01. Concepts and Principles

Electric Circuits as Applied Physics

Electric circuits are one of the most practical applications of our understanding of electric and magnetic fields. In general, an electric circuit is any device that consists of a closed path for charges to move (a current), a source of energy to "drive" the motion of the charges (a potential difference, or voltage, often in the form of a battery), and various circuit elements that can either convert (resistors) or store (capacitors and inductors) the energy supplied by the energy source.

The study of circuits is incredibly broad, since there are limitless ways to combine these elements into an electric circuit. We will restrict ourselves to studying circuits with only a limited number of elements, and with a source that supplies a constant voltage[1].

The Resistor

In general, a *resistor* is any device that converts electrical energy into another form of energy, often heat. For example, a fluorescent light bulb converts electrical energy into light (with about a 20% efficiency, the remaining energy is converted into heat) and an incandescent light bulb converts electrical energy very efficiently into heat (with only about 5% of the incident energy converted to light). Since a conversion of electrical energy takes place in these devices, they are resistors.

In all resistors, the electric potential energy of the charges entering the device is larger than the electric potential energy of the charges exiting the device, because some of the potential energy has been converted to other forms. This decrease in potential energy is due to a decrease in electric potential between the two ends of the device and is directly proportional to the *resistance* of the device.

The definition of resistance for a device is:

pic 1

where

- DV is the potential difference between the two ends of the device, often termed the *voltage drop* across the device,
- and i is the current that flows through the device.

The unit of resistance, pic 2, is defined as the ohm (W).

The previous expression relates the resistance of a resistor to properties of the circuit it is part of. However, it is also sometimes useful to directly relate the resistance to the actual physical parameters of the device itself. For simple, passive resistors (basically blocks of material connected to a voltage source), resistance is defined as:

pic 3

where

- is the *resistivity* of the material from which the resistor is constructed,
- L is the length of the resistor in the direction of current flow,
- and A is the cross-sectional area of the resistor.

Resistivity can range from 0 for a perfect conductor to for a perfect insulator.

One final note on the properties of resistors concerns their rate of energy conversion. Since electric potential is the electric potential per unit of charge, and current is the charge flowing through the devicde per second, the product of change in electric potential and current is the change in electric potential energy per second. Thus, the rate of energy conversion, or *power*, in a resistor is given by:

pic 4

The Capacitor

A *capacitor* is a device that stores energy in the electric field between two closely spaced conducting surfaces. When connected to a voltage source, electric charge accumulates on the two surfaces but, since the conducting surfaces are separated by an insulator, the charges cannot travel from one surface to the other. The charges create an electric field in the space between the surfaces, and the two surfaces have a difference in electrical potential.

pic 5

Once "charged", if the capacitor is removed from the original circuit and connected to a second circuit it can act as a voltage source and "drive" its collected charge through the second circuit. When used in this way, the capacitor clearly acts as a temporary storehouse of energy.

To determine the energy stored in a capacitor, we first need to define the *capacitance* of the capacitor. The capacitance of a capacitor is defined as:

pic 6

where

- Q is the magnitude of the electric charge stored on either conducting surface,
- and DV is the potential difference between the surfaces.

The unit of capacitance,pic 7, is defined as the *farad* (F).

The amount of energy that can be stored on a capacitor is a function of both its capacitance and the potential difference between its surfaces. The relationship between stored energy and these parameters is:

pic 8

The Inductor

An *inductor* is a device that stores energy in the magnetic field created when current passes through a coil of wire. When connected to a voltage source, current will flow through the inductor, establishing a magnetic field.

pic 9

If the voltage source is suddenly removed, current will continue to flow in the coil because of electromagnetic induction. This induced current will act to replace the disappearing source current. The energy needed to drive this current comes from the energy stored in the magnetic field, so in this case the inductor acts as a temporary storehouse of energy.

To determine the energy stored in an inductor, we first need to define the *inductance* of the inductor. The inductance of the inductor is defined as:

pic 10

where

- F is the magnetic flux within the inductor,
- and i is the current flowing through the inductor.

The unit of capacitance, pic 11, is defined as the *henry* (H).

The amount of energy that can be stored in an inductor is a function of both its inductance and the current flowing through it. The relationship between stored energy and these parameters is:

pic 12

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[1]Circuits with constant voltage sources are referred to as DC, or direct current, circuits.

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