11.5.1: Energy Transfer in Electric Circuits

Electrical transmission substation

Figure 17.1.1

Part of the electrical grid, an electrical transmission sub-station receives extremely high current levels, then passes the electrical energy on to as many as 200,000 homes. Approximately 5000 megawatt-hours of energy passes through this particular substation each year.

Energy Transfer in Electric Circuits

Electric power is the energy per unit time converted by an electric circuit into another form of energy. We already know that power through a circuit is equal to the voltage multiplied by the current in a circuit: $P=VI$. It is possible to determine the power dissipated in a single resistor if we combine this expression with Ohm's Law, $V=IR$. This becomes particularly useful in circuits with more than one resistor, to determine the power dissipated in each one. Combining these two equations, we get an expression for electric power that involves only the current and resistance in a circuit.

$$P=I^2R$$

The power dissipated in a resistor is proportional to the square of the current that passes through it and to its resistance.

Electrical energy itself can be expressed as the electrical power multiplied by time:

$$E=Pt$$

We can incorporate this equation to obtain an equation for electrical energy based on current, resistance, and time. The electrical energy across a resistor is determined to be the current squared multiplied by the resistance and the time.

$$E=I^2Rt$$

This equation holds true in ideal situations. However, devices used to convert electrical energy into other forms of energy are never 100% efficient. An electric motor is used to convert electrical energy into kinetic energy, but some of the electrical energy in this process is lost to thermal energy. When a lamp converts electrical energy into light energy, some electrical energy is lost to thermal energy.

Example 17.1.1

A heater has a resistance of 25.0 Ω and operates on 120.0 V.

1. How much current is supplied to the resistance?
2. How many joules of energy is provided by the heater in 10.0 s?

Solution

1. $I=V/R=120.0\ V/25.0\ \Omega=4.8\ A$
2. $E=I^2Rt=(4.8\ A)^2(25.0\ \Omega)(10.0\ s)=5760$ joules

Think again about the power grid. When electricity is transmitted over long distances, some amount of energy is lost in overcoming the resistance in the transmission lines. We know the equation for the power dissipated is given by $P=I^2R$. The energy loss can be minimized by choosing the material with the least resistance for power lines, but changing the current also has significant effects. Consider a reduction of the current by a power of ten:

How much power is dissipated when a current of 10.0 A passes through a power line whose resistance is 1.00 Ω? $P=I^2R=(10.0\ A)^2(1.00\ \Omega)=100.$ Watts

How much power is dissipated when a current of 1.00 A passes through a power line whose resistance is 1.00 Ω? $P=I^2R=(1.00\ A)^2(1.00\ \Omega)=1.00$ Watts

The power loss is reduced tremendously by reducing the magnitude of the current through the resistance. Power companies must transmit the same amount of energy over the power lines but keep the power loss minimal. They do this by reducing the current. From the equation $P=VI$, we know that the voltage must be increased to keep the same power level.

The Kilowatt-Hour

Even though the companies that supply electrical energy are often called “power” companies, they are actually selling energy. Your electricity bill is based on energy, not power. The amount of energy provided by electric current can be calculated by multiplying the watts (J/s) by seconds to yield joules. The joule, however, is a very small unit of energy and using the joule to state the amount of energy used by a household would require a very large number. For that reason, electric companies measure their energy sales in a large number of joules called a **kilowatt hour** (kWh). A kilowatt hour is exactly as it sounds - the number of kilowatts (1,000 W) transferred per hour.

$$1.00 \text{ kilowatt hour} = (1000 \text{ J/s})(3600 \text{ s}) = 3.6 \times 10^6 \text{ J}$$

Example 17.1.2

A color television uses about 2.0 A when operated on 120 V.

1. How much power does the set use?
2. If the TV is operated for 8.00 hours per day, how much energy in kWh does it use per day?
3. At $0.15 per kWh, what does it cost to run the TV for 30 days?

Solution

1. $P = VI = (120 \text{ V})(2.0 \text{ A}) = 240 \text{ W}$
2. $E = (240 \text{ J/s})(8 \text{ h})(3600 \text{ s/h}) / 3.6 \times 10^6 \text{ J/kWh} = 1.92 \text{ kWh}$
3. $\text{Cost} = (1.92 \text{ kWh})(30)(\$0.15) = \$8.64$

Launch the Dollhouse simulation below and click Show Power to observe the energy consumed by the dollhouse. Try to adjust the Potential slider and Device sliders to maximize the total power consumed by the dollhouse:

Summary

- Electric power is the energy per unit time converted by an electric circuit into another form of energy.
- The formula for electric power is $P = I^2R$.
- The electric energy transferred to a resistor in a time period is equal to the electric power multiplied by time, $E = Pt$, and can also be calculated using $E = I^2Rt$.
- Electric companies measure their energy sales in a large number of joules called a kilowatt hour (kWh) which is equivalent to 3.6×10^6 J.

Review

1. A 2-way light bulb for a 110. V lamp has filament that uses power at a rate of 50.0 W and another filament that uses power at a rate of 100. W. Find the resistance of these two filaments.
2. Find the power dissipation of a 1.5 A lamp operating on a 12 V battery.
3. A high voltage (4.0×10^5 V) power transmission line delivers electrical energy from a generating station to a substation at a rate of 1.5×10^9 W. What is the current in the lines?
4. A toaster oven indicates that it operates at 1500 W on a 110 V circuit. What is the resistance of the oven?

Explore More

Use this resource to answer the questions that follow.

1. What is the definition of electrical power?
2. What happens to the electrical energy that is not converted into work?

Additional Resources

Study Guide: Electrical Systems Study Guide

Interactive: Electric Analogies

Videos: