1.5 ELECTRIC POWER GENERATION FROM RENEWABLE ENERGY SOURCES

Water energy has been the most widely used form of renewable energy for the production of electricity. With today's emphasis on environmental considerations and conservation of fossil fuels, other renewable resources are being used to employ the energy sources of the sun and the earth for electricity generation. Some of these resources that represent a viable alternative to fossil fuels are solar power, wind power, geothermal, biomass, and tidal power. These resources, especially solar power and wind power, have the capability to produce sustainable energy indefinitely with no direct emission of pollutant and greenhouse gases. Power plants using these renewable sources of energy are described in the following sections.

The aspiration for bulk generation of power in the future is nuclear fusion. If nuclear fusion is harnessed economically, it would provide clean energy from an abundant source of fuel, namely water.

1.6 HYDROELECTRIC POWER PLANTS

Hydropower is considered to be a renewable energy source because it uses the continuous flow of water without using up the water resource. It is also nonpolluting, since it does not rely on burning fossil fuels. Hydropower is currently the leading renewable energy source in the United States. In 2009, it accounted for about 63 percent of all other renewable energy sources, such as wind, solar, and biomass. Reclamation is the nation's second largest producer of hydroelectric power, with 58 hydroelectric power plants and 194 generating units in operation and an installed capacity of 14,693 MW. Almost all suitable sites for dams have already been developed, so there is not much scope for further growth in water power. However, there are numerous areas where research can lead to increases in the efficiency and reliability of hydroelectric plants and decreases in maintenance costs. Presently, wind and solar energy are growing at a rapid rate, and in a near future they will be the major sources of renewable energy for production of electric power.

The hydroelectric power plants usually require a dam to store water, a penstock for delivering the falling water, electric generators, a valve house which contains the main sluice valves, automatic isolating valves, and related control equipments. Also, a surge tank is located just before the valve house to protect the penstock from a pressure surge, called *water hammer*, in case the turbine gates are suddenly closed. In addition to electric energy production, most dams in the United States are built for other uses, including recreation, irrigation, flood control, and public water supply. A schematic diagram of a hydroelectric power plant is shown in Figure 1.6.

The water from the dam is led to the water turbine through the penstock, and the potential energy of the elevated water is transformed into kinetic energy. The water turbine converts hydraulic energy into mechanical energy, and the generator

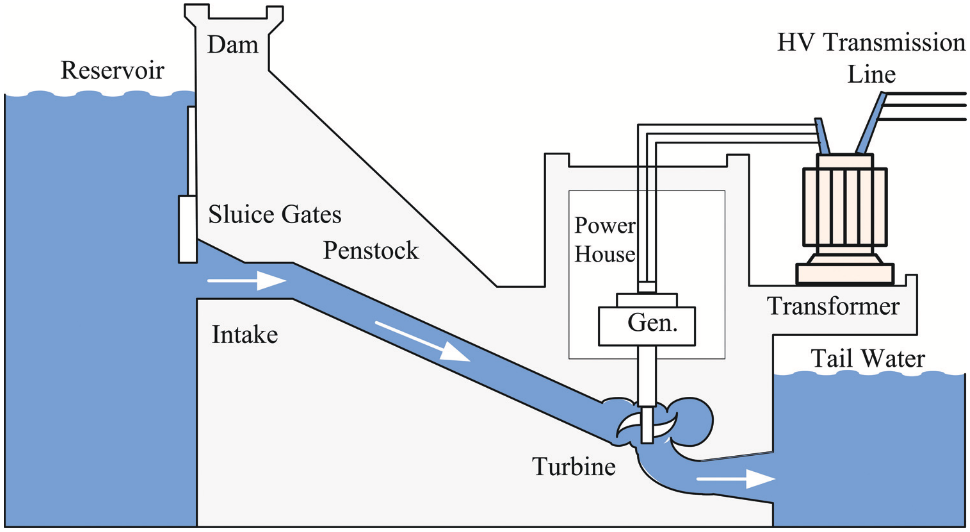

FIGURE 1.6
Schematic diagram of a hydroelectric power plant.

converts mechanical energy into electrical energy. After passing through the turbine, the water reenters the river on the downstream side of the dam. The most significant operating characteristics of hydropower plants are rapid start-up and loading, long life, and low operating and maintenance costs. Hydraulic turbines, particularly those operating with a low pressure, operate at low speed. Their generators are usually salient-type rotor with many poles. To maintain the generator voltage frequency constant, the turbine must spin the generator at a constant speed given by

$$n = \frac{120f}{p} \tag{1.1}$$

where f is the generated voltage frequency and p is the number of poles of the generator.

Elaborate control schemes are used to regulate the flow of water in order to keep the turbine speed constant.

The potential energy of the water in the reservoir is proportional to the mass of water and the difference in height between the water impoundment and the water outflow. This height difference is called the *head* or *effective head*. That is, $P.E. = mgh$. The mass of water is its volume times its density. Therefore, $P.E. = volume \times \rho gh$ and the available hydro power becomes

$$P_w = \frac{P.E.}{t} = \frac{volume}{t}\rho gh \tag{1.2}$$

or

$$P_w = q\rho g h \quad \text{W} \tag{1.3}$$

q = rate of flow of water in m^3/s
h = effective head of water in m
ρ = density of water ≈ 1000 kg/m^3
g = acceleration of gravity = 9.81 m/s^2

Given ρ = 1000, the available hydro power P in kW is given by

$$P = 9.81qh \quad \text{kW} \tag{1.4}$$

If η is the overall efficiency of the hydropower plant, the electrical power output in kW is

$$P_o = 9.81qh\eta \quad \text{kW} \tag{1.5}$$

where $\eta = \eta_p \eta_t \eta_g$
η_p = penstock efficiency, η_t = turbine efficiency, η_g = generator efficiency

There are three basic types of hydraulic turbines. Propeller or axial turbines are used for low heads (10 to 100 ft). A Kaplan turbine is a propeller turbine with variable-pitch blades that can be adjusted to give high efficiency during light loads. The Francis turbine is one of the more common radial turbines used for medium heads (15 to 1500 ft). Fixed-blade propeller turbines and Francis turbines have relatively low efficiencies at light loads. The Pelton wheel is an impulse hydraulic turbine that is normally used for heads above 150 ft to very high heads. In general, the hydraulic turbine efficiency during normal operation is between 80 and 94 percent, and the generator efficiency is from 95 to 99 percent.

The Three Gorges hydroelectric power plant in China is the largest development of its kind in operation in the world. Presently, the installed capacity is 19,600 MW. When completed by the year 2011, the total electric generating capacity will be 22,400 MW. The largest installation in North America is at La Grande on James Bay in Canada with a total installed capacity of 7,326 MW. The largest installation in the United States is at the Grand Coulee Dam on the Columbia River in the state of Washington, with a total capacity of about 6,500 MW. A panoramic view of the Grand Coulee dam is shown in Figure 1.7. Powerhouse number three is located at the lower left side of the dam.

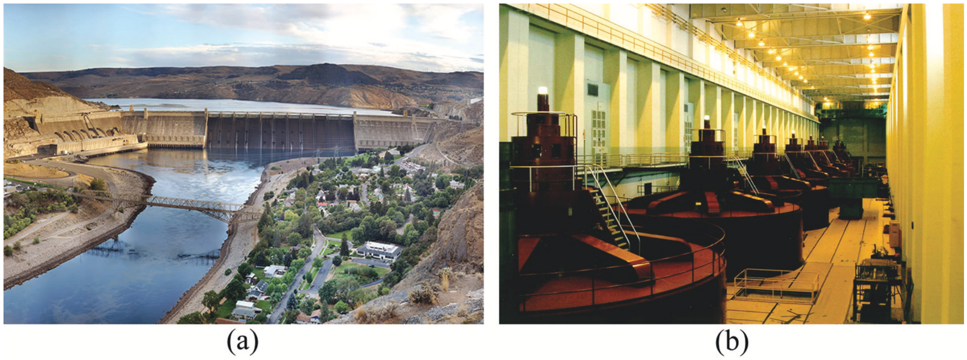

FIGURE 1.7
(a) Grand Coulee Dam, ”Courtesy of Wikimedia Commons, Credit - Gregg M. Erickson.”
(b) Right Powerhouse Generators, ”Courtesy of US Bureau of Reclamation, Credit - C. Hubbard.”

Example 1.1

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1.6.1 RUN-OF-THE-RIVER POWER PLANTS

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1.6.2 PUMPED-STORAGE HYDRO POWER PLANTS

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