ELECTRIC POWER INDUSTRY

IN NONTECHNICAL LANGUAGE
2ND EDITION

1 Power Generation

The electric power industry is comprised of many functions. From the generation of electricity flows the transmission and hence the distribution of power to homes, businesses, and other end users. It is, therefore, important to begin at the beginning—generation—particularly because this process happens to be one of the most capital-intensive functions of electric power producers.

To understand the generation of power, it is important to look at the process, the measurement, and the resources required. In general terms, ***generation*** has a two-fold meaning. First, it may be defined as the process of producing electric energy by transforming other forms of energy. Second, generation can also refer to the amount of electric energy produced for end-user consumption. Expressed in ***kilowatt-hours*** (kWh), or the electric energy produced in 1 hour (hr) by 1 ***kilowatt*** (kW) of electric capacity, generation is the amount individual consumers see on their electric bills.

Electricity may be defined as a class of physical phenomena that results from the existence of charge and from the interaction of charges. When a charge is stationary, it produces forces on objects in regions where it is present, and when it is in motion, the charge produces magnetic effects. ***Electric and magnetic fields*** (EMFs) are caused by the relative position and movement of positively and negatively charged particles of matter. Particles associated with electrical effects are classed as neutral, positive, or negative. However, electricity is concerned with the positively charged particles, such as ***protons***, that repel one another. Also of concern are the negatively charged particles, such as ***electrons***, which also repel one another. Later in this chapter, the generation process and its magnetic properties, among other aspects of generation, are discussed in detail. However, in summary of this brief discussion, it will suffice to simply state that like charges repel and unlike charges attract.

Electricity is measured in units called ***watts***. A watt equals the rate of energy transfer of 1 ampere (A) flowing at a pressure of 1 volt (V) at unity power factor. Electricity is also measured in ***watt-hours***, which are equal to 1 watt (W) of power supplied to or taken from an electric current steadily for 1 hr. A kilowatt-hour is equal to 1,000 watt-hours (Wh) used. Homes, businesses, and other end users have their electric power consumption measured by electric, or watt-hour, meters.

In generating electric power, utilities produce power by the megawatt, or 1 million watts. Ratings are used within the industry to denote the amount of electricity each power generating facility is capable of producing. The generation of electricity on a continual basis, at peak performance, is known as the ***nameplate capacity*** of the generating facility. The continuous, hourly output each generating facility supplies to the electric power grid is termed ***net capability***.

Generation Resources

The resources required to generate electricity are immense—particularly in the area of cost to electric utilities. Just as investor-owned utilities (IOUs) spend a lot of money in their operations and maintenance functions, they also happen to capture the lion's share of revenues. In 2003, major IOUs had earned well over $226 million.

As an aside, it is vital to note here, and in later references to financial data, that more recent information was unavailable at the time this book went to press. Data of this nature often lags behind, perhaps in part due to current regulatory schemes governing utility reporting of such data.

As shown in table 1–1, in 2003 electric IOUs spent more than $197 million. In 2000, IOUs spent a whopping $210 million on operations and maintenance and earned more than $235 million.

To understand the variance in expenditures and earnings, one can look at what IOUs spent on purchased power and administrative and general sales for these two years. These are telling dollar figures, in that well over one-half of electric IOU operating revenues is disbursed for expenses, such as the cost of producing electricity and maintaining electric generation plants.

Table 1–2 offers a further look at expenditures. It reveals where major U.S. publicly owned generator and nongenerator electric utilities spent their operations and maintenance dollars.

Table 1–1. Operation and maintenance expenses for major U.S. investor-owned electric utilities

	Million of Nominal Dollars (unless otherwise indicated)		
	1990	1995	2000
Utility Operating Expenses	142,471	165,321	210,324
Electric Utility	127,901	150,599	191,329
Operation	81,086	91,881	132,662
Production	62,501	68,983	107,352
Cost of Fuel	32,635	29,122	32,555
Purchased Power	20,341	29,981	61,969
Other	9,526	9,880	12,828
Transmission	1,130	1,425	2,699
Distribution	2,444	2,561	3,115
Customer Accounts	3,247	3,613	4,246
Customer Service	1,181	1,922	1,839
Sales	212	348	403
Administrative and General	10,371	13,028	13,009
Maintenance	11,779	11,767	12,185
Depreciation	14,889	19,885	22,761
Taxes and Other	20,146	27,065	23,721
Other Utility	14,571	14,722	18,995
Operation (Mills per Kilowatthour)[1]			
Nuclear	10.04	9.43	8.41
Fossil Steam	2.21	2.38	2.31
Hydroelectric & Pumped Storage	3.35	3.69	4.74
Gas Turbine and Small Scale[2]	8.76	3.57	4.57
Maintenance (Mills per Kilowatt hour)[1]			
Nuclear	5.68	5.21	4.93
Fossil Steam	2.97	2.65	2.45
Hydroelectric & Pumped Storage	2.58	2.19	2.99
Gas Turbine and Small Scale[2]	12.23	4.28	3.50

Source: EIA, Electric Power Annual 2003, DOE/EIA-0348(2003) (Washington, D.C., December 2004), Tables 8.1 and 8.2, and EIA, Electric Power Annual 2001, Tables 8.1 and 8.2.

Notes: 1 Operation and maintenance expenses are averages, weighed by net generation
2 Includes gas turbine, internal combustion, photovoltaic, and wind plants

Table 1–2. Operation and maintenance expenses for major U.S. publicly owned generator and nongenerator electric utilities

	Million of Nominal Dollars (unless otherwise indicated)				
	1990	1995	2000	2002	2003
Production Expenses					
Steam Power Generation	3,742	3,895	5,420	6,558	NA
Nuclear Power Generation	1,133	1,277	1,347	1,646	NA
Hydraulic Power Generation	205	261	332	746	NA
Other Power Generation	196	231	603	746	NA
Purchased Power	10,542	11,988	16,481	24,446	NA
Other Production Expenses	155	212	225	1,647	NA
Total Production Expenses[1]	15,973	17,863	24,398	36,188	NA
Operation and Maintenance Expenses					
Transmission Expenses	604	788	982	1,501	977
Distribution Expenses	950	1,274	1,646	1,853	1,044
Customer Accounts Expenses	375	448	662	710	754
Customer Service and Information Expenses	75	120	233	414	311
Sales Expenses	29	29	82	90	95
Administrative and General Expenses	1,619	2,128	2,116	4,058	2,742
Total Electric Operation and Maintenance Expenses	3,653	4,787	5,721	8,625	5,923
Total Production and Operation and Maintenance Expenses	19,626	22,651	30,100	44,813	NA
Fuel Expenses in Operation					
Steam Power Generation	2,395	2,163	4,150	4,818	NA
Nuclear Power Generation	242	222	316	433	NA
Other Power Generation	113	101	373	754	NA
Total Electric Department Employees[2]	N/A	73,172	71,353	93,520	NA

Source: EIA, Financial Statistics of Major US Publicly Owned Electric Utilities 1994, DOE/EIA-0437(94)/2 (Washington, D.C., December 1995), Table 8 and Table 17; EIA, Financial Statistics of Major US Publicly Owned Electric Utilities 1999, DOE/EIA-0437(99)/2 (Washington, D.C., November 2000), Table 10 & Table 21; EIA, Financial Statistics of Major US Publicly Owned Electric Utilities 2000, DOE/EIA-0437(00)/2 (Washington, D.C., November 2001), Table 10 & Table 21; EIA, Public Electric Utility Database (Form EIA-412) 2002; EIA, Electric Power Annual 2003, DOE/EIA-0348(2003) (Washington, D.C., December 2004), Tables 8.3 and 8.4

Notes: 1 Totals may not equal sum of components because of independent rounding.
2 Number of employees were not submitted by some publicly owned electric utilities because the number of electric utility employees could not be separated from the other municipal employees or the electric utility outsourced much of the work.

The number of U.S. electric utilities does fluctuate some with the popular advent of mergers and acquisitions (M&A) within the industry. However, sheer numbers do not necessarily make one type of regulated electric utility more profitable. (More on M&A activity is given in chapter 9.) Table 1–2 clearly shows the relative predominance of IOUs in power generation.

U.S. Department of Energy (DOE) data shows in 2003 total electric utility operating revenues were nearly $314 billion. This represents a 3.2% or $9.8 billion increase as compared to 2002 data. The nation's approximately 240 electric IOUs garnered more than 72% of these revenues.

Table 1–3 shows production, operation, and maintenance expenses for major IOUs and publicly owned electric utilities.

Table 1–4 shows selected electric utility data by ownership, and one may note that there are other utility types represented. Each utility type is discussed in detail in Part IV of this book. For now it will suffice to look at the relative statistical share of sales and revenue that publicly owned, cooperatively owned, and federally owned electric utilities offer to the industry.

Public or municipal electric utilities by and large are distributors of power. However, some of the larger ones produce (generate) and transmit electricity as well. The roughly 2,009 public utilities represent approximately 63% of the number of electric utilities, and supply around 10% of generation and generation capability. This class of utility accounts for 15% of retail sales and around 14% of revenue. Cooperative electric utilities represent approximately 29% of U.S. electric utilities, 9% of sales and revenue, and 4% of generation and generation capability.

Table 1–3. Production, operation, and maintenance expenses for major U.S. investor-owned and publicly-owned utilities (million of nominal dollars)

	Investor-Owned Utilities					Publicly-Owned Utilities[1]				
	1990	1995	2000	2002	2003	1990	1995	2000	2002	2003
Production Expenses										
Cost of Fuel	32,635	29,122	32,555	24,132	26,476	5,276	5,664	7,702	9,696	NA
Purchased Power	20,341	29,981	61,969	58,828	62,173	10,542	11,988	16,481	24,446	NA
Other Production Expenses	9,526	9,880	12,828	7,688	7,532	155	212	225	1,647	NA
Total Production Expenses[2]	62,502	68,983	107,352	90,649	96,181	15,973	17,863	24,398	36,188	NA
Operation and Maintenance Expenses										
Transmission Expenses	1,130	1,425	2,699	3,494	3,585	604	788	982	1,501	977
Distribution Expenses	2,444	2,561	3,115	3,113	3,185	950	1,274	1,646	1,853	1,044
Customer Accounts Expenses	3,247	3,613	4,246	4,165	4,180	375	448	662	710	754
Customer Service and Information Expenses	1,181	1,922	1,839	1,821	1,893	75	120	233	414	311
Sales Expenses	212	348	403	261	234	29	29	82	90	95
Administrative and General Expenses	10,371	13,028	13,009	12,872	13,466	1,619	2,128	2,116	4,058	2,742
Total Electric Operation and Maintenance Expenses	18,585	22,897	25,311	25,726	26,543	3,653	4,787	5,721	8,625	5,923

Source: EIA, Electric Power Annual 2003, DOE/EIA-0348(2003) (Washington, D.C., December 2004), Tables 8.1, 8.3 and 8.4 and EIA, Electric Power Annual 2001, DOE/EIA-0348(2001) (Washington, D.C., December 2002), Table 8.1; EIA, Financial Statistics of Major US Publicly Owned Electric Utilities 1994, DOE/EIA-0437(94)/2 (Washington, D.C., December 1995), Table 8 and Table 17; EIA, Financial Statistics of Major US Publicly Owned Electric Utilities 1999, DOE/EIA-0437(99)/2 (Washington, D.C., November 2000), Table 10 & Table 21; EIA, Financial Statistics of Major US Publicly Owned Electric Utilities 2000, DOE/EIA-0437(00)/2 (Washington, D.C., November 2001), Table 10 & Table 21.; EIA, Public Electric Utility Database (Form EIA-412) 2002.

Notes: 1 Publicly Owned Utilities include generator and nongenerator electric utilities.
2 Totals may not equal sum of components because of independent rounding.

Table 1–4. Selected electric utility data by ownership, 2000

Item	Type of Regulated Electric Utility				
	Investor-owned	Publicly-Owned	Cooperative	Federal	Total[1]
Number of Electric Utilities	240	2,009	894	9	3,152
Electric Utilities (percent)	7.6	63.7	28.4	.3	100.0
Revenues from Sales to Ultimate Consumers (thousand dollars)	169,444,470	33,054,956	20,506,101	1,242,031	224,247,558
Revenues from Sales to Ultimate Consumers (percent)	75.6	14.7	9.1	.6	100.0
Sales of Electricty to Ultimate Consumers (thousand megawatt hours)	2,437,982	516,681	305,856	49,094	3,309,613
Sales of Electricity to Ultimate Consumers (percent)	73.7	15.6	9.2	1.5	100.0
Average Revenue per kWh for Ultimate Consumers (cents)	6.9	6.4	6.7	2.5	6.8
Revenues from Sales for Resale (thousand dollars)	35,359,346	13,430,253	12,027,771	8,900,091	69,717,461
Revenues from Sales for Resale (percent)	50.7	19.3	17.3	12.8	100.0
Sales of Electricity Available for Resale (thousand megawatt hours)	854,228	301,412	311,935	248,664	1,716,239
Sales of Electricty Available for Resale (percent)	49.8	17.6	18.2	14.5	100.0
Average Revenue per kWh for Sales for Resale (cents)	4.1	4.5	3.9	3.6	4.1

1 Includes only those electric utilities in the United States and the District of Columbia.
Note: Totals may not equal sum of components because of independent rounding
Source: Energy Infomration Administration, Form EIA-861, "Annual Electric Utility Report." Data are based on calendar year submissions.

Generation Efficiency and Capacity

Electric power generators are in a precarious position, due to the somewhat immediate nature of electricity. Because technically electric power cannot be stored, generators must be continually producing power as it is consumed. Consumers of electric power, on the other hand, are obliging in that they produce a relatively constant demand for a basic quantity of electricity at any given time. Referred to as ***base load***, all electric utilities have a minimum amount of steadily required electric power that the utility will either purchase or generate itself to meet this demand.

Where do electric utilities obtain their power? If a utility is not in the generation side of the business, most generally electricity is being purchased from a source outside of the utility. Utilities desire to obtain the most efficient and most economical sources of electric power that can be supplied to them. Locale and region play large roles in where and from what sources electric utilities will obtain their electricity. Oftentimes, utilities are purchasing power from more than one source. More on this subject is discussed later in this chapter.

While base load is constant and fairly predictable, electric utilities must be prepared at all times for the sometimes unpredictable demand seasonal weather changes cause. An increase in demand is referred to as ***peak load*** and ***intermediate load.*** Typically, peak and intermediate loads are temporary in nature, and utilities generally are flexible enough with an alternate source of power to supply any increases in electric power demand. The vast majority of electric utilities will also have ***standby generating capacity***, also known as ***capacity margins***, which will be used when demand exceeds supply for a short period of time.

To illustrate how important an electric utility's capacity margins are, one could consider an unusually hot summer or particularly bitter, cold winter. Generation efficiency will drop under these extreme seasonal circumstances. To combat this, utilities will need to have additional sources of electric generation—whether they produce it themselves or purchase it—to meet the temporary increase in electric demand. ***Brown outs*** can occur should demand for electricity exceed supply, and supply is unable to be generated quickly enough to keep up with the demand.

Should an electric utility have excess capacity, it has the option of selling the "extra" supply of electricity to other utilities in the region through the power grid, otherwise known as ***interconnected networks*** and the ***U.S. bulk power system.***

A complete discussion of the interconnected networks appears in chapter 5. By way of brief introduction, the three interconnected networks are comprised of the Eastern, the Western, and the Texas interconnected systems.

Each electric utility is controlled from a central dispatch center, where adjustments to the production and flow of power are made to match electric utilities' customer needs. When demand exceeds supply, the dispatch center purchases power from the U.S. bulk power system.

The Generation Process

All fuel, regardless of type, possesses potential chemical energy. In turn, this chemical energy is converted into electrical energy. In figure 1–1, the power plant is assumed to be a standard steam power plant. It converts primary fuel into electricity, the boiler turns the water into steam, and the steam turns the fan (turbine) and the generator.

The turbine then rotates the magnet inside the generator. The magnet is surrounded by magnetic lines of force, stretching from one end of the magnet to the other. As the magnet turns, the lines of force are cut by a stationary coil inside the generator, inducing an electric current in the coil.

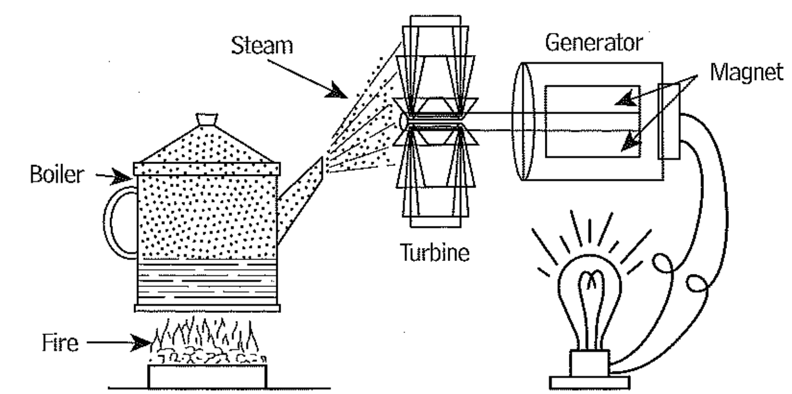

Fig. 1–1. The process of electricity generation

As illustrated in figure 1–1, an electric current is set up in the wire when the magnetic field from the ends of the magnet moves across the turns of wire in the stationary coil. In a standard steam turbine, fuel burns to heat the water until steam is produced. The steam turns a turbine blade, and as the blade of the turbine moves, the magnet inside the generator also turns. If one recalls that the magnet turns within coils of wire, it follows that when the magnet turns, the lines of force it creates cut through the wire and thus induce electric current into the wire. Simply put, this process converts mechanical energy into electrical energy, which is then distributed to the overall electricity grid.

Energy conversion

In order to produce electricity, the generator must have fuel. Generation units, using a variety of technologies, convert energy from falling water, coal, natural gas, oil, and nuclear fuels into electric energy. The majority of electric generators are driven by hydraulic turbines for conversion of fuel energy. And, as discussed earlier, electric power generating plants are interconnected by a transmission and distribution system to serve the electric loads of an area or region. Power transmission and distribution is discussed in chapter 2.

Peak loads, as discussed earlier in this chapter, are generally spikes in usage only lasting a few hours. Peaks are most usually served by gas or oil combustion-turbine or pumped-storage hydropower generating units. The pumped-storage type utilizes the most economical off-peak surplus generating capacity to pump and store water in elevated reservoirs to be released through hydraulic turbine generators during peak load periods. This type of operation improves the capacity factors or relative energy outputs of base-load generating units, hence their economy of operation.

As for the size and capacity of any given electric utility's generating unit or units, there is no ***one-size-fits-all***. Both size and capacity of generating units vary widely. They will depend upon the type of unit, duty required (base-, intermediate-, or peak-load service), system size, and the degree of interconnection with neighboring electric systems.

Of extreme importance to electric utilities is the study of annual load graphs and forecasts, which will indicate the rate at which new generation stations must be built to meet demand and expected demand. A look at table 1–5 shows the existing capacity by energy source for data year 2003. Table 1–6 illustrates the planned nameplate capacity additions until the year 2008.

According to the Energy Information Administration's (EIA) long-term forecast, 428 gigawatts (gW) of new generating capacity will be needed by 2025 to meet the growing demand for electricity. This is equivalent to 1,427 new power plants. Adding to this, EIA predicts that most of this new capacity will be fueled by natural gas.

Table 1–5. Existing capacity by energy source (Megawatts)

Energy Source	Number of Generators	Generator Nameplate Capacity (MW)	Net Summer Capacity (MW)	Net Winter Capacity (MW)
Coal[1]	1,535	335,793	313,019	315,237
Petroleum[2]	3,121	40,965	36,429	40,023
Natural Gas	3,069	238,967	208,447	224,366
Dual Fired	3,056	190,739	171,295	183,033
Other Gases[3]	105	2,284	1,994	1,984
Nuclear	104	105,415	99,209	100,893
Hydroelectric[4]	4,145	96,352	99,216	98,399
Other Renewables[5]	1,582	20,474	18,199	18,524
Other[6]	39	704	638	640
Total	16,756	1,031,692	948,446	983,099

1 Anthracite, bituminous coal, subbituminous coal, lignite, waste coal, and synthetic coal.

2 Distillate fuel oil (all diesel and No. 1, No. 2, and No. 4 fuel oils), residual fuel oil (No. 5 and No. 6 fuel oils and bunker C fuel oil), jet fuel, kerosene, petroleum coke (converted to liquid petroleum, see Technical Notes for conversion methodology), and waste oil.

3 Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

4 Conventional hydroelectric and hydroelectric pumped storage. The net summer and winter capacity exceeds the generator nameplate due to upgrades to hydroelectric generators.

5 Wood, black liquor, other wood waste, municipal solid waste, landfill gas, sludge waste, tires, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.

6 Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.

Notes: Where there is more than one energy source associated with a generator, the predominant energy source is reported here. • Totals may not equal sum of components because of independent rounding.

Source: Energy Information Administration, Form EIA-860, "Annual Electric Generator Report."

Table 1–6. Planned nameplate capacity additions from new generators, by energy source, 2004 through 2008 (Megawatts)

Energy Source	2004	2005	2006	2007	2008
Coal[1]	155	991	2,376	4,814	1,390
Petroleum[2]	238	361	344	168	180
Natural Gas	22,490	28,404	23,850	20,985	6,797
Other Gases[3]	–	–	–	580	580
Nuclear	–	–	–	–	–
Hydroelectric[4]	8	11	11	42	4
Other Renewables[5]	257	240	57	36	133
Other[6]	–	–	–	–	–
Total	23,149	30,007	26,638	26,624	9,083

1 Anthracite, bituminous coal, subbituminous coal, lignite, waste coal, and synthetic coal.

2 Distillate fuel oil (all diesel and No. 1, No. 2, and No. 4 fuel oils), residual fuel oil (No. 5 and No. 6 fuel oils and bunker C fuel oil), jet fuel, kerosene, petroleum coke (converted to liquid petroleum, see Technical Notes for conversion methodology), and waste oil.

3 Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

4 Conventional hydroelectric and hydroelectric pumped storage.

5 Wood, black liquor, other wood waste, municipal solid waste, landfill gas, sludge waste, tires, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.

6 Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.

Notes: Where there is more than one energy source associated with a generator, the predominant energy source is reported here. These data reflect plans as of January 1, 2004. Delays and cancellations may have occurred subsequently to the data reporting. • Totals may not equal sum of components because of independent rounding.

Source: Energy Information Administration, Form EIA-860, "Annual Electric Generator Report."

Generation plant circuitry

As shown in figure 1–2, there are a number of main and accessory power circuits in power plants. Main power circuits carry power from generators to the step-up transformers and then to the station high-voltage terminals, whereas auxiliary power circuits provide power to the motors used to drive the necessary auxiliaries.

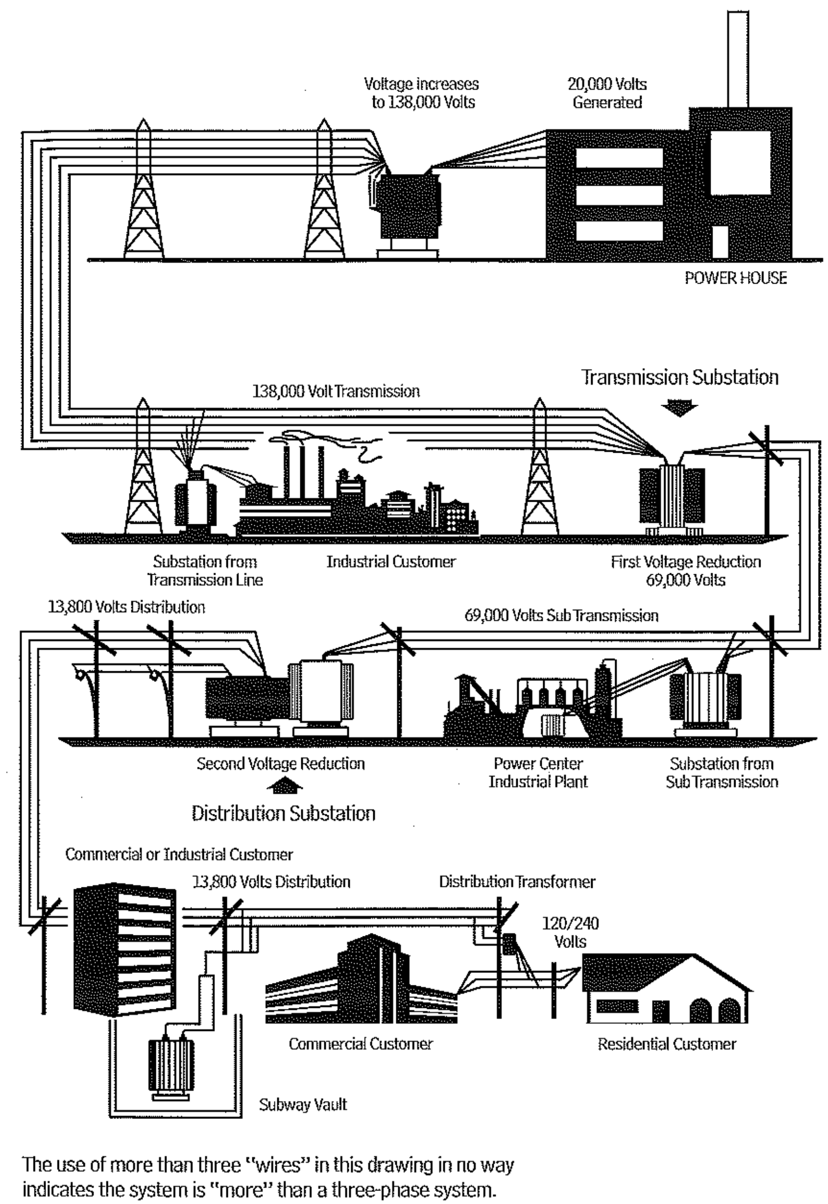

Fig. 1–2. Diagram of the power generation, transmission, and distribution system

There are other circuits needed:

- Control circuits for the circuit breakers and other equipment operated from the plant's control room
- Lighting circuits for the illumination of the plant and to provide power for portable equipment required for power plant maintenance
- Excitation circuits, which must be installed in locations where they will receive good physical and electrical protection, since reliable excitation is required for the operation of the plant
- Instrument and relay circuits for providing values of voltage, current, kilowatts, reactive kilovolt-amperes, temperatures, pressures, flow rates, etc., and to serve the protective system
- Communication circuits, for both plant and system communications (telephone, radio, transmission-line carrier, and microwave radio may be involved)

As can be imagined, the generation plant's power service reliability is at a premium. Because of this fact, the generating station is usually supplied power from two or more sources. To ensure adequate reliability, auxiliary power supplies are often provided for start-up, shutdown, and communications services.

In cases of equipment failure, generation stations must be prepared. Using differential- current and ground relays, over-current relays, and loss-of-excitation relays, generators are immediately (and often automatically) de-energized for electrical failure and shut down for any over-limit condition. Most larger generation plants are monitored constantly by computer- assisted load and frequency control and economic dispatch systems of generation supervision.

Electricity Production Methods

Steam turbines

Steam turbines are the most common method used to produce electricity. A steam turbine plant operation basically consists of four steps. First, water is pumped at high pressure to a boiler. Second, it is heated, most usually by

fossil-fuel combustion, to produce steam at high temperature and pressure. Third, this steam flows through a turbine, rotating an electric generator (connected to the turbine shaft), which converts the mechanical energy into electricity.

In the final of the four basic steps, the turbine exhaust steam is condensed by using cooling water from an external source to remove the heat rejected in the condensing process. The condensed water is then pumped back to the boiler to repeat the cycle.

Steam turbine plants can be divided into three categories:

1. Fossil fueled
2. Nuclear
3. Renewable

Fossil-fueled plants are by far the most common. Fossil fuels are of plant or animal origin and consist of hydrogen and carbon (hydrocarbon) compounds. Roughly 70% of the electricity produced in the United States comes from fossil-fueled steam turbine plants. Coal, petroleum, and natural gas are the dominant fossil fuels used in electricity production.

Other fossil fuels utilized include petroleum coke, coke oven gas, and liquefied petroleum. Still yet, there are other types of fossil fuels used for the production of electricity, although they are not commonly used. These other types include peat, oil shale, biomass (wood, etc.), and various waste or by-products, such as steel mill blast furnace gas and refuse-derived fuels.

Of all the fossil fuels, coal is the most widely used. Coal is an inexpensive fuel, as compared to other forms of fuel, and is readily available, since the United States has large deposits. According to the EIA, during 2004, 50% of the nation's electric power was generated at coal-fired plants.

Based upon 2004 net generation shares by energy source, nuclear and natural gas are next in popularity after coal. EIA data shows that there was a 1.8% increase in total net electric power generation for the period between January 1, 2003 and January 1, 2004. This growth in generation was led by natural gas-fired and nuclear generating stations. Natural gas generation increased by 7.6%, which according to EIA reflects the large amount of new gas-fired units electric utilities have installed in recent years. To the surprise of some, nuclear energy is making a comeback. Details of this revelation are included later in this chapter.

Nuclear generation

Nuclear generation increased in 2004 over 2003 usage, as an EIA analysis shows. This increase was primarily due to continued operation of nuclear power plants at high capacity factors and increases in capacity through plant upgrades. Nuclear power accounted for 19.9% of total net generation by the end of 2004.

The resurgence of nuclear power as a generating fuel is significant. As stated above, more details will be provided later in this chapter; however, it is important to have a base knowledge about how nuclear power works.

As presented earlier, figure 1–1 shows the basic process of electricity generation in a typical steam power plant. For purposes of nuclear power generation, however, one should refer to figure 1–3 and figure 1–4. In most electric power plants, water is heated and converted into steam, which drives a turbine-generator to produce electricity. To recap, fossil-fueled power plants produce heat by burning coal, oil, or natural gas.

In a nuclear power plant, the fission of uranium atoms in the reactor provides the heat to produce steam for generating electricity. There are two different reactor processes currently in use: the ***pressurized water reactor*** (fig. 1–3) and the ***boiling water reactor*** (fig. 1–4).

Several commercial reactor designs are in use in the United States. The most common is a design that consists of a heavy steel pressure vessel surrounding a ***reactor core***. The reactor core contains the uranium fuel. This fuel is formed into cylindrical ceramic pellets about one-half inch in diameter, which are sealed in long metal tubes called ***fuel tubes***. The pins are arranged in groups to make a fuel assembly. A group of fuel assemblies forms the core of the reactor.

Heat is produced in a nuclear reactor when neutrons strike uranium atoms, causing them to fission in a continuous chain reaction. Control elements, which are made of materials that absorb neutrons, are placed among the fuel assemblies. When the control elements, or control rods as they are often called, are pulled out of the core, more neutrons are available, and the chain reaction speeds up, producing more heat. Whey they are inserted into the core, more neutrons are absorbed, and the chain reaction slows or stops, reducing the heat.

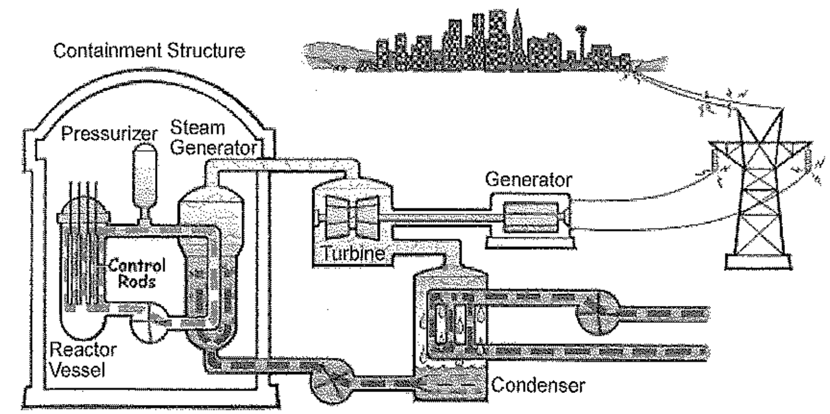

Fig. 1–3. Pressurized water reactor

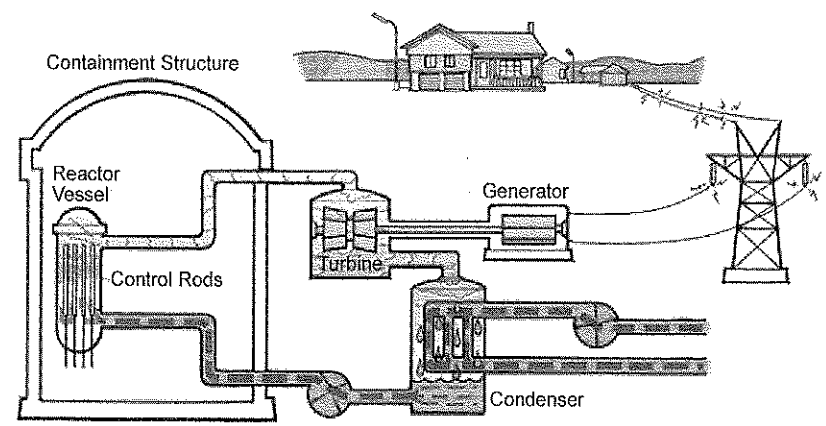

Fig. 1–4. Boiling water reactor

Most commercial reactors use ordinary water to remove the heat created by the fission process. These are called ***light water reactors***. The water also serves to slow down, or moderate, the neutrons. In this type of reactor, the chain reaction will not occur without the water to serve as a moderator. Figures 1–3 and 1–4 show the two different types of light water reactor designs currently in use.

In a pressurized water reactor (PWR), the heat is removed from the reactor by water flowing in a closed pressurized loop. The heat is transferred to a second water loop through a heat exchanger. The second loop is kept at a lower pressure, allowing the water to boil and create steam. This steam is used to turn the turbine-generator and produce electricity. Afterward, the steam is condensed into water and returned to the heat exchanger.

In a boiling water reactor (BWR), water boils inside the reactor itself, and the steam goes directly to the turbine-generator to produce electricity. As in a PWR, the steam is condensed and reused.

Gas turbine and combined-cycle generating plants

Power plants with gas turbine–driven electric generators are often used to meet short-term peaks in electrical demand. Gas turbine power plants use atmospheric air as the working medium, operating on an open cycle where air is taken from and discharged to the atmosphere and is not recycled.

As shown in figure 1–5, in a simple gas turbine plant, compressed gas is ignited, and the hot gases rotate a gas turbine, generating electricity. Put another way, air is compressed and fuel is injected into the compressed air and burned in a combustion chamber. Variations of this basic operation to increase cycle efficiency include regeneration, where exhaust from the turbine is used to preheat the compressed air before it enters the combustion chamber.

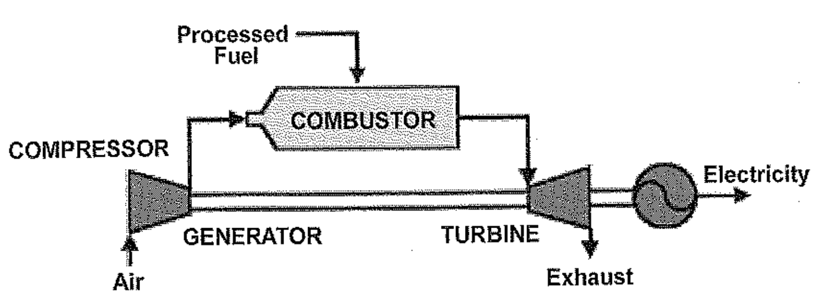

Fig. 1–5. Simple cycle gas turbine

The principle behind how gas turbines work is similar to a jet engine. Gas turbine generation is often used for peak, emergency, and reserve power production because of their quick start-up time. The downside is that gas turbines tend to be less efficient than their steam turbine counterparts. Generally, gas turbines are 100 MW or less. However, some are more, and they may be installed in a wide range of locations.

Gas turbines generally require smaller capital investments than coal or nuclear and can be designed to generate small or large amounts of power. The main advantage of gas turbines is the ability to be turned on and off within minutes, supplying power during peak demand. Large turbines may produce hundreds of megawatts.

Gas turbines may be described thermodynamically by the Brayton cycle (see fig. 1–6). Air is compressed isentropically, combustion occurs at constant pressure, and expansion over the turbine occurs isentropically back to the starting pressure.

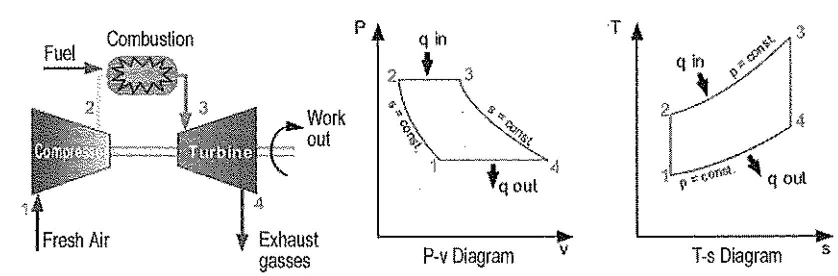

Fig. 1–6. Brayton cycle

As with all cyclic heat engines, higher combustion temperature means greater efficiency. The limiting factor is the ability of the steel, ceramic, or other materials that make up the engine to withstand heat and pressure. Considerable engineering goes into keeping the turbine parts cool.

Most turbines also try to recover exhaust heat to the compressed air, prior to combustion. Combined-cycle designs pass waste heat to steam turbine systems. Combined heat and power or cogeneration uses waste heat for hot water production. Both combined cycle and cogeneration are discussed later in this chapter.

Mechanically, gas turbines can be less complex than internal combustion piston engines. Simple turbines might have one moving part—the shaft/compressor/turbine/alternator-rotor assembly, not counting the fuel system. More sophisticated turbines may have multiple shafts (spools), hundreds of turbine blades, movable stator blades, and a vast system of complex plumbing, combustors, and heat exchangers.

The largest gas turbines operate at 3,000 or 3,600 rpm to match the AC power grid. They require a dedicated building. Smaller turbines, with fewer compressor/turbine stages, spin faster. Jet engines operate around 10,000 rpm, and microturbines around 100,000 rpm.

Thrust and journal bearings are a critical part of design. Traditionally, they have been hydrodynamic oil bearings, or oil-cooled ball bearings. This is giving way to hydrodynamic foil bearings, which have become commonplace in microturbines (discussed later) and auxiliary power units (APUs).

Power plant gas turbines can range in size from truck-mounted mobile plants to enormous, complex systems. For example, one could consider the GE H Series power generation gas turbine. This 400-MW unit has a rated thermal efficiency of 60% when waste heat from the gas turbine is recovered by a conventional steam turbine in a combined cycle.

According to the U.S. Department of Energy (DOE), with the restructuring of the industry, increasing numbers of power companies are planning units in the 30- to 200-MW range. The DOE forecasts that about one-half the U.S. demand for gas turbine systems through 2020 is likely to be for midsize turbines, suitable for both central and distributed power applications. Besides providing both steady electricity and meeting surges in power demand, these smaller turbines might also be ideal for repowering aging coal plants and relieving congestion in the power transmission system.

In order to make gas turbines more efficient, many electric utilities utilizing gas turbines for peak, emergency, or reserve power production will have hybrid generation units. These specialized units combine the benefits of gas and steam turbines. Known as ***combined-cycle generating units,*** the efficiency at which they can operate is far better than just using the gas turbine technology alone. Figure 1–7 is a simplified schematic of a combined-cycle generating unit.

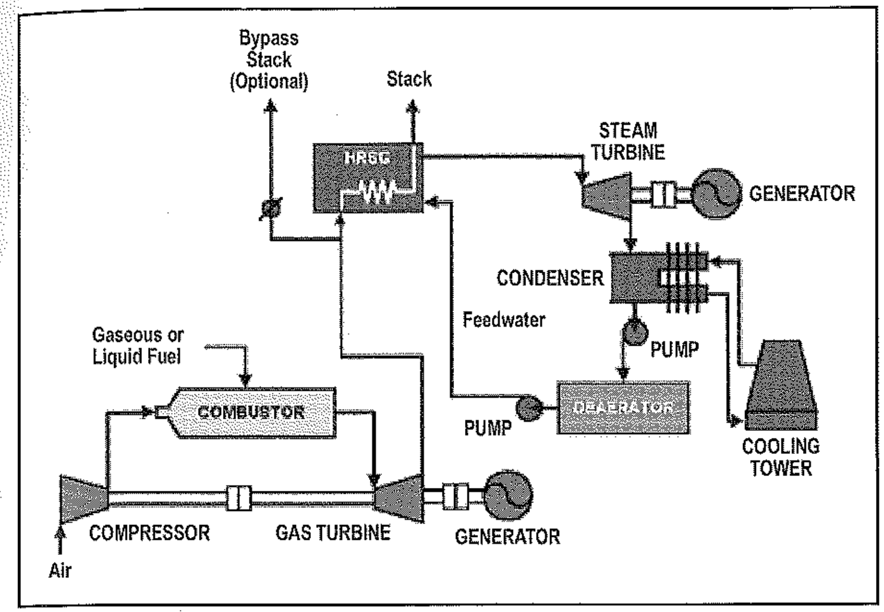

Fig. 1–7. Combined-cycle generating unit diagram

In a combined-cycle power plant, a gas turbine generator is combined with a steam turbine power plant with the overall objective of increasing the efficiency of electricity generation. In a thermal power plant, high-temperature heat as input to the power plant is converted to electricity as one of the outputs and low-temperature heat as another output. In order to achieve high efficiency, the temperature of the input heat should be as high as possible. And, as a rule, the temperature of the output heat should be as low as possible.

For gas turbine generators, the input temperature to the gas turbine is approximately 900°C to 1,200°C. This is a relatively high temperature; however, the output temperature of the flue gas is also rather high, at some 450°C to 650°C. For steam turbine power plants, the output temperature of the cooling water is significantly lower (20°C to 40°C), but the input temperature to the steam turbine is also significantly lower (420°C to 580°C).

Therefore, by combining both processes through the combined-cycle generation process, high input temperatures and low output temperatures can be achieved, and power plant efficiency can be increased.

The output heat of the gas turbine flue gas is utilized to generate steam in a heat recovery steam generator (HRSG) and therefore is used as input heat to the steam turbine power plant. The HRSG can be designed with or without supplementary firing. Without supplementary firing, the efficiency of the combined-cycle power plant is higher. With supplementary firing, the plant is more flexible to respond to fluctuations of electrical load.

Whereas gas turbines usually are fired by relatively expensive fuels, such as natural gas, gas from coal gasification, or light fuel oil, the HRSG can also be fired by less expensive fuels, such as heavy fuel oil or coal.

In the case of generating only electricity, power plant efficiencies of up to 58% can be achieved. In the case of combined heat and power generation, efficiency increases to about 5%.

Cogeneration. Also known as combined heat and power or CHP, this process uses a power station to simultaneously generate both heat and electricity. CHP allows a more total use of energy than conventional generation, potentially reaching an efficiency of 70% to 90%, as compared with around 50% for conventional plants. This means less fuel needs to be consumed to produce the same amount of energy.

Thermal power plants (including those using uranium, coal, petroleum, or natural gas) do not convert all available energy into electricity. Inevitably, a large amount of heat is released as a by-product. Conventional power stations emit this heat into the environment through cooling towers, as flue gas, or by other means.

To utilize this waste heat in places where it would otherwise need to be generated by other means is the most energy efficient usage. Often, these other means involve drawing upon electric power, while it would be more efficient to supply the heat directly, without first converting it into electricity. Heat is widely used, not only for residential buildings, but also for high-temperature industrial processes and other applications.

Cogeneration systems are generally economic on a large scale, for instance to provide heating water and power for an industrial site or an entire town. There are several common CHP plant types:

- Gas turbine CHP plants using the waste heat in the flue gas of gas turbines
- Combined-cycle power plants adapted for CHP
- Steam turbine CHP plants using the waste heat in the steam after the steam turbine

Small cogeneration units for hospitals, swimming pools, or groups of dwellings are also economic if standardized, mass-produced CHP plants are used. Examples are the internal combustion (IC) engines (gas or diesel engines) used for car manufacture. They use the waste heat in the flue gas and cooling water of a gas or diesel engine and replace the traditional gas- or oil-fired boiler (furnace) used in central heating systems.

Generating high-temperature heat (i.e., from industrial processes) usually results in some wasted low-temperature heat. This is usually emitted into the environment. A CHP system can also be used to recover some of this waste heat and to use it to generate electric power. For small systems, the waste heat can be recovered. One challenge with cogeneration is heat transmission over long distances. Thick, heavily insulated pipes are required, whereas electricity can be transmitted along a comparatively simple wire.

Microturbines. Microturbine technology is becoming widespread for distributed power and generator applications. Distributed generation is a new trend in electric power generation. The concept permits electric consumers who generate their own electricity to send their surplus electrical power back into the power grid. Microturbines range from handheld units producing less than 1 kW to power station units producing megawatts.

To understand why this technology has been such a hit for distributed power producers, it is important to dig a little deeper into their popularity. Part of the success of microturbines is due to advances in electronics, which allow unattended operation and interfacing with the commercial power grid. Electronic power switching technology eliminates the need for the generator to be synchronized with the power grid. This allows, for example, the generator to be integrated with the turbine shaft, and to double as the starter motor.

Another advantage of microturbines is that the technology's alternators have high power density in relation to volume and width, as compared with piston engines. This is due in large part to high rotation speed. The need for a recuperator, however, does mitigate this advantage.

Microturbine designs usually consist of a single-stage radial compressor, a single-stage radial turbine, and a recuperator. Recuperators are difficult to design and manufacture because they operate under high pressure and temperature differentials. Waste heat can be used for hot water production. Typical microturbine efficiencies are 20% to 35%. When in a combined heat and power system, overall efficiencies of greater than 90% can be achieved.

For the aforementioned reasons, there is little wonder why the technology has become so popular, particularly for distributed generators. The reason for the existence of distributed generation follows.

Most usually distributed generation is utilized by factories, offices, and especially hospitals, which require extremely reliable sources of electricity and heating for air conditioning and hot water. To safeguard their electricity supply and to reduce their costs, some institutions, factories, and offices install cogeneration or total energy plants, often using waste material, such as wood waste or surplus heat from an industrial process, to generate electricity.

In some cases, electricity is generated from a locally supplied fuel, such as natural gas or diesel oil, and the waste heat from the generator's thermal energy source is then used to provide hot water and industrial heating as well. It is often economic to have a cogeneration plant when an industrial process requires large amounts of heat that are generated from nonelectric sources, such as fossil fuels or biomass (these and other fuels are discussed later in this chapter).

Until recently, regulatory and technology issues meant domestic consumer-generated electricity could not be easily or safely coupled with the incoming electric power supply. Electric utilities need to have the ability to isolate parts of the power grid; when a line goes down, workmen have to be sure the power is off before they work on it. Utilities also spend much effort maintaining the quality of power in their grid. Distributed power installations can make control of these issues more difficult.

With the advent of extremely reliable power electronics, it is becoming economic and safe to install even domestic-scale cogeneration equipment. These installations can produce domestic hot water, home heating, and electricity. Surplus energy can then be sold back to the power company. Advances in electronics have eased electric companies' safety and quality concerns. Regulators can act to remove barriers to the uptake of increased levels of distributed generation by ensuring that centralized and distributed generation are operating on a level playing field.

To be sure, distributed generation is not limited to fossil fuels. Some countries and regions already have significant renewable power sources in power grid–tied wind turbines and biomass combustion, both of which are examined later in this chapter.

Increasing amounts of distributed generation will require changes in the technology required to manage transmission and distribution of electricity. There will be an increasing need for network operators to manage networks actively rather than passively. Increased active management will bring added benefits for consumers in terms of the introduction of greater choice with regard to energy supply services and greater competition. However, the switch to a more active management, currently under way, will likely be a difficult one. Distribution networks are considered natural monopolies, and are thus tightly regulated to ensure they do not draw excess profits at the expense of consumers. As will be discussed later in this book, network investment will be a key determinant of the costs networks can pass on to consumers.

As an aside, networks act to maximize their profits within the framework provided by their regulation. Currently such regulation does not lend itself very well to offering incentives for innovative behavior by networks, although some of that behavior is cropping up. This likely will prove to be a barrier both to the development of the networks and to increases in the levels of distributed generation that are added to networks.

On the upside, there are indications of regulatory authorities becoming more aware of the potential barriers. Regulation of connection charges and conditions has been introduced to enable distributed generators to participate in the electricity market.

There is the potential for a major portion of the electricity power supply to come from decentralized power sources. Thus billing and energy credits, generation control, and system stability remain significant issues limiting the widespread use of this technology. To maintain control and stability of the power system in some networks, neighboring consumers need to consume all the electric power a producing consumer may produce. This ensures there is a net flow of electric power from generators to consumers in the distribution network, even though there may be a local outflow within the local distribution.

With the continued growth of electricity markets and the requirement for open access to networks, the distributed generator may have more options for selling the excess production, either through physical or financial contracts (hedges).