CHAPTER I

Introduction

OF THE great construction projects of the last century, none has been more impressive in its technical, economic, and scientific aspects, none has been more influential in its social effects, and none has engaged more thoroughly our constructive instincts and capabilities than the electric power system. A great network of power lines which will forever order the way in which we live is now superimposed on the industrial world. Inventors, engineers, managers, and entrepreneurs have ordered the man-made world with this energy network. The half-century from 1880 to 1930 constituted the formative years of the history of electric supply systems, and from a study of these years one can perceive the ordering, integrating, coordinating, and systematizing nature of modern human societies. Electric power systems demanded of their designers, operators, and managers a feel for the purposeful manipulation of things, intellect for the rational analysis of their nature and dynamics, and an ability to deal with the messy economic, political, and social vitality of the production systems that embody the complex objectives of modern men and women. Robert Venturi, the contemporary architect, has asked architects to embrace the complexity and contradictions of the modern world and to make of that world a habitable environment.[1] Leading engineers and managers have also recognized that their drive for order must be tempered by tolerance of messy vitality. Modern electric systems have the heterogeneity of form and function that make possible the encompassing complexity.

Man's making of the complex modern world is an appropriate subject for the twentieth-century historian. Creation of the material environment shaped by—and shaping—mankind is not a peripheral subject that can be left to narrow specialists. To direct attention today to technological affairs is to focus on a concern that is as central now as nation building and constitution making were a century ago. Technological affairs contain a rich texture of technical matters, scientific laws, economic principles, political forces, and social concerns. The historian must take the broad perspective to get to the root of things and to see the patterns. Scientists and

[1] Robert Venturi, *Complexity and Contradiction in Architecture* (New York: The Museum of Modern Art, 1966), pp. 22–23.

engineers analyze the technical systems they build, but historians are needed to comprehend the complex, multifaceted relations of these systems and the changes that take place in them over time.[2]

For historians, the study of complexity and change is engaging. Edward Gibbon sat in the ruins of the Capitol in Rome and reflected on the contrast between what he saw before him and the earlier glory that was Rome. Upon seeing drums of oil being unloaded from an American ship in an African port, the American scholar Perry Miller asked how a civilization as new as the American one could already be exporting the products of its technology to remote areas of the world that had been settled centuries earlier. Other historians, taking bareboned statistics from widely separated times, have sought to explain quantitative change by means of qualitative analysis. The drama of change provides the historian with an emphasis that sets him or her apart from the social scientist, who often dissects situations without including a time dimension.

How did the small, intercity lighting systems of the 1880s evolve into the regional power systems of the 1920s? In this case, the change is not the decline that fascinated Gibbon; it is the expansion that attracted Miller. The focus is not on contrasting data; it is on contrasting physical configurations. The problem of this book is to explain the change in configuration of electric power systems during the half-century between 1880 and 1930. Such change can be displayed in network diagrams (see Fig. I.1), but the effort to explain the change involves consideration of many fields of human activity, including the technical, the scientific, the economic, the political, and the organizational. This is because power systems are cultural artifacts.

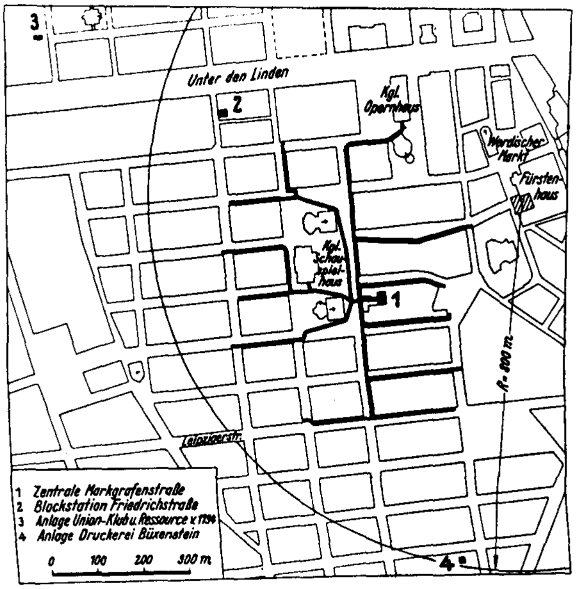
Electric power systems embody the physical, intellectual, and symbolic resources of the society that constructs them. Therefore, in explaining changes in the configuration of power systems, the historian must examine the changing resources and aspirations of organizations, groups, and individuals. Electric power systems made in different societies—as well as in different times—involve certain basic technical components and connections, but variations in the basic essentials often reveal variations in resources, traditions, political arrangements, and economic practices from one society to another and from one time to another. In a sense, electric power systems, like so much other technology, are both causes and effects of social change.

Power systems reflect and influence the context, but they also develop an internal dynamic. Therefore, the history of evolving power systems requires attention not only to the forces at work within a given context but to the internal dynamics of a developing technological system as well. This book is not simply a history of the external factors that shape technology, nor is it only a history of the internal dynamics of technology; it is a history of technology and society.

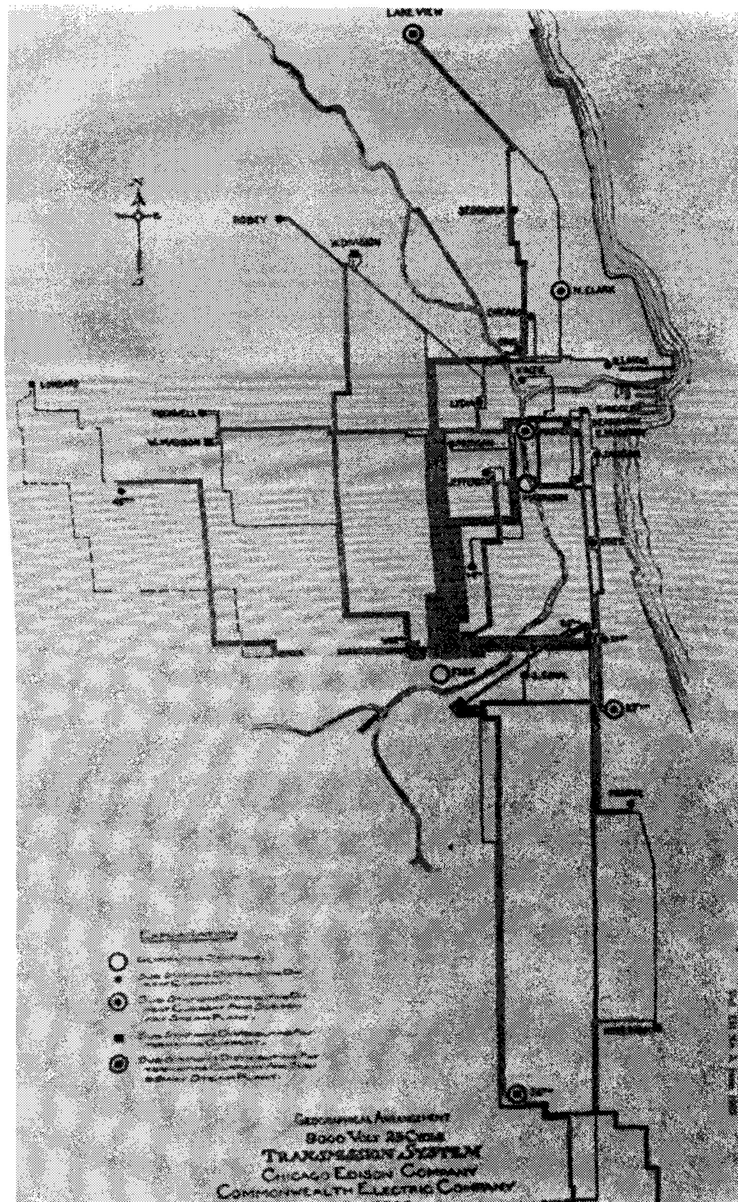
Scientists have done much to enlighten us about the nature of dynamics of the structures of the natural world, but historians have as yet only barely

[2] In his essays, Harvey Brooks, a scientist and engineer, addresses the multifaceted complexity of contemporary technosocial systems. See, for example, Brooks, "A Framework for Science and Technology Policy," *IEEE Transactions on Systems, Man, and Cybernetics*, SMC–2, no. 5 (1972): 584–88.

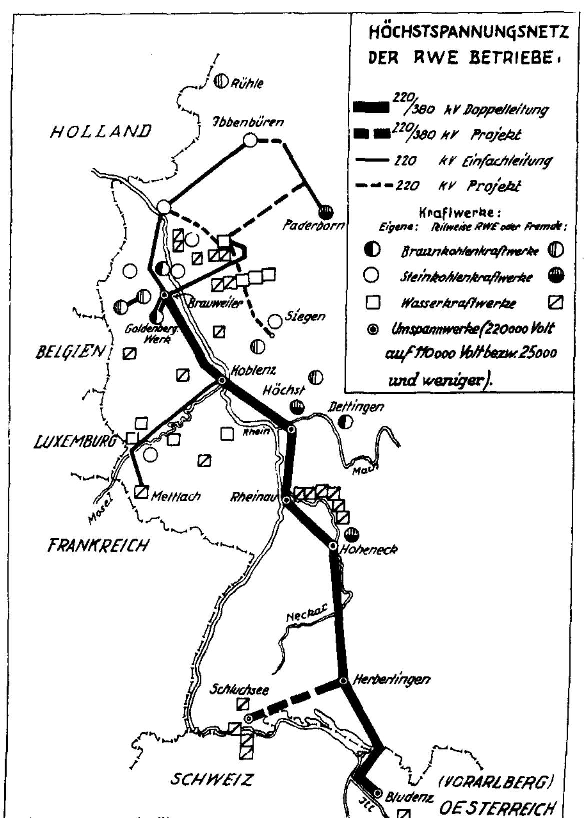
FIGURE I.1. THE CONFIGURATION OF EVOLVING SYSTEMS: INNER CITY (1885); CENTRALIZED URBAN (1906); AND REGIONAL (1930)



Distribution system, Berlin, 1885. From Matschoss et al., 50 Jahre, p. 13.

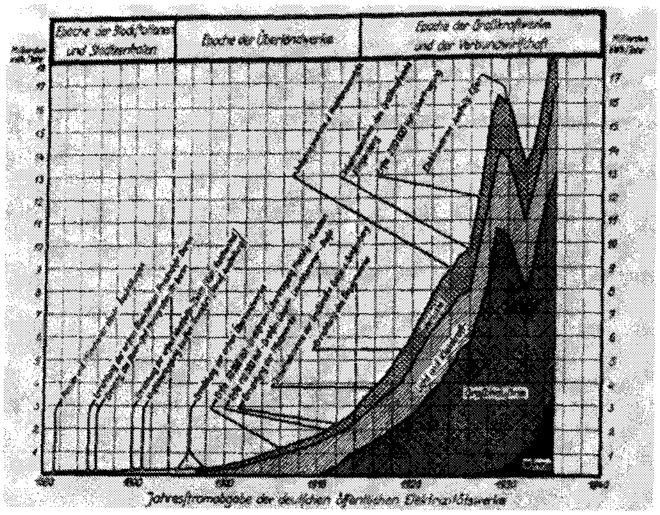


Distribution system, Chicago, 1906. Courtesy of Commonwealth Edison Co., Chicago, Ill.

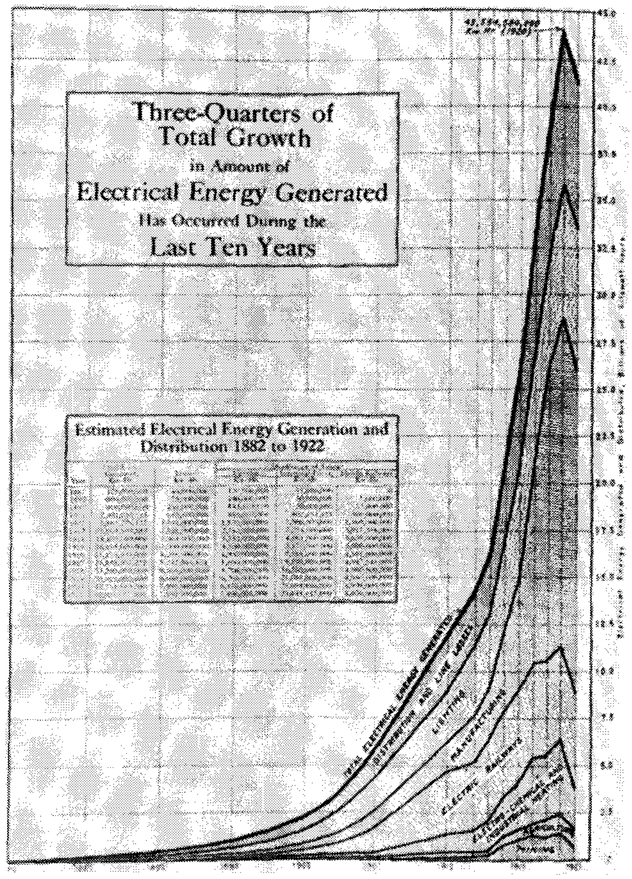


Transmission system from the Dutch border to Switzerland, 1930. From Koepchen, "Das RWE" (see Chapter XIV, note 17, below).

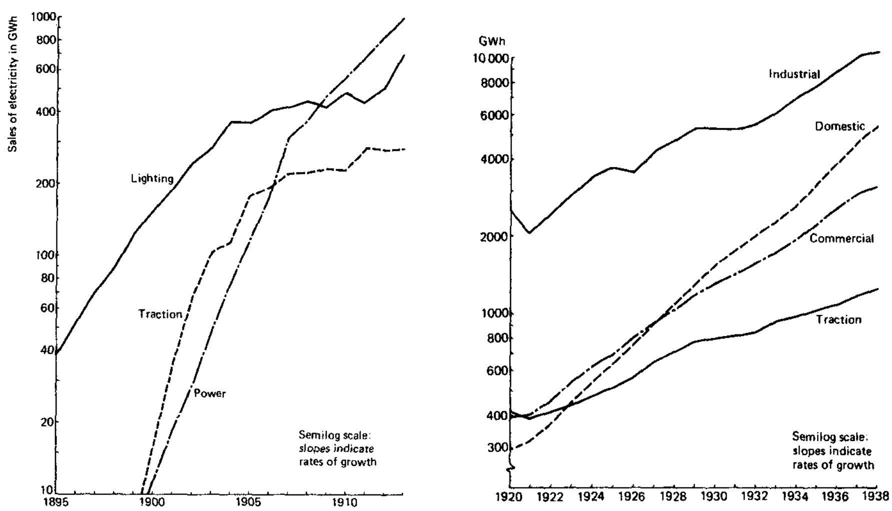
FIGURE I.2. THE STATISTICS OF EVOLVING SYSTEMS IN THREE COUNTRIES



Above: *Electricity generated by public utilities in Germany, 1880–1940. From Rudolf von Miller's article in* Technikgeschichte *25 (1936): 112.*



Right: *Electricity generated by utilities in the United States, 1882–1921. From* Electrical World *80 (1922): 546.*



The growth of electricity sales in the United Kingdom, 1895–1913 (left) *and 1920–1938* (right). *Data from I. C. R. Byatt, "The British Electrical Industry, 1875–1914" (D. Phil. thesis, Oxford University, 1962), p. 111; and Hannah,* Electricity Before Nationalisation, *table A.1.*

penetrated the surface of the highly organized and evolving systems of the man-made world. Historians interested in technology have written only a few monographs that concentrate on the evolution of the massive, extensive, vertically integrated production systems of the modern industrial world. Although the public senses the strong organizing forces that originated in these systems and that today influence their lives, they only dimly perceive the nature of these forces. The technological, or man-made, world awaits a Darwin to explicate the origins and dynamics of the forces that pervade it. Quoting Paul Valéry, historian Marc Bloch chides traditional historians for not taking up the task of explicating "the conquest of the earth" by electricity, one of those notable phenomena that have "greater possibilities of shaping our immediate future than all the political events combined."[3]

How might the technological systems that increasingly structure our material environment—specifically, electric power systems—be defined? Because these systems have varied over time and from place to place, the historian's definition cannot be as precise as the scientist's. Ludwig von Bertalanffy, one of the most articulate of systems theorists, needed a book, not a paragraph, to define "system."[4] Thus, an inadequate approximation must serve here as an introduction to the concept of systems. Some characteristics of systems are so general that they transcend time and place. A system is constituted of related parts or components. These components are connected by a network, or structure, which for the student of systems may be of more interest than the components. The interconnected components of technical systems are often centrally controlled, and usually the limits of the system are established by the extent of this control. Controls are exercised in order to optimize the system's performance and to direct the system toward the achievement of goals. The goal of an electric production system, for example, is to transform available energy supply, or input, into desired output, or demand. Because the components are related by the network of interconnections, the state, or activity, of one component influences the state, or activity, of other components in the system. The

[3] Marc Bloch, *The Historian's Craft* (New York: Knopf, 1959), p. 66.

[4] Ludwig von Bertalanffy, *General System Theory: Foundations, Development, Applications* (New York: Braziller, 1968). The literature on systems in general is extensive, and even a selected bibliography is beyond the scope of—and inappropriate for—a history of a particular kind of system. The interested reader might first consult the bibliography in Bertalanffy's *General System Theory* and the article by Talcott Parsons, "Social Systems," in *Encyclopedia of the Social Sciences*, 1968, 15: 458–72. More specific as an introduction to technological systems is Günter Ropohl, *Eine Systemtheorie der Technik: Zur Grundlegung der Allgemeinen Technologie* (Munich and Vienna: Hanser, 1979), which has an extensive bibliography.

In 1978, Bertrand Gille, the French historian of technology, published an extensive historical survey in which he used a systems model of the development of technology to place the history of technology in the context of general history. His model involved technology as structures, technical ensembles, and technical concatenations. These correspond roughly to machines, processes, and civil-engineering works (structures); production, communication, and transportation systems (ensembles); and such systems interrelated vertically and horizontally by general production or output (concatenations). Gille used the model to range over human history and explain technical progress. I am indebted to Professor Cecil Smith for sharing his unpublished English translation (1981) of Bertrand Gille's "A Systems History of Technology" (*Histoire des techniques* [Paris: Gallimard, 1978]). Gille's model was brought to my attention after I completed my manuscript, but I find no cause to revise my own model, which interprets a relatively circumscribed case history in fine detail.

network provides a distinctive configuration for the system. For example, a system can have its components arranged vertically or horizontally.

According to widespread usage, a horizontally arranged system interconnects components of the same kind or function, though not necessarily of the same magnitude, while a vertical system interconnects components joined in a functional chain. For example, an electrical system of the horizontal kind combines power plants under central control, while a production system of the vertical kind might link a coal mine to an electric power plant through a central control facility coordinating the supply of coal and the output of electricity. Systems are also arranged hierarchically, with small systems yielding to the overriding control of a large encompassing system. Systems also interact with one another through the coordination of semiautonomous controls, but without yielding to an overriding control. Although it is customary to define systems as technical, economic, political, or social, the centralization of at least a loose control over systems of these different kinds makes possible the conceptualization of sociotechnical systems and the like.

Those parts of the world that are not subject to a system's control, but that influence the system, are called the environment. A sector of the environment can be incorporated into a system by bringing it under system control. An open system is one that is subject to influences from the environment; a closed system is its own sweet beast, and the final state can be predicted from the initial condition and the internal dynamic. Some systems are planned to their full extent, while others grow by increments and by confluence with other systems over time. All of the kinds and conditions of systems noted in this abstract definition will be illustrated and described in detail in the history that follows.[5]

Usually in this study, "system" refers to a technical system, such as an electric transmission system. Sometimes reference is, as noted, to a system with interacting components, some of which are not technical. Centrally directed, interacting institutions and technical components comprise such a system. On occasions, however, the concept of system is used much more loosely. "System" then means interacting components of different kinds, such as the technical and the institutional, as well as different values; such a system is neither centrally controlled nor directed toward a clearly defined goal. This usage is similar to that of the historian who writes of a system of nation-states. Such a loosely structured system is similar to the concept embodied in "syndrome." All of the systems, it is important to stress, share the characteristic of interconnectedness—i.e., a change in one component impacts on the other components of the system.

[5] An interesting discussion of electrical systems and their management is found by Georg Boll, *Entstehung und Entwicklung des Verbundbetriebs in der deutschen Elektrizitätswirtschaft bis zum europäischen Verbund* (Frankfort on the Main: VWEW, 1969), pp. 13–15. Articles on interconnections and electric systems were frequently published in technical periodicals during the latter half of the period covered by the present study, and many are cited in the various chapters of this book. More recent helpful discussions of electrical systems include: Hans Glavitsch, "Computer Control of Electric-Power Systems," *Scientific American*, November 1974, pp. 34–44; Wallace Brand, "Northeast Electric Bulk Power Supply, *Public Utilities Fortnightly*, 9 June 1966, pp. 65–88; and U.S., Federal Power Commission, *The 1970 National Power Survey*, pts. 1–4 (Washington, D.C.: GPO, 1971).

Electric power systems of the technical kind consist of power generation, transformation, control, and utilization components and power transmission and distribution networks. (The primary distinction between transmission and distribution is the greater distance covered, and therefore the higher transmission voltages used, in transmission.) During the half-century 1880–1930, power generation components included coupled prime movers such as reciprocating steam engines and steam and water turbines. Various types of generators were coupled to the prime movers. Transformers became the principal mode of changing the characteristics of electric supply during transmission and distribution. Energy utilization components included lamps, motors, both stationary and traction (moving), and heating and electrochemical devices. The system incorporated a multitude of applications (see Fig. I.3). Power transmission increased in extent from a few city blocks to regions comprising tens of thousands of square miles. Power distribution networks carried the electric supply from the transmission network to the power utilization machinery and appliances. Control components regulated the supply system in accordance with established standards such as voltage and frequency and directed the system for optimum performance as measured by goals, including efficiency and economy. The most difficult challenge in defining an electric supply system arises at the extreme supply and demand ends of the system. For instance, should the mechanical prime mover be included in the definition of a system? Should the various loads be included, considering that they were usually outside the control of the system? In this study the prime movers have been included in the definition of the system because the inventors, engineers, and industrial scientists treated them as such and because the characteristics of the prime mover were coordinated with the other components of the electric system. Furthermore, the prime movers were under the system's control. The invention and development of motors have been treated in this study because inventors and designers matched the characteristics of motors to those of the electric supply system. Such complications will be clarified by historical example.

The rationale for undertaking this study of electric power systems was the assumption that the history of all large-scale technology—not only power systems—can be studied effectively as a history of systems. It is hoped, therefore, that this history of a particular kind of system will be of some assistance to other historians who wish to study other systems. The assumption of similarity is based in part on an analysis of studies of large systems by other historians who have used the concept of the system to organize, analyze, and draw conclusions from disparate materials.[6]

[6] In another source, I have discussed at some length the use of the systems approach by Lynn White, Jr., *Medieval Technology and Social Change* (New York: Oxford University Press, 1962); Karl Marx, *Capital: A Critique of Political Economy*, ed. Friedrich Engels, 3 vols. (Chicago: Kerr, 1932–33); and Alfred D. Chandler, Jr., *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, Mass.: Harvard University Press, 1977). See Thomas P. Hughes, "The Order of the Technological World," in *History of Technology, 1980*, ed. A. Rupert Hall and Norman Smith (London: Mansell, 1980), pp. 1–16.

Among recent books in which other historians discuss technology as systems are Hugh Aitken, *Syntony and Spark: The Origins of Radio* (New York: Wiley, 1976); Edward W. Constant II, *The Origins of the Turbojet Revolution* (Baltimore: The Johns Hopkins Unversity Press, 1980);

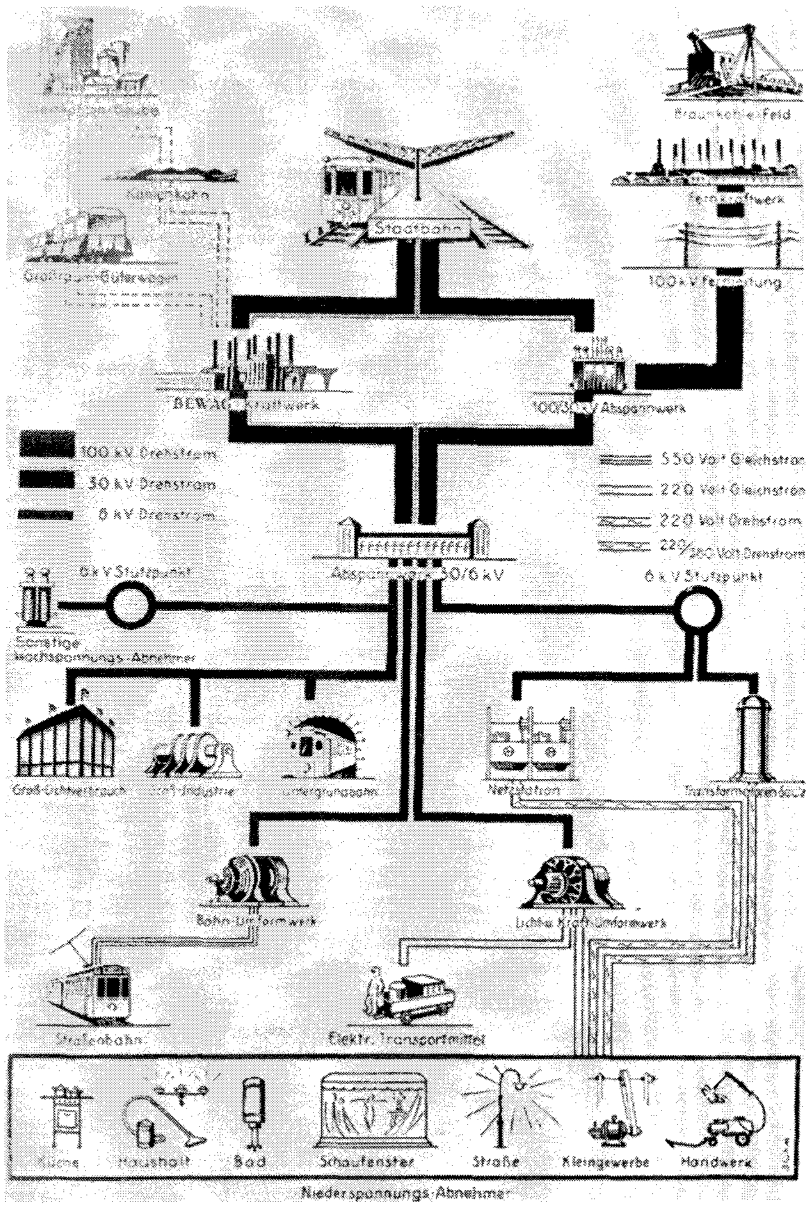


Figure I.3. *Universal supply system, Berlin, c. 1930. from Matschoss et al.,* 50 Jahre, *p. 90.*

John Enos, *Petroleum Progress and Profits: A History of Process Innovation* (Cambridge, Mass.: M.I.T. Press, 1962); Louis C. Hunter, *Steamboats on the Western Rivers: An Economic and Technological History* (Cambridge, Mass.: Harvard University Press, 1949); idem, *Waterpower: A History of Industrial Power in the United States, 1780–1930* (Charlottesville: University Press of Virginia, 1979); Arthur Johnson, *The Development of American Petroleum Pipelines: A Study in Private Enterprise and Public Policy* (Ithaca, N.Y.: Cornell University Press, 1956); David Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge: At the University Press, 1972); Otto Mayr, *Feedback Mechanisms in the Historical Collections of the National Museum of History and Technology* (Washington, D.C.:

Key to Figure I.3. Translation of terms

GERMAN	*ENGLISH*
Steinkohlen-Grube	*Hard-coal mine*
Braunkohle-Feld	*Brown-coal open-face mine*
Kohlenkahn	*Coal barge*
Stadtbahn	*City railway*
Fernkraftwerk	*Distant power station*
Grossraum-Güterwagen	*Long-distance coal transport*
Fernleitung	*Long-distance transmission lines*
BEWAG-Kraftwerk	*Berlin power station*
Abspannwerk	*Step-down transformer station*
Drehstrom	*Polyphase current*
Gleichstrom	*Direct current*
Stützpunkt	*Distribution center*
Sonstige Hochspannungs-Abnehmer	*Special high-voltage consumer*
Gross-Lichtverbrauch	*Large-scale light consumer*
Gross-Industrie	*Heavy industry*
Untergrundbahn	*Subway*
Netzstation	*Dispatching center*
Transformatoren-Säule	*Distribution transformer*
Bahn-Umformwerk	*Motor-generator converter (traction load)*
Licht-u. Kraft-Umformwerk	*Motor-generator converter (light and power load)*
Strassenbahn	*Streetcar*
Elektr. Transportmittel	*Electric truck*
Küche	*Kitchen appliances*
Haushalt	*Household appliance*
Bad	*Hot water*
Schaufenster	*Display window*
Strasse	*Street lighting*
Kleingewerbe	*Commercial consumer*
Handwerk	*Craftsman*

The emphasis on, and delineation of, technological systems by historians and social scientists; the drive of inventors, engineers, appliers of science, managers, and financiers to create systems;[7] and the obvious systematic character of electric power systems have all stimulated the organization of this study as a history of systems. The study is complex because it is a

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Smithsonian Institution, 1971); Bruce Mazlish, ed., *The Railroad and the Space Program: An Exploration in Historical Analogy* (Cambridge, Mass.: M.I.T. Press, 1965); Elting Morison, *Men, Machines, and Modern Times* (Cambridge, Mass.: M.I.T. Press, 1966); Nathan Rosenberg, ed., *The American System of Manufacturers* (Edinburgh: Edinburgh University Press, 1969).

There are interesting parallels between this study of electrical systems and the history of growth and technological change in the chemical industry as periodized and organized by L. F. Haber in *The Chemical Industry, 1900–1930* (Oxford: Clarendon Press, 1971).

[7] One such inventor and engineer, Elmer Sperry (1860–1930), devoted a lifetime to inventing and developing technological systems. His systems were mostly electromechanical in nature and involved highly complex feedback controls. The study of hundreds of his patents for these systems has influenced my own concepts of technological systems. See Thomas P. Hughes, *Elmer Sperry, Inventor and Engineer* (Baltimore: The Johns Hopkins Press, 1971).

comparative one involving developments in three different countries over a period of fifty years. The problem of organization was further complicated by the necessity of selecting representative power systems from different regions for different phases of the history. There were thousands of independent utility systems to choose from. An explanation of each selection will be given in the body of the text; here the overall structure of the history will be outlined.

Although the electric power systems described herein were introduced in different places and reached their plateaus of development at different times, they are related to one another by the overall model of system evolution that structures this study at the most general level. The model has phases, and dominant characteristics are shown to emerge during each; in addition, the model identifies the particular capabilities and interests of the professionals who presided over system growth in each of the phases. In the first phase, the invention and development of a system are considered. The professionals playing a predominant role during this phase are inventor-entrepreneurs, who differ from ordinary inventors in that the former preside over a process which extends from the inventive idea through development to the time when the invented system is ready to be used. Engineers, managers, and financiers also are involved in this first stage, but they do not preside over the system's growth until later phases.

The second phase of the model directs attention to the process of technology transfer from one region and society to another. The transfer of the Edison electric system from New York City to Berlin and London is a case in point. The sites are specific, but general observations about the transfer process can be made. During this phase the agents of change are numerous; they include inventors, entrepreneurs, organizers of enterprises, and financiers.

The essential characteristic of the third phase of the model is system growth. As noted earlier, the historian is responsible for analyzing growth, and analyzing the growth of systems is a particularly interesting and difficult challenge. The method of growth analysis used in this study involves reverse salients and critical problems. Because the study unit is a system, the historian finds reverse salients arising in the dynamics of the system during the uneven growth of its components and hence of the overall network. In labeling such areas of imbalance "reverse salients," the author has borrowed from military historians, who delineate those sections of an advancing line, or front, that have fallen back as "reverse salients." The metaphor is appropriate because an advancing military front exhibits many of the irregularities and unpredictable qualities of an evolving technological system. In the case of a technological system, inventors, engineers, and other professionals dedicate their creative and constructive powers to correcting reverse salients so that the system can function optimally and fulfill system goals.

Having identified the reverse salients, the system tenders can then analyze them as a series of critical problems. Defining reverse salients as critical problems is the essence of the creative process. An inventor or applier of science transforms an amorphous challenge—the backwardness of a system—into a set of problems that are believed to be solvable. Engineers in particular are known for their ability to define solvable problems. The inventor's or engineer's confidence that the reverse salient can be corrected increases dramatically once the problems are defined, because the articulation of a problem often implies its solution.

When engineers correct reverse salients by solving critical problems, the system usually grows if there is adequate demand for its product. On occasion, however, a critical problem cannot be solved. For instance, the first of the major types of electric systems, direct current, had a reverse salient in that it was uneconomical to transmit. Despite precise definitions of the problem, the direct-current inventors and engineers could not in the 1880s find a solution. As a result, other inventors found a solution outside the d.c. system, and for a time the two systems were in conflict. After a compromise was worked out, the two systems existed in a complementary way until the newer system became the dominant one. Thus, this study offers an explanation not only of the evolution of systems as reverse salients are identified and solved, but also of the occasional emergence of new systems out of the failure to solve critical problems in the context of the old.

As a system grows, it acquires momentum. The fourth phase of the system model is characterized by substantial momentum. A system with substantial momentum has mass, velocity, and direction. In the case of technological systems, as defined in this study, the mass consists of machines, devices, structures, and other physical artifacts in which considerable capital has been invested. The momentum also arises from the involvement of persons whose professional skills are particularly applicable to the system. Business concerns, government agencies, professional societies, educational institutions, and other organizations that shape and are shaped by the technical core of the system also add to the momentum. Taken together, the organizations involved in the system can be spoken of as the system's culture. A system with such mass usually has a perceptible rate of growth or velocity. Often the rate accelerates. A system usually has a direction, or goals. The definition of goals is more important for a young system than for an old one, in which momentum provides an inertia of directed motion.

In the case of electric power systems, the institutions that presided over and were influenced by them most directly were the utilities, both public and private. From about 1890 until World War I, the major electric power utilities in the United States, Germany, and England concentrated on supplying the most heavily populated and industrialized urban centers. The decisions made by the utilities' managers during this period shaped the character of the systems more obviously than did the decisions of inventors and engineers, whose solutions to critical problems of a technical kind had cleared the way for growth through the creation of a universal system of supply. With increasing frequency during the two decades before the Great War, the utilities found themselves confronting other institutional contenders for authority over economic development and social change. The tension between the utilities and political institutions such as local governments was high during this phase of systems development. In this instance, however, a *modus vivendi*, if not a lasting arrangement, was found by the contending powers. Three chapters in this study have thus been devoted to an examination of the evolution of the electric power systems in three major cities: Berlin, Chicago, and London.

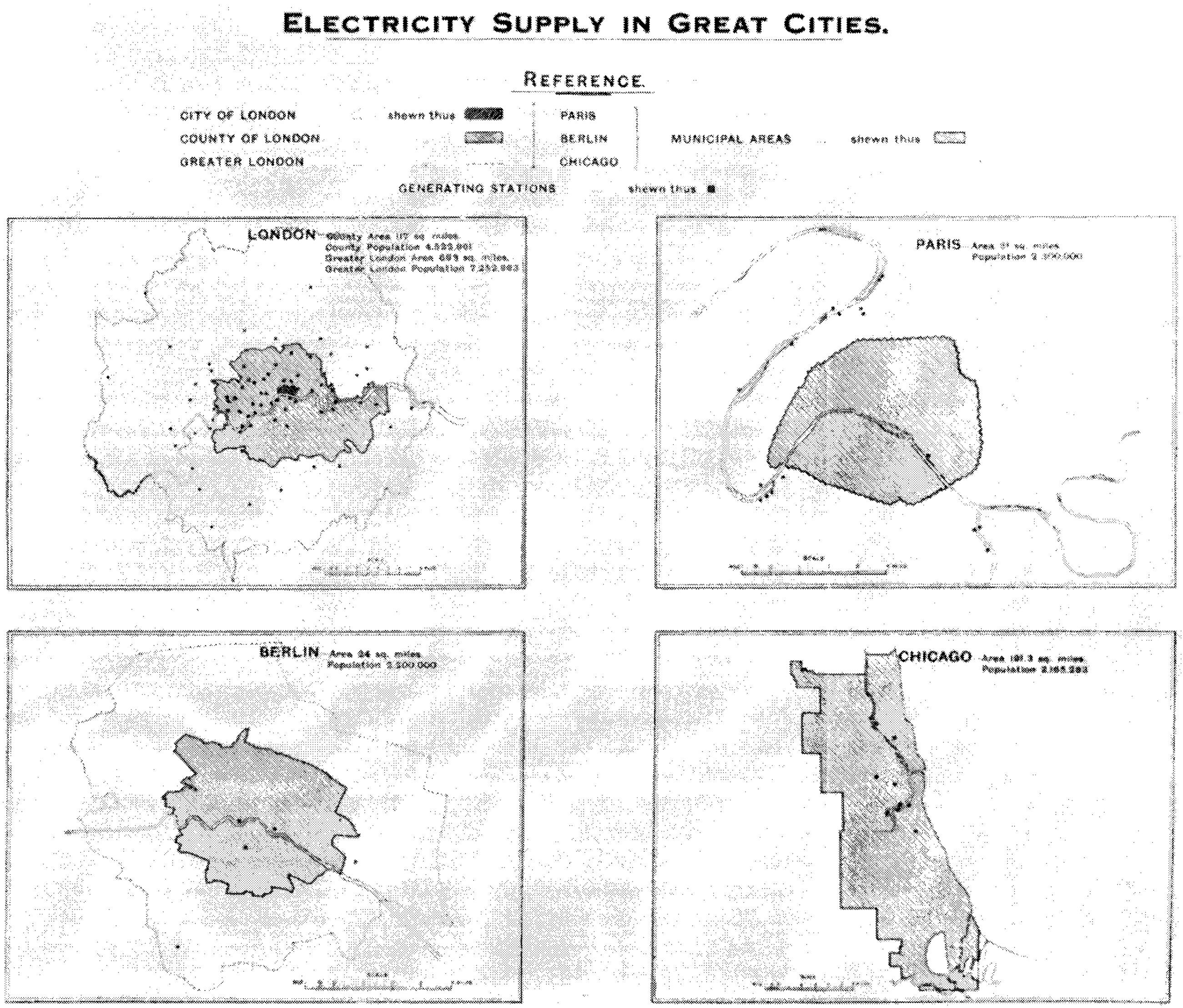

Figure I.5. *Central stations in London, Berlin, Paris, and Chicago, c. 1920. From the County of London Electric Supply Co., Ltd.,* Public Inquiry Held by the Electricity Commissioners in Connection with Application for Consent for the Erection of a Power Station at Barking. *Courtesy of NESCO, Newcastle upon Tyne, England.*

Despite the momentum of systems and the inertia of motion, however, contingencies push systems in new directions. To demonstrate this phenomenon, this study explores the impact of World War I on electric power systems. The engineers and managers who presided over these systems were persuaded by political and military leaders and by public pressure to attenuate their customary drive for autonomous growth and profit and to emphasize the cooperative production of energy. Assigning energy production a higher priority than either profit or organizational autonomy led to new managerial and engineering policies for the duration, and some of these survived the war. The essential point, however, is not the particular instance of war as a contingent and shaping force; rather, it is the possibility of external forces redirecting high-momentum systems.

The last phase of system history delineated by this study is characterized by a qualitative change in the nature of the reverse salients and by the rise of financiers and consulting engineers to preeminence as problem solvers. Managers played the leading role during the phase characterized by an increase in momentum. In the newer phase, which involved planned and evolving regional systems, major reverse salients became essentially problems of funding extremely large regional systems and clearing political and legislative ground. Financiers and associated consulting engineers responded effectively to problems of this kind and scale. The phase was also characterized by an increased capability on the part of engineers and managers, especially consulting engineers and managers, to plan new systems and the growth of old ones. In some cases planned systems were financed by government agency entrepreneurs drawing on public funds.

This loosely structured model has been used to bring order and comprehensibility to the myriad events in the history of electric power systems. In fact, utility systems did not evolve according to one strict pattern. Chapter XIV, which describes the different styles of three mature regional systems, demonstrates variations. All three had the same pool of technology to draw from, but because the geographical, cultural, managerial, engineering, and entrepreneurial character of the three regions differed, the power systems were appropriately varied as well (see Fig. I.5). The concept of style suggests that there was—and probably is—no one best way of supplying electricity. Embodied in the different power systems of the world is a complex variation on major themes that keeps the technology from becoming homogeneous and dull and that provides the historian with the challenging task of description and interpretation.

History of Technology

Awarded the Dexter Prize by the Society for the History of Technology

"An exciting, major contribution to the field of history, for it establishes very convincingly that the growth of . . . power networks is as intrinsic to and characteristic of modern society as the growth of manorialism was to medieval society."—*American Historical Review*

A unique comparative history of the evolution of modern electric power systems, *Networks of Power* not only provides an accurate representation of large-scale technological change but also demonstrates that technology itself cannot be understood or directed unless placed in a cultural context. For Thomas Hughes, both the invention of the simplest devices (like the lightbulb itself) and the execution of the grandest schemes (such as harnessing the water power of the Bavarian Alps) fit into an overarching model of technological development. His narrative is an absorbing account of the creative genius, scientific achievements, engineering capabilities, managerial skills, and entrepreneurial risks behind one of the most commonplace amenities of the modern age.

"That a range of historians not specialists in the history of technology, as well as those who are, will find this book impossible to ignore, is a measure of the interpretive challenge that Thomas Hughes has thrown out to the historians of two continents and beyond. The discussion of electric power systems will never be the same again. But it offers more than that. The quality of production is impeccable and the many illustrations are chosen to give an unmistakably authentic sense of the period. The very atmosphere of the pioneering utilities and the early electrical engineering profession permeates a work of scholarship that is no less pathbreaking in its field than they in theirs."—*Isis*

"How the West was wired."—*Times Literary Supplement*

Thomas P. Hughes is professor of the history of modern science and technology at the University of Pennsylvania and a member of the American Academy of Arts and Sciences. His books include *Changing Attitudes toward American Technology* and *Elmer Sperry, Inventor and Engineer.*

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