
UNDERSTANDING ELECTRIC POWER SYSTEMS

An Overview of the Technology
and the Marketplace

Jack Casazza
Frank Delea



IEEE Press Understanding Science & Technology Series



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Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada.

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Library of Congress Cataloging-in-Publication Data is available.

ISBN 0-471-44652-1

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

Our thanks go to many who helped with this book but particularly our wives, Madeline and Irene, who provided support and encouragement.

Jack Casazza
Frank Delea

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PREFACE

As Joseph Swidler, former Chairman of the Federal Power Commission (predecessor of FERC) often stated, “There are many disagreements about the best electric power policy for the USA, but there is no disagreement it is often being established without adequate analyses.” Government and business decisions on electricity supplies often fail to recognize how power systems work and the uncertainties involved. Those involved do not always mean the same thing although they use identical words. Incorrect assumptions have been made about the operation of the electric system and continue to be made based on the operation of telephone systems, gas systems, and other physical systems that are not applicable to electric power systems.

The purpose of this book is to help those in government, business, educational institutions, and the general public have a better understanding of electric power systems, institutions, and the electric power business. The first nine chapters focus on the technology of electric power; the last eight cover the institutions and business practices. Why must business practices be included in such a text? Because technical and institutional practices need to be coordinated to meet our needs. New technologies require new institutional approaches; new institutional mechanisms require new technology. Both must be understood.

The original text for this book was written in 1984. It was used for instructional purposes in a number of courses for electrical engineers who were not power systems engineers, for lawyers, accountants, economists, government officials, and public interest groups. Since then some technological changes and many institutional changes have occurred. With the advent of the internet, many new and valuable publications and information sources have become available and were used in its preparation. It includes ideas and information from many segments of the industry and many knowledgeable people in the industry, and is based on educational programs of the American Education Institute (AEI).

The book covers such subjects as electric power systems, their components (generation, transmission, distribution), electricity use, electric system operation, control and planning, power system reliability, government regulation, utility rate making, and financial considerations. It describes the “six net-

works”: (1) the physical network, (2) the fuel/energy network, (3) the money network, (4) the information, communication, and control network, (5) the regulatory network, and (6) the business network, which are interconnected in the provision of electric power. It provides the reader with an understanding of the equipment involved in providing electric power, the functioning of the electric power system, the factors determining the reliability of service, the factors involved in determining the costs of electric power, and many other technical subjects. It provides the engineer with background on the institutions under which power systems function. It can be used as a classroom text, as well as a reference for consultation. While a book of this length cannot provide in-depth discussions of many key factors, it is hoped it provides the broad understanding that is needed. Ample references are provided for those who wish to pursue important points further. The index facilitates the location of background material as needed. The authors welcome comments, suggestions, additional information and corrections. They hope you, your company, and all consumers benefit from it.

Jack Casazza
Jackcasazza@aol.com

Frank Delea
Fdelea@aol.com

American Education Institute
www.ameredinst.org

HISTORY OF ELECTRIC POWER INDUSTRY

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; 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.

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, 31; in 1886 48; and in 1887 62. 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; the first transmission line was built in Germany to operate at 2400 volts direct current over a distance of 37 miles

¹ Homer M. Rustelbakke, 1983, *Electric Utility Systems and Practices, Fourth Edition*, Wiley, New York.

(59km).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 1885 a commercially practical transformer was developed that 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 60Hz (cycles per second) was proposed. For many years 25, 50, and 60Hz were standard frequencies in the United States. Much of the 25Hz was 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 50Hz, but converted to 60Hz at the time that Hoover Dam power became available, with conversion completed in 1949. The Salt River Project was originally a 25 Hz system, but most of it was converted to 60Hz by the end of 1954 and the balance by the end of 1973.⁵

Over the first 90 years of its existence, until about 1970, the utility industry 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 2% per year.

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 1.5MW. By 1930 the maximum size unit was 208MW. 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 450MW was installed. In 1963 the maximum size unit was 650MW and in 1965, the first 1,000MW unit was under construction.

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 60kV. In 1923 the first 220kV facilities were installed. The industry started the construction of facilities at 345 kV in 1954, in 1964 500kV was introduced, and 765kV was put in operation in 1969. Larger generator stations

² *Ibid.*

³ *Ibid.*

⁴ *Ibid.*

⁵ *Ibid.*

required higher transmission voltages; higher transmission voltages 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. 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 de-rated 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 the new technology 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 voltages evolved together as shown in Figure 1.1.⁶

The need for improved technology continues. New materials are being sought in order that new facilities are more reliable and less costly. New technologies are required in order to minimize land use, water use, and impact 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 continues to decline.

DEVELOPMENT OF THE NATIONAL ELECTRIC POWER GRID⁷

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 provide mutual assistance. The investment required for generating capacity could be reduced. Reliability could be improved. This led to the development of local, then regional and subsequently three transmission grids which covered the United States. In addition, differences in the costs of producing

⁶ 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.

⁷ *Ibid.*

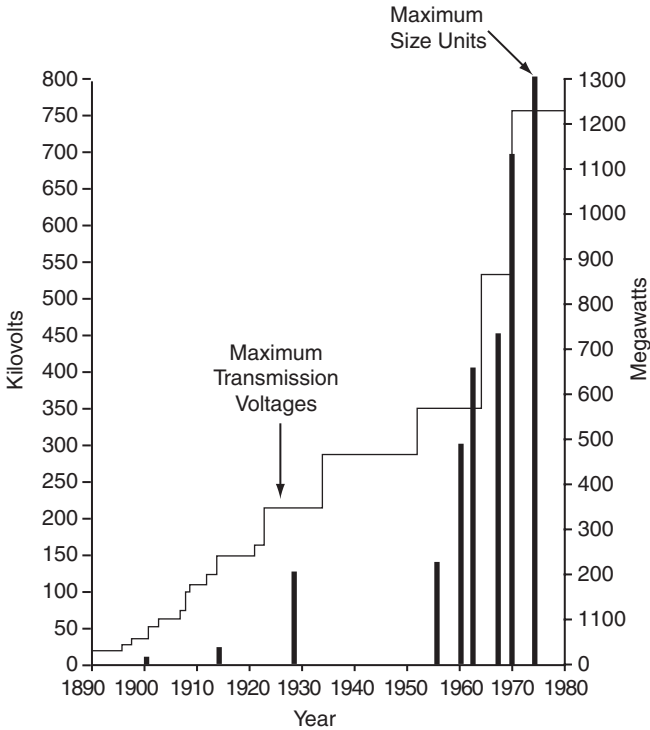


Figure 1.1. Progression of maximum generator size and highest transmission voltage.

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.⁸ Figure 1.3 shows the five synchronous power supply areas currently existing in the United States and Canada.⁹

The development of these huge synchronous areas, in each of which all generation is connected directly and indirectly by a network of transmission lines (the grid), presents some unique problems because of the special nature of electric power systems. Whatever any generator or transmitter in the synchronous region does or does not do affects all others in the synchronous region, those close more significantly and those distant to a lesser degree. The loss of a large generator in Chicago can affect systems in Florida, Louisiana, and North Dakota. Decisions on transmission additions can affect other

⁸ *Ibid.*

⁹ *Ibid.*