UNIT II

Electrical Power Production Systems

Unit II of this book describes *power production systems.* The fundamentals of power production are examined in Chapter 4. *Electrical power production systems* include modern power systems such as *fossil fuel* (coal, oil, gas) *systems, hydroelectric systems,* and *nuclear fission systems.* These systems are discussed in Chapter 4. However, there are also many *alternative energy systems* that are being studied as potential sources of electrical power. These alternative energy systems, which include *nuclear fusion, geothermal, solar, wind, fuel-cell, Goal gasification, tidal,* and *magnetohydrodynamic IMHD) systems,* are discussed in Chapter 5.

Most of the electrical power that is produced is *alternating current (AC) power.* Chapter 6 deals with the *single-phase* and *three-phase* alternators that are used to produce AC power. *Direct current (DC) power* can be produced by chemical action or rotating machinery, or it can be converted from AC sources by the process of rectification. Chapter 7 deals with the systems used for production of direct current.

Figure II shows the *electrical power systems model* used in this book and the major topics of Unit II, Power Production.

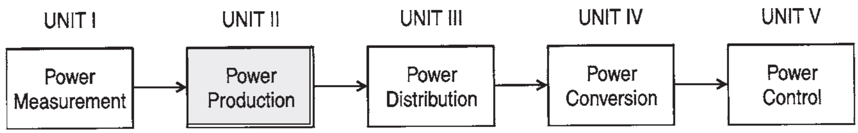


Figure II. Electrical power systems model

Modern Power Systems (Chapter 4)
Alternative Power Systems (Chapter 5)
Alternating Current (AC) Power Systems (Chapter 6)
Direct Current (DC) Power Systems (Chapter 7)

UNIT OBJECTIVES

Upon completing this unit, you should be able to:

1. Explain the basic operation of fossil fuel, hydroelectric, and nuclear fission electrical power systems.
2. Define the terms "load (demand) factor" and "capacity factor" for electrical power systems.
3. Describe coal, oil, and natural gas fossil fuel power production systems.
4. Describe the functions of steam turbines, boilers, and other auxiliary systems of power production systems.
5. Explain the difference between traditional hydroelectric systems and pumped storage hydroelectric systems.
6. Describe load-demand control of modem electrical power production systems.
7. List several alternative power production systems.
8. Explain the basic operation of the following alternative power production systems:
   Solar Energy Systems
   Geothermal Systems
   Wind Systems
   Magnetohydrodynamic (MHO) Systems
   Nuclear Fusion Systems
   Fuel-Cell Systems
   Tidal Power Systems
   Coal Gasification Systems
   Oil Shale Systems
   Biomass
   Fuel-Cell Systems
   Tidal Power Systems
9. State Faraday's law for electromagnetic induction.
10. Describe single-phase AC, three-phase AC, and DC generators.
11. Describe the effect of electrical generator speed, frequency calculation, voltage regulation, and efficiency.
12. Explain the difference between primary and secondary cells.
13. Calculate internal resistance of a DC cell.
14. Describe the following types of primary cells:
    Carbon-zinc
    Alkaline

Mercury
Nuclear

15. Describe the following types of secondary cells:
    Lead-Acid
    Nickel-Iron
    Nickel-Cadmium
    Silver-Oxide-Zinc
16. Explain the following types of DC generators:
    Permanent Magnet
    Separately Excited
    Self-Excited
17. Explain the following types of DC rectification systems:
    Single-Phase Half Wave
    Single-Phase Full Wave
    Single-Phase Bridge
    Three-Phase Half Wave
    Three-Phase Full Wave
18. Describe the effects of rotary converters, filtering methods, and regulation methods for the conversion of AC into DC.

Chapter 4

Modern Power Systems

There are many residential, commercial, and industrial customers of electrical power systems in the United States today. To meet this vast demand for electrical power, power companies work in combination to produce tremendous quantities of electrical power. This vast quantity of electrical power is supplied by *power generating plants.* Individual generating units that supply over 1000 megawatts of electrical power are now in operation at some power plants.

Electrical power can be produced in many ways, such as from chemical reactions, heat, light, or mechanical energy. The great majority of our electrical power is produced by *power plants* located throughout our country, which convert the energy produced by burning coal, oil, or natural gas, by falling water, or by nuclear reactions into electrical energy. Electrical *generators* at these power plants are driven by steam or gas turbines, or by hydraulic turbines in the case of hydroelectrical plants. This chapter will investigate the types of power systems that produce the great majority of the electrical power used today.

Various other methods, some of which are in the experimental stages, may become *future* power production methods. These include *solar cells, geothermal* systems, *wind-powered* systems, *magnetohydrodynamic (MHD)* systems, *nuclear fusion* systems, and *fuel cells.* These *alternative power systems* will be discussed in greater detail in Chapter 5.

IMPORTANT TERMS

This chapter deals with modern electrical power production systems. After studying this chapter, you should have an understanding of the following terms:

Fossil Fuel System
Electrical Power Plant
Steam Turbine

Load Factor (Demand)
Capacity Factor
Boiler
Superheater
Desuperheater
Feedwater
Reaction Turbine
Economizer
Feedwater Heater
Condenser
Feedwater Purifier
Coal Pulverizer
Hydroelectric System
Hydraulic Turbine
Pumped Storage Hydroelectric System
Nuclear Fission System
Nuclear Reactor
Moderator
Boiling-Water Reactor (BWR)
Pressurized-Water Reactor (PWR)

ELECTRICAL POWER PLANTS

Most electrical power in the United States is produced at *power plants* that are either *fossil fuel* steam plants, nuclear fission steam plants, or hydroelectric plants. Fossil fuel and nuclear fission plants utilize steam turbines to deliver the mechanical energy needed to rotate the large *three-phase alternators* that produce massive quantities of electrical power. *Hydroelectric plants* ordinarily use vertically mounted hydraulic turbines. These units convert the force of flowing water into mechanical energy to rotate three-phase alternators.

The *power plants* may be located near the energy sources, near cities, or near the large industries where great amounts of electrical power are consumed. The generating capacity of power plants in the United States is greater than the combined capacity of the next four leading countries of the world. Thus, we can see how dependent we are upon the efficient production of electrical power.

Supply and Demand

The *supply* and *demand* situation for electrical energy is much different from that of other products that are produced by an organization and later sold to consumers. Electrical energy must be supplied at the same time that it is demanded by consumers. There is no simple storage system that may be used to supply additional electrical energy at *peak demand* times. This situation is unique, and it necessitates the production of sufficient quantities of electrical energy to meet the demand of the consumers at any time. Accurate *forecasting* of load requirements at various given times must be maintained by utility companies in order that they may recommend the necessary power plant output for a particular time of the year, week, or day.

Plant Load and Capacity Factors

There is a significant variation in the load requirements that must be met at different times. Thus, the power plant generating capacity utilization is subject to continual change. For this reason, much of the generating capacity of a power plant may be idle during low demand times. This means that not all the generators at the plant will be in operation.

There are two mathematical ratios with which power plants are concerned. These ratios are called load factor *(demand factor)* and *capacity factor.* They are expressed as:

$$\text{Load (demand) factor} = \frac{\text{Average load for a time period}}{\text{Peak load for a time period}}$$

Sample Problem:

Given: a power plant has an average load of 220 MW and a peak load of 295 MW over a 24-hour period.

Find: the load factor of the power plant during the 24 hour period.

Solution:

$$\text{Load factor} = \frac{\text{Average Load}}{\text{Peak Load}}$$

$$= \frac{220\text{ MW}}{295\text{ MW}}$$

$$\text{Load factor} = 0.745$$

$$\text{Capacity factor} = \frac{\text{Average load for a time period}}{\text{Output capacity of a power plant}}$$

Sample Problem:

Given: a power plant has an average load of 112 MW and an output capacity of 166 MW.

Find: the capacity factor of the power plant.

Solution:

$$\text{Capacity factor} = \frac{\text{Average Load}}{\text{Capacity}}$$

$$= \frac{112\text{MW}}{166\text{ MW}}$$

$$\text{Capacity factor} = 0.675$$

It would be ideal, in terms of energy conservation, to keep these ratios as close to unity as possible.

FOSSIL FUEL SYSTEMS

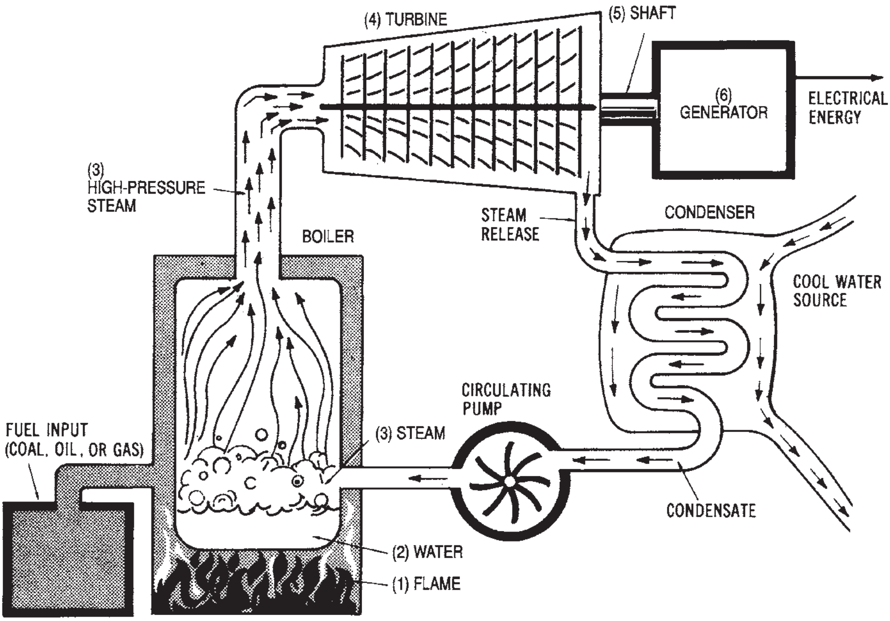
Millions of years ago, large deposits of organic materials were formed under the surface of the earth. These deposits, which furnish our *coal, oil,* and *natural gas,* are known as *fossil fuels.* Of these, the most abundant fossil fuel is coal, and *coal-fired electrical power systems* produce about one-half of the electrical power used in the United States. Natural-gas-fired systems are used for about one-fourth of our electrical power, while oil-fired systems produce around one-tenth of the power at the present time. The relative contributions of all of these systems to the total electrical power produced in the United States are subject to change, as the result of the addition of new power generation facilities and fuel availability. At the present time, over 80 percent of our electrical energy is produced by fossil fuel systems. It is important to note that these percentages vary from year to year.

A basic *fossil fuel power system* is shown in Figure 4-1. In this type of system, a fossil fuel (coal, oil, or gas) is burned to produce heat energy. The heat from the combustion process is concentrated within a boiler where circulating water is converted to steam. The high-pressure steam is used to rotate a turbine. The turbine shaft is connected directly to the electrical generator and provides the necessary mechanical energy to rotate the generator. The generator then converts the mechanical energy into *electrical energy.*

Fossil Fuels

Fossil fuels are used to supply heat, by means of chemical reactions, for many different purposes. Such fuels contain carbon materials that are burned as a result of their reaction with oxygen. These fossil fuels are used as a direct source of heat when burned in a furnace, and are used as a heat source for steam production when used in a power plant boiler system. The steam that is generated is used for rotating the steam turbines in the power plants.

Fossil fuels vary according to (1) their natural state (solid, liquid, or gas), (2) their ability to produce heat, and (3) the type of flame or heat that they produce. *Coal* and *coke* are solid fossil fuels, and coal is used extensively for producing heat to support electrical power production. *Oil,* gas-



Heat from burning fuel (1) changes water in boiler (2) into steam (3), which spins turbine (4) connected by shaft (5) to generator (6), producing electrical energy.

Figure 4-1. A basic fossil fuel power system

oline, and diesel fuel, which are liquid fossil fuels derived by petroleum processing, are used mostly in conjunction with internal combustion engines. However, oil is used as a heat source for many power plants. *Natural gas* is the primary gaseous fuel used for electrical power production.

Coal-fired Systems

The use of *coal* as a fuel to supply the necessary heat energy at a power plant requires the use of specialized stokers or grating units. These units reduce the size of the lump coal. Most of these units are mechanical systems that agitate the coal to reduce it into smaller lumps. The coal used at a power plant usually is sent through a stoker or grating unit by conveyer belts. A large gravity-feed hopper is often used to route very small lumps of coal into a pulverizing unit.

The *pulverizer* looks very similar in construction to a large ball-bearing unit. The coal is routed into the pulverizer unit, where large, rotating steel balls crush the coal until it is in particles about the same size and consistency as face powder. These fine particles are routed into the furnace by air pressure produced by *force-draft fans.* The coal is held in suspension until it is ignited. It then releases a large amount of heat energy. The suspended powder-fine coal particles allow sustained combustion to take place in the furnace. The pulverized coal speeds up the combustion process.

Coal-fired Plant Operation

Since the majority of electrical power produced today is from *coal-fired systems,* we will discuss the basic operation of this type of system. In a steam plant that produces electrical power, most of the operations are used for rotating the *steam turbine.* Remember that in any steam plant, heat must be produced. This heat produces steam, which moves the steam turbine, which produces a rotary motion, which finally produces electrical power. Figure 4-2 shows the layout of a typical *coal-fired electrical power plant.* Notice that it is located near a river, so that cooling water can be easily provided. The water is also used to produce steam to operate the *steam turbine* that rotates the generator unit. A cross-section of a coal-fired power plant is shown in Figure 4-3.

The maximum *efficiency* of the coal-fired plant of today is approximately 40 percent when using a powdered-coal spraying process. Efficiency is calculated as:

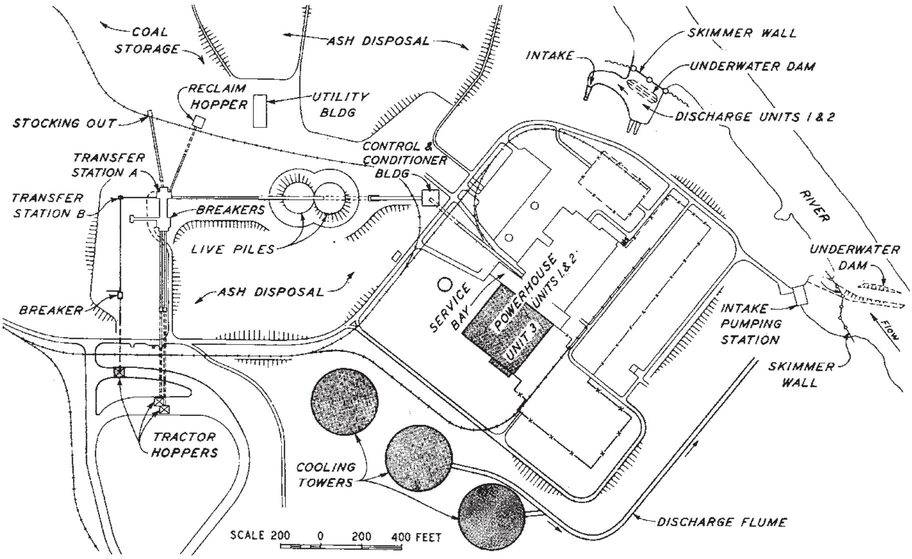


Figure 4-2. Layout of a typical coal-fired electrical power plant. (*Courtesy Tennessee Valley Authority*)

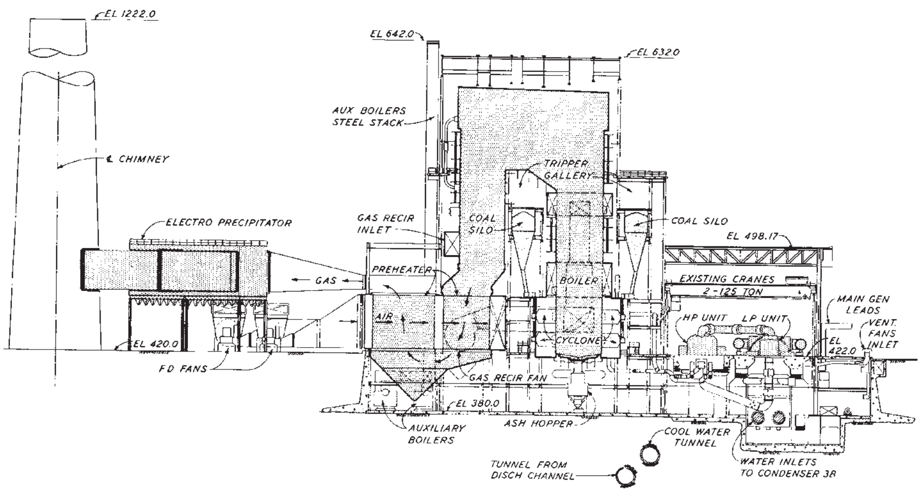


Figure 4-3. Cross-section view of a typical coal-fired power plant. (*Courtesy Tennessee Valley Authority*)

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}}$$

where power output is electrical power produced.

Coal requires extensive handling equipment. The coal itself must be handled, and then the ash and dust particles must be removed. At the power plant, the coal is moved to overhead hoppers by means of conveyor belts. These hoppers may typically be as large as eight stories high. The coal usually is fed into *pulverizing mills* by means of gravity. It is ground to a consistency similar to that of face powder, using the method discussed previously. The powdered coal is then dried using plant exhaust gases, and then blown into a *furnace.* The coal is ordinarily blown through a tangential or "T" burner into the furnace. These burners are placed in the four corners of a square furnace to create the turbulence needed for complete combustion.

Another method of firing the furnace is the fluidized bed. Advantages of the *fluidized bed* are that it produces less pollution and can burn a lower quality coal. In a fluidized bed, coal is crushed to form 1/8-inch to 1/4-inch diameter particles. When air is blown through a layer of this coal, the particles will float on a cushion of air. The pressure has to be adjusted very accurately, so that the particles are fluidized without being blown away from the bed. The fluidized bed is the basis of a direct-combustion process. If the bed is hot enough, the flow of air through the bed leads to almost total combustion, and can provide a greater efficiency with less ash and dust.

Power plant *boilers,* such as the one shown in Figure 4-4 incorporate several special units to improve their thermal efficiency and economy of operation. An *economizer* is placed at the exhaust exit to preheat the water coming into the boiler. The economizer also preheats the air blowing into the furnace. A *superheater* is a bank of tubes located at the hottest spot of the furnace. These tubes take up the steam after it leaves the boiler and before it enters the turbine. The purpose of the superheater is to raise the temperature of the *steam.* Increased superheat decreases the percent of water per unit volume in the steam, which increases turbine life. A desuperheater is the next part of the system. The *desuperheater* brings the steam down to a temperature at which it can be condensed. The *feedwater* in a power plant is used over and over, with water added only to account for losses. The feedwater must be very pure to ensure long life of the boiler tubes. Some common power plant terminology is summarized in Table 4-1.

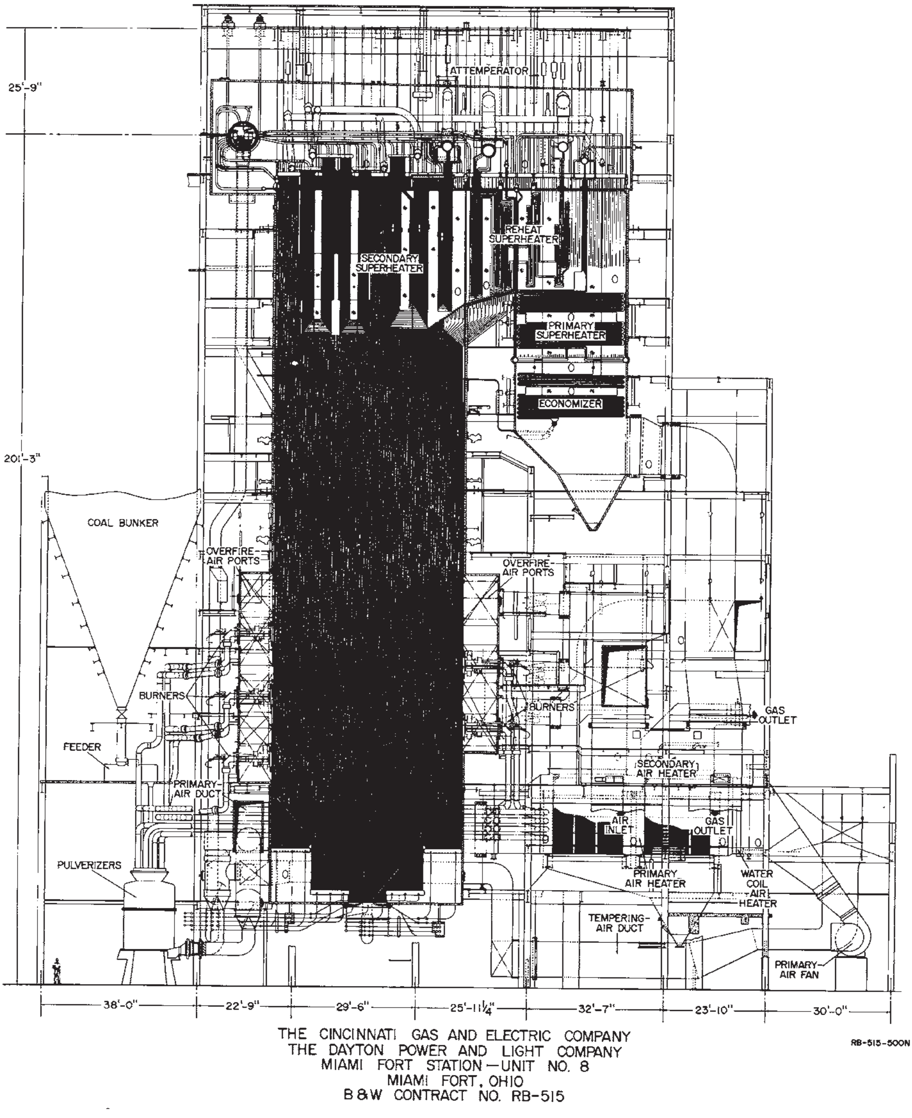


Figure 4-4. Natural circulation radiant boiler used by the Cincinnati Gas and Electric Company *(Courtesy Babcock* and *Wilcox)*

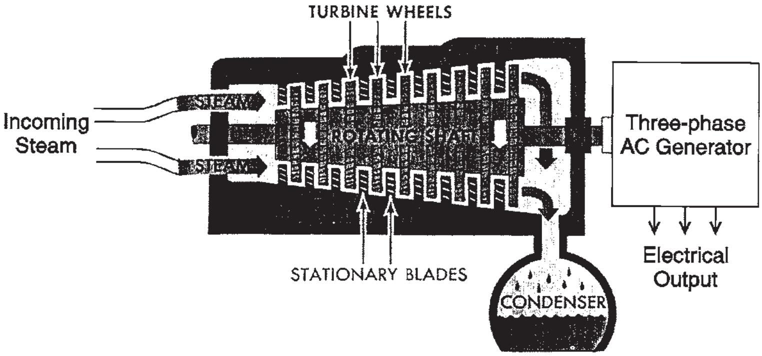
Table 4-1. Power Plant Terminology

Boiler (steam generator)	An enclosed unit that is used to produce steam by heat developed within the unit. Water that flows through it is converted to steam as a result of the heat of combustion.
Superheater	A grouping of tubes inside a boiler that absorbs heat from the combustion gases to raise the temperature of the steam to a very high temperature.
Feedwater	Water that is supplied to the boiler to produce steam.
Coal Pulverizer	A machine that reduces coal to a fineness suitable for burning in suspension. Coal is ground to a talcum powder consistency.
Forced Draft (FD) Fan	A fan to supply preheated combustion air under pressure to the furnace, for mixture with the fuel stream.
Economizer	A heat-absorbing section of the boiler that preheats incoming cold boiler feedwater by transferring heat from the outgoing combustion gases to the water.
Condenser	A unit that converts steam into water.

After steam has been produced, a rotary motion must be developed. This rotary motion is produced by a *steam turbine.* A steam turbine, shown in Figure 4-5 is typically made up of as many as 1500 blades. The rotor is usually divided into two parts—the *high pressure rotor* and the *low pressure rotor.* The low-pressure rotor is larger in diameter than the high-pressure rotor. Steam is channeled to the high-pressure rotor, and it is then routed to the low-pressure rotor.

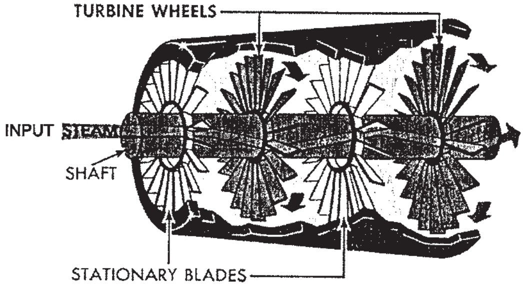
Steam turbines ordinarily achieve a maximum efficiency of less than 30 percent, but only when run at very high speeds. Some turbines can produce as much as 160,000 horsepower. A speed of 3600 rpm is needed to develop a 60-Hz electrical power output. The standard power frequency in the U.S. is 60-Hz. Large three-phase AC generators are connected to DC *exciters.* Generators are often cooled with hydrogen because hydrogen has less than one-tenth the density of water. Therefore, much less energy is required to recirculate the hydrogen for cooling purposes.

The process just described summarizes the operation of a steam power plant. There are several variations to the basic process; however, most plants use similar methods. The individual parts of a steam-generating system will be discussed in more detail in the following sections.



Steam from the boiler rushes through the turbine, rotating a series of bladed wheels mounted on a shaft. As the steam leaves the turbine, a condenser cools it and changes it into liquid water. This creates a vacuum that pulls steam through the turbine.

Expanded View of Turbine



Sets of stationary blades fastened to the turbine aim the steam at the wheels. These blades guide the steam so that it strikes the wheels at the correct angle.

Figure 4-5. Steam turbine principle of operation

STEAM TURBINES

Steam turbine systems are now used to produce over 80 percent of the electrical power used in the United States. The force of steam produces a rotary motion (mechanical energy) in a steam turbine. This mechanical energy is converted to electrical energy by three-phase generators connected by a common shaft. Both fossil fuel systems and nuclear fission systems utilize steam turbines as *prime movers* (rotary motion producers).

A *reaction turbine* channels high-velocity steam through a set of blades mounted on a rotary shaft. The *reaction turbine* usually has more than one set of blades, with each set having a different diameter. As the steam passes though the first section of blades, its pressure is reduced, and its volume is increased. Due to the increased volume, the additional sections of blades must have larger diameters and longer sets of blades. These combined sections of blades direct the high-velocity steam in such a way that a maximum rotational force is produced by the turbine.

The design of a *steam turbine* is very critical for the efficient production of electrical power. Several characteristics of steam turbines cause design problems. Steam turbines must be operated at high rotational speeds, so the blades must be designed to withstand a tremendous amount of centrifugal force. The rotor and blade assemblies for steam turbines are usually machined from a forged piece of chromium and steel alloy. This assembly must be very precisely balanced before the machine is put into operation. The leakage of steam from the enclosed rotor and blade assembly must be prevented. Solid seals cannot be used along the rotor shaft, so so-called "steam" seals are used to provide a minimum clearance between the seals and the shaft. The bearings of a steam turbine must be carefully designed to withstand both axial and end pressures of high magnitudes.

Steam turbines used in electrical power production must be rotated at a constant speed. If turbine *speed* changes, the *frequency* of the generator output voltage will be changed from the standard 60-Hz value. Therefore, a system of governors is used in a steam turbine to regulate its speed. The *governor system* adjusts the turbine speed by compensating for changes in generator power demand. As more load is placed on the generator (increased consumption of electrical power), the generator offers an increased resistance to rotation. Thus, power input to the turbine must be increased accordingly. The governor system of the turbine automatically adjusts the steam input to the turbine blades to compensate for increases and decreases in the load demand placed upon the generator that it drives.

BOILERS

Boilers (see Figures 4-4 and 4-6) are an important part of steam power production systems. The function of a boiler is to provide an enclosure in which pressurized water can be heated to a high temperature to produce

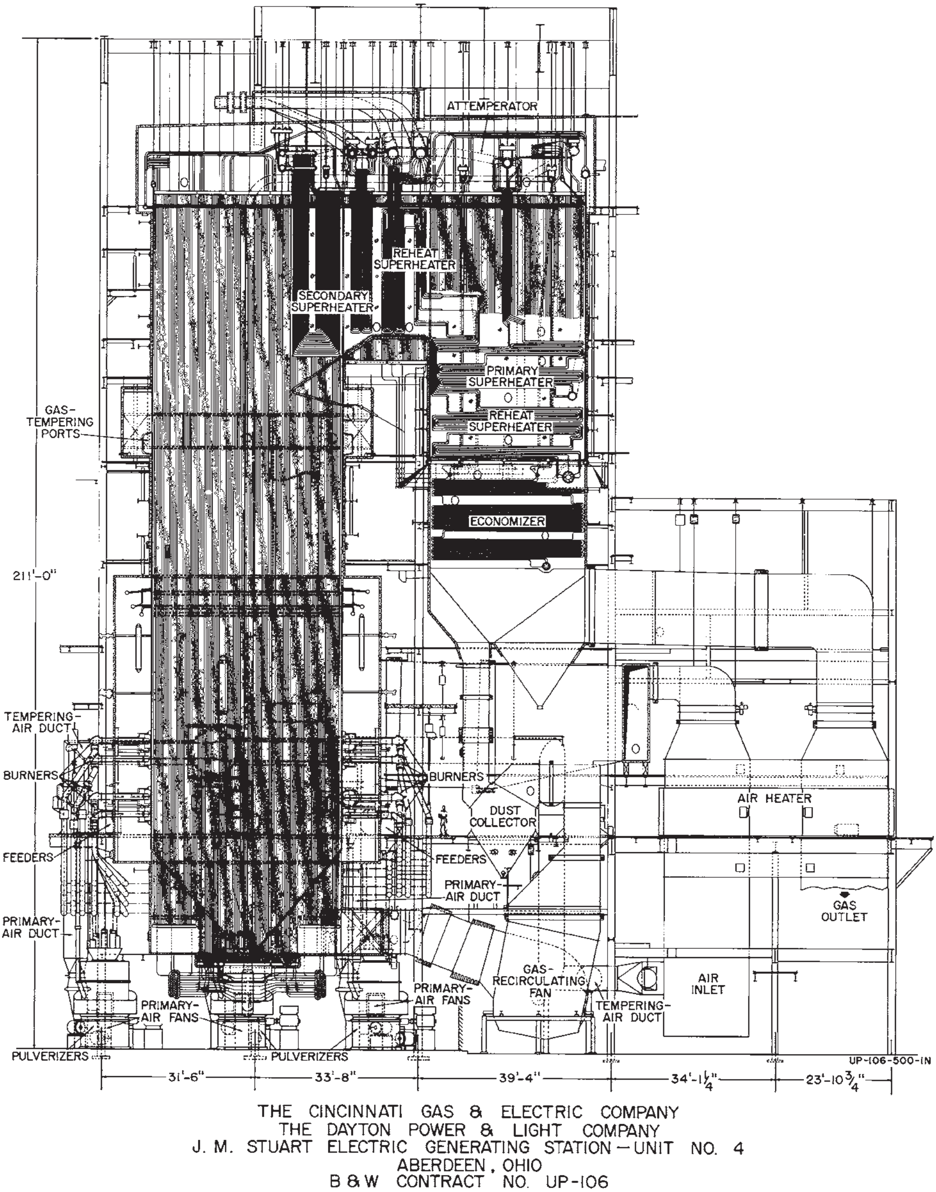


Figure 4-6. Once-through universal boiler used by the Cincinnati Gas and Electric Company (*Courtesy Babcock and Wilcox*)

steam. The heat from burning fossil or nuclear fuels is transferred to an area through which pressurized water flows, and the water is converted to steam through this procedure.

The transfer of heat within a boiler utilizes the three methods of *heat transfer: radiation, convection,* and *conduction.* The *radiation* method involves the movement of heat energy from a warm area to a cool area, and is dependent upon temperature difference and the ability of materials to absorb heat. The *conduction* method requires contact between the heat source and the heated area, and it relies upon the heat conductivity of the heated material. *Convection* is the movement of heat from a hot area to a cooler area by means of an intermediate substance, such as gas. Each of these three methods of heat transfer occurs in varying amounts, depending upon boiler design.

A *boiler* that functions properly is a very critical part of the power production system, as the boiler operation determines the quantity of steam available to produce the rotary motion of the turbine. When more power input for the generating process is required because of an increased load on the system, the boiler must deliver more steam to the turbine. Boilers must be able to provide effective water circulation, efficient fuel combustion, and maximum heat transfer to the circulating water. The boilers used in most steam power plants today are called water-tube boilers. Their design consists of banks of tubes, separated by heat insulation; water is circulated through the tubes under high temperature and high pressure. Boiler design is very important for an efficient steam power plant operation.

Boiler Auxiliary Systems

There are several auxiliary systems used in a steam power plant to increase the operation and efficiency of the boilers. Some of these systems were mentioned briefly in previous sections. One auxiliary system is called an *economizer.* Economizers utilize the hot exhaust gases from the fuel reactions within a boiler to preheat the cold feedwater that is pumped into the boiler. Thus, the economizer uses the waste gases, which would otherwise be emitted through the exhaust stack, for an important purpose. This improves the efficiency of the power plant.

In addition to the *economizer, feedwater heaters* and *preheaters* are used to increase the water temperature before its entry into the boiler. These systems heat the pumped feedwater by means of steam, which is circulated through the unit. In some plants, systems called *superheaters* are used.

These units consist of banks of tubes located at the hottest area of the boiler. Steam flows through these tubes before its entry into the steam turbine. The purpose of the superheater is to cause the steam to reach a higher temperature so as to produce more energy in the steam turbine. Each of these auxiliary systems helps to improve the efficiency of steam power plants.

Condensers and Purifiers

The *condensers* and *feedwater purifiers* used at steam power plants are also important in the production of energy. *Condensers* are used to cool the used steam that has passed through the steam turbine. The condensed water is continuously recirculated through the system. *Feedwater purifiers* are used to clean the impurities from the feedwater, which is obtained from a water source located adjacent to the power plant. The feed water purifiers play an important part in power plant operation. Without them, the metal used in the construction of the boiler would corrode, producing a slag build-up on the boiler walls, which eventually would destroy the boiler. Also, impurities in the steam can cause damage to the precision blades used in the steam turbines. In addition, the gases that are contained in the feed water must also be removed. These gases are removed by a unit called a *deaerator.*

The quantity of *feedwater* that reaches the steam turbine in the form of steam is dependent on the amount of evaporation that takes place in the system. In the power plant, a comparative analysis must be made of the quantity of water entering the boiler and the quantity of steam coming out of the steam turbine. Adjustments in feedwater flow are based on this comparison.

Future of Coal-fired Power Systems

Pulverized-coal systems have been used for many years to produce energy for conversion to electrical power. However, there are now more environmental restrictions on these systems. Major problems include sulfur dioxide and nitrogen oxide emission controls for the power plants, particularly sulfur-dioxide controls. More stringent environmental controls increase the capital cost of power system operations. Even though coal is the most abundant fossil fuel, it is also the dirtiest in terms of environmental factors. Thus, a significant problem of electrical power technology is how to utilize coal in an environmentally acceptable way.

Electrical power systems are the largest consumers of coal in the United States. With a decrease in the availability of oil and natural gas, coal must again be relied upon as the prime electrical power source of the future. Power production systems must be designed that will produce electrical energy in the most economical and environmentally responsible way.

Coal-fired System Simulator

A *coal-fired electrical power system simulator* can't be used to study this method of power production. The various subsystems of the coal-fired power plant are interconnected within the overall system. There are basically five subsystems for this type of power plant. These subsystems are the *feedwater system,* the *fuel and air system,* the *coal-pulverizing system,* the *boiler-water system,* and the *steam and turbine system.* Each of these five subsystems is shown in the diagrams of Figures 4-7 through 4-11.

Oil-fired System Simulator

An *oil-fired electrical power system simulator* is very similar to the coal-fired system. The subsystems are identical to those used in the coal-fired

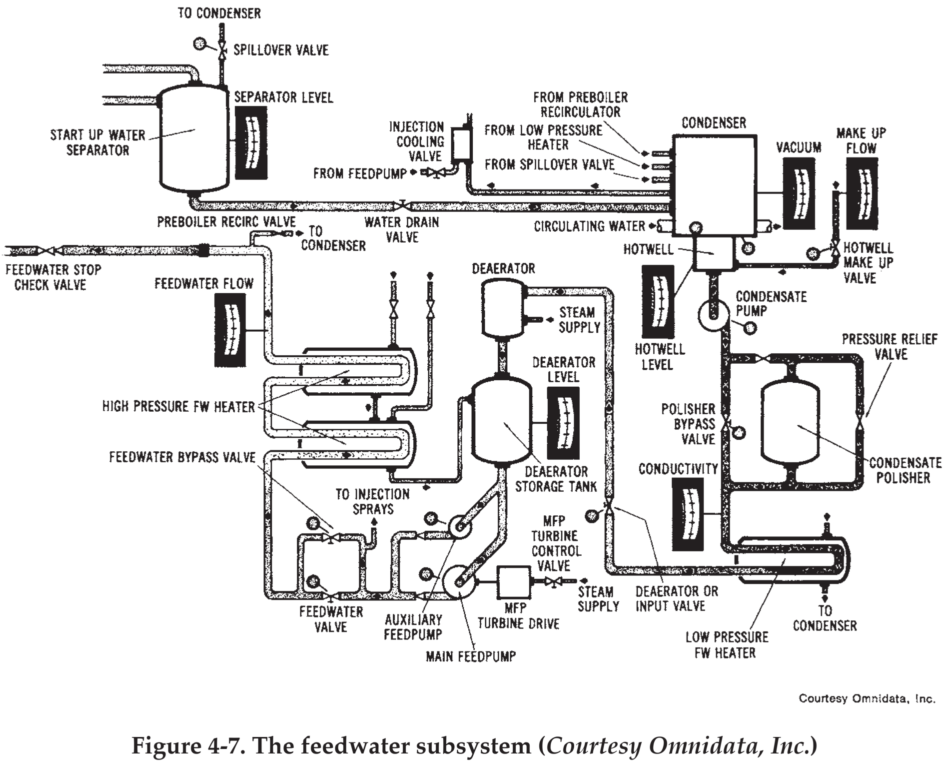


Figure 4-7. The feedwater subsystem (*Courtesy Omnidata, Inc.*)

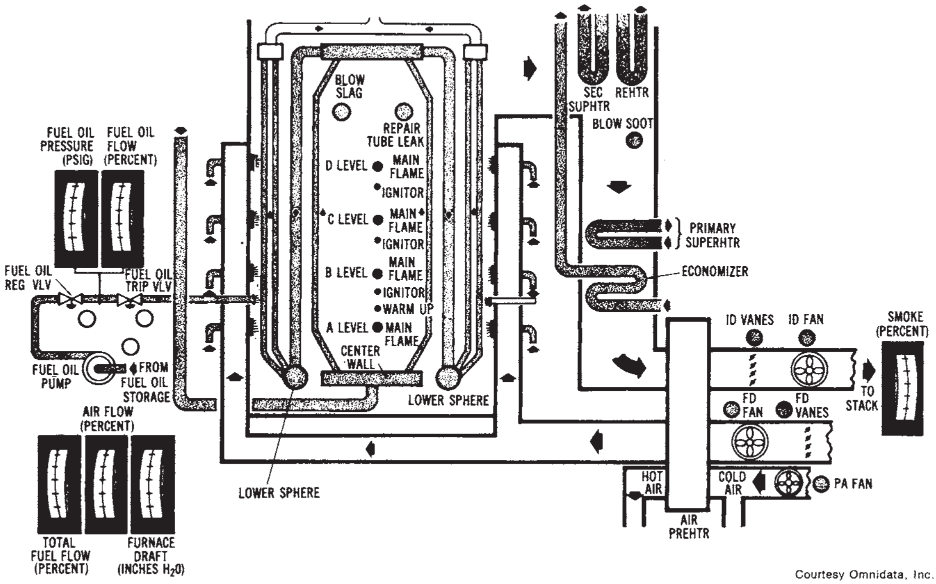


Figure 4-8. The fuel and air subsystem (*Courtesy Omnidata, Inc.*)

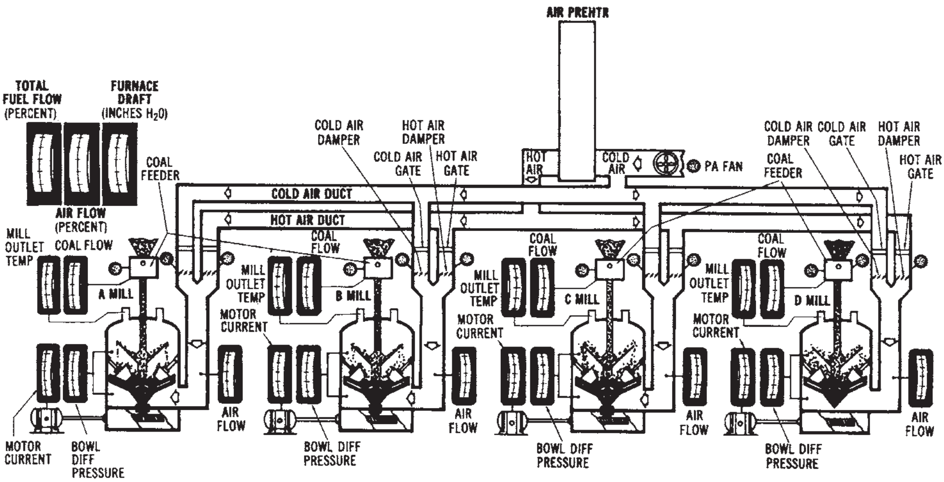


Figure 4-9. The coal pulverizer subsystem (*Courtesy Omnidata, Inc.*)

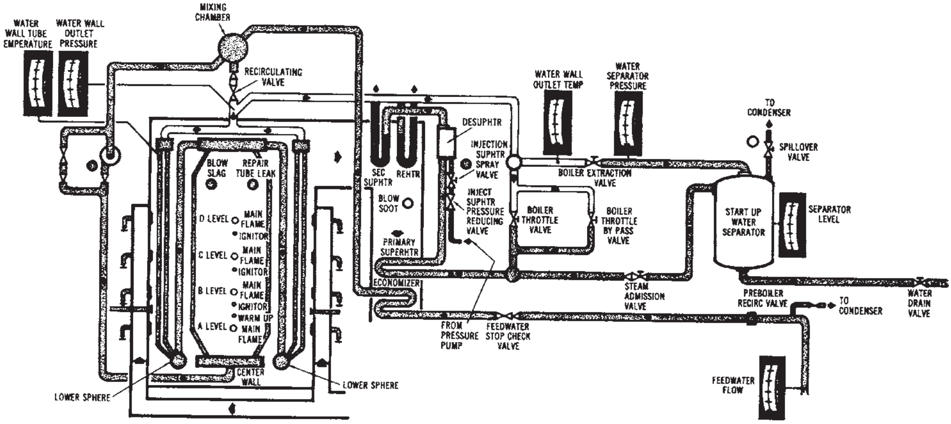


Figure 4-10. The boiler-water subsystem (*Courtesy Omnidata, Inc.*)

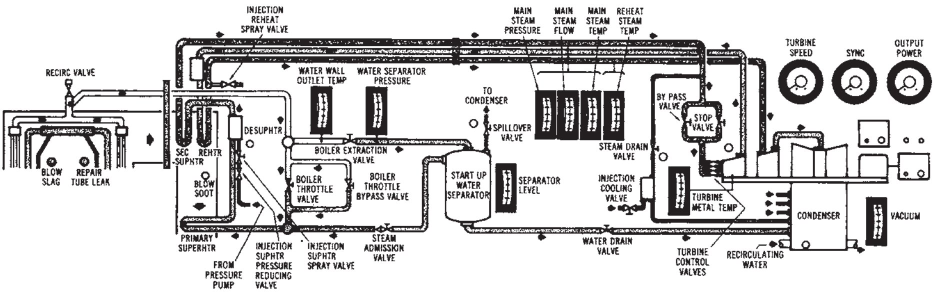


Figure 4-11. The steam and turbine subsystem (*Courtesy Omnidata, Inc.*)

system except, of course, that there is no coal-pulverizing system. These subsystems may be studied to learn the various parts of a power system in more detail.

HYDROELECTRIC SYSTEMS

The use of water power goes back to ancient times. It has been developed to a very high degree, but is now taking a secondary role due to the emphasis on other power sources that are being developed in our country today. Electrical power production systems using water power were developed in the early twentieth century.

The energy of flowing water may be used to generate electrical power. This method of power production is used in *hydroelectric power systems,* as shown by the simple system illustrated in the diagram in Figure 4-12. *Water,* which is confined in a large reservoir, is channeled through a control gate, which adjusts the flow rate. The flowing water passes through the blades and control vanes of a *hydraulic turbine,* which produces rotation. This mechanical energy is used to rotate a generator that is connected directly to the turbine shaft. Rotation of the alternator causes electrical power to be produced. However, hydroelectric systems are limited by the availability of large water supplies. Many hydroelectric systems are part of multipurpose facilities. For instance, a hydroelectric power system may be part of a project planned for flood control, recreation, or irrigation. Some hydroelectric power systems are shown in Figures 4-12 through 4-14.

Hydroelectric System Operation

The *turbines* used as the mechanical energy sources of hydroelectric systems are very efficient machines. They are ordinarily connected

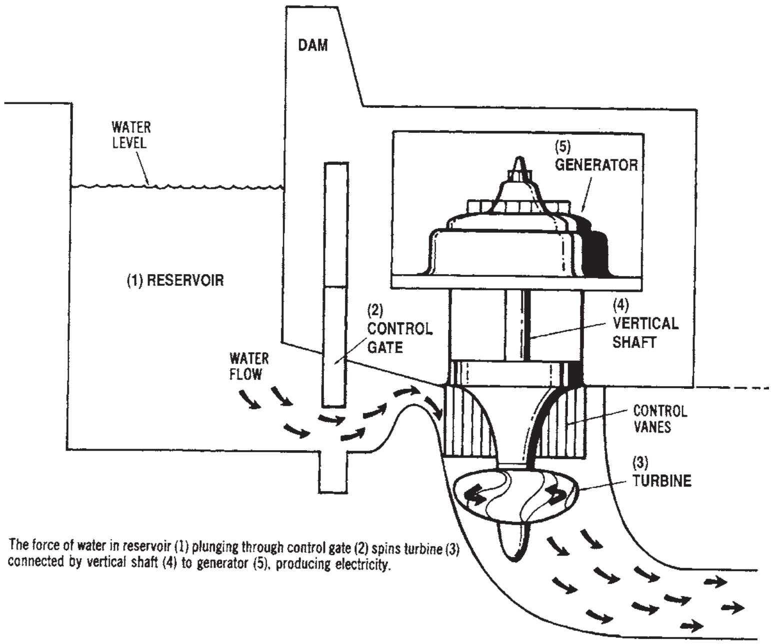


Figure 4-12. Drawing of a basic hydroelectric power system

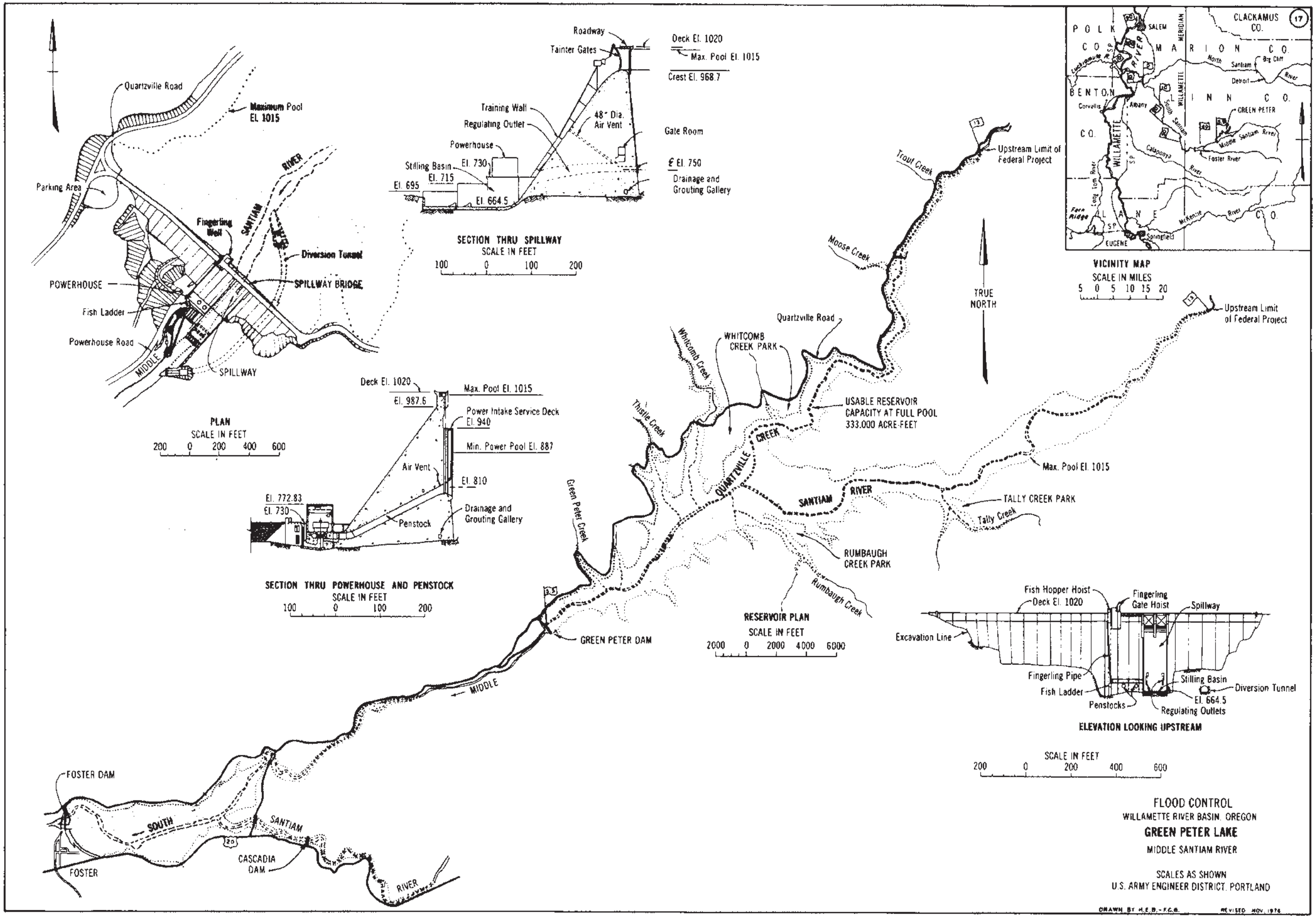


Figure 4-13. Site layout of a hydroelectric project (*Courtesy Portland District, U.S. Army Corp of Engineers*)

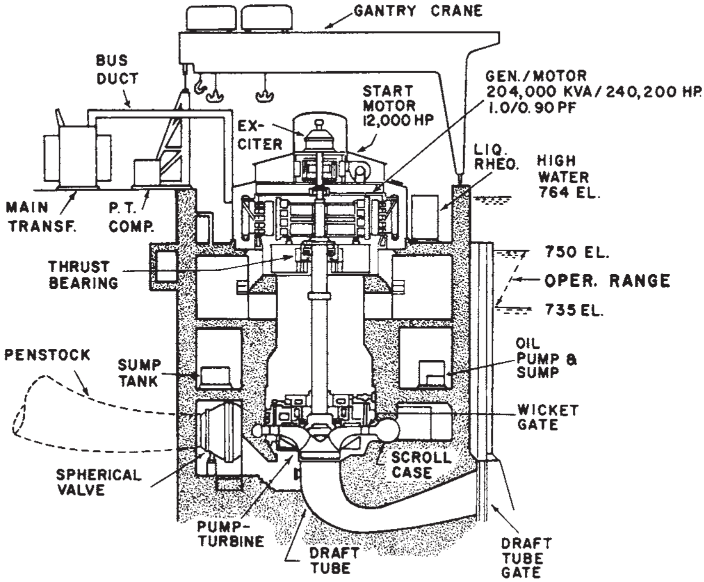


Figure 4-14. Cutaway drawing of a hydroelectric power section at a main unit showing equipment arrangement (*Courtesy Allis-Chalmers Co.*)

directly to the shaft of a *three-phase generator,* which produces the electrical power. *Water* is channeled in from a higher level down into a spiral set of blades on the turbine. The force of water flowing onto these blades causes a rotation of the turbine in the desired direction. The water that flows past the turbine blades is then channeled into a lower-level lake or *reservoir* area. The angle of the *turbine blades* can be adjusted to control the speed of rotation of the turbine. Since rotational speed must remain constant to produce a 60-Hz *frequency,* the blade-angle adjustment and the amount of water channeled onto the blades must be adjusted continuously. Also, varying amounts of force are required to turn the turbine so that different amounts of power are delivered by the turbine to rotate the generator. As the *load demand* delivered by the generator increases, the power input to the turbine must be increased accordingly. This control is accomplished by adjusting the angle of the blades and the amount of water channeled into the blades. The adjustments are automatically accomplished by servocontrol systems.

Hydraulic Turbines

The production of electrical energy by *hydroelectric* systems is dependent upon the operation of *hydraulic turbines.* Hydraulic turbines convert the energy produced by the force of moving water into mechanical energy. This type of turbine is connected to the shaft of a generator at a hydroelectric plant. Since AC generators at power plants must rotate at a constant speed, the hydraulic turbine must turn at a fixed rate of speed. The *efficiency* of hydraulic turbines is much greater (in excess of 85 percent) than that of most rotating machines.

The type of *hydraulic turbine* used with a hydroelectric power system determines whether the generators have horizontal or vertical shafts. Vertical shaft designs are the most common. Electrical power is produced by a *three-phase AC generator* connected directly to the shaft of the *hydraulic turbine.* Several hydroelectric systems are used as "reserve" systems for peak load times. They may be put into operation much faster than steam-driven power systems. It is also possible for the generators of a hydroelectric system to be operated as three-phase synchronous motors during low-demand periods. The motor can rotate the hydraulic turbine, which is then capable of pumping water. Sufficient water is pumped so that a higher external water level is achieved. The higher water elevation will then assist in the production of power during *peak load* intervals.

Future of Hydroelectric Systems

About 10 percent of the power produced in the United States is produced by *hydroelectric* power systems. After the initial cost of constructing a hydroelectric generating facility, the electrical power production cost is relatively inexpensive. Hydroelectric systems are easier to start up and stop than are other power production systems in use today. There are other advantages to hydroelectric systems that are not associated with the production of electrical power. These benefits, derived from the construction of multipurpose dams, include navigational control of waterways, flood control, irrigation, and development of recreational area. Another advantage is that hydroelectric systems do not cause a consumption of the energy source that produces the electrical power, as do other systems in use today.

Hydroelectric generating projects are considered to be low cost, and they produce little pollution. However, in the United States, we have already used the most desirable sites for installing hydroelectric systems. Since the cost of developing other alternative power systems, such as nuclear and geothermal, has become so great, the development of less desirable hydroelectric sites is now feasible. Future development of hydroelectric power systems may be inevitable.

A motivation for the use of water to produce electrical power is the fact that, if we used this natural resource to its full potential, it would give us other benefits. These were discussed earlier. Although the cost to produce electrical power with *hydroelectric* systems depends on a number of factors, it is generally considered to be a very cheap source of energy. The costs are primarily dependent upon the location of the power plant. The desirability of the site is dependent upon its natural characteristics, which affect the cost of development, and its regional characteristics, which, in turn, affect the market for the power.

In the late 1930s, water power supplied about 40 percent of the electrical power in the United States. Now, however, water power supplies only about 10 percent of the nation's electrical power. This is due to the massive development of other power production methods. It is estimated that, in the future, water power will account for an even smaller percentage of electrical power generation. Despite this projected decrease, *hydroelectric* plants are still being built, and the hydroelectric capacity of the United States is still substantial. Hydroelectric systems are not now being developed rapidly; however, with our ever-increasing energy problems and the shortages of our other natural resources, water systems may still have a useful potential.

Pumped-Storage Hydroelectric Systems

Several megawatts of electrical power are produced in the United States by *pumped-storage hydroelectric systems.* This type of system operates by pumping water to a higher elevation and storing it in a reservoir until it is released to drop to a lower elevation to drive the hydraulic turbines of a hydroelectric power-generating plant.

The variable nature of the electrical *load demand* makes *pumped-storage* systems desirable systems to operate. During low-load periods, the hydraulic turbines may be used as pumps to pump water to a storage reservoir of a higher elevation, from a water source of a lower elevation. The water in the upper reservoir can be stored for long periods of time, if necessary. When the electrical load demand on the power system increases, the water in the upper reservoir can be allowed to flow (by gravity feed) through the hydraulic turbines, which will then rotate the three-phase generators in the power plant. Thus, electrical power can be generated without any appreciable consumption of fuel. The pump-turbine and motor-generator units are constructed so that they will operate in two ways: (1) as a pump and motor, and (2) as a turbine and generator. In both cases, the two machines are connected by a common shaft and operate together. However, the multiple use of these machines, although economically very attractive, limits the amount of time that a pumped-storage system can generate electrical power.

Future of Pumped-storage Systems

The future of *pumped-storage* systems depends primarily on economic factors. If fuel and capital construction costs continue to rise, pumped-storage systems might be developed. The conversion of conventional hydroelectric systems to pumped-storage systems has been considered. Also, underground pumped-storage systems have been studied. The underground system would have an upper reservoir at ground level and the lower reservoir underground. The operating principle is the same as in a conventional pumped-storage system.

NUCLEAR FISSION SYSTEMS

Nuclear power plants in operation today employ reactors that utilize the *nuclear-fission* process. Nuclear fission is a complex reaction that results in the division of the nucleus of an atom into two or more nuclei. This splitting of the atom is brought about by the bombardment of the nucleus with neutrons, gamma rays, or other charged particles, and is referred to as induced fission. When an atom is split, it releases a great amount of heat.

In recent years, several *nuclear fission* power plants have been put into operation. A nuclear fission power system, shown in Figure 4-15, relies upon heat produced during a nuclear reaction process. Nuclear reactors "burn" nuclear material, whose atoms are split, causing the release of heat. This reaction is referred to as nuclear fission. The heat from the fission process is used to change circulating water into steam. The high-pressure steam rotates a turbine, which is connected to an electrical generator. This is shown in the diagram of Figure 4-16.

The *nuclear fission system* is very similar to fossil fuel systems in that heat is used to produce high-pressure steam that rotates a turbine. The source of heat in the nuclear fission system is a nuclear reaction; in the fos-

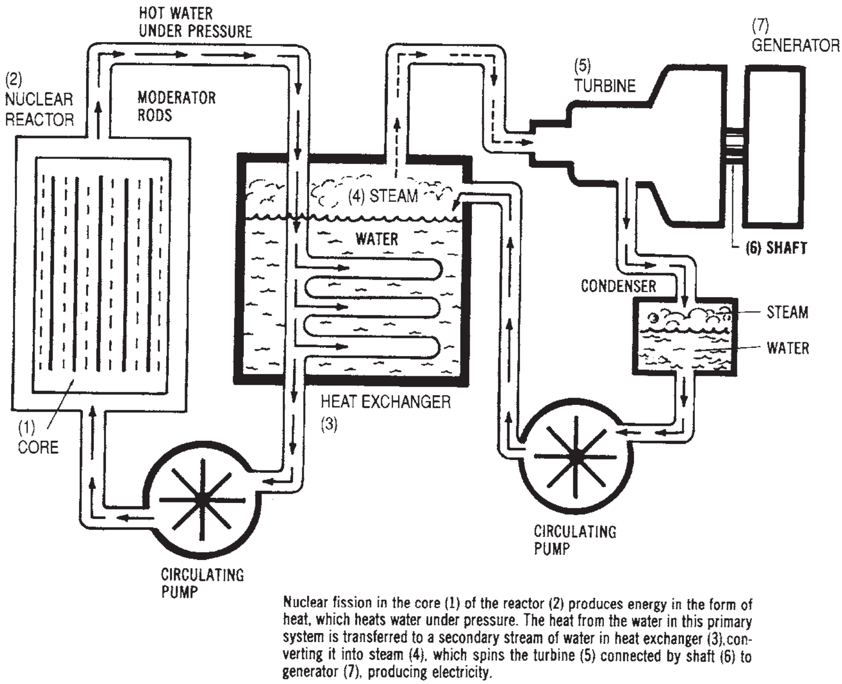


Figure 4-15. Drawing illustrating the principles of a nuclear fission power system.

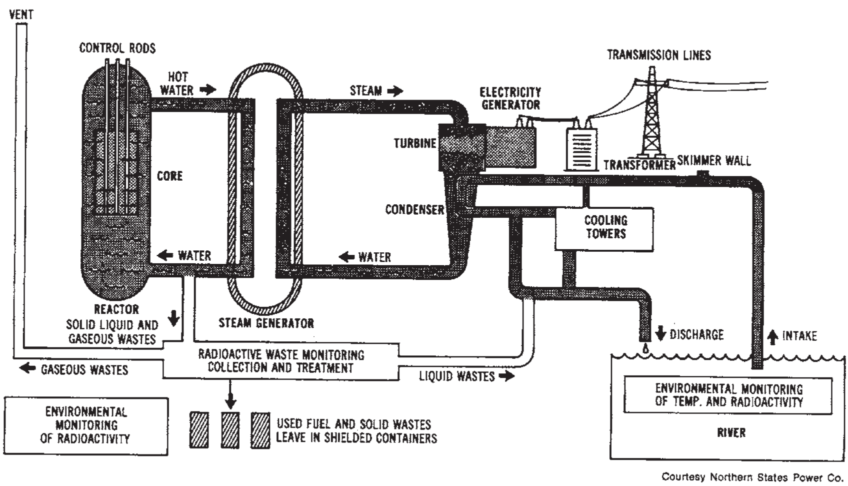


Figure 4-16. Diagram of the nuclear reaction process (*Courtesy Northern States Power Company*)

sil-fuel system, heat is developed by a burning fuel. At the present time, less than 10 percent of the electrical power produced in the United States comes from nuclear fission sources. However, this percentage is also subject to rapid change as new power facilities are put into operation. A typical nuclear power plant site layout is given in Figure 4-17.

Nuclear Power Fundamentals

In order to better understand the process involved in producing electrical power by *nuclear fission* plants, we should review some fundamentals. An atom is the smallest particle into which an element can be broken. The central part of an atom is called its *nucleus* (this is how the term "nuclear power" was derived). The nucleus of an atom is composed of

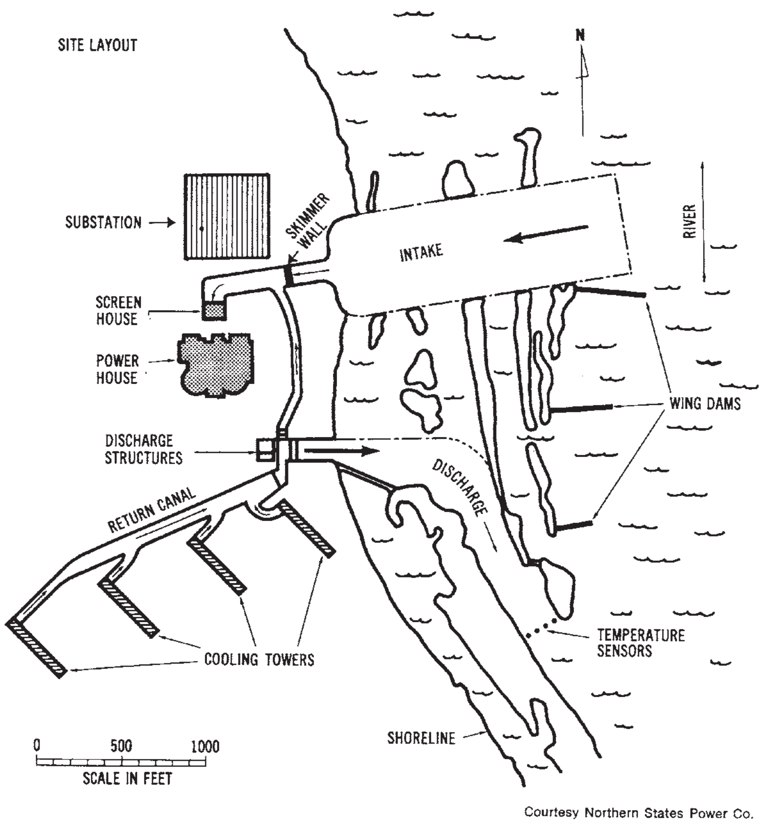


Figure 4-17. Typical site layout of a nuclear power plant (*Courtesy Northern States Power Company*)

protons, which are positively charged particles, and neutrons, which have no electrical charge. Electrons, which are negatively charged particles, orbit around the nucleus. An atom of any element is electrically neutral in its natural state, since the number of protons in the nucleus is equal to the number of electrons that orbit around the nucleus.

The number of protons (+) and electrons (–) contained by an atom varies from one atom to another. (For further information concerning atomic number, mass, et cetera, refer to the table of Elements given in Appendix B.) The number of neutrons (0) in an atom is not always the same as the number of protons and electrons. *Atoms* that have additional neutrons are called isotopes. For instance, a hydrogen atom normally has one electron, one proton, and no neutrons. If one neutron is added to this atomic structure, heavy hydrogen, or deuterium, is formed. Deuterium is an isotope of hydrogen.

The element *uranium* has many different isotopes, each of which contains 92 protons. If the isotope has 143 neutrons in the nucleus, uranium-235 is formed. *Uranium-235* has proved to be a valuable nuclear fuel, but less than 1 percent of the uranium metal ore mined is of the uranium-235 type.

The *fission* or splitting reaction of uranium-235, or other nuclear fuels, is an interesting process. It requires separate controlled neutrons, traveling at high velocities, to penetrate the orbiting electrons around the nucleus of the U-235 isotope. Once a high-velocity neutron has struck the nucleus, the nucleus will split into smaller nuclei. This reaction causes a large quantity of heat to be released. When a nucleus splits, other neutrons from within it are released. These neutrons can cause additional fission reactions in other U-235 isotopes. Thus, the fission reaction occurs as a chain reaction, which causes massive amounts of heat energy to be given off.

Nuclear Fuels

A sustained *nuclear fission* reaction is dependent upon the use of the proper type of fuel. The most desirable fuels for nuclear fission reactions are uranium-233, uranium-235, and plutonium-239. These three nuclear materials are the only fissionable isotopes capable of producing sustained reactions. Of these nuclear fuels, the only one that occurs naturally is uranium-235. The other two isotopes are produced by artificial means. Ordinarily, nuclear reactors that use uranium-235 as a fuel are called *converter* reactors.

The possibility of a nuclear fission reaction producing as much or more fuel than is used has been investigated. Such reactors are called *breeder reactors* and use uranium-233 and plutonium-239 as fuels. During the nuclear reactions that take place in a breeder reactor, materials that are used in the reaction process are converted into fissionable materials. The long-range development of nuclear power production may be dependent upon whether or not breeder reactors can be made available soon. Since the types of *nuclear reactors* that are presently being used consume uranium-235, it is thought that, in the future, the supply of *this* fuel will become low, forcing its price to rise substantially. A price increase in this naturally available nuclear fuel would make nuclear power production less economically competitive with other systems.

Uranium fuel for nuclear fission reactors is produced from ore and is then purified and converted to the desired state through a series of processes. Most nuclear fuel elements are made into plates or rods, which are protected by a cladding of stainless steel, zirconium, or aluminum. The cladding must be capable of containing the nuclear fuel, so as not to allow the release of radioactive materials.

Used fuel is released from the fission reactors when it no longer produces heat effectively during the nuclear reaction. It is not depleted at *this* time; therefore, further processing can bring about the recovery of more fuel from the used fuel. The used *fuel,* which is released from a nuclear reactor, is usually stored underwater for a period of time to permit cooling and radioactive shielding. This type of storage reduces the radioactivity of the fuel. After the storage period has elapsed, the fuel may be reprocessed more safely and easily. The reprocessing of nuclear fuel is very expensive. A large factor contributing to *this* cost is the expense of constructing a reprocessing facility. These facilities must be extensively shielded for radiation protection, both internally and externally. The production and use of nuclear fuels in the United States is rigidly controlled. An agency of the federal government keeps a continuous account of all nuclear fuels produced, used, or reprocessed.

Nuclear Reactors

There is a variety of types of *nuclear reactors.* The major type used in the United States has been the water-moderated reactor. The fundamental difference between a nuclear power plant and a conventional power plant is the fuel that is employed. Most conventional power plants burn coal, oil, or gas to create heat, while the present nuclear plants "burn" uranium. Burning uranium has proved to be a very effective source of power production; however, there is much controversy over this source of power.

It is estimated that burning one ounce of uranium produces roughly the same energy output as burning 100 tons of coal. The "burning" that takes place in a nuclear reactor is referred to as *nuclear fission.* Nuclear fission is the method used in nuclear power generation, and it is quite different from ordinary combustion. The burning of coal results from the carbon combining with oxygen to form carbon dioxide, along with the release of heat. The fissioning or splitting of the uranium atom results in the uranium combining with a neutron and, subsequently, splitting into lighter elements. This process produces a massive quantity of heat.

The *reactors* used at nuclear power plants must be capable of controlling *fission* reactions. When nuclear fuels are bombarded by neutrons, they split and release energy, radiation, and other neutrons. This process is a sustained chain reaction, producing a great amount of heat energy, which is used for the production of steam, which is used to rotate a steam turbine-generator system. The nuclear fission power-generating system is about the same as a conventional fossil fuel steam plant, except that a nuclear reactor is used to produce the heat energy, rather than a burning fuel confined in a furnace.

Within the *nuclear reactor,* there is a mixture of fuel and a moderator material. There are three known nuclear fission fuels: *uranium-235, uranium-233,* and *plutonium-239.* Moderators are used to slow the speed of neutrons in fission reactions. Since the neutrons involved in the fission reaction have high energy levels, they are called fast neutrons. They are slowed by collisions with moderator materials such as water, deuterium oxide, beryllium, and other lightweight materials. Neutrons that have been slowed down possess an energy equilibrium and are referred to as thermal neutrons. These thermal neutrons aid in additional fission reactions. Thus, moderators playa significant role in sustaining nuclear fission reactions.

Nuclear reactors differ in several ways. Differences include the type of fuel and moderator, the thermal output capacity, and the type of coolant. Several classifications of nuclear reactors, according to types of coolant, are discussed in the following sections.

Moderating Nuclear Reactors

A uranium atom undergoes *fission* when it absorbs a neutron and, at the same time, produces two lighter elements and emits two or three neutrons. These neutrons, in turn, react with other uranium atoms, which will undergo fission and produce more neutrons. Heat is increased in the reactor as the number of neutrons is increased. If a *reactor* is left uncontrolled, it may destroy itself. *Moderating* a reactor, therefore, means controlling the multiplication of neutrons in the reactor core. There are several methods used for moderating nuclear reactors.

Boiling-Water Reactor (BWR)—Water is a popular coolant for reactors. In this type of reactor, shown in Figure 4-18, water is pumped into the reactor enclosure. The water is then converted into steam, which is delivered to a steam turbine. The water also serves as the moderator material of the reactor.

Pressurized-Water Reactor (PWR)—The pressurized-water reactor, shown in Figure 4-19 is similar to a boiling-water reactor, except that the coolant water is pumped through the reactor under high pressure. Steam is produced in an adjacent area from a separate stream of water, which is pumped through the steam-production system. Just as in the BWR, the water within the reactor serves as the moderator.

High-temperature Gas-cooled Reactor (HTGR)—The high-temperature gas-cooled reactor, shown in Figure 4-20 uses pressurized helium gas to transfer heat from the reactor to a steam-production system. The advan-

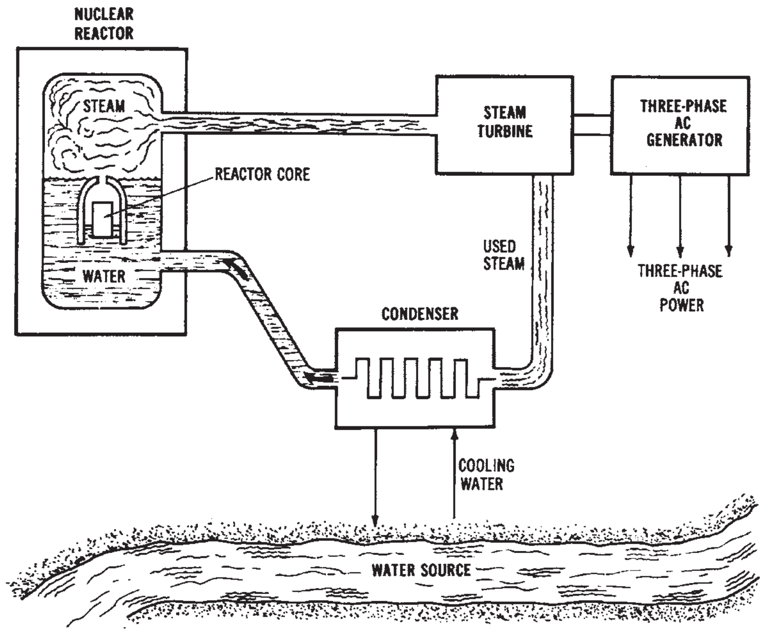


Figure 4-18. Simplified diagram of a boiling water reactor (BWR)

tage of helium gas over water is that the helium can operate at much higher temperatures.

Other types of reactors, such as the *liquid-metal fast-breeder reactor (LMFBR)* and the molten-salt-cooled reactor, have some potential in electrical power production systems. The LMFBR type is shown in Figure 4-21.

OPERATIONAL ASPECTS OF MODERN POWER SYSTEMS

There are several operational aspects of modern electrical power production systems that must be considered. These considerations include the location of power plants, electrical *load requirements,* and electrical *load demand* control. Each of these will be discussed in the following sections.

Location of Electrical Power Plants

A critical issue that now faces those involved in the production of electrical power is the location of power plants. Federal regulations associated with the National Environmental Policy Act (NEPA) have made the location of power plants more difficult. At present, there are a vast number of individual power plants throughout the country. However, the addition

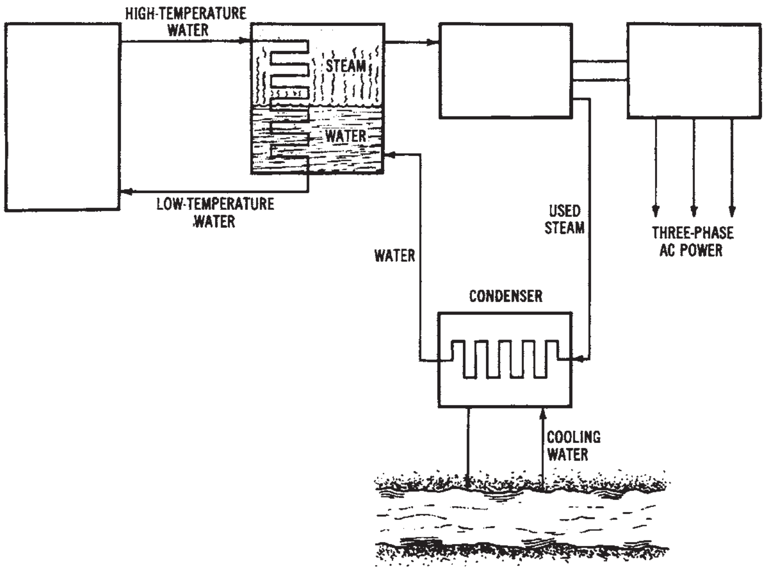


Figure 4-19. Simplified diagram of a pressurized water reactor (PWR)

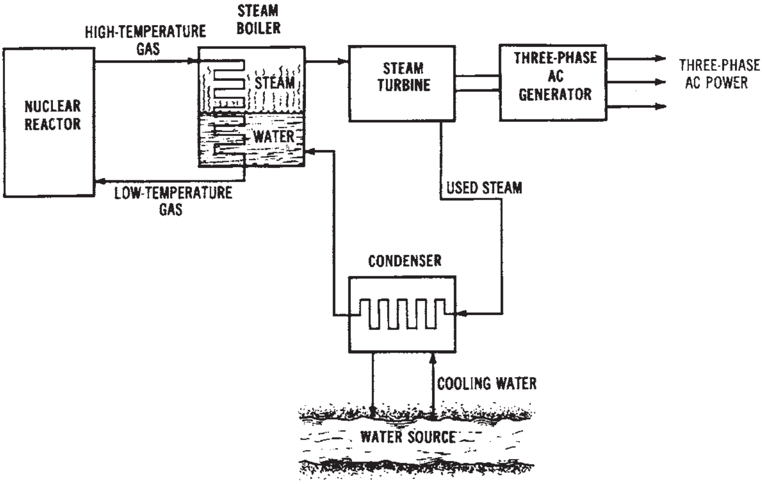


Figure 4-20. Simplified diagram of a high-temperature gas-cooled reactor (HTGR)

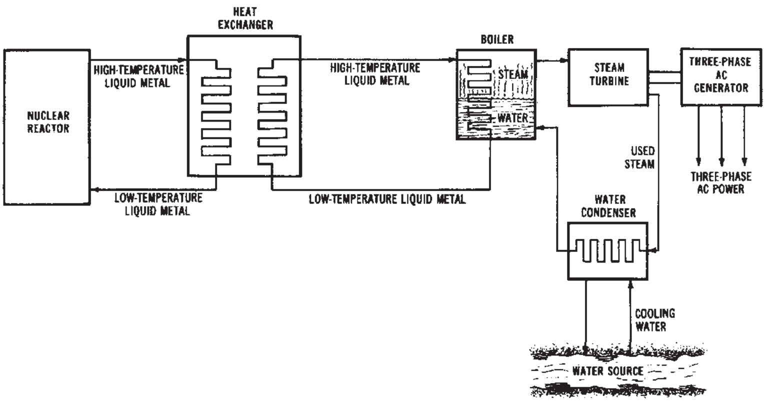


Figure 4-21. Simplified diagram of a liquid-metal fast-breeder reactor (LMFBR)

of new generating plants involves such current issues as air pollution, water pollution, materials handling (particularly with nuclear plants), fuel availability, and federal, state, and municipal regulations.

These issues have brought about some recent thought about the construction of "energy centers." Such systems would be larger and more standardized than the power plants of today. This concept would reduce the number of plants that are needed to produce a specific quantity of electrical power. Other advantages of this concept include better use of land resources, easier environmental control management, and more economical construction and management of facilities. These advantages may make centralized power production the best alternative, socially, economically, and technically, for meeting future electrical power requirements.

Electrical Load Requirements

The electrical power that must be produced by our power systems varies greatly according to several factors, such as the time of the year, the time of the week, and the time of the day. The level of electrical power *supply* and *demand* is much more difficult to predict than that of most quantities that are bought and sold. Electrical power must be readily available, in sufficient quantity, whenever it is required. The overall supply and demand situation is something most of us take for granted until our electrical power is interrupted. Electrical power systems in the United States must be *interconnected* on a regional basis, so that power stations can support one another in meeting the variable *load demands.*

The use of electrical power has been *forecasted* to increase every ten years at a rate that will cause a doubling of the kilowatt hours required. Some forecasts, however, show the rate of electrical power demand to have a "leveling-off" period in the near future. This effect may be due to a saturation of the possible uses of electrical power for home appliances, industrial processes, and commercial use. These factors, combined with greater conservation efforts and other social and economic factors, support the idea that the electrical *power demand* will increase at a slower rate in future years. The forecasting of the present demand by the electrical utility companies must be based on an analysis by regions. The demand varies according to the type of consumer supplied by the power stations that constitute the system. Different types of load are encountered when *residential, industrial,* and *commercial* systems are supplied by the electrical utility companies.

Industrial use of electrical power accounts for approximately 40 percent of the total kilowatt-hour (kWh) consumption, and the industrial use of electrical power is projected to increase at a rate similar to its present rate, in the near future. The shortage of natural gas should not significantly affect electrical power consumption by industry. Most of the conversions of gas systems will be to systems that use oil in place of gas.

The major increases in *residential power demand* have been due to an increased use by customers. A smaller increase is accounted for by an increase in the number of customers. Such variables as the type of heating used, the use or nonuse of air conditioning, and the use of major appliances (freezers, dryers, ranges) affect the residential electrical power demand. At present, residential use of electrical power accounts for approximately 30 percent of the total consumption. The rate of increase will probably taper off in the near future.

Commercial use of electrical power accounts for less than 25 percent of the total kWh usage. Commercial power consumption includes usage by office buildings, apartment complexes, school facilities, shopping establishments, and motel and hotel buildings. The prediction of the future electrical power demand by these facilities is somewhat similar to the prediction of future residential demand. The rate of increase in the commercial use of electrical power is also expected to decline in the future. These percentages are subject to change over time.

Electrical Load-demand Control

As the costs of producing power continue to rise, power companies must search for ways to limit the maximum rate of energy consumption. To cut down on *power usage,* industries have begun to initiate programs that will cut down on the load during *peak* operating periods. The use of certain machines may be limited while other large, power-consuming machines are operating. In larger industrial plants, and at power production plants, it would be impossible to manually control the complex regional switching systems, so computers are being used to control loads.

To prepare the *computers* for power-consumption control, power companies must determine the *peak demand patterns* of local industries, and the surrounding region, supplied by a specific power station. The load of an industrial plant may then be balanced, according to area demands, with the power station output. The computer may be programmed to act as a switch, allowing only those processes to operate that are within the load calculated for the plant for a specific time period. If the load drawn by an industry exceeds the limit, the computer may deactivate part of the system. When demand is decreased in one area, the computer can cause the power system to increase power output to another part of the system. Thus, the industrial load is constantly monitored by the power company to ensure a sufficient supply of power at all times.

Chapter 5

Alternative Power Systems

Several methods of producing electrical power are either in limited use or in the experimental stage at the present time. Some of these methods show promise as a possible electrical power production method for the future. *Alternative power systems* are discussed in Chapter 5.

IMPORTANT TERMS

Chapter 5 deals with alternative electrical power production systems. After studying this chapter, you should have an understanding of the following terms:

Solar cell
Solar energy system
Solar heating
Geothermal power system
Wind energy system
Magnetohydrodynamic (MHD) system
Nuclear fusion power system
Magnetic confinement fusion
Fuel cell system
Tidal power system
Coal gasification
Oil shale fuel production
Alternative nuclear power plants
Biomass

POTENTIAL POWER SOURCES

Solar power is one potential electrical power source. The largest energy source available today is the sun, which supplies practically limitless energy. The energy available from the sun far exceeds any foreseeable future need. *Solar cells* are now being used to convert light energy into small quantities of electrical energy. Possible solar-energy systems might include home heating or power production systems, orbiting space systems, and steam-driven electrical power systems. Each of these systems utilizes *solar collectors* that concentrate the light of the sun so that a large quantity of heat will be produced. Potentially, this heat could be used to drive a steam turbine in order to generate additional electrical energy.

Geothermal systems also have promise as future energy sources. These systems utilize the heat of molten masses of material in the interior of the earth. Thus, heat from the earth is a potential source of energy for power generation in many parts of the world. The principle of *geothermal* systems is similar to other steam turbine-driven systems. However, in this case, the source of steam is the heat obtained from within the earth through wells. These wells are drilled to a depth of up to two miles into the earth. *Geothermal* sources are used to produce electrical energy in certain regions of the western United States.

Wind systems have also been considered for producing electrical energy. However, winds are variable in most parts of our country. This fact causes wind systems to be confined to being used with *storage* systems, such as batteries. It is possible that wind machines may be used to rotate small generators which could, potentially, be located at a home. However, large amounts of power would be difficult to produce by this method.

Another energy source which has some potential for future use is *magnetohydrodynamics (MHD).* The operation of an MHD system relies upon the flow of a conductive gas through a magnetic field, thus causing a direct current (DC) voltage to be generated. The electrical power developed depends upon the strength of the magnetic field that surrounds the conductive gas, and on the speed and conductivity of the gas. At the present time, only small quantities of electrical energy have been generated using the MHD principle; however, it does have some potential as a future source of electrical energy.

Still another possible energy source is *nuclear fusion.* This process has not been fully developed, due to the extremely high temperatures that are produced as fusion of atoms takes place. A *fusion reactor* could use *tritium* or *deuterium* (heavy hydrogen) as fuels. These fuels may be found in sea water in large quantities, thus reducing the scarcity of nuclear fuel. It is estimated that there is enough deuterium in the oceans to supply all the energy the world would ever need.

If *nuclear-fusion reactors* could be used in the production of electrical energy, the process would be similar to the nuclear-fission plants which are now in operation. The only difference would be in the nuclear reaction that takes place to change the circulating water into steam to drive the turbines. The major problem of the *nuclear-fusion* process is controlling the high temperatures generated, estimated to reach 100 million degrees Fahrenheit.

Another energy source which could be used in the future is the *fuel cell.* This type of cell converts the chemical energy of fuels into direct current electrical energy. A fuel cell contains two porous electrodes and an electrolyte. One type of fuel cell operates as hydrogen gas passes through one porous electrode and oxygen gas passes through the other electrode. The chemical reactions of the electrodes with the electrolyte either release electrons to an external circuit, or draw electrons from the external circuit, thus producing a current flow.

Still another possible alternative power production system utilizes *tidal energy.* Tidal systems would use the rise and fall of the water along a coastal area as a source of energy for producing electrical power. Coal gasification is yet another process that could be used for future power systems. This process is used to convert the poorer grades of coal into a gas. The use of oil shale to produce fuel is also being considered.

It should be pointed out that many of the future energy sources are *direct conversion* processes. For example, the fuel cell converts chemical energy directly to electrical energy, and the solar cell converts light energy directly to electrical energy. A more complex transformation of energy takes place in most power plants today. Heat energy is needed to produce mechanical energy, which produces electrical energy. This explains the inefficiency of our present systems of producing electrical energy. Perhaps advances in electrical power technology will bring about new and more efficient methods of producing electrical energy.

SOLAR ENERGY SYSTEMS

For many years, many have regarded the *sun* as a possible source of electrical power. However, few efforts to use this cheap source of energy have been made. We are now faced with the problem of finding alternative sources of energy, and solar energy is one possible alternative source. The sun delivers a constant stream of radiant energy. The amount of *solar energy* coming toward the earth through sunlight in one day equals the energy produced by burning many millions of tons of coal. It is estimated that enough solar energy is delivered to the United States in less than one hour to meet the power needs of the country for one year. This is why solar energy is a potential source for our ever-growing electrical power needs. However, there are still several problems to be solved prior to using solar energy. One major problem is in developing methods for controlling and utilizing the energy of the sun. There are two methods for collecting and concentrating solar energy presently in use. Both of these methods involve a mirror-like reflective surface.

The first method uses *parabolic mirrors* to capture the energy of the sun. These mirrors concentrate the energy from the sun by focusing the light onto an opaque receiving surface. If water could be made to circulate through tubes, the heat focused onto the tubes could turn the water into steam. The steam, then, could drive a turbine to produce mechanical energy. The mirrors could be rotated to keep them in proper position for the best light reflection.

The second method uses a *flat-plate solar collector.* Layers of glass are laid over a blackened metal plate, with an air space between each layer. The layers of glass act as a heat trap. They let the rays of the sun in, but keep most of the heat from escaping. The heated air could be used to warm a home.

The first widespread use of solar energy will probably be to heat homes and other buildings. Experiments in doing this are already underway in many areas. To heat a home, a flat-plate collector may be mounted on the part of the roof that slopes in a southward direction. It should be tilted at an angle to receive the greatest amount of sunlight possible. The sun would be used to heat a liquid (or air) that would be circulated through the collector. The heated liquid (air) would be stored in an insulated tank and, then, pumped into the house through pipes and radiators (air ducts). By adding a steam turbine, a generator, etc., to the solar collector just discussed, the heat could be used to drive the steam turbine to generate electrical energy. This *solar power system* is illustrated in Figure 5-1.

Another major problem in solar heating is in the *storage* of the heat produced by the sun. In areas that have several cloudy days each year, an auxiliary heating system is required. However, solar energy is being used

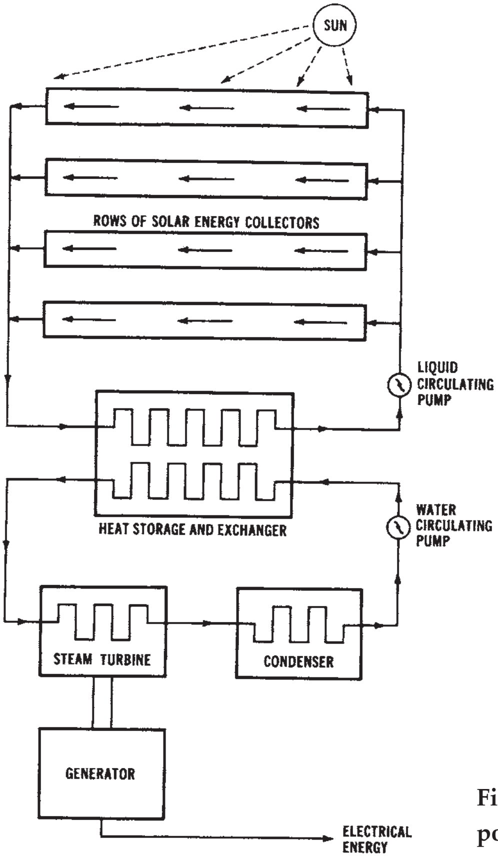


Figure 5-1. Block diagram of a solar power system

today on a limited basis. For instance, flashlights and radios can be powered by solar cells. The main advantage of this usage is that a solar battery can be used for an infinite period of time. Considering all of these aspects of solar energy and its potential, many feel that solar energy will be the next major form of energy to be utilized extensively in the United States. The development of large-scale power production systems which use solar energy, however, remains questionable.

GEOTHERMAL POWER SYSTEMS

About 20 miles below the crust of the earth is a molten mass of liquid and gaseous matter called *magma,* which is still cooling from the time that the earth was formed. When this magma comes close to the crust of the earth, possibly through a rupture, a volcano could be formed and erupt. Magma could also cause steam vents, like the ones at the *"Geysers"* area in California. These are naturally occurring vents that permit the escape of the steam formed by the water that comes in contact with the underground magma. A basic *geothermal power system* is shown in Figure 5-2, and the understructure for such a system is illustrated in Figure 5-3.

In the 1920s, an attempt was made to use the Geysers area as a power source, but the pipelines were not able to withstand the corrosive action of the steam and the impurities in it. Later, in the 1950s, stainless steel alloys were developed that could withstand the steam and its impurities, so the Pacific Gas and Electric Company started development of a power system to use the heat from within the earth as an energy source. The first generating unit at the *Geysers power plant* began operation in 1960. At present, more than 500 megawatts of electrical power are available from the generating units in the Geysers area.

In the *geothermal system,* steam enters a path (through a pipeline or a vent) to the surface of the earth. The pipelines that carry the steam are constructed with large expansion loops, causing small pieces of rock to be

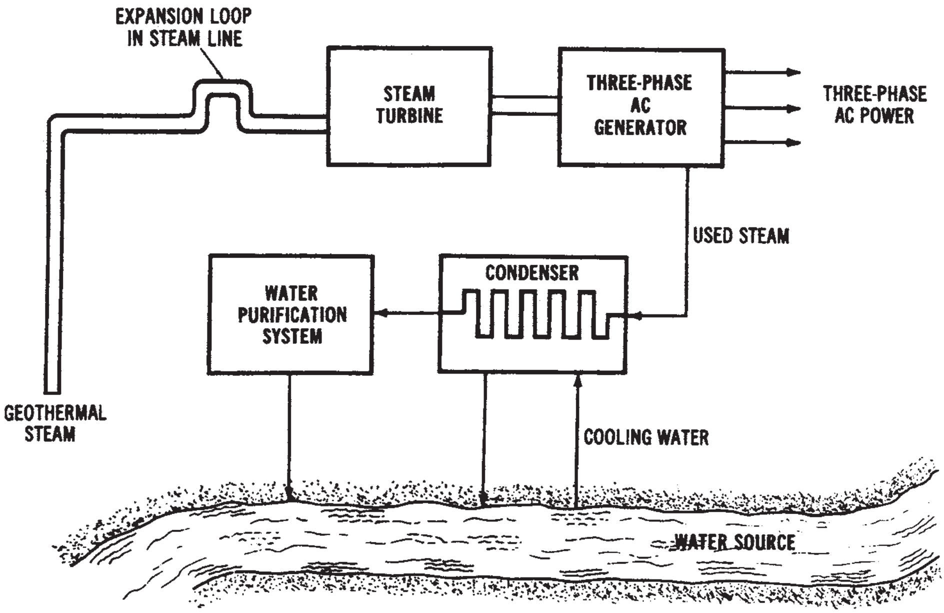


Figure 5-2. Drawing of a basic geothermal power system.

left in the loop. This system of loops avoids damage to the steam turbine blades. After the steam goes through the turbine, it goes to a condenser, where it is combined with cooler water. This water is pumped to cooling towers, where the water temperature is reduced. This part of the *geothermal* system is similar to conventional steam systems.

The *geothermal* power production method offers another alternative method of producing electrical power. This method makes it possible to control energy, in the form of steam or heated water, that is produced by natural geysers or underground channels. The high-pressure steam for power production is made without burning any of our fossil fuels. Thus, this method can be used to drive turbine-generator systems, such as the one at the Geysers system in California.

The setting up of a *geothermal power plant* requires the drilling of holes deep into the surface of the earth. One hole may be used to send cold water down into the tremendously hot material located under the surface of the earth. An adjacently drilled hole could be used to bring steam back to the surface. This method is capable of being used in any area of the world, but it requires drilling holes up to 10 miles deep. On the other hand, natu-

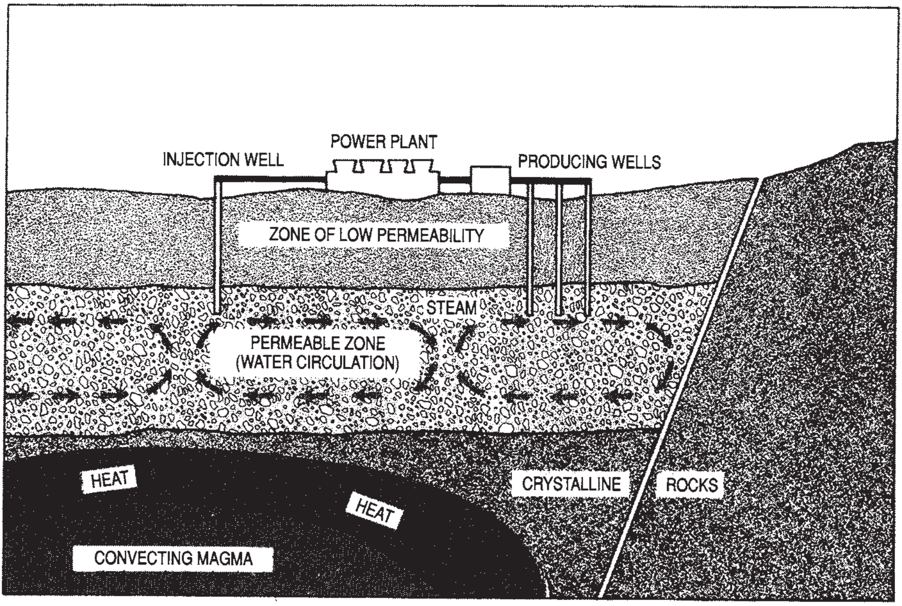


Figure 5-3. Drawing of a basic geothermal power system that illustrates the underground structure ***(Courtesy*** **Pacific** ***Gas and Electric*** **Co.)**

ral geothermal steam production is limited to active volcanic areas, such as the Geysers area of the United States. Since no fuel is burned, geothermal methods represent one way of saving our valuable and diminishing quantities of fossil fuels. The major problem associated with *geothermal* power production is the drilling of the deep holes into the ground.

WIND SYSTEMS

Nonpolluting, inexpensive power systems have been desired for many years. Now, technology has advanced to the point where there may be some inexpensive methods of producing electrical power that we have not used significantly before.

In the early 1900s, in many farm areas, particularly in the Midwest, electrical power had not been distributed to homes. It was conceived that the *wind* could be used to provide a mechanical energy, not only for water pumps, but also for generators with which to provide electrical power. The major problem was that the wind did not blow all the time and, then, when it did, it often blew so hard that it destroyed the windmill. Most of these units used fixed-pitch propellers as fans. They also used low-voltage DC electrical systems, and there was no way of storing power during periods of nonuse, or during times of low wind speeds. These early units used a rotating-armature system (see Chapter 6) and, therefore, along with other maintenance problems, had to have the brushes replaced very often.

The *wind-generating plants* used today have a system of storage batteries, rectifiers, and other components that provides a constant power output even when the wind is not blowing. They also have a 2-blade or 3-blade propeller system that can be "feathered" during periods of high winds so that the mill will not destroy itself. A simplified *wind-power system* is shown in Figure 5-4. Most of the systems that are in use today are individual units capable of producing 120-volt alternating current (AC) with constant power outputs in the low-kilowatt range. The generator output may be interconnected through a system of series-connected batteries with an automatic, solid-state voltage control that is designed to convert the DC voltage to 120-volt AC. The cost of these individual, electrical power-generating systems is fairly low, and these systems provide a complete, self-contained, nonpolluting, power source. Wind systems would be ideal for remote homes that have a low-power requirement. They should prove to be very dependable and have low maintenance costs. Larger power-generating plants could be possible when located in very windy places. These plants would probably be limited in their power output, due to the requirement for large storage batteries. Because of the varying wind speeds, it would be difficult to connect two or more units in parallel and keep them in a phase relationship. Compared with other inexpensive types of power production plants, such as solar or hydroelectric, *wind systems* are smaller in physical size per kilowatt output and have a lower initial cost. Also, a solar power plant can only produce power during the daylight hours, while a wind-generator will operate whenever there is a wind.

The primary disadvantage of a windmill is obvious. What do you do on days without wind? One answer is the use of *storage batteries.* Another disadvantage is the fact that windmills generally have a very low efficiency—about 50 percent. Although windmill power will probably never be a large contributor to the solving of any power crisis, some individuals have

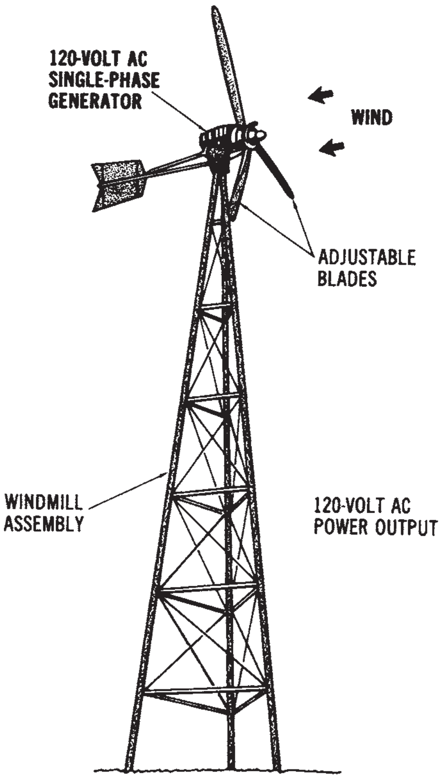


Figure 5-4. A simplified wind power system

calculated that several large-diameter windmills, with a fairly constant wind, could produce many kilowatts of electrical power. They could play an important role in reducing the use of our natural resources for electrical power production, particularly on an individual basis.

MAGNETO HYDRODYNAMIC (MHD) SYSTEMS

MHD stands for *magnetohydrodynamic,* a process of generating electricity by moving a conductor of small particles suspended in a superheated gas through a magnetic field. The process is illustrated in Figure 5-5. The metallic conductors are made of metals such as potassium or cesium, and can be recovered and used again. The gas is heated to a temperature much hotter than the temperature to which steam is heated in conventional power plants. This *superheated gas* is in what is called a plasma state at these high temperatures. This means that the electrons of many of the gas atoms have been stripped away, thus making the gas a good electrical conductor. The combination of metal and gas is forced through an electrode-lined channel which is under the influence of a superconducting magnet that has a tremendous field strength. The *magnet* must be of the superconducting type, since a regular electromagnet of that strength would require too much power. A superconducting magnet, therefore, is one of the key parts to this type of generation system.

With high operating temperatures and a high-speed gas flow, it becomes a difficult task to keep the conductive channel from becoming destroyed. *Cooling* is very important and is accomplished by circulating a suitable coolant throughout jackets built into the channel. Also, due to the high temperatures and the metal particles moving at high speed, erosion of the channel becomes a critical problem. This problem has been eased by using a coal slag injected into the hot gas and metal stream. The coal slag acts to replace the eroded material as it is lost.

Pollution problems are very few. The main one is the high levels of nitrogen oxides that are produced as a direct result of the high combustion temperatures inherent to the system. Sulfur oxides and ash are also a problem for any plants using coal or oil. An afterburner system has been proposed to eliminate the nitrogen oxides, while the sulfur oxides and the ash would be collected, separated chemically, and then recycled.

At this time, *MHD generators* are primarily experimental. There have been several large units made, but they have not operated for any signifi-

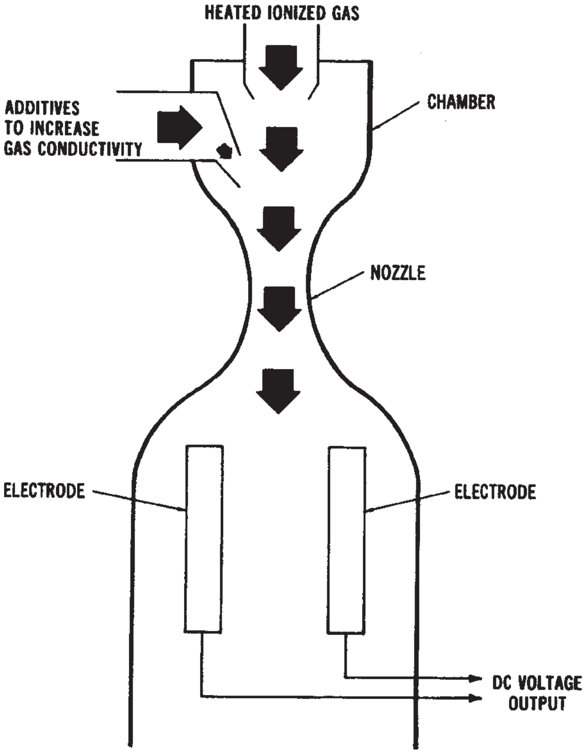


Figure 5-5. Simplified drawing of a magneto hydrodynamic (MHD) generator system

cant time periods. Efficiency is of importance for this type of generation system. While the conventional steam generation system (fired by coal) is at most 40 percent efficient (that is, it turns 40 percent of the coal energy into electricity), and most nuclear-powered plants are about 33 percent efficient, MHD plants could operate at 60 percent efficiency. Thus, fuel supplies could be enhanced by using this generation system. At present, the future of MHD systems for large-scale electrical power generation is questionable.

NUCLEAR-FUSION POWER SYSTEMS

Another *alternative power* production method which has been considered is *nuclear fusion. Deuterium,* the type of fuel used for this process, is very abundant. The supply of deuterium is considered to be unlimited, since it exists as heavy hydrogen in sea water. The use of such an abundant fuel could solve some of our problems that are related to the depletion of fossil fuels. Another outstanding advantage of this system is that its radioactive waste products would be minimal.

The *fusion process* results when two atomic nuclei collide under controlled conditions to cause a rearrangement of their inner structure and, thus, release a large amount of energy during the reaction. These nuclear reactions or fusings of atoms must take place under tremendously high temperatures. The energy released through nuclear fusion would be thousands of times greater per unit than the energy from typical chemical reactions, and considerably greater than that of a nuclear-fission reaction.

The *fusion reaction* involves the fusing together of two light elements to form a heavier element, with heat energy being released during the reaction. This reaction could occur when a deuterium ion and a tritium ion are fused together. A deuterium ion is a hydrogen atom with one additional neutron, and a tritium ion is a hydrogen atom with two additional neutrons. A temperature in the range of 100,000,000° C is needed for this reaction to produce a great enough velocity for the two ions to fuse together. Sufficient velocity is needed to overcome the forces associated with the ions. The deuterium-tritium fusion reaction produces a helium atom and a neutron. The neutron, with a high enough energy level, could cause another deuterium-tritium reaction of nearby ions, providing the time of the original reaction is long enough. A much higher amount of energy would be produced by a *nuclear-fusion reaction* than by a *fission reaction.* There are several different techniques being investigated for producing nuclear fusion. At this time, each is still in the theoretical development stage.

NUCLEAR-FUSION METHODS

Several methods are being considered today for using the heat from nuclear fusion to generate electrical power.

Magnetic-confinement Method

One method is called *magnetic confinement.* The proposed design of a magnetic-confinement power system is shown in Figure 5-6. At present, it is thought that fusion reactors could be economical if the reaction can be carried out in an intense magnetic field provided by superconducting magnets. The magnet and the magnetic-field designs are very complex, however, and the forces associated with them are tremendous. Controlling the fusion reaction is still one of the major problems of trying to use this method; therefore, it remains to be studied further.

Laser-induced Fusion

Laser-induced fusion should also be mentioned. This method relies on inertia rather than an intense magnetic field for the confinement of the nuclear fuel. In this method, a small pellet of frozen fuel is injected into a combustion chamber. There, it is hit by several short, intense, laser beams coming into the chamber from several directions. This process happens very quickly and causes the pellet to collapse, due to the intensity of the beams. The fuel is rapidly heated. The fusion reaction takes place at an instant just before the material in the pellet can overcome its inertia and expand, due to the intense heating effect. This process uses a laser beam to produce a sufficient amount of heat to cause the nuclear-fusion reaction. A proposed design for a laser-induced fusion power system is shown in Figure 5-7. As with other fusion methods, this method has not been tested. It is being theoretically developed. However, since the magnetic-confinement method has not been developed beyond the conceptual stage, other methods, such as

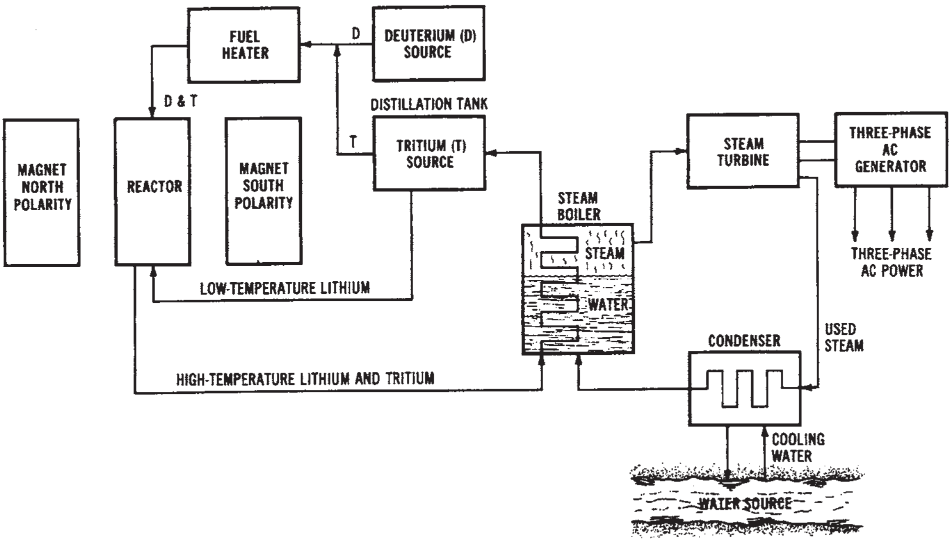


Figure 5-6. Proposed design of a magnetic-confinement nuclear fusion power system

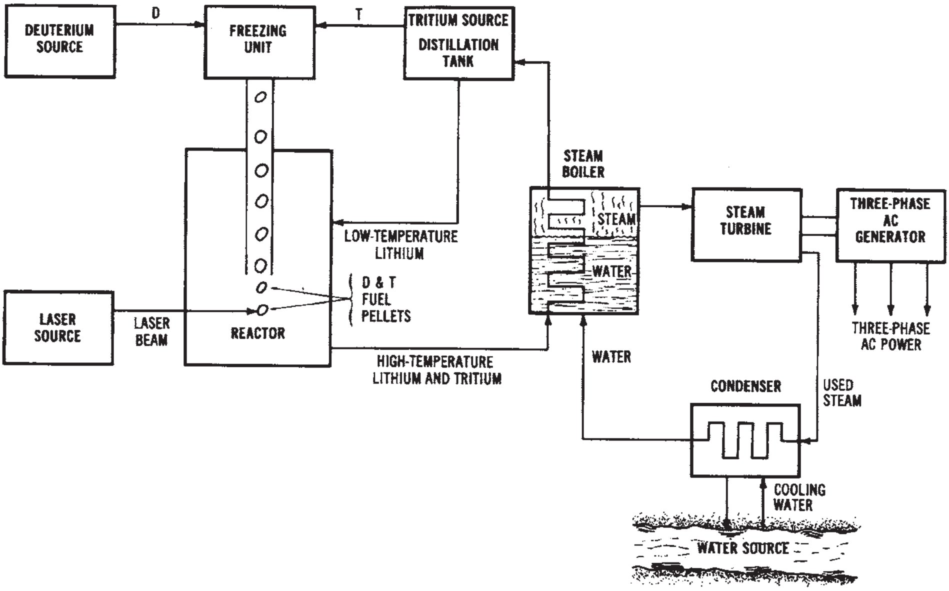


Figure 5-7. Proposed design of a laser-induced nuclear fusion power system

the laser-induced method, must be considered. It is thought that the pulsed-laser technique may be a viable alternative method for producing sustained nuclear-fusion reactions. This process is presently being developed with *deuterium* being considered as the proposed fuel.

FUTURE OF NUCLEAR FUSION

Since *nuclear fusion* is considered to be environmentally safe and would use a very abundant fuel, much research is being done to formulate ways of controlling the fusion-reaction process. Fusion reactors have not yet been developed beyond the theoretical stages. The problems involved in constructing a fusion reactor center around the vast amounts of heat produced. The fusion fuel must be heated to a high temperature and, then, the heated fuel must be confined for a long enough period of time that the energy released by the fusion process can become greater than the energy that was required to heat the fuel to its reaction temperature. This is necessary in order to sustain the fusion reaction and to produce continuous energy.

All present fusion power-plant designs have basic *problems.* Solutions to these problems, and development of economically attractive commercial systems, will take many years and much money. However, it seems possible that such systems may someday be developed.

FUEL-CELL SYSTEMS

Another alternative energy system which has been researched is the *fuel cell.* Fuel cells convert the chemical energy of fuels into electrical energy. An advantage of this method is that its efficiency is greater than steam turbine-driven production systems, since the conversion of energy is directly from chemical to electrical. Ordinarily, fuel cells use oxygen and hydrogen gas as fuels, as shown in Figure 5-8. Instead of consuming its electrodes, as ordinary batteries do, a *fuel cell* is supplied with chemical

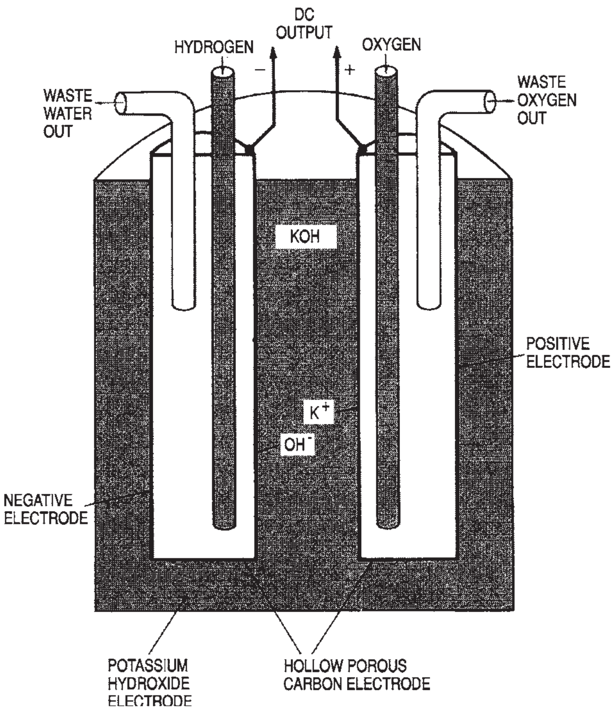


Figure 5-8. Simplified drawing of an oxygen-hydrogen fuel cell

reactants from an external source. Ordinarily, *hydrogen gas* is delivered to the anode of the cell and *oxygen gas* or air is delivered to the cathode. The reaction of these gases is similar to the reverse of electrolysis. (During the electrolysis process, an electric current decomposes water into hydrogen and oxygen.)

Fuel cells were developed long ago. It was known early that electrochemical reactions could be used to convert chemical energy directly to electrical energy. The first commercial fuel cells were used as auxiliary power sources for United States space vehicles. These were hydrogen-oxygen fuel cells. The development of fuel cells has brought about some cells with a power capacity of up to 500 watts. Some cells that are in the research stages have a power output of up to 100 kilowatts. These fuel cells produce low-voltage direct current. Several cells may be connected in series-parallel configurations to produce greater voltage and current levels. Several large companies are performing experiments with the design of *fuel cells.* Many new technological approaches to fuel cells are being developed. Large-scale systems are planned that may use phosphoric acid as an electrolyte. This system will operate with a variety of hydrocarbon fuels. Cells presently being developed use high-temperature carbon or alkaline electrolytes. Cells in the developmental stages might use synthetic fuels derived from coal.

Some problems have been encountered in the development of *fuel cells.* The chemical reaction brought about by the fuels requires a catalyst. The importance of the catalyst is greater at lower operating temperatures. At higher temperatures, cheaper and more abundant catalysts may be used. However, some designers speculate that the catalysts required for lower temperature operation may become unavailable or, if not, at least very expensive in the future. At present, the initial cost of a fuel-cell system is very great. A system, at this time, would not be competitive with other power systems in operation. Another developmental problem is that of water disposal. A vast amount of water is produced by the chemical reactions of the fuels.

In addition to space applications, other *applications* could potentially include mobile electrical power sources. It has been suggested that fuel cells could be used as power sources to drive electric cars. Also, fuel cells are being considered as power sources for trains, submarines, and military vehicles. However, the use of fuel cells for large-scale power systems would not be feasible.

TIDAL POWER SYSTEMS

The rise and fall of waters along coastal areas, which is caused by gravitational forces, is the basis for the tidal electrical power production method. There are presently some *tidal power systems* in operation. Tidal systems would be desirable, since they do not pollute the atmosphere, do not consume any natural resource, and do not drastically change the surrounding environment as some conventional *hydroelectric* systems do.

The depth of tidal water varies greatly at different times of the year. These depths are determined by changes in the sun and moon in relation to the earth. Tides are readily predictable, since the same patterns are established year after year. A *tidal power system* would have to be constructed where water in sufficient quantity could be stored with a minimum amount of dam construction. A tidal system could be made to operate during the rise of tides and the fall of tides. Also, the pumped-storage method could be used in conjunction with tidal systems to assure power output during peak load times. A potential tidal system site along the United States-Canada border has been studied; however, the economic feasibility of tidal systems at this time is not too promising. One tidal system that is in operation is at Normandy, France.

COAL-GASIFICATION FUEL SYSTEMS

The process of *coal gasification* has aroused interest in recent years. This process involves the conversion of coal or coke to a gaseous state through a reaction with air, oxygen, carbon dioxide, or steam. Many people feel that this process will be able to produce a natural gas substitute. Some of the methods of producing gas from coal include:

1. The *BI-CAS process,* in which a reaction of coal, steam, and hydrogen gas produces methane gas.
2. The *COCAS process,* in which a liquid fuel and a gaseous fuel are produced.
3. The CSG process (or *consolidated synthetic gas process),* which develops a very slow reaction to produce methane.
4. The *Hydrane process,* in which methane is produced by a direct reaction of hydrogen and coal, with no intermediate gas production.
5. The *Synthane process,* in which methane is produced by a method in-

volving several different steps.

Coal gasification may be one solution to the problem of our depleting natural gas supply. Since some electrical power systems use natural gas as the fuel, we should be concerned about coal gasification as an alternative method to aid in the production of electrical power.

OIL-SHALE FUEL-PRODUCTION SYSTEMS

Another method which should be mentioned as an alternative method that could aid in the production of electrical energy is fuel from *oil shale.* There is a potential fuel source located at the oil-shale deposits which exist primarily in Colorado, Wyoming, and Utah. This *oil shale* was formed by a process similar to that which created crude petroleum. However, there was never enough underground heat or pressure to convert the organic sediment to the same consistency as oil. Instead, a waxy hydrocarbon called *kerogen* was produced. This compound is mixed with fine rock and is referred to as oil shale.

Extracting crude petroleum from this substance is a very complex process that starts with either underground or strip mining. The mined rock is crushed and then heated to produce a raw oil, which, in turn, must be upgraded to a usable level. All of these operations could take place at the mining site. In addition, large amounts of *shale waste* must be removed. The resulting waste substance is about the consistency and color of fireplace soot. The waste occupies more volume than the original oil-shale formations. The potential impact of oil-shale development is questionable. Vast quantities of land might be disturbed. There are definitely many factors to consider in addition to our energy needs.

ALTERNATIVE NUCLEAR POWER PLANTS

A unique concept in electrical power production, considered in the 1970s, was called a *floating nuclear power plant*. Floating nuclear plants were proposed to be nuclear-fission plants mounted on huge floating platforms for operation on the water. These systems were planned for use on the Atlantic Ocean. Breakwaters would surround the power plant to protect it from waves and ship collisions. These units could be located on rivers, inlets, or in the ocean. The plants could be manufactured on land and then transported to the area where they would be used. The electrical power produced by the plant could be distributed by underwater cables to the shore. The power lines could then be connected to onshore overhead power-transmission lines. The *floating nuclear power plants* could be mass-produced, unlike conventional nuclear plants which are individually built.

Floating nuclear plants could have advantages over other power systems. There are obvious ecological benefits. A plant located on the ocean would have less thermal effect on the water due to heat dissipation over a large body of water. Also, these units would not require the use of land for locating power plants. They would be flexible, since they could be located on rivers, inlets, or oceans.

This discussion is included to *stimulate thought* about potential "alternative" systems for producing electrical power. Each of the systems discussed have potential problems; however, serious experimentation must be conducted to assure that electrical power can be produced economically. Our technology is dependent upon low-cost electrical power.

BIOMASS SYSTEMS

Another alternative system being considered as a potential method of producing electrical power is *biomass.* Biomass sources of energy for possible use as fuel sources for electrical power plants are wood, animal wastes, garbage, food processing wastes, grass, and kelp from the ocean. Many countries in the world use biomass sources as primary energy sources. In fact, the United States used some of the biomass sources of energy almost exclusively for many years. The potential amount of energy which could be produced in the United States by *biomass sources* is substantial at this time also. There are still several questions about using biomass sources of energy for producing electrical; however, as fossil fuels become less abundant, biomass sources may receive more active consideration.

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