CHAPTER 1

BENEFITS OF ELECTRIC POWER AND A HISTORY OF THE ELECTRIC POWER INDUSTRY

1.1 SOCIETAL BENEFITS OF ELECTRICITY

Electric power is one of the mainstays of our lives and the life of our nation. It differentiates advanced societies from third world nations. It touches almost every facet of our lives: our homes, our businesses, our schools, our transportation, and our leisure time. It is there when we are born, and it is there when we die. Think of the impact on our lives if we were not able to watch our favorite TV shows, use our home computers, heat and cool our homes, refrigerate our food, wash our clothes or our dishes, or read at night. Yet most people take it for granted, except during those relatively rare times when it is unavailable or when we receive our electric bills and note that the charges have suddenly and unexplainedly increased.

We know we have power outlets in our homes and businesses and we may notice the distribution wires running along our streets or if we pass high-voltage transmission towers, but many of us do not know how the whole system works. Some of us are affected because we live close to new or proposed electric power facilities, generating plants, or transmission lines and substations. Some may have concerns about the economic or environmental effects of producing electricity.

The National Academy of Engineering has described the development of the national electric power system as the greatest en-

Understanding Electric Power Systems. By Jack Casazza and Frank Delea

gineering achievement of the 20th century. It has involved legions of electrical, civil, mechanical, nuclear, software, and environmental engineers working for utilities and manufacturers. It also required individuals involved in everything from meter reading, to construction, operation, and maintenance of the power plants and the transmission and distribution lines, and to specialists in accounting, finance, customer relations, public affairs, and even law. Unfortunately, electric power is not a topic covered in our schools and is barely covered in our media. Even individuals who work for utilities may not know the "big picture" outside of their specialties. Decisions are often made about electric power issues with little or no input from the general public and little or no understanding of the technical and economic issues by lawmakers.

The electric industry is large and complex, involving technical, business, and governmental aspects. It cannot be viewed or understood unless one is also familiar with the regulatory environment in which it operates. This book attempts to inform its readers so that they may understand the continuing discussions and debates about the industry and its future and may be able to participate and have their own views heard.

1.2 ORIGIN OF THE INDUSTRY

The electric utility industry can trace its beginnings to the early 1880s. During that period, several companies were formed and installed water-power-driven generation for the operation of arc lights for street lighting, which was the first real application for electricity in the United States. In 1882, Thomas Edison placed into operation the historic Pearl Street steam-electric plant and the pioneer direct current distribution system by which electricity was supplied to the business offices of downtown New York. By the end of 1882, Edison's company was serving 500 customers that were using more than 10,000 electric lamps. The early Edison systems delivered the electricity by using low-voltage direct current (DC).

Satisfied with the financial and technical results of the New York City operation, licenses were issued by Edison to local businessmen in various communities to organize and operate electric lighting companies.[1] By 1884, twenty companies were scattered in communities in Massachusetts, Pennsylvania, and Ohio; in 1885, thirty-one; in 1886, forty-eight; and in 1887, sixty-two. These companies furnished energy for lighting incandescent lamps, and all operated under Edison patents.

Two other achievements occurred in 1882: a water-wheel-driven generator was installed in Appleton, Wisconsin; and the first transmission line was built in Germany to operate at 2400 volts direct current over a distance of 37 miles (59 km).[2] Motors were introduced and the use of incandescent lamps continued to increase. By 1886, the DC systems were experiencing limitations because they could deliver energy only a short distance from their stations since their voltage could not be increased or decreased as necessary. In the United States, the use of alternating current (AC) was championed by George Westinghouse and Nikola Tesla. In 1885, a commercially practical transformer was developed, which allowed the development of an AC system. A 4000 volt AC transmission line was installed between Oregon City and Portland, 13 miles away. A 112 mile, 12,000 volt, three-phase line went into operation in 1891 in Germany. The first three-phase line in the United States (2300 volts and 7.5 miles) was installed in 1893 in California.[3] In 1897, a 44,000-volt transmission line was built in Utah. In 1903, a 60,000-volt transmission line was energized in Mexico.[4]

In this early AC period, frequency had not been standardized. In 1891, the desirability of a standard frequency was recognized and 60 Hertz (Hz)[5] was proposed. For many years 25, 50, and 60 Hz were standard frequencies in the United States. Much of the 25 Hz was used for railway electrification and has been retired over the years. The City of Los Angeles Department of Water and Power and the Southern California Edison Company both operated at 50 Hz, but converted to 60 Hz at the time that Hoover Dam power became available, with conversion completed in 1949. The Salt River Project was originally a 25 Hz system; most of it was converted to 60 Hz by the end of 1954 and the balance by the end of 1973.[6]

[1]Homer M. Rustebakke, 1983, *Electric Utility Systems and Practices,* 4th ed., Wiley.
[2]Ibid.
[3]Ibid.
[4]Ibid.
[5]One hertz is equal to one cycle per second.
[6]Rustebakke, op. cit.

Over the first 90 years of its existence, until about 1970, electric consumption doubled about every ten years, a growth of about 7% per year. In the mid-1970s, due to increasing costs and serious national attention to energy conservation, the growth in the use of electricity dropped to almost zero. Today, growth is forecasted at about 1% per year until 2030.[7]

The growth in the utility industry has been related to technological improvements that have permitted larger generating units and larger transmission facilities to be built. In 1900, the largest turbine was rated at 1.5 MW. By 1930, the maximum size unit was 208 MW. This remained the largest size during the Depression and war years. By 1958, a unit as large as 335 MW was installed, and two years later in 1960, a unit of 450 MW was installed. In 1963, the maximum size unit was 650 MW and in 1965 the first 1000 MW unit was under construction. Unit sizes continued to grow, with generating units now as large as 1425 mW.[8]

Improved manufacturing techniques, better engineering, and improved materials allowed for an increase in transmission voltages in the United States to accompany the increases in generator size. The highest voltage operating in 1900 was 60 kV. In 1923, the first 220 kV facilities were installed. The industry started the construction of facilities at 345 kV in 1954, in 1964 500 kV was introduced, and 765 kV was put in operation in 1969 and remains as the highest transmission voltage in the United States.[9] Larger generator systems required higher transmission voltage; higher transmission voltage made possible larger generators.

These technological improvements increased transmission and generation capacity at decreasing unit costs, accelerating the high degree of use of electricity in the United States. At the same time, the concentration of more capacity in single generating units, plants, and transmission lines had considerably increased the total investment required for such large projects, even though the cost per unit of electricity had come down.

[7]Energy Information Agency (EIA), *Annual Energy Outlook,* 2009.

[8]The vast majority of the approximately 65 units larger than 1000 mW are nuclear units constructed in the 1970s and 1980s. Since then, the largest of the new capacity additions have been significantly smaller. For example, the Energy Information Agency's list of new capacity for the period September 2007–August 2008 indicates the largest unit was 558 mW.

[9]Work on UHV (voltages 1000 kV or higher) is underway in China, India, and Brazil. The State Grid Corporation of China is working on a 1000 kV UHV transmission project connecting North and Central China.

Not all of the pioneering units at the next level of size and efficiency were successful. Sometimes, modifications had to be made after they were placed in operation; units had to be derated because the technology was not adequate to provide reliable service at the level intended. Each of these steps involved a risk of considerable magnitude to the utility, first to install a facility of a new type or a larger size or a higher transmission voltage. Creating new technologies required the investment of considerable capital that in some cases ended up being a penalty to the utility involved. To diversify these risks, companies began to jointly own power plants and transmission lines so that each company would have a smaller share and, thus, a smaller risk, in any one project. The sizes of generators and transmission voltage levels evolved together, as shown in Figure 1-1.[10]

A need for improved technology continues. New materials are being sought in order that new facilities can be more reliable and less costly. New technologies are required in order to minimize land use, water use, and the impact of the industry on the environment. The manufacturers of electrical equipment continue to expend considerable sums to improve the quality and cost of their products. Unfortunately, funding for such research by electric utilities through the Electric Power Research Institute (EPRI)[11] continues to decline.

1.3 THE DEVELOPMENT OF THE NATIONAL ELECTRIC POWER GRID[12]

Electric power must be produced at the instant it is used. Needed supplies cannot be produced in advance and stored for future use. At an early date, those providing electric power recognized that peak use for one system often occurred at a different time from peak use in other systems. They also recognized that equipment failures occurred at different times in various systems. Analyses showed significant economic benefits from interconnecting systems to pro-

[10]J. A. Casazza, 1993, *The Development of Electric Power Transmission—The Role Played by Technology, Institutions, and People,* IEEE Case Histories of Achievement in Science and Technology, Institute of Electrical and Electronic Engineers.

[11]See Chapter 19 for a discussion of EPRI, the industry's research organization.

[12]Casazza, op. cit.

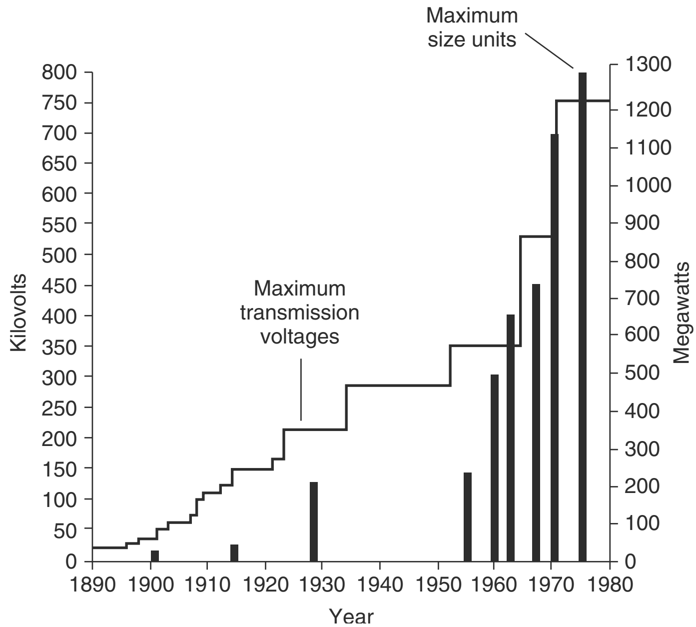

Figure 1-1. Evolution of generator sizes and transmission voltages.

vide mutual assistance; the investment required for generating capacity could be reduced and reliability could be improved. This lead to the development of local, then regional, and, subsequently, three transmission grids that covered the United States and parts of Canada. In addition, differences in the costs of producing electricity in the individual companies and regions often resulted in one company or geographic area producing some of the electric power sold by another company in another area. In such cases, the savings from the delivery of this "economy energy" were usually split equally among the participants. Figure 1-2 shows the key stages of the evolution of this grid. Figure 1-3 shows the five synchronous power supply areas currently existing in North America.

The development of these huge areas in each of which all generation is connected directly and indirectly by a network of transmission lines (the grid) that allows the generators to operate in synchronism presents some unique problems because of the special nature of electric power systems. Whatever any generator or transmission line in one area does or does not do affects all other generators and transmission lines in the same area, those nearby

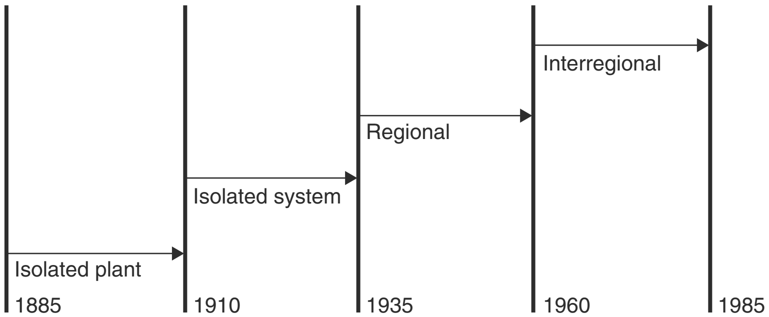

Figure 1-2. Key stages in the evolution of the grid in the United States.

more significantly and those distant to a lesser degree. In the Eastern Grid (or Interconnection), the loss of a large generator in Chicago can affect generators in Florida, Louisiana, and North Dakota. Decisions on transmission additions can affect other systems many hundreds of miles away. This has required the extensive coordination in planning and operation between participants in the past. New procedures will be needed in the future.

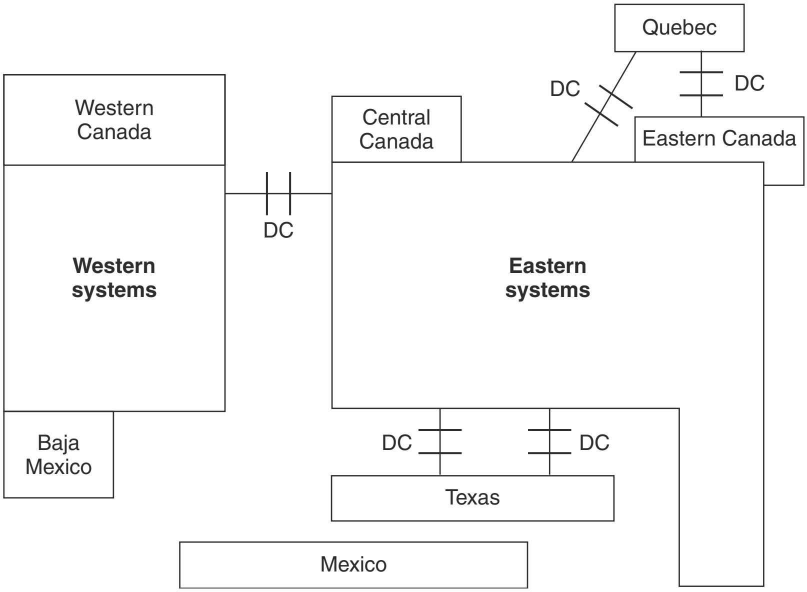

Figure 1-3. Synchronous power grids in North America.

As stated by Thomas P. Hughes of the University of Pennsylvania in the September 1986 issue of *CIGRE Electra*:[13]

> Modern systems are of many kinds. There are social systems, institutional systems, technical systems, and systems that combine components from these plus many more. . . . An example of such a technological system . . . is an electric power system consisting not only of power plants, transmission lines, and various loads, but also utility corporations, government agencies, and other institutions. . . . [P]roblems cannot be neatly categorized as financial, technical, or managerial; instead they constitute a seamless web. . . . [E]ngineering or technical improvements also require financial assistance to fund these improvement(s) and managerial competence to implement them.

1.4 "THE GOLDEN AGE"

The golden age of electric utilities was the period from 1945 to 1965. During this period, there was exponential load growth accompanied by continual cost reductions. New and larger plants were being installed at a continuously lower cost per kilowatt, reflecting economics of scale. Improvements in power plant efficiency were being obtained through higher temperatures and pressures for the steam cycle, which lowered the amount of fuel required to produce a kilowatt hour of electric energy. New generating plants were being located at the mine mouth, where coal was cheap, and power was transmitted to the load centers. This required new, higher voltage transmission lines since it had been found that transmitting electric energy, called "coal by wire," was cheaper than the existing railroad rates.

The coordination between utilities was at a maximum. The leaders of the industry involved in planning the power systems saw the great advantage of interconnecting utilities to reduce capital investments and fuel costs. Regional and interregional planning organizations were established. The utilities began to see the advantage of sharing risk by having jointly owned units.

On the analytical side, improved tools were rapidly being developed. Greatly improved tools for technical analysis, such as

[13]J. A. Casazza, 1993, *The Development of Electric Power Transmission—The Role Played by Technology, Institutions, and People,* IEEE Case Histories of Achievement in Science and Technology, Institute of Electrical and Electronic Engineers.

computers, began to appear, first as analog computers and then as digital computers. At the same time, the first corporate financial models were developed for analyzing future plans for possible business arrangements for joint projects, of costs to the customers, for the need for additional financing, and the impact on future rates.

All of these steps reduced capital and fuel costs, which resulted in lower rates to customers. Everyone was happy. The customers were happy because the price of electricity was going down. Investors were happy because their returns on investments and the value of their stock were increasing. System engineers were happy because they were working on interesting and challenging problems that were producing recognized benefits, and their value to the utility organizations was increasing. Finally, business managers were happy that they were running organizations that were functioning smoothly and were selling their product to satisfied customers.

Blackouts and the Reliability Crisis

The first blow to this "golden age" was the blackout of New York City and most of the Northeast in 1965, which was caused by events taking place hundreds of miles away at Niagara Falls. The government's reaction was immediate. Joseph C. Swidler was then Chairman of the Federal Power Commission. On order from President Johnson, he set up investigative teams to look into the prevention of future blackouts. As a result, they wrote an excellent report called *Prevention of Power Failures,* which is a classic to this day.[14] This report and a number of subsequent blackouts lead to increasing attention by Congress and the Federal regulatory agencies—the Federal Power Commission (FPC), now called the Federal Energy Regulatory Commission (FERC),[15] and the Department of Energy (DOE)[16]—to questions of reliability and increasing study. As an alternate to additional legislation, the industry recognized the need to govern itself and formed the National Reliability Council (NERC)[17] and the Electric Power Research Institute

[14]Federal Power Commission, *Prevention of Power Failures,* Volume I, Report to the Commission, Washington, D.C., July 1967.

[15]FERC, The Federal Energy Regulatory Commission, is the successor to the Federal Power Commission (FPC). See Chapter 14 for a discussion of FERC.

[16]After its formation in 1977. See Chapter 14 for a discussion of the DOE.

[17]See Chapter 10 for a discussion of NERC.

(EPRI). Formal regional reliability criteria were developed, reliability conditions monitored, and major funds contributed to develop new technology.

Notwithstanding these criteria, the start of the twenty-first century was marked by the largest blackout the United States has ever experienced. Influenced by the blackout, Congress passed the Energy Policy Act of 2005 (EPAct05), including a provision that adherence to nationwide planning and operating standards be mandatory and providing for an expanded role for FERC in oversight of the planning and operation of the industry's operation in the name of reliability.

The Environmental Crises—The Shift to Low-Sulfur Oil

Starting shortly after the reliability crisis, and overlapping it considerably, was the environmental crisis. Both the public and the government became concerned about air quality, water quality, and the effect of electricity production on the environment. New environmental legislation was passed. These concerns made the siting of new power plants very difficult. The power industry began installing nuclear units (which essentially have no exhaust), converting some of the existing coal-burning units to low-sulfur oil, providing electrostatic precipitators to filter out particulate emissions, installing scrubbers to remove sulfur combustion products, and installing cooling towers so rivers would not heat up. All of these steps helped meet new government environmental requirements but significantly increased capital costs and fuel costs.[18]

The Fuel Crisis—The Shift from Oil

While these changes and additions were still underway, the industry was overtaken by another crisis. In 1973, the OPEC organization stopped all delivery of oil to the United States. This raised serious questions about plans to reduce air pollution by converting existing coal-burning units to oil. Plans were cancelled to convert generation to oil (at a considerable financial penalty). Huge increases in the price of fuel occurred.

[18]In the early 2000s, concerns about perceived global warming and the effect of carbon-based fuels are driving measures to reduce carbon emissions.

The Financial Crisis

At the same time, the country found itself in an inflationary spiral; the cost of money rose to double-digits rates. All utility costs increased rapidly, requiring large rate increases. Because of the political impacts of such rate increases, many state regulatory commissions rejected these requests, thus exacerbating the financial problems of utilities. The depressed economy and rising costs of electricity dampened electric sales and load growth. The financial crisis resulted in a period of increasing costs, declining revenue, the lack of load growth, and large amounts of generating capacity under construction that would not be needed as soon as originally projected. Utilities were forced to cancel construction of projects already underway, resulting in large cancellation payments.

In 1979, a major accident occurred at the Three Mile Island Nuclear Plant in Pennsylvania. In response, the Nuclear Regulatory Commission issued orders greatly increasing the safety standards for nuclear power plants and requiring major design modifications. In combination with the high levels of inflation being experienced at the same time, massive overruns occurred in the cost of nuclear plants still under constructions. The service dates for many plants were delayed, in some cases for many years. These delays amplified the utilities' financial crisis even further because there was an appreciable investment in these partially completed plants on which earnings were required, even though the plants were not operating and producing any electricity. Ten-fold cost increases were experienced by many of these plants. Some units that were built were never run. As a result of the cost issues and the greatly increased public concern over the safety of nuclear plants, proposals to construct new nuclear generation plants were brought to a standstill. There have been no new nuclear power plants built in the United States for many years, although the nuclear industry continued to flourish overseas. Recent Federal legislation seeks to reinvigorate the nuclear option,[19] primarily as an alternative to imported oil and as a noncarbon-emitting source of electricity, although the issue of nuclear waste disposal remains to be solved.[20]

[19]See discussion in Chapter 6 of new nuclear technologies.

[20]"President Obama's proposed budget all but kills the Yucca Mountain project, the controversial Nevada site where the U.S. nuclear industry's spent fuel rods were to spend eternity. There are no other plans in the works, so for now the waste will remain next to Zion and 103 other reactors scattered across the country." See *Los Angeles Times,* March 11, 2009 article by Michael Hawthorne.

The Legislative and Regulatory Crisis

At about the same time, the Federal Government had become very chaotic and unpredictable in the regulations it issued. Some believed that paying to reduce peak power consumption was more economical than building new generating and transmission capacity. This concept has been called least-cost, demand-side, or integrated resource planning.

The Public Utility Regulatory Policies Act (PURPA) legislation, passed in 1978, prescribed the use of "avoided costs" for determining payments to independently owned cogenerators and qualifying facilities (QFs), such as low-head hydro and garbage burners. These "avoided costs" were the alternate utility costs for producing electricity based on the alternates available to the utility system. They were based on estimates of future costs, made by state regulators, which turned out to be much higher than the actual costs that occurred, primarily because of the significant overestimates of the future price of fuel. Unfortunately, many utilities were required to sign long-term contracts for purchased energy reflecting these cost estimates. The avoided-cost approach led to excessive payments to some cogenerators and other qualifying facilities. Subsequently, some utilities had to make very large payments to the plant owners to cancel such contracts or to purchase the plants.

The next step by some state regulatory commissions was the proposal and, in some cases, the adoption, of competitive bidding procedures for new generators.

The Energy Policy Act of 1992 (EPAct92), FERC Orders 888 and 889, and various other FERC orders and notices followed, all seeking to foster a competitive wholesale market for electricity. One of the approaches implemented in some areas called for competitive bidding for the provision of the electricity needed each hour. It required all bidders whose proposals were accepted to be paid the highest bid accepted for the hour even though their proposal was lower. Proponents of the industry restructuring claim that restructuring has reduced costs to consumers. This claim is not accepted by all observers. Additionally, the rapid development of expanded wholesale markets with many new participants resulted in an increased level of complexity in operations, not always matched by the development and deployment of the necessary hardware, software and operational control necessary to maintain reliability. Rapidly rising costs, declining reliability, and developing procedures for manipulating electricity prices, have all increased concern and scrutiny of the electric power industry.

The Energy Policy Act of 2005 (EPAct05) and subsequent orders by FERC greatly increased the role of the federal government in the oversight of the planning and operation of the industry.

1.5 GLOBAL WARMING CRISIS AND CONCERNS ABOUT CARBON EMISSIONS

Scientists and environmentalists have been sounding a warning that the earth is becoming warmer and that the potential effects on the world's population and ecosystems would be a disaster. Although recent data indicates that the earth has, on average, experienced a warming trend, the argument for the existence of long-term global warming is still contentious. Data on the earth's temperature can be found at the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center.[21]

Irrespective of the validity of either the position of the global warming proponents or those who argue against global warming, a groundswell of political/environmental opinion is seeking to determine if the activities of mankind have contributed to or are causing the temperature increase and what steps could be taken to mitigate or eliminate any such causes. Proposals to reduce greenhouse gas emissions, including those of the utility industry, are being considered by Congress as this book goes to press.[22]

1.6 RESTRUCTURING, COMPETITION, AND THE INDUSTRY OWNERSHIP STRUCTURE

At the turn of the twentieth century, the United States was dotted with approximately 5000 isolated electric plants, each servicing a small area. Entrepreneurs bought these systems to form larger systems. It was easier to raise cash and savings could be obtained by coordinating generation, transmission, and the distribution system development over a wider region.

In the 1920s and early 1930s, large utility holding companies were formed. Practices in the electric power industry that lead to

[21]http://www.ncdc.noaa.gov/oa/climate/globalwarming.html#q3.

[22]See Chapter 5 for a discussion of this issue.

Table 1-1. Installed net summer generation capacity by producer type, Summer 2007

Producer type	Number of generators	Net summer capacity (mW)
Electric utilities	9,237	571,200
Independent power producers	5,138	357,278
Subtotal	14,375	928,478
Customer owned	646	37,254
Commercial	635	2,312
Industrial	1,686	26,844
Subtotal	2,967	66,410
Total all sectors	17,342	994,888

Source: EIA.

additional economies of scale often lead to opportunities for major financial abuses. The concentration of economic power in fewer and fewer organizations, through highly leveraged purchases of companies, led to Congress passing the Public Utility Holding Company Act of 1935 (PUHCA).[23]

Over more than 100 years, the ownership of generation plants and transmission and distribution systems has evolved. For many years, generation was owned by investor-owned companies; rural electric cooperatives; various nonfederal governments, such as municipals, states, irrigation districts, and so on; and a number of Federal Authorities. Since the early 1990s, private ownership of generation has greatly increased. Table 1-1[24] shows the ownership of U.S. generating facilities. In 2007, independent power producers owned 35.9% of the capacity, up from 25.8% in 2000.

Transmission systems are still owned by the same entities as above although operational control has been ceded to independent third parties such as ISOs and RTOs. A few merchant transmission lines have been built and others are proposed.

[23]PUHCA was repealed by the Energy Policy Act of 2005, discussed in Chapter 13.

[24]In the first edition of this text, additional information was provided in more detail on ownership interests. Unfortunately, the Energy Information Agency no longer publishes reports with the additional detail.