SPH3U UNIVERSITY PHYSICS

ELECTRICITY & MAGNETISM

- Electric Generators (P.599-604)

Electric Generators

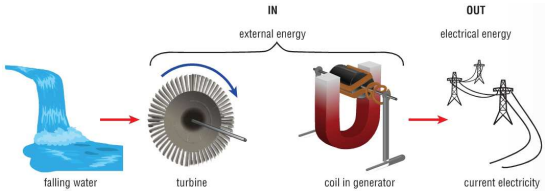
The large-scale production of electrical energy that we have today is possible because of electromagnetic induction. The electric generator, which provides electricity for most places in the world, relies on the law of electromagnetic induction to operate. Without electric generators, our supply of current would have to be obtained from more expensive sources like voltaic cells.

Electric Generators

*An **electric generator** is a device that transforms other forms of energy, such as thermal, gravitational, and kinetic energy into electrical energy. As you know, the energy used to power generators can come from either renewable sources (i.e., wind, falling water, ...) or non-renewable sources (i.e., coal, oil, natural gas, or nuclear), each with its own benefits, disadvantages, and environmental impacts to be considered.*

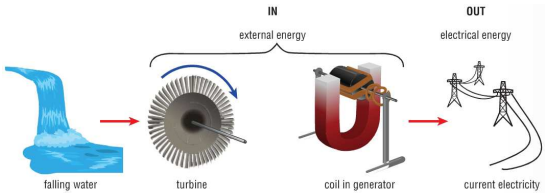
Electric Generators

A basic generator consists of a magnet and a coil of wire (recall that electromagnetic induction requires a changing magnetic field to produce an electric current). In a generator there are two ways of changing the magnetic field. ① Either a permanent magnet can be spun inside a coil or ② a coiled conductor can be spun inside a magnetic field. The faster the wire coils are rotated, the more electricity that is generated.



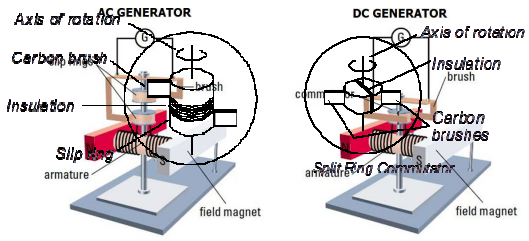
Electric Generators

The construction of a generator is identical to that of an electric motor, although its function is just the opposite. In the case of a motor, electrical energy is transferred into the motor to cause rotation or kinetic energy. In the case of a generator, kinetic energy (for example from falling water, wind, or high-pressure steam) is used to turn the turbine which then turns the coil to generate electrical energy.



Electric Generators

The main components of a generator are external magnets, an armature, brushes and either slip rings (for an AC generator) or a split ring commutator (for a DC generator).



Electric Generators

ELECTRIC GENERATOR

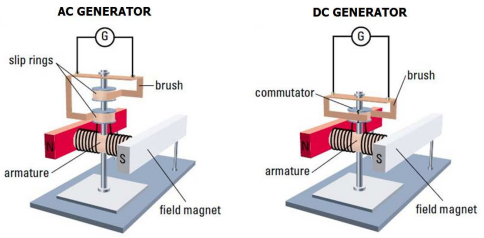
- device that transforms other forms of energy (thermal, gravitational, kinetic, ...) into electrical energy
- construction is identical to an electric motor (function is the opposite)
- main components are:
  - coil of wire
  - armature (a soft iron core)
  - external magnets
  - brushes
  - slip rings (AC) or split ring commutator (DC)

NOTE!

Any type of generator needs an external force to turn the turbine which then spins the coil of wire inside the magnetic field.

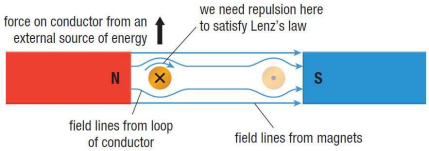
Electric Generators

To explain the operation of AC and DC generators, a single-loop coil being forced to rotate clockwise will be used. Since the loop is moving inside the magnetic field provided by the external magnets, an electric current will be induced in the loop as described by Faraday's law.



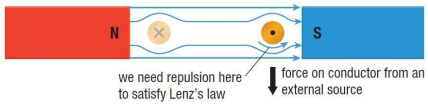
Electric Generators – Single Loop Coil

This diagram shows an upward force being exerted on the left part of the loop. According to Faraday's law, current is induced in the conductor. The direction of the current is such that the induced magnetic field repels or opposes the motion that produced it. Thus, the induced magnetic field must be clockwise, and the current must be flowing into the page.



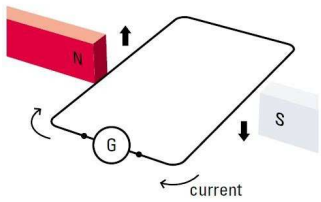
Electric Generators – Single Loop Coil

In this diagram the right part of the loop is being forced downward by an external source. Using a similar analysis, the induced magnetic field on the conductor must be counter-clockwise and the current must be flowing out of the page.



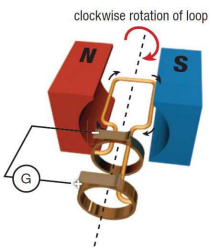
Electric Generators – Single Loop Coil

This diagram shows the entire loop, with directions indicated.



The AC Electric Generator

The AC generator shown shows a single loop of conducting wire set between the poles of two permanent magnets. There are two slip rings and two brushes. Each slip ring is connected to a different side of the loop. Slip ring 1 is connected to the left side of the loop, while slip ring 2 is connected to the right side of the loop. The slip rings rotate with the loop. The brushes are stationary and make contact with the slip rings to allow current flow.



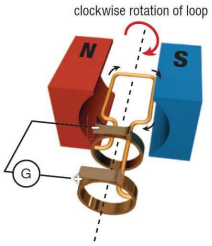
The AC Electric Generator

AC GENERATOR

- produces alternating current
- similar in design to a DC motor except the ends of the loops are connected to two different slip rings

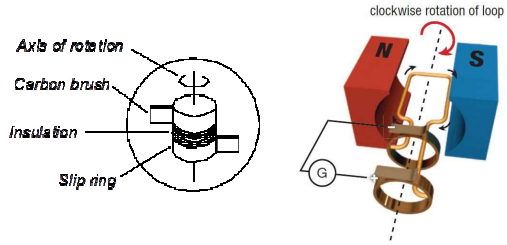
NOTE!

Commercial AC generators have several sets of coils, each with a great number of windings, and they often use electromagnets rather than permanent magnets for the field.



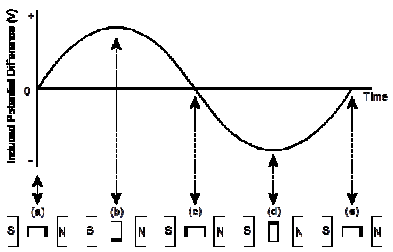
The AC Electric Generator – How It Works!

Consider an armature connected to slip rings being forced to spin clockwise by an external source of energy.



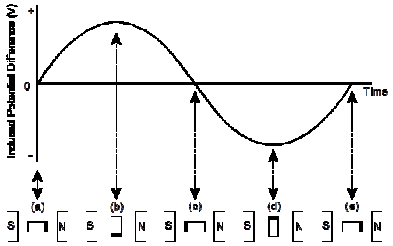
The AC Electric Generator – How It Works!

In (a) the shaded end of the armature becomes a south pole and remains a south pole in (b) to oppose the motion. As a result the current flows in one direction.



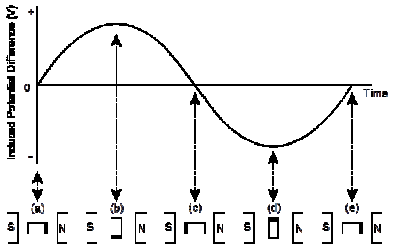
The AC Electric Generator – How It Works!

When the shaded end reaches (c) it switches to become a north pole and remains a north pole in (d) in order to again oppose the motion. As a result the direction of current flow also reverses.



The AC Electric Generator – How It Works!

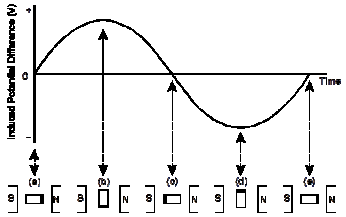
When the shaded end reaches (e) it switches to become a south pole again and the process is repeated.



The AC Electric Generator – How It Works!

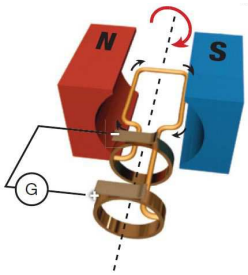
NOTE!

Maximum current is induced when the armature is perpendicular to the magnetic field (b & d). In North America the frequency of rotation, and thus the frequency of generation, is 60 Hz. This means that the electric current switches direction 120 times in one second.



The DC Electric Generator

If the slip rings of an AC generator are replaced by a split ring commutator, the generator is able to produce direct current (DC). The split ring commutator serves to prevent the current from changing direction in the external circuit as it does in the AC generator. However, the induced current in the coil in the armature is still the same.



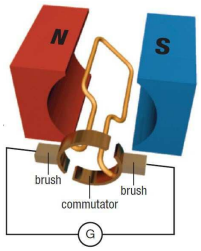
The DC Electric Generator

DC GENERATOR

- designed like a DC motor (i.e. uses a split ring commutator)
- produces direct current

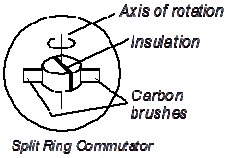
NOTE!

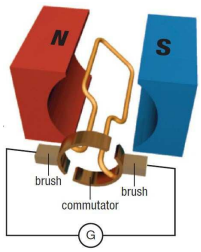
Commercial DC generators have coils with numerous windings and iron cores, and they also have more than two commutator segments. In this way, the output current is kept very nearly constant.



The DC Electric Generator – How It Works!

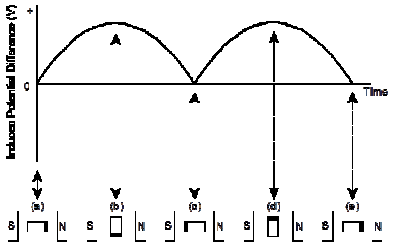
Consider an armature connected to a split ring commutator being forced to spin clockwise by an external source of energy.





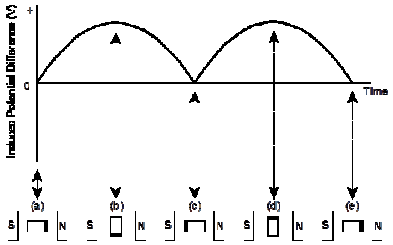
The DC Electric Generator – How It Works!

In (a) the shaded end of the armature becomes a south pole and remains a south pole in (b) to oppose the motion. As a result the current flows in one direction.



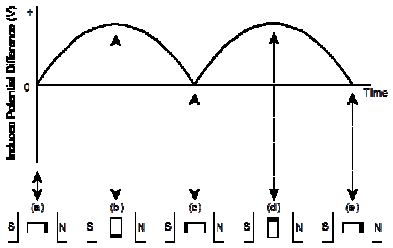
The DC Electric Generator – How It Works!

When the shaded end reaches (c) it switches to become a north pole and remains a north pole in (d) in order to again oppose the motion. However, the direction of current flow does not change because of the split ring commutator.



The DC Electric Generator – How It Works!

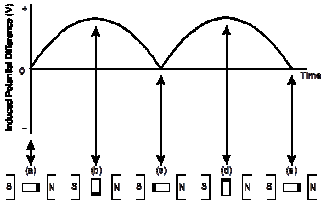
When the shaded end reaches (e) it switches to become a south pole again and the process is repeated.



The DC Electric Generator – How It Works!

NOTE!

Similar to the AC generator, maximum current is induced when the armature is perpendicular to the magnetic field (b & d). However, the current produced by a simple DC generator is ***not*** *the same as the constant DC current from a chemical source such as a battery. The DC generator produces a pulsating current in one direction as shown below.*



Electric Generators – Maximizing Output

For an electric generator to be economically viable, it must be able to produce as much electrical energy as possible in the most efficient way. Several factors can be used to help accomplish this:

- *increase the number of coils and the number of windings in each coil*
- *place a soft iron core (armature) in the centre of each coil to increase the strength of the inducing field*
- *keep the relative motion between the armature and external magnet as high as possible*
- *make the external magnet as strong as possible (use an electromagnet)*

Electric Generators – Maximizing Output

ELECTRIC GENERATOR (continued …)

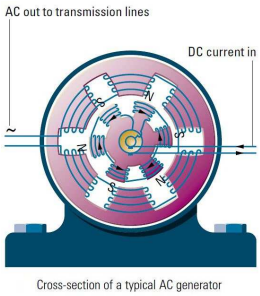
- to maximize the output:
  - increase the # of coils and the # of windings in each coil
  - place a soft iron core (i.e. an armature) in the centre of each coil to increase the strength of the inducing field
  - spin the armature as fast as possible
  - make the external magnet as strong as possible (i.e. use an electromagnet)

Electric Generators – DYK?

The generators used in power plants contain multiple coils and armatures. The field magnets are not permanent magnets because it is difficult to make a strong enough magnet. Also, permanent magnets lose their magnetism over time because of the strong magnetic fields in the coil. So, instead, electromagnets are used.

NOTE!

The current needed to power the electromagnets comes from the generator itself or another generator.

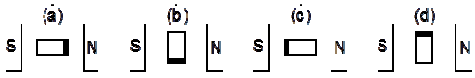


Cross-section of a typical AC generator

Electric Generators

PRACTICE

1. Various positions of the armature in an electric generator are given. At what position(s) would the (i) maximum and (ii) minimum current occur?



(i) b & d (perpendicular to the magnetic field)
(ii) a & c (parallel to the magnetic field)

Electric Generators

PRACTICE

2. (a) Sketch a graph of the induced current in the external circuit for both a DC and AC generator. Include the orientation of the armature in your sketches.
   (b) What effect would reversing the polarity of the external magnets have on your sketches?
   (c) What effect would reversing the direction of rotation have on your sketches?

Electric Generators

PRACTICE

3. How does the rotation rate of the armature in an AC generator compare to the frequency of the alternating current?

   the same – rotates at 60 Hz

✔ Check Your Learning

TEXTBOOK

P.604 Q.4