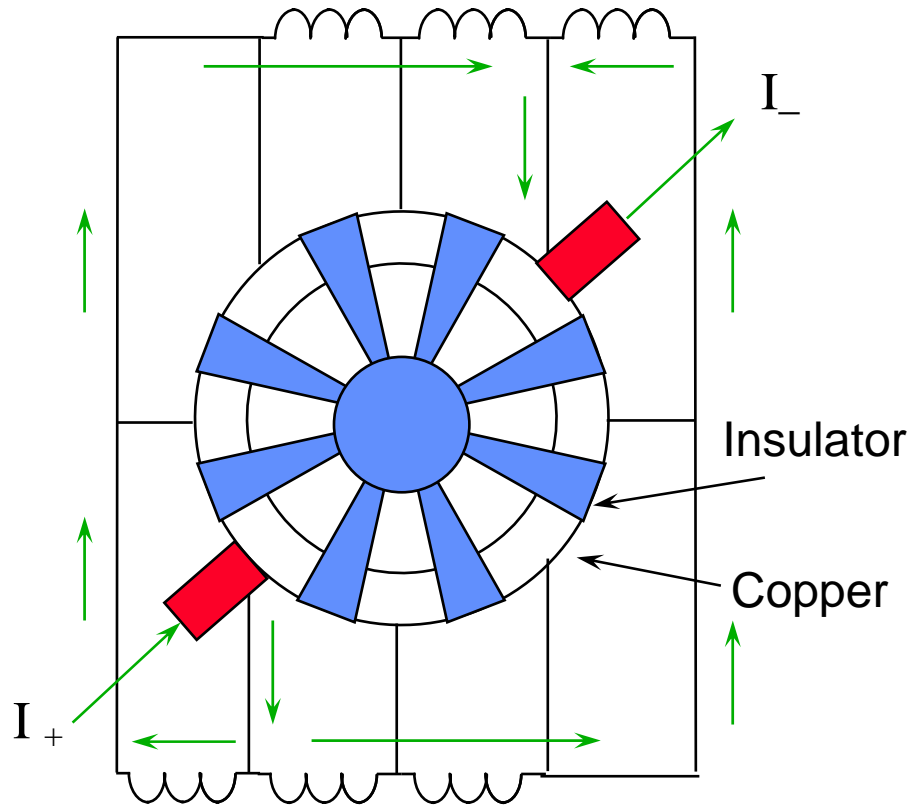


Figure 4 Armature conductors and Commutator Connections

3. Principles of Operation

The poles are supplied by DC current producing a DC magnetic field.

The poles are shaped in such a way the field distribution along the pole is more or less sinusoidal.

When the rotor coil is rotated, the flux linkage changes during the rotation. It is maximum when the coil is in vertical position and zero when it is in horizontal position.

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The voltage generated inside the coils is alternating. It will be converted into DC through the action of the commutators and brushes.

In order to understand how the voltage is converted into a DC voltage, let us consider Figure 5.

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Figure 5 shows a pair of brushes and two commutator segments.

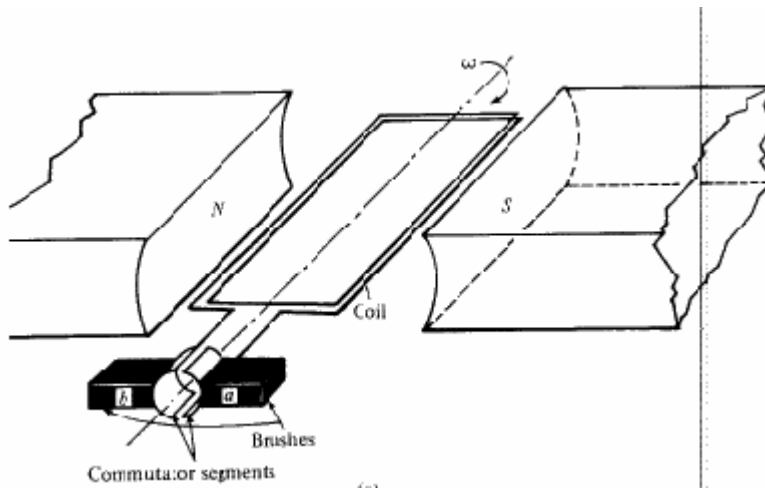


Figure 5 Two-Pole Machine

By applying the Right Rule, it can be shown that the brushes will maintain their polarities regardless of the coil they are connected to.

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Brush a will always be positive while brush b will always be negative.

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The voltage and current in a conductor changes polarity as it passes from north pole to a south pole region.

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This process is called commutation. It is accomplished by the commutator-brush arrangement.

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The voltage across the brushes will be as shown in figure 6.

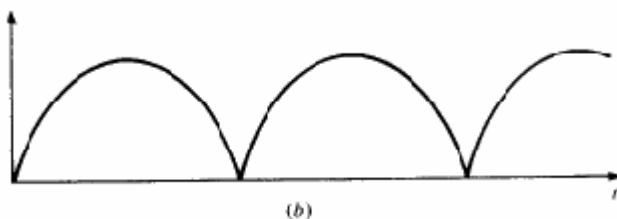


Figure 6 Output Voltage between the brushes

This is unidirectional. It is a rectified form of the alternating generated voltage.

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By increasing the number of loops and commutator segments, the out voltage may appear as shown in figure 7.

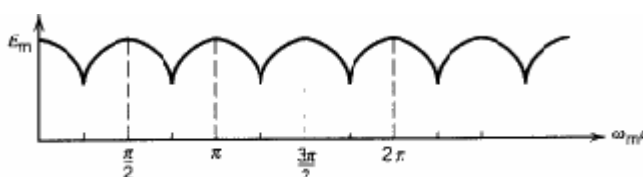


Figure 7 Output Voltage between the brushes with more commutator segments

