BIOGRAPHY OF A TECHNOLOGY: NORTH AMERICA'S POWER GRID THROUGH THE TWENTIETH CENTURY

A Dissertation

Presented to

The Faculty of the Department

of History

University of Houston

In Partial Fulfillment

Of the Requirement for the Degree of

Doctor of Philosophy

By

Julie A. Cohn

May 2013

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Abstract

North Americans are among the world's most intense consumers of electricity. The vast majority in the United States and Canada access power from a network of transmission lines that stretch from the East Coast to the West Coast and from Canada to the Mexican Baja. This network, known as the largest interconnected machine in the world, evolved during the first two thirds of the twentieth century. With the very first link-ups occurring at the end of the 1890s, a wide variety of public and private utilities extended power lines to reach markets, access and manage energy resources, balance loads, realize economies of scale, provide backup power, and achieve economic stability. In 1967, utility managers and the Bureau of Reclamation connected the expansive eastern and western power pools to create the North American grid. Unlike other power grids around the world, built by single, centrally controlled entitities, this large technological system emerged as the result of multiple decisions across eighty-five years of development, and negotiations for control at the economic, political, and technological levels.

This dissertation describes the process of building the North American grid and the paradoxes the resulting system represents. While the grid functions as a single machine moving electricity across the continent, it is owned by many independent entities. Smooth operations suggest that the grid is a unified system; however, it operates under shared management and divided authority. In addition, although a single power network seems the logical outcome of electrification, in fact it was assembled through aggregation, not planning. Interconnections intentionally increase the robustness of individual sub-networks, yet the system itself is fragile, as demonstrated by major cascading power outages. Finally, the transmission network facilitates increased use of energy resources and consumption of

power, but at certain points in the past, it also served as a technology of conservation. While this project explores the history of how and why North America has a huge interconnected power system, it also offers insights into the challenges the grid poses for our energy future.

Acknowledgements

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This dissertation is dedicated to Nathan Cohn, accomplished engineer, avid story-teller, and loving father. Thank you for the invitation to wonder about our interconnected world.

Biography of a Technology: North America's Power Grid Through the Twentieth Century

Introduction

To an elementary-age girl on vacation in Florida, an insider's view of the control room at a power plant was a dull side-trip. The noisy buzzing of a transformer station could not stand up to the allure of beach sand, waves, and sunshine. The droning voices of men admiring meters and charts held little interest. And yet, when this girl's father explained the control of generation and power flow on interconnected systems – a string of words that would normally induce sleep in any child - his passion for his work was palpable. After all, he was discussing a collection of technologies known as the world's largest machine: the interconnected power system that kept the lights on and industry moving. It was and still is a network that connects nearly every living soul on the continent. The side-trips, the buzzing, the meters, the droning voices, the long explanations, all were part of the story of North America's power grid.[1]

For most Americans, the grid is nearly invisible, utterly essential, and taken for granted, except when it fails. The most recent spectacular example, the blackouts resulting from Hurricane Sandy, merely reinforces the extent to which this legacy technology is underappreciated and poorly understood. In the twenty-first century, as countries grapple with high consumer demand for electricity, fraught discussions of energy resources, global warming, and new technologies for producing power, the grid will play a role in determining

[1] According to *Merriam-Webster* a machine is "an assemblage of parts that transmit forces, motion, and energy one to another in a predetermined manner." *Merriam-Webster Online*, s.v. "machine," accessed February 16, 2013, http://www.merriam-webster.com/dictionary/machine. For the past several decades, journalists, scientists, engineers, and utility experts have referred to North America's electric power grid as the biggest machine in the world, or sometimes more specifically the biggest *interconnected* machine in the world.

the energy future. To make reasonable choices for the future, as historians are wont to remind the public, it is necessary to consider the past. In this instance, the past can inform a contemporary understanding of what the grid does, why Americans chose this path to electrification, and how the North American approach to moving power is unique across the globe.[2]

The term "grid" is a colloquialism used to describe the collection of machines and wires that transmits large quantities of electricity across long distances. The machine referred to as the North American grid serves most of the continental United States and Canada, plus a small part of Mexico. The US Energy Information Administration describes the grid as "the network of nearly 160,000 miles of high voltage transmission lines" that moves electricity from power plants to substations and eventually to consumers.[3] The North American Electric Reliability Corporation (NERC) uses similar terms: "the network of interconnected electricity lines that transport electricity from power plants and other generating facilities to local distribution areas."[4] An expert with NERC noted, however, that the broadest definition also includes power stations and transformers as well as the transmission lines used to move electricity. While these definitions capture in nontechnical terms what the grid is and does,

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[2] Hurricane Sandy, and the Nor-easter storm that followed, together left nearly nine million customers without electricity along the eastern seaboard. Utilities spent nearly a month repairing power lines, transformers, and other electrical equipment in order to fully restore power to consumers. The effects of the storm highlighted both the elements of the power system that are vulnerable to weather events and those that are vulnerable to outages due to age, location, and weak protections. "Hurricane Sandy-Nor-easter Situation Reports," US Department of Energy website, last updated December 3, 2012, http://energy.gov/articles/hurricane-sandy-noreaster-situation-reports.

[3] "Electricity Explained: How Electricity is Delivered to Consumers," US Energy Information Administration website, accessed March 5, 2013, http://www.eia.gov/energyexplained/index.cfm?page=electricity_delivery. Depending on the voltage used, some entities state that there are over 200,000 miles of high-voltage power lines comprising the grid.

[4] "Understanding the Grid: *Reliability Terminology*," North American Electric Reliability Corporation website, accessed March 5, 2013, http://www.nerc.com/page.php?cid=1|15|122.

the essence of the grid is both more and less than these explanations offer, the first paradox in the story of building North America's interconnected power system.[5]

The grid is more, in that it is a crucial lifeline in the modern world's energy-dependent economy. The network of power lines reaches across hundreds of thousands of miles to connect 334 million people in the continental United States, Canada, and parts of Mexico. More than 3.9 trillion kilowatt-hours of electricity travel through the grid each year. That is enough electricity to keep one 100-watt incandescent light bulb burning for 4.4 billion years (if it did not otherwise wear out). Further, in the United States, electric power accounts for forty percent of the energy used annually. The interconnected power system allows North Americans to rank among the top energy consumers in the world.[6]

The grid is less, in that it is, to a degree, a phantom and a hodgepodge. There really is no "one" grid, even though the physical links between many smaller systems exist. There are actually four major discreetly operated grids in North America, and each of these is comprised of many smaller grid systems. In general, power generated in California is used in the west, not in New York, although technically it could be. While a single, national, government-certified, private "electric reliability organization" (namely, NERC) oversees reliability of the system in the United States, eight regional reliability councils coordinate operation of the grid, dozens of state and provincial agencies regulate segments of the grid in the United States and Canada, and thousands of entities own the bits and pieces of the networks that comprise the grid. In fact, when a speaker refers to "the grid," he or she may be

[5] Dave Nevius, recently retired Senior Vice President, North American Electric Reliability Corporation (NERC), personal communication with the author, January 9, 2013.
[6] "Energy in Brief," US Energy Information Agency Website, accessed January 20, 2013, http://www.eia.gov/energy_in_brief/article/major_energy_sources_and_users.cfm.

talking about the entire system that reaches from coast to coast and across international boundaries, or any one of the subsystems that serves a region.[7]

The grid is also less because there are several major regions of North America that operate independently, namely Texas, Quebec, and large parts of Mexico. Texas offers the most interesting parallel narrative to the development of the larger grid. As in other parts of the country, numerous entrepreneurs built small power systems in Texas in the late 1800s. The first long-distance power line connected Waco to Fort Worth in 1912. Private utilities dominated the Texas power industry, although rural electrification took place under the auspices of federally financed cooperatives beginning in the 1930s. Texas utilities were often early adopters of new technology, and electrification grew steadily throughout the century. Texas legislators, however came late to the regulatory process, instituting state level utility oversight in 1975. Private utilities likewise avoided federal regulation by maintaining intra-state interconnections but shunning interstate interconnections even to this day. Weak links tie the majority of Texas to the rest of the United States, but they remain open (which means that power does not cross the link) and have seldom been used. Areas along the eastern state line connect with Louisiana rather than the rest of Texas. Likewise, parts of far west Texas connect into New Mexico, but not the rest of Texas. The Electric Reliability Council of Texas manages the movement of the majority of the state's power supply over a network operationally separate from the rest of the United States. Quebec's power system operates independently as well, primarily for physical rather than economic or political reasons. Past

[7] The four major interconnected systems are: The Electric Reliability Council of Texas (ERCOT), The Quebec Interconnection, The Eastern Interconnect (states and provinces east of the Rocky Mountains), and The Western Interconnect (states and provinces west of the Rocky Mountains). "About NERC," The North American Electric Reliability Corporation website, accessed January 20, 2013, http://www.nerc.com/page.php?cid=1.

attempts to link Quebec utilities to the rest of the grid resulted in major instability on the power lines.

The story of how North Americans built the world's largest machine reveals several additional paradoxes. First, from the twenty-first century perspective, interconnecting large power lines to achieve widespread electrification, economies of scale, and long-distance movement of energy appears rational and logical. The grid, however, was assembled through aggregation, not planning; the technology was problematic; and opponents periodically contested the project. Electrifying the continent with interconnected power systems was not inevitable. Second, while the grid functions smoothly as a unified power delivery network, it operates under systems of shared management and divided authority. No one central entity plans, builds, owns, operates, or regulates the grid. Numerous public and private entities cooperate to move power across the continent, but maintain autonomous physical and economic operations. Third, interconnections increase the robustness of individual sub-networks, yet the use of alternating current and the lack of a single controlling authority together render the system fragile. Finally, historically, the grid made electricity more affordable and reliable. Power companies reaped profits because they promoted increased consumption with the promise of reasonable rates and never-failing power. But, the grid also provided utilities with the means of carefully managing energy resources for the long-term. The grid was a technology of conservation for the power industry at different points during the twentieth century.

The Paradoxes of the Grid

Today, with communications and data networks that span the globe, the idea of building electric power systems into a giant network appears natural, if not inevitable. Yet, the interconnected power systems of North America grew in fits and starts, with significant regional differences, and resistance from multiple sectors along the way. The technologies selected in early decades to extend power markets and link generating and transmission networks, did not determine the direction of electrification. But they did present both opportunities and challenges to utility managers and engineers.

Over the course of the twentieth century, the power producers chose to interconnect when to do so achieved particular goals related to profitable operations, reliability, equitable access for customers, and resource conservation. However, the preference for alternating current posed particular stability problems that challenged experts for decades. As a result, while many argue that a consensus in favor of interconnections had been established by the 1930s, in fact two more decades passed before the majority of electric companies really shared power on a full-time basis. And even then, in the early 1960s, many utilities still operated independently, without links to the large power pools.

With a wide array of governmental and economic entities involved in electrification, plans for interconnection were contested throughout the process. Although most in the industry favored interconnections, no one plan provided a guiding blueprint for how to achieve this and no one entity ever succeeded in gaining control over the process. Many power companies, whether owned by municipalities, rural cooperatives, or private investors, resisted widespread interconnections. Regional differences in energy resources, political preferences, geographic limitations, and technical choices further complicated the process. When networks of power east and west of the Rocky Mountains began to trade electricity in 1967, albeit in very small quantities, it was the result of deliberate choices, technical innovations, political debates, and varying economic interests negotiated across the decades of the twentieth century.

While the rest of the world admired the stability and sophistication of the North American power system, for over a century no entity regulated the grid. Instead, utilities traded information, negotiated operating agreements, and adopted standards, on a totally voluntary basis. The uniformity of power delivery belied the array of agencies at all levels of government that shared responsibility for regulating private utilities. In the United States and Canada, governments have chosen to regulate private enterprises for a variety of reasons, including protection of the public interest, improving conditions of the market to benefit business interests, achieving social objectives, and accomplishing economic aims. At different times, governments at all levels attempted to intervene in the power business to address each of these regulatory goals, using treaties, laws, administrative rules, and even direct competition.

Investor-owned utilities, otherwise known as private utilities, dominated electrification from the very start in North America. The utility owners pushed back against regulatory interference with the power business, except when it served to protect their own monopoly status and improve the conditions of the market. The grid itself, which served to move power from place to place, tended to fall into a regulatory gap. As a result, multiple governments shared responsibility for protecting the public interest with regard to electricity, primarily guarding against exorbitant rates and assuring equitable access to power. But the industry essentially regulated itself with regard to the safety, stability, and reliability of power networks. In the vacuum left by repeated defeat of proposals to control electrification, multiple governments and the utilities themselves cobbled together a system of shared management and divided authority that respected both the capitalist origins of electric service and the democratic push to make access to electricity equitable.

Organizationally the grid functioned under systems of shared management and divided authority as well. From the earliest experiments to link power stations owned by more than one company, at the end of the nineteenth century, utilities agreed to trade power across interties, while respecting the economic autonomy of each participant. As networks grew, so too did the nature of cooperating agreements. By the 1920s, some utilities created formal power pools with written contracts determining how to operate interconnected. Yet, as late as the 1960s, many power pools still shared electricity through informal interactions. Whether contractual or word-of-mouth, the nature of the operating arrangements consistently included provisions to assure stable conditions on the network. At the same time, never did a power pooling agreement abrogate the economic independence of any participating utility, whether owned by a municipality, a rural co-operative, a government agency, or private investors. Regional and national organizations, formed by the utilities themselves, established technical and operating standards, but only for voluntary compliance.

The technical approach to moving power across complex interconnections grew to resemble these regulatory and organizational schemes. At first, system operators controlled shared power by maintaining communications over the telephone and manually switching levers at the power stations. In the 1920s and 1930s, engineers modeled early automatic control technologies on the central station approach to electrification. A device at one station attempted to maintain stability on the network for several interlinked power stations. But, just as companies operating the power stations had distinct economic objectives, so too each station had to respond to distinct demands for electricity. Over time, the engineers devised the means to distribute the authority for responding to local demand to the local power station while assuring that all stations shared responsibility for keeping the system stable and avoiding shut-downs.

Interconnection offered power companies cost-effective redundancy. In other words, through interconnections, public and private utilities were able to minimize investment in back-up power by relying on neighbors to share electricity during planned and emergency outages. This approach to electrification gained praise for adding robustness to the expanding power system. North America uses primarily alternating current (ac), and this introduced an element of instability that plagues the grid even today. Operating multiple ac power stations on an interconnected network requires precise and constant oversight and adjustment. One small error can cause a huge power failure, as witnessed several times over the past fifty years. The engineers and operators who assembled the grid through the 1930s, 1940s, and 1950s assumed that they designed procedures and apparatus sufficient to prevent major outages, yet the 1965 blackout, a cascade of failures resulting from one mistaken relay setting, illustrated the inherent fragility of the grid.

The preference for alternating current over direct current in North American power systems, which dates back to the early decades of electrification, opened up opportunities for expansion. Utilities selected ac current because they could transmit it over longer distances at an affordable cost and, with the introduction of the induction motor and transformers, they could provide power to more customers for a greater variety of uses. This met a key goal of power companies – to build bigger markets and improve the profitability of operations. Power companies further elected to interconnect for several reasons, mostly economic, but also to gain greater reliability. As more and more customers adopted electricity for various uses, uninterrupted service became essential. Through an interconnection, utilities could provide each other with backup power. But, because the power companies were sharing alternating current, they had to address certain physical properties of electricity that threatened to undo the interconnections. It fell to the engineers and system operators to design techniques and apparatus for controlling the electricity moving across the links between two or more systems. Of course, these individuals usually worked for multiple employers, which added another set of concerns to the already challenging technical problem at hand.

For the most part, the inventions for controlling interconnections kept pace with the growth of power pools through the middle of the twentieth century. Power control experts in North America addressed the goals of their employers, by devising automatic control techniques that matched the increasing complexity of the electrical networks and the growing demand for electricity. These engineers prided themselves on their success in managing expansion with a minimum of disruption. Power system engineers also tended to see their work as a service to the public, even when they worked for profit-seeking companies, because they were assuring customers of a steady and safe supply of electricity. But, maintaining stability on large and complex power networks demanded solutions that took decades of experimentation and revision, and are not perfectly resolved. Nearly every major blackout of the past half-century not attributed to natural weather events can be traced to a flawed setting that triggered a series of failures in a very short period of time. In essence, the utilities sought physical security through large networks, but at the same time they exposed themselves to failure on a very large scale, often resulting from minor oversights.

Perhaps the most significant paradox of the grid is the role it played in both consumption and resource conservation. In the early decades of the twentieth century, industry experts frequently used the term "conservation" to describe the benefits offered by interconnection. In fact, they lauded the opportunity to reduce reliance on coal, maximize the use of falling water, and limit urban air pollution through the development of interlinked power systems, all aligned with the contemporaneous Progressive Era conservation movement. At the same time, however, utilities actively promoted increased consumption of electricity. They shared with each other tips for bringing down the cost of electricity through interconnection so that they could encourage greater usage. Rising consumption had the dual benefit of allowing utilities to reduce the cost per kilowatt-hour of electricity while bringing in more revenues, both of which increased profits. In the case of publicly owned power companies, increased consumption improved operating economies, even when profits were not at stake.

The term “conservation” has a mixed history in North American usage. The word itself originated in Latin, and means to preserve, to guard, and to observe. In the nineteenth century, physicists formulated the law of conservation of energy, stating that the total amount of energy in a closed system, while it may move or change form, remains constant. This is relevant to the history of the grid because inventors, engineers, and others working on electrification studied the laws of physics and adopted terminology from that scientific field to describe phenomena in power systems. For example an electrical engineer might use the word “conservation” to describe the effort to curb the loss of energy as power was transmitted across a distance. In the later nineteenth century, the notion of conservation was applied to various initiatives that arose to protect scenic beauty and manage natural resources.

By the early twentieth century, political leaders appropriated the word to define elements of Progressive Era activism that sought greater central control and increased scientific authority over management of North American resources, including energy resources. Influenced by the relatively young scientific field of ecology, over the course of the mid-twentieth century the meaning of conservation expanded to include protection of natural resources against destruction by pollution and overuse. By the end of the twentieth century, the word conservation was often conflated with environmentalism.[8]

The trajectory of electrification took place in the context of this evolving meaning of conservation. While experts within the industry adopted the use of "conservation" to address specific issues related to the production and distribution of electricity, they were not immune to broader public use of the term. In the early decades of electrification, utility managers, engineers, and system operators frequently embraced the Progressive Era notion of conservation to represent the technical and economic concerns of the industry. Likewise, Progressive leaders lauded engineers as the ideal experts to plan resource conservation projects. From World War II to 1960, when public interest in conservation of resources faded, engineers still focused on energy efficiency through improved operation of interconnected systems. Control engineers saw themselves as advocates for energy conservation throughout the mid-century. During the rise of the modern environmental movement in the 1960s and after, however, the power experts lost their stature as "conservationists" from the outsider perspective. Instead, environmentalists challenged utilities as wasteful destroyers of natural habitats, through the damming of rivers; as polluters, through the burning of coal and other

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[8] *Merriam-Webster Online,* s.v. "conservation" and "conserve," accessed February 17, 2013, http://www.merriam-webster.com; *Encyclopedia Britannica Online,* s.v. "conservation of energy," accessed February 17, 2013, http://www.britannica.com; Martin V. Melosi, "Environmental Policy," in *A Companion Guide to Lyndon B. Johnson*, ed. Mitchell Lerner (New York: Blackwell Publishing, 2012).

hydrocarbons; and as promoters of danger, through the development of nuclear plants. Many utility engineers were surprised to find that they were no longer seen as advocates for conservation.

In the late twentieth and early twenty-first centuries, attention has returned forcefully to conserving natural resources, and maximizing use of renewable resources, and the grid is once again the center of attention in several ways. First, existing transmission lines and interconnections are not well located to carry electricity from areas offering large quantities of solar and wind power to consumer centers. Newer and bigger grid connections are needed to bring these forms of renewables into the power mix. Second, advocates for renewables have, in some cases, rejected the grid as a model for electrification. Instead, they propose disaggregation of electrical networks into smaller discrete systems. This would entail abandoning portions, if not all, of the grid. Third, "smart grid" technologies, deployed over transmission lines, offer both generators and customers the opportunity to measure and moderate exact electricity usage. Theoretically this may result in greater energy conservation. In the meantime, power from hydroelectric dams, nuclear plants, and coal-fired plants traverses the continent to supply North America's electricity demand, among the highest per capita in the world.

Approaching a History of the Grid

This dissertation explores the history of North America's power grid through the first two-thirds of the twentieth century, and the paradoxes it presents. The research project began with the question of "why?" Why did utilities build an interconnected system that reaches from coast-to-coast? Historians as well as industry experts have provided two primary answers. Interconnections offered cost-effective operations through improved economies of scale and interconnections provided greater reliability because neighboring utilities could provide each other with back-up power. The data from the early decades of interconnection offer a third related explanation. The grid proved to be a technology of conservation in line with Progressive Era initiatives to exert more responsible development of natural resources for current and future use. In essence, interconnections offered utilities a sustainability paradigm. Closer examination of the process of grid development also reveals the outsized influence of wartime experiences, particularly the benefits offered by interconnections during World War II. During those years, the electric utility industry cooperated with government on an unprecedented scale to increase power delivery to war manufacturers, without building significant new generating plants. Further, in the post-war years, giant power pools grew hand-in-hand with rapid economic growth. In addition to the twin pillars of economic efficiency and reliability, the functions of conservation, wartime pressures, and rapid growth must be added to the explanation for why we have an interconnected power system.

The research continued with the question of "how?" How did so many entities cobble together such a stable and large machine over so many decades? This question led to a focus on the issue of control at several levels: economic control of the power companies, regulatory control over the systems, and physical control of moving electrical current. In *The Governance of Large Technical Systems,* Olivier Coutard et al. ask that scholars examine large socio-technical systems together with "society-at-large" to understand how both evolve together.[9] This project will explore the specific governance problems that relate to electricity itself, and a few of the technical inventions that allowed humans to better control the flow of power across a network. These technical fixes mapped neatly to the social fixes applied to

[9] Olivier Coutard, *The Governance of Large Technical Systems* (London, New York: Routledge, 1999), p. 2.

economic, political, and organizational governance of the power grid. The project addresses very large issues of industry structure, legislative trends, and organizational solutions as they changed over time. The study also zooms in to examine very small pieces of apparatus and nuanced decisions about device settings because they had outsized impact on overall system stability.

This *Biography of a Technology* also explores what the grid really is. By the second half of the twentieth century, myriad individuals and organizations collaborated to complete interconnections across an entire continent. Each interest group, from engineers to politicians to consumers, understood the grid in a different light. Engineers saw the grid as a giant test model on which they could experiment with advanced technologies and at the same time serve the public good with safe, reliable, and abundant electricity. For utility owners and politicians the grid was the means to an end. For many years, the technology represented efficiency, stability, equity, and economic growth. During the era of deregulation, from 1980 to 2000, the grid and its attendant technologies provided a support structure for a drastically changing electricity market and regulatory environment. More recently, the grid has offered a conundrum, as policy makers and investors wrestle with the energy future. Consumers barely noticed the grid, except when they observed giant power lines along the highway, or when the entire system failed. The grid is both more and less than the collection of technologies that comprise a giant machine to move electricity across the continent.

The Grid in Other Histories

Historians, political scientists, economists and journalists have considered the history of electrification from multiple perspectives.[10] Some of the earliest scholarly treatments of electrification focus on the electric manufacturers and address questions of entrepreneurship and technical innovation in America.[11] In addition, writers have focused on the contributions

[10] For a complete overview of the North American electric power system, including a brief history, explanation of technologies, and analysis of rates and regulation, see Leonard S. Hyman, Andrew S. Hyman, and Robert C. Hyman, *America's Electric Utilities: Past, Present and Future*, 8th ed. (Vienna, VA: Public Utilities Reports, 2005). Thomas Hughes produced the seminal work comparing the process of electrification in the United States, England, and Germany, Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983). In the same vein as the Hughes work, other studies that examine the technology of electrification and its meaning within a particular country include Christopher Armstrong and H. V. Nelles, *Monopoly's Moment: The Organization and Regulation of Canadian Utilities, 1830-1930*, Technology and Urban Growth (Philadelphia: Temple University Press, 1986); Robert L. Frost, *Alternating Currents: Nationalized Power in France, 1946-1970* (Ithaca, NY: Cornell University Press, 1991); Leslie Hannah, *Electricity before Nationalisation: A Study of the Development of the Electricity Supply Industry in Britain to 1948*, Johns Hopkins Studies in the History of Technology (Baltimore: Johns Hopkins University Press, 1979); Gabrielle Hecht, *The Radiance of France: Nuclear Power and National Identity after World War II*, Inside Technology (Cambridge, MA: MIT Press, 1998). For a broad history of energy development and consumption in North America, see Martin V. Melosi, *Coping with Abundance: Energy and Environment in Industrial America*, 1st ed. (Philadelphia: Temple University Press, 1985). For a closer investigation of energy consumption, see David E. Nye, *Consuming Power: A Social History of American Energies* (Cambridge, MA: MIT Press, 1998). For a narrower focus on the power business over the course of the twentieth century, see Richard Munson, *From Edison to Enron: The Business of Power and What It Means for the Future of Electricity* (Westport, CT: Praeger Publishers, 2005). Several individuals from within the industry have prepared histories of electrification, including Bill Beck, *Interconnections: The History of the Mid-Continent Area Power Pool*, 1st ed. (Minneapolis: The Pool, 1988); John Casazza, *The Development of Electric Power Transmission: The Role Played by Technology, Institutions, and People*, IEEE Case Histories of Achievement in Science and Technology (New York: Institute of Electrical and Electronics Engineers, 1993); National Electrical Manufacturers Association., *A Chronological History of Electrical Development from 600 B.C* (New York: National Electrical Manufacturers Association, 1946); John Rowland, *Progress in Power: The Contribution of Charles Merz and His Associates to Sixty Years of Electrical Development, 1899-1959* (London: Privately published for Merz and McLellan, 1961).

[11] Prominent examples include Alfred D. Chandler, *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, MA: Belknap Press, 1977); Malcolm MacLaren, *The Rise of the Electrical Industry During the Nineteenth Century* (Princeton: Princeton University Press, 1943); Harold C. Passer, *The Electrical Manufacturers, 1875-1900; a Study in Competition, Entrepreneurship, Technical Change, and Economic Growth*, Technology and Society (New York: Arno Press, 1972).

of inventors, innovators, and engineers to explain how and why electric systems grew.[12] Numerous projects explore the development of particular companies and the influence of electrification on particular cities and regions.[13] Alternatively, others broadly examine the role of electrification in society.[14] Many studies address the development of the power

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[12] Thomas Edison, George Westinghouse, Nikola Tesla and others attracted scholarly attention as the fathers of electrification. See for example Paul Israel, *Edison: A Life of Invention* (New York: John Wiley, 1998); Jill Jonnes, *Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World*, 1st ed. (New York: Random House, 2003); Marc J. Seifer, *Wizard: The Life and Times of Nikola Tesla: Biography of a Genius* (Secaucus, NJ: Carol Publishing Group, 1996); Forrest McDonald, *Insull* (Chicago: University of Chicago Press, 1962). Others focused on earlier innovators in the field of electrical experiments, see for example Michael B. Schiffer, *Power Struggles: Scientific Authority and the Creation of Practical Electricity before Edison* (Cambridge, MA: MIT Press, 2008). Studies of groups of individuals who shaped the industry also inform the history of electrification: Erwin C. Hargrove, *Prisoners of Myth: The Leadership of the Tennessee Valley Authority, 1933-1990*, 1st ed. (Knoxville,TN: University of Tennessee Press, 2001); Edwin T. Layton, *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Baltimore, MD: Johns Hopkins University Press, 1986).

[13] For studies addressing the regional development of electric power systems see Jay L. Brigham, *Empowering the West: Electrical Politics before FDR*, Development of Western Resources (Lawrence: University Press of Kansas, 1998); Paul W. Hirt, *The Wired Northwest: The History of Electric Power, 1870s-1970s* (2012); James F. Hornig, *Social and Environmental Impacts of the James Bay Hydroelectric Project* (Montreal: McGill-Queen's Press, 1999); Jean Manore, *Cross-Currents: Hydroelectricity and the Engineering of Northern Ontario* (Waterloo, ON: Wilfrid Laurier University Press, 1999); Gus Norwood, *Columbia River Power for the People: A History of Policies of the Bonneville Power Administration* (Portland, OR: Bonneville Power Administration, 1981); T. D. Regehr, *The Beauharnois Scandal: A Story of Canadian Entrepreneurship and Politics* (Toronto: University of Toronto Press, 1989). Examples of projects addressing single power companies include H. Craig Miner, *Wolf Creek Station: Kansas Gas and Electric Company in the Nuclear Era*, Historical Perspectives on Business Enterprise Series (Columbus: Ohio State University Press, 1993); Joseph A. Pratt and Bernard P. Stengren, *A Managerial History of Consolidated Edison, 1936-1981* (New York: Consolidated Edison Company of New York, 1988). In addition, authors have linked the development of particular power companies to urban and suburban growth: Harold L. Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930* (Chicago: University of Chicago Press, 1991); Mark H. Rose, *Cities of Light and Heat: Domesticating Gas and Electricity in Urban America* (University Park, PA: Pennsylvania State University Press, 1995).

[14] David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940* (Cambridge, MA: MIT Press, 1990); Wolfgang Schivelbusch, *Disenchanted Night: The Industrialisation of Light in the Nineteenth Century* (Oxford, New York: Berg, 1988); Ruth Schwartz Cowan, *More Work for Mother: The Ironies of Household Technology from the Open Hearth to the Microwave* (New York: Basic Books, 1983); Ronald C. Tobey, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home* (Berkeley: University of California Press, 1996).

industry in terms of its political, regulatory, and economic ramifications.[15] The transition to electrification over the twentieth century resulted in lasting environmental changes to watersheds, to cities and rural regions alike, to air and water quality. Several scholars, in writing about the electric power industry, focus on the health, safety, and environmental consequences of particular projects.[16]

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[15] At several points during the twentieth century, political scientists, historians, and economists have closely examined the regulation of power companies. For works contemporaneous with early federal investigations of utilities, see Jerome G. Kerwin, "Federal Water-Power Legislation" (PhD diss., Columbia University, 1926); William S. Murray, *Government Owned and Controlled Compared with Privately Owned and Regulated Electric Utilities in Canada and the United States* (New York: National Electric Light Association, 1922); Hilmar Stephen Raushenbush and Harry Wellington Laidler, *Power Control* (New York: New Republic, 1928). For analyses of New Deal initiatives related to electric power, see Douglas D. Anderson, *Regulatory Politics and Electric Utilities: A Case Study in Political Economy* (Boston: Auburn House Publishing Co., 1981); Philip J. Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941* (Pittsburgh: University of Pittsburgh Press, 1973); Thomas K. McCraw, *TVA and the Power Fight, 1933-1939* (Philadelphia: Lippincott, 1971). For international comparisons see Richard J. Gilbert and Edward Kahn, *International Comparisons of Electricity Regulation* (Cambridge: Cambridge University Press, 1996); H. V. Nelles, *The Politics of Development; Forests, Mines & Hydro-Electric Power in Ontario, 1849-1941* (Toronto: Macmillan of Canada, 1974). Richard Hirsh provides extensive analysis of the relationship between the industry, the technologies of electrification, and the changes in regulation across the twentieth century in two books: Richard F. Hirsh, *Technology and Transformation in the American Electric Utility Industry* (Cambridge: Cambridge University Press, 1989); Richard F. Hirsh, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System* (Cambridge, MA: MIT Press, 1999).

[16] For studies related to hydroelectric dams, see David P. Billington and Donald C. Jackson, *Big Dams of the New Deal Era: A Confluence of Engineering and Politics* (Norman, OK: University of Oklahoma Press, 2006); Karl Boyd Brooks, *Public Power, Private Dams: The Hells Canyon High Dam Controversy* (Seattle: University of Washington Press, 2006); Jared Farmer, *Glen Canyon Dammed: Inventing Lake Powell and the Canyon Country* (Tucson: University of Arizona Press, 1999); Robert Douglas Lifset, "Storm King Mountain and the Emergence of Modern American Environmentalism, 1962--1980" (PhD diss., Columbia University, 2005); Marc Reisner, *Cadillac Desert: The American West and Its Disappearing Water* (New York: Viking, 1986); Robert W. Righter, *The Battle over Hetch Hetchy: America's Most Controversial Dam and the Birth of Modern Environmentalism* (New York: Oxford University Press, 2005); Richard Rudolph and Scott Ridley, *Power Struggle: The Hundred-Year War over Electricity*, 1st ed. (New York: Harper & Row, 1986); Donald Worster, *Rivers of Empire: Water, Aridity, and the Growth of the American West*, 1st ed. (New York: Pantheon Books, 1985). For studies addressing the effects of nuclear power development, see Thomas Raymond Wellock. *Critical Masses: Opposition to Nuclear Power in California, 1958-1978*. Madison: University of Wisconsin Press, 1998; Daniel Pope, *Nuclear Implosions: The Rise and Fall of the Washington Public Power Supply System* (New York: Cambridge University Press, 2008); J. Samuel Walker, *Three Mile Island: A Nuclear Crisis in Historical Perspective* (Berkeley: University of California Press, 2004); J. Samuel Walker and US

Only a handful of these scholars interested in the history of electrification have explored the grid as a lens for understanding other historical trends. For example, in *Networks of Power*, Thomas Parke Hughes examines the first fifty years of electrification as a means of developing a model for how large modern technological systems evolve. For Hughes, the network expands beyond the machines and wires of interconnection to include the people and social institutions that comprise a larger system of electrification. In Hughes's assessment, the grid emerged as a result of both internal momentum and external factors. To achieve greater economies of scale and to access back-up power, utilities began to interconnect in the early years of electrification. Further, events like World War I revealed the shortcomings of smaller, independent power systems in the face of burgeoning demand for electricity. Utilities embraced the advantages of interconnection to meet the needs of wartime. Once networks became sufficiently widespread, by the end of the 1930s, the trend to interconnect carried momentum of its own, causing utilities to continue building pools throughout the mid-century. Hughes's analysis ends with the advent of World War II and he suggests that by this date the mechanisms and processes in place rendered continued expansion of the grid inevitable.[17]

The details of interconnection in North America offer a challenge to Hughes' analysis. Hughes theory of technological momentum suggests that the level of commitment to a technological system - in human, institutional, and technical terms - reaches a point after which growth continues in the same pattern, unless a major external event, such as a war,

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Nuclear Regulatory Commission., *A Short History of Nuclear Regulation, 1946-1999* (Washington, DC: US Nuclear Regulatory Commission, 2000).

[17] Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*. Philip Schewe, a physicist and science writer, in *The Grid: A Journey Through the Heart of Our Electrified World*, provides a history of the power industry, including a discussion of interconnections and blackouts, primarily for a lay audience. Phillip F. Schewe, *The Grid: A Journey through the Heart of Our Electrified World* (Washington, DC: J. Henry Press, 2007).

causes major changes. As this project explains, the major external event after the 1930s, World War II, actually furthered the technological momentum of interconnected networks, while seemingly minor internal problems, like selection of instrument settings, threatened to undermine the process. Further, shortly after utilites closed ties in 1967, linking ninety five percent of North American power into a single grid, electricity prices rose, and public opinion of utilities declined. In *Technology and Transformation in the American Electric Utility Industry,* Richard Hirsh details the confluence of world energy dramas, economic patterns, political movements, and physical limits on generator efficiency that led to this change in the fortunes of American utilities.[18] The utilities were in trouble in the 1970s and by the 1980s a process of deregulation and disaggregation of monopolies began. While the transmission grid itself remained relatively unchanged, the power industry as a whole restructured significantly by the end of the twentieth century. The evidence suggests that ideas and trends have momentum, but specific choices and responses to problems are separately determined and may not lead to a predictable endpoint for large technological systems.

Offering a different economic perspective, Harold Platt delineates the calculations and choices made by Samuel Insull in building his electric utility empire in the greater Chicago area. For Platt, investigating the piece-by-piece assembly of a seminal regional grid affords insight into the relationship between cities and leaders, economics and urban development, and technology and social change. Platt explores Insull's recognition of generating efficiencies, load balancing, and the advantages of a diverse customer base for profitability. Insull's project resulted in a vertically and horizontally integrated system that stretched from coalfields to kitchens, delivering electricity at attractive prices. Insull married

[18] Hirsh, *Technology and Transformation in the American Electric Utility Industry.*

the growing electrical network to a marketing push that promoted consumption. In this scenario, interconnections resulted directly from careful calculation by an exceptional entrepreneur seeking profits and economic control. The grid was a key tool for achieving both.[19]

David Nye, in *When the Lights Went Out*, focuses on the need for reliability in the early years of electrification. In examining the effects of blackouts on our society, Nye begins with an inquiry into the origins of the grid. At the outset, linking systems into regional networks gave utilities greater "security against breakdown."[20] Later, Nye argues, utilities were forced by consumer demand to join into networks. In this instance, a technical choice to improve reliability also improved customer enthusiasm for electricity. The grid emerged at the center of a social and technical reliability paradigm. As in his other works addressing energy history in North America, Nye's study of blackouts enables him to explore how social behavior influences technical choices, and in turn, how technical choices inform the way society defines itself.[21]

In a less sweeping narrative, Paul David Wellstone and Barry M. Casper describe the grid as an unwanted necessity in *Powerline: The First Battle of America's Energy War.* For the farmer-citizens of Minnesota and their champions, giant transmission lines benefitted utilities at one distant end, and consumers at another, but only marred the world in-between. While this tale focuses on attempts to prevent construction of only one segment of the nation's interconnected system, it draws attention to the sense of inevitability that attached to

[19] Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*.
[20] David E. Nye, *When the Lights Went Out: A History of Blackouts in America* (Cambridge, MA: MIT Press, 2010), p. 17.
[21] Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*; David E. Nye, *American Technological Sublime* (Cambridge, MA: MIT Press, 1994); Nye, *Consuming Power: A Social History of American Energies*.

grid development. As Hughes suggests, and as Casper and Wellstone describe, utilities and regulators alike seemed to view the grid as a necessity rather than an option by the late mid-century. This technology facilitated profits and consumption.[22]

While these and other studies discuss the grid at some length, none focus closely on how North America's interconnected system developed. This project will examine the grid itself; how early technical choices influenced the path to interconnection; why governments, utilities, and investors converged on interconnection rather than isolated systems; and how technicians and operators managed to operate this difficult and increasingly complex system. A study of the grid will provide a unique lens on the interplay of politics, economics, and engineering during the construction of a central technology of modern life. Although the primary focus of this study is the process of interconnection in the United States, some parts will also address activities in Canada, because systems in the two countries were, and still are, closely linked.

Organization of the Study

This biography of the grid will cover its origins in the late 1800s and its growth up to the 1965 blackout, when the system failed. The story concludes when a national grid is realized, in 1967, through the closure of four small interties linking eastern and western power systems across the Rocky Mountains. This endpoint coincides with a major industry shift, when electric rates rose and utilities lost their status in American estimation. Indeed, by 1970 an era of public approbation for power system expansion ended and a new phase in electrification began. During the later decades of the twentieth century, the American power industry restructured amid deregulation, financing woes, environmental protests, fears related

[22] Paul David Wellstone and Barry M. Casper, *Powerline: The First Battle of America's Energy War*, 1st ed. (Minneapolis: University of Minnesota Press, 2003).

to nuclear power, physical limits to the expansion of generating plants, rising energy costs, and concerns about human effects on climate change. The story of the grid after 1970 is set in a different framework, beyond the scope of this dissertation.

Part I, Expansion for Conservation, 1880-1920, addresses the fundamental question: "why do we have a grid?" Covering the years 1880-1920, this section argues that in addition to facilitating economic operations and offering improved reliability, interconnection gave utilities a distinct opportunity to manage energy resources for the long-term, in keeping with the Progressive Era concept of conservation. The first chapter explores the origins of the power industry and the elements of electrification that form the building blocks of an interconnected system. The second chapter illustrates that utilities expanded in ways that prefigured the grid, but also experimented with technologies that competed with interconnections. As other historians noted, the experiences of energy shortages during World War I persuaded utility owners and politicians alike that interconnections offered advantages other approaches could not match. Chapters 1 and 2 together describe the fits and starts of integration that took place during the first four decades of electrification.

The third chapter places early electrification and interconnection in the context of Progressive Era conservation movements. This chapter addresses more forcefully the question of why utility owners converged on the idea of an interconnected power system. All three chapters illustrate that, among other issues, interconnection offered a distinct advantage to an industry with a legitimate business interest in resource conservation. One answer to the question of why we have a grid follows: interconnection served as a technology of conservation for utilities that sought to carefully manage energy resources, preserve access to coal and falling water over a long period of time, and provide orderly, scientific leadership to a Progressive-minded public.

Part II, Contest for Control, explores the efforts of utility owners, politicians, government regulators, engineers, and the public to exert control over the burgeoning power system. Covering the years 1920 to 1945, this section argues that during this contest for control, systems of shared management and divided authority allowed multiple entities to build and operate interconnected systems. In the absence of any central plan or single oversight authority, growth took place organically, on a piecemeal basis, under the care of a cadre of technical professionals who actively shared information across business and government boundaries around the world. Chapter 4 describes the economic and political negotiations for control that took place during the interwar years. This chapter hints at the complex relationships between legislators at all levels, federal agencies, and state and local governments in the United States. Not only did different levels of government vie for authority over power systems, regional politics marked the negotiations during this period and throughout the mid-century. This chapter touches on these government-to-government interactions to the extent that they framed development of the grid, but leaves more detailed analysis of this significant issue largely unexplored. Chapter 5 addresses particular technical issues that plagued utilities attempting to operate interconnected. There were difficult issues related to the physical labor of installing transmission lines; the geographic challenges to interconnecting certain regions; and the effects of weather, lightning, animal behavior, and other natural phenomenon on the reliability of power transmission. While not intending to minimize the significance of these other aspects of building the grid, this project zeroes in on the physical characteristics of electricity and the need for both apparatus and practices that allowed humans to exert control over moving power on interconnected systems.

Part III, overlapping somewhat with Part II, covers the years 1940 to 1965. This was the heyday of the power industry, and this part of the dissertation illustrates that systems of shared management and divided authority became enshrined as utilities, governments, and the public embraced large-scale interconnected power systems. Chapter 6, covering 1940-1945, argues that both industry and the government stepped outside normal roles to collaborate on behalf of the war effort. Significantly, the industry provided sufficient electricity to the war industries and to the general public through aggressive interconnections rather than through the construction of large new generating plants. Immediately after the war, utilities disentangled from government oversight. Chapter 7, covering 1945-1965, explores the process of bringing uniformity to the multiple interconnected systems sprouting across the country. The fraternity of technical experts dominated the piecemeal growth of the grid, and developed techniques for power control that protected both operating stability of the system and the autonomy of each entity that participated. Chapter 8, covering the same period, argues that during the industry heyday, the grid enjoyed a brief revival as a technology of conservation. Just on the eve of the emergence of modern environmentalism, politicians and power industry leaders once again touted interconnections as a means of conserving key resources.

The final segment of the dissertation, Part IV, documents both the collapse of the industry's dominance following the Northeast power failure of 1965, and the completion of a true North American power grid with the closing of east-west interties in 1967. This part argues that in the face of failure, the power industry retrenched and recommitted to the grid, in its historical form. The grid was and remained an organically built technology, periodically serving as a tool for resource conservation and simultaneously facilitating massive consumption, and operated under systems of shared management and divided authority. The technologies of control continued to match the systems of control through the end of the century. While ostensibly robust, events revealed the largest machine in the world to be fragile. When the United States finally attempted to exert authority over the reliability of the grid, if not the physical grid itself, Congress merely validated the approaches of the past.

Two characteristics of the grid can propel it into the spotlight: failure and achievement. Grid failure results in widespread public attention. In North America, cascading blackouts, while not common, have occurred regularly for the past six decades. Blackouts have practical, economic, and even life-threatening consequences for millions. Grid achievement generally garners the enthusiastic approbation of a very small community of technical experts. But the delight experienced by those individuals results from both technical accomplishment in the face of complex challenges and a sense of purposeful betterment of humankind through improved electrical service. Thus, while the public paid less and less attention to milestones in electrification over the course of the twentieth century, a fraternity of engineers, system operators, and utility managers celebrated each new advance in interconnection. These two aspects of the grid – its overall success and its devastating failures – make it a technology worthy of investigation.

As a little girl in the 1960s, challenged by ennui while visiting power plant control rooms, I was intrigued by my father's passion for his work. My father, Nathan Cohn, was one of many electrical engineers and utility managers who participated in the technical fraternity that built the grid. He and his colleagues relished each new accomplishment in electrical advance. They designed the apparatus that allowed humans to control electricity and deliver it from generators to light switches, traffic signals, farm milking parlors, and industrial machines across the globe. His passion was well placed, though widely misunderstood. Solving the mysteries of how to control electricity as it moves across time and space through wires is both mind-boggling and mind numbing. The story of the grid is his story, and his colleagues' story, as well as a North American story. It exemplifies how we tackle fundamental human needs in our regulated capitalist economy. The story illustrates how our governments engage with the complex technologies that simplify our lives and how technicians, politicians, and business owners collaborate and compete at the very same moments. It shows how enthusiastic consumption of energy both introduces equity to multiple lifestyles and compromises the integrity of our ecosystems. The grid is and was a conundrum. How and why it was built, who owns and operates it, what it signifies for our daily lives all will play a role in the choices we make for our energy future.

Part I. Expansion for Conservation, 1880-1920

Today, the grid appears as a cohesive, nearly invisible, totally functional, and essential technology. Stretching across the continent, any electrical customer can flip a switch at will and the power flows. The generating plant may be nearby or two states away, but the customer does not know and does not care. Given the scale and reach of the contemporary power system, the grid seems to be a logical and rational means for moving electricity from producer to consumer with great efficiency. Yet, in the earliest decades of electrification, the grid was not an obvious or necessary choice. Instead the interconnected power system resulted from multiple individual choices and the influence of many trends. Chief among these, the grid served as a technology of conservation for an industry focused on managing energy resources, achieving operating efficiencies, making electricity affordable, increasing consumption, and reaping profits.

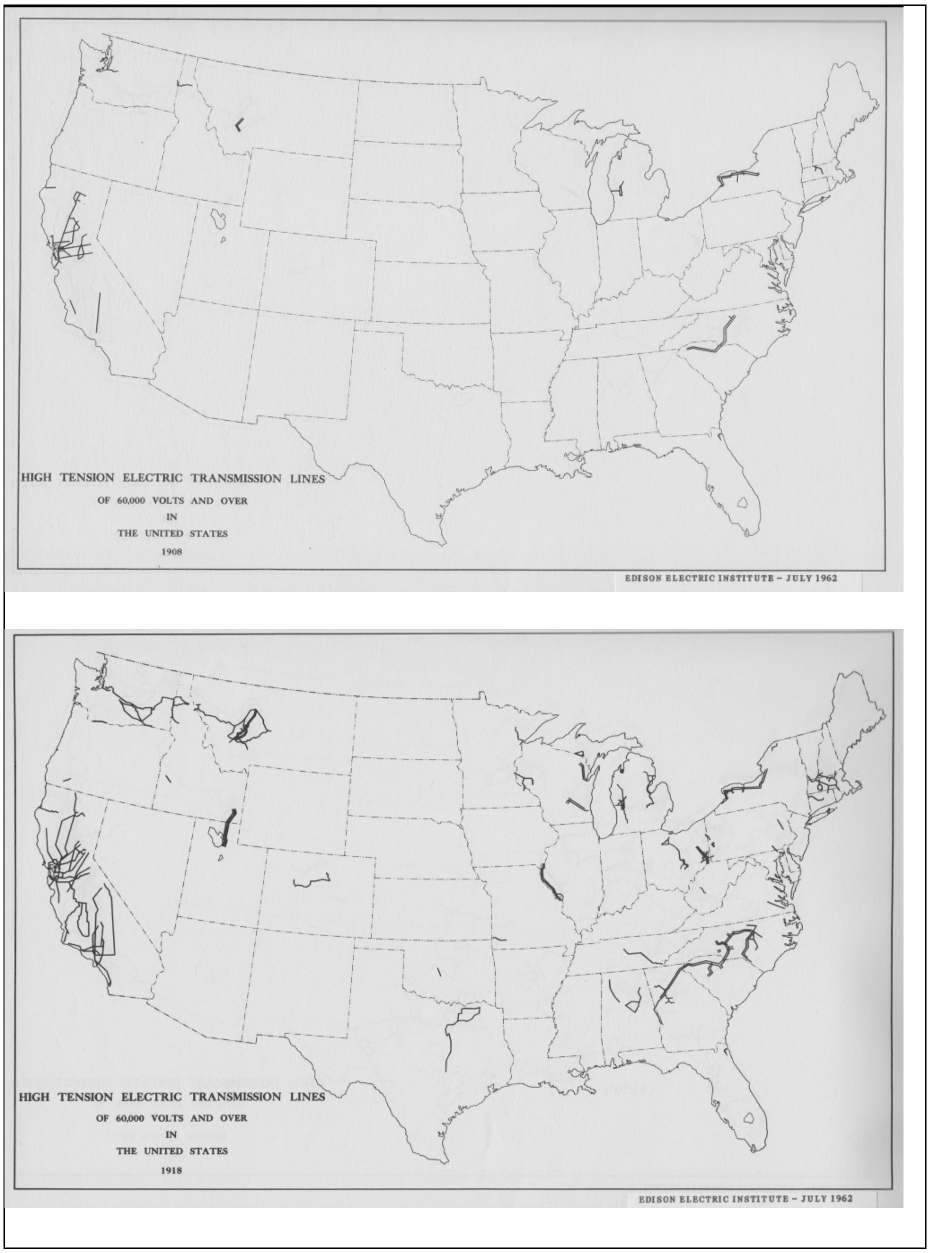
Glimmers of the grid appeared in the very earliest elements of power system development. For example, when Thomas Edison fired up the Pearl Street Station in New York City in 1882, he introduced a soup-to-nuts concept of system design. His company developed and manufactured every piece of his small network, from the generator to the light bulbs. In some respects, the grid is merely an enlarged and expanded version of the central station network. Nicola Tesla claimed that in 1877 he first envisioned an induction motor and later contemplated an alternating current system that would add great flexibility to the transmission and use of electricity. Tesla's innovations in electrical apparatus still form fundamental building blocks of modern grid technology. George Westinghouse recognized by the 1880s that electricity could potentially illuminate rooms, move transit vehicles, and power industrial motors all at the same time. Today's grid provides electricity for a multitude of uses beyond those Westinghouse imagined. While the ideas, aspirations, and inventions of Edison, Tesla, Westinghouse and many, many others offered a clear line of descent to the grid today, they did not prefigure today's power network. Too many different types of power providers, public and private, small and large, urban and industrial, ac and dc, steam generated and waterpower driven, entered the early electrical market to allow an obvious path to emerge.[1]

The first segments of major transmission lines and interconnections barely foretold the extent of the future grid. As shown in Map A, the major transmission lines in the United States in 1908 appeared in California, Montana, New York, and the Southeast. By 1918, early interconnections appeared in California, the Pacific Northwest, and the southeastern states. Looking at these maps, it is difficult to imagine the dense interconnections that would later appear in the northeast, the Midwest, and in Texas. Yet these early systems offered hints of the paths utilities later followed to interconnect.

Amidst the diversity of electric companies dotting the continent during the final decades of the nineteenth century and the beginning of the twentieth century, certain common operating and economy challenges emerged. The electrical business entailed a very high capital cost and required many paying customers over the long term to amortize the initial investment. First and foremost, all types of electric companies sought longevity. Second, electricity, unlike carbon fuels and water, cannot be stored economically and must be available at the exact instant of demand. Yet power providers competed directly with gas-lighting companies and other energy systems that could rely on storage and predictable

[1] Tesla gives this date in his own memoirs, describing watching a professor operate a sparking direct current generator that would soon burn out. There is no verification of this date. Tesla received his first patents for elements of his induction motor and alternating current transmission system in 1886. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p. 113.

market schedules. Utilities had to provide a steady and reliable source of electricity to attract and keep customers. Third, electric companies strove to bring down costs from luxury levels to utility levels in order to expand. This entailed improving operating efficiencies while marketing electricity as a necessary commodity or service. A wide variety of power producers united in a common pursuit of economic stability for each system.



Map A. High Tension Transmission Lines in United States in 1908 and 1918. ***Source:*** **Edison Electric Institute,** ***Report on the Status of Interconnections and Pooling of Electric Utility Systems in the United States*****, 1962.**

Numerous trends shaped the paths that different power providers chose to follow during these years. Overall shifts in how Americans consumed energy, both in terms of absolute quantity and in variety of uses, deeply influenced the patterns of electrical growth. Demand for electricity rose quickly, and from multiple parts of the economy at different times. For example, towns sought streetlights, transit companies built electric trolleys, homeowners wanted interior illumination, department stores produced fancy displays, and factories installed isolated power plants. Electricity providers expanded in multiple ways to meet, and in many cases increase, burgeoning requests for light and power. Industrial expansion as a whole also influenced how electrical companies grew, and how they interacted with government. Early regulatory forays into the previously unharnessed growth of enterprise led to further restructuring of business-government relations. In addition, Progressive Era movements favoring efficiency of operations, conservation of natural resources, urban cleanup and beautification, and preservation of scenic areas defined many of the issues that challenged power companies.[2]

Several Progressive Era conservation ideas directly influenced electric power development. Conservation leaders advocated full development of river basins for irrigation, flood control, and power production. They believed that not a drop of water should be wasted before it reached the ocean. Further, they argued that hydroelectric power generation could displace, if not fully replace, coal-fired power plants. This had multiple benefits, including

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[2] Ibid; Melosi, *Coping with Abundance: Energy and Environment in Industrial America*; Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*; Nye, *Consuming Power: A Social History of American Energies*; Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*; Rose, *Cities of Light and Heat: Domesticating Gas and Electricity in Urban America*; Louis Galambos and Joseph A. Pratt, *The Rise of the Corporate Commonwealth: U.S. Business and Public Policy in the Twentieth Century* (New York: Basic Books, 1988); Thomas K. McCraw, *Prophets of Regulation: Charles Francis Adams, Louis D. Brandeis, James M. Landis, Alfred E. Kahn* (Cambridge, MA: Belknap Press of Harvard University Press, 1984).

reduced reliance on resources potentially in short supply, "free" energy from falling water, and less smoke pollution. Some deemed electricity the ideal alternative to other forms of energy used in manufacturing, both for its increased efficiency and its flexibility. In addition, many advocated locating planning and management of these projects under the expertise of professionals in the central government. Progressive Era conservationists focused on the wise use of natural resources so that they would be available to future generations, unlike later environmentalists who addressed the possibility of reducing overall consumption to protect natural ecological systems.

Eventually, electric companies embraced a conservation paradigm in which management of energy resources, improved operating efficiencies, and lower cost electricity, combined with increased consumption, led to economic stability and longevity. If power producers brought down per unit costs, slowed the pace of coal depletion while maximizing the use of falling water, and increased consumption, revenues followed. With favorable regulatory schemes that granted monopoly status, privately owned utilities earned profits. Government owned utilities likewise expanded the consumer base and realized steady returns. In the process, some strategies that served the interests of utilities also furthered the goals of Progressives. Increased use of hydroelectric power, ostensibly inexhaustible, aligned nicely with plans to develop fully river basins, and addressed concerns about urban smoke pollution and coal depletion. Improved operating efficiencies within power plants reflected contemporary ideas about time, labor, and resource management. In some instances, utilities interested in access to waterpower sites even agreed with movements to preserve forests in scenic areas.

Utilities deployed multiple technologies and strategies to conserve energy resources, and over time regional interconnection proved to be a lynchpin technique. Long-distance transmission allowed utilities to reach distant waterpower sites and to serve wide markets. Storage batteries assisted with both operating efficiency and reliability. Larger and better generators reduced the amount of coal needed to produce a kilowatt-hour of electricity. Innovative rate meters and well-structured fees allowed operators to both increase consumption and flatten the peaks and valleys of demand. Interconnections provided all this and more. Through interconnections, plant operators accessed distant energy resources and also switched between different types of power plants, depending on cost and availability. Interconnection allowed plants to reach broad and diverse markets, further flattening the demand curve. Operators provided each other with back-up power for emergency and scheduled outages. By 1920, interconnection clearly aided utilities in achieving a conservation paradigm, while other approaches reached limits of applicability for that time.

The economic and political structure of the industry reflected the wide variety of interests at play in electrification. In the private sector, multiple types of holding companies and aggregates oversaw the financial arrangements, and in some cases operating agreements, of hundreds of smaller utilities. Other companies remained independent. Some states provided rate and entry regulation, others did not, and still others allowed only government-owned utilities to operate. The national government carried on a forty-year negotiation over how to manage waterpower sites under federal control. The public expressed an uneasy concern about monopoly utilities, in the wake of major trust-busting initiatives in various sectors, including the closely related oil and railroad industries. In the early instances of inter-utility collaboration on long-distance transmission and interconnection, agreements outlined terms for sharing power, but preserved the full economic autonomy of participants. While the Congress, and several presidents pushed for greater central control over the power industry, the political will to infiltrate an essentially capitalist enterprise did not prevail. One Canadian province bucked this trend by establishing a central agency to generate and transmit power for municipal customers. Overall, however, the contest for economic and political control in North America was indisputably in flux.

The experiences of World War I sharpened an appreciation for the benefits to be gained from coordinated planning and interconnection. The federal government asserted control over power generation and distribution and directed war industries to areas with excess power. Utility executives collaborated with each other and with the administration to maximize access to electricity for war production. Energy shortages highlighted the importance of carefully managing fuel sources, while planning for emergency outages. Both public and private sectors relied on interconnections to minimize energy difficulties during the war. By the end of 1919, many in North America strongly favored a power system that followed a careful plan for interconnected expansion. During the next two decades, the multiple stakeholders in electrification negotiated economic, political, and technical control over the emerging grid.

Chapter 1. Glimmers of the Grid: From Edison's Central Station Service to Interlinking Power Stations, 1880-1905

At the most basic, physical level, the electric power grid is merely an interconnected and coordinated complex of generating stations, high-voltage power lines, and regional service areas. The birth of North America's grid took place during the first quarter century of electrification when various early approaches to providing electricity formed the building blocks of the future interconnected network. Inventors and electric providers introduced central station service, long distance transmission lines, and even interlinked systems. Yet, at the end of 1904, only a few visionaries gathered at a technical conference really comprehended the potential of linking the continent in a giant power network. During these years, engineers, inventors, plant operators, and utility owners from a wide variety of enterprises formed a fraternity of sorts. Through technical publications, conferences, and visits to each other's facilities, they shared information, ideas, and techniques while they advanced the art of electrification. At an international meeting of this "fraternity" during the St. Louis Exposition, power experts contemplated an interconnected future.

In the early 1880s, Thomas Edison introduced central station service for incandescent lighting and by 1904 the editor of *Electrical World* extolled the future of interlinking power stations. The earliest electric stations, designed to provide lighting, served roughly a one square mile area, limited by the expense and technical challenges related to transmitting electricity over longer distance lines. Innovations in the generation of alternating current (ac) rather than direct current (dc) power, and the development of an induction motor that allowed greater flexibility in power applications made long distance transmission possible. In California, Colorado, and Utah, system builders embraced long-distance transmission as the key to moving energy from distant waterpower sources to consumers. Some even began to link hydroelectric plants and steam plants in order to address seasonal fluctuations in waterpower availability. At the 1904 St. Louis Exposition, experts discussed the details of these systems and extolled the future of the industry.[1]

The Very Beginning: Central Station Service and its Limitations

In 1882 Edison flipped a switch at his brand new Pearl Street central generating station and illuminated 400 lamps in downtown Manhattan, changing the world's understanding of electrification and its practical use. His dc system replicated the benefits of existing urban gas lighting in which a central station provided the energy through connected lines to the points of illumination, and added the advantages of fire safety, cleanliness,

[1] "The Value of Water Storage," *Electrical World* 44, no. 20 (1904). "Construction of Transmission Lines," *Electrical World* 40, no. 12 (1902); *American Newspaper Directory (Issued Quarterly)*, (New York: George P. Rowell & Co., 1898); "Electricity in a Paper Mill," *Electrical World* 40, no. 12 (1902); Carl Hering, "83 Miles of Power Transmission," *Electrical World* 34, no. 20 (1899); "Transmission System of the Bay Counties Power Company, California," *Electrical World* 37, no. 7 (1901); "The Year in Power Transmission," *Electrical World* 45, no. 1 (1905); "Transactions of the International Electrical Congress, St. Louis, 1904", (paper presented at the The International Electrical Congress, St. Louis, St. Louis, MO, 1904); Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*. *Electrical World* began publication as *Operator and Electrical World* in 1874 and, over the years, merged with numerous other periodicals that carried similar stories. Journal articles addressed telegraphy, telephony, electricity, lighting, power, automobiles, and transit systems. Of the journals targeting experts in the fields of electrification, lighting, power station operations, and general advances in electrical technologies, *Electrical World* was one of the preeminent publications at the turn of the last century. Circulation for *Electrical World* in the United States exceeded 10,000 per week by the mid-1890s – higher than other similar journals – and continued to grow to over 18,000 by 1922. For example, between 1895 and 1920 *Electrical World* circulation regularly exceeded *Cassier's Magazine*, *Electrical Record, Electricity,* and *Proceedings of the American Institute of Electrical Engineers.* In addition, *Electrical World* published a digest of news from other related periodicals – including those from foreign countries - every week – thus offering the reader broad coverage of technical, regulatory, and operating advances in the electric power field from around the world. *Electrical World* articles and editorials seldom included a by-line, thus most contributors, presumably knowledgeable about electrification and the utility business, remained anonymous. Hyman, Hyman, and Hyman, *America's Electric Utilities: Past, Present and Future*, p. 16. Utility experts Leonard S., Andrew S., and Robert C. Hyman offer a straightforward explanation of ac and dc current: "Electric currents come in two kinds: *alternating* current (AC) and *direct* current (DC). Of the two, DC is the simpler. The current flows in one direction. Batteries produce DC, which flows from one pole, through the electrical circuit, to the other pole. AC, on the other hand, changes its direction on a regular basis. Each complete trip, before reversing direction, is called a *cycle.* The frequency of the alternation is measured in cycles per second, or in hertz (Hz). That is, 30 Hz means 30 cycles per second."

improved quality of light, and the "wow" factor of electrification. Within a very short time, Edison systems, in competition with both gas systems and other types of electric lighting systems, appeared in cities all over the world. By 1890, there were 1,000 central station plants in the United States alone.[2]

Before 1882, the public from Europe to California had been captivated by many experiments in electrification. Theaters in Paris, London, and New York employed lighting for special stage effects, arc lights illuminated central cities, generators powered lighthouses, and several inventors had introduced incandescent bulbs. Charles Brush installed the first true central station service for arc lighting in San Francisco in 1879. During the mid-

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[2] Hirsh, *Technology and Transformation in the American Electric Utility Industry*; Thomas P. Hughes, "The Electrification of America: The System Builders," *Technology and Culture* 20, no. 1 (1979); Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*; Thomas Parke Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970* (Chicago: University of Chicago Press, 2004); Hyman, Hyman, and Hyman, *America's Electric Utilities: Past, Present and Future*; Israel, *Edison: A Life of Invention*; Jonnes, *Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World*; Melosi, *Coping with Abundance: Energy and Environment in Industrial America*; Martin V. Melosi, "Energy and Environment in the United States: The Era of Fossil Fuels," *Environmental Review: ER* 11, no. 3 (1987), pp. 167-188; Passer, *The Electrical Manufacturers, 1875-1900; a Study in Competition, Entrepreneurship, Technical Change, and Economic Growth*; Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*; Steven W. Usselman, "From Novelty to Utility: George Westinghouse and the Business of Innovation During the Age of Edison," *The Business History Review* 66, no. 2 (1992), pp. 251-304; Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*. Louis C. Hunter and Eleutherian Mills-Hagley Foundation, *A History of Industrial Power in the United States, 1780-1930, Vol. 3, The Transmission of Power* (Charlottesville, VA: University Press of Virginia, 1991), p. 191-192. The Pearl Street Station relied upon coal-fired generators to produce electricity. As Hyman, et al. explain, "Most electricity is generated by burning a fossil fuel (coal, oil, or natural gas), or from the burnup of nuclear fuel, or from the force of water (hydroelectricity)." In very rough terms, both fossil fuel and nuclear generators heat water to produce steam, which then turns the blades of a turbine. A magnet surrounded by coils of wire is attached to the turbine, and the spinning creates a magnetic field, which then induces electric current into the wire. In the case of hydroelectricity, falling water rather than steam causes the turbine to spin. For more details, please see Hyman, Hyman, and Hyman, *America's Electric Utilities: Past, Present and Future*, pp. 19-24. Both private investors and municipalities organized power companies all over the world. Those that franchised the Edison system included "Edison" in the company name. Thomas Edison, however, had nothing to do with the operations of these franchises after the merger of Edison General Electric and Thompson Houston in 1892. The merger resulted in the creation of the General Electric Company, and Thomas Edison held a position on the board, but he directed his attention to areas other than electric power in the ensuing years. Israel, *Edison: A Life of Invention*, pp. 303-337.

nineteenth century, applications of electricity to motor force drew the interest of scientists and inventors as well. The first invention of a dynamo electric machine appeared in 1860, and Nikola Tesla defined the challenge of developing a simple induction motor in 1877. In 1879, an English physicist and engineer forecast the advantages of central station service for a combined lighting, motor power, and heating system, built on the model of gas service. The beauty of Edison's lighting system lay in the integration of generator, distribution lines, and long-lasting incandescent bulbs in a single, and potentially profitable, dc network.[3]

Within a very short time, however, operators recognized the limitations of the Edison, Brush, and other lighting systems. Three significant issues dominated discussions about future directions in electrification: (1) longer distance transmission of electricity, (2) electrification of trains and other forms of transportation, and (3) application of electricity in

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[3] Schiffer, *Power Struggles: Scientific Authority and the Creation of Practical Electricity before Edison*, pp. 255, 290-291. Both arc lights and incandescent lights, with innumerable technical and material variations, are still in wide use. An arc lamp consists of two electrodes separated by gas. The lamp produces light when the gas in the gap between the electrodes is electrified. Arc lamp technology in the nineteenth century produced very bright and difficult to regulate lights, and was used mostly in outdoor or theatrical lighting. An incandescent bulb produces light when a metal filament is heated by electricity until it glows. In the nineteenth century, designers and producers of incandescent bulbs successfully introduced softer and longer lasting lighting that could serve a wide variety of indoor and outdoor functions. Hughes, p.19; Jonnes, *Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World*; Seifer, *Wizard: The Life and Times of Nikola Tesla: Biography of a Genius*. Nikola Tesla, mechanical and electrical engineer, was born in Serbia in 1856 and emigrated to the United States in 1884 where he worked in Thomas Edison's Menlo Park Laboratory for a year. Following a financial dispute, Tesla left Edison and eventually formed his own company before working with Westinghouse. Throughout his lifetime, Tesla conducted experiments and refined inventions addressing a variety of electrical matters beyond the ac induction motor, including x-rays, wireless transmission of electricity, and radio transmission. A visionary, in 1904 Tesla described a wireless world much like our communications systems today, involving "the interconnection and operation of all the telephone exchanges on the Globe; the world transmission of typed or hand-written characters, letters, checks, etc; the inauguration of a system of world printing; the world reproduction of photographic pictures and all kinds of drawings or records. ... I have no doubt that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort and convenience, and maintenance of peaceful relations. It involves the employment of a number of plants ... each of them will be flashed to all points of the globe. A cheap and simple device, which might be carried in one's pocket, may then be set up somewhere on sea or land, and it will record the world's news or such special messages as may be intended for it." Nikola Tesla, "The Transmission of Electrical Energy without Wires," *Electrical World* (1904). Nikola Tesla died in 1943.

manufacturing shops and plants. In Edison's dc system, the generators and the load (lamps or motors) operated at the same voltage, carried over a three-wire copper line. To carry more power over a longer distance, the copper line had to be ever larger. The high cost of copper made it prohibitively expensive to locate generators more than one mile away from the load. Further, the system did not have the flexibility to support motors at higher or lower voltages. George Westinghouse and others who operated ac lighting systems in competition with Edison faced problems of their own, chiefly the lack of a practical motor. Edison overcame multiple shortcomings in his central station service during the 1880s, and even experimented with alternating current systems. But he still promoted direct current as the safest and most technically feasible approach to providing electrical service and engaged in a period of bitterly fought publicity contests and patent litigation with Westinghouse. During this time, inventors outside the Edison system resolved the challenge to provide power economically beyond a one-mile radius.[4]

The key to building a flexible system to provide both light and power over long distances hinged on using alternating current rather then direct current, converting it to high voltage as it left the generator for economical long-distance transmission, then converting it to mechanical energy or light when it reached its point of use. While several inventors

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[4] Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, pp. 14, 81-105. Passer, *The Electrical Manufacturers, 1875-1900; a Study in Competition, Entrepreneurship, Technical Change, and Economic Growth*, p. 123. Israel, *Edison: A Life of Invention*, pp. 318-335. Paul A. David and Julie Ann Bunn, "The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History," *Information Economics and Policy* 3, no. 2 (1988). George Westinghouse was born in Central Bridge, NY, in 1846. At age 22, he invented the first railroad braking system using compressed air. Westinghouse founded the Unions Switch and Signal Company in 1881 and later entered the electric lighting business, hoping to compete with Edison and others using an ac lighting system. In 1889, he incorporated the Westinghouse Electric and Manufacturing Company, for many years known as the energy, appliance, and manufacturing giant Westinghouse Electric Corporation. Westinghouse died in 1914. "Our Heritage: Westinghouse and the World," Westinghouse Electric Corporation, http://www.westinghouse.com/timeline.html.

experimented with the use of alternating current for motors, Nikola Tesla achieved the most successful conceptualization of the problem and the solution. In May 1988, Tesla patented the first alternating current induction motor and polyphase system, which formed the basis for much of the twentieth century electrical industry. Tesla's system began with an alternating current generator in which a rotating magnetic field was created. Rotors placed in this magnetic field then whirled to produce mechanical power. Transformers "stepped up" the voltage for long-distance transmission, then "stepped down" the voltage for a wide variety of uses at the customer end. By July 1888, George Westinghouse purchased rights to Tesla's patents, hired Tesla to collaborate with Westinghouse engineers, and began experiments to implement the Tesla system for long-distance transmission of power.[5]

Building Outward: Long Distance Transmission and its Benefits

For decades, experimenters and visionaries touted the potential benefits of long-distance electric power transmission. As early as 1729, British experimenter Stephen Gray demonstrated that he could transmit electricity a distance of 765 feet. Roughly fifty years later, Charles Babbage, considered a "father of the computer," predicted that there were advantages to be realized from long distance power transmission without major loss of energy. More significantly, in 1873, Zenobe Gramme demonstrated the feasibility of transmitting electric power over wires about three fourths of a mile long from one dynamo to another. During the next ten years, one engineer forecast that electricity from a waterpower plant could theoretically be transmitted over thirty miles and another successfully transmitted power over sixteen miles at the Munich Electrical Exhibition. Inventors described the

[5] Kenneth M. Swezey, "Nikola Tesla," *Science* 127, no. 3307 (1958); Eliot Marshall, "Seeking Redress for Nikola Tesla," *Science, New Series* 214, no. 4520 (1981); Watson Davis, "Strange Electrical Genius," *Science News Letter* 70, no. 1 (1956); Seifer, *Wizard: The Life and Times of Nikola Tesla: Biography of a Genius*; Jonnes, *Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World*.

opportunities created by long-distance transmission that would be limited neither by the distance between power plant and consumer, nor by the number of consumers. As Table 1.1 illustrates, after nearly 150 years of ideas, but no real progress, inventors advanced the art of long-distance transmission from hundreds of feet to tens of miles very quickly in the late 1800s. The push was on to find an economical, functional, and reliable system for generating power at the most cost-effective location and transmitting it over any distance to many types of consumers.[6]

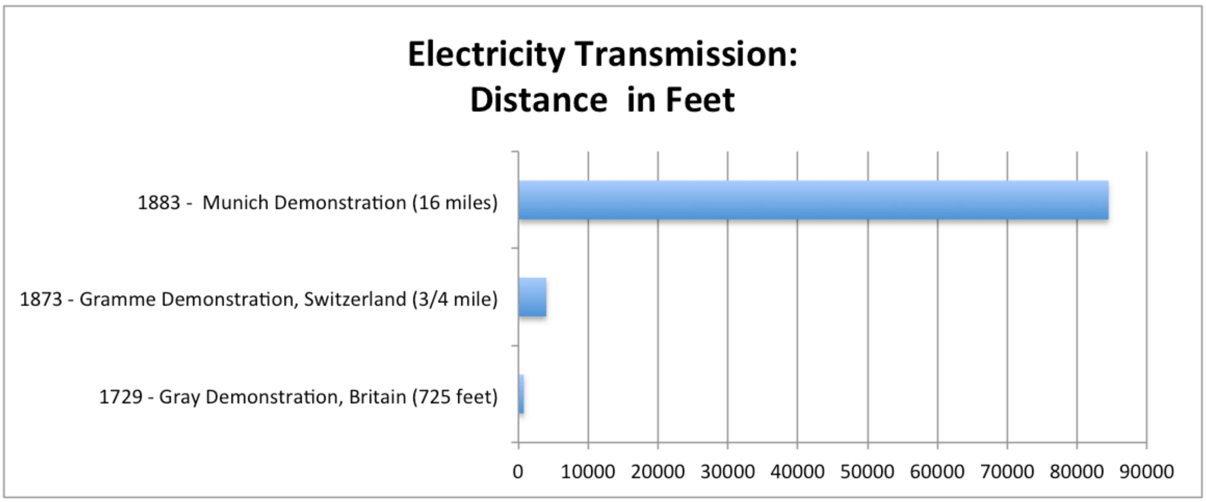

Table 1.1. Increased distance of electric power transmission, 1729-1883. *Sources*: MacLaren, *The Rise of the Electrical Industry During the Nineteenth Century*, 1943 and Hughes, *Networks of Power*, 1983.

Attention to power transmission came from multiple sectors. Industrialists and manufacturers were keenly interested in motive power for factories and workshops. Steam power proved a tremendously useful resource for factories not located adjacent to waterwheels. But for a factory using a waterwheel or a steam engine, it was nearly

[6] MacLaren, *The Rise of the Electrical Industry During the Nineteenth Century*, pp. 90, 170-171. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p.87. Schiffer, *Power Struggles: Scientific Authority and the Creation of Practical Electricity before Edison*, p.263. Hunter and Eleutherian Mills-Hagley Foundation, *A History of Industrial Power in the United States, 1780-1930. Vol. 3, The Transmission of Power*, p. 255; "Gaulard and Gibbs System of Electrical Distribution," *Engineering* 35 (1883): 205, as cited in Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p. 91;Thomas P. Hughes, "Managing Change: Regional Power Systems, 1910-30," *Business and Economic History* 6 (1977).

impossible to subdivide the energy for different applications. The mechanics of lines and pulleys further limited the layout of the workshop floor and the timing of the work procedures. By the 1860s, "there were few enterprises that in time did not feel the restraints imposed by the established means of power distribution."[7] In 1891, Louis Bell, an early transmission engineer who worked for General Electric, wrote in *Electrical World,* "we must look upon electricity as an enormously powerful and convenient means of transferring power from one point to another."[8] The solution lay in long distance transmission of electricity.[9]

Central station operators, businessmen, urban leaders, and the public also expressed interest in long-distance transmission. Central station operators chafed at the limits of electric power transmission as they sought to improve the finances of their stations and reach larger markets. They competed with gas lighting systems that could serve thousands of customers from a single station. At the 1889 meeting of the Edison Illuminating Companies, participants called for a cost-effective method of expanding the service area of central stations beyond one square mile. Electric lighting had become a symbol of class status as well as urban sophistication. Commercial leaders in rapidly expanding cities, like Chicago, eagerly embraced electrification, but were also dismayed by the geographic limitations of early electric systems. Suburban developers, similarly, found early central station systems to be too expensive for the more dispersed communities they were building. By the early 1890s, the potential benefits of longer-distance transmission of electricity were widely understood. In 1892, engineer Charles F. Scott described to the American Institute of Electrical

[7] Quoted in Warren D. Devine, Jr., "From Shafts to Wires: Historical Perspective on Electrification," *The Journal of Economic History* 43, no. 2 (1983), p. 355, from Louis Bell, "Electricity as the Rival of Steam," *Electrical World* 17 (Mar. 14, 1891), 212.
[8] Ibid.
[9] Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*, pp.193-194; Hunter, and Eleutherian Mills-Hagley Foundation., *A History of Industrial Power in the United States, 1780-1930. Vol. 3, The Transmission of Power*, p. 140.

Engineering (AIEE) a lighting plant in Portland, Oregon, and a power plant in Telluride, Colorado, which had each operated successfully for more than a year, transmitting electricity over distances of several miles, a rare achievement at that time.[10]

The first major and practical demonstration of long-distance power transmission appeared in 1893, at Chicago's Columbian Exposition. The Westinghouse Corporation introduced an integrated ac electrical system capable of powering lights as well as multiple types of motors at a distance. George Westinghouse had previously pioneered a series of devices that shared the two characteristics of transmission over a distance and crucial linking mechanisms, often providing feedback to allow regulation of the system. In the mid-1880s, Westinghouse installed a natural gas well and patented pipeline that provided the most compelling model for his later ac power system. Natural gas entered the pipeline under high pressure at the well. The pressure pushed the gas through narrow pipes over a long distance. Finally the gas moved through widening pipes to a lower pressure level safe for use at the consumer end. Over the course of several years, Westinghouse aggregated inventions, inventors, and patents to create an analogous system for electric power. Inventors introduced transformers, rotary converters, and motors that formed the basis of the Westinghouse system. The Tesla induction motor and polyphase system lay at the heart of the Westinghouse approach. "The essence of the concept was a unified system embracing, or coupling, generators (supply) and loads of varying characteristics (demand)."[11]

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[10] Passer, *The Electrical Manufacturers, 1875-1900; a Study in Competition, Entrepreneurship, Technical Change, and Economic Growth*, p. 123; Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*, p. 28. Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*, pp. 21-37; Charles F. Scott, "Long Distance Transmission for Lighting and Power," *Transactions of the American Institute of Electrical Engineers* 9, no. 1 (1892).
[11] Usselman, "From Novelty to Utility: George Westinghouse and the Business of Innovation During the Age of Edison," pp. 269-273; Jonnes, *Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World*, p. 129; Passer, *The Electrical Manufacturers, 1875-1900; a Study in*

Electricity experts immediately recognized the advantages of a universal system. Within the year, the managers of the very high profile project to build a power plant at Niagara Falls contracted with Westinghouse to design an ac powerhouse and transmission system. Shortly thereafter, Chicago Edison installed one of the first Westinghouse ac rotary converters in a commercial electric system. Utility developers now imagined reaching larger territories with central station service, waterpower investors envisioned moving energy from the mountains to the cities, while manufacturers located factories closer to labor and market sources while transmitting motor power from far away.[12]

The successful demonstration of the Westinghouse universal ac power system at the World's Fair in 1893 encouraged a number of electric companies, notably power developers at Niagara Falls, the Telluride Power Transmission Company in Utah, the Bay Counties Power Company in Northern California, and the Los Angeles Edison Company in Southern California, to adopt long-distance transmission in the ensuing years. In Boston, Chicago, Philadelphia, Montreal, and Hartford, installation of larger generators and long-distance transmission lines facilitated urban expansion. In mountainous regions, like Switzerland in Europe, and Utah and California in the United States, long-distance transmission lines carried electricity from waterpower sites to consumer centers. Over the next ten years, electric power systems blossomed.[13]

Competition, Entrepreneurship, Technical Change, and Economic Growth, p. 131; David and Bunn, "The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History"; Paul M. Lincoln, "The Development of Long Distance Electric Power Transmission," *The J. E. Aldred Lectures on Engineering Practice* (1920), p. 208; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p. 122.

[12] Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*, pp. 80-81; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, pp. 125; Jonnes, *Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World*, pp. 283-306, 135-139.

[13] Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, pp. 262-284, "Long-Distance Transmission of Power," *Electrical World* 30, no. 2 (1897); "Pacific Coast Notes: An 81-

At the Turn of the Century: Stunning Growth

The 1890s began an era of stunning growth of both supply and demand in electrification. Despite an economic panic beginning in 1893, competition from gas lighting systems, and the continued use of steam engines and water wheels in manufacturing plants, investment in electric power installations climbed into the new century. The US Bureau of the Census counted 1,646 power stations in the United States in 1893 and more than double that number in 1902. During that decade, electricity production increased over 700 percent. In the next five years, the number of power stations increased again by one third while electric capacity more than doubled. Isolated plants grew at a similar rate. Table 1.2, which measures the percent change from a base year of 1892, illustrates the climb in the number of plants, and the much steeper growth in the amount of power produced. Electricity quickly became a popular commodity.[14]

Mile Transmission Line in Successful Operation," *Electrical World* 33, no. 6 (1899); Hering, "83 Miles of Power Transmission"; "Power Transmission in Utah," *Electrical World* 37, no. 15 (1901); J.R. Cravath, "Extension of the 40,000-Volt Lines of the Telluride Power Transmission Company in Utah," *Electrical World* 37, no. 8 (1901); "Transmission System of the Bay Counties Power Company, California"; "The Bay Counties, California Power Transmission System, Colgate Plant," *Electrical World* 38, no. 15 (1901); "Electrical Transmission on the Pacific Coast," *Electrical World* 39, no. 1 (1902); "Electrical Transmission in Boston," *Electrical World* 42, no. 10 (1903); "The Electrical Hub," *Electrical World* 43, no. 21 (1904); "Expansion of the Boston Edison System," *Electrical World* 43, no. 21 (1904); "The Growth of Central Station Practice," *Electrical World* 40, no. 22 (1902); "The Concentration of Philadelphia Lighting Stations," *Electrical World* 35, no. 8 (1900); "Light and Power in Montreal," *Electrical World* 42, no. 23 (1903); Alton D. Adams, "Montreal, the Greatest Centre of Transmitted Power - I," *Electrical World* 42, no. 23 (1903); Alton D. Adams, "Montreal, the Greatest Centre of Transmitted Power - II," *Electrical World* 42, no. 24 (1903); Alton D. Adams, "Montreal, the Greatest Centre of Transmitted Power - III," *Electrical World* 42, no. 26 (1903); Alton D. Adams, "Development of a Great Water Power System at Hartford, Conn."," *Electrical World* 39, no. 10 (1902).

[14] Bureau of the Census, *Central Electric Light and Power Stations, 1902* (Washington, DC: Government Printing Office, 1905), pp. 7, 15; Hyman, Hyman, and Hyman, *America's Electric Utilities: Past, Present and Future*, p. 125; Bureau of the Census, *Central Electric Light and Power Stations* (Washington, DC: Government Printing Office, 1910), p. 50. "Isolated plant" refers to a generating facility located on the grounds of a building, factory, or city block perhaps, and that serves only that entity without connection to other customers or generating facilities. While central station and industrial power use data are not available for Canada as a whole, employment within electric and gas works grew from 184 in 1891 to 570 in 1901, and then increased to 7,323 in the next ten years,

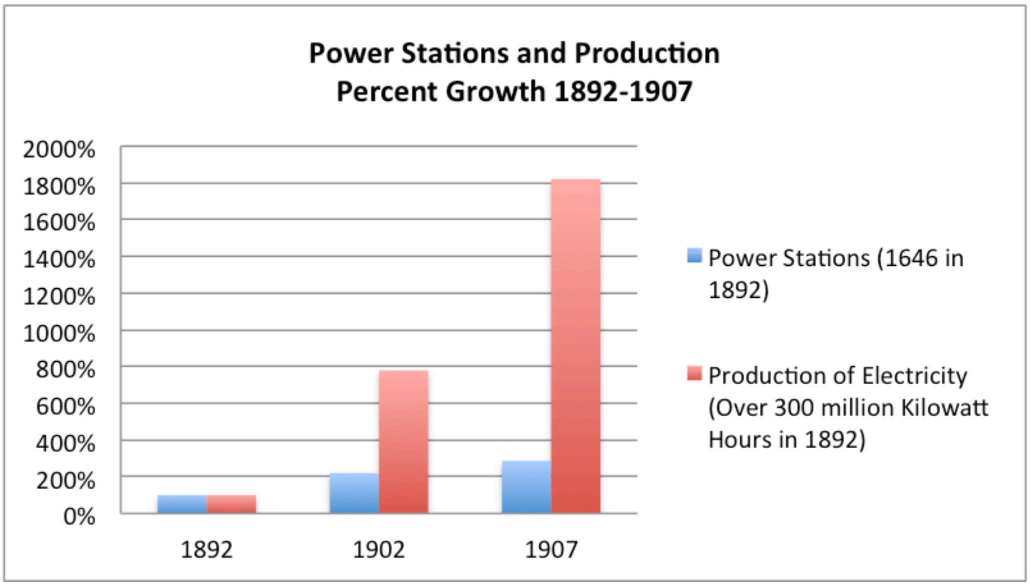

Table 1.2. Comparison of growth in number of power stations and amount of electricity produced, 1892-1907. *Sources:* Bureau of the Census, *Central Electric Light and Power Stations, 1907*; *Electrical World,* 80:11, p. 546; Bureau of the Census, *Historical Statistics of the United States, 1789-1945.*

Demand came from industry, commercial buildings, and residential customers. According to the 1900 US Census of Manufactures, the use of electric power for industrial motors grew over nineteen-fold in just ten years. Investment in electric stations in New York State alone nearly quadrupled in those years and doubled again by 1907. Across the country, electricity sales increased as well from 650,000 consumers in 1902 to over 2 million by 1907. Despite this expansion, far fewer than ten percent of all households had electricity at this point, illustrating the continuing potential for adding customers. In the United States, for example, there were 235 lamps of every type, including streetlights and factory lights, for every 1,000 people. Long distance transmission acted as an important factor in this growth process. While the technology was "just announced" in 1893, forty-five waterpower companies transmitted electricity over 1,396 miles of lines by 1902.[15]

suggesting similar expansion. Armstrong and Nelles, *Monopoly's Moment: The Organization and Regulation of Canadian Utilities, 1830-1930*, p. 222.

[15] Bureau of the Census and Social Science Research Council, *Historical Statistics of the United States, 1789-1945; a Supplement to the Statistical Abstract of the United States* (Washington, DC:

In both the United States and Canada, municipalities and private investors jockeyed to build electric light and power systems. Government-owned utilities issued bonds to build generators and power lines, in theory securing more attractive financing terms and promising lower rates to customers. Investor-owned utilities, however, could build systems that reached beyond the geographic boundaries of cities, often obtaining more customers and more diverse customers than municipal systems. With geographic and customer diversity, these private utilities operated their plants more efficiently, often providing service at low rates. Private utilities often faced brutal political negotiations at the local level, whether they were competing with other utilities for franchises or competing directly with local governments for the right to build a power plant. The debate over public ownership versus private ownership continued throughout the twentieth century. In the twenty-first century, countries in North America, unlike other parts of the world, still feature an amalgamation of government-owned and privately owned electric services, with a variety of regulatory schemes at all levels of government.[16]

Government Printing Office, 1949), pp. cccxxii, 159; Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*; Bureau of the Census, *Central Electric Light and Power Stations and Street and Electric Railways, with Summary of the Electrical Industries, 1912*, (Washington, DC: Government Printing Office, 1915). As a point of comparison, well over 1.6 billion standard light bulbs were shipped to US markets in 2009, that is, roughly 5.5 per person. In that year, the average residence in the US had 40 sockets for standard light bulbs. Thus, while every four people shared a light bulb at the turn of the century, now we each have at least five, and more likely ten, of our own. Stephen Bickel, Tobias Swope, and Daniel Lauf, "Energy Star CFL Market Profile: Data Trends and Market Insights," (Washington, DC: US Department of Energy, 2010), p. 8, 30. United States Census Office, *Twelfth Census of the United States Taken in the Year 1900: Manufactures, Part I, United States by Industries, William R. Merriam, Director*, (Washington, DC: Government Printing Office, 1902); "Power Transmission before the International Electrical Congress," *Electrical World* 44, no. 13 (1904).

[16] For fuller discussions of public versus private ownership and the regulatory schemes that developed over the twentieth-century, please see Armstrong and Nelles, *Monopoly's Moment: The Organization and Regulation of Canadian Utilities, 1830-1930*; G. Bruce Doern, *Canadian Energy Policy and the Struggle for Sustainable Development* (Toronto: University of Toronto Press, 2005); Gilbert and Kahn, *International Comparisons of Electricity Regulation*; Hirsh, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System*; Hughes, *Networks of Power:*

A New Challenge of Growth: Reliability

With long distance transmission came technical challenges. Various problems afflicted transmission, including protection from lightning and other outdoor hazards, insulation, and pole construction. For the system operators, issues existed at the generating stations as well. Reliable service regularly topped the list of concerns discussed by electricity experts, although the terminology varied from year to year. As one of the contributors to *Electrical World* noted in 1897, "with the growth of systems, the service which was in its early days rather fitful and liable to shutdowns at any time has become more reliable, and the feeling has grown up that the shutting down of a line is something almost criminal."[17] Others noted that "continuity of service has been one of the prime requisites of commercial success" and with growth it "has become imperative."[18]

Engineers understood that steady service was critical to consumers. In professional publications, power experts expressed concern about preventing outages when apparatus failed. Power providers employed several approaches to addressing reliability, depending

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Electrification in Western Society, 1880-1930; Hyman, Hyman, and Hyman, *America's Electric Utilities: Past, Present and Future*; Nelles, *The Politics of Development; Forests, Mines & Hydro-Electric Power in Ontario, 1849-1941*; Rudolph and Ridley, *Power Struggle: The Hundred-Year War over Electricity*.

[17] "The Tendency of Central Station Development - III," *Electrical World* 30, no. 26 (1897).

[18] Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*; Bayla Schlossberg Singer, "Power to the People, the Pennsylvania - New Jersey - Maryland Interconnection, 1925-1970" (Thesis (PhD diss., University of Pennsylvania, 1983); "Chicago Meeting of the A.I.E.E. - Transmission Lines," *Electrical World* 43, no. 19 (1904); Louis Duncan, "Possible Voltages and Distances of Transmission: Possible Voltages and Distances of Transmission," *Electrical World* 28, no. 16 (1896); "Flexibility in the Transmission and Distribution of Electrical Energy," *Electrical World* 29, no. 7 (1897); Carl Hering, "Installations, Systems and Appliances: Subdividng Central Stations," *Electrical World* 32, no. 19 (1898); "Power Transmission in Utah"; "Los Angeles Transmission Plants," *Electrical World* 37, no. 25 (1901); "Electrical Progress During 1901," *Electrical World* 39, no. 1 (1902); H. A. Lardner, "Central Station Steam Plant," *Electrical World* 41, no. 18 (1903); "Electric Power Transmission," *Electrical World* 44, no. 2 (1904); "Reliability of High Tension Lines," *Electrical World* 44, no. 18 (1904); "The Value of Water Storage"; "The Year in Power Transmission"; "Annual Meeting of the American Institute of Electrical Engineers," *Electrical World* 45, no. 20 (1905). Quote from Howard S. Knowlton, "The Storage Battery in Transmission Plants," *Electrical World* 41, no. 20 (1903).

upon the size and shape of the electrical system. For on-site isolated plants, storage batteries were "essential."[19] At first, storage batteries provided good back-up power only for direct current systems. Later innovations allowed the use of storage batteries with alternating current systems as well. Large urban utilities connected central stations to multiple substations in order to provide reliable operations. A notable case took place in 1901 when an accident shut down Harrison station in Chicago – Commonwealth Edison's largest generating station at the time. Following calls to the utility's other stations to put on all their generators and storage batteries, full power was restored to consumers within minutes. At hydroelectric plants, steam generators installed at the powerhouse often provided back-up power. In 1896, fifty percent of the United States' hydroelectric plants included steam generators. The Telluride Power Company was one of the first to operate plants in parallel with other companies to ensure reliability. Utility operators thus had a number of reliability options by the early twentieth century, including storage batteries and/or back-up generators at the power house, networked power stations under the control of a single company, and interlinked and parallel operations among two or more companies.[20]

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[19] "Economy of Isolated Electric Plants," *Electrical World* 39, no. 9 (1902).
[20] Louis Duncan, "Present Status of the Distribution and Transmission of Electrical Energy," *Electrical World* 28, no. 15 (1896); "Flexibility in the Transmission and Distribution of Electrical Energy"; "Buffalo and Niagara Notes: Buffalo General Electric Company," *Electrical World* 33, no. 2 (1899); "The Central Station of the Buffalo Generael Electric Company," *Electrical World* 33, no. 4 (1899); Joseph Appleton, "Latest Progress in the Application of Storage Batteries," *Electrical World* 33, no. 5 (1899); Frank C. Perkins, "Buffalo General Electric Company's Stoage Battery Plant," *Electrical World* 34, no. 17 (1899); "The Storage Battery," *Electrical World* 35, no. 7 (1900); "The New Storage Battery of the Kansas City Electric Light Co.," *Electrical World* 36, no. 18 (1900); "Transmission Line Construction," *Electrical World* 38, no. 7 (1901); "Storage Batteries in Central Stations," *Electrical World* 38, no. 8 (1901); R.F. Schuchardt, "Storage Batteries in Central Stations," *Electrical World* 38, no. 7 (1901); "A Notable Water Power System," *Electrical World* 39, no. 10 (1902); "Construction of Transmission Lines"; Knowlton, "The Storage Battery in Transmission Plants"; "Institute Meeting in Chicago on Storage Batteries," *Electrical World* 43, no. 4 (1904); Henry Floy, "A Unique Storage Battery Installation," *Electrical World* 44, no. 8 (1904); "The Storage Battery," *Electrical World* 45, no. 1 (1905); "Annual Meeting of the American Institute of Electrical Engineers"; Charles Blizard, "Storage Battery Regulators," *Electrical World* 45, no. 4 (1905); Platt,

Comparing Strategies: Storage Batteries and Interlinking Systems

Storage batteries and interlinking topped the list of choices for ensuring system reliability by the early 1900s. Each approach addressed a number of challenges for electricity providers, and for the most part the same challenges. Between 1896 and 1905, over forty articles appeared in the pages of *Electrical World* specifically addressing the uses and benefits of storage batteries at generating stations and over thirty focused on the operation of systems in parallel, interlinking of systems, or interchange of power. Those describing storage batteries with great enthusiasm noted that they provided for energy storage and load balancing. In addition, batteries provided back-up power during an outage and aided with peak loads. Batteries even afforded water conservation when charged during low load, when the waterpower would have been otherwise "wasted," then used to meet the peak load when the power was most needed.[21] As one contributor noted in 1899, to operate large-scale generating machinery with the greatest economy, to maintain a constant load, and to realize the best return on investment, storage batteries were "indispensable."[22]

Interlinking systems offered benefits similar to those of storage batteries. The trailblazing connection between the San Gabriel–Los Angeles transmission line and the Los Angeles Railroad circuit allowed two separate companies to equalize their loads and provide each other with back-up reserve power. The power company relied on hydroelectric plants and purchased electricity from the railway when water flow was low. The railway was the

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The Electric City: Energy and the Growth of the Chicago Area, 1880-1930. Schuchardt, "Storage Batteries in Central Stations"; *Electrical World* 29, no. 10 (1897); Cravath, "Extension of the 40,000-Volt Lines of the Telluride Power Transmission Company in Utah"; "Power Transmission in Utah." The operation of multiple power plants "in parallel," regardless of ownership, meant that they generated power in exact synchrony and could share transmission lines.

21 W.L. Robb, "Rotary Transformers and Storage Batteries," *Electrical World* 33, no. 23 (1899).

22 "Flexibility in the Transmission and Distribution of Electrical Energy"; "Buffalo and Niagara Notes: Buffalo General Electric Company"; "The Storage Battery Substations of the Metropolitan Street Railway, New York City," *Electrical World* 33, no. 3 (1899); Appleton, "Latest Progress in the Application of Storage Batteries."

"dumping ground" for surplus power when there was high water in the winter.[23] Across parts of France, as in urban Philadelphia, neighboring stations were connected in order to share current, make the load on individual stations more uniform, and distribute the load among stations economically. In Utah, where river flow could cause variability in the amount of electricity available from any one plant, "the throwing together in parallel a number of them greatly increases the reliability of current supply."[24] The editor of *Electrical World* touted interlinked systems as the key for realizing the benefits of water storage reservoirs in both economical use of generating plants and the elimination of waste. And, by 1904, engineers calculated that interlinking would allow plants to take on a "surprising amount of load," plants that would be uneconomical on their own could be profitable when part of a network.[25]

The demonstration of the technical feasibility of long-distance ac transmission in 1893 triggered a debate between those who favored centralized electric power delivery and those who favored isolated power plants that served a single building. As long-distance transmission lines grew, those who favored local service and those who advocated regional power systems continued the disagreement. Differing approaches emerged to address the challenges of providing reliable, flexible, and affordable power to a growing consumer base, including the development of rate structures to improve load balance and increase consumption, installation of storage batteries to draw power during low load periods and aid with peak loads, design of more efficient generators, and interlinking of generating plants to provide back-up power. Among the diverse approaches to electrification, interconnected

[23] Carl Hering, "San Gabriel - Los Angeles Transmission," *Electrical World* 33, no. 1 (1899); "Los Angeles 33,000-Volt Transmission Plant and Electric Railway," *Electrical World* 37, no. 26 (1901).
[24] "Power Transmission in Utah."
[25] Carl Hering, "Transmission Plant of the Northern Railway of France," *Electrical World* 33, no. 10 (1899). "The Value of Water Storage"; "The Concentration of Philadelphia Lighting Stations"; "Economics of High Voltage Transmission," *Electrical World* 44, no. 19 (1904).

regional power systems had hardly taken hold as the preferred path for growth, but the idea was on the table by the time power planners from around the world met in St. Louis at the Louisiana Purchase Exposition in 1904. A full session was devoted to the now rapidly advancing technologies of long-distance transmission and regional systems, marking a turning point in the industry. The majority of advances in long-distance transmission had occurred in just the previous five years.[26]

The 1904 Congress – Interest in Parallel Systems

The international discussions about power systems at the St. Louis Exposition in 1904 illustrate the emerging fraternity of engineers, managers, and owners within the utility industry. The focus on electrification coincided with a brief spike in publications about the state of the electrical arts, including the first extended discussions in print of long distance transmission of power. The Electric Power Transmission Section of the International Electrical Congress met over three and a half days at the Exposition, and covered the pressing issues concerning movement of bulk power. Presenters addressed a range of subjects from descriptions of regional systems in Europe and the western United States to much more technical matters related to high-tension transmission. Participants pondered the stunning possibility that 500,000 kilowatts of power could travel over 550 miles in the foreseeable future. This collection of engineers and utility operators from around the world shared insights that they later took home to inform the development of their own systems.[27]

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[26] Scott, "Long Distance Transmission for Lighting and Power."

[27] "Fifth International Electrical Congress, St. Louis, Mo, Sept 12-17, 1904," *Electrical World* 44, no. 12 (1904), pp. 199-484. Searches of several online bibliographic databases available through *Engineering Village* indicated a peaking interest in electricity and long-distance power transmission in the years 1902-1905. A search for the term "electric" in engineering publications for each year from 1890 to 1910 shows a definite spike between 1902 and 1905. There were, on average, 1300 publications each year including the term "electric" before 1902, between 1600 and 1800 publications during each of the peak years, and an average of 1423 publications per year after 1905 until 1910. For

Discussions following each presenter focused on technical details, and reflected extensive exchange of ideas – especially between engineers from both sides of the Atlantic. Participants also indicated a great deal of curiosity about the experiences of presenters who had operated stations in parallel – a requisite of interconnection. Nevertheless, they found many areas of disagreement, often on seemingly minor points. Towards the end of the final day, Chairman Scott noted that "matters which were of no concern before, come up to the first rank of importance. Take our whole discussion this morning and what has it been? It has been on the insulator pin, a thing which a man not familiar with the subject would think one of the least consequence, but we have found that it is one of the vital points."[28] There were wide differences in experiences and approaches, yet a common interest in resolving even minute technical problems. This session defined a growing segment of the industry, beset by challenges, and sharing divergent opinions how best to move forward.

In the first years of a new century, two key technologies for expanding and strengthening electric power systems emerged. In January of 1905, the editor of *Electrical World* heaped equal praise on storage batteries and interlinked systems as the wave of the future. Of the former, he stated, "... the conviction forces itself that this former 'ugly duckling' of the electrical art has, in its later perfection, become a swan." Storage batteries leveled load curves, cut off peaks, filled in holes, and formed an "... integral part of almost

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the search term "long distance transmission," the peak years were 1904 (11 publications) and 1905 (17 publications). During the prior years, there were an average of 8 publications per year and during the following years there were an average of 5 publications per year. This latter data also suggests a drop-off in the novelty of long distance transmission as a technical publication topic. "Engineering Village, Compendex Database," (Elsevier Inc., 2010) accessed January 14, 2011, http://www.engineeringvillage2.com/controller/servlet/Controller

[28] "Transactions of the International Electrical Congress, St. Louis, 1904," The International Electrical Congress, St. Louis, St. Louis, MO, 1904, pp. 408-409.

every modern equipment." [29] In the same issue, he offered, "Probably the most important present tendency in power transmission is the union of several plants in feeding a great network."[30] The following month, the editor suggested that the interlinked system operated by the Edison Electric Company in Southern California represented the "last great step" in maximizing use of water resources. Interlinked systems allowed plants to give and receive help, share in the general average of supply, balance out flows, render multiple flows more valuable, provide a virtual energy storage reservoir to others, and serve as "duplicate" systems.[31] Storage batteries and interlinked systems rendered more reliable and efficient electrical service and offered opportunities to conserve energy resources.

Summary

With the advent of central station service, electricity became wildly popular. Systems evolved quickly from geographically circumscribed direct current service lighting the homes and businesses of the wealthy to spreading networks of alternating current service moving machines, transporting people, and lighting an array of indoor and outdoor settings. As both government and private utilities evolved, the operators discovered the importance of setting and maintaining a high standard of service. Reliability, stability, and affordability were paramount as electrification transitioned from novelty to utility. Innovations, including storage batteries, the linking of multiple stations, and even connections between different systems, provided utility operators with both operating economies and reserve power for reliability. The industry had many paths to consider as the demand for electricity grew during the first decades of the twentieth century. As the editors of *Electrical World* and the

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[29] "The Storage Battery."
[30] Ibid.
[31] "The Year in Power Transmission." The Edison Electric Company System in Southern California was comprised of seven plants and 600 miles of transmission and distribution lines.

international fraternity of engineers involved in power systems understood, interconnections would play a key role in the continuing growth of electrification.

In the 1880s, power companies sold expensive electricity as a luxury commodity, while working to make it affordable enough to become a necessity. The utility owners set early goals for reduced costs per kilowatt-hour of electricity, expanded markets, and profitability. Direct current presented an early technical barrier to these goals. Utilities found it was too expensive to distribute direct current beyond one mile. Innovations in delivering alternating current opened the opportunity for power entrepreneurs to build long-distance transmission lines and reach larger and a greater variety of markets. This technical choice had long-term ramifications for industry growth. Reliability posed a second barrier to industry goals. Once customers began to depend on electricity for lighting and driving motors, power failures were considered practically criminal. To achieve greater reliability, utilities adopted a variety of technologies, including storage batteries, back-up generators, connections to substations, and interlinking with other systems. Interconnections were by no means the only option for improving system reliability, nor were they necessarily the preferred option. Manufacturers' early preference for in-house power plants posed the third barrier to electric company goals. Manufacturing plants represented a significant potential market for utilities, but central stations competed directly with their own possible customers, who often chose to replace mechanical power systems with internal electrical systems.

In 1905, the notion of large-scale interconnected power systems was visionary at best. Indeed, other industries that shared similarities with electrification, including telephony and oil, were tending toward national monopolies by the early 1900s. Many investor-owned utilities also expanded in this direction. But the physical characteristics of electricity, the technical options available by this date, and the emerging public service aspect of electric power all posed challenges to the industry. Further, this very young industry was characterized by variety in every respect. Both for-profit and municipal companies proliferated and competed across the continent. Power stations ranged in size from tiny to very large. Many still provided dc rather than ac service and there was no consensus about voltage. Most power plants operated in isolation while some traded power across state and international boundaries. In no sense was the development of a grid inevitable at this early stage of electrification.

Power providers used alternating current service to reach wider markets with greater flexibility. Alternating current gave them nearly unlimited geographic opportunity for electrification. Over the coming years, the barriers to distance transmission fell quickly. Further, providers discovered improved techniques for stepping the voltage up and down, dividing the electricity between multiple uses, and generally serving a wider variety of consumers. At the same time, interconnected plant operators enjoyed the benefits of access to back-up power from neighboring companies. Investors in private power companies consolidated through the device of holding companies while governments developed a deeper interest in regulating this increasingly popular public service. In North America, electrification varied regionally in both degree and style. As the next chapter illustrates, an early consensus among some industry experts favoring interconnection began to appear during the 1910s, and intensified during World War I.

Chapter 2. Spreading Towards a Grid: Multiple Configurations of Growing Electrification, 1905-1920

Between 1905 and 1920, utilities across the continent expanded in ways that prefigured the grid. Many aggressive private utilities built regional interconnected power systems as they sought increased profits through larger and more diverse markets. But variety marked electrification. Investors, owners, operators, engineers, politicians, and customers made choices that led to growth in fits and starts. Significant numbers of manufacturers, smaller independent utilities, and municipal power companies resisted joining larger power networks. Instead, they sought affordability and reliability within discrete service areas. Other areas still awaited the first generating station to bring electricity to local consumers. In the early 1900s, only a fraction of homes and communities in North America enjoyed access to electricity. In the 1910s, visionaries began to talk about a national grid in the United States. Most power providers, however, focused on local, or perhaps regional systems, extending power lines to improve the utility bottom line. By 1920, while many understood the advantages offered through interlinking with neighboring stations, it was still a limited practice.

After the turn of the century, both utility marketing and public demand accelerated the growth of power systems. Power producers aggressively marketed electrification to homeowners, public entities, and commercial outfits. Politicians joined in advancing the cause, urging modernization and resource conservation through the use of electricity. Utilities also employed technologies and operating practices that made electricity more affordable, further encouraging greater numbers of consumers to electrify their homes and workplaces. The specific patterns of growth during this period illustrate trends toward economies of scale, increased use of waterpower, and improvement in long-distance transmission technologies. These trends favored future interconnections. The patterns of growth also reflect the wide variation in styles of electrification: power providers might be large or small; public or private; serving just one building or an entire city; independent or part of a holding company; based on hydroelectric energy or coal; selling ac or dc power; generating at frequencies of 25, 50, or 60 hertz. While there was a unified push to increase the amount of electricity produced and used, the industry was comprised of a multiplicity of entities that generated and sold power.

Technical, organizational, and political choices framed the small, but growing number of interconnected systems. For example, as many utilities elected to enlarge the size of generating stations, some options for back-up power reached practical and economic limits. Interconnection became increasingly attractive as a cost-effective way to minimize service interruptions. Further, electrification was still a fairly young industry in the first decades of the twentieth century. Some considered electricity a commodity while others saw it as a service. The organization of power businesses was still in flux, as was the government response to this growing economic sector. Organizational trends, such as consolidation of utilities in order to reach a broader array of markets, also favored interconnection. Other trends, however, such as regional political preferences for municipal power companies, proscribed the advance of interconnections. During these years, national and regional governments entered the power market, both as regulators and as competitors, creating conditions that generally favored interconnection across most of the continent, except where there was strong political opposition to private power companies. Decisions to interconnect took place in the context of broader choices about the shape, size, function, and operation of the industry.

During World War I, the power industry endured energy crises, collaborated with government, formed organizations among competitors to aid the country, and built interconnections under the direction of a central authority. These experiences led utility leaders and others to extol the value of interconnections and propose plans for building very large-scale systems. While utility executives had exchanged information and ideas for years through the National Electric Lighting Association, the American Institute for Electrical Engineers, and other trade and technical organizations, during the war they worked together much more closely to achieve common national goals. Significantly, this endeavor focused on building interconnections and directing electricity to war production industries. This was the first iteration of a form of shared management and divided authority that marked the way the industry and governments organized around interconnections through the remainder of the century. By 1920, technical choices, regional interconnected networks, political inclinations, and organizational strategies suggested that the industry would move toward a unified grid. But the physical infrastructure on the ground and the fragmentation within both industry and government indicated that many more decisions and innovations lay ahead before the grid could become a reality.

Patterns of Electrification

Electrification took place in a variety of configurations across the country in the early 1900s. Both for-profit utilities and not-for-profit municipal companies built power systems. Some were quite large, but most were small and very local. Residents and businesses in urban centers had early access to electricity, most rural areas had none at all. The pace of both power generation and consumption accelerated during these years for several reasons. Coupled with aggressive marketing campaigns, utilities and manufacturers introduced a plethora of uses for this highly flexible source of energy. From the practical to the ridiculous, electrical devices entered homes, towns, farms, and industry. Power companies also improved generating technologies and practices, bringing down the per-unit cost of electricity. Electricity rates designed to encourage consumption morning, noon, and night, further improved operating costs at the power plants, leading to higher profits for the utilities. Electrification barely slowed for ups and downs in the broader economy.

Through the first two decades of the twentieth century, the use of electricity grew dramatically in North America. The pattern of growth reflects the dual facts that consumers used more electricity and producers found ways to produce and deliver it more efficiently. In 1902, utilities sold 2.2 billion kilowatt-hours of electricity to consumers. Fifteen years later, they sold ten times that much power. During this time installed generating capacity increased steadily, doubling roughly every five years. Despite this phenomenal growth rate, the total number of central stations did not quite double over the entire twenty-year period, from 3,620 to 6,542. This apparent slower growth reflects the effort of utilities to improve economies of scale. Many utilities, particularly in urban areas, installed larger and more efficient generators, acquired nearby plants, repurposed them into substations, and reached larger markets with less expensive power. Table 2.1 below illustrates the dramatic increase in power generation and consumption between 1902 and 1922, and an equally significant increase in the number of power customers. By contrast the total number of generating plants appears nearly flat, reflecting the trend toward larger and more efficient power stations. Trends toward greater demand and greater efficiency, both of which continued for several decades, contributed to a growing interest in interconnections in later years, because interconnections introduced greater reliability, energy savings, and bigger markets for utilities.[1]

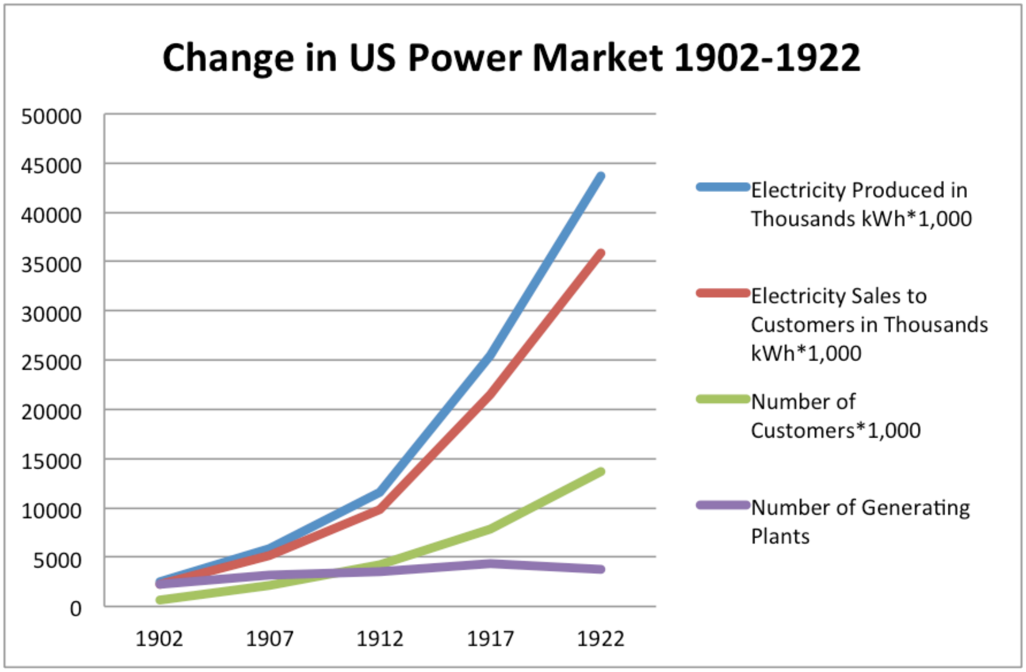

Table 2.1. Trends in generation and consumption of electricity, number of utility customers, and number of generating plants in the United States between 1902 and 1922. *Sources:* Bureau of the Census, *Census of Electrical Industries, 1932: Central Electric Light and Power Stations*.

[1] Bureau of the Census and Social Science Research Council, *Historical Statistics of the United States, 1789-1945; a Supplement to the Statistical Abstract of the United States*. p. 156 -149. The Census Bureau of the US Department Commerce published results of surveys of the electric light and power field every five years beginning in 1902, reporting power use in terms of horsepower until 1917. The Census of Manufactures contained data about electric power use in 1889, 1899, and every five years thereafter. The Census of Manufactures continued to report in terms of horsepower in 1919. In 1949, the Bureau of the Census published *Historical Statistics of the United States, 1789-1945* and converted horsepower into kilowatts in order to standardize the available data. In terms of energy production, utilities generated nearly 7 billion kilowatt hours in 1902, and 43 billion kilowatt hours in 1917. To establish a sense of scale, in 2009, the average household in the United States used about 11,000 kilowatt-hours. In 2009, it took only 200,000 US households to use as much electricity as the entire industry sold in 1902. "Frequently Asked Questions: How Much Electricity Does an American Home Use?," US Energy Information Administration website, last modified June 1, 2011, http://205.254.135.24/tools/faqs/faq.cfm?id=97&t=3; Bureau of the Census Department of Commerce, *Census of Electrical Industries: 1917, Central Electric Light and Power Stations with Summary of the Electrical Industries*, (Washington, DC: Government Printing Office, 1920), pp. 9, 15, 22-23. The 1917 Census also documents the changes in dynamos, the total number increased 2.2 percent in the prior decade while the kilowatt capacity increased by 236.4 percent – a stark indication of the great improvements made in plant efficiency during these years, p. 25. The number of stations did pick up speed in the 1910s, with a growth rate of 10.8 percent between 1907 and 1912, and a growth rate of 25.3 percent in the following five years.

Geography played a role in energy choices during these years, as did advances in long-distance transmission technology. Until the early 1900s, by far the majority of power stations used fossil fuel, primarily coal, to generate electricity. In regions of the country where river systems adjoined potential power markets, utilities did build hydroelectric dams. A hydroelectric dam on the Fox River in Appleton, Wisconsin began producing power in 1882, the very same year in which Edison's Pearl Street Station began operations. But most of the attractive waterpower sites in North America were located at a significant distance from potential customers. The very high capital cost associated with building dams on the largest rivers limited early private investment in hydropower development. Improvements in long-distance power transmission, and a new federal role in river development, changed the calculus for waterpower in the early 1900s.

Long distance transmission of power advanced dramatically after 1900. Engineers found the means to overcome limits to both distance and voltage. For example, in 1902, prominent utility engineer C.P Scott had predicted that a 60,000-volt transmission line probably represented the outer limit. This equaled a six-fold increase over the transmission lines displayed by Westinghouse at the Columbia Exposition ten years earlier. Seven years later, the Central Colorado Power Company broke new ground with a 100,000-volt line, shattering Scott's prediction. In 1912 the Ontario Hydroelectric Commission carried power over 281 miles on a 100,000-volt line; and in 1913 the Pacific Light and Power Company put a 240-mile, 150,000-volt line into operation, obtaining the highest voltage in North America through the end of the decade. By 1914, *Electrical World* reported nearly 4,000 miles of transmission lines at or above 70,000 volts in the United States, Canada and Mexico. Transmission distance approached the 300 mile mark by 1914, while, as Table 2.2 illustrates, transmission voltage grew stepwise, increasing by about 40,000 kilowatts every five years. Three hundred miles stood as a barrier to power transmission, but with interconnections, utilities could move electricity even further.[2]

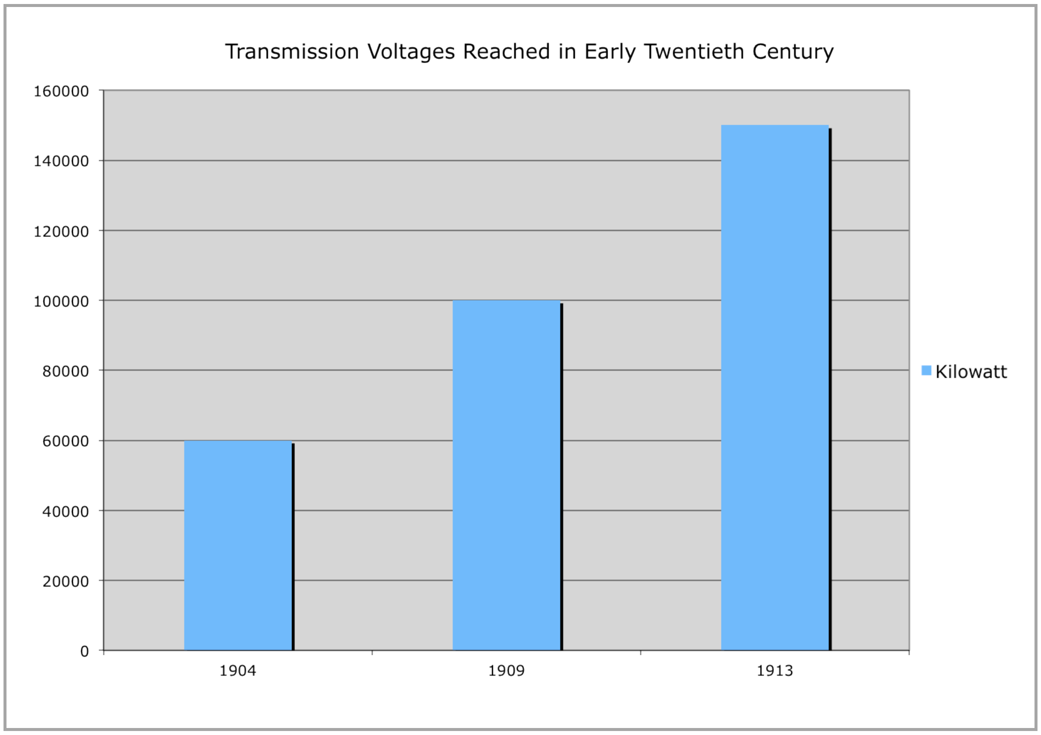

Table 2.2. Increased transmission voltages between 1904 and 1914 *Sources: Electrical World,* various issues, 1904-1914.

Power companies in the Rocky Mountains, California, and at Niagara Falls were among the first to seek very long transmission lines moving power at high voltage. When utilities like Central Colorado Power Company demonstrated the feasibility of transmitting electricity

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[2] "Limits of Power Transmission," *Electrical World* 40, no. 16 (1902); "Maximum Distance to Which Power Can Be Economically Transmitted.," *Electrical World* 44, no. 26 (1904); "Transmission Committee of the American Institute for Electrical Engineering ", *Electrical World* 40, no. 22 (1902); Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970*, p. 123; "Transmission Lines of the Central Colorado Power Company," *Electrical World* 55, no. 4 (1910); Lincoln, "The Development of Long Distance Electric Power Transmission"; "The 110,000-Volt Transmission System of the Province of Ontraio," *Electrical World* 59, no. 1 (1912); "The Great Ontario Transmission," *Electrical World* 59, no. 4 (1912); "Highest Voltage Transmission System in the World," *Electrical World* 59, no. 15 (1912); "Recent Developments in Transmission-Line Voltages," *Electrical World* 59, no. 18 (1912); "The Big Creek Transmission System," *Electrical World* 64, no. 14 (1914); Selby Haar, "High-Voltage Transmission Systems of the World," *Electrical World* 63, no. 17 (1914); Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, pp. 282-283.

across a stretch of 240 miles, interest in developing sites on the Colorado River, the Columbia River and other major western tributaries blossomed. In 1902, Congress passed the Reclamation Act, designed to promote irrigation, flood control and transportation improvements on western rivers. The Bureau of Reclamation quickly discovered that hydroelectric dams, built to power irrigation projects, also generated revenue to finance other river development activities. In time Progressive Era activists encouraged full river development projects that featured large hydroelectric dams, which in turn offered economic development benefits to large regions in both the west and the south. For purposes of examining the expansion of interconnection, the important point is that hydroelectricity provided an increasing share of the power market in the early twentieth century.[3]

Hydroelectric plants posed two challenges for utilities. First, power companies faced the difficulty of moving electricity from generating sites to distant consumers. With limits to the effective distance to which a company could transmit power, interconnections provided vital access to markets. Second, hydroelectric plants are subject to the vagaries of seasons and weather. Utilities quickly discovered that by linking to power plants in river basins with different seasonal water flow they could aid each other during complementary low- and high-

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[3] Between 1902 and 1917, the generating capacity of hydroelectric plants increased more than twelve times, with most of the growth in western states. Hydroelectric plants generated 220,000 kilowatts in 1902 and nearly 2,800,000 kilowatts in 1917. It is noteworthy that in terms of plant value, investment, dynamo capacity, and income from sale of current, growth increased at a faster rate for hydroelectric plants than for all power plants in the years immediately after 1912. In 1902, the Census Bureau identified 1,308 commercial and municipal stations operating water wheels and turbines. That number nearly tripled by 1917 while total generating capacity of all types of hydroelectric plants increased one thousand percent between 1902 and 1917. The census data does not include isolated plants and federally owned and operated plants for these years. Waterpower comprised less than 20 percent of the electricity provided by utilities at the start of the century, but over 30 percent by 1917. *Census of Electrical Industries: 1917, Central Electric Light and Power Stations with Summary of the Electrical Industries*, p. 35; Bureau of the Census and Social Science Research Council, *Historical Statistics of the United States, 1789-1945; a Supplement to the Statistical Abstract of the United States*, p. 158.

water periods. Further, if they linked with a thermal power plant, the two types of plants could aid each other when their respective energy sources were scarce.

A Variety of Regional Interconnected Systems

Electrification across North America continued in fits and starts, following regional trends and organic paths of expansion. With bigger generators, lower costs, long distance transmission lines, interlinking stations, and growing demand, utilities built systems that suited the geography, energy resources, and population density of each part of the country. In mountainous areas with little access to fossil fuels, power companies transmitted electricity across hundreds of miles to urban and agricultural centers. Within dense urban areas, small central stations stretched their services beyond city limits as they added larger generators and longer high voltage lines to their systems. In addition, one utility often acquired many smaller utilities under the rubric of a holding company in order to expand regionally. Utilities serving smaller communities across lightly populated regions, like the Southeast, combined to provide each other with back-up power and to build more balanced demand loads. In addition, some holding companies, like Stone and Webster, consolidated a large collection of central stations under one owner, but served non-contiguous communities.

Modern energy transmission was "born and raised on the Pacific Coast" according to a journalist reporting in 1912.[4] With almost no locally available fossil fuel for power plants, the western states depended upon water resources for electrification. Waterpower, while plentiful, was also variable, and interlinking allowed systems to aid each other during dry seasons or periods of overabundance of hydroelectricity. Power companies generated electricity in the mountains and carried it long distances across municipal and county lines to

[4] "The Transmission Systems of the Great West," *Electrical World* 59, no. 22 (1912).

the ultimate customers. Technical breakthroughs, including methods for synchronizing multiple power stations on a network, accrued to these pioneer projects. "If three or four stations must be operated together in defiance of all precedents, in go the switches, and the plants operate as if they had worked together from the very beginning."[5] In California especially, regional systems achieved superlative status over and over again. In 1905, the Edison Electric Company in Southern California operated a “notable” system.[6] In 1911, the company provided a “veritable … high tension busbar running the length of the state.”[7] The state exhibited “thorough” amalgamation of transmission lines into networks.[8] In 1912, Pacific Gas and Electric operated the “largest transmission system in the world,” supplanted two year’s later by the Big Creek line, deemed “The World’s Largest.”[9] For years the industry looked to the west for innovation in building and operating large-scale systems.

Regional expansion occurred in urban areas east of the Mississippi through vertical and horizontal integration of entrepreneurial utilities. Samuel Insull took the lead at Commonwealth Edison in Chicago. He acquired competitors in electric lighting, traction, and gas services. He promoted state-level regulation to sidestep the politics and limits of municipal control. He marketed power to a diverse array of customers and designed rate structures to promote consumption. Insull pushed electrical manufacturers to build larger, more energy-efficient generators and he interlinked these with older and smaller stations that had been repurposed into substations. Building a market of diverse users who would demand

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[5] Ibid. Plant operators used switches to open or close connections between power systems. For electric current, a “closed” switch allows power to flow and an “open” switch prevents power from flowing.
[6] “A Notable Transmission System,” *Electrical World* 45, no. 8 (1905).
[7] “Modern Transmission Problems,” *Electrical World* 57, no. 12 (1911). A “busbar” is the strip of metal – aluminum or copper – that conducts electricity in a switchboard.
[8] “The Transmission Systems of the Great West.”
[9] “World's Largest Transmission System,” *Electrical World* 59, no. 22 (1912); “The World's Largest Transmission Line,” *Electrical World* 63, no. 2 (1914).

electricity day and night allowed Commonwealth Edison to operate generators at maximum efficiency and charge affordable rates. Insull also held stakes in coal mining operations and railroads, thus securing his empire's access to energy supplies. This type of regional expansion was replicated both in the greater Chicago area and in other dense urban areas around the country, including Boston, New York, and Philadelphia.[10]

One example from the New England area illustrates the economies realized through interconnection. In the early 1910s, a group of utilities in eastern Massachusetts examined the possibility of interconnecting in order to gain surplus generating capacity. According to a 1921 report in *Electrical World,* the utilities took great care in planning their linked system. After building ties between the systems and operating an interconnected network for several years, the companies realized a number of advantages. With adequate combined surplus generating capacity, Malden Electric Company avoided investing $1,500,000 in new facilities at the Malden power plant and Suburban Gas & Electric Company avoided an additional $150,000 in increased capacity. With a more diverse customer base than any one plant sustained, the combined peak load for the entire network was lower than the sum of separate peak loads. The companies lowered rates charged to customers, saved 10,000 tons of coal per year, and shared in the effiency of a large plant at Salem.[11]

Niagara Falls offered a tremendous quantity of potential power to communities and industries on both sides of the border, and regional development took distinctly different forms in the United States and Canada. In the United States, Niagara power fed new

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[10] Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*, p. 119 and footnote no. 42, p. 322. , *Electrical World* 53, no. 22 (1909), pp. 1269-1300. In *The Electric City* Harold Platt provides a detailed account of Samuel Insull's management of the Commonwealth Edison Company in Chicago and his political, social, and economic innovations in building a regional system. The majority of information in this paragraph is based upon *The Electric City.*
[11] Sargent, F. C. "An Interconnection of Increasing Value." Electrical World 78 (1921): pp. 204, 16, 17.

industries close to the falls and cities like Buffalo at a distance. Private companies with interlocking directorates dominated power development, which took place amidst competing regulatory initiatives at municipal, state, and federal levels. In Ontario, the province established the Ontario Hydroelectric Power Commission (HEPCO) in 1906. HEPCO operated as a branch of government designed to supply power to Canadian industries and municipal distribution systems. During its first years of activity, HEPCO built a major transmission line from Niagara to Southwestern Ontario, contracted for electricity from private generators, and sold power to municipalities.[12]

In the southeastern United States, power companies aggregated into networks, developing regional systems across lightly populated areas. The impetus for hydroelectric development, in particular, came from cotton mills using power for growing numbers of spindles, looms, and knitting machines. By 1910, plants on different streams operated in parallel to increase service reliability. For example, the Southern Power Company in North Carolina (later Duke Power) engineered a large and reliable system serving mainly textile mills. By 1914, Southern Power joined five other electric companies to create a single network crossing 1,000 circuit miles in several states. Although these systems "controlled by separate and distinct syndicates" could in theory operate together, they did not, serving instead to provide each other backup power.[13]

[12] Robert Blake Belfield, "The Niagara Frontier: The Evolution of Electric Power Systems in New York and Ontario, 1880-1935" (PhD diss., University of Pennsylvania, 1981); Nelles, *The Politics of Development; Forests, Mines & Hydro-Electric Power in Ontario, 1849-1941*.

[13] "The Great Southern Transmission Network," *Electrical World* 63, no. 22 (1914); "Interconnected Systems of the South," *Electrical World* 63, no. 22 (1914); "Southern Water Power Developments," *Electrical World* 50, no. 26 (1907); "Southern Convention of A.I.E.E.," *Electrical World* 55, no. 14 (1910); "Electric Energy Transmission," *Electrical World* 57, no. 1 (1911); "The Steam Auxiliary Question," *Electrical World* 58, no. 1 (1911).

Over the years, accounts of new, innovative, and very large regional power systems across the globe occupied the attention of the power industry fraternity. From Europe to Latin America, writers in *Electrical World* and other trade journals documented the advances in growth. Engineers focused on load factor, operating efficiencies, and reliability while managers and utility executives addressed expanding markets and profitability. Journalists regularly revisited Southern France, Switzerland, Spain, Germany, and Latin America to better understand technical advances and geographic variations. Writers took note of significant differences – the success and limitations of the Thury system of direct current lines in France, the political barriers to unification of electric power in England, and the challenging terrain of mountainous areas like Peru. The growth of regional power networks both south of the border and across the Atlantic reinforced the notion that interconnected long-distance lines offered great benefits to both industry and the power consuming public.[14]

Isolated Plants

Regional systems were not the only path to electrification. Up until the beginning of the First World War, engineers debated the merits of isolated plants compared to central

[14] Load factor refers to the concept of maintaining a regular load on a generator so that it can run constantly and at maximum efficiency. "High Tension Energy Transmission in Peru," *Electrical World* 51, no. 5 (1908); "The Growth of a Transmission Network," *Electrical World* 51, no. 16 (1908); "Delaware River Water Power," *Electrical World* 51, no. 16 (1908); "The System and Operating Practice of the Commonwealth Edison Company, Chicago," *Electrical World* 51, no. 20 (1908); "Combination of Stations in France," *Electrical World* 51, no. 20 (1908); Chas. F. Scott, "Conservation of Power Resources," *Electric Journal* 5, no. 9 (1908); "Power Stations in Southern France," *Electrical World* 52, no. 13 (1908); "Energy Supply on British Northeast Coast," *Electrical World* 52, no. 17 (1908); "Hydro-Electric Development in Europe," *Electrical World* 52, no. 18 (1908); "Hydro-Electric Stations of Switzerland," *Electrical World* 52, no. 18 (1908); "Austrian Water Power," *Electrical World* 52, no. 18 (1908); Haar, "High-Voltage Transmission Systems of the World"; "Bulk Electric Supply for London," *Electrical World* 63, no. 18 (1914); "A Daring Power Transmission Project," *Electrical World* 53, no. 22 (1909); "Electric Power Transmission in Southern France," *Electrical World* 54, no. 21 (1909); Louis Bell, "Transmission Plant without a Switchboard," *Electrical World* 63, no. 11 (1914). In some parts of Europe, France in particular, power companies used direct current technologies to deliver electricity to customers. Swiss engineer Renee Thury developed a system for transmitting direct current over long distances – this was known as the Thury System. Thury systems operated until the 1930s.

station service and the efficiency of transporting fuel compared to the efficiency of transporting electricity. In the early 1900s, isolated plant installations, particularly with accompanying storage batteries, were favored for far-flung farms and country residences, as well as self-contained establishments like hotels, because they afforded "absolute reliability and continuous service."[15] Manufacturing establishments likewise tended to prefer replacing waterwheels and steam engines with in-house electric generators. Factory owners believed in-house electricity was more affordable than central station service. However, efforts to compare the economics of in-house power generation with central station service for manufacturers led some to promote the latter approach. This was described as "The Industrial Power Problem." Some speculated that the solution would involve placing a power plant at a coal mine and transmitting electricity to industrial centers. The debate continued for several years inconclusively.[16]

Central station managers eyed the market share of manufacturers with envy. Over the twenty years from 1899 to 1919, the amount of electricity used in manufacturing grew forty-fold. This presented a huge opportunity because utilities that succeeded in selling power, called "rented power," to manufacturers added an excellent customer to the consumer mix. Manufacturers often demanded power during periods when residential, traction, and commercial customers did not. For example, most factories operated during the day, when lights in homes were out and traffic on electric rail lines was light. Some factories even introduced round-the-clock operations once they used electric lighting, thus benefitting the utilities even more. Central station managers actively exchanged ideas for luring industrial

[15] Note that far fewer than ten percent of all farms enjoyed any electrification at all. "Small Isolated Plants," *Electrical World* 50, no. 18 (1907). Quote in William H. Stuart, "Isolated Plants," *Electrical World* 50, no. 5 (1907).
[16] "The Industrial Power Problem," *Electrical World* 48, no. 19 (1906); "Small Isolated Plants."

customers in order to expand service areas. But utilities competed directly with their own potential customers, and the latter tended to choose to install isolated plants. As the US Census of Manufactures reported, “electric motors ... are in most cases owned by the establishments using the power.”[17]

When utilities finally added industrial customers in large numbers, towards the end of the 1910s, the benefits of interconnection grew more attractive. The isolated plants began to lose ground to central station service after 1910. In 1912 industry journals began to report on mine-mouth plants that offered economical electricity to manufacturers. By 1913, engineers considered the comparative economy of an isolated plant to be a “moot point.”[18] According to the trade journals, central stations used a third of the fuel burned by isolated plants, conserving 1,750,000 tons of coal per year. As utilities succeeded in bringing down the cost of electricity, manufacturers began to shift to central station service. In Table 2.3, there is a clear point close to 1915 when the primary electrical source for manufacturers shifted from in-house power to central station service. During World War I, many industries faced coal shortages and found they could not generate electricity onsite. By the end of the war, the majority of manufacturers shifted to “rented electric power” and the trend continued

[17] Bureau of the Census, *Abstract of the Census of Manufactures 1919*, (Washington, DC: Government Printing Office, 1923), p. 460. The number of horsepowers used in manufacturing grew from 492,936 in 1899 to 16,317,277 in 1919. Bureau of the Census “Isolated Plants”; W. F. Lloyd, “Isolated Power Plant Costs and Their Relation to Central Station Service,” *Electrical World* 52, no. 22 (1908); “Co-Operation with the Isolated Plant,” *Electrical World* 62, no. 3 (1913); Bureau of the Census Department of Commerce, *Abstract of the Census of Manufactures 1914*, (Washington, DC: Government Printing Office, 1917), p. 491. By 1919, key markets for electricity use included the transportation sector, textiles production and related industries, mills and food preparations, foundries, iron and steel industries, lumber and timber industries, and paper goods and printing.
[18] “Isolated Plant Economy,” *Electrical World* 61, no. 8 (1913).

thereafter. Post-war proposals for large-scale interconnected systems specifically focused on delivering electricity to the growing industrial market for power.[19]

While some engineers continued to argue about the advantages of isolated plants, others began to envision regional systems connecting across the continent. In 1911, the American Institute of Electrical Engineers (AIEE) met in New York City and discussed papers addressing long-distance transmission and interconnection. With large systems

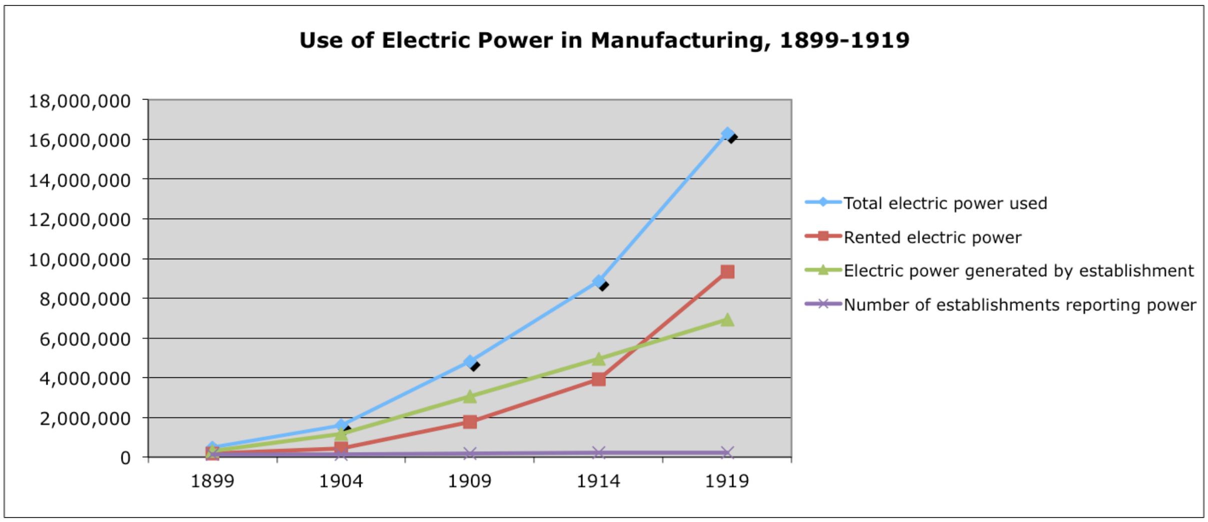

Table 2.3. Increased use of electricity in manufacturing, 1899-1919. ***Sources:*** **Bureau of the Census, *Historical Statistitics of the United States, 1789-1945; Census of Electrical Industries, 1917; US Census of Manufactures, 1919.***

offering centralized and shared reserves, and diversity factors, "it is to be expected that in time the country will be covered with high-tension lines," one contributor noted.[20] One year later, the head of one of the country's largest holding companies explained "It is possible to-day to cover the entire area of the United States with a network of high-tension lines connecting together, with efficient distribution, all of the waterpowers capable of

[19] "Electricity Directly from the Coal Mine in Pennsylvania," *Electrical World* 59, no. 19 (1912); "Competition of Coal-Mine Power Plants with Central Stations," *Electrical World* 60, no. 9 (1912); "Station Efficiencies," *Electrical World* 52, no. 22 (1908). The term "mine-mouth plant" refers to the strategy of placing a generating plant close to the mouth of an active coal mine, then transporting the electricity from the mine to a load center such as an industrial complex or an urban area.
[20] "Economic Limitations to Aggregation of Electrical Systems," *Electrical World* 57, no. 8 (1911).

development."[21] At his annual lecture in Chicago, famed General Electric engineer, Charles P. Steinmetz, predicted a coming era of cooperation among power companies, and "a network of energy transmission wires covering the country."[22] Although isolated plants still dominated some sectors of the electrified world, the idea of nationally interconnected, energy efficient systems began to emerge.

Stability, Reliability, Energy Efficiency, and the Limits of Technologies

Operators of all types of power stations relied on an array of technologies to achieve stable, reliable, and economical operations. Utilities relied on storage batteries, auxiliary plants, and interlinking systems to balance loads, to aid with exceptionally high demand and unexpected outages, and to restart systems after they had been stopped. At the turn of the century, all three approaches offered similar benefits. Over the next ten years, however, storage batteries reached practical limits while interlinking systems became increasingly popular.

In 1905, engineers declared that storage batteries were a mature and necessary element of electric power systems. Storage batteries reduced the need for duplicate equipment, increased reliability by providing back-up power and aiding with starting up generators, lowered costs by smoothing loads and carrying peaks, and conserved resources by maximizing the use of hydroelectric dams. In 1907, the storage battery was termed "the watchdog of electric service," and experts prophesied increased usage as internal combustion

[21] "Proposed National Commission to Solve Water-Power Problems," *Electrical World* 60, no. 17 (1912).
[22] "Steinmetz on the Future of the Electrical Industry," *Electrical World* 60, no. 18 (1912). Charles Proteus Steinmetz headed General Electric's Research Laboratory from its founding in 1900 and drew fame for his innovations in alternating current machines and circuitry, hysteresis, and long-distance transmission. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p.164.

engines displaced turbines in power plants.[23] Steel manufacturers, especially, relied on storage batteries for both efficient operations and back-up power. Several locales pioneered an alternative approach to the use of storage batteries, placing the batteries at the site of a consumer, charging the batteries during the off-peak hours, and allowing the consumer to run on battery power during the rest of the day. This proved cost-effective in several instances and prompted the proposal to locate storage batteries at distribution points distant from a generating station in order to serve a region.[24]

Despite the rosy predictions of engineers, by 1910, the business of installing storage batteries in central station plants slowed considerably and remained flat for several years. By this time, the "use of storage batteries ... as insurance against interruption of service," had become so universal that "it may be considered conventional."[25] Yet, the lagging economy in general, the preference for large steam turbines, and the continued high cost of gas plants, contributed to a flat market for batteries. Batteries met their practical limits during these years. As generating plants and regional systems grew larger, the size of a back-up battery

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[23] "Storage Batteries Discussed at the Western Society of Engineers," *Electrical World* 49, no. 13 (1907); S.H. Sharpsteen, "The Storage Battery for Web Printing-Press Control," *Electrical World* 52, no. 11 (1908); "Recent Developments in Storage Battery Applications," *Electrical World* 55, no. 15 (1910).

[24] "The Storage Battery"; "Annual Meeting of the American Institute of Electrical Engineers"; "The Storage Battery," *Electrical World* 49, no. 2 (1907); W. Harvey Kelly, "The Use of Telephones in Generating Station," *Electrical World* 53, no. 8 (1909); "Storage Battery," *Electrical World* 53, no. 22 (1909); "Abstracts of National Electric Lighting Association Convention," *Electrical World* 53, no. 24 (1909); "Storage Battery Substation for Detriot River Tunnel Electric Railway Installation," *Electrical World* 57, no. 4 (1911); "Electricity in New York City," *Electrical World* 57, no. 21 (1911); "Storage Battery Regulation of Low-Head Water-Power Plant," *Electrical World* 60, no. 18 (1912); "The Problem of Distribution," *Electrical World* 63, no. 10 (1914); "Electrical Distribution Engineering in Chicago - II," *Electrical World* 63, no. 11 (1914); "Large Storage-Battery Equipment," *Electrical World* 51, no. 8 (1908); "Storage Batteries in Steel Mills," *Electrical World* 53, no. 12 (1909); "Storage Battery for Central Station Night Load," *Electrical World* 54, no. 4 (1909); "The Sorage Battery," *Electrical World* 59, no. 1 (1912); "Storage Batteries in Isolated Plants," *Electrical World* 50, no. 19 (1907); "Limits of Energy Transmission," *Electrical World* 53, no. 14 (1909); "Restricted Supply of Power," *Electrical World* 56, no. 11 (1910); "Storage Batteries vs. Isolated Plant," *Electrical World* 64, no. 12 (1914).

[25] "Restricted Supply of Power."

grew as well. Electric light companies installed "extremely large" standby or reserve batteries. In 1912, Baltimore boasted the largest installation in the world, depicted in Figure 2.1. Built to insure against interruption of either power plants or on the 40-mile transmission line, it contained 152 cells and weighed 616.5 tons, but could provide backup power to downtown Baltimore for only six minutes at full load.[26]

Figure 2.1. Storage Battery Installation, Baltimore, MD, 1912. *Source:* "Largest Single Storage Battery Installation in the World," *Electrical World*, Volume 59, Number 24, 1912, p. 1390.

There was frequent debate about the efficacy of storage batteries and auxiliary plants for handling peak loads and, for a period of time, auxiliary plants appeared to be more cost effective. Interlinking multiple stations, however, trumped both approaches. In the ensuing years, storage batteries and auxiliary plants remained essential to power operations. But, utilities looked increasingly to interconnections for economy and reliability during the very

[26] "The Storage Battery," *Electrical World* 57, no. 1 (1911); Lamar Lyndon, "Storage Battery Industry," *Electrical World* 61, no. 1 (1913); "Large Central Station Storage Battery," *Electrical World* 58, no. 25 (1911); "Largest Single Storage Battery Installation in the World," *Electrical World* 59, no. 24 (1912).

same years that technical experts began to predict links between power systems across the entire continent.[27]

Consolidation: Holding Companies and Monopolies

The trend toward consolidation of private power companies into larger corporations or holding companies unfolded in parallel with the trend toward interconnection. Adjacent utilities often merged to improve both operating economies and balance sheets. Like Commonwealth Edison in Chicago, some utilities integrated both vertically and horizontally into giant power monopolies. Holding companies provided an attractive vehicle for building large aggregations of smaller utilities under a single ownership entity. Notably, not all consolidations contributed to the expansion of geographically linked networks. Some holding companies sought the financial advantage of owning widely dispersed utilities with a diversity of markets, rather than the potential economies of regional systems. Overall, however, the economics of consolidation were often directly linked with the technical and operating advantages of interlinking.

The trend to consolidation worried many Progressive Era politicians who resisted the advance of trusts in industry. Others, however, noted that monopoly operation of power companies, under appropriate regulation, could produce benefits to consumers through more efficient use of natural resources and the resulting lower prices. Still others opposed private utilities in principle and especially fought large private monopolies. As consolidation advanced, politicians at the federal and state levels pushed for greater government control.

[27] "Storage Batteries for Peak Loads," *Electrical World* 52, no. 5 (1908); "Storage Batteries for Three-Phase Systems," *Electrical World* 53, no. 17 (1909); "The Operation of Large Generating Systems," *Electrical World* 53, no. 22 (1909); "Future Requirements of Central Stations," *Electrical World* 53, no. 25 (1909); "Most Economical Methods of Carrying Peak Loads," *Electrical World* 56, no. 18 (1910).

Engineering trade journals tended to justify consolidations for their practical benefits and "natural" advantages. Toward the end of the nineteenth century, system builders had been especially interested in the combination of traction and lighting stations, seeking balanced loads and greater reliability. By 1899, consolidation was viewed as an "inevitable tendency of the management of all industry."[28] The editors of *Electrical World* noted that consolidation reduced the need for duplication of services and increased the value of properties. Financier and advocate for industrial efficiency, George W. Perkins, lamented that lawmakers tried to prevent "business getting together." He depicted consolidation as a force of nature: "We have had the uses of steam and electricity so perfected that the business world has been irresistibly drawn together, and the attempts of man to make laws that will nullify conditions that have come about through the conquest of the mysteries of Nature will never permanently succeed."[29] Early in the twentieth century, "combination" suggested the aggregation of multiple central stations into a single system, offering a "physical advantage ... which is inevitably shared by the public."[30] Arguably, the public gained better, cheaper service and greater reliability, while the investor had access to a broader, more balanced, centrally controlled market. Participants in the electric industry shared a goal of making electricity "a necessity" accessible to everyone – much like the telephone monopoly.[31]

Consolidation of central stations offered advantages beyond economies of scale and access to wider markets. Often small stations suffered numerous shortcomings. According to

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[28] "Consolidation in the Electrical Industries," *Electrical World* 33, no. 5 (1899).
[29] "Government and Corporation," *Electric Journal* 8, no. 4 (1911).
[30] "Electrical Combinations," *Electrical World* 47, no. 3 (1906).
[31] Carl Hering, "Combined Traction and Lighting Stations," *Electrical World* 33, no. 3 (1899); Carl Hering, "Combination of a Central Station and a Private Plant," *Electrical World* 33, no. 11 (1899); Carl Hering, "Combined Lighting and Traction Stations," *Electrical World* 34, no. 3 (1899); Carl Hering, "Combined Lighting and Traction Plants " *Electrical World* 35, no. 3 (1900); "Electrical Combinations"; "Station Efficiencies."

Samuel Insull, owners found it difficult to attract investors, managers, and good engineers. David Rushmore, a power and mining engineer working for General Electric Company, explained to the AIEE in 1911 that many small stations failed financially because they could not address the needs of a diverse market. By contrast, a combination of utilities could operate under centralized management, reach rural and suburban areas affording greater equity in electrification, keep up with the most contemporary technologies, facilitate the growth of small industries by offering twenty-four hour service, and benefit from good engineering. Overall, by 1914, engineers tended to agree that consolidation led to both more efficient and higher quality service for consumers.[32]

Politicians, municipal plant managers, and the public did not necessarily agree with the private utility industry with regard to consolidation. Through the early years of the twentieth century, presidents, congressmen, news reporters and the like expressed concern about the continuing problem of industrial monopolies. Frustrated with the limitations of the 1890 Sherman Antitrust Act, Progressive Era leaders promoted further legislation to regulate industrial monopolies. In 1908, President Roosevelt declared that aggressive private utilities undermined the public benefit to be gained from waterpower development, "among the monopolies there is no other which threatens or has ever threatened such intolerable interference with the daily life of the people as the consolidation of companies controlling water power."[33] The 1912 presidential campaign focused on this issue, and President Wilson

[32] "Consolidation of Small Central Stations," *Electrical World* 54, no. 6 (1909); "Modern Transmission Problems"; "Unified Electric Systems," *Electrical World* 57, no. 7 (1911); L.H. Conklin, "Consolidation of Central Stations," *Electrical World* 61, no. 1 (1913); A.K. Baylor, "Influence of Holding Companies on Electric Utilities," *Electrical World* 63, no. 1 (1914).
[33] "President Roosevelt on Monopoly of Water Powers," *Electrical World* 51, no. 10 (1908).

made passage of the Clayton Anti-trust Act and the Federal Trade Commission Act priorities for his administration.[34]

During this year, advocates for the private power companies shared deep concern that the trend toward consolidation, which appeared to them to be beneficial to both the industry and to consumers, would be curtailed by the Wilson legislative platform. The editor of *Electrical World* expressed dismay when Wilson claimed that "we agree that holding companies should be prohibited" and solicited remarks from industrial representatives assessing the proposed legislation. Utility executives consoled themselves by noting that Wilson did not mean to extend new laws to the utility holding companies because they were already regulated at the state level. Further, under state regulation, utilities were bound to provide a reliable and equitably priced service to the public, the executives argued, and therefore they did not pose a threat to consumers. The power companies operated in line with the notion of "natural monopoly" that had arisen in the late nineteenth century. Companies that provided a product or service with a high initial capital investment, and that would be rendered highly inefficient with direct market competition, were described as "natural" monopolies. State governments began to regulate these monopolies to protect consumers from the unfair pricing practices and inequitable access to goods or services that could result in the absence of competition. At association meetings and before the US Chamber of Commerce, industry leaders made their case. Despite enactment of the Clayton anti-trust legislation in 1914, the utility industry continued to trend toward consolidation, and holding companies expanded into the next decade.[35]

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[34] Ibid.
[35] "The President and Industry," *Electrical World* 63, no. 4 (1914); "Comments on the President's Message," *Electrical World* 63, no. 6 (1914); "Holding Companies," *Electrical World* 63, no. 13 (1914); "The Utility Holding Company," *Electrical World* 63, no. 21 (1914); "The N.E.L.A. And

In response to years of public debate, the 63rd Congress directed the Secretary of Agriculture to produce a report regarding the ownership and control of waterpower sites in the United States. The resulting three-volume study, produced in 1915, details the location and potential horsepower of US waterpower sites, both developed and undeveloped, and provides a thorough description of the utility industry structure. By 1915, a small number of companies directly controlled 69 percent of the power industry and had indefinite relationships with the balance of the industry, through common directorships. The report noted a "marked tendency toward association or community of interests, particularly between the principal holding companies, that can not be viewed without concern."[36] However, the Secretary of Agriculture argued that concentration in the power industry was not necessarily an "ill omen."[37] With interconnections, utilities could provide customers with more economical service at a lower rate and with fewer interruptions.[38]

Government Incursions into the Electric Power Business

Early interconnections in the United States and most of Canada took place without government involvement. The state and federal governments in the United States were latecomers to the power game. Before the 1900s, electric companies operated principally under municipal franchises, with government contracts, or in direct competition with

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Legislation," *Electrical World* 63, no. 8 (1914); "Trust Legislation," *Electrical World* 63, no. 8 (1914); "Trust Legislation, Retail Prices, and Patents," *Electrical World* 63, no. 8 (1914); "The Anti-Holding Company Act," *Electrical World* 63, no. 13 (1914).

[36] *Electric Power Development in the United States, in Three Parts*, ed. Department of Agriculture (64th Congress, Senate Document 316, 1st Session, 1916).Part I, pp.15.

[37] Ibid.Part I, pp. 55.

[38] Ibid.Part I, pp.15, 55. The report provides a detailed discussion of the direct and indirect relationships between 1500 companies engaged in the power business in 1915. Of these, 16 groups of related companies control over 45 percent of the public service power generated in the United States. (Part I, pp.58-60 and Part III) Nearly 66 percent of this public service power was under the control of only 85 companies, and a mere 18 of those companies controlled the majority of the developed waterpower.

municipal companies. Fewer than half of the states had utility commissions before 1900, and those that did addressed the service areas and rates of transportation companies, water companies, and gas utilities. Under the US Constitution, the central government had authority over interstate and international trade and activities affecting navigation on rivers. Historically, the federal government aided and curbed US business enterprises through tariffs, treaties, land grants, and the work of the Interstate Commerce Commission. Canadian governance evolved slightly differently, because the Crown owned natural resources, including those used to generate electricity. In general, however, Canadian regulatory practices matched those in the United States. Further, appreciation for a laissez-faire approach to business characterized North American economic activities in the nineteenth century. Overall, there was little regulation of business in the United States and Canada, and virtually none addressing the very young power industry.[39]

Only as electricity began the shift from commodity to service did state and provincial governments become actively involved in power markets. This coincided with a larger social and political trend. Both populist movements and Progressive politicians called for government to play a more significant role in equitable access to goods and services, and in managed development of natural resources. States began to join the regulatory movement in

[39] For a general discussion of regulation in the United States see Stephen G. Breyer, *Regulation and Its Reform* (Cambridge, MA: Harvard University Press, 1982); Galambos and Pratt, *The Rise of the Corporate Commonwealth: U.S. Business and Public Policy in the Twentieth Century*; McCraw, *Prophets of Regulation: Charles Francis Adams, Louis D. Brandeis, James M. Landis, Alfred E. Kahn*. For examination of regulation and the early electric power industry in the United States and Canada see Armstrong and Nelles, *Monopoly's Moment: The Organization and Regulation of Canadian Utilities, 1830-1930*; Gilbert and Kahn, *International Comparisons of Electricity Regulation*; Hirsh, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System*; Hyman, Hyman, and Hyman, *America's Electric Utilities: Past, Present and Future*; Rudolph and Ridley, *Power Struggle: The Hundred-Year War over Electricity*; Anderson, *Regulatory Politics and Electric Utilities: A Case Study in Political Economy*; Hirt, *The Wired Northwest: The History of Electric Power, 1870s-1970s*; Melosi, *Coping with Abundance: Energy and Environment in Industrial America*.

the early 1900s. At the federal level, the focus was on waterpower sites, not interstate power trades, of which there were very few. Beginning in the late 1800s, Congress and the Forest Service attempted to address increasing private utility interest in developing hydropower on major rivers and on federal land. Over the long run, federal legislation to regulate this activity had a major influence on interconnections. But until 1920, when Congress passed the Federal Water Power Act, federal authority over the power industry was minimal. As a result, the piecemeal development of interconnections followed the initiative of individual utilities rather than the direction or planning of any central agency.[40]

While utility leaders generally resisted the idea of any sort of regulation before 1900, most embraced, and many operated under state utility commissions by 1920. At the end of the nineteenth century, and in the early twentieth century, a number of utility executives also recognized that some regulation could work to their advantage. Utilities operating under state regulation, with regional monopolies, were able to extend their markets beyond municipal boundaries, without competition. Further, if they chose to move power across state lines, this took place outside the purview of state commissions. Samuel Insull notably advocated to his counterparts that state regulation would benefit private companies in the long run and by the time they met at the National Electric Lighting Association Meeting in 1907 they agreed.

[40] Melosi, *Coping with Abundance: Energy and Environment in Industrial America*; Galambos and Pratt, *The Rise of the Corporate Commonwealth: U.S. Business and Public Policy in the Twentieth Century*; McCraw, *Prophets of Regulation: Charles Francis Adams, Louis D. Brandeis, James M. Landis, Alfred E. Kahn*; Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*; Armstrong and Nelles, *Monopoly's Moment: The Organization and Regulation of Canadian Utilities, 1830-1930*; Nelles, *The Politics of Development; Forests, Mines & Hydro-Electric Power in Ontario, 1849-1941*; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*.

Massachusetts, New York, and Wisconsin first adopted regulation of electric utilities in 1907. By 1914, commissions in 43 states regulated rates and entry for electric utilities.[41]

As a point of comparison, Canada followed a similar pattern, and, with the exception of Ontario, adopted regulatory models from the United States. In Ontario, municipal leaders pushed for creation of a provincial entity that would assure delivery of electricity to cities to aid economic growth. Business owners likewise supported government involvement in electrification, provided they were the beneficiaries. The province formed the Ontario Hydroelectric Commission (HEPCO) in 1906, initially to transmit and distribute electricity to towns and industrial centers. Until 1935, the construction of long-distance transmission lines, the interlinking of systems owned by different entities, and the movement of power across long distances within the United States and Canada took place outside the strictures of any government oversight, except during World War I.[42]

Experiences of War, 1914-1920

When war broke out in Europe in the summer of 1914, the power industry focused initially on foreign markets for electrical manufacturers, not on the size and shape of electric systems at home. With a healthy and growing lighting market in the United States, central stations anticipated little change resulting from conflict abroad. Equipment manufacturers, on the other hand, felt the pinch of limits on the export of electrical equipment to Europe. Electrical manufacturers had enjoyed a healthy sales business in European countries, but

[41]Hirsh, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System*, pp. 23-24. "Emergence of Electric Utilities in America," website of the National Museum of American History, Smithsonian Institute, http://americanhistory.si.edu/powering/past/h1main.htm, accessed January 14, 2013; "Regulatory Commissions," website of the National Association of Regulatory Utility Commissioners, http://www.naruc.org/Commissions/, 2013, accessed multiple dates.

[42] Armstrong and Nelles, *Monopoly's Moment: The Organization and Regulation of Canadian Utilities, 1830-1930*; Nelles, *The Politics of Development; Forests, Mines & Hydro-Electric Power in Ontario, 1849-1941*.

access to these markets was terminated once the war began. Industry experts viewed this as a technical and commercial setback. They turned their attention to South America, which was nearby and relatively undeveloped as an export market for electrical equipment. By September 1914, *Electrical World* introduced a weekly section on "Prospects for Domestic and Foreign Business" documenting industry adjustments to the wartime economic environment. The real effects of war did, however, affect the central stations and domestic utilities – as demand for war materiel rose, so did demand for power, and power producers turned to interconnections to meet the need.[43]

During World War I, regions of the United States and war-related manufacturers experienced severe energy shortages. Following the end of hostilities, Lt. Col. C. Keller of the Army Corps of Engineers reported to the Secretary of War, the president, Congress, and the public, "We were taken by surprise by the shortages that finally became evident and we were without really effective means for curing them."[44] Utilities measured the time from design of new plants to full operations in years, rather than months, and the demand for power during the war years was immediate. Together, industry and government leaders developed strategies for providing power where and when needed. The federal government found three approaches especially important for war production. First, the government directed materiel production to parts of the country with excess electrical capacity and relatively low demand. Second, the government rationed and managed shipping of coal,

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[43] "Central Stations and the War," *Electrical World* 64, no. 8 (1914); "The War's Effect on the Electrical Industry," *Electrical World* 64, no. 9 (1914); "Effect of War on the Industry," *Electrical World* 64, no. 8 (1914); "Attention to Export Trade," *Electrical World* 64, no. 9 (1914); "Prospects for Domestic and Foreign Business," *Electrical World* 64, no. 11 (1914).

[44] Corps of Engineers, *The Power Situation During the War*, (Washington, DC: Government Printing Office, by Authority of the Secretary of War, 1921), p. 28.

giving priority to areas with war industries. Third, the government called upon utilities to interlink stations and run them at maximum load and efficiency.[45]

The problems began in 1917 at Niagara, when Canadian authorities curtailed hydropower exports to the United States in order to meet demand at home. Niagara was considered a "war load center."[46] Manufacturers in the region had been overloaded with orders for wartime production from the English, French, and Russian governments, heavily taxing the existing generating capacity. Especially icy conditions in the winter of 1917-1918 further slowed power production. This hindered electrochemical industry along the river, and ultimately affected production of war materiel. The two countries successfully negotiated a plan to curtail hydro-power delivery for non-essential purposes, to increase reliance on steam power on the interconnected system, even when uneconomical, to accelerate the construction of new steam plants, and to increase coal deliveries to Canada.[47]

Other regions, however, also suffered energy shortfalls. Before the war ended, New England, New Jersey and Eastern Pennsylvania, North Carolina, South Carolina, Georgia, Alabama, Eastern Tennessee, Pittsburgh and eastern Ohio, Western New York, and the entire Pacific Coast experienced shortages. Residents in urban centers faced a long cold winter with insufficient food and fuel while the Wilson administration ordered industry shutdowns and established rules for limiting the use of artificial lighting.[48]

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[45] For more detailed analyses of energy shortages, the power industry, and the war years, see Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*; Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*; Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*.
[46] "Niagara Falls a War-Load Center," *Electrical World* 73, no. 20 (1919); "Niagara Power in War Industries," *Electrical World* (1918).
[47] Keller, "The Power Situation During the War."
[48] Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*, pp. 202-203, Robert Cuff, "Harry Garfield, the Fuel Administration, and the Search for a Cooperative Order During World War I," *American Quarterly* 30, no. 1 (1978); "Wartime Lighting Economies,"

The power shortages of wartime highlighted the "desirability of interconnection" as some sections of the country formed plans to distribute power over large areas with a "maximum of economy and reliability."[49] Electric utilities took credit for aiding war production. The industry found that transmission lines were key to conserving fuel and insuring sufficient electric power for wartime loads. Notably, ten utilities serving New England, including Boston Edison, reported improved reliability as a result of interconnected and enforced operating efficiency.[50]

In the months immediately after the war ended, industry leaders pled the case for building a power network across the country. Guy E. Tripp, Chairman of the Board of Westinghouse and Assistant Chief of Ordnance during the war, favored "one reservoir" of power. He noted that the industry was hampered by fuel waste, poor loading of stations, and the inefficiency of small power utilities. Commonwealth Edison engineer Rudolph F. Schuchardt predicted, "ultimately the country will have a network of transmission lines."[51] Noting the lessons of the war, he advocated for universal interconnection and a common frequency of 60 cycles and he urged Congress to stop wasting waterpower. Lt. Keller, in his report on the power situation during the war, offered a plan for preventing future wartime energy shortages that highlighted the importance of linking adjoining systems with long-distance power lines. On the eve of the Roaring Twenties, the idea of large-scale,

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Electrical World 72, no. 19 (1918); Charles E. Stuart, "War Conservation of Power and Light," *Electrical World* (1918).

[49] C.S. Cook, "The Future Power Station," *Electric Journal* 15, no. 6 (1918).

[50] "Present War Production Made Possible by Utilities," *Electrical World* (1918); "Spirit of War in the Central West," *Electrical World* (1918); "Electrical Interconnections to Conserve Fuel," *Electrical World* (1918); "New England -- Boston Power Interconnection," *Electrical World* (1918); "How the South Handled War-Time Loads," *Electrical World* 73, no. 20 (1919); "Niagara Falls a War-Load Center"; Gustave P. Capart, "Use of Electricity in the European War," *Electrical World* (1917); "War-Time Service Problems in New England," *Electrical World* 73, no. 20 (1919).

[51] R.F. Schuchardt, "The Significance and the Opportunities of the Central Station Industry.," *Electric Journal* 16, no. 5 (1919).

interconnected power systems crossing North America fully captured the interest of engineers, executives, and government officials alike.[52]

Summary

Over the course of fifteen years, the power industry matured significantly, but remained a disaggregated collection of public and private entities seeking long-term financial stability in a variety of markets. Production and consumption grew rapidly, while private companies consolidated. Not all holding companies, however, fostered regional interconnection. Rather, interlinking took place under the aegis of monopoly utility expansion, mergers among similar companies, or compelling opportunities for independent entities to provide each other with back-up power and diversity. The growing sector of industrial power users tended to favor isolated plants through most of this period, until the demands of World War I illustrated the benefits of central station service. For all types of power stations, stable, reliable, and efficient operations were key to financial longevity. While storage batteries met physical limits as sources of load balancing and reliability, interconnection still held promise as a feasible approach for accessing diverse energy resources and markets, providing backup power, and achieving economic stability.

Before the war, engineers, politicians, and utility managers had just begun to conceptualize a national grid, but after the war, these same individuals seized upon the grid as a policy opportunity. The combination of increased efficiency in operations, the ability to move electricity further and with greater flexibility, the desire to develop waterpower, the experience of energy shortages, and the rising demand for electricity from multiple sectors across the continent elevated the desirability of regional interconnected power networks. The

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[52] Guy E. Tripp, "A Central Station Opportunity," *Electric Journal* 16, no. 2 (1919); Keller, "The Power Situation During the War."

electric power industry remained fragmented, with ownership by both private and governmental entities, regulation at local and state levels, and questionable profitability in some markets. The backbone of the future grid barely made an impression on the map of the country. There was no clear path for developing an integrated system in the post-war years.

Several trends marked growth of the power industry between 1905 and 1920. First, while the industry was unified in the push to generate more power and promote more consumption, the organization of power companies varied greatly across the continent. This was matched by an equally fragmented regulatory system. Authority was most certainly divided among a wide array of public and private utilities, holding companies, state utility commissions, the Ontario Hydroelectric Power Commission, federal agencies, and the Congress. World War I brought power companies and government officials together to address critical energy shortages in certain areas. The experience demonstrated that collaboration around interconnections could be successful. In addition, in the west, the Rocky Mountain states, and parts of the southeast, independent power companies effectively traded power across interlinked power lines. On both the business side of the industry and the government side, systems of shared management and divided authority began to take shape.

Despite the diversity of power systems growing across North America, a significant number of experts began to promote the idea of very large-scale interconnections during these years. This marked a second trend during the early 1900s. Indeed, the economic success of regional systems suggested that further expansions offered both greater financial benefits and improved reliability for utilities. Consolidation in the private sector industry and the growth of holding companies further advantaged this trend. The systems in California especially illustrated that parallel operations were both desirable and feasible. However, even by 1920, very few power companies operated in parallel continuously. Instead, most shared power during scheduled exchanges or during emergencies, and operated autonomously for the majority of the time. In addition, a significant number of municipal and independent companies had no interest in interconnecting. Political movements to halt the growth of a putative power trust further complicated the process of building large power networks. Full-fledged interconnection across an entire continent, or even throughout a major region, still faced substantial political, organizational, and practical challenges. In neither Canada nor the United States did anyone assume that the next necessary step in electrification was the construction of a national or international grid.

Throughout these years, individuals in the power industry grew to appreciate the importance of resource management as a key to long-term economic stability. High capital costs accompanied the construction of power stations and long-distance transmission lines. Steady profits depended upon uninterrupted access to energy resources as well as diverse markets and reliable service. As station managers and engineers touted the advantages of operating interconnected with other companies, they used the language of Progressive Era conservation. Interconnections offered utilities the opportunity to maximize the energy in falling water, shift from one energy source to another depending upon availability, minimize reliance on coal, reduce smoke pollution in urban areas, and improve the energy efficiency of operations. A third trend framed the growth of electrification during these years, the growing conservation movement intersected neatly with the concerns of the electric power industry.

Chapter 3. Conservation and the Power Industry

Between the turn of the century and the advent of the First World War, electric power expansion took place against the backdrop of an increasingly influential conservation movement and perceived energy resource shortages. By the late nineteenth century, coal and falling water provided the foundation for multiple systems of electrification, and these resources were at the heart of conservation debates. The movement grew out of several concerns, including loss of monumental places of natural beauty; the wasteful use of nature's bounty; the need for large-scale irrigation to develop arid regions of the country; inequities resulting from private monopoly control of resources; and the lack of orderly, scientific, and efficient procedures in manufacturing. A number of conservationists directly addressed energy production and electrification while power producers expressed a growing concern with long-term resource management. During this era, however, conservationists focused little, if at all, on reducing consumption, and utilities actively promoted increased use of electricity.

The utility industry engaged in the conservation movement in several different ways. First, utilities joined in the call to slow the rapid depletion of anthracite coal. Later, efforts to preserve forest stands and protect scenic areas from development intersected with utility plans to invest in hydroelectric plants. Third, conservation movement leaders promoted professionals, and especially engineers like those working for utilities, as the individuals best suited to conduct centralized resource planning and management. Fourth, power station managers actively pursued operating efficiencies, both in terms of technologies to achieve greater energy efficiency, and in terms of work performance, in line with promoters of industrial workplace productivity. Finally, utility efforts to reduce or eliminate smoke pollution, particularly in urban plants, aligned with Progressive Era movements to control smoke and otherwise clean up cities. As the century turned, the power industry moved from a preoccupation with operating efficiency to participation in the conservation debates. The utilities found themselves at the start of a lengthy and complex courtship with conservation in the United States.[1]

Electrical engineers, utility leaders, and politicians began imagining a national interconnected power system at the height of the Progressive Era conservation movement. Interconnections neatly addressed all of the areas of intersection between conservation and electrification. With interlinking power systems, utilities could more closely manage coal and water resources, and also operate more efficiently. Utilities that participated in full river development projects could carry electricity to distant customers with interconnected long-

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[1] More detail on the role of the utilities in these initiatives follows. For some investigations into business and industry initiatives that aligned with Progressive Era movements, see Christine Rosen, "Business Men against Pollution in Late Nineteenth Century Chicago," *The Business History Review* 69, no. 3 (1995); Hugh S. Gorman, "Efficiency, Environmental Quality, and Oil Field Brines: The Success and Failure of Pollution Control by Self-Regulation," *The Business History Review* 73, no. 4 (1999); Christine Meisner Rosen and Christopher C. Sellers, "The Nature of the Firm: Towards an Ecocultural History of Business: [Introduction]," *The Business History Review* 73, no. 4 (1999); David Stradling and Joel A. Tarr, "Environmental Activism, Locomotive Smoke, and the Corporate Response: The Case of the Pennsylvania Railroad and Chicago Smoke Control," *The Business History Review* 73, no. 4 (1999); Frank Uekoetter, "Divergent Responses to Identical Problems: Businessmen and the Smoke Nuisance in Germany and the United States, 1880-1917," *The Business History Review* 73, no. 4 (1999). For a selection of works on resource depletion, river development, expert planning and efficiency, smoke pollution, and preservation of nature during the Progressive Era, see Robert Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement*, Rev. and updated ed. (Washington, DC: Island Press, 2005); Samuel P. Hays, *Conservation and the Gospel of Efficiency: The Progressive Conservation Movement, 1890-1920* (Pittsburgh: University of Pittsburgh Press, 1999); David A. Hounshell, *From the American System to Mass Production, 1800-1932: The Development of Manufacturing Technology in the United States*, Studies in Industry and Society (Baltimore: Johns Hopkins University Press, 1984); Martin V. Melosi, *Effluent America: Cities, Industry, Energy, and the Environment* (Pittsburgh: University of Pittsburgh Press, 2001); Martin V. Melosi, *Garbage in the Cities: Refuse, Reform, and the Environment*, Rev. ed., History of the Urban Environment (Pittsburgh: University of Pittsburgh Press, 2005); Righter, *The Battle over Hetch Hetchy: America's Most Controversial Dam and the Birth of Modern Environmentalism*; Theodore Steinberg, *Down to Earth: Nature's Role in American History*, 2nd ed. (New York: Oxford University Press, 2009); Joel A. Tarr, *Devastation and Renewal: An Environmental History of Pittsburgh and Its Region* (Pittsburgh: University of Pittsburgh Press, 2003); Worster, *Rivers of Empire: Water, Aridity, and the Growth of the American West*.

distance transmission lines. Experienced power system engineers sat at the central controls of interlinking networks. Interconnections allowed a utility to move smelly, polluting, coal-fired plants away from urban centers and closer to either coalmines or industrial centers. Finally, the Progressive Era conservation movement focused on producers, not consumers.

Utilities joined conservation leaders in addressing resource management and energy efficiency, primarily in order to deliver more electricity to more consumers. Herein likes a paradox of the power industry's relationship with conservation. During these years, the industry, despite aligning with conservation initiatives in many respects, never sought to reduce the use of energy resources in absolute terms and instead promoted increased consumptions. With interconnections, utilities achieved conservation at the producer end of the power lines while encouraging use at the customer end.

From Energy Efficiency to Resource Conservation

Like other businesses, nineteenth-century power companies demonstrated a serious concern with operating efficiency. Power providers strove to bring down the unit cost of electricity, both to attract more customers and to increase the returns on investment. With very high initial capital costs, utilities faced a long period of amortization in order to realize economic stability. Unlike other industries, however, utilities could not hoard electricity for future use. Nor could they clear inventory. Instead, utilities sought steady access to energy resources while lowering the per-unit cost of electricity. Thus, as the century turned, and the president of the United States articulated fears about resource depletion, the industry likewise began to focus on access to fuel. The term "conservation" crept into the discourse and became increasingly important to utilities.[2]

Engineers and utility operators initially focused on economies of scale and energy efficiency. Projects that incorporated larger generating stations, and storage batteries or interlinking systems, proved to be more successful at reducing waste and lowering operating costs. For example, at a meeting in 1896, the AIEE considered the benefits of concentrating power generation "at some point where the expenses will be a minimum" and distributing electricity by "recently developed methods," such as ac transmission.[3] To keep the load steady, the stations used storage batteries. In another example, London engineers noted that sending electricity to "outlying districts … opens up the possibility of a substantial reduction in the price and that they will be very remunerative."[4] The industry trended toward "the concentration of generating machinery, the highest possible economy in operation … so that the investment may produce the greatest return."[5] By this time, "the present practice of large power stations, and distribution at higher voltages over large areas, [was] said to be the only economical one."[6] In 1899, industry experts also discussed a number of early interconnection projects (although the term "interconnection" was not used) notable for the way in which they conferred benefits of both operating efficiency and back-up power.[7]

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2 Theodore Roosevelt: "First Annual Message," December 3, 1901, Online by Gerhard Peters and John T. Woolley, The American Presidency Project, http://www.presidency.ucsb.edu/ws/?pid=29542.
[3] Duncan, "Present Status of the Distribution and Transmission of Electrical Energy."
[4] Carl Hering, "Installations, Systems, and Appliances," *Electrical World* 28, no. 2 (1896).
[5] Appleton, "Latest Progress in the Application of Storage Batteries."
[6] Carl Hering, "Electrical Progress," *Electrical World* 34, no. 25 (1899).
[7] Hering, "San Gabriel - Los Angeles Transmission"; Hering, "Combined Traction and Lighting Stations"; Hering, "Transmission Plant of the Northern Railway of France"; Hering, "Combination of a Central Station and a Private Plant"; Hering, "Combined Lighting and Traction Stations"; Hering, "83 Miles of Power Transmission."

By the end of the nineteenth century, utility experts began to consider energy supply issues as well as operating efficiency. North Americans had been enjoying a romance with hydrocarbon fuels. Manufacturers used steam engines to power factories; the railroads crossed the country with coal-fired transportation, oil and natural gas found their way into lighting and heating systems and a variety of other uses. The boom and bust cycles of oil, natural gas, and coal served to highlight the potential for resource depletion. From the earliest days of electrification, the majority of generating stations relied on coal. Thus, the utility industry was not immune to the vagaries of the coal market, including predictions of shortfalls.[8]

In 1900, the editor of *Electrical World* declared that the 1800s were a "wasteful century."[9] With coal shortages looming in England, American coal supplies under threat, and multiple natural resources used carelessly, he declared that it was time to find new wealth in the new century through the use of electricity. Electricity would reclaim waterpower and central stations would operate more efficiently than isolated plants. At the beginning of 1901, noted electrical engineer Elihu Thomson articulated the concerns of the coming conservation movement. He stated, "in the past, valuable resources have been shamefully wasted and they are still often used without much regard to economy. … the loss of valuable minerals, such as coal, oil and natural gas is a veritable world impoverishment, worse indeed than the terrible

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[8] Louis C. Hunter and Eleutherian Mills-Hagley Foundation, *A History of Industrial Power in the United States, 1780-1930* (Charlottesville: University Press of Virginia, 1979); Melosi, *Coping with Abundance: Energy and Environment in Industrial America*; Nye, *Consuming Power: A Social History of American Energies*; Brian Black, *Petrolia: The Landscape of America's First Oil Boom*, Creating the North American Landscape (Baltimore: Johns Hopkins University Press, 2000); Christopher James Castaneda, *Invisible Fuel: Manufactured and Natural Gas in America, 1800-2000*, Twayne's Evolution of Modern Business Series (New York: Twayne, 1999); Daniel Yergin, *The Prize: The Epic Quest for Oil, Money, and Power* (New York: Simon & Schuster, 1991).

[9] "A Wasteful Century," *Electrical World* 36, no. 8 (1900).

destruction of forest timber."[10] Thomson, like many others, advocated finding even more efficient production of electricity from carbon and oxygen, as a "hope for the future."[11]

Utility engineers lamented the coming depletion of coal reserves and acknowledged that shifting to waterpower offered only a partial solution. Many advocated building power plants at waterpower sites and using long distance transmission lines to bring energy to industry. By 1905, representatives of the power industry measured the failure to exploit waterpower sites in terms of coal used. For example, undeveloped waterpower at Niagara Falls equaled burning $50,000,000 of coal per year. Yet, the "reckless and destructive" practices of the prior fifty years had lessened "the availability of our water powers."[12] The fraternity of power industry experts shared a growing anxiety that their access to essential energy reserves, coal and falling water, would soon be curtailed.[13]

While nineteenth-century utility engineers did not use the term "conservation," other technical professionals did. In the broader engineering literature, the term "conservation" began to appear regularly in 1895. Notably, the term "efficiency" appeared nearly 30 times as often, indicating how much more important it was to engineers at that time. Before the turn of the century, "conservation" in these publications specifically referred to capturing a greater percentage of energy from burning fuel, building reservoirs to save water for future use, minimizing the evaporation of moisture from irrigated soil, and purifying dirty rivers. By 1908, the term was often used to address saving forests from overcutting, finding economies within the process of resource use, protecting labor, eliminating urban smoke, and increasing

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[10] Elihu Thomson, "Electricity in Two Centuries: Retrospect and Forecast Electricity in the Coming Century," *Electrical World* 37, no. 1 (1901).
[11] "A Wasteful Century"; Thomson, "Electricity in Two Centuries: Retrospect and Forecast Electricity in the Coming Century."
[12] Louis Bell, "Electrical Power Transmission," *Electrical World* 37, no. 1 (1901).
[13] "The Age of Reckless Waste," *Electrical World* 39, no. 16 (1902); O.A. Kenyon, "Utilization of Niagara Falls," *Electrical World* 45, no. 22 (1905).

the use of resources through careful development. In other words, for technical professionals at large, the term “conservation” encompassed the major ideas of efficient resource use, long-term resource management, and reducing pollution.[14]

[14] D. Decker, “Gas Stoves,” *American Gas Light Journal* (1896); W. P. Hardesty, “The Twin Lakes Reservoir, Colorado,” *Engineering News* (1898); E. W. Hilgard and R. H. Lougbridge, “The Conservation of Soil Moisture and Economy in the Use of Irrigation Water,” *Indian Forester* (1898); “The Water Problem of Lancaster, Pa,” *Engineering Record* (1899); R. S. Hale, “Economy in the Use of Superheated Steam,” *Engineering Magazine* (1899); “Our Fuel Supply,” *Colliery Guardian* (1902); E. O. Mawson, “Conservation and Increase of Subterranean Water,” *Engineer, London* (1903); Arthur J. Martin, “Coal Conservation, Power, Transmission, and Smoke Prevention,” *Journal of the Society of Arts* (1906); Morris R. Sherrerd, “Flood Control and Conservation of Water Applied to Passaic River,” *Engineering Record* (1906); Dennis H. Stovall, “Conserving the Water Supply in Placer Mining,” *Ores and Metals* (1907); “The Conference on the Conservation of Natural Resources,” *Engineering News* (1908); “New York State Water-Storage and Water-Power Investigations,” *Engineering News* (1908); “Waterways of New Jersey,” *Engineering Record* (1908); “The Need for Conserving the Mineral Wealth of the United States,” *Engineering News* (1908); “The Cataract-Dam,” *Scientific American Supplement* (1908); “Conservation of Life and Health by Improved Water Supply,” *Engineering Record* (1908); “April Meeting on the Conservation of Our Natural Resources,” *Proceedings of the American Society of Mechanical Engineers* (1908); Andrew Carnegie, “Conservation of Ores and Minerals,” *Engineering and Mining Journal* (1908); E. M. Griffith, “The Conservation of the Forests and Water Powers of Wisconsin,” *Journal of the Western Society of Engineers* (1908); James J. Hill, “The Natural Wealth of the Land and Its Conservation,” *Iron Age* (1908); A. H. Horton, “The Effect of the Conservation of Flow in the Ohio Basin on Floods in the Lower Mississippi,” *Engineering News* (1908); R. S. Kellogg, “Forest Conservation,” *Journal of the New England Waterworks Association* (1908); M. O. Leighton, “The Relation of Water Conservation to Flood Prevention and Navigation in the Ohio River,” *Engineering News* (1908); M. O. Leighton, “The Conservation of Water Resources,” *Journal of the New England Waterworks Association* (1908); Henri V. Lemenager, “The Government's Great Storage Dams,” *American Review of Reviews* (1908); John Mitchell, “Conservation in the Coal Industry,” *Proceedings of the American Mining Congress* (1908); Frank M. Osborne, “Conservation in the Mining Industry,” *Proceedings of the American Mining Congress* (1908); Clair H. St. Putnam, “Conservation of Power Resources,” *Proceedings of the American Institute of Electrical Engineers* (1908); Edward R. Taylor, “Natural and Artificial Conservation of Water Power for Electrical Purposes,” *Journal of the Franklin Institute* (1908); J. V. Thompson, “Needs for Conservation of Our Coal Deposits,” *Proceedings of the American Mining Congress* (1908); Glenn W. Traer, “Conservation in the Coal Industry, Protection of Life and Prevention of Waste,” *Proceedings of the American Mining Congress* (1908); H. von Schon, “The Use and Conservation of Water Power Resources,” *Engineering Magazine* (1908); Herbert M. Wilson, “Conservation of the Natural Resources of the United States: The Work of the U. S. Geological Survey,” *Engineering News* (1908); H. M. Wilson, “Conservation of National Resources,” *Cement Age* (1908); J. B. Zerbe, “Conservation of Mineral Resources,” *Proceedings of the American Mining Congress* (1908). A search for “conservation” in Compendex for the years 1884 (when the records begin) to 1908 produced 62 results, the first occurring in 1895. A number of these articles addressed conservation of mass in chemical processes. Of those 62, 39 were published in English and did not refer to chemical processes. Engineering Village, Compendex Database, accessed May 15, 2012,
http://www.engineeringvillage2.org.ezproxy.lib.uh.edu/controller/servlet/Controller?CID=quickSearc

By 1906, the term "conservation" had entered the power industry lexicon, and it specifically meant reserving a resource for future use. One engineer suggested that "conservation of rainfall" would be key to making long-distance transmission cost effective in southern Vermont.[15] Another, in reference to debates over the use of Niagara, suggested that waiting to build more power plants until coal became "too expensive" would have the result of "conserving a tremendous block of power until such time as it may be utilized to greater public benefit."[16] By 1908, the power industry journals contained many submissions that addressed resource depletion, efficiency of generating plants, economy of the industry, and the relative merits of long-distance transmission in overcoming the challenges of accessing distant energy resources. These issues all fell under the rubric of conservation as delineated by President Theodore Roosevelt and Gifford Pinchot, leaders of the Progressive Era conservation movement.

Progressives, Engineers, and Conservation

The Progressive Era conservation movement had its roots in several nineteenth century ideas and trends. Dating back to the earliest years of the new republic, law and public policy tended to promote economic activity. Private business had great freedom in logging, mining, farming, and manufacturing with minimal interference from the federal government. The 1890 census, however, illustrated that the resource abundance underlying the country's economic development was limited. Overcut forests, dwindling supplies of arable soil, landownership concentrated in fewer and fewer hands, and intensified development in the

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h&database=3. IEEExplore is a similar database, which covers publications of the associations later grouped together as the Institute for Electrical and Electronic Engineering. A search in IEEExplore for the years 1872 (when the records begin) to 1908 produced only 3 results, with the first appearing in 1905. IEEE website, accessed May 15, 2012, http://ieeexplore.ieee.org/Xplore/guesthome.jsp.

[15] "Progress in Power Transmission," *Electrical World* 47, no. 1 (1906).

[16] "The Preservation of Niagara," *Electrical World* 48, no. 1 (1906).

western states all pointed to resource depletion. Progressives tended to blame private corporations that exploited resources carelessly, without consideration for the needs of the country over the long-term. Anti-monopoly sentiments grew in the late nineteenth century as private businesses opportunistically exploited resources at the expense of the public good. The invisible hand of the market had unleashed resource extraction and economic instability at an alarming rate.[17]

During the latter years of the nineteenth century and the beginning of the twentieth, activists looked increasingly to government to correct the nation's ills. This marked a shift in how North Americans understood the relationship between government and the capitalist economy. Profit-making interests had failed to meet social goals while simultaneously meeting economic goals. Corporations grew larger as did the scale of problems, from smoky cities to overcut forests. Different interest groups delineated social and industrial ills for the public and lobbied cities, states, and the federal government to intervene. Efforts arose to protect fisheries, manage timber harvesting, provide irrigation to family farmers in the west,

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[17] James Willard Hurst, *Law and the Conditions of Freedom in the Nineteenth-Century United States* (Madison: University of Wisconsin Press, 1956); Clayton R. Koppes, "Efficiency/Equity/Esthetics: Towards a Reinterpretation of American Conservation," *Environmental Review: ER* 11, no. 2 (1987); Richard N. L. Andrews, *Managing the Environment, Managing Ourselves: A History of American Environmental Policy*, 2nd ed. (New Haven: Yale University Press, 2006); Frederick Jackson Turner and State Historical Society of Wisconsin, *The Significance of the Frontier in American History* (Madison: State Historical Society of Wisconsin, 1894); Census Division Department of the Interior, *Abstract of The Eleventh Census: 1890*, (Washington, DC: Government Printing Office, 1896); Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement*, p. 21; Curt Meine, "Conservation and the Progressive Movement: Growing from the Radical Center," in Ben A. Minteer and Robert E. Manning, *Reconstructing Conservation: Finding Common Ground* (Washington, DC: Island Press, 2003); J. Leonard Bates, "Fulfilling American Democracy: The Conservation Movement, 1907 to 1921," *The Mississippi Valley Historical Review* 44, no. 1 (1957); Koppes, "Efficiency/Equity/Esthetics: Towards a Reinterpretation of American Conservation"; John M. Meyer, "Gifford Pinchot, John Muir, and the Boundaries of Politics in American Thought," *Polity* 30, no. 2 (1997); Adam Rome, "Conservation, Preservation, and Environmental Activism: A Survey of the Historical Literature," National Park Service, US Department of the Interior, http://www.cr.nps.gov/history/hisnps/NPSThinking/nps-oah.htm; Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement*.

and set aside scenic areas for enjoyment rather than development. At the national level, activists sought federal investment and oversight, the involvement of experts in planning, and limitations on private sector resource extraction. Irrigation advocates favored federal investment in river development. Nature enthusiasts called for government withdrawal of scenic areas from land grants and sales. New agencies like the Forest Service sought increased authority to determine how and when to harvest timber and replant on federal lands. By the end of the century, views of resource management, government responsibilities, and economic activity began a shift away from the unfettered release of creative enterprise.[18]

Theodore Roosevelt and Gifford Pinchot appropriated the term "conservation" to describe their particular initiatives to manage and develop the nation's resources. As the president told a meeting of foresters in 1903, "Your attention must be directed to the preservation of the forests, not as an end in itself, but as a means of preserving the prosperity of the Nation."[19] In this speech, he invoked "wise use" and linked careful management of forests to mineral extraction, transportation, manufacturing, commerce, agriculture, and water supply. In his 1907 letter appointing the Inland Waterways Commission, Roosevelt called upon this entity to plan for the multiple uses of rivers for "navigation, the development of power, the irrigation of arid lands, the protection of lowlands from floods, [and the] supply of water for domestic and manufacturing purposes."[20] Roosevelt termed this a policy to

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[18] Kevin C. Armitage, *The Nature Study Movement: The Forgotten Popularizer of America's Conservation Ethic* (Lawrence: University Press of Kansas, 2009); Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement*; Hays, *Conservation and the Gospel of Efficiency: The Progressive Conservation Movement, 1890-1920*; Minteer and Manning, *Reconstructing Conservation: Finding Common Ground*; Worster, *Rivers of Empire: Water, Aridity, and the Growth of the American West*; Hurst, *Law and the Conditions of Freedom in the Nineteenth-Century United States*.

[19] Theodore Roosevelt, "Speech Given at a Meeting of the Society of American Foresters," (Washington, DC, 1903).

[20] Theodore Roosevelt, Letter to Create the Inland Waterways Commission, March 14 1907.

"consider" and "conserve" natural resources because industrial development had largely depleted many resources already. In November of that year, the president called together the country's governors to meet in 1908 and discuss the "conservation of natural resources."[21] In fact, the rise in the appearance of the term "conservation" in technical literature neatly mapped to President Roosevelt's pronouncements about conservation, and especially the 1908 Governor's conference.[22]

On May 13-15, 1908, the governors met with the president, Gifford Pinchot, representatives of numerous federal agencies, and individuals from a wide array of interests groups, including the electric power industry. They discussed the status of the nation's natural resources and the opportunities for managing those resources for the country's long-term benefit. Roosevelt called for the application of scientific research to soils and crops, the wise use and management of public forest lands, the federal engineering of rivers and streams for flood control and irrigation, the reclamation and settlement of arid lands, and the development of new industries. H. St. Clair Putnam represented the American Institute of Electrical Engineers (AIEE) at the Governors' Conference, and said of electric power, "New economies are possible of accomplishment and the resulting effect upon the conservation and utilization of our power resources is of the greatest importance."[23] He lamented the pending disaster if the rate of coal exhaustion could not be slowed and lauded the possibility of garnering more energy from rivers. Putnam closed with a plea for "wise governmental

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[21] Newton C. Blanchard, et al., *Proceedings of Conference of Governors* (Washington, DC: Government Printing Office, 1908), pp. ix-x.
[22] In the Compendex search, the term "conservation" appeared an average of 2.5 times per year through 1907, it appeared 29 times in 1908. The term appeared an average of 35 times each year through 1920, with a low of 16 occurrences in 1915 and a high of 85 in 1918. Engineering Village, Compendex Database.
[23] H. St Clair Putnam, "Conservation of Power Resources," *Transactions of the American Institute of Electrical Engineers* 27, no. 1 (1908).

guidance" to assure development of the nation's resources with the "highest practicable degree of economy which scientific knowledge and engineering can attain."[24]

The engineering profession developed an ideology logically placing engineers at the center of Progressive Era conservationism. Speakers before the major professional societies in the years 1895-1920 explained that the engineer was seen as: (1) "the agent of all technological change," (2) "a logical thinker free of bias," and (3) holding a "special social responsibility to protect progress and to insure that technological change led to human benefit."[25] Practitioners believed that engineers could solve almost any problem: "whenever a demand arises for improvement in a machine or a process, the requirements are sure to be met, and it is an excellent commentary on the skill and training of engineers and technicians to be able to meet any extraordinary conditions that are presented in the evolutionary process of an industry."[26] Engineers did not, in reality, embody these ideals; they nonetheless aspired to them and the conservation movement offered an opportunity for engineers to participate in resource planning and control the social consequences of technological change.[27]

Resource Conservation and the Power Industry's Long View

Utility engineers and managers took the long view when building systems in order to address economic and technical aspects of the industry. The cost of constructing large dams and steam-generating plants required utilities to insure long-term operations in order to attract capital at reasonable rates. Further, to operate economically, plant managers sought stable and diverse loads. Operators had to promise steady and reliable service to attract large

[24] Theodore Roosevelt, "First Annual Message, December 3, 1901"; Putnam, "Conservation of Power Resources."
[25] Layton, *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession*, p. 57.
[26] "Economic Automatic Engines," *Electrical World* 30, no. 3 (1897).
[27] Layton, *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession*, pp. 60-61.

groups of consumers, especially manufacturers, who would pay the rates that then repaid the investors, over many years. From the technical perspective, electric power could not be stored and had to be available on demand. Thus it behooved utility operators to know where energy sources were located and when they would be available. For this reason, the utility industry maintained a vital interest in access to energy resources and efficiency of operations, topics central to the conservation debate unfolding in the early 1900s.

Coal, water, and forests topped the conservation issues of concern to the power industry. In 1907 a professor reporting on a recently completed survey of the nation's resources for the United States Geological Survey (USGS) warned that the "prodigious waste of [natural] resources must stop at once."[28] He declared that half the coal supply was left underground, water as a source of power was wasted daily and yearly, forest fires burned more lumber than had been used, and the "waste of coal [was] appalling."[29] He predicted an end to the coal supply by the year 2000. Utility operators were acutely aware of resource waste within their operations. Fluctuating coal prices and perceived mineral shortages also dogged the utility industry. From light bulb design to generator efficiency, engineers sought to minimize the use of copper, coal, and other materials in their operations.

A large segment of the electric power industry united in favor of waterpower development to curtail the depletion of coal. For these utilities, development of techniques for transmitting more power, and over longer distances, was critical. In addition, access to sites for hydroelectric generation became increasingly important as national leaders, both within and outside the federal government, expressed dismay about a real or perceived private monopoly controlling waterpower. Power providers also faced challenges from

[28] "National Waste," *Electrical World* 50, no. 15 (1907).
[29] Ibid.

preservationists seeking to retain scenic areas in their natural conditions, but found common cause when the scenic area included forests protecting watersheds.

Coal – Waste and Efficiency

The power industry addressed the coal problem in several different ways. In the early 1900s, utilities strongly preferred anthracite (hard) coal for its flammability and minimal smoke production. Yet there were multiple forecasts of anthracite shortages – in 1907 anthracite would last only fifty more years, in 1908 Charles Steinmetz forecast a severe shortage and Gifford Pinchot reminded a special conservation meeting of the AIEE that only fifty percent of the available coal was extracted properly, and of the quantity mined, ninety percent was wasted. While the industry generally concurred and sought technically feasible means of addressing this problem, at the other end of the spectrum, one Commonwealth Edison engineer oddly proposed burning the coal left in the ground in order to produce more carbon dioxide, which in turn would promote forest growth. In 1912, the predicted shortage, called the "anthracite scare," was deemed "fictitious," yet in 1918 Steinmetz once again predicted that coal would eventually "fail."[30]

Fearing anthracite shortages, electricity producers attempted to use lower grades of coal, refuse coal, gas, and other combustibles, including vegetation, in their power plants. They also encouraged manufacturers to switch from coal-fired steam plants to electricity. In absolute terms, engineers argued, electricity increased the "efficiency" of energy production from coal. Efforts to use low-grade or refuse coal at the mine-mouth dated back to the

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[30] "The Conservation of Natural Resources," *Electrical World* 51, no. 11 (1908). In 1907, the Technologic Bureau of the Geological Survey produced a report stating that "nearly one-half of the total coal supply is being left underground" as reported in *Electrical World.* "Conservation of Resources," *Electrical World* 54, no. 11 (1909); "Central Station Smoke," *Electrical World* 50, no. 5 (1907); "Steinmetz on Natural Resources," *Electrical World* 51, no. 21 (1908); "Anthracite Coal Situation," *Electrical World* 60, no. 22 (1912); Charles P. Steinmetz, "America's Energy Supply," *Transactions of the American Institute of Electrical Engineers* 37(1918), p. 164.

industry's origins, and in 1914, a power company in Hauto, Pennsylvania, finally realized the industry's "dream of conservation."[31] The Lehigh Navigation Electric Company used waste coal at the mine to generate power for nearby mines and industries, with plans to eventually serve New Jersey and New York City.[32]

The use of bituminous (soft) coal in place of anthracite coal increased smoke pollution. Smokeless electricity production became a secondary goal of the power industry, especially for plants located in urban areas. Utility managers struggled to improve the efficiency of plant operations in order to reduce the amount of coal used to generate each kilowatt of power. More efficient generators also resulted in cleaner exhaust and less air pollution, a major benefit in dense urban areas. Further, power planners worried that coal sources might disappear over time. In 1909, the USGS issued a report on smoke pollution and power plants in thirteen US cities. Engineers experimented with mixtures of natural gas or producer gas and bituminous coal. As one remarked, "We shall not get the smokeless city of our dreams until such combinations are carried out."[33]

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[31] "Electricity Directly from the Coal Mine in Pennsylvania"; "Unmarketable Coal Used for Generating Electricity - I," *Electrical World* 63, no. 19 (1914); "A Real Case of Conservation," *Electrical World* 63, no. 20 (1914).

[32] "The Conservation of Fuel," *Electrical World* 54, no. 6 (1909); C.M. Ripley, "Low Grade Fuels and the Power Plant," *Electrical World* 53, no. 14 (1909); "Low-Grade Fuel for the Production of Electrical Energy," *Electrical World* 60, no. 5 (1912); "Vegetation as a Source of Fuel," *Electrical World* 52, no. 23 (1908); "Gas Power," *Electrical World* 53, no. 15 (1909); "Steinmetz on Natural Resources"; Scott, "Conservation of Power Resources"; "Electricity Directly from the Coal Mine in Pennsylvania"; "Unmarketable Coal Used for Generating Electricity - I"; "A Real Case of Conservation."

[33] "Smoke Production," *Electrical World* 49, no. 13 (1907); "Smoke Prevention," *Electrical World* 49, no. 18 (1907); "Central Station Smoke"; "Smoke Nuisance," *Electrical World* 50, no. 23 (1907); "Relation of Government Fuel Investigation to the Solution of the Smoke Problem," *Electrical World* 52, no. 1 (1908); W.F. Murphy, "Smokeless Combustion of Slack and Natural Gas," *Electrical World* 52, no. 23 (1908); "Smokeless Combustion," *Electrical World* 53, no. 16 (1909); "Some Advances in Producer Gas," *Electrical World* 54, no. 6 (1909); "The Conservation of Natural Resources"; "Conservation Congress," *Electrical World* 52, no. 25 (1908); Clarence P. Fowler, "Some Notes on the Limitations and Advantages of Hydroelecrtric Power," *Electrical World* 57, no. 21 (1911); Scott, "Conservation of Power Resources"; Morris Knowles, "Hydro-Electric Development and Water

Domestic and foreign coal prices plagued the power industry during the first decades of the century. The rising price of coal in 1907 threatened the power industry with short-term supply problems. Labor strikes often affected coal availability. In some instances, as in Britain in 1912, the coal strike worked to the power industry's favor, leading to "an enormous increase in the use of electricity for manufacturing, printing and other machines, the increase being over 100% in many cases."[34] Power producers responded, in part, by stockpiling coal, as illustrated in Figure 3.1. (Similar piles are visible at coal-fired power plants today). By 1911, urban power plants included sizable mounds onsite. Companies like

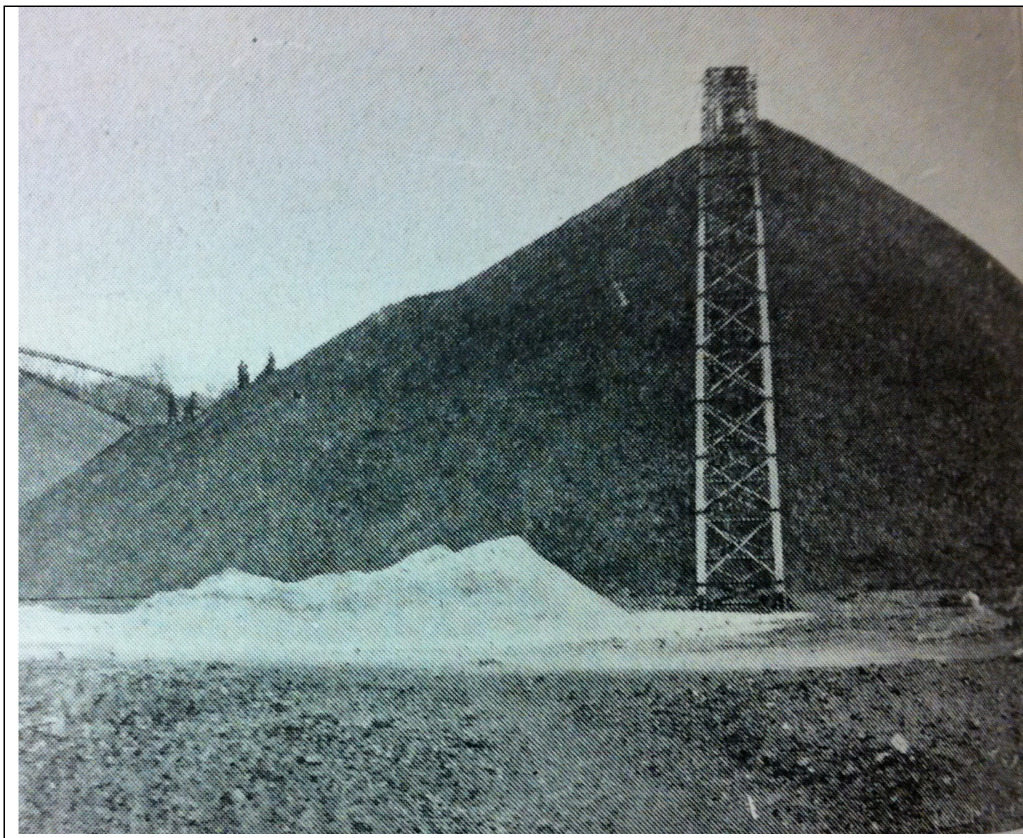

Figure 3.1. New York Edison Coal Pile at Shadyside New Jersey, 200,000 tons of coal. Source: "Electricity in New York City," ***Electrical World*****, Volume 57, Number 21, 1911, p. 1272.**

Conservation," *Electric Journal* 10, no. 7 (1913); Putnam, "Conservation of Power Resources."Quote from "Some Advances in Producer Gas."

[34] "Electricity as a Substitute for Coal," *Electrical World* 59, no. 14 (1912).

New York Edison in New York and Commonwealth Edison in Chicago had over 200,000 tons of coal in onsite storage at any given time. The anticipation of labor problems grew so routine that companies prepared against the "biennial April strikes.[35]While the vagaries of coal prices and availability plagued the power industry, the fate of other minerals in the marketplace further sharpened the utilities' interest in resource conservation. Copper took second place to coal as an essential element of power systems, because copper was one of the best conductors for use in long-distance transmission lines. In 1907, *Electrical World* marked a slowing in the growth of long distance transmission lines linked to the high price of copper. Later in 1907, as copper prices crashed, and mining companies curtailed production, creating shortages, *Electrical World* nonetheless forecast benefits for the electric power industry. To reduce dependence on this volatile market, engineers looked to increase the voltage on long distance lines, because a line with higher voltage would use less copper. Engineers also hoped to find alternative conductors, like aluminum, to alleviate reliance on copper.[36]

From load factor to generator size to consolidation of companies, engineers and managers sought greater operating efficiencies over the long run. In 1906, engineers focused on reducing the waste in incandescent lighting. Managers also addressed the abilities of operating personnel, noting that hiring a "first class boiler-maker" kept the generator in "top form." [37] Consolidating with other stations would result in greater economies than competition among small stations. By 1914, the Associates of Edison Illuminating

[35] "Cost of Coal in Substations," *Electrical World* 50, no. 16 (1907). With limited access to coal during this strike, some manufacturers replaced power from steam engines with electricity. "Electricity in New York City"; "Electricity as a Substitute for Coal"; "Storing Coal for Strikes," *Electrical World* 63, no. 5 (1914); "A Question of a Million Tons of Coal in Storage," *Electrical World* 63, no. 6 (1914).
[36] "The Copper Crash," *Electrical World* 50, no. 17 (1907); "Electrical Power Transmission," *Electrical World* 49, no. 1 (1907); "Questions of High Tension," *Electrical World* 49, no. 15 (1907).
[37] "Station Efficiencies."

Companies offered definitive proof of the benefits of producing power at larger central stations rather than at small stations or isolated plants. A large plant used only 3.3 pounds of coal per kilowatt hour of electricity produced, while small isolated plants used three times that much. According to the Association of Edison Illuminating Companies, large central stations saved the country 1,750,000 tons of coal per year. In fact, between 1900 and 1920, great advances in generator size and thermal efficiency took place. In 1918, Steinmetz noted that energy demand had grown so dramatically that "If all the water powers of the country were now developed, and every rain drop used, it would not supply our present energy demand. … This is probably the strongest argument for efforts to increase the efficiency of our methods for using coal."[38]

Utility executives and engineers worked to use mineral resources more efficiently as part of the effort to address the long-term economic stability of individual companies. By managing use of vital resources, power producers minimized the effects of other markets on their own business activities. They sought to switch manufacturers from coal-fired steam engines to electricity. They developed methods to burn coal more efficiently. They introduced techniques to use waste and brown coal rather than anthracite. They stockpiled coal, increased transmission line voltage, and reduced reliance on copper. Electricity producers understood the vagaries of the mineral resource markets and sought secure long-term access to the essential elements of the power system. Both conservationists and

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[38] R. H. Campion et al., "Discussion on 'Waste in Incandescent Electric Lighting, and Some Suggested Remedies,'" *Journal of the Institution of Electrical Engineers* 37, no. 179 (1906); G. Wilkinson, "Leeds Local Section: Waste in Incandescent Electric Lighting, and Some Suggested Remedies," *Journal of the Institution of Electrical Engineers* 37, no. 179 (1906); "Station Efficiencies"; "Coal Consumption of New York's Generating Stations," *Electrical World* 64, no. 14 (1914). For a detailed discussion of improvements in thermal efficiency and gains in economies of scale, see Hirsh, *Technology and Transformation in the American Electric Utility Industry*, pp. 40-46. Quote in Steinmetz, "America's Energy Supply."

engineers alike nonetheless touted the benefits of waterpower over coal power, and advocated the full use of rivers through strategic planning. In the 1910s, engineers estimated that one horsepower of hydroelectricity could displace the burning of twelve tons of coal. Further, they estimated that anywhere from 30 million to 200 million horse powers of water sat unused in the United States.[39]

Water Power – an Inexhaustible Supply

Waterpower offered several advantages to the electrical industry. Waterpower was a seemingly inexhaustible resource, it did not cause pollution, and it had been barely developed by the early 1900s. In 1905, F.A.C. Perrine, the first chair of Stanford University's Electrical Engineering Department, lectured on the differences between steam and hydraulic turbines. He noted that the value of the mine decreases as coal is used while the value of waterpower increases as the coal supply dwindles. Three years later, he reminded his peers that waterpower cannot be exhausted. His colleague, Westinghouse engineer Charles F. Scott, noted that the United States was "wasting" 30 million horse powers of waterpower, and perhaps another 150 million that could be made available with storage reservoirs. Referring to waterpower in the first instance and coal in the second, the editor of *Electrical World* criticized the past use of "natural sources of energy" that have "hitherto been utterly wasted through thousands of years, while finite sources have meantime been diminished or wiped out."[40]

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[39] *Electric Power Development in the United States. Letter from the Secretary of Agriculture Transmitting a Report ... As to the Ownership and Control of the Water-Power Sites in the United States*, 3 vols. (Washington, DC: Department of Agriculture, 1916).

[40] "Economics of Transmission Problems," *Electrical World* 45, no. 8 (1905); "The Conservation of Natural Resources"; Scott, "Conservation of Power Resources." Quote in "Water Power Conference," *Electrical World* 57, no. 13 (1911).

Utilities claimed waterpower development as a number one conservation goal, for their own long-term economic interests, and for the wellbeing of the country. The AIEE told the National Waterways Commission in 1911 that every cubic foot of water unused represented a "definite monetary loss to the nation."[41] Efforts to irrigate the west coincided neatly with the power company push to maximize the use of waterpower. Irrigation advocates focused on a federal role in developing rivers and delivering inexpensive water to agricultural regions. The Secretary of the Interior agreed that "the water power that is developed is perpetual and continuous, and its use is the most living and vital example of conservation."[42] Many engineers concurred that once waterpower was made profitably productive, then "definite saving is made in the apparently exhaustible fuel assets of the nation."[43]

Electricity experts also disagreed about waterpower as a conservation panacea. Energy demand worldwide outpaced the growth of electrification and power conversions away from coal. Some argued that long distance transmission of power from hydroelectric plants had the potential "to change the fate of nations," in much the same way that a wealth of coal and minerals had in the prior century.[44] Others differed. "Many of the best engineers … have arrived at the conclusion that, on the whole, any new installation of steam power can be employed with much greater chances of profit than almost any water power in any part of the United States, except where coal is very high in cost."[45] Waterpower sites were located at a long distance from markets, use was often restricted by federal and state actions, the

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[41] "The National Water-Power Situation," *Electrical World* 58, no. 23 (1911).
[42] "The Conservation Movement," *Electrical World* 61, no. 4 (1913).
[43] Worster, *Rivers of Empire: Water, Aridity, and the Growth of the American West*. Quote in William B. Jackson, "The Water-Power Situation," *Electrical World* 63, no. 1 (1914).
[44] "Low Priced Fuels for Energy Transmission," *Electrical World* 60, no. 5 (1912).
[45] A.C. Dunham, "The Comparative Values of Water-Power and Steam Power," *Electrical World* 59, no. 1 (1912).

construction cost of hydroelectric dams was high, and long distance transmission was both difficult and costly. By 1918, Steinmetz cautioned the AIEE that a complete shift to waterpower when coal ran out was only a dream. Utilities faced many challenges to gain access to these seemingly ideal and inexhaustible sources of energy.[46]

Economic, technical, and political factors figured into the very public debates about how both the United States and Canada, and the interrelated power industries should proceed. The cost of dams, the long distances to markets, and the weather all affected the economic equation for waterpower development. A hydroelectric dam, even in the early twentieth century, was an enormous financial and engineering undertaking. Private utilities feared they could not attract capital at a reasonable rate for dam construction unless they could demonstrate long-term access to waterpower sites and a ready market to consume the power generated. Markets, however, were seldom located close to attractive and usable waterpower sites. Long distance transmission was also expensive. Often, power could be generated more cheaply at a coal-fired plant near industry or an urban area than it could be transmitted from a distant dam. Finally, stream flow is variable, both seasonally and over several years. A large hydroelectric dam might be idle, or operating far below capacity, during a drought, causing dual problems – lack of revenue for the operator and lack of power for the consumer. Interconnections offered one solution to the challenges of developing hydroelectric power.[47]

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[46] Steinmetz, "America's Energy Supply"; "Question of Local Supply," *Electrical World* 52, no. 14 (1908).

[47] "Electric Power Transmission," *Electrical World* 53, no. 2 (1909); "The Engineer's Duty as a Citizen," *Electrical World* 56, no. 1 (1910); "Conservation without Development," *Electrical World* 56, no. 18 (1910); "The National Water-Power Situation"; "Progress of Water-Power Legislation," *Electrical World* 64, no. 5 (1914). For example, Roosevelt Dam on the Salt River in Arizona, authorized by the Congress under the 1903 Newlands Reclamation Act and completed in 1911, cost $10,000,000 in 1911 dollars. Arizona's Homepage, AZCentral.com, accessed May 25, 2011, http://www.azcentral.com/news/roosevelt/.

The Politics of Waterpower

As high voltage transmission lines crossed city, county, state, provincial, and international boundaries, waterpower sites lay at the heart of the Progressive Era conservation debate. Conservationists favored full river development following planning by engineers and scientists at the central government level. Some state and provincial leaders advocated for local levels of control. Even a few municipalities joined the wrangle over regulatory authority. Within this negotiation, private utilities lobbied against government ownership of facilities. Engineers generally expressed a neutral opinion on the topic of waterpower control, as long as development could proceed.

During the first two decades of the twentieth century, the Congress considered legislation to more tightly control waterpower. The achievement of the Federal Water Power Act of 1920 marked a shift in US regulatory policy. In the past, states exercised regulatory authority over utility industries, specifically to protect consumer interests through sunshine laws, rate control, granting monopoly service areas, and legislating for safety. The federal government had exercised modest authority over interstate trade and activity on navigable rivers, primarily through passage of the Interstate Commerce Act and creation of the Interstate Commerce Commission in 1887. Congress had begun exerting control over waterpower development on federal lands in the late nineteenth century, but private utilities had successfully operated with minimal oversight building dams on rivers across the country. Progressives, however, advocated for more planning and more central control over river development, including the installation of hydroelectric dams. With the passage of the

Federal Water Power Act, the national government took a new step in the direction of regulating business activity by tightly controlling access to a major energy resource.[48]

Congressional consideration of new laws to control hydropower development coincided with another regulatory shift, promulgated by those opposed to the excesses of big business. In the early twentieth century intellectual leaders like Supreme Court Justice Louis Brandeis pushed to limit the influence of giant corporations. Progressives also called for government action to promote the social good. Within the context of a changing regulatory stance at the federal level, utilities focused on their parochial business interest. Power industry leaders closely followed efforts to introduce federal laws that might limit their ability to expand unfettered. While the utility leaders agreed with conservationists that full and rational development of rivers worked to the benefit of all, they resisted the idea that anyone other than members of the power fraternity should direct the path of development.[49]

Political challenges to waterpower development dominated utility sector concerns for many years. Theodore Roosevelt, Gifford Pinchot, and others expressed deep concerns about a putative waterpower trust. The editors of *Electrical World* politely opposed this view. The tendency to monopoly and consolidation did not equal the formation of a trust, they argued, rather, "it is well known to engineers that a group of plants consolidated into a network can produce power more cheaply and reliably when acting together than when acting

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[48] Galambos and Pratt, *The Rise of the Corporate Commonwealth: U.S. Business and Public Policy in the Twentieth Century*; McCraw, *Prophets of Regulation: Charles Francis Adams, Louis D. Brandeis, James M. Landis, Alfred E. Kahn*; Brigham, *Empowering the West: Electrical Politics before FDR*; Hirt, *The Wired Northwest: The History of Electric Power, 1870s-1970s*; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*; Melosi, *Coping with Abundance: Energy and Environment in Industrial America*.For a detailed discussion of the Progressive movement to control dam construction, see especially Hirt, *The Wired Northwest: The History of Electric Power, 1870s-1970s*, pp. 132-165.

[49] McCraw, *Prophets of Regulation: Charles Francis Adams, Louis D. Brandeis, James M. Landis, Alfred E. Kahn*; Melosi, *Coping with Abundance: Energy and Environment in Industrial America*.

independently."[50] Natural monopoly served to link a region into a network "which should be established and regulated rather than prevented."[51] The utility spokespeople explained that the financial relationships between investors, electrical manufacturers, and owners of waterpower sites did not represent "a plot for general control."[52] Nonetheless, the Congress considered proposals for federal control of the nation's waterpower. By 1913, engineers relented slightly, arguing that no waterpower trust yet existed, but "would without regulation."[53]

Privately owned utilities feared lack of access to waterpower sites, but over time favored a role for the federal government that might include some degree of planning or even regulation. For example, while *Electrical* World accused Gifford Pinchot of fighting the "'zeitgeist' of the century" when he rallied against the water power trust, the journal advocated for some government role in both conservation of water resources and comprehensive planning for their use.[54] In 1910, when President Taft withdrew 102 streams from the private market, he stated his support of waterpower development. "It is a certain inference that in the future the power of water falling in the streams to a large extent will take the place of natural fuel."[55] But he identified the need for the federal government to institute controls that would avoid domination by a trust. In that same year, the president of the AIEE gave an address on "Conservation of Water Powers." He generally opposed proposals to limit

[50] "Getting after the 'Electric Trust,'" *Electrical World* 54, no. 23 (1909).
[51] "The Water Power Situation," *Electrical World* 55, no. 1 (1910); "The Logic of Consolidation," *Electrical World* 54, no. 10 (1909).
[52] "The Alleged Water-Power Trust," *Electrical World* 54, no. 8 (1909).
[53] "President Roosevelt on Monopoly of Water Powers"; "President Roosevelt Attacks Electrical Corporations," *Electrical World* 53, no. 4 (1909); "Power Project Vetoed," *Electrical World* 53, no. 4 (1909); "United States Water-Power Regulation," *Electrical World* 53, no. 4 (1909); "The Alleged Water-Power Trust." Quote in Louis Bell, "The Water-Power Situation," *Electrical World* 61, no. 1 (1913).
[54] "The Alleged Water-Power Trust."
[55] "Conservation of Water Powers," *Electrical World* 55, no. 3 (1910).

private waterpower operations on federal land, and in particular he objected to any royalties or fees that could be construed as a tax. He did, however, offer three alternative schemes "should the American people decide" to tax natural resources in order to conserve and develop those resources.[56] First, he demanded a tax on coal lands equivalent in value to any tax on water resources. Second, he called for a method of determining how much water was used that would encourage power companies to install high efficiency plants. And third, he proposed an alternative that obviated the need for taxes and measurement. In this scheme, "government engineers …[would] … prepare comprehensive preliminary plans for the development of water powers of a given watershed and that these water powers collectively or severally be leased to the highest bidder…"[57] Engineering experts would determine how to develop watersheds and industry would undertake the development. During the next several years, electrical journals closely tracked the fate of several pieces of legislation, including the Adamson Bill, which came closest to passage in 1914.[58]

Under a regime of federal oversight, private utility executives also feared controls that excessively favored wilderness protection. Over time, however, utilities found common cause with forest preservation. The preservationists advocated for guarding scenic federal lands from development, citing the over-cutting of forests that had ruined many parts of the country. Some engineers shared a concern that deforestation resulted in changes in rainfall

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[56] Lewis B. Stillwell, "Conservation of Water Powers," *Transactions of the American Institute of Electrical Engineers* 29, no. 2 (1910).

[57] Ibid.

[58] "Bill in Congress to Regulate Dams across Navigable Rivers," *Electrical World* 63, no. 19 (1914); "Congressional Action Likely on General Dam Amendments," *Electrical World* 63, no. 24 (1914); "Condition of Water-Power Legislation," *Electrical World* 64, no. 2 (1914); "Progress of Water-Power Legislation"; "House Passes Water-Power Bill," *Electrical World* 64, no. 6 (1914); "Status of Water-Power Legislation," *Electrical World* 64, no. 7 (1914); "Prospect for Adamson Bill Lessened ", *Electrical World* 64, no. 13 (1914); "Hearing on Water-Power Bill," *Electrical World* 64, no. 23 (1914); "Hearings on the Water-Power Bill," *Electrical World* 64, no. 25 (1914).

patterns and water flow, thus wreaking havoc on the reliability of hydroelectric power. Care should be taken, they said, "to preserve the forests, the great storehouses of rain and flywheels of river flow."[59] On the other hand, many belittled the preservationists, claiming that scenic spots, like Niagara, should be fully developed for power generation, but turned off to show people the natural beauty on "special holidays."[60] Both sides claimed scientific authority about the relationship between rainfall, forests, runoff, and waterpower, but in fact understanding of forest ecology was nascent during these years. The scientific field of ecology emerged in the early 1900s, but there was still plenty of room for disagreement regarding the climatic, geological, and biological processes underway in forested river systems.[61]

A debate ensued addressing whether tree cover affected regional water cycles, an issue near to the hearts of the operators of hydroelectric plants. At a joint meeting of many engineering associations in 1909, one presenter reported that deforestation had not, in fact, affected stream flow on the Hudson River, but that forest fires posed a larger problem. Yet one year later, Lewis Stillwell declared that there was consensus among engineers that the presence of forest at a watershed does regulate runoff. Without strict enforcement of state laws protecting forests and watersheds, utilities favored a federal role in forest preservation. A journalist identified three sides to the problem. The "enthusiasts" believed in the "beneficent effects" of preservation. The "political manipulators, promoters, and attorneys" saw no relationship between forests and water-flow. And the "practical engineers"

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[59] "Hydroelectric Developments," *Electrical World* 59, no. 22 (1912).
[60] "Niagara Falls Power," *Electrical World* 60, no. 19 (1912). "Hydroelectric Developments"; Kenyon, "Utilization of Niagara Falls"; "The Preservation of Niagara."
[61] Stillwell, "Conservation of Water Powers"; Donald Worster, *Nature's Economy: A History of Ecological Ideas*, 2nd. ed. (Cambridge: Cambridge University Press, 1994).

understood the measurable effect of deforestation on hydraulic development.[62] Sound government policy should follow from the recommendations of the engineers. By the 1910s, the utility industry believed that forests maintained river flow and that "preservation [was] a matter of general concern," not just a sentiment.[63]

Over time discussion of waterpower development and resource management converged on the idea that interconnection could achieve conservation goals. As early as 1908, engineers observed that in regions like the Pacific Northwest, with roughly one fourth of the United States' potential waterpower, "great combinations" would provide "general and conclusive value ... in electrical generation and transmission," and that an interconnected network could "do in efficiency and reliability what no one plant can reasonably hope to accomplish."[64] Even if aggregation of hydroelectric plants gave the appearance of an emerging power trust, interconnection tended "distinctly toward conservation of our natural resources."[65] By 1911, some argued that waterpower represented a beneficial natural monopoly, and by linking multiple hydroelectric plants into a single system, the possibility of one manufacturer monopolizing waterpowers for internal use would be minimized.

Further, utilities gained even greater economic advantages by linking hydroelectric plants to small steam plants. Interlinked plants could smooth the variations in rainfall and runoff within and between watersheds to maximize power use and minimize waste. In

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[62] "The Policy of Conservation," *Electrical World* 55, no. 26 (1910).
[63] "The Preservation of Niagara"; "Natural Resources," *Electrical World* 51, no. 19 (1908); "Engineers Discuss Conservation of Natural Resources at Boston," *Electrical World* 55, no. 23 (1910); "The Policy of Conservation"; "A Study in Conservation," *Electrical World* 57, no. 21 (1911); "Forestry and Water Powers," *Electrical World* 49, no. 13 (1907); "Conservation of Natural Resources," *Electrical World* 53, no. 14 (1909); "Conservation of Hydraulic Resources," *Electrical World* 51, no. 11 (1908); "Water-Power and Conservation," *Electrical World* 57, no. 22 (1911).
[64] "The Growth of a Transmission Network"; *Electric Power Development in the United States. Letter from the Secretary of Agriculture Transmitting a Report ... As to the Ownership and Control of the Water-Power Sites in the United States*.
[65] "Getting after the "Electric Trust"."

praising the interconnection of seven systems in the South in 1914, one journalist noted that it was the means by which each plant "could be utilized to its greatest advantage and the waste of water ... could be averted."[66]

Summary

During the ten years between the Louisiana Purchase Exhibition and World War I, the electric power industry embraced resource conservation as a fundamental goal of operations. The economics of successful power plant operations called for a very long view with respect to initial investments and to management of energy sources. As coal prices rose and fell, and coal shortages threatened, the industry sought both to increase the efficiency of generating stations and to reduce reliance on fossil fuels for electrification. To accomplish this, power planners negotiated for access to waterpower sites, to financing, and to markets. This took place during the rise of the Progressive Era conservation movement when governments, and most especially the federal government in the United States, weighed legislation to regulate access to water power sites and to preserve areas of scenic beauty.

For the power industry, building ever-larger interlinked systems offered an important path to achieving conservation goals. Bigger coal-fired plants operated more efficiently, using smaller units of coal for every kilowatt generated. Large hydroelectric dams connected to distant markets with long-distance transmission lines offered seemingly unlimited and non-polluting energy for growing electricity demand. Some forest preservation efforts appeared to allay the concerns of utilities worried about the loss of flow in key energy-rich watersheds. By linking hydroelectric stations with coal-fired stations into large regional

[66] Clarence P. Fowler, "A Few Reaons Why Hydroelectric Development Should Be Encouraged.," *Electrical World* 58, no. 3 (1911); "The National Water-Power Situation"; "Some Peculiarities of Water-Power," *Electrical World* 60, no. 18 (1912). Quote in "The Great Southern Transmission Network."

networks, the industry began to realize economies of scale, seasonal efficiencies, and profits, especially when they promoted electricity consumption.

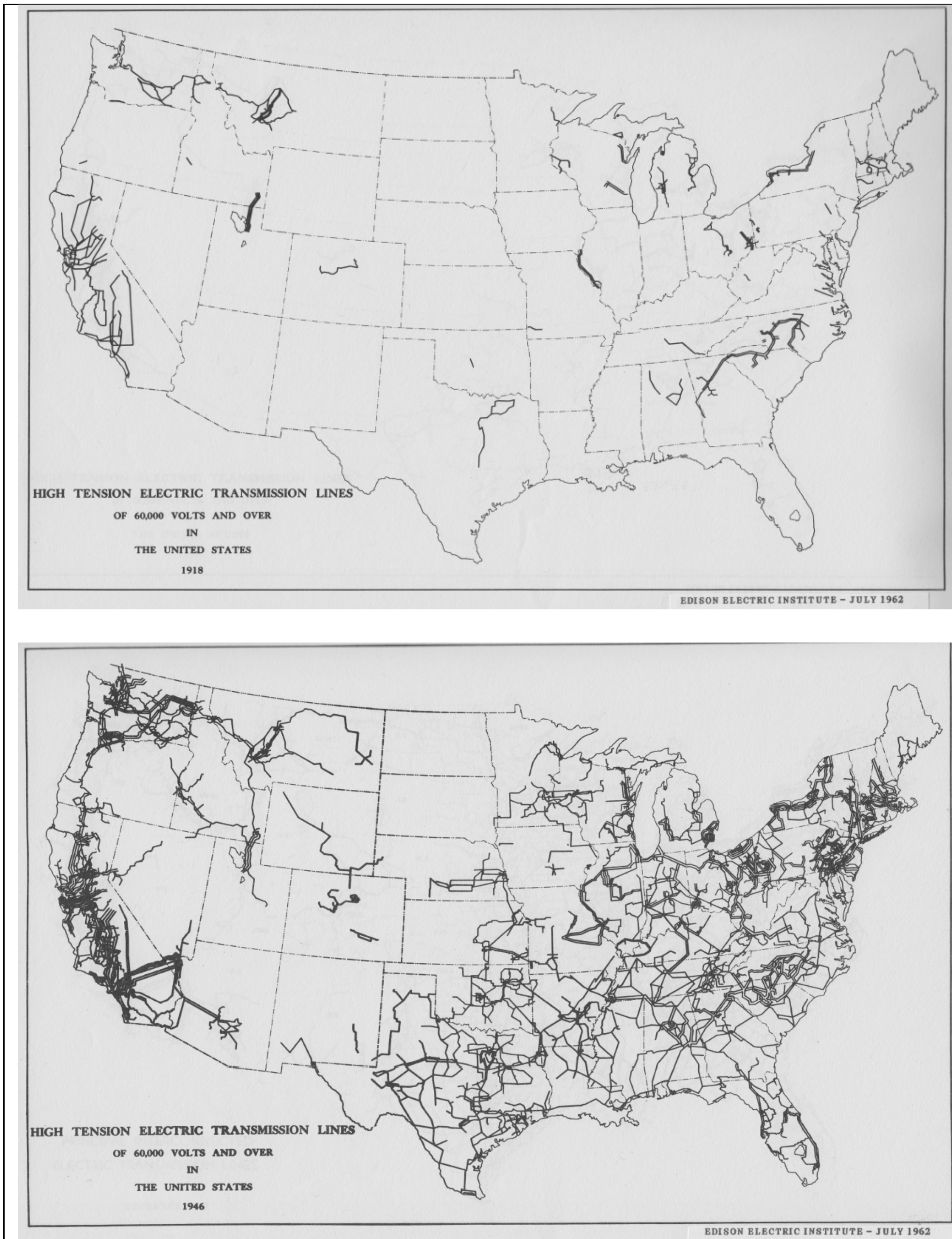
Specialists within the power industry developed ideas regarding efficiency, resource management, and smoke abatement in parallel with Progressive Era conservation movements. Further, the ideologies of conservation activists often influenced engineers and utility managers. For example, when Progressive leaders, like Gifford Pinchot, called for experts to take a strong role in planning and directing the development of natural resources, power industry engineers congratulated themselves for occupying a central position in the conservation debate. On the other hand, when proposals for resource management directly affected plans for industry expansion, utility leaders strenuously lobbied for minimal government intrusion into the power business. During fraught public debates about water resources and forests, representatives from the power industry often couched their own proposals in conservation terminology, sometimes to counter the opposition and at other times to gain consensus from the broader public. The rising significance of conservation ideas and ideologies during these years framed the discourse about interconnections. Long-distance, interlinked power lines provided utilities with a key technology for achieving conservation goals.

The opportunity to manage essential energy resources and operate more efficiently by interconnecting introduced a paradox to the industry's conservation stance. Utilities both public and private were in business to sell power. Politicians, industry, and the public at large all supported increased electrification and increased power consumption. Interconnections allowed utilities to reach larger markets and to sell power more economically by diversifying energy sources. While the emerging regional electricity networks could be construed as technologies of conservation, they were, without any doubt, also technologies of consumption. Although the Progressive Era activists focused on opportunities for producers to husband natural resources more effectively, in later years conservationists and environmentalists embraced the notion of total reduced use by both producers and consumers. During the two decades following World War I, however, the power industry successfully touted the notion of using interconnections to conserve essential resources, because the focus had not yet shifted to the consumer side of the power line.

Part II. Contest for Control, 1920-1945

Comparing maps of high-tension power lines at the ends of the two world wars, it is obvious that major change occurred during the intervening years. (See Map B) Utilities stretched their service areas, joined into power pools, and electrified new regions of the country. Federal dam projects and river basin authorities added to the infrastructure. Clearly a strong trend toward interconnection was underway. The fact that this took place without any central plan or oversight authority determining the paths of growth makes the North American Grid unique compared to most other parts of the world. Individual utilities, and later federal agencies, chose to create links that permitted power sharing. They forged political and economic relationships that allowed for stable operations across long distances, but respected the autonomy of each participant. The growth of interconnections during these years took place organically, on a piecemeal basis, with significant regional differences.

The First World War magnified a number of the benefits of interconnection. For example, operators on interlinked systems shifted loads from coal-fired plants to hydroelectric plants to slow the pace of fuel depletion and maximize the advantages of waterpower. In addition, operators moved electricity across interconnections from regions with low demand to regions with high war-related industrial activity. Utilities effectuated Progressive Era ideals of resource conservation, operating efficiency, and expert planning when they collaborated with government agencies to meet wartime production needs. By 1920, a few sketchy outlines of interconnections appeared on the nation's map, as shown in Map B, but this was not a grid.



Map B. High Tension Transmission Lines in United States in 1918 and 1946. *Source:* Edison Electric Institute, *Report on the Status of Interconnections and Pooling of Electric Utility Systems in the United States*, 1962.

Ideas for giant networks abounded. From Superpower and Giant Power, to coast-to-coast networks, to giant transmission lines linking rivers in British Columbia to customers in

Los Angeles, the concept of a grid found favor across the continent. But building an interconnected system of power providers and consumers was hardly inevitable. No government agency exercised control over all power systems. No single holding company commanded the majority of utilities. No group of engineers dominated the planning of network expansion. Instead, a fragmented industry, an array of governments, a variety of owners, and a plethora of customers characterized electrification in North America. Out of this collection of interests, the skeleton of the power grid emerged by the time the country went to war again in 1941, and was firmly in place when the war ended, as is in evidence in Map B.

The pursuit of interconnections took place in the context of negotiations for economic and political control. As had been the case from the outset, privately owned utilities resisted government intervention, unless it could be structured to benefit the power companies economically. Although utilities acceded to the oversight of state and provincial regulatory commissions in most parts of the United States and Canada, they pushed back aggressively against any central government efforts to exert control. During the 1920s, government and industry leaders considered several schemes for achieving widespread interconnections, but none gained sufficient momentum to become an actual plan. Instead power companies pursued interconnections independently.

The contest for control unfolded in multiple arenas. At the beginning of the 1920s, politicians and utility leaders debated various plans for expanding and unifying interconnections. While some legislators advocated for a national scheme, others sought statewide, or regional approaches. Private utilities resisted those proposals and offered their own competing strategy for building an integrated system. Later in that decade, politicians challenged utility holding companies and directed the Federal Trade Commission to investigate the economic relationships among owners. With the New York stock market crash of 1929, the reputation of utilities fell hard. In the 1930s, the president of the United States railed against utility leaders, Congress debated strict controls on the industry, and ultimately the federal government stepped into a regulatory relationship with power companies active in interstate trade.

In the midst of these negotiations, or perhaps despite them, individual utilities pursued interconnections on their own. The financial advantages of interconnection compelled private companies to find both opportunities and methods for sharing power. Later, government agencies joined the process. From the political perspective, interconnections aided economic development and fostered greater equity in access to electricity. While Progressive era conservation was on the wane, those interested in resource development still touted the conservation benefits offered by building long-distance transmission lines and interlinking different types of power generators. During the 1920s, governments generally favored interconnection, even if they lacked the authority to require them. During the 1930s, the federal government actively invested in regional distribution networks in order to advance economic development in hard-hit parts of the country. There were many incentives to build interconnected systems, even in the vacuum left by the unresolved contest for political and economic control.

The economic and political structures created to facilitate interconnections led to significant technical problems for the system operators. Managing the flow of power on a system owned and operated by a single entity offered sufficient challenges to make it technically interesting for engineers. Adding the requirement that power sharing take place under certain economic agreements between two or more entities complicated the project. The absence of enforceable standards deepened the challenge. The technical attributes of alternating current rendered some problems unsolvable for years. System operators, engineers, and manufacturers collaborated, and competed, to find workable solutions for controlling the flow of electricity on interconnections. In the process, the fraternity of individuals who dealt with these challenges built for themselves a reputation of technical expertise that was admired around the world.

Systems of shared management and divided authority characterized the economic, regulatory, and technical approaches devised to control power. Federal and state governments shared responsibility for regulating separate aspects of the power networks while the utilities themselves undertook to control the physical designs and operations of power systems. Public and private entities entered pooling agreements that allowed all to share management of the interconnections while protecting the economic independence of each. Engineers evolved techniques for physical control of power that respected the autonomy of dispatchers at individual power plants while assuring the stability and reliability of the networks.

By the end of World War II, the roles of the actors in North American electrification solidified and consumers enjoyed increasing quantities of electrical energy at stable and often decreasing rates. Utilities both public and private joined into self-regulating power pools. Governments in the United States and Canada invested in large-scale electricity infrastructure. Engineers embraced automated control to assure a reliable supply of power across the continent. Expansion into a network of interlinked power systems was attractive, but not inevitable after World War I. By the end of World War II, with significant infrastructure in place, a growing grid looked like a foregone conclusion.

Chapter 4. Economic and Political Control of Power, 1920-1945

The contest for control began with competing proposals for building integrated power networks. During the post-war years, advocates called for planned expansion of regional systems, under the control of a central authority, to bring electricity to industry, to the countryside, and to urban and suburban households. In other countries, notably Great Britain, France, and parts of Canada, legislatures formed central agencies to build giant transmission networks. In Europe especially, this was considered essential to post-war recovery. In Ontario, Canada, this was a further expression of a project begun at the beginning of the century. In the United States, the power industry fraternity observed these experiments in public utility development and offered proposals for similar projects closer to home. In fact, politicians, engineers, college professors, and utility executives put forward a variety of ideas for the orderly development of interconnected systems.

The details of assembling an integrated network out of the numerous entities involved in producing and delivering electricity dogged the industry. To many, it seemed inevitable. "Ultimately the country will have a network of transmission lines … Electricity will bring cheap power and comfort to every man's door."[1] But stakeholders had numerous issues to negotiate, from who exerted regulatory control and how, to who owned which pieces of the system, to which techniques most effectively insured a reliable and integrated network. By the mid-1920s, the visible hands of American capitalists had retaken the reins. Privately owned utilities resisted efforts to introduce government planned networks. Politicians differed over which level of government should exert what level of authority over electrification. Consumers happily purchased electricity as prices fell. Specific schemes for

[1] Schuchardt, "The Significance and the Opportunities of the Central Station Industry.." Rudolf Frederick Schuchardt was Chief Electrical Engineer of Commonwealth Edison Company from 1909 until his death in 1932.

building a grid fell by the wayside as producers linked into their own regional network configurations.

Variety defined the approach to interconnection in the United States. In some regions, holding companies organized contiguous utilities into interconnected systems. In others, economically separate power producers formed pools to move electricity across wide areas. In still others, small municipal utilities remained steadfastly independent. While utilities participating in networks shared responsibility for managing the interconnections, they carefully preserved their operating and economic autonomy.

For many years, the private utilities operated in a gray area of uncertain responsibility when it came to sharing electricity across state lines. By the late 1920s, governments in North America stepped back from a central role in grid development and instead undertook regulatory and infrastructure projects on a piecemeal basis. State and provincial utility commissions continued to regulate rates and service areas, but only to the boundaries of their jurisdictions. Treaties between the United States and Canada governed international power sales. In the 1930s, new United States laws addressed the licensing of waterpower sites, the interstate sales of electricity from those sites, and the financial structure of holding companies. Together, these laws provided a framework that ultimately encouraged private sector development of interconnections, but did not institute centrally designed plans.

World War II caused a brief detour from this path of shared management and divided authority as public and private sectors worked together to arm for combat. The war also accelerated the expansion of the grid. In the post war years, however, there was no revival of plans for a centrally controlled national grid. Instead, the industry returned to business as usual, with independent strategies for building bigger plants, longer power lines, and more complex interconnections. Giant power pools took on the task of coordinating this system of multiple enterprises. And consumers enjoyed access to more and cheaper power. The skeleton of the future grid was visible.

"Our Ultimate System" – Competing Visions of Control

A wide variety of schemes for integrated power networks appeared across the globe in the late 1910s. Government specialists, utility executives, and college professors all put forward ideas for building unified systems of power generation and delivery. Some focused on averting energy shortages during crises. Others addressed opportunities for generating enormous amounts of electricity at waterpower sites. Privately owned utilities sought self-determination as well as economic benefits through interconnection. Political leaders advocated for equity in power delivery to underserved populations and regions. From Europe to the Pacific Northwest, all of the strategies included a central entity that would determine the size and shape of a future grid. Political and economic differences, however, heavily influenced the feasibility of creating a controlling entity. While England nationalized its grid in 1926, each Canadian province sported a different approach to interconnection, and the United States enjoyed an odd assemblage of public and private utilities operating regionally configured networks.

The central coordination of energy resources during the Great War was a highly attractive model to both utility executives and politicians for future electricity growth. Utility operators had cooperated with the United States and Canadian governments to direct electricity to the areas of greatest need for war production. At the government's behest and through coordinated study and planning, utilities formed interconnections that increased the amount of electricity available through more efficient operation of generating stations. The government directed producers of war materiel to areas of the country with excess power, and operators linked steam and hydroelectric plants in order to address coal shortages. To many observers, high voltage interconnection represented “our ultimate system.”[2] North Americans could achieve greater access to electricity while avoiding energy shortages. At the same time, power producers could conserve natural resources through a centrally planned national network, with links into Canada.

The private utilities, however, resisted efforts to support this type of government authority. In addition, members of the American public and many politicians felt that centralized government control of electrification foreshadowed socialization of a capitalist enterprise. Americans considered several proposals, for a “national grid,” a “superpower” system, a “giant power” system, and creation of a common carrier network of power lines. In the end, none of these ideas gained sufficient support to provide planned power development. By 1930, formal plans for national power development disappeared, but utilities undertook to create a growing network on their own.

From the Exigencies of War, Multiple Proposals for a National Policy

Numerous individuals in the United States had imagined a “national grid” in the early 1910s, and during the war the first formal government actions embraced the idea. Proposals arose from the War Industries Board, the Army Corps of Engineers, the Smithsonian Institute, private industry, and academia. The two most prominent schemes came from the private utilities and Progressive politicians respectively. Titled “Superpower” and “Giant Power,” these proposals occupied pubic debate for several years in the 1920s.

[2] “Power Transmission and Industrial Development,” *Electrical World* 75, no. 1 (1920).

The first suggestions for a national interconnection plan came from within the Wilson administration. Bernard Baruch, advisor to President Woodrow Wilson at the start of the war, and later chairman of the War Industries Board (WIB), explored interconnections of disparate utilities as a fast approach to increasing available power for war production. Power shortages first felt in Niagara in 1917, then Pittsburgh, and then New Jersey, led Baruch and the Power Section of the WIB to conduct surveys of electrical industry status along the eastern seaboard, the location of the majority of war industry production. With the results of those surveys, as well as severe capital shortages and increasing construction costs for private utilities, the WIB called for numerous interconnections to ease a looming energy crisis.[3]

More ideas appeared in the immediate aftermath of the war. Officials from the Army Corps of Engineers reported after the war that the status of the power industry "shows clearly the need of adopting a comprehensive policy with definite plans for the construction of unified power systems over large areas, many of which are interstate in context."[4] The Smithsonian Institute offered a competing vision in which a network of transmission lines would serve as common carriers to facilitate the development of mine mouth and waterpower site plants, and thus alleviate the transportation burdens experienced by the country.[5]

The private utilities shared an interest in comprehensive planning for future electrical development. Engineers and utility managers well understood the opportunities for conserving coal, reducing costs, and increasing available power through specific strategies of

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[3] United States War Industries Board, *American Industry in the War: A Report of the War Industries Board*, (Washington, DC: Government Printing Office, 1921); Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*, p. 232-233; Keller, "The Power Situation During the War," pp. 16-19, 40-41.
[4] Keller, "The Power Situation During the War," p. 21.
[5] Report of the Smithsonian Institution, *The Mineral Industries of the United States: The Energy Resources of the United States: A Field for Reconstruction*, (Washington, DC: Government Printing Office, 1919).

coordination and electrification. In July 1918, Ross McClelland, chief engineer of the Electric Bond and Share Company, outlined a plan in *Electrical World* that closely resembled the later "Superpower System."[6] As the subhead to the McClelland article stated, "Shortage of power a major war problem – critical railroad situation calls for generation of energy near mines and transmission electrically – interconnection of central-station systems in war industries districts will greatly increase capacity."[7] McClelland noted that projects already underway in Britain and France called for "comprehensive increase, interconnection and centralization of electrical supply."[8] To keep pace, he proposed that the United States centralize the power supply in large and efficient generating plants built in the mining districts, fully exploit waterpowers, electrify steam railroads, electrify coal mining, and interconnect. He called for "a comprehensive and rational policy for future power supply for maintaining our industrial standing after the war."[9]

While Mclelland focused on the eastern seaboard, utilities in the Pacific Northwest echoed the growing national interest in regional planning and interconnection. In 1918, Puget Power and Washington Water Power formed the first regional interconnection in the Northwest. One year later, electrical engineer and University of Washington professor Carl Edward Magnusson proposed the idea of developing a 220,000-volt interconnection to link power generators and consumers from British Columbia to Southern California. Magnusson, who later consulted on the Grand Coulee Dam project, continued to publish maps and reports promoting the feasibility of West Coast interconnection throughout the 1920s. While fifty

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[66] R. J. McClelland, "Electric Power Supply for War Industries," *Electrical World* 72, no. 3 (1918).Over time, the term "superpower," sometimes appearing as "super power," came into wide use referring in general to very large generating plants, located at the energy source, and transmitting power over long distances on high-voltage lines, usually as part of an interconnected system.

[7] Ibid.

[8] Ibid.

[9] Ibid.

years passed before Magnusson's grand scheme for giant transmission lines running the length of the west coast became reality, this engineer's vision matched the plans unfolding elsewhere.[10]

England Invents the National Grid

Power planners in the United States observed closely central planning of power systems in other countries. In England, for example, the war temporarily unified an otherwise disaggregated and disorganized electrical industry. Unlike systems in the United States, British power stations, both public and private, generally operated independently, on a small scale, some with direct current and some with alternating current, and in a wide array of frequencies. Local and national legislation in Britain had made integration economically unattractive and politically unpalatable. Regional preferences for municipal ownership, fear of socialism, and segregated private suppliers blocked efforts to aggregate the industry. However, as in the United States, the need to coordinate war production resulted in coordination of power generation and delivery as well. The electric power industry acted in greater unison to provide electricity where and when needed. Even before hostilities ended, Parliament named a Ministry of Reconstruction Committee to consider how to unify the country's electric power system during peacetime. Britain emerged from the war deeply in debt, facing labor problems, and falling behind other countries in terms of industrial strength.

[10] Northwest Power Pool "Northwest Power Pool," accessed November 6, 2007; http://www.nwpp.org/Norwood, *Columbia River Power for the People: A History of Policies of the Bonneville Power Administration*. Edward Wilson Kimbark, *Power System Stability*, 3 vols., vol. 2 (New York: Wiley, 1950).

A concerted investment in electrification promised energy for industrial growth and overall economic recovery for the country.[11]

Consulting engineer Charles Merz had promoted the idea of an integrated electrical supply system for England since the early 1900s. In 1917, while serving as an advisor to the Ministry of Reconstruction, Merz, with others, proposed an interconnected national power system, which eventually led to Parliament's passage of the relatively weak Electric Supply Bill in 1919. Under this act, utilities in districts across the country voluntarily formed joint electricity authorities to coordinate and develop regional power supply. In addition, the Board of Trade named five commissioners to promote, regulate, and supervise electric utilities. The commissioners devised electricity districts in which utilities could standardize their power systems. Seven years later, when the Act had failed to produce a unified network, Parliament nationalized the "Grid," a term coined by Merz.[12]

The Electric Supply Act of 1926 called for a central commission to identify priority locations for generating plants, and to develop and operate a high-speed transmission network to carry power from generating plants across the island to local distribution companies. The plan also called for standardization of the entire network at 50 Hz. The processes of building a national grid and establishing central government control of power development had been contentious, but the need for postwar industrial and economic growth

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[11] Hannah, *Electricity before Nationalisation: A Study of the Development of the Electricity Supply Industry in Britain to 1948*; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p. 318-319, 350-351.
[12] "Electric Power Supply," *Electrical World* 39, no. 16 (1902); "Power in Bulk," *Electrical World* 44, no. 12 (1904); "The Industrial Power Problem"; "Proposed Consolidation of London Electric Supply Systems," *Electrical World* 51, no. 6 (1908); "Energy Supply on British Northeast Coast"; "British Energy Supply," *Electrical World* 57, no. 5 (1911).

as well as the opportunity for resource conservation drove the eventual acceptance of the plan. Similar initiatives advanced in France and Germany.[13]

Neighboring Influence: The Ontario Hydroelectric Power Commission

Closer to home, US power planners observed the experiences of the Ontario Hydroelectric Power Commission (HEPCO), not only as an example of central government control, but also as an element of the growing interconnected system in North America. Canada and the United States developed electric power systems along similar pathways initially, but the regulatory structures shaping electrification diverged over the course of the twentieth century as the countries addressed differences in energy resources, markets, corporate structures, social goals, and environmental restrictions. In both countries, electrification took place under a federated government system in which certain powers are delegated to the national government and others are assumed at the provincial and state levels respectively. Additionally, Canada adopted both technologies and public utility commission approaches from the United States. The two country's systems were linked through river treaties that facilitated the exchange of power across the international border. In Canada, however, crown ownership of energy resources, locally articulated social and economic goals for electrification, a weak central government, and the general flow of power from northern

[13] Hannah, *Electricity before Nationalisation: A Study of the Development of the Electricity Supply Industry in Britain to 1948*; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*; Rowland, *Progress in Power: The Contribution of Charles Merz and His Associates to Sixty Years of Electrical Development, 1899-1959*; Hughes, "Managing Change: Regional Power Systems, 1910-30"; John Price Jackson, "Policies for Future Power Development," *Mechanical Engineering* 43, no. 2 (1921); W. H. Onken Jr., "Electrical Development in England," *Electrical World* 82, no. 21 (1923); Heber Blankenhorn, "Power Development in Great Britain," *Annals of the American Academy of Political and Social Science* 118(1925); Casazza, *The Development of Electric Power Transmission: The Role Played by Technology, Institutions, and People*; "Power Transmission and Industrial Development." For more discussion of network expansion in Germany and France, see Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*; Frost, *Alternating Currents: Nationalized Power in France, 1946-1970*; Hughes, "Managing Change: Regional Power Systems, 1910-30."

energy sources to southern cities and the United States shaped provincial electrical systems different in kind from their southern neighbors.[14]

In 1906, the Ontario Parliament created HEPCO to regulate and develop waterpower in the province, with a particular mission to supply power to municipalities. Over time, HEPCO expanded its duties and services to include operation of a test lab, purchase and construction of its own generating plants, safety inspection and repair services for municipal systems, and outreach to rural districts. The Commission was a "monopolistic" generator, transmitter, and distributor of power, both competing with and regulating all hydroelectric concerns in the province. As an agency of the provincial government and a representative of municipalities, HEPCO exploited the political influence of both. HEPCO purchased power

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[14] *Electrical World* began regular coverage of the Ontario Hydroelectric Commission in 1908 and other journals provided ample opportunity for United States engineers and utility executives to track progress in Ontario. A few examples of journal articles from 1907 to 1925 follow: "Power in Canada," *Electrical World* 49, no. 13 (1907); "Canadian Niagara Power," *Electrical World* 49, no. 20 (1907); "Canadian Niagara Power," *Electrical World* 51, no. 15 (1908); "The Ontario Hydro Electric Power Commission at Ottawa," *Electrical World* 52, no. 14 (1908); "Ontario Electric-Power Scheme Attacked," *Electrical World* 54, no. 5 (1909); "One Hundred and Sixty Five Thousand-Volt Transmission," *Electrical World* 56, no. 11 (1910); "The 110,000-Volt Transmission System of the Province of Ontraio"; "The Great Ontario Transmission"; "Ontario Hydro-Electric Commission Bill," *Electrical World* 59, no. 12 (1912); "Canadian Water-Power Commission," *Electrical World* 62, no. 4 (1913); "Ontario Water-Powers under Commission Control," *Electrical World* 62, no. 17 (1913); "Hydro-Electric System of Province of Ontario Investigated," *Electrical World* 79, no. 10 (1922); "Extension to the Ontario Power Co," *Contract Record and Engineering Review* 33, no. 29 (1919); T. C. James, "Nipigon Power Development of Ontario Hydro Commission," *Contract Record and Engineering Review* 35, no. 16 (1921); "War-Time Service Problems in New England"; "Hydro-Electric Development at Cameron Falls, Nipigon River, Ontario," *Electrical News* 31, no. 15 (1922); E. T. J. Brandon, "Project, Ontario, 50,000-Hp. Wheels for 500,000-Hp. Plant," *Electrical World* 77, no. 13 (1921); J. B. Challis, "Canada Shows Rapid Hydro Development," *Electrical World* 77, no. 17 (1921); "Design of the New Canadian Niagara Power Project," *Engineering News-Record* 85, no. 16 (1920); H. A. Gardner, "Ontario Power Co.'S Plant Extension," *Engineering World* 14, no. 11 (1919); Harry Gardiner, "Queenston-Chippawa Development at Niagara Falls," *Engineering World* 15, no. 9 (1919); F. G. Gaby, "Hydroelectric Developments in Ontario," *Mechanical Engineering* 45, no. 7 (1923); Louis B. Black, "Canada Builds 300,000 Hp. Niagara Hydro Plant," *Mine and Quarry* 11, no. 1 (1918); "Queenston-Chippawa Hydro Development Largest in the World," *Power* 55, no. 26 (1922); Armstrong and Nelles, *Monopoly's Moment: The Organization and Regulation of Canadian Utilities, 1830-1930*; Doern, *Canadian Energy Policy and the Struggle for Sustainable Development*; Regehr, *The Beauharnois Scandal: A Story of Canadian Entrepreneurship and Politics*; Nelles, *The Politics of Development; Forests, Mines & Hydro-Electric Power in Ontario, 1849-1941*.

from US-owned private generating companies at Niagara, sold excess electricity to consumers in the United States, and participated in wartime agreements on both sides of the border to maximize electricity for war production. In addition, HEPCO benefited from Canadian preference under the 1909 Boundary Waters Treaty. HEPCO modeled a centrally planned, large-scale, regional public power system, and also linked into the growing interconnections of the northeastern part of the United States.[15]

Due to its large size, unusual administrative structure, service to rural districts, and relatively lower rates, HEPCO gained notoriety in the United States and abroad. In 1918, Sir Adam Beck, chair of the Commission, appeared before US House Committee on Waterpower and impressed Congress with the news that his system was larger than Insull's Commonwealth Edison system in Chicago. In 1921, HEPCO became the largest distributor of electricity in the world, aggregating 1.4 million horsepower. "By virtue of its achievements, the Commission has become recognized as a unique adventure in economic

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[15] Harald S. Patton, "Hydro-Electric Power Policies in Ontario and Quebec," *The Journal of Land & Public Utility Economics* 3, no. 2 (1927); Belfield, "The Niagara Frontier: The Evolution of Electric Power Systems in New York and Ontario, 1880-1935"; E. B. Biggar, "The Ontario Power Commission: Its Origin and Development," *Journal of Political Economy* 29, no. 1 (1921); Nelles, *The Politics of Development; Forests, Mines & Hydro-Electric Power in Ontario, 1849-1941*, p. 365, 373-399, 400. Under the 1909 Treaty, the United States had explicit rights to divert twenty thousand cubic feet of water per second while the Dominion of Canada or the Province of Ontario had the right to divert thirty-six thousand cubic feet of water per second, in both cases for the purpose of generating power. "Treaty Relating to the Boundary Waters and Questions Arising Along the Boundary between the United States and Canada," in *36 Stat. 2448, TS 548; 12 Bevans 319* (1909). As in the case of other power monopolies, growth marked the early development of HEPCO. The Commission began with seven municipalities as customers and no infrastructure and grew rapidly in size, scope, and consumer appeal. By the end of the war, HEPCO served 1.7 million consumers in over 200 municipal and rural systems. By 1910, the system charged lower rates than utilities in Quebec, New York, and other US states and saved Toronto an estimated $17 million and 2 million tons of coal over 8 years. The popularity of this public transmission grid appeared well deserved. Murray, *Government Owned and Controlled Compared with Privately Owned and Regulated Electric Utilities in Canada and the United States*, pp. 9, 42, 54, 64; Patton, "Hydro-Electric Power Policies in Ontario and Quebec"; Biggar, "The Ontario Power Commission: Its Origin and Development," p. 48

legislation as well as in its plan of administration."[16] Numerous states and provinces sought to emulate HEPCO.[17]

HEPCO enjoyed its share of detractors as well. Opponents of public power, particularly from the United States, argued that the Commission's activities bordered on socialism, if not mental illness. Remembering boss politics, one critic offered, "any honest person who, knowing the political history of New York, Chicago, Boston, Philadelphia, et al., desires to see public ownership of electric utilities undertaken by them should be sent to the psychopathic ward for observation."[18] Fear of socialism also filtered into many critiques of government-owned power plants, particularly because this industry had its start as a capitalist enterprise. In Canada, local private utilities resented the competition from a growing entity with advantageous financial arrangements. Some suspected the Commission overspent on its infrastructure projects. In 1917, HEPCO initiated a plan to construct its own hydroelectric generating station, known as the Queenston plant – destined to be the largest in the world when it opened in 1921. The project cost significantly more than originally estimated and in 1921 the legislature established the Gregory Commission to investigate this as well as other questions raised by HEPCO's activities.[19]

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[16] Biggar "The Ontario Power Commission: Its Origin and Development," p. 32.

[17] HEPCO served as a model for proposed projects in California, Georgia, Pennsylvania, New York, Manitoba, New Brunswick, and Nova Scotia. Ibid., p. 52; Belfield, "The Niagara Frontier: The Evolution of Electric Power Systems in New York and Ontario, 1880-1935," p. 308, 340; William Eugene Mosher et al., *Electrical Utilities* (New York and London: Harper & brothers, 1929).

[18] "Dangerous Lure of Statistics," *Electrical World* 80, no. 4 (1922).

[19] "Ontario Electric-Power Scheme Attacked"; Samuel S. Wyer, *Niagara Falls: Its Power Possibiliites and Preservation*, Smithsonian Institutions's Study of Natural Resources (Washington, DC: Smithsonian Institution, 1925); Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941*; Kerwin, "Federal Water-Power Legislation"; Belfield, "The Niagara Frontier: The Evolution of Electric Power Systems in New York and Ontario, 1880-1935," pp. 342 – 347, 372.

The high-profile investigation vindicated HEPCO when released in 1924, while attracting public attention locally and abroad. In 1921, the National Electric Lighting Association (NELA), representing utilities in both the United States and Canada, ordered its own independent study of HEPCO, with special concern for public versus private ownership of power systems. Consulting engineer William S. Murray, who had previously completed a study of HEPCO cost estimates for the Ontario legislature, carried out the examination. He produced a report that condemned HEPCO as a model for US power development, stating "to attempt the substitution of its principles of control and operation within the States would be to strike a blow at economic structures."[20] Murray's analysis indicated that even in Ontario, private utilities bore the brunt of investment risk, while in the United States private utilities provided more power with greater reliability and at a cheaper price to consumers, although this latter point was debated.[21]

The Private Sector Proposition – "Superpower"

In fact, William S. Murray had already played a key role in the development of an alternate vision for regional interconnected power systems in the United States, termed "Superpower." Immediately following the end of the war, Murray, a pioneer in high tension rail electrification, and E.G. Buckland, President of the New York, New Haven, & Hartford Railroad Co., urged Franklin Lane, Secretary of the Department of the Interior to survey energy sources from Maine to Washington, D.C., Murray, as the lead promoter of this project, envisioned a plan much like the one proposed previously by McClelland,

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[20] Murray, *Government Owned and Controlled Compared with Privately Owned and Regulated Electric Utilities in Canada and the United States*, p. 1.

[21] Belfield, "The Niagara Frontier: The Evolution of Electric Power Systems in New York and Ontario, 1880-1935," p. 348; Murray, *Government Owned and Controlled Compared with Privately Owned and Regulated Electric Utilities in Canada and the United States*; W. S. Murray, "Hydroelectric System of Province of Ontario Investigated," *Electrical World* 79, no. 10 (1922).

encompassing development of trunk lines connecting power plants along the eastern seaboard, electrification of the rail system, and construction of new hydroelectric plants. In January 1919, Secretary Lane proposed that Congress appropriate $200,000 for a survey of electric power, primarily along the Atlantic coast, in preparation for producing a plan for future electrification. In 1921, Congress set aside $125,000 for the United States Geological Service (USGS) to survey power production and to investigate the "possible economy of fuel, labor, and materials" that could result from a comprehensive power system.[22]

The USGS and the engineering and utility societies promoted the project on two fronts. First, the expected plan would allow the United States to provide adequate power to meet growing industrial demand for electricity and to compete internationally for industrial prominence. "The enormous development of war industries had created an almost insatiable demand for power, a demand that was overreaching the available supply with such rapidity that had hostilities continued it is certain that we should now be facing an extreme power shortage."[23] Second, the "Superpower Plan" would address conservation of natural and labor resources. "Such a comprehensive system of power supply, making use as it would of unutilized or undeveloped waterpower and of fuel now wasted at the mines, will result in

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[22] United States Geological Survey Department of the Interior, *A Superpower System for the Region between Boston and Washington*, (Washington, DC: Government Printing Office, 1921), p. 8,9; "Wm. Murray Dead; Noted Engineer, 68," *New York Times*, January 10, 1941; "Secretary Lane Asks for $200,000 for Power Survey," *Electrical World* 73, no. 5 (1919). According to Mr. Murray's obituary, he conceived the idea of the survey and the subsequent "Superpower" plan while on vacation in the Rocky Mountains in 1919. In the forward to the USGS report cited above, George Otis Smith of the USGS states that Murray and Mr. Buckland first presented the idea to Secretary Lane in December 1918. Because Secretary Lane requested funding from Congress for the survey in January 1919, this time sequence appears more probable.
[23] Murray et al., "A Superpower System for the Region between Boston and Washington," p. 9.

large savings in coal."[24] Reduced reliance on coal would equate to reduced need for labor at the coalmines.[25]

Murray assured the utility and engineering communities that a federal appropriation for this project would not lead to government meddling in electrification. In a letter to the Editor of *Electrical World*, he claimed, "I gained not the slightest impression from [Secretary Lane] that the government was interested beyond the desire to determine the economies to be secured by the adoption of such a comprehensive system of power generation and transmission."[26] The Department of Interior would simply exercise its legitimate interest in conserving the nation's natural resources. In return, the utilities offered support for Superpower.

Between July 1, 1920 and June 30, 1921, Murray and his expert team of engineers carried out the survey and completed the Superpower System report. The plan called for creation of a "superutility," that could either incorporate as its own entity or function under the cooperation of multiple private utilities serving a zone reaching from Boston to Washington, D.C. Private utilities, industries, and the railroad would provide a market demanding 31 billion kilowatts of electric power by 1930. The superutility would deliver electricity across trunk lines linking giant steam-driven and hydroelectric plants. Murray explained, "the superpower system begins at the generating stations connected to its lines and ends at the busses of existing electric utilities."[27] The project would save an estimated fifty million tons of coal annually, while maximizing the existing installed capacity in the

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[24] "Secretary Lane's Proposal for Power Resource Survey," *Electrical World* 73, no. 6 (1919).
[25] "Good Meeting of A.I.E.E. In Boston," *Electrical World* 73, no. 12 (1919); "Third General and Executive Session," *Electrical World* 73, no. 21 (1919); George Otis Smith, "National Planning for Electric Power," *Electrical World* 73, no. 23 (1919); W. S. Murray, "The Superpower System as an Answer to a National Power Policy," *General Electric Review* 25, no. 2 (1922).
[26] "The Super-Power Transmission Plan," *Electrical World* 73, no. 20 (1919).
[27] Murray et al., "A Superpower System for the Region between Boston and Washington."

northeastern states. At the technical end, the proposal called for standardizing frequency at 60 cycles in order to achieve stable interconnection. To carry out the project, Congress would have to enact legislation to create a company with the right of eminent domain, owned essentially by existing power companies.

The Superpower system received wide support from the business community in the ensuing years. Numerous engineering and utility associations, including the National Electric Lighting Association (NELA), the American Institute of Electrical Engineers (AIEE), state and regional engineering societies, the US Chamber of Commerce, and many local chambers of commerce endorsed the plan. The Superpower system promised economic benefits to the private sector. In presenting the plan to the AIEE, Murray explained that regardless of the source of funds (government or private), capital costs would be reduced by the existence of a plan to insure long-term production and use of power. Samuel Insull, of Commonwealth Edison, predicted before the Bond Club of Philadelphia that the plan would save the United States from two to three-and-a-half billion dollars by 1950. Herbert Hoover had served on the Survey committee as a consulting engineer beginning in 1920 and later, as Secretary of Commerce, continued to promote the plan to the business sector through the mid-twenties. Hoover indicated that the plan could stabilize the coal industry, expand electrical service, and lower costs, but only if the state and federal governments played a minimalist role, "free from deadening influence both of bureaucracy and of socialistic experiment."[28]

[28] W. S. Murray, "Economical Supply of Electric Power," *Transactions of the American Institute of Electrical Engineers,* 39, no. 1 (1920); "Advocates Super-Power," *New York Times*, April 16, 1924; "Hoover on Power Survey," *New York Times*, October 5, 1920; Herbert Hoover, "Superpower and Interconnection," *Electrical World* 83(1924); Singer, "Power to the People, the Pennsylvania - New Jersey - Maryland Interconnection, 1925-1970," pp. 28, 47; "Super-Power Development," *Wall Street Journal*, May 20, 1922; H. W. Hoover, "Superpower and Its Public Relations," *United States War Department -- Military Engineer* 16, no. 88 (1924); Herbert Hoover, "Superpower and Interconnection," *Electrical World* 83, no. 21 (1924); T. H. E. Wall Street Journal Washington

The Progressive Alternative – "Giant Power"

Not all utility engineers, politicians, and government leaders supported the Superpower system plan. In fact, many progressives felt that the Murray proposal fell far short of addressing the growing menace of holding companies, inequities in access to power, and the proper role of government in providing utility services. Governor Gifford Pinchot of Pennsylvania, formerly Chief of the US Forest Service under President Theodore Roosevelt, and a key leader of the Progressive Era conservation movement, promoted an alternative proposal, "Giant Power," focused on his own state. Consulting engineer and former Philadelphia Director of Public Works, Morris Cooke encouraged Pinchot in this project and served as chief architect of the plan. While similar in many respects to the Superpower system, the Giant Power plan defined a power district entirely within Pennsylvania and specifically addressed rural electrification, byproduct recovery at mine mouth plants, stringent state regulation, a "common carrier" status for transmission lines, and heavy government oversight.[29]

Cooke and Pinchot first pursued a Pennsylvania plan in 1920, when Cooke broke with Murray over his unfavorable assessment of HEPCO before the AIEE. After Pinchot took the office of governor in 1922, he formed a Giant Power Survey Board, headed by Cooke. The board presented its report to the Pennsylvania legislature in 1925. The proposal included elements favorable to private utilities, including advanced technologies, large-scale plants, and a wide area transmission network. But it also called for government-directed development of the system, perceived by many to be overreaching. Pinchot and Cooke

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Bureau From, "Northeast Calls for Electric Power," *Wall Street Journal*, July 29, 1924. Quote in "Superpower and Interconnection," 1924.

[29]Singer, "Power to the People, the Pennsylvania - New Jersey - Maryland Interconnection, 1925-1970," p. 62

framed Giant Power as a program to revitalize country life and provide equity to rural parts of the state. They also promoted the plan as an opportunity to conserve energy through interconnection while limiting industry consolidation. Progressives, social reformers, political scientists, and economists received the Giant Power proposal with enthusiasm. *The Annals of the American Academy of Political and Social Science* dedicated an entire issue to Giant Power in 1925. A wide array of contributors addressed government regulation, interstate commerce, female domestic activities, work life, labor, mining, and national defense.[30]

Many engineers, utility directors, and some politicians opposed the Giant Power plan. In the technical literature, engineers and utility managers showed very little interest in the details of the system. The journal *Electrical World* published a straightforward summary of the plan when it was first released, but titled the article, "Pinchot Takes Radical Stand."[31] Shortly thereafter, Murray submitted a letter to the editor opposing the Pinchot/Cooke plan. Utility managers found the proposal "radical," technically impractical, commercially limited, and financially experimental. Investors saw Giant Power as meddling with private initiative and undermining existing rate structures. One described it as based upon "socialistic theory." Engineering clubs described the plan as "imaginative," "fanciful," and "speculative."[32] When

[30]Leonard DeGraaf, "Corporate Liberalism and Electric Power System Planning in the 1920s," *The Business History Review* 64, no. 1 (1990), pp. 17-18; Singer, "Power to the People, the Pennsylvania - New Jersey - Maryland Interconnection, 1925-1970," pp. 51-62; Tobey, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home*, pp. 50-51; T. P. Hughes, "Technology and Public Policy: The Failure of Giant Power," *Proceedings of the IEEE* 64, no. 9 (1976); Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, pp. 297-310; Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*, p. 297; Jean Christie, "Giant Power: A Progressive Proposal of the Nineteen-Twenties," *The Pennsylvania Magazine of History and Biography* 96, no. 4 (1972); Morris Llewellyn Cooke, Editor, *Annals of the American Academy of Political and Social Science* 118(1925).

[31]Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p. 302.

[32]Christie, "Giant Power: A Progressive Proposal of the Nineteen-Twenties," p. 496.

the Pennsylvania legislature held hearings to consider the Giant Power proposal, three professional engineers spoke against the project and none spoke in its favor. The engineers argued that the utility industry was already investing in "interconnection for the exchange of surplus power; economically prudent rural electrification; load factor increases; and improvements in the economics of generation."[33]

Over time, the question of control doomed both Superpower and Giant Power proposals in front of legislative bodies. The Pennsylvania legislature voted down the Giant Power proposal in 1926 and Congress never formally considered the Superpower plan. The issue of who wielded the greatest authority over electrification lay at the heart of the matter. Private utilities opposed a central government planning agency. Progressive politicians opposed excessive private sector control. Even the Superpower plan, embraced by privately owned companies, required government to "possess some control over the operation of local utilities."[34] Utilities, however, actively avoided federal or state meddling in system development and instead found opportunities to achieve interconnection on their own.[35]

The debates over Superpower and Giant Power unfolded in the context of a larger contest over economic control of electric power itself. Advocates of public power pushed for

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[33] As paraphrased in Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p. 310; Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940*; Singer, "Power to the People, the Pennsylvania - New Jersey - Maryland Interconnection, 1925-1970." Regarding technical community interest in the competing plans, a search of databases of technical literature for the terms "Superpower" and "Super Power" between the years 1918 and 1930 returned 155 and 157 results respectively. A search for the terms "Giant Power" for the same dates returned 24 results. Of those articles, only a handful addressed the actual Pinchot/Cooke proposal. The other articles included the terms "Giant" and "Power" but addressed topics unrelated to the "Giant Power" plan. Engineering Village, Compendex Database, accessed July 20, 2011, http://www.engineeringvillage2.com/controller/servlet/Controller. Similarly, in a general Google News search for the years 1918-1926, the term "Giant Power" produced 98 results, "Superpower" returned 311 results, and "Super Power" returned 697 results. It is important to note that all three searches returned some results that were unrelated to electric power. Google News, accessed on August 2, 2011, http://news.google.com/nwshp?hl=en&tab=nn.
[34] DeGraaf, "Corporate Liberalism and Electric Power System Planning in the 1920s," p. 8.
[35] Ibid., p. 11.

increased government oversight, if not outright ownership, of the electricity infrastructure. The dominance of holding companies increased as private sector ownership concentrated into fewer and fewer hands. Consumers – domestic as well as industrial – continued to demand more and more power, while some complained that rates, though lower than in the past, were inexcusably high. In fact, during the 1920s, while formal legislative proposals for a planned transmission grid languished at the state and federal levels, the private utility magnates solidified a dominant role in power growth, as well as in interconnecting systems.

Economic Structures of Control – Holding Companies

In the 1920s economic contest over interconnected power systems, the holding companies were winning. The private sector generated roughly 95 percent of all the power produced. Further, through the device of holding companies, an increasingly tight-knit group of shareholders managed an ever-larger portion of the electricity market. After World War I, the public expressed increasing concern about excessive speculation in electricity holding company financial instruments. At the same time, small private and municipal generating plants found it difficult to function economically without joining larger systems, whether through interconnections alone or as part of larger financial organizations. The success of holding companies during this decade rendered proposals for government oversight of the industry politically impractical. The rise of a putative "power trust" influenced the development of the grid both politically and economically.[36]

The Holding Company Trend – Fewer, Larger, New Types of Investors

In the early 1920s, the success of the private utilities in resisting government control of power system development was due in no small part to the reach of the power trust. Not

[36] Federal Trade Commission, *Control of Power Companies* (Washington: Government Printing Office, 1927), p. 29.

only did holding companies financially control the majority of the utility market and provide a substantial portion of electricity to consumers at fairly reasonable rates, they also captured a large share of consumer sympathy through innovative investment strategies. When segments of the power trust crumbled at the beginning of the Depression, many middle class consumers lost money, although electricity kept flowing. The door was open for the federal government to step in and exert greater regulatory and financial influence.

The economic strength of a small number of holding companies increased in proportion to the amount of electricity generated and used. As in earlier decades, the quantity of power generated and the number of customers served grew exponentially faster than the number of generating stations serving consumers. For example, between the beginning of the century and the end of the 1920s, the number of generating stations had not even doubled and actually fell between 1917 and 1927. By contrast, consumption increased steadily. In 1917, utilities sold over 21 billion kilowatt-hours to nearly 8 million customers. Ten years later, those numbers tripled. As Table 4.1 illustrates, a smaller number of generating stations served a growing market. The consolidation of ownership under holding companies, and interlocking directorates linking multiple operating companies, further exaggerated the concentration of financial power over the generation, transmission, and delivery of electricity.[37]

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[37] The census bureau reported 4,364 generating stations in 1917 and only 3,707 in 1927. Bureau of the Census, *Abstract of the Census of Manufactures 1914*; Bureau of the Census, *Census of Electrical Industries, 1932: Central Electric Light and Power Stations*, (Washington, DC: Government Printing Office, 1934); Bureau of the Census and Social Science Research Council, *Historical Statistics of the United States, 1789-1945; a Supplement to the Statistical Abstract of the United States*, pp. 155-159.

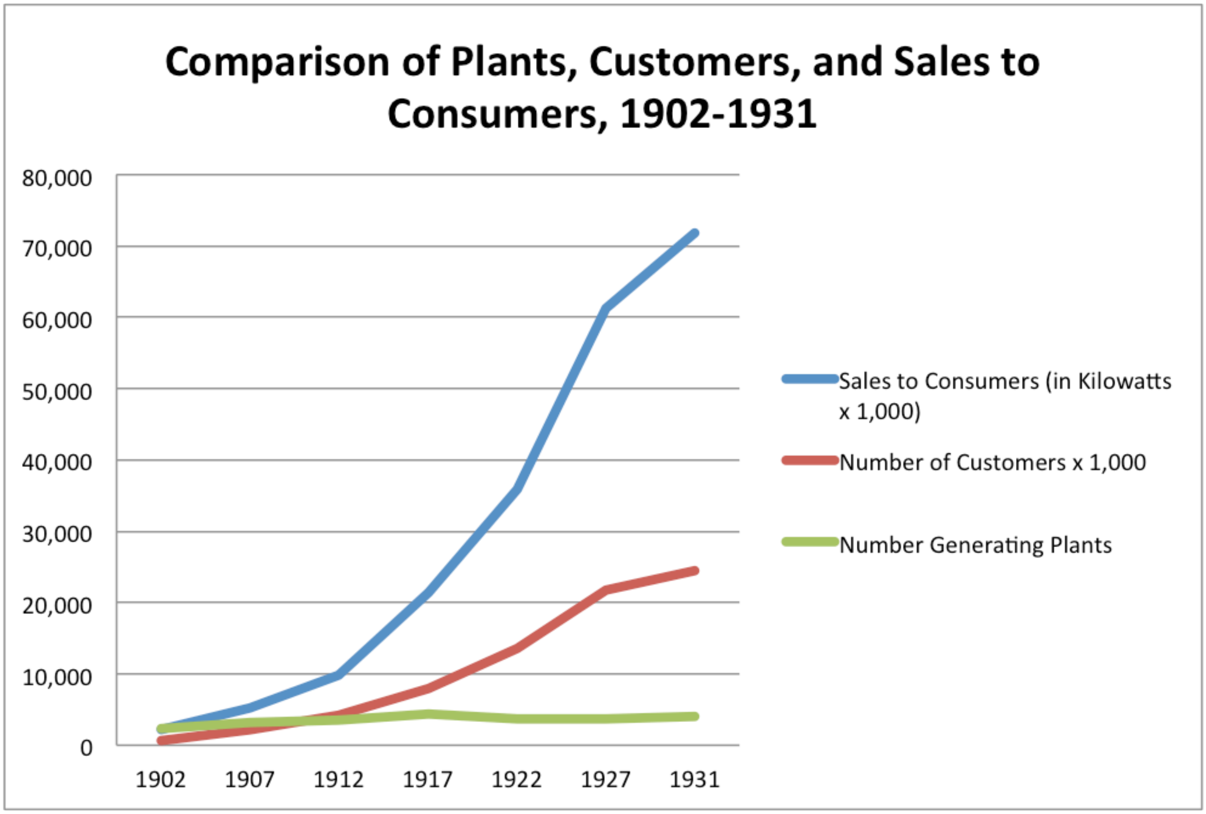

Table 4.1 Comparison of number of generating plants, number of customers and sales to customers between 1902 and 1931. ***Source:*** **Bureau of the Census,** ***Historical Statistics of the United States, 1789-1945.***

The holding company trend in the utility industry, begun in the early 1900s, reached full flower in the 1920s. By mid-decade, twenty large holding companies controlled 61 percent of the generating capacity of electric power plants and all holding companies together controlled 74 percent of the industry. By the end of the decade, the holding company slice of the pie had grown to an estimated 82 percent of the industry. Two major types of holding companies dominated the market. Investment holding companies derived all their profits from the interest, dividends, and earnings of operating companies. Management holding companies additionally contracted for construction, engineering, and other services with their subsidiaries, thus adding other types of revenue streams to their portfolios.

Pyramiding, however, was the most prominent method for concentrating ownership and economic control in fewer and fewer hands.[38]

Pyramiding schemes allowed a small number of investors, with a relatively small amount of their own financial capital at risk, to control hundreds of millions of dollars of electric utility activity. Under ideal circumstances, the apex holding company in a typical utility pyramid might invest as little as one percent of the value of an operating company to command a controlling interest and reap more than 100 percent annual returns in dividends. In a case documented by the Federal Trade Commission in its 1927 report to Congress, H.M. Byllesby & Co., "with an investment of less than $1,000,000 is able to exercise the voting control over more than $370,000,000 of operating capital."[39] The nature of these relationships meant owners of an apex holding company could reap enormous profits, but small deficiencies in profitability of operating companies could have a large impact on investors of all types, including the proverbial "widows and orphans" who placed their life savings in utility securities. [40]

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[38] Federal Trade Commission, *Control of Power Companies*, p. 168; Mosher et al., *Electrical Utilities*, p. 82, 91-92. Another way of assessing holding company control addresses power production. In 1925, the 20 largest holding companies produced, through their subsidiaries, 83 percent of the nation's electricity. Brigham, *Empowering the West: Electrical Politics before FDR*, p. 31

[39] Federal Trade Commission, *Control of Power Companies*.

[40] Brigham, *Empowering the West: Electrical Politics before FDR*, pp. 37-38; McDonald, *Insull*, pp. 194-195, 197. In the example given by McDonald, a fictional operating company is capitalized at $1,000,000, divided into $500,000 of bonds payable at 5 percent, $200,000 of non-voting preferred stock payable at 6 percent, and 300,000 shares of common stock at par value of $1 – the only instrument with voting rights. Holding Company A owns all the common stock, and is thus capitalized at $300,000. Holding Company A, like the operating company, is capitalized with bonds ($150,000), non-voting preferred stock ($60,000), and common stock ($90,000), and all the common stock is owned by Holding Company B. Holding Company B, owning 90,000 shares of common stock (30 percent of Holding Company A), and capitalized at $90,000, is likewise divided into the three types of securities and all the common stock is owned by the apex company – Holding Company C. Holding Company C owns 30 percent of Holding Company B, and is capitalized at $27,000. For the sake of argument, Holding Company C is capitalized at $14,000 in non-voting preferred stock and $13,000 in common stock. Thus, a single investment of $13,000 in Holding

The 1920s witnessed a further innovation in holding company finances through the device of customer owners. Pioneered by utility executives like Samuel Insull, holding companies sold small quantities of non-voting shares of stock directly to utility customers (such as the "widows and orphans" noted above). Capital was in short supply immediately after the First World War and this prompted the initial foray into opening new markets. Insull, for example, sent his sales force out to visit customers door-to-door and sell utility stocks, just as they had previously sold war bonds. By 1923, ninety percent of Commonwealth Edison's shareholders were Chicago residents. This offered utilities numerous advantages, including low-cost debt, retention of management control, a strong credit position, stable market value, and customer good will. By issuing stock to customers, utilities could access untapped capital for new and upgraded infrastructure to meet the rapidly growing demand for electricity. Further, utilities sold these shares directly to purchasers, bypassing investment bankers.[41]

Through pyramid schemes and customer ownership, consumers had an increasing economic interest in the financial wellbeing of private power companies, but no economic control. At least one critic of private domination of electric power described this as a ploy to undermine public ownership initiatives. "With big and little wage earners taking a

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Company C would grant the investor operating control over each of the other companies in the pyramid, including the $1,000,000 operating company. The theoretical operating company is regulated by a state utility commission and is allowed to charge rates that will bring it a 7 percent profit annually. Thus, in a given year, after the bondholders and preferred stockholders have received their income, and the operating company holds back a surplus for expenses of, say, $3,000, Holding Company A will earn $30,000 – a 10 percent dividend. In the same sample year given above, Holding Company B's common stock owners will net $19,900, and Holding Company C's common stock holders will net $15,730, a pretty nifty return on $13,000 in one year. In this example, however, if the operating company's income drops to only 5 percent, the finances will be disastrous for the holding companies due to the guaranteed commitments to bondholders and preferred stock holders.

[41] Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*, p. 231 and footnote no. 59, p. 356; Ralph E. Heilman, "Customer Ownership of Public Utilities," *The Journal of Land & Public Utility Economics* 1, no. 1 (1925); Brigham, *Empowering the West: Electrical Politics before FDR*, pp. 34-36, 139-141.

proprietary interest in the conduct of corporations, [economists] say, socialistic doctrines that invade the rights of private initiative have met a stalemate that probably could not have been effected through any pressure of political events."[42] At the same time, holding companies exerted an outsize influence on any proposals to give the public sector greater authority over the electric power industry.[43]

Countertrend – Proliferation of Municipals

Despite this concentration of control in the 1920s, small independent generating plants proliferated across the country, and the actual number of municipal plants grew. Between 1902 and 1922, the number of privately owned plants increased by about 30 percent while the number of municipal plants tripled. During the intensive consolidation of the 1920s, the number of private plants fell by a third while the number of municipal plants decreased by only five percent. In the later years of the decade, there were more municipal than private systems. Notably, municipal systems were quite small while privately owned systems grew much larger.[44]

Table 4.2 illustrates graphically the growth trends of commercial and municipal power plants, and particularly the slower decline in the number of the latter during the 1920s. In this representation, the number of each type of system is shown, but the relative size of systems is not reflected. Municipal plants were limited by the political boundaries in which they operated and tended to remain small. Integration into larger networks,

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[42] Fred Brandt, "User Ownership a Gift from West," *New York Times*, September 18, 1927.
[43] Raushenbush and Laidler, *Power Control*, p. 43; Brandt, "User Ownership a Gift from West."
[44] Bureau of the Census, *Census of Electrical Industries, 1932: Central Electric Light and Power Stations*

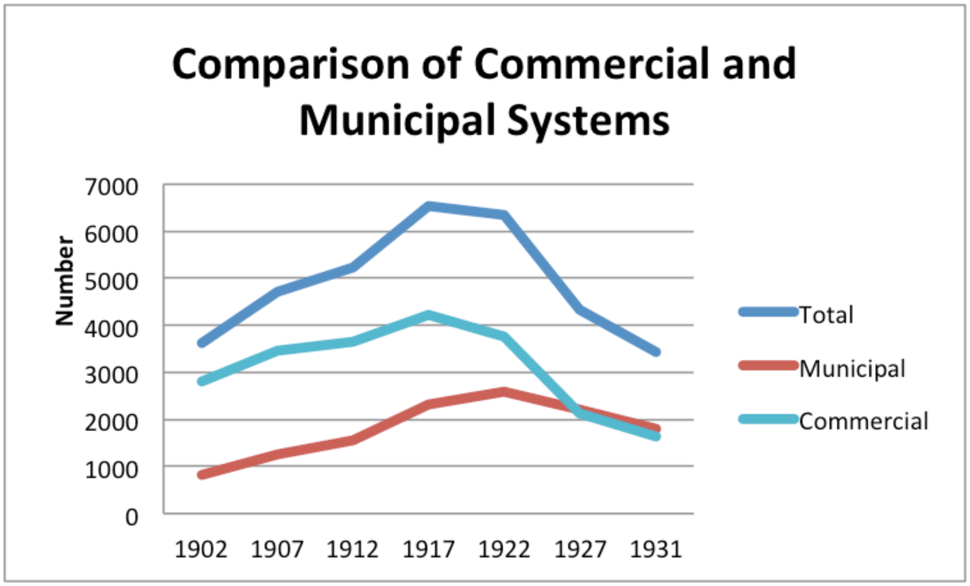

Table 4.2. Municipal and Commercial Power Companies, 1902-1931. *Source:* Bureau of the Census, *Census of Electrical Industries, 1932.*

though a strong trend in the 1920s, did not touch every entity providing electric power in North America.

Political Pushback – Federal Investigation of the "Power Trust"

In the first decades of the century, holding companies, though considered suspect by Progressives and other anti-trusters, offered benefits to operating companies and consumers alike. As previously noted, holding companies facilitated access to capital, lower debt, skilled engineering, and experienced management for operating companies, often providing less expensive and more reliable electrical service to customers. In many ways, the benefits resembled the advantages of interconnection – geographical diversity of operating companies reduced the financial risk associated with each in much the same way that load diversity improved the efficiency of each plant. But critics saw the holding companies of the 1920s as "merely speculative."[45] As one political economist noted in 1936, "Perhaps the primary reason for the organization of so many holding companies in the twenties was the desire for banking profits."[46] Critics rejected the argument that holding companies facilitated interconnection and increased efficiency of power plants. As one offered, men of industry and engineers together "have one simple aim, that the people say 'Oh!' and 'Ah!' and that theirs be the power and the glory forever."[47]

Over time, economic control concentrated in the hands of fewer and fewer holding company directors and aggressive investors. Politicians and public power advocates raised the specter of a growing "Power Trust" that would undermine equitable development and delivery of electricity to the citizenry. In 1925, Progressives in Congress persuaded the Senate to adopt a resolution directing the Federal Trade Commission (FTC) to investigate holding companies in general and General Electric Company in particular. The 1927 FTC report detailed the stockholding and interlocking directorate positions of individuals involved with the industry. The FTC had surveyed 60 holding companies, three investment companies, 1500 operating companies, and 140 electrical manufacturers. The report found "119 men exercise one-fifth and 57 men one-eighth of the total voting power of the directors in the control of an industry with nearly $7,000,000,000 of investment."[48] This concentrated

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[45]As quoted in Norman S. Buchanan, "The Origin and Development of the Public Utility Holding Company," *Journal of Political Economy* 44, no. 1 (1936), p. 48, from *Supply of Electrical Equipment and Competitive Conditions: Sen. Doc. 46* (70th Cong, 1st sess.), p. 216.
[46] Ibid., p. 50.
[47] E.O. Malott, "Technology and the Widening Market for Electric Service," *The Journal of Land & Public Utility Economics* 4, no. 2 (1928); Buchanan, "The Origin and Development of the Public Utility Holding Company"; Raushenbush and Laidler, *Power Control*, p. 20.
[48] Federal Trade Commission, *Control of Power Companies*.

financial control equated to political influence, while smaller enterprises found it increasingly difficult to remain independent.[49]

Holding Companies and Interconnections – An Uncertain Relationship

The advance of holding companies did proceed arm-in-arm with increased interconnections in many instances. For example, by 1929, 200 utilities produced power in eleven northeastern states. Many of these operated under common ownership and 45 percent were interconnected. The advantages of interconnection could be more easily realized when plants operated under the control of a single entity. Holding companies facilitated power exchanges across state lines by avoiding the oversight of state regulatory agencies and by establishing markets for high cost generating stations. Often the opportunity to achieve economies of scale and fuel conservation through interconnection served as a justification for the expansion of investor holdings.[50]

Critics, however, minimized the significance of interconnections in the spread of holding companies during the 1920s. Not all holding companies acquired contiguous utilities. For example, Stone and Webster, which produced two percent of the nation's electricity in 1926, owned unrelated operating companies in Oregon, Virginia, and Ohio, without any intention of linking these geographically distant utilities. Some argued that the engineering achievements of interconnection had virtually nothing to do with the expansion of holding

[49] "Power Inquiry Referred," *New York Times*, January 21, 1925; "Asks Direct Inquiry of General Electric," *New York Times*, February 3, 1925; "General Electric to Be Investigated," *New York Times*, February 10, 1925; "La Follette Sees Power Combination," *New York Times*, October 30, 1924; "Coolidge Attacked on Muscle Shoals," *New York Times*, December 18, 1924; "Asks "Power Trust" Inquiry," *New York Times*, December 30, 1924; "Norris to Press Inquiry," *New York Times*, December 31, 1924; "Advocates Super-Power"; "Sees Conspiracy of "Power Trust"," *New York Times*, October 31, 1923; Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941*, pp. 3-31. Funigiello provides a detailed chronology of this first FTC study of the power industry, the second study initiated in 1929, and the political maneuvering surrounding Congressional intervention in the affairs of the electric power industry.

[50] Mosher et al., *Electrical Utilities*.

companies. The authors of a 1928 book published by *New Republic* claimed, "spectacular engineering" has "done more to carry the Roosevelt anti-trust movement on [its] shoulders than the power financiers have done."[51] The FTC suggested that first economic and then technical advantages contributed to the holding company trend. "The remarkable activity during the past few years in the organization of electric power operating companies into various power groups appears to have been induced by the opportunity to exploit their earnings, as well as for the purpose of increasing their efficiency."[52]

Neither fans nor critics managed to resolve whether holding companies in the aggregate benefited consumers and investors, or merely increased the wealth of those at the top of the pyramid. Congress finally established pyramiding limits with enactment of the Securities Exchange Act in 1934 and the Public Utilities Holding Company Act in 1935 (PUHCA). The Securities Exchange Act established the Securities Exchange Commission and vested the federal government with regulatory authority over the financial transactions of numerous industries. The PUHCA specifically addressed the activities of utility holding companies, limiting the freedom with which the primary investors could establish control over the power business. Notably, the PUHCA advantaged holding companies that maintained or added interconnections between subsidiaries that were geographically contiguous. This represented one aspect of federal governance that encouraged the spread of interconnections through the mid-century. Despite the intense scrutiny of holding companies in the 1930s, and the new federal regulations limiting investor activity, by the time World War II began private companies still operated the majority of the North American power system. On the government side, municipal and rural cooperatives provided measurable

[51] Raushenbush and Laidler, *Power Control*, p. 78; Brigham, *Empowering the West: Electrical Politics before FDR*, p. 34.
[52] Federal Trade Commission, *Control of Power Companies*, p. xiii.

sources of power, and federal agencies began to build large-scale electricity infrastructure, including major transmission lines in the Pacific Northwest and the South.

Permits, Laws, and Money – The Federal Side of the Contest

Central government construction of electricity infrastructure influenced the landscape of interconnected power systems across North America. While the private sector maintained financial control over the power industry, federal dollars invested in dams, transmission lines, and delivery networks, significantly advanced interconnected systems in certain areas of the United States. Dams on the Columbia, Colorado, and Tennessee River systems, for example, greatly altered the regional economy and ensuing demand for power. Transmission lines built by federal agencies linked rural cooperatives, new industries, and urban customers across large stretches of the Upper Midwest, the Pacific Northwest, and the Tennessee Valley. The earliest federal investment in power infrastructure took place at the turn of the century, Congress and the president instituted government structures to support federal investment in the 1930s, and federal agencies initiated major construction projects, including large pieces of the future grid, by the start of World War II.

The first federal power infrastructure projects in the early twentieth century addressed demands for reclamation aid, primarily from Western states. The Reclamation Service (later the Bureau of Reclamation) began investing in hydroelectric dams after 1906, when the Congress authorized the agency to generate and sell hydroelectric power. Reclamation plants went into service in 1908 and 1909 in the Pacific Northwest. The Bureau completed its first truly large-scale project, Roosevelt Dam, in 1911 as part of a major multi-use project on the Salt River in Arizona. During these years, the Board of Engineers for Rivers and Harbors suggested that changing public views in favor of multi-use river development might cause the federal government to build power dams as part of flood control projects as well.[53]

The Great War increased federal involvement in dam building. In anticipation of a growing need for aluminum, Congress in 1916 authorized the War Department to build a hydroelectric dam at Muscle Shoals, Alabama for expanding nitrate plants. Completed after the war, and at the center of a long controversy over federal operation of power plants, the dam at Muscle Shoals (Wilson Dam) later became the starting project of the Tennessee Valley Authority. During the war years, seven western states commenced negotiations for access to water and power from the Colorado River. After the war, and with Congressional authorization, the states signed the Colorado River Compact in 1922, establishing a basis for distributing both water and power. The first major federal power project resulting from the compact, Boulder Dam (now Hoover Dam), likewise anchored both political controversy and engineering achievement.[54]

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[53] "Bureau of Reclamation Power Plants," Bureau of Reclamation, US Department of the Interior, last modified February 2, 2007, http://www.usbr.gov/projects/powerplants.jsp?SortBy=4; Billington and Jackson, *Big Dams of the New Deal Era: A Confluence of Engineering and Politics*, pp. 26-46, 89-107; "Brief History: Bureau of Reclamation," in *Bureau of Reclamation Website*, ed. Bureau of Reclamation (Washington, DC: Bureau of Reclamation, US Department of the Interior, 2011). During Congressional Hearings following World War I, the Board of Engineers for Rivers and Harbors assured Congressmen that public opinion was shifting in favor of government support of private sector river development. US Congress Select Committee on Expenditures in the War Department, *War Expenditure: Hearings before Subcommittee No. 5 (Ordnance)*, Sixty Sixth Congress, Second Session on War Expenditures, 1920.

[54] For more detailed discussions of the Muscle Shoals Project and the origins of the Tennessee Valley Authority, see Hargrove, *Prisoners of Myth: The Leadership of the Tennessee Valley Authority, 1933-1990*; McCraw, *TVA and the Power Fight, 1933-1939*; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, pp. 292-297; Brigham, *Empowering the West: Electrical Politics before FDR*, pp. 50-72; Billington and Jackson, *Big Dams of the New Deal Era: A Confluence of Engineering and Politics*. Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming formed the League of the Southwest in 1917 and later signed the Colorado River Compact in 1922. Arizona, however, did not ratify the compact until 1944, and water allotments were in dispute for decades.

The Congress made a further commitment to federal involvement in electrification with the River and Harbor Act of 1925. The Act authorized the Army Corps of Engineers to survey of the country's major rivers. In part, the corps attempted to ascertain whether power development on the rivers could accompany navigation and flood control projects, thus making the latter financially feasible. The federal government would pay for navigation improvements while the private sector would pay for hydroelectric facilities. On very large rivers, like the Columbia in the Pacific Northwest, the corps identified ample power, with the challenge of carrying electricity to distant markets.[55]

With Big Dams, The Search for Big Markets

Big federal dams, like private power projects, relied on big power markets. The importance of large, long-distance transmission lines and interconnections grew with the changing federal power role. As the FPC noted in 1929: "Water-power sites without a market are of no practical value, and although within the past decade great strides have been made in the art of transmitting power for long distances at low cost the limit of economic transmission is now about 300 miles under normal conditions."[56] For example, the City of Los Angeles, the first and largest customer for power from Boulder Dam, would have to transmit the electricity nearly 300 miles and link it into the large, mostly private network already serving Southern California.[57]

Interconnection also assured increased reliability for federal power projects in the event of an emergency. In the southeastern United States, an operating committee met eight

[55] Billington and Jackson, *Big Dams of the New Deal Era: A Confluence of Engineering and Politics*, p. 9; Norwood, *Columbia River Power for the People: A History of Policies of the Bonneville Power Administration*; Kimbark, *Power System Stability*, 2.
[56] Federal Power Commission, *Ninth Annual Report of the Federal Power Commission*, 71, 2, (Washington, DC: Government Printing office, 1929).
[57] Brigham, *Empowering the West: Electrical Politics before FDR*, pp. 50-72.

times yearly to maintain parallel operations of multiple companies across the region, including the federal plant at Muscle Shoals. These operations "facilitated the prompt handling of the exchange of power in emergencies."[58] In fact, a 600-mile line between Muscle Shoals and Raleigh, North Carolina operated interconnected for several weeks in 1925. And, "On December 3, 1927, systems from Chicago to Mobile and Pensacola were interconnected and thus over a thousand miles of transmission line and literally millions of kW of generating capacity operated in parallel for some fifteen minutes."[59] By 1930, federal dams did not dominate the landscape, but they contributed to the growing consensus in favor of interconnected systems.

Federal Regulation, From None to Some

The federal government in the United States also made inroads into planning for private development of hydroelectric power and shaping interstate power exchanges. Control of waterpower sites had been central to Progressive Era conservation initiatives within the federal government. After two decades of debate, the Congress finally passed the Federal Water Power Act in 1920, exerting explicit control over the location of hydroelectric dams on federal lands and navigable rivers. The Federal Power Commission (FPC), as established by the Act, exercised oversight over waterpower site development, issued 50-year licenses to private power developers, and collected annual license fees. The Secretaries of War, Interior, and Agriculture comprised the Commission. The FPC, working through these federal agencies, gathered water resource data and determined whether proposed waterpower projects represented the most advantageous use for the region. Notably, within its first three

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[58] W. E. Mitchell, "Progress and Problems from Interconnection in Southeastern States," *Transactions of the American Institute of Electrical Engineers* 47, no. 2 (1928).
[59] Ibid.

years of operation, the Commission issued licenses and permits to double the developed hydroelectric power in the United States. The Act also laid out provisions for regulation of rates for power generated at licensed plants and used in interstate commerce, marking the first time the federal government assumed an oversight role in this nearly fifty-year-old industry.[60]

By 1930, the limited regulatory authority of the FPC, and the limited purview of its membership, led to a push to amend the Federal Water Power Act. Among other issues, the ability of utilities to sidestep state and federal regulation when selling power across state lines created numerous problems for consumers and government alike. In one prominent 1927 case, *Public Utilities Commission of Rhode Island v. Attleboro Steam and Electric Company,* the Narragansett Electric Light Company, located in Rhode Island, sought to increase rates for power sold to the Attleboro Steam and Electric Company, located in Massachusetts. The Rhode Island Public Utility Commission granted the rate increase, finding that the old rate was harmful to both the Rhode Island utility and its in-state customers. The Attleboro Steam and Electric Company appealed this increase to the Rhode Island Supreme Court, which found that the higher rate would become a burden on interstate commerce. The US Supreme Court concurred, finding that "The rate is therefore not subject to regulation by either of the two States in the guise of protection to their respective local interests; but, if such regulation is required it can only be attained by the exercise of the power vested in Congress."[61] While this established interstate rate regulation as entirely a

[60] Federal Water Power Act of 1920 (41 Stat. 1063); Kerwin, "Federal Water-Power Legislation"; Walter H. Voskuil, "Water-Power Situation in the United States," *The Journal of Land & Public Utility Economics* 1, no. 1 (1925).
[61] F. G. Crawford, "Control of Interstate Transmission of Electricity," *The Journal of Land & Public Utility Economics* 5, no. 3 (1929).

federal matter, no statute allowed the FPC, nor any other federal agency, to address the situation.[62]

Debate over how to regulate interstate trades of power, as well as how to bring holding companies under control, and whether to expand overall federal involvement in electrification, began anew in the 1930s. The financial crash of 1929 undermined the solvency of numerous utility holding companies, and in fact many public figures blamed the Depression on the excesses of the Power Trust. Franklin Roosevelt identified Samuel Insull and the utilities as a particular target of his wrath in public diatribes against the private power industry both before and during his presidency. "The Insull failure has done more to open the eyes of the American public to the truth than anything that has happened. It shows us that the development of these financial monstrosities was such as to compel inevitable and ultimate ruin."[63] At the same time numerous power companies completed and expanded interconnections, linking more and more of the country together in shared electrical networks. In 1930, Congress amended the Federal Water and Power Act to expand the FPC from three administration executives to five independent members. But this change barely touched the uncontrolled growth of power companies and the inequities in both cost of and access to electricity across the country.[64]

The New Power Deal

As the Great Depression gripped regional and national economies, and private utility holding companies collapsed, citizens looked to the federal government to restore stability.

[62] Ibid. Public Utilities Commission of Rhode Island v. Attleboro Steam and Electric Company, 273 US 83 (1927).
[63] Franklin D. Roosevelt, "The 'Portland Speech: A Campaign Address on Public Utilities and Development of Hydro-Electric Power, Portland Oregon, September 21, 1932," The New Deal Network, accessed November 7, 2007, http://newdeal.feri.org/speech/1932a.htm.
[64] Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930*, p. 272.

Campaigning for President in Portland, Oregon in 1932, Franklin D. Roosevelt invoked electrification as a means of addressing the welfare of the people. Through federal regulation of interstate utility holding companies and federal development of power sites on major rivers, the public sector could institute equitable distribution of electricity and fair rates. Federal river power systems in each of the four quarters of the country could be "forever a national yardstick to prevent extortion against the public and to encourage the wider use of that servant of the people – electric power." Roosevelt stopped far short of proposing a fully public electric system, stating that "as a broad general rule the development of utilities should remain, with certain exceptions, a function for private initiative and private capital."[65]

The Roosevelt administration attempted to organize the federal role in electrification and introduce policy planning. New Deal priorities for electric power included creation of multipurpose watershed management authorities, expansion of FPC oversight, legislation to rein in holding companies, rural electrification, and preparation for national defense. Although no comprehensive national power policy emerged by the end of the 1930s, the federal government made significant advances in capital investments and regulatory expansion. Both the new power infrastructure built with federal dollars and the new authority exerted over utility holding companies and interstate power trades influenced the expanding grid. Yet control of the network remained elusive for the federal government.[66]

Beginning with the creation of the Tennessee Valley Authority (TVA) in 1933 and continuing until the start of United States participation in World War II, federal administrators and elected officials negotiated for increased influence over US power systems. Government expenditures resulted in major additions to growing regional power

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[65] Franklin D. Roosevelt, "The "Portland Speech," lines 66, 79.
[66] Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941*.

networks. Roosevelt sent his TVA message to Congress within one month of his 1933 inauguration and the bill to create the agency was introduced the next day. By mid-May, despite significant utility opposition, Roosevelt had signed the authorizing legislation and, with Congress, had officially initiated central government participation in power generation and transmission on a large scale. Congress chartered the TVA to build dams, generate and transmit power (including completion of the Muscle Shoals project), install flood control and navigation improvements, institute regional economic planning, and provide jobs in the Tennessee River Valley. During Roosevelt's first one hundred days in office, Congress also created the Public Works Administration (PWA), which spent $50,000,000 in loans and grants for power projects within two years. During 1933, Roosevelt authorized construction of Grand Coulee and Bonneville Dams on the Columbia River, representing both significant federal investment in hydroelectric power, and the addition of tens of thousands of kilowatts of electricity to the Pacific Northwest. By 1939, federal investment in electric power facilities totaled over $1,000,000,000. Even if private utilities controlled the majority of the industry, the federal government was busily shaping the landscape of electrification across the country.[67]

Power production increased during the 1930s, despite the country's financial woes, and government spending directly influenced both generation and demand for electricity. In addition to funding for large-scale dam projects, numerous federal agencies invested in the construction of new transmission and distribution facilities across the country. The Rural

[67] McCraw, *TVA and the Power Fight, 1933-1939*, p. 85; Edward Eyre Hunt, *The Power Industry and the Public Interest, a Summary of a Survey of the Relations between the Government and the Electric Power Industry* (New York: Twentieth Century Fund, 1944), p. 190. Wendell Wilkie led the utility opposition and especially opposed federal ownership of transmission lines. He argued that the electric business "was the child of a single parent – private enterprise." McCraw, p. 52. Willkie opposed Roosevelt on many elements of the New Deal power program, and ultimately ran against him, unsuccessfully, in the 1940 Presidential election.

Electrification Administration (REA), established in 1935, provided a revolving loan fund to rural power cooperatives to build distribution lines for this largely underserved portion of the country. Congress authorized the REA to spend $50 million in its first year of activity and $40 million in each of the ten succeeding years. PWA funds also enhanced non-federal electricity infrastructure. The authorizing legislation included "transmission of electrical energy into districts not hitherto served" within the list of projects eligible for funding. In some instances, the PWA funded projects that later became part of the grid. Between 1933 and 1935, PWA financed 31 power and light projects in 20 states, the majority of which served cities with populations under 25,000. In 1937, Congress created the Bonneville Power Administration to specifically transmit power from federally funded dams in the Columbia River Valley to consumers, with priority given to publicly owned utilities. As a result of these actions, the federal government established regional systems that demonstrated the elasticity of consumer rates, contested the dominance of integrated private utility systems, and provided a competitive advantage to public utilities in certain markets.[68]

On the consumer side, federal agencies further contributed to expanded electrification in the 1930s. New Deal era programs targeting rural and low-income Americans also contributed to the demand for larger generating facilities, longer transmission lines, and more widespread distribution networks.[69] Programs that encouraged residential consumers to switch to electricity increased the customer base for utilities. With a larger customer base,

[68] Arthur D. Gayer, *Public Works in Prosperity and Depression* (New York: National Bureau of Economic Research, 1935), p. 106. Hyman, et al, p. 99, 146; Hirsh, *Power Loss*, p. 53; Melosi, pp. 130, 132-133; Rudolph and Ridley, pp. 62-68, 71-72; Brigham, pp. 50-72; Hughes, p. 401. Congress also considered, and rejected, proposals to create seven river valley authorities similar to the TVA. Tobey, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home*.
[69] Tobey, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home*.

utilities expanded the network of power lines, including long-distance transmission lines and interconnections. The National Housing Acts of the mid-decade provided home rehabilitation loans and appliance purchase loans intended to modernize and electrify dwellings. The Federal Housing Administration establishing wiring standards for buildings qualifying for mortgage insurance, further pushing for electrification. The Reconstruction Finance Corporation provided a loan to the municipal power company of Los Angeles for construction of its major transmission line from Boulder Dam to southern California. Numerous other agencies pushed consumers to electrify and modernize, through a variety of loan and credit programs. The federal role, while undefined as a comprehensive policy, in fact influenced power growth across the board, and this in turn made interconnection more attractive.[70]

The Roosevelt administration also pursued a planning role in power development. In 1934, Roosevelt created the National Power Policy Committee in an attempt to unify the many federal agencies involved in electrification and establish an actual power policy. By 1935, however, 15 different agencies were involved in electrification across the United States. In that same year, the FPC undertook to divide the United States into power regions and to effect "voluntarily or by compulsion … the interconnection and coordination of power facilities within such districts."[71] Like the effort to promulgate a national power policy, this initiative likewise failed. "The concept of a national power grid had fallen before the decision to build a series of regional and local grids.[72]

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[70] Ibid., pp. 113-115; Brigham, *Empowering the West: Electrical Politics before FDR*, p. 141.
[71] Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941*, p. 261.
[72] McCraw, *TVA and the Power Fight, 1933-1939*, pp. 81-81; Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941*.

The Public Utilities Holding Company Act of 1935 (PUHCA) stands as one of the most contentious and sweeping power initiatives of the Roosevelt administration. The Act restructured the way in which utility holding companies conducted their business until passage of the Public Utility Regulatory Policies Act of 1979. Proponents of the PUHCA sought to correct the harms – both real and perceived – caused by unregulated holding company expansion in the prior two and a half decades. Opponents sought to preserve a status quo that both facilitated operating efficiencies and enriched utility investors. As finally enacted, the PUHCA required utilities involved in interstate power or securities transactions to register with the SEC. In addition, holding companies could not purchase or sell securities without SEC approval. Further, the Act called for the simplification of holding companies – if the subordinate operating utilities of a holding company were interconnected, or capable of being interconnected, the organization could continue, but if not, the holding company structure had to be eliminated. This, of course, favored the retention and expansion of interconnections. Holding companies could prepare their own reorganization plans, but required SEC approval to stay in business. In the ensuing years, the holding companies appeared before the Securities Exchange Commission to argue that they met the criteria for continued operation. Many retained their status because they operated entirely within one state, or could demonstrate that their interstate entities were contiguous, while others broke up into smaller entities across the country.[73]

With the 1935 amendments to the Federal Water Power Act, Congress also expanded the regulatory powers of the FPC. The amendments gave the FPC the authority to regulate interstate sales of power and to require interconnections between utilities when demanded by

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[73] Energy Information Administration, *Public Utility Holding Company Act of 1935: 1935-1992*, reprint (Washington, DC: Government Printing Office, 1993).

the public interest. The PUHCA provided an incentive for utility holding companies to strengthen interconnections. The newly empowered FPC could go even further to compel interconnections. Together, these pieces of legislation established a strong federal bias in favor of building an electricity network across the country.[74]

The private utilities instituted a "mass of litigation" against New Deal legislation.[75] Power companies filed 92 suits opposing PWA allotments, but in 1938, the US Supreme Court affirmed the federal role in financing of public power facilities. Utilities also filed 58 suits against the SEC regarding Public Utilities Holding Company Act, and 34 additional suits against the TVA. Despite this full-out assault on the federal government's efforts to shape electrification of the United States, the New Deal legislation survived. President Franklin Roosevelt and the Congress together dramatically altered the role of the federal government in electrification during the 1930s. In the process, federal laws, regulations, and investments promoted expansion of interconnections across the continent.

War and Power

In the years leading up to the start of World War II, Roosevelt and his senior administrators revisited the idea of a centrally managed power grid. As political crises rose in Europe, Americans began to review the country's preparations for defense. The energy shortages of World War I had not been forgotten. Early in 1938, the National Association of Railroad and Utility Commissioners issued a warning that power-generating capacity should be increased well in advance of engagement in another World War. By this time, President

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[74] Philip Funigiello offers a detailed discussion of Roosevelt's efforts to establish a national power policy and the passage of the Public Utilities Holding Company Act. Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941*. In his biography of Benjamin Cohen, one of the authors of the PUHCA, William Lasser offers further discussion of the political maneuvers that led to passage of the Act. William Lasser, *Benjamin V. Cohen: Architect of the New Deal* (New Haven: Yale University Press, 2002). Federal Power Act of 1935 (49 Stat. 803)

[75] McCraw, *TVA and the Power Fight, 1933-1939*, p. 109.

Roosevelt had asked the FPC and the War Department to survey the country's generation and transmission capacity. The resulting report indicated that wartime power needs in the 1940s could be anticipated to be four times greater than peacetime power needs. The FPC proposed beefing up interconnections to achieve greater capacity, while the War Department proposed scrapping widespread networks and instead expanding regional generating facilities in order to have a surplus for armaments production. Notably, disagreement about the future configuration of the country's power system, and the value of a national transmission network, persisted in the late 1930s.[76]

In September of 1938, Roosevelt appointed the National Defense Power Committee (NDPC) to plan a more formal preparation for war. Comprised of Secretary of the Interior Harold Ickes, Frederic Delano of the National Resources Committee, Chairs of both the FPC and the SEC, and senior representatives of the War Department, the NDPC wrangled over who should build a stronger transmission system with greater generating capacity, how it should be funded, and who should operate it. Some hoped the pending crisis would further the cause of public power. Others hoped for better regulation of private companies to bring them into line with national defense priorities. Traditional Progressive politicians feared that proposals to build public-private power pools would merely strengthen private utilities and undo New Deal programs to limit the reach of holding companies. Within the Roosevelt administration, Secretary Ickes worked to consolidate power system activities under his own authority. Meanwhile, private utility executives argued that sufficient electricity already existed to satisfy war production needs. In the midst of both public and clandestine

[76] The following section draws heavily on the following works: Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941*; McCraw, *TVA and the Power Fight, 1933-1939*.

communications regarding a national grid, the Public Works Administration announced allocation of $200,000 to research the feasibility of constructing a national power network.

Questions of control plagued government efforts to understand potential power needs in the event of war and organize a reasonable approach. In early 1939, the FPC sidestepped the NDPC and quietly proposed to key administration officials a Defense Power Corporation wholly owned and operated by the federal government. The NDPC undertook its own survey of wartime electricity requirements. Shortly Secretary Ickes persuaded President Roosevelt to combine the newly designated NDPC with the now dormant National Power Policy Committee in an effort to consolidate his own authority over public power.

Ickes's new National Power Policy and Defense Committee (NPPDC) caused further dissent within the administration. Several key administrators sought cooperation from the private utilities for the development of more interconnections. Ickes, however, distrusted the private utilities and embraced the notion that the FPC already had authority to compel interconnections in the event of a declaration of war. Leaders from the private sector, meanwhile expressed concern that a national grid was neither economically feasible, nor could its construction be completed in a timely manner. By 1940, administration infighting had doomed the NPPDC to a lame duck role. In the vacuum, the president asked the FPC to coordinate more closely with the War Department. Nonetheless, the US electric power system was poorly prepared for war at the start of 1942 and the question of control was unresolved.

During World War II, the federal government increased participation in power planning, energy research, and regional interconnections. Access to abundant electricity was essential to the war industries, and the federal government insured availability through regional authorities like the TVA and the Bonneville Power Administration (BPA). For example, in 1942, the BPA created the Northwest Power Pool to interconnect public and private utilities throughout the region. In 1943, the Army ordered BPA to reserve a sizeable block of the power generated at Bonneville Dam for use by the secret Hanford facility, in support of development of the nuclear bomb. Federal investment in atomic energy research was later promoted as a means of advancing new and cheap forms of energy for domestic use. Finally, the FPC, exercising its authority under the revised Federal Power Act, directed the interconnection of numerous utilities to ensure that war industries had access to sufficient electric power supplies.[77]

Summary

Between World War I and World War II, the landscape of long-distance interconnected power lines changed dramatically in North America. In 1918 a few scattered networks appeared on the east and west coasts; by 1945, concentrated and widespread backbones of interconnection were visible across large portions of the continent. Utilities interconnected in these years for the same reasons they interlinked in prior years. They sought access to diverse energy resources and larger diversified markets. They collaborated to achieve more economic operations and to reduce the amount of coal used per kilowatt-hour of electricity generated. They participated in river development projects that maximized the use of falling water and linked large dams to markets. They shared power during planned and emergency outages. Further, the trend toward economic consolidation in the private sector industry, especially through holding companies, favored the trend toward physical linking of systems.

[77] Norwood, G., p. 126, 221; Gray, p. 545; Wirtz, p. 1717.

The question of how the private utilities accomplished interconnection in the absence of any central authority or consensus plan is of primary importance during this period. Several proposals to institute plans and oversight for the industry were considered and abandoned during the interwar years. On the surface, this suggests that the already fragmented industry might abandon the project of interconnection and simply focus on regional expansion. Instead, the private and public sectors alike continued to build toward large-scale, if not coast-to-coast, interconnection. Through bitterly contested negotiations over Superpower and Giant Power plans, over holding companies, and over the creation of new federal agencies, the private sector retained economic control over the power market. Industry leaders promoted the advantages of interconnections and utility owners cobbled together power pools.

The political battle for control of power systems failed to produce strong government oversight of the power industry, but it did result in both regulatory structures and government investments that favored interconnections. Although governments enjoyed unprecedented command over industrial activity during World War I, private industry reasserted its independence after the war ended. Proposals to establish national and state planning for power networks foundered, but politicians and government agencies continued to push for greater sunshine authority over private power companies. This resulted in two rounds of FTC investigation of holding companies, in the 1920s and the 1930s, and new federal laws regarding interstate power trades in 1935. The regulatory structures adopted in North America provided an ideal environment for private utilities to build interconnections. Before the 1930s, interstate power trades fell into a gray area of regulation that left private companies free to move electricity when and where they pleased without government oversight. International treaties likewise encouraged cross-boundary power trades. After 1935, both the Public Utility Holding Company Act and the amended Federal Water Power Act favored interconnections among private power companies. Thus, while governments exerted greater regulatory control over the power industry, the private electric companies found themselves in the happy position of continuing to pursue interconnections as they pleased. In addition, as new federal projects came online, they presented new opportunities for building power pools, albeit in situations sometimes contested by the private utilities.

Independent power companies managed to build interconnections on their own schedule and without government oversight, and system operators had to find ways to make these complex networks function. Two plants sharing electricity, even under separate ownership, scheduled and managed power flow with relative ease. But engineers confronted much greater complexity when multiple plants exchanged power more and more frequently across larger networks. Not only did they have to manage more power, but also they had to contend with the nature of electricity itself and how it moves. Electricity literally follows the path of least resistance. Changes on one generator affect the operations of the entire the network practically instantly. Physical control of the electricity moving across shared power lines opened another arena for negotiation.

Chapter 5. Technologies of Control: The Tools for Operating a Grid, 1920-1945

A blackout today is considered an anomaly, and a major blackout is considered a disaster. For many years, when power producers first interlinked alternating current systems, maintaining stability was no easy feat. On the earliest networks, two or three companies exchanged electricity on a scheduled basis. If there was an emergency outage, the affected firm obtained electricity from another operator only until the original equipment was up and running again. Systems maintained parallel frequencies, but did not operate "interconnected" all the time. Closing the ties between systems (in other words, allowing electricity to flow between them) required communication between the respective operators and manual switching of controls. Once connected, operators maintained close contact to prevent the frequency and load variations on one system from upsetting the stability of the other(s). Before the 1920s, utilities operated in parallel only for the length of time necessary to accommodate the scheduled or emergency power exchange. True interconnection was impractical.[1]

Interconnection, however, became increasingly attractive to power producers, especially after World War I. Over the prior twenty years, operators had realized significant advantages by linking systems with diverse load patterns and energy resources. Utilities succeeded in lowering electricity rates through interconnections in part through shifting between energy sources according to availability, thus maximizing the use of falling water

[1] Usage of the term "load" has changed over the course of the history of electrification. In the past, "load" referred to the amount of demand to be supplied. Now, "load" is used to indicate the power delivered to meet demand. Throughout this dissertation, the term shall be used to mean the amount of demand to be supplied. The exception to this usage shall be in the term "load dispatcher." In this case, the term indicates that the individual managing power generators is determining which generator (or station) shall be used to meet how much demand. The load dispatcher is determining which generator will send out electricity to meet the demand (load).

and moderating the use of coal; relying on neighbors for backup power; and reaching wider markets. More and more companies entered electricity-sharing arrangements. Regional networks grew larger and more complex. Key to the economic and conservation benefits of these networks was the careful shifting of load from one system to another. By the early 1920s, the information exchange and manual adjustments required to keep electricity moving economically, and without system failures, challenged operators. Apparatus for managing frequency and load was as important to power networks as the physical power lines and interties. By the end of World War II, with automated frequency and load control, private and public systems provided a steady supply of electricity across large areas of the continent.

The interwar years witnessed negotiations over political and economic control of interlinking power systems. While specific plans to integrate and expand power systems languished, individual utilities and several government agencies pursued their own schemes for building networks. As a consequence, no one entity claimed responsibility for the physical control of electricity moving across the network. Different power producers in different regions effected a variety of arrangements for sharing power. Thus interconnections took place in the absence of uniform standards and uniform approaches to operations. System operators spent years resolving the challenges created by this situation, particularly as the networks grew larger and more complex.

Looking back, it is easy to identify many signs that suggested building interconnected power networks was the inevitable path for increased electrification after the First World War. Politicians and engineers alike promoted plans for grids. The trend in both government and the private sector favored development of large integrated networks. In other countries, legislatures took over control of the power industry, in particular focusing on building national transmission systems. Other energy systems, as well as communication and transportation systems, operated through national and international networks. By the time historians explored the process of electrification, North American power did travel across hundreds of thousands of miles of high-voltage power lines. But, in assuming that utilities would eventually complete coast-to-coast interconnections, historians have paid little attention to the difficult and complicated task of managing alternating current electricity on these networks. In fact, the grid was much more an idea than a reality for several decades. Even as late as 1940, the utilities that operated interconnections shared power only on short-term schedules or during emergencies. Keeping multiple networks in synchrony full-time was simply too problematic.[2]

As engineers devised new technologies and strategies for managing flowing electricity, they also sought methods for respecting the autonomy of each operating entity. Initially, many groups of interconnected companies designated one power station as the autocratic controller for the entire system. Load distribution was the key to achieving energy efficiency and resource conservation. The dispatcher at the controlling station determined which generating station provided what amount of electricity to meet the ever-changing load. This worked for several years, until the constant changes in system operating characteristics overwhelmed the station load dispatcher in charge.

Power companies turned increasingly to automatic measurement and control devices to aid the individuals managing interconnected systems. The process of inventing frequency and load control devices offers a good example of how the industry addressed the challenge of developing new technologies in an environment of rapid and varied growth. The

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[2] The seminal work in the history of electrification in North America, Thomas Hughes' *Networks of Power,* was published in 1983, sixteen years after the linking of the eastern and western grids.

foundation technologies included automatic frequency control apparatus, automatic long-distance data meters (telemeters) and data aggregators (totalizers), network analyzers (analog computers), and automatic load control devices. An electric clock, patented in 1918, provided the starting point for frequency control on the grid. An analog computer, first applied by an electric utility in 1937, performed the increasingly complex and lengthy calculations needed to determine load flow. Between the advent of these two innovations, utilities asked engineers and manufacturers for help with the array of problems unique to the grid system.[3]

Each new federal dam or link between pairs of large regional systems resulted in a gathering of engineers to scratch their heads, scribble out equations, and devise an even more sophisticated system of control. Bit by bit, utilities experimented with devices to collect and analyze data and automate procedures. In addition, engineers began to distribute these devices to multiple generating stations. Every new device brought with it both benefits and challenges. Instrument manufacturers and utility operators experimented directly on the power systems, to test solutions in real time. By the beginning of World War II, engineers had introduced a variety of automated apparatus that allowed operators to quickly amass information about the system and maintain stable and economical power flow. As the war drew to a close, engineers began to introduce a new idea for grid operations – fully distributed system control. This replicated more closely the economic and regulatory structure of the industry.

Efficiency, Economy, Conservation: Three Objectives of Interconnections

Utilities continued to pursue economic stability during the interwar years, and increasingly turned to interconnection as a means of achieving both operating efficiency and

[3] Casazza, *The Development of Electric Power Transmission: The Role Played by Technology, Institutions, and People*, p. 79.

resource management. Utilities engaged in interconnections sought careful distribution of loads between participating systems. This was the key to taking advantage of diverse energy resources, and producing electricity with the greatest energy efficiency. As engineers developed techniques and instruments for managing load distribution, they kept in mind the industry's economy, efficiency, and conservation objectives.

For the engineering profession, the terms "conservation," "efficiency," and "economy" were sometimes synonymous and sometimes distinct. In keeping with Progressive Era usage, "conservation" usually meant the careful management of natural resources, and in some cases the preservation of wilderness areas or the reduction of pollution associated with industrial activity. The utility experts used "conservation" in this sense at the beginning of the interwar years, but later often used it to mean energy efficiency as well. The term "efficiency" typically meant operating equipment in the most efficient manner possible – that is at the least cost for the highest level of production. Often it also referred to energy efficiency in particular, that is producing the greatest amount of electricity at the lowest per unit rate of coal or gas usage. "Economy" typically referred to operating at the lowest per unit cost possible, although it frequently also referred to energy efficiency.

The importance of conservation, efficiency, and economy to professionals in the power industry fluctuated over the years. Tracking the use of the terms in the professional literature, while a very crude form of analysis, is suggestive of how closely linked all three ideas were, until the Second World War. "Conservation" first entered the professional literature at about the same time that President Roosevelt called for a Conservation Congress in 1908. Another bump up in the use of "conservation" occurred in the late 1910s, at the same time that the nation experienced energy crises and shortages in raw materials needed for war production. The use of the term fell slightly after the war until the late 1920s. Another sharp rise in the occurrence of "conservation" took place in 1928, followed by a steady fall through the 1930s. The patterns of use for "economy" and "efficiency" were slightly different. But, in general, the three terms followed general trends of use together, until World War II. Table 5.1 illustrates how the usage of the three terms in the professional literature changed between 1910 and 1950.

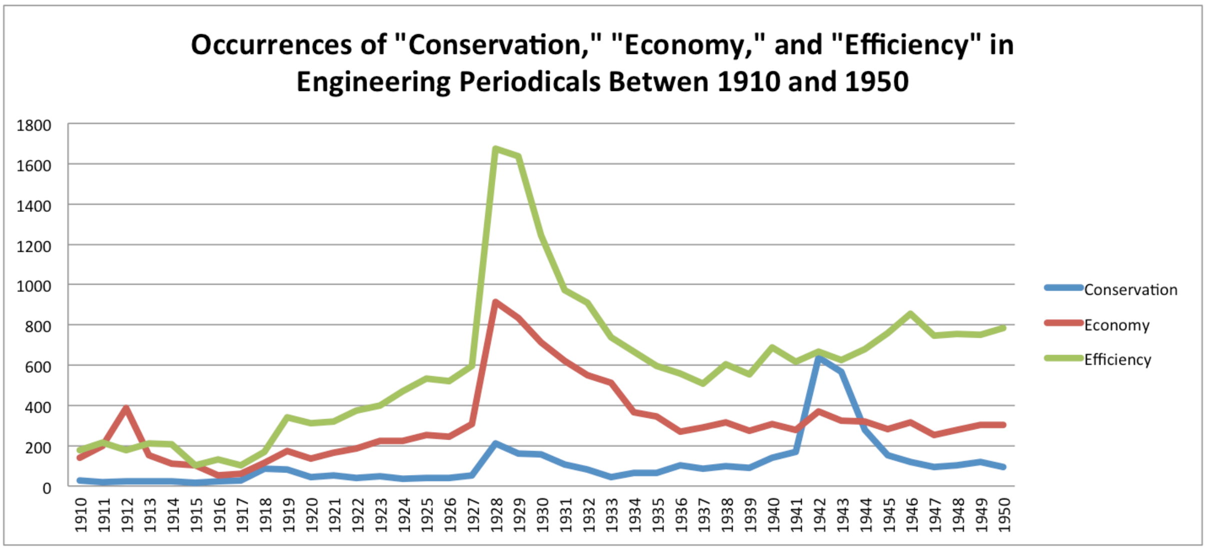

Table 5.1. Changed use of terms "Conservation," "Efficiency" and "Economy" in engineering literature for the years 1910-1950. ***Source: Engineering Village, Compendex Database.***

There is a notable and distinct increase in the use of the "conservation" term during the early 1940s, decoupled from the other two terms. This is the only time that the use of "conservation" exceeds the use of "economy" and nearly matches the use of "efficiency" in the technical literature. The war diminished interest in wilderness preservation and anti-pollution aspects of Progressive Era conservationism, focusing instead on industrial resource conservation. The visible spike in Table 5.1 may also reflect a conflation of terms on the part of the engineers. The industry focus, during these years, was primarily on increasing overall electricity production and transmission in order to meet war production needs, with minimal regard for cost. Interconnection provided the key means by which utilities “conserved” energy and delivered the maximum amount of electricity to critical industries. The pressure to improve load distribution on interconnected systems, in conjunction with the war effort, further accelerated the widespread use of automated control instruments at the same time.

Between 1920 and 1950, the art of automated control took shape within the power industry. Both frequency control and load control affected the ability of utilities to achieve optimal operating economies, conserve energy, and, by extension, manage natural resources. These instruments became part of the collection of apparatus and techniques that enabled the grid to be a technology of conservation. Hardly an art at the outset, system control began when engineers tinkered with a clock.

A Clock, Selling Time, and Frequency Control

Electricity is useful only when it is available at the very instant it is needed. Power stations must meet demand on a moment by-moment basis to keep customers happy. System frequency (the speed at which generators produce electricity) offers a good indication of whether or not operators are matching the needs of consumers. Stable frequency indicates that generation is meeting load. Accelerating frequency means that generation is too high. Decelerating frequency means that generation is too low. Interconnecting alternating current systems could not share power unless they operated at identical and synchronized frequency. Thus, control engineers began with the challenge of controlling frequency on ever larger and more complex systems. The first step involved an electric clock.

A Reliable Electric Clock: The First Step to Automated Control

Long before interconnected power systems captured the public interest, tinkerers, clock-makers, and engineers explored the possibility of creating a reliable electric clock. As one claimed in 1937, “for a hundred years, more or less, inventors yearning for mental exercise have concerned themselves with the problem of using electricity to drive clocks.”[4] Experiments in battery-powered timepieces provided the market with a variety of electric clocks through much of the nineteenth century. Alexander Bain patented the first electric clock in England in 1840, although he failed to put this expensive timepiece into wide production. In 1862, engineer Matthias Hipp installed a networked system in Geneva, with a master clock controlling 15 secondary clocks connected by low voltage wires. Western Union later used similar systems in numerous cities as it made accurate time both accessible and a necessity. Independently controlled battery-operated timepieces were fragile, expensive, and no more accurate, in general, than hand wound clocks and watches. Systems of master regulators connected to secondary clocks, like the one used by Western Union, required the installation of dedicated wires. By the early 1900s inventors still sought a reasonably priced, sturdy, and reliable clock that would surpass traditional clocks and watches in accuracy, longevity, and low maintenance.[5]

Henry E. Warren, an MIT engineering graduate, joined the fray as a hobbyist shortly after 1900, and ultimately patented the Warren Telechron Master Clock. The Warren Master Clock became a foundation technology for the future automated control of electric power systems. Warren’s first efforts to build a better machine resulted in several patents for battery-powered clocks, beginning in 1906. He established a clock manufacturing business in 1912. By about 1915, “the inadequacy of the battery clocks which [he] had been able to

[4] Henry E. Warren, “Modern Electric Clocks,” ClockHistory.com wesbite, accessed January 24, 2011, http://clockhistory.com/telechron/company/documents/warren_1937/.
[5] *Electric Clocks*, (London, England: N. A. G. Press, 1931); “Obituary: Dr. M. Hipp,” *The Electrical Engineer* 15, no. 268 (1893); Warren, “Modern Electric Clocks”.

design and build impressed [him] so forcibly" that he looked instead to linking a clock to "an existing communication system for the distribution of time."[6]

Modern electric power systems using alternating current presented themselves as an attractive option. Power generators involved in large-scale transmission and distribution of electricity had begun to converge on a 60 cycles per second system speed – coincidentally ideal for synchronizing a clock. Warren quickly developed and, in 1916, patented a self-starting synchronous motor that would spin at the same speed as the generator powering it. This synchronous motor provided the movement for a clock face. Sadly, the accuracy of the clock was limited by the ability of a central station to maintain constant frequency, and by 1916, central station service had not yet achieved this level of control.[7]

Frequency on Shared Power Lines: a Perennial Problem

For utilities, maintaining steady frequency increased consumer satisfaction, attracted industrial customers, and minimized wasted power generation. Station operators controlled frequency fairly well by the early 1900s, but as loads changed minute-by-minute in the course of a day, the systems experienced minor frequency variations. Customers complained, whether they were frustrated by lights dimming or by interruptions in industrial processes.

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[6] Warren, "Modern Electric Clocks". In 1917, General Electric acquired a major interest in The Warren Clock Company. The name changed to Warren Telechron in 1926, and eventually GE absorbed the company entirely.

[7] Harry S. Holcombe and Robert Webb, "The Warren Telechron Master Clock Type A," *NAWCC Bulletin* 27, no. 1 (1985); Nathan Cohn, "The Way We Were," *IEEE Computer Applications in Power Magazine* 1, no. 1 (1988). Engineers debated the merits of various frequencies for many years, and settled upon different solutions in different countries and for different uses. No governing body or industry group has ever formally adopted 60 Hz as a standard for North America, although the vast majority of installations operate at this frequency. B. G. Lamme, "The Technical Story of the Frequencies," *Transactions of the American Institute of Electrical Engineers* 37, no. 1 (1918); P. M. Lincoln, "Choice of Frequency for Very Long Lines," *Transactions of the American Institute of Electrical Engineers* 22 (1903); Samuel Sheldon, "Discussion on "Frequency" (Rushmore), Schenectady, N. Y., May 17, 1912," *Transactions of the American Institute of Electrical Engineers* 31, no. 1 (1912). P. Mixon, "Technical Origins of 60 Hz as the Standard Ac Frequency in North America," *Power Engineering Review, IEEE* 19, no. 3 (1999).

For example, textile mills, when connected to a central station for power, depended upon a steady frequency to keep machines operating at a constant speed. This was the only way to minimize the fabrication of flawed goods and maximize productivity. Within the central station itself, and between interconnected stations, maintaining stable frequency increased operating economy and reduced energy waste. "Assigning frequency control to a specific generator meant that that unit would follow the utility's load changes while other operating units would remain at essentially constant output. This was a means of loading units sequentially for improved economy."[8]

From the earliest use of alternating current for electrification, utility managers and engineers had worked to stabilize central station service, but early measurement and regulating instruments fell short of delivering absolute frequency control. Operators relied upon meters that measured frequency at an instant. The operator had to collect measurements over time to document a change, and then manually adjust generator governors – devices that controlled the speed at which a single generator turned – to respond to frequency changes. Temperature variations, as well as wear and tear over time, led to calibration errors on ordinary frequency meters. This often caused operators to over- or under- correct the frequency, making the variance worse. Thus, in 1916, two problems converged. A successful electric clock driven by a central station required almost perfect frequency control to

[8] H. E. Warren, "Synchronous Electric Time Service," *Electrical Engineering* 51, no. 4 (1932); J. U. Benziger and Jr J. T. Johnson, "Automatic Frequency Control at Mitchell Dam," *Electrical World* 93, no. 26 (1929); "Correct Time, A New Central-Station Service," *Electrical World* 87, no. 8 (1926). Charles Steinmetz, in 1918, noted that improved synchrony between stations could result in "a saving of many millions of tons of coal." Steinmetz, "America's Energy Supply," p. 161. Quote in Nathan Cohn, "Historical Perspectives" (paper presented at the The Professional Workshop on Power Systems Control, San Luis Obispo, CA, April 28-29 1977), p. 4.

maintain accurate time, and, ironically, central stations required electric clocks to regulate frequency.[9]

Marrying A Clock to a Power Station and Selling Time

Henry Warren faced a conundrum: How could electric clocks relying on frequency generated by a central station provide accurate time if the central station itself could not maintain a steady 60 cycles per second? Warren's solution required two clocks, "one regulated by a pendulum and the other driven by one of [his] self-starting synchronous motors."[10] Warren connected an electric clock to a central station system and a pendulum-driven master clock to the electric clock. The station operator set the highly accurate pendulum clock to standard time as provided by the Naval Observatory. A special gold hand, on the pendulum clock, moved with the hands on the electric clock. The station operator could see, at an instant, if the gold hand moved faster or more slowly than the black hands on the pendulum clock, and this would signal a change in frequency. The operator could then make a frequency adjustment, bring the system back to 60 Hz, and bring the electric clock back to standard time. Warren patented the Telechron clock in 1918. "The master clock may be considered as a device to maintain a true base line for the frequency."[11]

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[9] Henry E. Warren, "Utilizing the Time Characteristics of Alternating Current," *American Institute of Electrical Engineers -- Proceedings* 38, no. 5 (1919). "Governors" provided speed control on electric power generators from the very earliest days of electrification. Governors "detect acceleration or deceleration of system frequency and act to … arrest this change in speed" thereby assuring that the generator will match demand. When inventors and engineers began to address frequency control on larger systems, virtually every generator on the system had its own speed governor. The challenge, for a system with multiple generators, was that any governor might respond to a load change and cause generators to speed up or slow down randomly. Nathan Cohn, "Power Flow Control - Basic Concepts for Interconnected Systems," *Electric Light and Power* (1950), p. 4.
[10] Warren, "Utilizing the Time Characteristics of Alternating Current," p. 769.
[11] Ibid., p. 770. In the ensuing years, the efficacy of Warren's design received global affirmation. Booker, "A New Design for an Electrically Driven Clock," *Model Engineer and Electrician* 44, no. 1039 (1921); P. Schubert, "Electrically Operated Timekeepers," *Engineering Progress* 3, no. 8 (1922); Alex Steuart, "An Electric Clock with Detached Pendulum and Continuous Motion," *Royal*

Warren's innovation offered utilities new economic opportunities. With an accurate electric clock, power companies could sell both electricity and time, and selling time reinforced the need to keep the frequency stable. Previously, in order to reset their watches and clocks, consumers checked chronometers in a jeweler's window or a Western Union clock for standard time. Until the service was discontinued during the war, they could also call telephone operators to request the correct time. Power companies began to sell Warren electric clocks that would show accurate and uniform time without winding or recalibration. By 1919, the Boston Edison system had been selling time for over two years. In May 1925, Philadelphia Electric Company placed "a line of clocks with perfectly synchronized sweeps in show windows. Crowds stood and watched and for two weeks this display brought an average of 200 persons into the electric shop daily to ask about them."[12] After ten years on the market, 5,000 communities in 37 states from California to Maine relied on Telechron clocks for accurate time. Radio stations advertised "Telechron time, brought to you by XXX utility."[13] Electric clocks comprised sixty percent of all clocks sold in the US.[14]

Utilities that acquired the Warren system and sold electric clocks found the technology to be financially advantageous. The Warren system provided central stations with a small but continuous and even load, especially during off-peak periods when time comprised as much as 85 percent of the demand, and resulted in appreciable revenue. Electric clocks also improved public relations for power companies. "It is to be hoped that eventually

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Society of Edinburgh -- Proceedings 43, no. Part 2 (1923); H. Voigt, "Electrical Clocks," *Engineering Progress* 4, no. 8 (1923); "Clocks and Timing Devices," *Electrical West* 60, no. 6 (1928).

[12] "Correct Time, A New Central-Station Service," p. 400.

[13] E. Whitehorne, "Correct Time for Public Relations," *Electrical World* 92, no. 4 (1928), p. 171.

[14] M. Thomas, "Automatic Frequency Regulations," *Electrical World* 92, no. 23 (1928); Warren, "Utilizing the Time Characteristics of Alternating Current," p. 779; Whitehorne, "Correct Time for Public Relations"; "Synchronous Electric Clocks," *Electrical Engineer and Merchandiser* 9, no. 2 (1932).

every community that enjoys the use of modern electric service will have this added comfort to be thankful for – a new bond of friendship between the public and the power industry."[15]

Using Time to Maintain Frequency on Interconnections

Warren predicted in 1919 that the greatest benefit of his Telechron clock for power producers would be its efficacy in allowing utilities to operate in parallel without disturbance. "Generally, where many systems are feeding into a large network, the individual variations in the frequency meters are such that it is necessary to make adjustments … before an individual station can come into synchronism with the network; but where master clocks are installed it is only necessary to wait until the machines have the right phase relation."[16] Without master clocks, errors in frequency indicators handicapped operators trying to bring systems into synchrony. In fact, utilities found that the Warren Telechron installations could address three objectives: 1) maintaining very tight frequency control in order to sell accurate time; 2) simultaneously controlling several generators within a station in order to achieve automatic and economic loading of each; and 3) regulating frequency among interconnected systems in order to control tie line loading. The "tie line" serves as the connection between interlinked generating stations.[17]

In the early 1920s "the load dispatchers attempted to keep the tie lines somewhere near on schedule by a process of alternate begging and threatening over the telephones" with

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[15] "Correct Time, A New Central-Station Service"; Warren, "Modern Electric Clocks", p. 8. Quote in Whitehorne, "Correct Time for Public Relations."
[16] Warren, "Utilizing the Time Characteristics of Alternating Current."
[17] G. E. Moore, "Synchronous Motor Clocks," *Engineer* 148, no. 3859 (1929). Tie lines are the connectors between two power systems on an interconnection. Loading the tie lines means "closing" the connection, that is, allowing electricity to flow between them. "Opening" the tie lines means ending the flow of electricity between the two systems. Nathan Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," *Automatica* 20, no. 2 (1984).

their counterparts at interconnected stations.[18] Utilities scheduled transfers of power, referred to as "loading," over the tie lines. Operators also transferred power over the tie lines during emergencies. For the power transfer, the system operators had to assure that the systems were operating in parallel. By the end of the decade, those that used the Warren system found that frequency measurement "now ranks as the most accurate of all industrial electrical measurements," and that they could maintain "more accurate speed time than could be hoped for by hand regulation."[19] Warren clocks, and those made by competitors, found widespread use in the power market by the early 1930s.[20]

While numerous technical issues affected the successful parallel operation of multiple plants owned by more than one company, the Warren clock solved the initial frequency control problem. An operator at a central plant with a Telechron master clock provided

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[18]Literally, individual load dispatchers communicated by telephone to open and close tie lines. Robert Brandt, "Historical Approach to Speed and Tie-Line Control," *Power Apparatus and Systems, Part III. Transactions of the American Institute of Electrical Engineers* 72, no. 2 (1953).

[19] "Frequency Control," *Electrical Review* 105, no. 2713 (1929); "Speed-Time -- A Method of Time Control," *Electrical West* 62, no. 6 (1929).

[20] "Speed-Time -- A Method of Time Control"; S. Jimbo, "Measurement of Frequency," *Institute of Radio Engineers -- Proceedings* 17, no. 11 (1929); R. Meyerowitz, "Automatic Time Recording Clocks," *AEG Progress (English Edition)* 5, no. 3 (1929); A. Rabinowitsch, "Master Frequency Clock," *AEG Progress (English Edition)* 5, no. 2-3 (1929); A. O. Gibbon, "Electrical Control of Time Services in British Post Office," *Institution of Post Office Electrical Engineers – Papers* (London: Institution of Post Office Electrical Engineers, 1930); C. F. Merriam, "Report of Hydraulic Power Committee (Eng. Sec.) Presented at 23rd Annual Mtg. Of Pa. Elec. Assn. (Eastern Geographic Div. N.E.L.A.)" (paper presented at the 23rd Annual Meeting of Pacific Electrical Association, 1930); A. Rabinowitsch, "Clocks and Apparatus with Synchronous Motor," *AEG Progress (English Edition)* 6, no. 12 (1930); J. C. Runyon, "Electric Clock Systems and Specifications," *Electrical Specifications* 1, no. 3 (1930); *Electric Clocks*; S. F. Philpott, "Electric Clocks," *Electrical Review* 109, no. 2813 (1931); A. B. Lewis, "Clock-Controlled Constant-Frequency Generator," *United States Bureau of Standards -- Journal of Research* 8, no. 1 (1932); A. L. Loomis and W. A. Marrison, "Modern Developments in Precision Clocks," *American Institute of Electrical Engineers -- Transactions* 51, no. 2 (1932); Warren, "Synchronous Electric Time Service"; P. Nimier, "Control of Frequency Le Controle De La Frequence," *Electricite* 18, no. 2 (1934); "Electric Clock Motors," *American Machinist* 76, no. 14 (1932); "Electric Clocks," *Electrical Engineer and Merchandiser* 9, no. 2 (1932); "Automatic Hydro Operation Shows Definite Increase," *Electrical World* 97, no. 4 (1931); "Hydraulic Turbine Governors and Frequency Control", (paper presented at the National Electric Light Association -- Meeting, Jun 8-12 1931, New York, NY, United States, 1931); "Synchronous Electric Clocks."

oversight and correction to all the other plants on the system. As systems grew, however, "this proved to be an arduous task, particularly considering the many other activities for which the operators were responsible."[21] Engineers concurred that to gain the benefits of interconnection, adequate control over the operation of an interconnected group was an absolute necessity. By the early 1920s, utilities operating interconnected, and selling time, sought to automate frequency control.[22]

Precision: Moving Beyond a Clock

The Warren clock provided a good method for managing frequency on interconnected systems, but not all utilities sold time, and not all measurements and control could be satisfactorily accomplished solely with the clock. In fact, utilities sought more and more precise measurement of their operations as the systems became increasingly complex. As Farley Osgood, a prominent electrical engineer noted, "We are just on the threshold of major interconnection work in America and the only way to learn about it is by absolutely infallible records."[23] The new technology of electric clocks held promise, but did not sufficiently address the economic objectives of utilities. To continue linking power plants, utilities had to find new ways to closely measure and control their operations.

In the early 1920s, utilities turned to Leeds & Northrup Company (L&N), a small company with a very short prior history in the electric power industry. Philadelphia-based L&N offered high precision instruments manufactured in the United States, and, by the post-war years, had garnered the confidence of local utilities. With Philadelphia Electric

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[21] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," p. 148.
[22] C. L. Edgar, "Discussion," *Transactions of the American Institute of Electrical Engineers* 47, no. 2 (1928).
[23] Farley Osgood was an MIT trained engineer and utility executive who worked in both the telephone and electric power industries. By 1928, he worked as a private consultant. Ibid., p. 414.

Company's first request for an automated frequency meter in 1923, L&N became a pioneer in the field of automated frequency control, and later the market leader. By 1948, ninety percent of the interconnected infrastructure in North America used L&N load frequency equipment.[24]

Leeds & Northrup Company: A Newcomer to the Power Industry

Morris Leeds organized Morris E. Leeds & Company, later Leeds & Northrup, in 1899, hoping to bring affordable precision instrument manufacturing to the United States. Through the nineteenth century, laboratories, classrooms, and industry looked to German manufacturers for highly accurate and reliable measuring instruments. Leeds, a Quaker from Philadelphia, obtained his graduate degree in physics at the University of Berlin and worked for German instrument makers for several years before returning to the United States. Leeds & Northrup established itself as a top quality company from the start, winning the Grand Prize at the 1904 Louisiana Purchase Exposition for a uniquely accurate potentiometer. Scientific test labs quickly made wide use of the L&N Type K potentiometer. Leeds followed in 1909 with the development of an instrument that could both measure and record very small electric forces, the L&N Recorder, with the additional abilities to activate a controlling mechanism, to transmit data for telemetering, and to make arithmetic computations. Later, the Recorder became a component of automatic control systems. During these early years, L&N targeted the market of research and academic laboratories.[25]

[24] "Look at Load through the Dispatcher's Eyes," *Modern Precision* 8, no. 1 (1948).

[25] Leeds & Northrup Company, "Research and Development Center, North Wales, Pennsylvania," ed. Leeds & Northrup Company (Philadelphia, PA: Leeds & Northrup Company, 1960); Thomas G. Smith, "John Kennedy, Stewart Udall, and New Frontier Conservation," *The Pacific Historical Review* 64, no. 3 (1995); William P. Vogel, Jr., *Precision, People and Progress: A Business Philosophy at Work* (Philadelphia, PA: Leeds & Northrup Company, 1949). A potentiometer is an instrument to measure or control low voltages. It was primarily used at this time to measure voltage.

In 1911, Leeds took a step unusual for a small company, yet significant for the power industry, and created an "Experimental Committee" of the board. Through the work of this group, L&N hoped to improve regular apparatus, develop special apparatus on order, test materials, and conduct "experiments required in connection with other work."[26] One year later, Leeds established the Research Department. The Experimental Committee followed industry trends, watched for competition, identified problems with existing apparatus, and defined new opportunities based on reports from the Selling Department. The Experimental Committee, through the work of the Research Department, also developed test data for use by the Selling Department to promote new equipment. In 1916, when L&N decided to expand its market beyond schools and laboratories, the Experimental Committee and Research Department took on even greater importance to the company.[27]

By 1919, L&N still had a very slim presence in the electric power industry. While the Executive Committee debated plans for reorganizing to address the financial constraints posed by the War, one man was "assigned to the development of the Power Plant business and also … general scouting in such lines as Ceramics."[28] The total budget for sales to electric plants was just $800. The Executive Committee saw real potential, however, in the power industry, noting that there were opportunities to provide meters to measure power loss

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Telemetering means the automatic transmission of data, for example by wire or radio, from a remote source to a receiving station.

[26] Experimental Committee, Reports and Minutes, December, 1911, Acc. 1110, Reel 1, Leeds & Northrup Company, Hagley Library, Wilmington, DE. Hereinafter, manuscripts from this collection will be identified as L&N, Hagley.

[27] Vogel, Jr., *Precision, People and Progress: A Business Philosophy at Work*; Experimental Committee, Reports and Minutes, June 17, 1912, Acc. 1110, Reel 1, L&N, Hagley; C. E. Kenneth Mees, "The Organization of Industrial Scientific Research," *Science* 43, no. 1118 (1916); Experimental Committee, Reports and Minutes, Development Department Annual Report, May 31, 1916, July 5, 1916, Acc. 1110, Reel 1, L&N, Hagley.

[28] Executive Committee Minutes, Leeds & Northrup Company, December 5, 1918, Acc. 1110, Reel 1, L&N, Hagley.

on cable insulation, standardization apparatus for alternating current systems, and apparatus for testing insulation. By mid-year the board had established a new committee to oversee the development of power plant equipment. Leeds also embraced a vision of automated control that would "perform better than the best human operator taking account of all the factors needed to run a system."[29] The company had patented its first automatic control device in 1917. In 1920, Leeds reorganized the board to increase the focus on the utility market. By 1923, Leeds recorders found wide application in power systems, measuring generator and transformer temperatures.[30]

The Wunsch Frequency Recorder: Another Step Closer

Through its sales force of 15 or 16 people, L&N actively solicited ideas and concerns from its customers and learned of both shortcomings in products and opportunities for growth. By this time a Development Committee, of which Leeds himself was a member, had subsumed the Experimental Committee. In 1923 the committee learned, for example, that utilities needed better regulation of the charts connected to L&N recording devices. A memo from I.M. Stein to the Committee stated: "The Central Station companies use large numbers of recorders driven by clocks and are accustomed to having a fairly high degree of accuracy in the timing. Many of the records obtained in a power plant would have little meaning alone but have considerable value when considered in combination with other records."[31] Several of the largest power companies in North America – including the Ontario Hydro-electric Power Commission (HEPCO), Philadelphia Electric Company, New York Edison, and

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[29] Speech: "Our Company - Leeds & Northrup" A Unit of General Signal (Company History and Growth), March 6, 1989, L&N, Hagley.

[30] Executive Committee Minutes, Leeds & Northrup Company, August 19, 1919, Acc. 1110, Reel 2, L&N, Hagley; "Speech: "Our Company - Leeds & Northrup" A Unit of General Signal (Company History and Growth)"; Experimental Committee, Reports and Minutes, May 31, 1920, Acc. 1110, Reel 1, L&N, Hagley; Cohn, "The Way We Were," p.6.

[31] Development Committee, January 30, 1923, Acc. 1110, Reel 1, L&N, Hagley.

Boston Edison - shared in this critique. For example, Stein offered, Boston Edison engineers stated "definitely that they will not purchase the [L&N] recorder unless we furnish a better timing device."[32] These engineers were otherwise impressed with the L&N product and urged the company to consider linking the chart of the recorder to a Warren synchronous motor for greater accuracy. The sales force asked the Development Committee to consider this problem with some urgency.[33]

A direct request from the Philadelphia Electric Company pushed L&N to invent and patent a high precision recorder specifically to measure and chart frequency on power systems. According to L&N company historians, in 1923 Nevin Funk, chief engineer of Philadelphia Electric Company, told his L&N sales representative that he wanted an instrument that would tell him how much his system varied from 60 Hz. Funk predicted that L&N could sell at least a dozen a year if they worked well. By this time, Philadelphia Electric Company was one of the largest independent, investor-owned utilities in North America. If Funk's company introduced a successful frequency control innovation, other utilities were likely to follow suit. Within the year, the Development committee reviewed ideas for a recorder that would address Funk's request.[34]

L&N's impedance-bridge frequency recorder (the Wunsch recorder) joined the Warren Clock as a second major building block for automated frequency control. Felix Wunsch, an inventor in L&N's Engineering Department presented his first frequency

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[32] Ibid.
[33] Development Committee, June 10, 1924, Acc. 1110, Reel 3, L&N, Hagley; "Development Committee."
[34] Vogel, *Precision, People and Progress: A Business Philosophy at Work*, pp. 99-100."Speech: "Our Company - Leeds & Northrup" A Unit of General Signal (Company History and Growth)," p. 6; The 1927 Federal Trade Commission report on the Control of Power Companies listed Philadelphia Electric Company as one of five local companies, not under the control of a holding company, that together generated thirteen percent of the electricity in the United States. Federal Trade Commission, *Control of Power Companies*, p. xxxviii; "Development Committee."

recorder design to the Development Committee in June 1924 and the company submitted a patent application by March 1925. Wunsch adapted the original Leeds recorder to address frequency measurement. In the patent application, he explained, "My invention relates to a system for measuring or recording the frequency of a fluctuating or

Figure 5.1. View of the Control Room at the Philadelphia Electric Company in 1925, with installation of the first Leeds & Northrup Company frequency controller. *Source:* Private collection of Leeds & Northrup Documents, courtesy of N.E.R.C.

alternating current or the speed of a moving system."[35] In retrospect, prominent engineer Philip Sporn credited this frequency recorder with being the "critical piece" in stabilizing frequency and load control.[36] The Development Committee initially asked for the

[35] Felix Wunsch, "System of Frequency and Speed Measurement and Control," US Patent 1751538, United States, filed March 27, 1925, and issued March 25, 1930. The Wunsch Frequency Recorder was finally patented in 1930.

[36] Philip Sporn, *Vistas in Electric Power*, 1st ed. (Oxford: Pergamon Press, 1968), p. 325. Reprint of "Progress in Power" speech given to the Edison Electric Institute, Los Angeles, CA, June 16, 1955. Philip Sporn was an electrical engineer who began his career with American Gas and Electric Company (AGE), later American Electric Power (AEP), in 1920, eventually overseeing one of the

manufacture of six units for the sales force to show their customers. By 1926, before there was even a patent in place, L&N had sold "at least fifty 60-cycle frequency recorders and three 25-cycle frequency recorders."[37] Figure 5.1 offers a view of the Philadelphia Electric control room, with the L&N frequency control apparatus installed. A company brochure published in 1927 touted the benefits of the Wunsch recorder and noted its potential for aiding in interconnections. In 1928, with 214 recorders sold, the Development Committee learned of their product's shortcomings.[38]

Accuracy: The Key to Breaking Into the Market

At a 1928 meeting, the Committee considered a memo from a young engineer, Leslie Heath, who described L&N's rival recorders – a device produced by Westinghouse and the Warren clock system. Heath reported that participants in the New England System Operator's Network felt the L&N recorder was still not sufficiently accurate. He declared that there was a "ready market for a more accurate recorder."[39] Further, as engineers well understood, accurate frequency control was essential to successful interconnection. Yet, when two systems with L&N recorders were connected together, "if there is a discrepancy between the two controllers, there would almost certainly be a tendency for the two instruments to "fight" [*sic*]."[40]

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largest power networks in the country. He retired as President in 1961 and served on the Board of Directors until 1969.

37 Development Committee, October 19, 1926, Acc. 1110, Reel 7, L&N, Hagley.

38 "Development Committee"; Acc. 1110, Reel 4; Development Committee, October 7, 1924, Acc. 1110, Reel 4, L&N, Hagley; Wunsch. System of Frequency and Speed Measurement and Control; Cohn, "The Way We Were," p. 6; Leeds & Northrup Company, "Frequency Measurement and Control," in *Leeds & Northrup Company*, ed. Leeds & Northrup Company (Philadelphia, PA: Leeds & Northrup Company, 1927); Development Committee Misc. Report 180, 2-6-28, February 6, 1928, Acc. 1110, Reel 7, L&N, Hagley.

39 "Development Committee Misc. Report 180, 2-6-28."

40 Ibid.

Heath proposed "to cross our recorder with the Warren type instrument."[41] He explained that the Warren master clock showed instant deviation from 60Hz, while the L&N instrument showed change over time. "It is believed that some sort of a device similar to this could be applied to our system, provided, of course, that no patent difficulties are involved."[42] Heath outlined the two issues: (1) the Wunsch recorder fell short of market demand for accuracy, and (2) interconnected systems using multiple frequency controllers experienced a new problem, namely "fighting" controllers that caused inadvertent shifting of loads from one generator to another.

Operating Interconnected: From Manual to Automatic Frequency Control

As more and more utilities operated interconnected, managers worked to perfect the techniques of sharing power, both on a schedule and in emergencies. Estimating loads, determining which station would handle how much load and when, bringing stations online, disconnecting areas experiencing difficulties, and maintaining stability comprised the basic and crucial elements of running a network. Some interconnected systems operated under the purview of a single holding company, while others included multiple autonomous utilities. This further complicated the efficacy of operating strategies. Within this set of challenges, maintaining uniform frequency control became first an overriding goal of system operators, and then the cause of a problem – the inadvertent exchange of power.

Traditional Operations: One Man In Charge

Originally, interlinked power systems relied on a designated central station, under the watchful eye of a primary load dispatcher, to maintain a stable and functional network. Prior to the introduction of automated systems, this central load dispatcher exercised authoritarian

[41] Ibid.
[42] Ibid.

control over all segments of the network. He scheduled the stations much as he would generators within his own station, using the most economical station the most and the least economical the least. For example, in 1919 at the Philadelphia Electric Company, the load dispatcher "computes the demand to be met; schedules it on his generating stations; ascertains that each station will have sufficient steam and electrical capacity to carry the load; and that there will be reserve equipment on the system to compensate for the loss of the largest unit running."[43] He had "full control of the load from its generation (beginning in the boiler room) to the customers' premises."[44] To accomplish this, the dispatchers at Philadelphia and elsewhere often had a dedicated telephone exchange linking them to all connected stations and substations. In California, home to the largest interconnected systems, all operations were "under the supervision of the Load Dispatcher, who has absolute authority of the amount of load each plant or connected company shall deliver."[45] The dispatcher's responsibility was to insure the maximum of both safety and efficiency in operations.[46]

In a few instances, load dispatchers simply coordinated their operations without oversight from a central location, relying on collegial goodwill for success. In the case of a large New England system, successful operation required "only the complete cooperation of load dispatchers in control of system operation."[47] In this instance, Boston Edison exchanged

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[43] George P. Roux, "Load Dispatching System of the Philadelphia Electric Company," *Electric Journal* 16, no. 11 (1919), p. 473.
[44] Ibid.
[45] J. P. Jollyman, "Operation of Interconnected Systems," *Electrical World* (1918).
[46] Nevin E Funk, "The Economic Value of Major System Interconnections," *Journal of the Franklin Institute* 212, no. 2 (1931); Roux, "Load Dispatching System of the Philadelphia Electric Company"; A. Person, "The Function of the Load Dispatcher," *Electric Journal* 16, no. 11 (1919).
[47] L.L. Elden, "Notes on Operation of Large Interconnected Systems" (paper presented at the Proceedings of the 37th Annual and 10th Pacific Coast Convention of the American Institute of Electrical Engineers, Salt Lake City, UT, June 22 1921), p. 1126.

power with two adjacent utilities, but they did not exchange power with each other. For a large Ohio-based interconnection, no load dispatcher acted as the central dispatcher. Instead, the various dispatchers "operate on the give and take principle, realizing that the fellow giving help today may be the one who will need it tomorrow."[48]

Of course, utilities owned by a single holding company shared a common interest in profitability and hence cooperated well when operating interconnected. Engineers and utility executives engaged in debate about whether fully autonomous utilities could likewise gain the full benefits of interconnection, especially with respect to energy efficiency. At a special American Institute of Electrical Engineers (AIEE) symposium on interconnection, held in 1928, the executive from a large interconnection in the Southeast claimed, "unquestionably, the greatest benefits are derived … when the interconnected companies while maintaining their independent corporate identity are subsidiaries of one holding company. … Full advantage is taken of diversity of time, diversity in rainfall, and in seasonal load."[49] At the same meeting, however, representatives from California and the Mid-Atlantic States illustrated that "excellent results are obtained … even though the systems are not under one ownership."[50] The autonomous companies participating in interconnections relied on well-delineated operating agreements and procedures, and succeeded in sharing power as well as the utilities controlled by a single holding company.

Balancing Multiple Interests on the Interconnection

The operations of interconnected systems reflected the shared management and divided authority of the economic and regulatory authorities overseeing them. In the case of

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[48] George S. Humphrey, "The Interconnection of Power Systems Surrounding the Pittsburgh District," *Electric Journal* 24, no. 6 (1927), p. 255.
[49] Mitchell, "Progress and Problems from Interconnection in Southeastern States," p. 382,385.
[50] Edgar, "Discussion," p. 414.

the Pennsylvania-New Jersey Interconnect (PNJ), for example, the parallels between physical management of the network and organizational relationships between the companies were explicit. In this instance, three utilities joined to build the Conowingo Dam on the Susquehanna River in Maryland, and power traveled to Pennsylvania and New Jersey. The PNJ promised to maximize power generated at the hydroelectric dam and minimize reliance on coal-fired steam plants, thus furthering resource conservation. To sustain the profitability of the participants and assure a fair distribution of responsibilities, the utilities signed an agreement that later became the model for many power pools.[51]

Under the PNJ operating agreement, each member utility designated one person to serve on an operating committee, which then established the policies for operations, exchanges of energy, and forecasts of loads. The chair of the committee rotated according to the order in which the members had signed the agreement. The participating companies retained autonomy in developing their regional power systems, but shared planning information. "In the interconnection plan, each company designs and constructs the lines lying within its own operating territory, although all three have agreed upon the climatic loading conditions and general basis of design."[52] In addition, "one company usually regulates the frequency and another company controls the power flow."[53] The group established a central interconnection headquarters which "will be in direct communication at all times, through the load dispatchers of the individual systems, with the steam and

[51] W. C. L. Eglin, "Symposium on Interconnection Conowingo Hydroelectric Project with Particular Reference to Interconnection," *Transactions of the American Institute of Electrical Engineers* 47, no. 2 (1928), pp. 373-374; Singer, "Power to the People, the Pennsylvania - New Jersey - Maryland Interconnection, 1925-1970," pp. 106-117.
[52] Eglin, "Symposium on Interconnection Conowingo Hydroelectric Project with Particular Reference to Interconnection," pp. 376-377.
[53] Funk, "The Economic Value of Major System Interconnections," p. 206.

hydrogenerating [*sic*] stations of the three companies."[54] Despite the careful organization of the operating committee, and the effort to protect the autonomy of each participating utility, there were "many delicate problems of load apportionment" and "only the most alert and skilled load dispatching [would] realize all the possible benefits" of the interconnection.[55]

Other operating groups formed to share management and divide authority on interconnected systems. The typical agreement called for representatives from each company to serve on an operating committee and communicate regularly. In addition to questions of current load distribution, outages, and seasonal changes, operating committees discussed longer-term infrastructure planning. In Chicago and the Middle West, for example, utilities signed a "three-party exchange agreement," coordinated plans for power station construction through a committee of two representatives from each company, and assigned load dispatchers to meet weekly to arrange operating schedules.[56]

Technological Complexity: Load Control as well as Frequency Control

By 1927 interconnections between multiple utilities were more common. An engineer with the West Penn Power Company, which operated in a network incorporating five systems altogether, enumerated the principal operating problems for interconnections: (1) control of frequency, (2) control of voltage, (3) control of power flow, (4) stability, both static and dynamic, (5) disturbances, (6) short-circuit currents, (7) relaying, and (8) dispatching. The engineer described many of these as challenges already met. For example, all the

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[54] Eglin, "Symposium on Interconnection Conowingo Hydroelectric Project with Particular Reference to Interconnection," pp. 376-377.
[55] Singer, "Power to the People, the Pennsylvania - New Jersey - Maryland Interconnection, 1925-1970," pp. 118-121; Eglin, "Symposium on Interconnection Conowingo Hydroelectric Project with Particular Reference to Interconnection," pp. 376-377. The PNJ did not adopt automated load and frequency control until much later than other interconnected groups.
[56] H. B. Gear, "Interconnection and Power Development in Chicago and the Middle West," *Transactions of the American Institute of Electrical Engineers* 47, no. 2 (1928), p. 402.

participating plants had installed Warren clocks to maintain the same average frequency. But the difficulty of controlling the flow of power on this system led the companies to operate interconnections only on a scheduled basis, rather than operating the entire system interconnected at all times.[57]

Several presenters at the 1928 AIEE interconnection symposium described load control problems. As a Commonwealth Edison executive explained, the multi-state, long-distance "systems can be operated in parallel successfully for such periods of time as may be necessary to meet the needs of operation during emergency transfers of energy."[58] When the long lines experienced surges, however, "there is instability of operation, and lack of continuity is likely to result."[59] The general manager of Georgia Power Co. noted that all the interconnected utilities in the southeastern states used master clocks and accurate frequency recorders to maintain 60Hz to achieve continuous parallel operation. He acknowledged, however, that "with the increasing amount of load carried over the lines, the problem of system stability has been encountered … [and] … calculation of load division was becoming "practically impossible."[60] He concluded that many problems remained, among others load dispatching in increasingly complex systems, and load division between parallel circuits. Another participant discussed control of the amount of energy passing over interconnection points in complicated networks. A "disastrous situation may develop in a few minutes if two large systems or groups of a single system fall out of step due to major distribution trouble or

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[57] Humphrey, "The Interconnection of Power Systems Surrounding the Pittsburgh District," p. 254.
[58] Gear, "Interconnection and Power Development in Chicago and the Middle West," p. 401.
[59] Ibid., p. 404.
[60] Mitchell, "Progress and Problems from Interconnection in Southeastern States," pp. 383-384.

other causes."[61] But the real problem lay with the effect of frequency control at one station on load distribution for the entire system.[62]

Load control represented an economic as well as an engineering problem. One engineer noted, "The load-dispatching system of an interconnected group is the heart of the whole question, and it must be solved not only from the engineering but from the executive standpoint on very broad lines."[63] Another participant suggested that "the engineering of interconnections has been worked out farther and better than the commercial or contract features. … There is a need for a simple but equitable form of agreement that does not require a Philadelphia lawyer or a Schenectady engineer to interpret."[64] Along with simple and comprehensible power sharing agreements, the discussants highlighted the increasing complexity of interconnections, and the challenge this posed to maintaining 60 Hz throughout the network while also assuring stable operating conditions under both normal and unexpected loads.[65]

In the late 1920s, utilities turned to automatic frequency control on interconnected systems and this had the inadvertent effect of upsetting scheduled loading of power plants. The centrally located load dispatcher on an interconnection managed the changes needed to maintain frequency, which became increasingly time consuming as systems grew larger and more complex. As companies introduced automated frequency control, the load dispatcher was relieved of this responsibility. Clearly frequency remained closer to the ideal of 60Hz

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[61] Edgar, "Discussion," p. 419.
[62] Gear, "Interconnection and Power Development in Chicago and the Middle West"; Mitchell, "Progress and Problems from Interconnection in Southeastern States"; Edgar, "Discussion."
[63] Edgar, "Discussion," p. 408.
[64] Ibid., p. 411.
[65] Ibid. Attachment titled "Summary of Regulating Methods on Principal Interconnected Power Systems and Recommendations on Automatic Load-Frequency Control for Grand Coulee Dam of the Bureau of Reclamation, p. 3 and letter from P.B. Juhnke to Leeds & Northrup Co. dated March 12, 1940.

with automatic control as illustrated in Figure 5.2. But, as one engineer noted in retrospect, the automatic frequency controller is "imperious" and as it restored system frequency and time, "it had the adverse effect of disturbing scheduled power exchanges between areas."[66] Over the next several years, several companies, including Leeds & Northrup, Westinghouse, and General Electric, experimented with combined automated frequency and load control. In the end, both competition and collaboration produced an initial, but incomplete, solution.

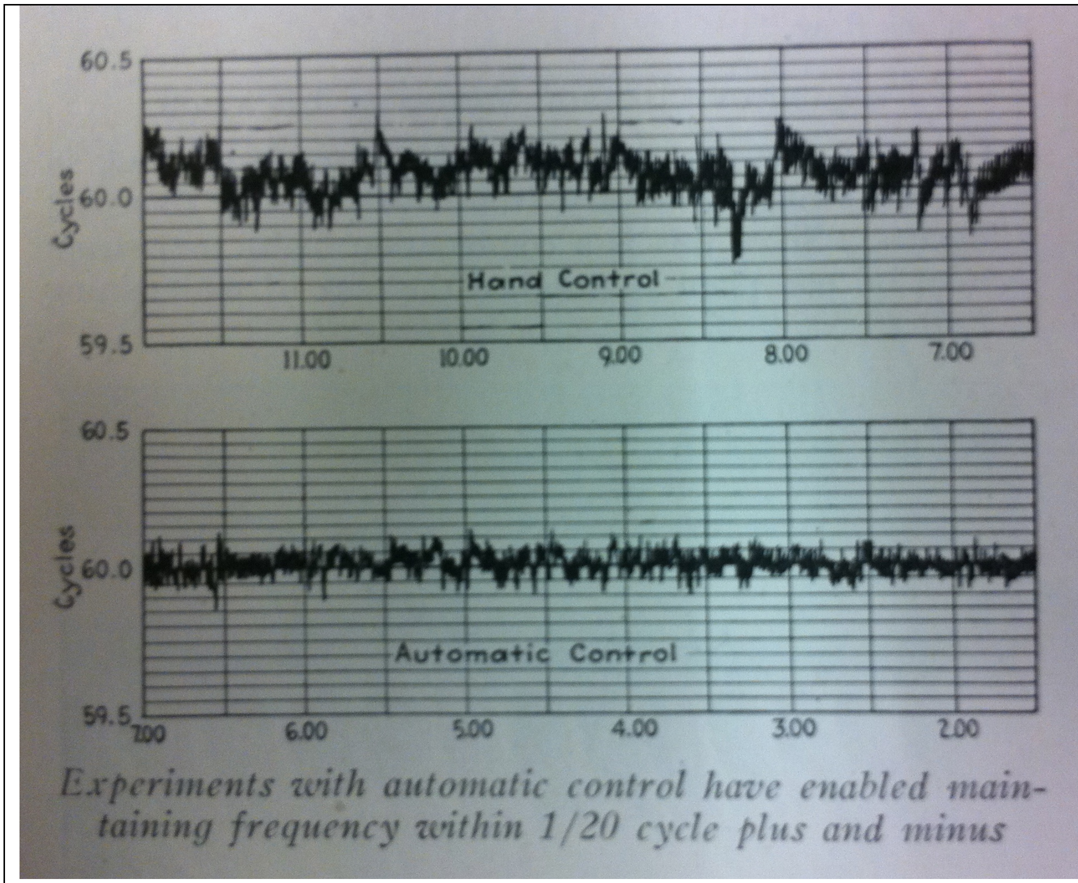

Figure 5.2. Example of chart recording showing the difference between manual and automatic frequency control. ***Source:*** **Thomas, Dean M. "Automatic Frequency Regulation."** ***Electrical World*** **92, no. 23: 1142.**

[66] Nathan Cohn, "Developments in Computer Control of Interconnected Power Systems: Exercises in Cooperation and Coordination among Independent Entitites, from Genesis to Columbus," in *The measurement, computation, and control section of the South African Institute of Electrical Engineers, 75th Anniversary Year* (Johannesburg, Durban, Capetown, SA1984), p. 2.

Load Control: Economics and Resource Conservation

The chief benefits to interconnection for utilities included energy efficiency, economic viability, and reliability. Utilities realized these benefits only through careful estimation of demand and determination of which plants should operate at what level and when. Load dispatchers scheduled load distribution to match the anticipated demands with the most efficient generating source. With automated frequency control, operators found their optimization of an interconnected system seriously compromised. As one engineer explained in 1930, "The factor of maximum economy is rapidly coming to the fore as an essential element in effecting constant frequency [on interconnected systems]. It is possible to maintain constant frequency but at an expense that far outweighs its intrinsic value."[67]

Load changes affected both single generators and interconnected systems in the same way. When a load change occurred, the generator(s) responded by slowing down or speeding up accordingly. For example, if a large industrial customer greatly increased the amount of electricity in use, the turbines in the generating station would slow down, causing the frequency to drop. An automated frequency controller could detect the dropping frequency and cause the turbines to speed up all at the instant. On an interconnected system, with one station managing frequency control, the automated frequency controller caused the generators in that station to speed up. As a consequence, the controlling station started to carry more load because it was generating more electricity.

A load dispatcher handling this manually could notify the other connected stations and require them to continue operating their generators in a manner to maintain the load

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[67] Humphrey, "The Interconnection of Power Systems Surrounding the Pittsburgh District"; H. S. Fitch, "Some Phases of Operation of Interconnected System," *N.A.C.A. Bulletin* 19, no. 5 (1932). Quote in S. L. Kerr, "Frequency and Load Control on Electric System," *Power Plant Engineering* 34, no. 12 (1930), p. 682.

distribution without changing the schedule. However, with automated frequency control, other generators on the system would lose load to the controlling station, at the same time causing another frequency change. As a British engineer explained, this was called "hunting and load pinching."[68] In addition to requiring constant calibration of the system frequency, these load changes upset the scheduled distribution of demand among the stations.

A second economic problem accompanied interrupted load distribution schedules. Utilities participating in an interconnection followed accounting systems designed to equitably distribute the costs and benefits of operating certain stations more and other stations less. If load inadvertently shifted from one company's station to another's, outside of the scheduled interchange, a cost accounting problem occurred. How would the accountants address the electricity sales under this circumstance, who would pay, and who would collect? Different owners on a single system had to "sort out, classify, and account for the different classes of power flowing" because this was the basis on which money was exchanged."[69]

A Field Test Highlights the Load Control Problem

The New England Power Company (NEPCo) took the lead in experiments with automated frequency control. In 1927, NEPCo installed both an L&N automatic frequency controller and a Warren Telechron controller at the Harriman station, a hydroelectric plant interconnected with four different utilities. After testing both devices, the operating engineers determined that each worked well enough to validate the principles of automated control, although neither was yet entirely reliable. Hunting occurred regardless of which device was used. An *Electrical World* description of the project, written by engineer and future vice

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[68] "Frequency Control."

[69] G. M. Keenan, "Interconnection Development and Operation," *Electrical Engineering* 51, no. 3 (1932).

president of New England Power, Robert Brandt, noted "if the bulk of the load change, however, should come on one system, then the automatic controllers, while bringing the frequency to normal, would necessarily upset the steady flow of power over the tie line. From this it appears that it may be necessary to incorporate with straight frequency controllers some sort of tie line load control."[70] The author lamented that with the growing complexity of systems, "the development of satisfactory apparatus to accomplish all the desired results automatically still appears to be in the distance."[71]

Several customers, and the National Electric Lighting Association (NELA), pushed Leeds & Northrup to address the related problems of frequency regulation and load control. Philadelphia Electric Company asked for a quote for a combined system in 1928. The L&N Development Committee acknowledged "load-frequency control is an important development which promises to result in a considerable amount of business, as, if the System is successful, it will mean application of a Frequency Controller to practically every machine in the Stations in which the System might be installed."[72] The committee determined to devote energies to making a "real success" of the installations at Philadelphia Electric Company, to proceed with marketing of automated control directly to prospective customers, and to also investigate and settle the patent situation.[73] But, the field of frequency-load control was so young that it was "not possible to determine very accurately at this time the ultimate extent of the field."[74] Nonetheless, Leslie Heath and others took on the task of

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[70] R. Brandt, "Automatic Frequency Control," *Electrical World* 93, no. 8 (1929), p. 387.
[71] "Statement by the Leeds & Nortrhup Company for the Annual Report of the Operating Committee of the Empire State Gas & Electric Associaton," (Empire State Gas & Electric Association, 1930). Quote in Brandt, "Automatic Frequency Control," p. 388.
[72] Development Committee Misc. Report 192, 7-24-28, July 24, 1928, Acc. 1110, Reel 8, L&N, Hagley.
[73] Development Committee, December 10, 1929, Acc. 1110, Reel 13, L&N, Hagley.
[74] Development Committee Misc. Report 268, August 15, 1929, Acc. 1110, Reel 11, L&N, Hagley.

developing apparatus to simultaneously control frequency and load on interconnected power systems.

A Solution and the Problem with Patents

Leeds & Northrup faced active competition from much larger and more established electrical manufacturing companies. General Electric Company posed "stiff price competition using Warren type equipment" and boasted of technical advantages.[75] As Heath reported to the Development Committee in 1929, "unless we produce substantial advantages over the [Warren] apparatus" L&N would have to meet General Electric's very low price.[76] Heath outlined the technical considerations of frequency-load control. If every station in a system had a frequency controller, there would be undesirable load shifts. If only one station controlled frequency, and the others operated with a fixed load, the controlling station would be subject to "undesirably large load fluctuations."[77] The L&N frequency controller was reliable for keeping frequency stable, but could not guarantee correct time. In contrast, General Electric claimed that the Warren system operated in each station at the same time, and kept correct time, without "undesirably shifting load between stations."[78] Heath concluded that this was theoretically possible, but he doubted its practical success.

The system L&N proposed to pursue combined the L&N frequency controller, a synchronous motor and clock like the Warren system, and separate wires to carry the control signals. In early 1929, Heath applied for a patent for the automatic control apparatus. Heath and several other engineers continued to consider approaches for automatically regulating both frequency and tie-line load. The proposed solution included a separate system of wires

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[75] Ibid.
[76] Development Committee Misc. Report 287, December 10, 1929, Acc. 1110, Reel 12, L&N, Hagley.
[77] Ibid.
[78] Ibid.

(pilot wires) between all participating stations to carry load-controlling signals. By the end of 1929, the team understood that the rapid growth of interconnections would make proprietary pilot wires impractical. “the implication … is that practically a national system of pilot wires would be required for the successful carrying out of such a scheme,” and the utilities were in no position to promote this.[79] The Development Committee urged the engineering team to approach AT&T and by 1930 the telephone company not only expressed interest in participating, but also engaged in experimental installations at utilities. The engineering team (including Heath and another engineer named Doyle) finally submitted a patent application for this method and system of automated frequency and load control in 1931.[80]

The patent situation posed an additional problem for the engineering team. In 1929, the Development Committee appointed a special committee to address the complicated patent considerations. The art of frequency control appeared “to be very old,” with patents dating back to 1896.[81] Practically every element the engineering team wanted to use, other than L&N proprietary apparatus, was subject to prior claims, though they might be invalid. Most significantly, General Electric, Westinghouse, Allis Chambers, and American Telegraph and Telephone owned all the relevant patents. Heath’s team reported that all of these companies “appear to be aware of our activities in this field.”[82] The inaction of patent owners might imply acquiescence and it was hoped that patent negotiations would be reasonable. By 1930, L&N believed that their apparatus was ready for a wide market, but the patent situation was still unresolved. It was hoped that within a year L&N’s “own patent

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[79] Development Committee Misc. Report 288, February 25, 1930, Acc. 1110, Reel 12, L&N, Hagley.
[80] Leslie O. Heath. Apparatus for Speed Control. United States, filed February 14 1933; Edgar D. Doyle and Leslie O. Heath. Method and Apparatus for Controlling Alternating Current Generating Units. United States, filed December 18 1934.
[81] Quote in “Development Committee Misc. Report 287”; Development Committee Misc. Report 288, December 10, 1929, Acc. 1110, Reel 12, L&N, Hagley.
[82] “Development Committee Misc. Report 287.”

situation may be in such shape that we will have something tangible to offer should we attempt an interchange of licenses under the patents involved."[83]

In 1930, L&N proceeded with collaborators and competitors to develop a working system for frequency and load control. As one engineer noted in retrospect, there was "relatively little control theory. Simulation as practiced in recent years was not available for control experimentation. It was not, however, especially missed … experimentation on the best of all simulators, power systems themselves, was feasible, and was practiced."[84] L&N worked with multiple utilities to run field tests of its equipment. As had taken place in 1927, several experimented with both the General Electric Warren System and the L&N system. For example, Philadelphia Electric Company and Pennsylvania Power and Light Company eagerly sought automatic frequency and load control on their interconnected system. They conducted tests with several manufacturers of control instruments, including General Electric and L&N, and they kept other manufacturers, such as Westinghouse, informed of their results. At the end of 1930, Heath suggested that L&N send a letter to Warren "telling him what we are doing and perhaps make the suggestion that we work together on the basis that he will supply clocks where such are required, and we will supply frequency controllers, the clocks being used to compensate our controllers."[85]

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[83] Ibid. Quote in Development Committee, July 8, 1930, Acc. 1110, Reel 13, L&N, Hagley.
[84] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," p. 146.
[85] Lloyd F. Hunt and Hydraulic Power Committee Subcommittee on Automatic Frequency Control, "Automatic Frequency Control in Hydroelectric Plants," *Electrical West* 64, no. 6 (1930). R. Bailey, "Fundamental Plan of Power Supply in the Philadelphia Area," *American Institute of Electrical Engineers -- Transactions* 49, no. 2 (1930); Philip Sporn and W.M. Marquis, "Frequency, Time and Load Control in Interconnected Systems," *Electrical World* (1932); Brandt, "Automatic Frequency Control"; Development Committee Technical Report #333, July 8, 1930, Acc. 1110, Reel 12, L&N, Hagley. Quote in Development Committee Miscellaneous Report No. 340, December 16, 1930, Acc. 1110, Reel 8, L&N, Hagley.

The issue of patent infringements clouded this year of experiments. In the case of Commonwealth Edison, for example, the Development Committee held repeated discussions about whether or not the utility planned to relinquish patent rights to L&N or simply buy equipment from L&N to add to their existing system. At this time, Commonwealth Edison operated a frequency control system that employed Seth Thomas clocks, Westinghouse graphic totalizing wattmeters (a device to measure, add up, and record total power on a system), L&N frequency recorders, and several other pieces of equipment. General Electric's Warren system posed a particularly thorny problem because the L&N engineers found that their solution incorporated Warren's synchronous motor. Mr. Ehret, the L&N patent attorney had laid out four options for the Development Committee: (1) negotiate with the four patent owning companies; (2) find patents that might invalidate current claims; (3) informally inform the companies of L&N's program and note that no infringement was intended while the patent situation was "muddled;" (4) proceed with publicity and sales efforts and wait for notices of infringement to arrive. He recommended the fourth option, noting that the field was just opening up. Echoing a letter from NELA, Ehret stated "it is of great advantage to yourselves to enter [the field] before it greatly develops."[86] He thought L&N would avoid infringement entirely or secure immunity "because of your friendly relations with others in or about to enter the field."[87]

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[86] "Development Committee Technical Report #333."
[87] "Development Committee Misc. Report 287"; "Development Committee Misc. Report 180, 2-6-28"; "Development Committee Technical Report #333." Utilities conducting field tests and mentioned in the minutes of the Development Committee include Philadelphia Electric Company, Pennsylvania Power and Light Company, New England Power Company, Commonwealth Edison. Development Committee Technical Report #337, September 2, 1930, Acc. 1110, Reel 8, L&N, Hagley; "Development Committee." "Development Committee Miscellaneous Report No. 340." Quote in "Development Committee Technical Report #333." This reflects a characteristic of the industry dating back to the multitude of lawsuits between General Electric and Westinghouse regarding early lighting systems. After years of litigation, the companies decided to pool patents in

Taking Ehret's advice, L&N moved ahead with direct sales to potential customers. Heath prepared a memo for the company's branch offices describing the experiences at twelve stations that had installed L&N automated frequency control devices, some of which also used the Warren system. He noted both successes and limitations. Those stations that controlled frequency from one generator found problems with load distribution, undermining the plans to generate power more economically. One station that had flexible frequency and load control – in other words, control responsibility shifted from one station to another depending upon operating conditions with looser frequency control – experienced great improvements in operating efficiency. Operating losses were reduced to less than one-half of one percent for extended periods of time and station economy rose by eight percent. Heath reported that a second station with similar flexibility showed promise in the area of biased load frequency control, that is the generators were adjusted to help a little with load swings, but without dramatically affecting economy. There were no immediate legal actions from competitors and Heath encouraged the continued sales of the existing L&N equipment.[88]

Experiments in Frequency and Load Control – Collaboration

Collaboration proved to be fruitful for L&N in the near term. As Philip Sporn recalled, "Results have been achieved by the work of progressive manufacturers, and by co-operation between technicians of many companies, hundreds and even thousands of miles apart."[89] Several utilities installed the L&N system in the early 1930s, and some ran comparison tests with other automated frequency and load control approaches. Southern

1896 and carry on with their work. Passer, *The Electrical Manufacturers, 1875-1900; a Study in Competition, Entrepreneurship, Technical Change, and Economic Growth*.

[88] Memorandum: Automatic Frequency Control, March 20, 1930, Box 40, Nathan Cohn Papers, MC 317 Institute Archives and Special Collections, MIT Libraries, Cambridge, MA. Hereinafter, Manuscripts from this archive will be identified with NC Papers, MIT.

[89] Sporn, *Vistas in Electric Power*. Reprint of "Progress in Power Transmission," Edison Electric Institute, Los Angeles, California, June 16, 1955, p. 325.

California Edison incorporated the L&N frequency controllers with an in-house time error correction system (similar to the Warren system) to regulate load shifting between steam and hydroelectric plants "as indicated by water storage and flow conditions and economy considerations."[90] At the Carolina Power and Light Company, L&N together with I.P. Morris, Baldwin Southwark Company installed apparatus to automatically load hydroelectric units to achieve optimum water use efficiency. This system also incorporated Westinghouse wattmeters.[91]

American Gas & Electric Company (AGE) conducted an extensive experiment with L&N and Warren systems for frequency control at three stations. Both collaboration and competition marked this project. For nearly a dozen years, utilities in eastern Ohio, western Pennsylvania, and part of West Virginia had sought to operate interconnected, but frequency and load control problem plagued the systems. By fall of 1930, with intense observation from the NELA Subcommittee on Frequency Control and from other utilities, both General Electric and Leeds & Northrup agreed to lend AGE control equipment for testing on the Pennsylvania-Ohio interconnection. Heath justified this to the L&N Development Committee by noting it would be an inexpensive way to learn if the new apparatus worked "under real life conditions." [92] Further, if the company failed to match GE's commitment to this experiment, L&N would lose its prestige. Finally, the trials would certainly determine whether the L&N apparatus was superior to, equal to, or inferior to the GE products.[93]

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[90] Cohn, "Historical Perspectives."
[91] Ibid; Factors Effecting the Utilization of Hydroelectric Plants for Automatic Control, November 30, 1931, Box 44, NC Papers, MIT; Kerr, "Frequency and Load Control on Electric System."
[92] N.E.L.A. Subcommittee Frequency Control Status, October 2, 1930, Leeds & Northrup Company, W. Spencer Bloor Collection courtesy of North American Electric Reliability Corporation, Atlanta, GA. Hereinafter, manuscripts from this collection will be titled L&N, NERC.
[93] H. S. Fitch, "The Pennsylvania-Ohio-West Virginia Interconnection," *Transactions of the American Institute of Electrical Engineers* 50, no. 4 (1931); Memorandum to R.L. Thomas: New

Trials took place beginning in 1931. In frequent handwritten letters, formal memoranda, and committee reports, L&N engineers documented the progress at the Pennsylvania-Ohio interconnection. The experiment also extended to an interconnection with the Commonwealth Edison system. From the beginning, the L&N team closely observed the GE approach. "If we had known before what we do now about … what G.E. was supplying we would have changed our layout considerably."[94] At first, the team noted that GE "knows of negotiations on our combined frequency recorder and Warren so a very friendly spirit exists."[95] Later, the team expressed concern that GE had an engineer onsite continuously during the tests while the L&N personnel were there only intermittently. With such close attention, GE was getting very good results. To counteract this "propaganda," one engineer suggested that L&N needed a person to "camp on the job."[96] By the end of 1931, it appeared to L&N that the people at the utility favored GE and gave them all the advantages. It was time for L&N to "stop playing ball."[97] Despite the fact that L&N was "pre-eminent in the field of frequency control, having more installations than all other manufacturers put together," it was necessary to "improve the stability of our frequency control."[98]

Problems between the utility systems plagued the tests as well. Operators at Commonwealth Edison and AGE disagreed about their respective frequency and load control responsibilities. The Pennsylvania and Ohio utilities wanted Commonwealth Edison to

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England Trip General Summary, August 28, 1931, L&N, NERC; Heath, "N.E.L.A. Subcommittee Frequency Control Status."

[94] Memorandum to Development Committee: Your Note of March 3, 1931 on Frequency Control for Crawford Station of Commonwealth Edison Company, October 2, 1931, L&N, NERC.

[95] Handwritten Letter from Morehouse to Heath: Frequency Control Philo, March 30, 1932, 1931, L&N, NERC.

[96] Memorandum to Leslie Heath: Pennsylvania-Ohio Frequency Control Tests, December 7, 1931, L&N, NERC.

[97] Memo to Heath: Interconnection Frequency Control Test, November 30, 1931, L&N, NERC.

[98] Memo to Heath: Field Tests of Frequency Control Equipment on Penn-Ohio Interconnection, December 29, 1931, L&N, NERC.

regulate frequency and load at the tie line. Commonwealth Edison maintained that due to its excellent internal system regulation, there would be no need to install additional controls at the tie line. Without clear agreement from the operating companies about what was to be controlled, the L&N team lamented that manufacturers could not design satisfactory equipment. Ultimately the executives of the two systems, who both wanted to see unified operations, had to meet to restore a more cooperative spirit.[99]

The results of the year-long tests indicated that automated frequency control at multiple stations was a step in the right direction, but problems occurred with tie-line control (load shifting) where "very rigid contractual relations have been set up between systems."[100] Reporting in *Electrical World*, operating engineers from American Gas & Electric explained that a set-up with "automatic frequency control in each area, supplemented by tie-line control where necessary," would solve the problem.[101] Engineers from all teams began to consider "tie-line bias" to be a workable solution. Tie-line bias is the option of allowing some frequency variation within an established range so that loading stayed on schedule. Through collaboration with the utilities, close observation of competitors, pursuit of collegial relations despite disagreements, and acknowledgement of shortcomings, L&N learned important lessons from this and other installations and pursued methods for distributed control in ensuing years. The fraternity of experts, from manufacturing companies and utilities, collaborated to build critical control pieces of the expanding power network.[102]

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[99] Report on System Operations Meeting at Windsor Station, West Pennsylvania Power Pool, July 16, 1932, 1932, L&N, NERC; Resume of Events, March 30, 1932, L&N, NERC; Report of Parallel Tests of Crawford Station, June 6, 1934, L&N, NERC; Report, May 1932, L&N, NERC.
[100] Sporn and Marquis, "Frequency, Time and Load Control in Interconnected Systems." Letter to Langstaff, H.A.P., Copy to Moat, December 7, 1931, L&N, NERC.
[101] Sporn and Marquis, "Frequency, Time and Load Control in Interconnected Systems."
[102] Reardon, "Letter to Langstaff, H.A.P., Copy to Moat"; Merriam, "Memorandum to R.L. Thomas: New England Trip General Summary"; Morehouse, "Report of Parallel Tests of Crawford Station."

Central Control or Distributed Control: Technical and Economic Considerations

By this time, power system engineers understood that there were several possible approaches to managing frequency and load control. Until later in the decade, all relied upon a designated central control station for frequency control. On a relatively small system, straight (or flat) frequency control allowed a central dispatching location to monitor and correct system frequency. Operators made manual adjustments to address unscheduled load shifting. Small load swings did not create a burden for the regulating generator. A slightly more complex system involved one automatically controlled station, and tie-line load controllers (also called watt controllers) on the other stations. In this case, the automatically controlled station responded to frequency changes, while the watt controllers responded to load changes at the tie-line. This method still allowed intermittent load changes on the interconnection, undermining the efficiencies to be gained from planned load schedules for each station.[103]

Installation of automatic frequency control devices at multiple stations on a system allowed each station to regulate its own frequency. However, every control device tended to respond to changes anywhere on the system, not only to local changes, causing overcorrection and instability. A further iteration of this approach added constant tie line controls to the system. This control held the load to its scheduled flow at each tie line, regardless of system frequency. As a result, individual stations, while retaining their planned

[103] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," p. 148; Hunt and Subcommittee on Automatic Frequency Control, "Automatic Frequency Control in Hydroelectric Plants," pp. 337, 348-350. In 1935, S.B. Morehouse, a senior engineer at Leeds & Northrup, delineated the main types of frequency-load control to a meeting of the Interconnected Systems Committee. He listed five variations: (1) flat frequency control, (2) flat tie line load control, (3) selective frequency control, (4) selective tie line control, and (5) tie line load bias control. Others used slightly different terminology to describe the same approaches. S.B. Morehouse, "Frequency-Load Control on Interconnected Power Systems," (Atlanta, GA: Interconnected System Operating Committee, 1935).

operating activities, might fail to help the larger interconnection address major load and frequency changes. The ideal system, yet to be developed in 1930, incorporated frequency regulation and tie-line control at each location. Called "tie line bias frequency control," this method allowed for shared management of grid frequency and load distribution with divided authority over each area's scheduled functions, thus maximizing the energy efficiency promised by interconnections. By this time, "there was full agreement that each company should endeavor to absorb its own load changes."[104]

Utilities and manufacturers shared concern that centralized frequency and load control failed to address the diverse needs of interconnected power companies. Following the experiment at American Gas & Electric Company, the participating utilities determined that "the principle of having any unit or plant operate as a master frequency station" was not satisfactory.[105] In an unrelated publication, the superintendent of the PNJ explained, "The interconnected system is a synchronized system, but the parts of it are owned by different companies, each of which must look out for its own interests … an ideally regulated interconnected system would economically and promptly distribute load variations over all generating equipment in operation."[106] Robert Brandt summed it up neatly in 1934, "today we do a great deal and much of it is wrong."[107] He laid out the challenge for the rest of the decade: "What is required is a mechanical device which can not only be made so intelligent that it will be ready to respond, positively and accurately, when there is a real need for

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[104] Hunt and Subcommittee on Automatic Frequency Control, "Automatic Frequency Control in Hydroelectric Plants." Quote in Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," p. 151.
[105] History and Highlignts, Undated, NC Papers, MIT.
[106] G. M. Keenan, "Interconnection Development and Operation," *Transactions of the American Institute of Electrical Engineers* 50, no. 4 (1931), pp. 1275, 1277.
[107] R. Brandt, "To Control System Frequency," *Electrical World* 104, no. 10 (1934), p. 71.

response, but, what is fully as important, that it will sit back and do nothing when the logical correction point is elsewhere."[108]

With acknowledged shortcomings, the Leeds & Northrup apparatus for automatic frequency and load control established the industry standard in the early 1930s. Engineers followed the results of the system tests in the major professional journals and numerous utilities purchased the L&N controllers. Operators participating in the AGE experiment expressed a preference for the L&N equipment. Reflecting the collaborative nature of technical innovation in the power industry at this time, installations included devices from numerous manufacturers, including the Warren clock and a Westinghouse recorder. In 1933, the US Patent Office acknowledged the instrument claims in the Doyle/Heath application, and the following year awarded the complete patent. This marked the resolution of the ambiguities surrounding L&N's potential patent infringements.[109]

In 1935, L&N engineers filed an additional patent application for an improved system that allowed one station to provide frequency control while others held tie line load to "capacity or contractual agreements" yet assisted somewhat with frequency. This achieved the desired "tie line bias frequency control" previously described. For the L&N engineers, and others pursuing an effective frequency and load control solution, the next steps included distributed measurement, data collection, and analysis. This innovation pushed the industry closer to effecting resource conservation, energy efficiency, and economic operations through interconnections.[110]

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[108] Ibid.
[109] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," pp. 148-152; Sporn and Marquis, "Frequency, Time and Load Control in Interconnected Systems."
[110] Development Committee Miscellaneous Report No. 371, July 17, 1934, Acc. 1110, Reel 10, L&N, Hagley; Albert J. Williams and Stephen B. Morehouse, "Electrical Generating System," US Patent 2124724, filed July 8, 1936, and issued July 26 1938.

Measuring to Control – Early Analog Computing

Power systems offered an early market for machine computing. From the beginning, system operators gathered an enormous amount and variety of data. Instruments measured load, output, frequency, and voltage, variables that changed moment-by-moment. "It is a self-evident maxim that what you cannot measure, directly or inferentially, you cannot control, or at least you ought not try to control."[111] Early on, load dispatchers developed a high level of skill for calculating system behavior based on this data and estimating future demand. With several systems sharing power, however, the task grew too large.[112]

Metering and calculating the combined data from multiple generating stations proved essential to the penultimate solution to frequency and load control. For many years, interconnected networks relied on the operator at one central station to provide system oversight and control. With generators spread far apart, telemetering provided the central operator with information about frequency and loading at distant plants. As systems became more complex, engineers added totalizing mechanisms, machines that could add up multiple bits of data, to the telemeters and recorders at the central station. With this information, the station operator could monitor activity system-wide. In addition, utilities used network analyzers to prepare models of system behavior. A network analyzer, in effect a computing device, provided step-by-step calculations of system conditions at various levels of load and during interruptions. By the late 1930s, the GE Network Analyzer served as the industry's first analog computer, and provided capable modeling for power systems for several decades.

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[111] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," p. 147.

[112] For images of early data charts, see Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, pp. 213-221.

Measurement, calculation, and visual representation of system behavior became essential tools for achieving system economies and operating stability.

The Telemeter and the Totalizer: First Steps in Automated Data Collection

Telemetering became critically important for system dispatchers who needed immediate information about the status of distant parts of a network. In the 1920s, "telemetering was quite limited."[113] Telemetering involved the transmission of "instrument readings or their equivalents from one point to another" for operations management, not for billing purposes. For example, Robert Brandt, looking back, suggested that without telemetering, it would be impossible to address loading along with automatic frequency control. As he explained, the telemeter brought information to the load dispatcher, but telemeters were costly, and impractical to place in more than one location on a system. Publications on the topic reflected the pressure to find more practical telemetering techniques.[114]

Before 1928, an occasional article including the term "telemeter" appeared in technical journals. From 1928 going forward, technical publications regularly featured coverage of new telemetering apparatus, integration of telemetering with system control devices, and discussions of the use of telemetering on power systems. In 1933, Leeds & Northrup published a bulletin describing proprietary telemetering and totalizing equipment. The company explained that advantageous distribution of load on an interconnected system required the dispatcher to have direct and immediate knowledge of all station and load conditions at all times. Telephone communications were inadequate to the task. An engineer

[113] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems."p. 146.
[114] C. H. Linder et al., "Telemetering," *Transactions of the American Institute of Electrical Engineers* 48, no. 3 (1929); Brandt, "Historical Approach to Speed and Tie-Line Control."p. 8.

from the Washington, D.C.area cautioned that interconnection was "justifiable when it makes economies possible," but this could not be achieved without the highly accurate data made available through telemetering and totalizing.[115] A New York utility operator affirmed that telemetering made it possible to achieve energy efficiency on the network.[116]

By the end of the 1930s, telemetering and totalizing apparatus found wide application on interconnected power systems in the United States and abroad. With the advent of extensive data collection, engineers began to contemplate fuller analysis of system operations, beyond the algebraic sums performed by totalizing equipment.[117]

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[115] W. J. Lank, "Interconnection Economies through Telemeter Totalizing," *Electrical World* 103, no. 26 (1934).

[116] Leeds & Northrup Company, "Telemetering and Totalizing Station Loads," in *Leeds & Northrup Company*, ed. Leeds & Northrup Company (Philadelphia, PA: Leeds & Northrup Company, 1933); F. Zogbaum, "Load Totalizing in the New York Area," *American Institute of Electrical Engineers, Transactions of the* 53, no. 6 (1934); "Reading Electric Meters over Telephone Circuits," *Power Plant Engineering* 32, no. 13 (1928); "New Telemetering Equipment," *General Electric Review* 32, no. 9 (1929); "Developments in Automatic Stations," *Electrical News and Engineering* 39, no. 1 (1929); P. M. Lincoln, "Totalizing of Electric System Loads," *American Institute of Electrical Engineers, Transactions of the* 48, no. 3 (1929); C. E. Stewart, "Synchronous Selector Supervisory Equipment and Telemetering," *American Society of Mechanical Engineers -- Transactions -- Fuels and Steam Power* 51, no. 1 (1929); A. S. Fitzgerald, "An Electron Tube Telemetering System," *Transactions of the American Institute of Electrical Engineers* 49, no. 4 (1930); "Electrical Instruments and Measurements -- 1932-33," *Electrical Engineering* 52, no. 11 (1933); G. De Croce, "Telemetering with Supervisory Control," *Electric Journal* 30, no. 6 (1933); Lank, "Interconnection Economies through Telemeter Totalizing"; "Recording and Integrating Mechanisms," *Power Plant Engineering* 39, no. 1 (1935); R. A. Rutter and P. MacGahn, "Demand Totalization Using Simplified Impulse Telemeter System," *Electric Journal* 32, no. 4 (1935). A search for the term "telemeter" on Compendex for the years 1900-1945 produced 174 results. Of these, only 12 appeared in publications before 1928. The rest of the articles were evenly spread across the remaining years, with a low of only 3 published in 1924, a high of 15 published in 1945, and an average of 9 per year. http://www.engineeringvillage2.org/controller/servlet/Controller?CID=home. Accessed 2/8/2012.

[117] A. Trenner, "Automatic Telemetering and Supervisory Control," *AEG Progress (English Edition)*, no. 2 (1935); "A-C Network Operation 1936-1937," (New York, NY, United States: Edison Electric Institute, 1939); Iwane Schigyo and Takashi Hioki, "Power Line Carrier Telemeter," *Shibaura Review* 16, no. 4 (1937); S. Jimbo and T. Ito, "Carrier-Current Telemeter," *Electrotechnical Journal -- Japan* 2, no. 2 (1938); B. O. Mongain, "Electrical Devices for Distant Supervision and Control of Engineering Plant," *Institution of Civil Engineers of Ireland -- Transactions* 64(1938); F. Jaggi, "Telemetering Equipments for Transmission of Any Desired Measurements over Long Distances," *Brown Boveri Review* 32, no. 4 (1945).

The Network Analyzer: Another Step Closer to a Computer

As early as 1924, investigators experimented with the use of an instrument that would automatically measure, record, and analyze electrical frequency. This instrument offered the industry a major benefit - speed of calculation. As interconnected systems grew, manual calculation of information from multiple sources became increasingly difficult and time consuming. In 1929 and 1930, engineers from MIT and General Electric (GE), working in collaboration, published the results of their lab experiments with a device they titled the Network Analyzer, designed to compute data collected from an ac power system. This project acknowledged the challenge of completing a daunting number of calculations in order to determine the behavior of a power system under various conditions of operation. "The chief function of the Network Analyzer is to serve as an experimental substitute for the lengthy and generally impractical calculations of … electric power networks."[118] While the apparatus described in 1930 served a research function in an MIT lab, the design engineers gave thoughtful consideration to its application to real, interconnected power systems. This early computer indicated the potential benefits of system modeling for the electric power industry.[119]

Over the next several years, MIT and GE improved the Network Analyzer, under the leadership of Vannevar Bush, and sold the first device for commercial use in 1937. Operators of complex interconnections hoped to better understand how their network functioned in

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[118] H. L. Hazen, O. R. Schurig, and M. F. Gardner, "The M. I. T. Network Analyzer Design and Application to Power System Problems," *American Institute of Electrical Engineers, Transactions of the* 49, no. 3 (1930), p. 1108.

[119] R. L. Wegel and C. R. Moore, "An Electrical Frequency Analyzer," *Transactions of the American Institute of Electrical Engineers* 43(1924), p. 465; H. L. Hazen and M. F. Gardner, "Solving System Problems by Means of the Power Network Analyser," *Power Plant Engineering* 33, no. 22 (1929); Hazen, Schurig, and Gardner, "The M. I. T. Network Analyzer Design and Application to Power System Problems," p. 1102. "Solution of Commercial Power-System Problems on M.I.T. Network Analyzer," *Massachusetts Institute of Technology -- Department of Electrical Engineering* (1931); "M.I.T. Network Analyser," *Electricien* 106, no. 2770 (1931).

Figure 5.3 Vannevar Bush and the Differential Analyzer, also known as a Network Analyzer, at MIT in about 1928-1930. Image Courtesy of the MIT Museum.

order to both optimize energy efficiency on a daily basis and to plan for expansion. "The analyzer was an analogue computer with direct correspondence between the elements of the model and the real network of interest. [Elements] might represent a load, transmission line, and so on."[120] This device could "solve differential equations that could not practically be solved 'by hand' or by ordinary analytical methods. … though an analog not digital) machine, it marked the beginning of … the Information Revolution."[121] As shown in Figure

[120] F. Preston, "Vannevar Bush's Network Analyzer at the Massachusetts Institute of Technology," *Annals of the History of Computing, IEEE* 25, no. 1 (2003), p. 77. Vannevar Bush is best known for his role as director of the Office of Scientific Research and Development, which controlled The Manhattan Project during World War II. His work at MIT on the Network Analyzer laid the theoretical groundwork for digital circuit design, pursued later by his graduate student Claude Shannon, the "father of information theory." "Highest Voltage Transmission System in the World"; Ioan James, "Claude Elwood Shannon 30 April 1916 -- 24 February 2001," *Biographical Memoirs of Fellows of the Royal Society* 55(2009).
[121] Karl L. Wildes and Nilo A. Lindgren, *A Century of Electrical Engineering and Computer Science at Mit, 1882-1982* (Cambridge, MA: MIT Press, 1985), p. 84.

5.3, the Network Analyzer took up quite a bit of space and required hands-on attention from the individuals preparing calculations.[122]

While this analyzer could model steady-state operations easily, additional manual calculations were required to represent changes on the network, such as major load increases, failures, or the addition of a new generator. GE introduced a "new" Network Analyzer in 1938, and this quickly became a useful component of power systems control apparatus. In 1939, the federal government approached MIT about expanding the device to model a proposed federal power grid. During World War II, the Network Analyzer provided important data for determining the effects of emergency interconnections in various parts of the country. Over the ensuing years, engineers used the Network Analyzer to model system behavior, understand the limits of long-distance and interconnected transmission, and ultimately to improve the control of shared power on the grid.[123]

Automated data gathering and analysis provided engineers at L&N and elsewhere with further tools for improving frequency and load control on interconnected power systems. Diversity of size, distance, technology, ownership, and operating practices characterized the utilities participating in interconnections by the early 1930s. As evidenced by the early L&N approach to addressing frequency and load control, engineers had assumed that a single point of dispatch authority could most ideally effect economic, efficient, and resource conserving operations. Yet the consensus shifted. The shortcomings of centralized

[122] Casazza, *The Development of Electric Power Transmission: The Role Played by Technology, Institutions, and People*, pp. 80-84. Preston, "Vannevar Bush's Network Analyzer at the Massachusetts Institute of Technology."
[123] H. P. Kuehni and R. G. Lorraine, "A New A-C Network Analyzer," *American Institute of Electrical Engineers, Transactions of the* 57, no. 2 (1938); Wildes and Lindgren, *A Century of Electrical Engineering and Computer Science at Mit, 1882-1982*, p. 103; Edith Clarke and S. B. Crary, "Stability Limitations of Long-Distance A-C Power-Transmission Systems," *Transactions of the American Institute of Electrical Engineers* 60, no. 12 (1941); Preston, "Vannevar Bush's Network Analyzer at the Massachusetts Institute of Technology."

control led engineers and utility operators to seek techniques for distributed control. Innovators realized that new instruments of measurement and calculation, harnessed to automated control apparatus, could offer solutions to the continuing challenges of sharing the management of the grid.

Bringing in the Big Dams: Bulk Power Transfers, Distributed Control

The big federal dams of the New Deal introduced large amounts of power into regional networks, and magnified the need for effective frequency and load control in interconnections. The federal commitment to dam construction stemmed in part from conservationist goals of developing and managing watersheds to maximize energy production. Load control was essential to achieving those goals. With the big dams came bulk power transfers, that is, the sharing of very large amounts of power across tie lines. These power transfers also increased the potential for greater interruptions of frequency and scheduled power exchanges. "From the time the first unit comes on the bus, until the ultimate in generating and tie line capacity is installed, one of the principal operating problems [for a big dam] will be the directing and maintaining of a scheduled power transfer on certain tie lines or a combination of them, or maintaining the system frequency."[124] Engineers sought methods for allowing individual utilities on a network to follow their own load changes with adjustments of generation in their own areas, while honoring interconnection agreements and maintaining constant frequency at 60 Hz. Leeds & Northrup jumped eagerly into this market with telemeters, totalizers, and a patented system for automatic frequency and load control.

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[124] Letter to United States Department of the Interior, Bureau of Reclamation: Subject: Automatic Frequency-Time-Load Control for Grand Coulee Power Plant, October 10, 1939, Box 43, NC Papers, MIT. Attachment titled "Summary of Regulating Methods on Principal Interconnected Power Systems and Recommendations on Automatic Load-Frequency Control for Grand Coulee Dam of the Bureau of Reclamation, p. 1.

During the 1930s, competition between technical experts grew as interconnection accelerated across North America. The marketing team at Leeds & Northrup urged expedited development of high-speed frequency control for this very active field. Other companies posed aggressive competition for metering and totalizing equipment in particular, but for automated frequency and load control as well. From Australia to Detroit, General Electric, Westinghouse, and a number of smaller companies vied for the business of measuring and controlling power exchanges on networks.[125]

The L&N engineers tracked the competition closely, and gathered testimonials from utilities using L&N equipment to garner additional business. Leslie Heath made a point of sharing installation results with his sales team in the field. In a 1934 memo, he forwarded information about recorders and meters on the Pennsylvania Railroad system, the Philadelphia Electric system, and the Philadelphia Electric interchange with the Aldred Company, another large regional utility. He later provided details of the New York Edison test of totalizing equipment. L&N bid for, and won, the contract to install load control devices at Boulder Dam, which went into service in 1936.[126]

Successful field tests of apparatus and acquisition of big dam contracts propelled L&N forward in the power control market. In 1935, Nathan Cohn, a young engineer tasked

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[125] Development Committee, November 14, 1934, Acc. 1110, Reel 3, L&N, Hagley; Remote Metering Demand and Integration, 1930, Box 43, NC Papers, MIT; General Electric, "General Electric Torque Balance Telemetering Bulletin," (General Electric Company, 1931); Memorandum to Cohn, Emerich, Moat, Robinson, Wyeth, Greer, Cleeland, Keene, April 16, 1931, Box 43, NC Papers, MIT; Memorandum to Cohn, Emerich, Robinson, Moat, Morehouse, Wyeth, June 1, 1931, Box 43, NC Papers, MIT; Memorandum to Technical Division Salesmen, March 20, 1933, Box 43, NC Papers, MIT.

[126] Memorandum to N. Cohn Regarding Lincoln Thermal Converters, January 22, 1934, Box 43, NC Papers, MIT; Memorandum to L. O. Heath Regarding Load Recording, September 17, 1934, Box 43, NC Papers, MIT; Memorandum to L. Heath Regarding Lincoln Thermal Converters, January 18, 1934, Box 43, NC Papers, MIT; Letter to Leeds & Northrup Company, Attn.: L.O. Heath, September 5, 1934, Box 43, NC Papers, MIT; Letter to Leeds & Northrup Company, Attn.: L.O. Heath, August 23, 1934, Box 43, NC Papers, MIT; Cohn, "Historical Perspectives," p. 7. Billington and Jackson, *Big Dams of the New Deal Era: A Confluence of Engineering and Politics*, p.143.

with selling L&N apparatus on the West Coast, faced direct competition from GE for the Los Angeles Department of Water and Power (LADWP) contract for control devices. This city-owned utility claimed eighteen percent of the power to be produced by the Boulder Dam project. Cohn provided LADWP, and the neighboring private utilities, with letters from Commonwealth Edison Company in Chicago, The United Electric Light and Power Company in New York, The New England Power Engineering & Service Corporation in Boston, The Ohio Power Company of Canton, and the West Penn Company of Pittsburgh extolling the performance of L&N automatic frequency control equipment. The testimonial from Ohio included confirmation that the utilities in that area had dropped GE control equipment in favor of L&N apparatus. "GE is no longer in use while L&N is."[127]

Of course, in the long run it made sense for companies sharing power over interconnected transmission lines to use compatible control apparatus, and Boulder Dam had already committed to the L&N apparatus. By March, Cohn could report back to his supervisors that the Los Angeles area public and private utilities planning to use power from Boulder Dam, including LADWP, had all approved L&N frequency and load control equipment. He noted that not only had the company beaten GE on these contracts, but also that the L&N apparatus would replace a Westinghouse system currently in use in Los Angeles.[128]

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[127] Billington and Jackson, *Big Dams of the New Deal Era: A Confluence of Engineering and Politics*, p. 125Letter to S.B. Morehouse, March 4, 1935, Box 43, NC Papers, MIT; Telegram to N. Cohnn (Sic), March 4, 1935, Box 43, NC Papers, MIT; Telegram to Heath, March 4, 1935, Box 43, NC Papers, MIT; Letter to L.O. Heath, March 5, 1935, Box 43, NC Papers, MIT; Letter to L. E. Emerich, March 5, 1935, Box 43, NC Papers, MIT; Letter to Emerich, March 11, 1935, Box 43, NC Papers, MIT.

[128] Memorandum to Emerich Re: Boulder Dam Frequency Load Control, March 20, 1935, Box 43, NC Papers, MIT.

Tie-Line Bias Frequency Control: An Industry Standard with Problems

Through these years, tie line bias frequency control techniques found wide application in the power industry. This system of control called for one power station to regulate frequency for the entire system, and for tie lines to maintain scheduled loading, with minor and gradual adjustments of load as needed to help with frequency control. The strategy called for the removal of this aid after a certain period of elapsed time regardless of whether or not system frequency had stabilized. This could cause ongoing problems for certain interconnections, and prompted innovation and experimentation as engineers attempted to install apparatus. As Cohn later recalled, "[In 1937] it fell to my lot to place into service … these new "tie line bias frequency controllers," at the Twin Branch Station of Indiana and Michigan Company.[129] Getting satisfactory operation was, however, not easy, and in fact we didn't achieve it."[130] He described a controller that would "cooperate nicely, act to assist the remote areas and permit its own tie line to go off schedule."[131] But as soon as the aid to the remote area was withdrawn, there was a further upset in frequency, hunting between areas, and "a totally unneighborly [*sic*] kind of operation."[132]

Cohn and his associates decided to eliminate the automatic withdrawal of assistance and allow the tie lines to restore the scheduled loads essentially on their "own accord."[133] He rebuilt the controller and it worked. "And of course we did most of the experimental work over the midnight shift."[134] He later remarked, "It was another example of using the system

[129] Cohn, "Historical Perspectives," p. 8.
[130] Ibid., p. 8.
[131] Ibid., p. 8.
[132] Ibid., p. 8.
[133] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," p. 154.
[134] Ibid., p. 154.

as our test simulator."[135] As a result of this engineering on the fly, "sustained" tie line bias control became the new industry standard, and remained such until the late 1940s. Notably, this technical approach incorporated a shared response to trouble, but autonomous regulation to bring the system back into synchrony and scheduled loading, much like the human systems of shared management and divided authority that governed the political and economic relationships of power companies.[136]

By the end of the decade, Leeds and Northrup dominated the market for power control on major interconnected systems. In a 1939 bid for equipping the Grand Coulee Dam, and attached materials dated 1940, the company enumerated and described installations on nearly every major federal dam in the country and most of the largest interconnected systems. The bid opened with a strong statement, "Our experience with the regulating problems of over fifty power systems on which we have over seventy control installations prompts us to make this broad presentation."[137] L&N provided the Bureau of Reclamation with descriptions of installations at Boulder/Hoover Dam in the Nevada, Norris and Wilson Dams in the south, and Bonneville Dam on the Columbia River. It detailed controls used by the Tennessee Valley Authority, in New England, in Central Texas, and in the Pacific Northwest.

Notably, the bid included a further denunciation of the GE system, except when it operated as a component of the larger L&N system. In the 1920s, the Warren clock, owned by GE, posed a potential patent challenge for L&N. In the early 1930s, L&N and GE collaborated on tests of their equipment on the AGE system. In the mid-1930s, GE & L&N

[135] Ibid., p. 154.
[136] Cohn, "Historical Perspectives," pp. 8-9.
[137] Morehouse, "Letter to United States Department of the Interior, Bureau of Reclamation: Subject: Automatic Frequency-Time-Load Control for Grand Coulee Power Plant." Cover Letter.

competed directly for major installations of control instruments. Over the years, the Warren clock signified the shifting alliances, the need for cooperation between rivals, and the organic cobbling together of solutions that characterized development of the grid.[138]

Part of the pitch to the Bureau covered the potential for Grand Coulee's role in future interconnections and the need to resolve problems as they arose. L&N made the point that, as had been the case elsewhere, for example at the TVA, "it was not possible to foresee all of their present interconnections and types of regulation which the various plants have since been called upon to handle. … [L&N] wished to insure that the control which you install will operate satisfactorily with similar equipment" in the Pacific Northwest.[139] The bid offered a variety of equipment options, but stressed the benefits and flexibility of sustained tie line bias control. L&N argued "similar changing requirements are being handled automatically on other systems, and it has been definitely proven, repeatedly, that the present extent of interconnections could not exist without automatic control to coordinate the regulation of the various areas."[140] In essence, L&N promised the tools and capabilities to meet unforeseen demands and operating conditions, and to engineer solutions as the interconnections in the Columbia River basin grew.

The proposal also described the Midwest Power System, which stretched from Chicago to the Gulf of Mexico and from Pittsburgh to Texas. Of all the systems, this one perfectly exemplified the need for L&N's premiere package of automated controls that allowed both cooperation and independence among the participating utilities. "You can

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138 Ibid. Attachment titled "Summary of Regulating Methods on Principal Interconnected Power Systems and Recommendations on Automatic Load-Frequency Control for Grand Coulee Dam of the Bureau of Reclamation."
139 Ibid., p. 11.
140 Ibid., p. 11.

appreciate that this Midwest interconnection involves many different operating companies, owned by different financial interests, no one of which has authority to dictate the policy to be followed."[141] Called the Interconnected Systems Group, this huge system operated through a Test Committee that decided what apparatus to employ and how to control the flow of power. In an attached letter, the Chairman of the Test Committee, who also worked for Commonwealth Edison, noted, "It required considerable effort to have these [L&N] controllers installed. They were installed from an appreciation of their merits in the attainment of the high standard of service to which this interconnection subscribes."[142] Using tie-line bias frequency control, utilities within the interconnection maintained authority over their autonomous operating areas while sharing responsibility for stability and energy efficiency across the network. In the end, Leeds & Northrup installed controls at Grand Coulee Dam.

With growth comes the exposure of limitations. By the early 1940s, most interconnected power systems in North America employed some form of distributed and automated frequency and load control. But all of these systems still relied upon a central station to govern overall network frequency, and, as more utilities interconnected, the burdens on this station increased. In addition, the configuration of the control network could be described as a "cascading of controllers."[143] The load controller on the tie line furthest from a central frequency controlling station acted to hold it's own load steady and contribute a little bit to frequency control. At the next tie line closer to the central station, the controller adjusted load both for overall frequency control and for it's own as well as the further

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[141] Ibid.
[142] Ibid.
[143] Earle Wild, "Methods of System Control in a Large Interconnection," *American Institute of Electrical Engineers, Transactions of the* 60, no. 5 (1941), pp. 234-235.

station's scheduled load. Thus, each controller closer to the central station carried a larger burden of adjustment. This limited the potential of an interconnection to expand indefinitely and created operating problems for controllers at the heart of a network.

The intense demand for electricity during World War II, and the resulting increase in the scale of interconnections exaggerated these problems. Innovations during and after the war led to nearly complete distribution of automated control responsibility among power plants cooperating on a network, mediated by analog computers.[144]

Cooperation and Autonomy: Experimenting with Distributed Control

With its entry into World War II, the United States faced a huge demand for electricity, as anticipated by the Roosevelt administration. Federal agencies diverted power from newly constructed dams to the production of war materiel in general, and the development of the atomic bomb in particular. Utilities joined interconnections and the scale of power networks grew. In addition, the Federal Power Commission required utilities to interconnect when they did not undertake expansion on their own. As Robert Brandt noted afterward, the impact of World War II "brought about the formation of several new and very large interconnections," and the consequent system of operating on "net interchange."[145]

For example, following opening of the Bonneville and Grand Coulee Dams, "formation of the Northwest Power Pool in 1942 created the need for a new type of automatic load and frequency control application called "net interchange control."[146] This kept tie line loads "as near to their operating limit" as possible and "was extremely important

[144] Cohn, "Developments in Computer Control of Interconnected Power Systems: Exercises in Cooperation and Coordination among Independent Entitites, from Genesis to Columbus," p. 3.
[145] Brandt, "Historical Approach to Speed and Tie-Line Control," p. 8.
[146] A. W. Walton and H. W. Lensner, "Carrier Telemetering Load Control," *Electrical Engineering* 68, no. 4 (1949); S. B. Smith and M. L. Blair, "Automatic Load and Frequency Control in Northwest Power Pool," *Electrical World* 124, no. 25 (1945).

during the war."[147] The approach "had the effect of drawing an imaginary line completely around a predetermined load area and then requiring an amount of generation which is sufficient to hold the load in that area at 60 cycles."[148] In other words "there is no master frequency station … as was thought to be necessary in the early developmental period."[149]

Before and during the 1940s, engineers continued to experiment directly on segments of the grid to achieve a fully distributed control technique for frequency regulation and load management. Instrument manufacturers and utility operators collaborated on definition of problems and development of solutions. The Indiana and Michigan Electric Company experimented with the new technique, "net interchange," to segregate control areas so that no one station would be overburdened with frequency control responsibilities. As Cohn explained, he worked closely with Jack Girard, the operations chief at Indiana and Michigan Electric. Girard "had a clear concept of the potential benefits of interconnected operation, and in preparing new contracts with neighbors he stipulated their use of tie line bias control to optimize reliability and economy."[150] Cohn and Girard met regularly for many years after the initial introduction of sustained tie-line bias control on Girard's system to "analyze operations and explore new and expanded needs."[151] They "sent many restaurant tablecloths to the laundry laden with exploratory and tutorial sketches."[152] Net interchange, however, did not find widespread adoption until after World War II.[153]

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[147] Brandt, "Historical Approach to Speed and Tie-Line Control"; Walton and Lensner, "Carrier Telemetering Load Control"; Smith and Blair, "Automatic Load and Frequency Control in Northwest Power Pool."
[148] Brandt, "Historical Approach to Speed and Tie-Line Control," p. 8.
[149] Ibid., p. 8.
[150] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," p. 154.
[151] Ibid., p. 154.
[152] Ibid., p. 154.
[153] Ibid., p. 154.

By 1945, networks like the Interconnected Systems Group, had grown so extensively that a central frequency control station regulated an enormous geographic area. Cohn developed analyses to illustrate that it would be possible to maintain 60 Hz frequency on a very large interconnection without a master frequency control station, as had been illustrated on the smaller Indiana and Michigan Electric system. L&N shopped the idea of "net interchange" to utilities in the mid-forties, but skepticism prevailed. Cohn explained to one potential customer, "It would appear that the biggest virtue to such complete tie-line bias operation would be on large interconnections."[154]

In 1947, L&N finally found an opportunity to test this approach on a larger interconnection, the United Pool that included utilities in Iowa, Illinois, Kansas, and Missouri. The Power Operating Committee, comprised of representatives from each participating utility, agreed to designate a Pool Dispatcher's Office, which would collect and analyze telemetered data about system operations and plan for distribution of load, but would NOT regulate the system in any way. The system would be divided into multiple operating areas and within each area, a dispatch office would meter and control load and frequency. Tie line control would "be on a net basis with provision for selecting the ties to be included in the net."[155] The installed apparatus began operations in 1948, "fully in accord with expectations."[156]

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[154] Memorandum to N. Cohn Regarding Union Electgric Company Load Frequency Control, May 19, 1947, Box 39, NC Papers, MIT; Memorandum to C Nichols Regarding Union Electric Company Load Frequency Control, July 9, 1947, Box 39, NC Papers, MIT. Quote in Letter to Iowa Power & Light Company, Attention Mr. W.G. Kaldenberg, April 21, 1945, Box 47, NC Papers, MIT.
[155] Memorandum to S.B. Morehouse Regarding United Light and Railways Service Company, Missour Kansas, Iowa and Illinois Interconnection., January 29, 1947, Box 39, NC Papers, MIT; Preliminary Memorandum and Approximate Estimate of Load Control Equipment for the Union Electric Company, October 14, 1949, Box 39, NC Papers, MIT.
[156] T.W. Schroeder, "Midwest Interconnection to Permit Pool Operation," *Electric Light and Power* 25, no. 5 (1947); Cohn, "Memorandum to S.B. Morehouse Regarding United Light and Railways

Numerous control areas comprised the interconnection. Within each, control equipment maintained frequency and load distribution. Control apparatus at the ties between areas regulated only the net of power moving from one area to the next, so that stations within one area would not have to respond to frequency or load adjustments in another area. In 1947, Robert Brandt of New England Power independently developed a similar approach for the Northeast interconnection. In 1984, Cohn remarked, "The fully distributed frequency biased net interchange control technique in all areas, without a central frequency regulating area, has, for close to 35 years, been the standard inter-area control practice on all U.S.-Canada interconnected systems."[157]

$$E = (T_1 - T_0) - 10B(F_1 - F_0)$$

Figure 5.4. Equation for Net Interchange Tie-Line Bias Control. ***Source:*** **Standard Handbook for Electrical Engineers, 10th Edition.**

According to power system engineers working in the industry today, Cohn's equation for net interchange tie-line bias control, shown in Figure 5.4, is still in use today, sixty years later. The equation given above is represented today using slightly different symbols, but produces the same result. For Cohn and his colleagues, the most astonishing difference in today's electricity control room would be the array of high definition, multi-color displays and the ability of contemporary digital computers to process enormous quantities of data nearly instantly. Mid-century engineers could only imagine the fine-grained detail available now to system operators at the instant. Notably, for purposes of understanding the history of the grid, Cohn and others spent decades refining their understanding of electricity on

Service Company, Missour Kansas, Iowa and Illinois Interocnnection"; Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems."

[157] Robert Brandt, "Theoretical Approach to Speed and Tie Line Control," *American Institute of Electrical Engineers, Transactions of the* 66, no. 1 (1947). Quote in Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems," p. 155.

interconnected networks and developing strategies for controlling increasingly complex power exchanges with a minimum of system instability.[158]

Summary

A halting and challenging path to power control on interconnected systems unfolded during the interwar years. Yet, finding methods for managing the exchange of electricity between utilities, without bringing down the entire network, and respecting the economic autonomy of participants, was critical to building a grid. "Operation of large complex systems, and particularly interconnected groups, would have been greatly hampered, if not impracticable, without the techniques and equipment for automatic control of frequency and tie-line loading which are in widespread use today."[159] As utilities awoke to the problems inherent in operating interconnected, they turned to apparatus manufacturers to configure control techniques. The increasingly complex relationships between power producers led to an overload of data for system operators. Automated control became the preferred means of keeping interconnections stable and reliable.

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[158] John Adams, Principal Engineer, Electric Reliability Council of Texas, Inc., and Joel Mickey, Director, Market Design and Development, Electric Reliability Council of Texas, Inc., personal communication with author, March 1, 2013. Nathan Cohn, "Power-System Interconnections Control of Generationa and Power Flow," in *Standard Handbook for Electrical Engineers*, ed. Fink & Carroll (New York: McGraw-Hill, Inc., 1968). The contemporary version of this equation is Area Control Area = (Ta – Ts) – 10B(Fa-Fs). John Adams provides the following explanation: Ta = tie-line actual flow, Ts = tie-line schedule flow, Fa = frequency actual, Fs = frequency scheduled, B = frequency bias – a conversion factor which is intended to represent the energy deficit producing a 0.1 hertz frequency change in a control area. As a practical matter this represents the energy of inertia of the rotating masses in the control area, and how much energy a 0.1 hertz change impacts their rotating mass's energy, i.e. how much additional energy a 1/10 change in frequency will draw from the rotating masses. The 1/10 accounts for the 10-multiplier in the equation. Adams, personal pommunication with author, March 4, 2014.

[159] Sporn, *Vistas in Electric Power*, p. 44, Reprint of "Quarter Century of Electric Power, Electrical Engineering, 75th Anniversary Issue, June 1, 1959.

Close control of frequency permitted two or more systems to share power. Careful management of load allowed utilities to achieve operating efficiencies, reduce the rate of depletion of coal, and maximize the use of hydroelectric power when rivers ran high. In keeping with the goals of Progressive Era conservationism, utilities sought very tight control of load distribution among interlinked power plants. When advances in automated frequency control upset scheduled load shifts, engineers faced a serious problem. They spent nearly two decades attempting to perfect a solution. World War II increased the pressure to resolve this problem and by the end of the 1940s, the industry began to adopt the most effective solution to date: distributed frequency, biased net interchange control.

From the beginning, operators and engineers assumed that system control should mirror station control. Ideally one load dispatcher at a designated station kept the whole network running. In the meantime, however, utilities built pooling arrangements that respected the economic autonomy of each entity. Except when all the utilities operated under the aegis of a single holding company, each had its own financial arrangements, service area, and construction plans. The utilities shared management of interconnections, but retained authority over their own sub-networks. The government regulatory structure mirrored this arrangement. The Federal Power Commission regulated only the rates for power exchanges that crossed state lines. Public utility commissions regulated the monopoly activities of individual entities within their states. And, the industry itself regulated stability and reliability on the power lines without government oversight. Ironically, the characteristics of alternating current electricity caused the operators and engineers to devise technical control methods that matched the economic and regulatory arrangements adopted by the industry.

The pressure to achieve stable interconnected operation came from within the industry as well as from political leaders. Utilities sought the economies and reliability offered by linking with neighboring companies. Some, along with politicians, also promoted the resource conservation and economic development benefits that would accrue to projects that maximized the use of waterpower. Legislators as well as government agencies added to the pressure for effective interconnections. They saw opportunities to advance regional development, they noted that other countries were building national grids, and in some cases, they built government-owned transmission lines that made economic sense only when interconnected with other power networks. However, in the 1920s, the technologies available to transmit alternating current were inadequate to the task of sustaining full-time interconnection.

System operators, utility managers, and engineers sought to accomplish the goals of their employers, but the process of developing control mechanisms that kept pace with the increasing complexity of power networks took decades. Because several power companies succeeded in sharing power by the late 1910s, and because interconnections served the energy demands during World War I so well, it appeared that the technology itself might determine the choices utilities made in the coming years. Instead, the preferences of power companies and government agencies, and the hard-fought political and economic battles of the 1920s and the 1930s, established a consensus in favor of building grids. It was left to the engineers and operators to find techniques that allowed grids to work.

A close examination of the slow and difficult development of automated controls for power networks complicates our understanding of the grid. Because it was technically challenging to operate ac power networks, the successful construction of a grid was not inevitable. Instead, it was accomplished in fits and starts, through the collaboration of many individuals, some of whom were in direct competition within their equipment markets. The unusual organizational and regulatory configuration of the power industry in North America, while it favored interconnections conceptually, further complicated the process. Stakeholders in the power business devised systems of shared management and divided authority in order to meet economic goals within a fairly permissive political environment. This left individual utilities and government agencies on their own to assemble power pools and determine approaches for distributing the costs and benefits of sharing power. The techniques for controlling power came to resemble the power pools themselves, both to accomplish the financial goals of the individual participating entities and to manage the unpredictability of alternating currents racing around the networks. Government and utility leaders turned to interconnections to address major production and energy needs during World War II, and this accelerated the process of seeking solutions to power control in the ensuing years.

Part III. Taking the Shape of a Grid, 1940-1965

From many perspectives, the power industry reached an apex in the years following World War II. Various observers from within the industry described the years from 1945 to 1965 as "the golden age of electric utilities" and the "good old days."[1] Historian who are more critical of the industry, still offer, "power company managers justifiably took pride in the knowledge that they controlled a closed system that produced universal benefits."[2] One describes these decades as "the high-energy economy" during which the "injection of power … had no historical precedent."[3] Another notes "in many ways, the postwar era was truly an age of electrical marvel and wonder."[4] Pent up demand immediately after the war, and industrial expansion in the 1950s created an ideal climate for power system growth.

These were the years in which the North American power grid finally took shape. Discrete networks that expanded rapidly during the war soon stretched across major portions of the continent. By the late 1950s, utility engineers and operators predicted coast-to-coast links. As illustrated in Map C, the growth of interconnections between 1946 and 1960 made a single grid look nearly complete. In 1965, a full 97 percent of the power capacity in the United States was interconnected in five large networks, and two years later interties linked all but Texas and Quebec into a single network. By the 1960s notion of "the grid" had at last reached a point of inevitability. Indeed the United States' first fully realized National Power Survey, issued at the end of 1964, predicted functional interconnections across the United States by 1980.

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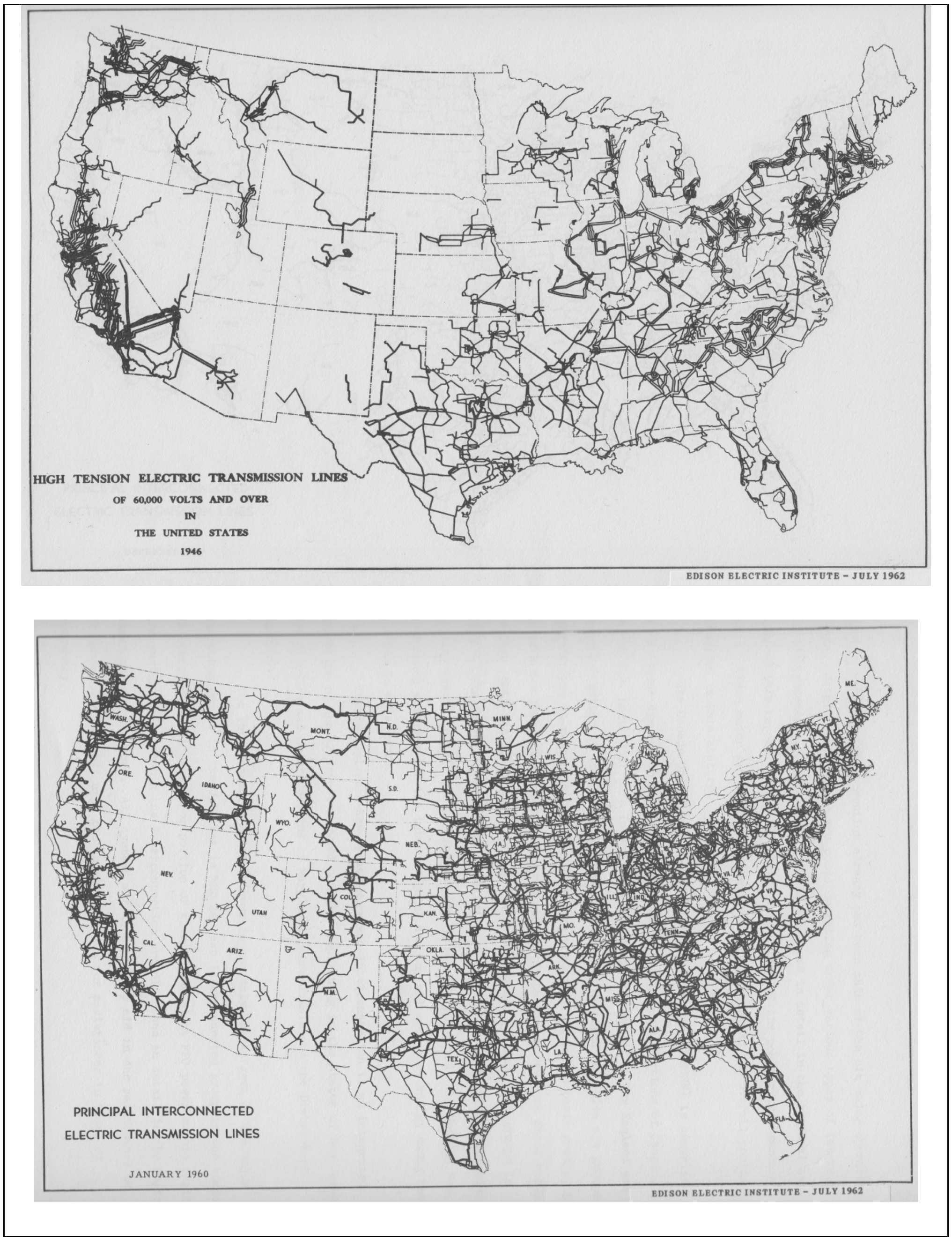
[1] Casazza, *The Development of Electric Power Transmission: The Role Played by Technology, Institutions, and People*; Hyman, Hyman, and Hyman, *America's Electric Utilities: Past, Present and Future*, p. 151.
[2] Hirsh, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System*, p. 55.
[3] Nye, *Consuming Power: A Social History of American Energies*, p. 187.
[4] Melosi, *Coping with Abundance: Energy and Environment in Industrial America*, p. 213



Map C. High Tension Transmission Lines in United States in 1946 and 1960. ***Source:*** **Edison Electric Institute,** ***Report on the Status of Interconnections and Pooling of Electric Utility Systems in the United States*****, 1962.**

The practical concerns of operating a network of widely diverse power systems on such a large scale remained daunting. For example, in the central and eastern parts of the country, over 200 smaller electricity pools crossing 39 states and 2 provinces shared power in a single network. Within this network, however, many ties were “sufficient for emergencies only."[5] Utility engineers had not yet resolved all of the physical challenges to operating fully interconnected, and each new expansion of power pools introduced new complexities to the process. Also, the fragmented nature of the industry suggested that accomplishing a uniform system in a few short years might require conceding to some central commanding entity, either governmental or private, to institute plans, standards of technology and practice, and to regulate stability. Instead, the industry adhered to traditional systems of shared management and divided authority and put together "the grid" through entirely voluntary arrangements.[6]

World War II provided a laboratory for close collaboration between government and industry, and rapid expansion of interconnections. War industries required huge quantities of power in specific locations in order to meet wartime demands. The national government closely controlled the use of raw materials in order to supply war needs first. By building interconnections rather than new generating facilities, utilities were able to meet those needs more quickly, and with fewer capital and material resources. In addition, the interconnections facilitated maximized use of existing plants. Engineers continued to experiment with techniques for managing power on the networks and made advances in both operating practices and automated control apparatus. By the end of the war, the power industry was well situated to meet pent-up consumer demand for electricity, and soon thereafter, new demand from a growing industrial sector. From the late 1940s through the 1950s, the utilities accelerated construction of new and larger power plants as well as more interlinked

[5] Commission Federal Power Commission, *National Power Survey: A Report* (Washington, DC: Government Printing Office 1964), p. 14.
[6] Ibid., p. 13,200. Five interconnected groups served the United States – the Eastern group – which also served parts of Canada, the Northwest Interconnected Systems Group – which likewise served parts of Canada, the Pacific Southwest interconnected Systems Group, the Rio Grande-New Mexico Pool, and the Texas Interconnection. In Canada, Hydro-Quebec operated as a separate interconnection.

transmission lines. At the same time, the private power sector withdrew from close collaboration with the central government, preferring autonomous operation and independent decision-making.

On the surface, it appears that individual utilities participated in a unified push to build a coast-to-coast grid after World War II. In fact, the process of interconnection continued to be fragmented, with significant regional differences. In the late 1950s, the variability in organization of power pools, choices of operating practices, and sophistication of control techniques actually began to worry engineers who contemplated a grid. The fraternity of power experts worked through industry-sponsored voluntary organizations to share experiences, debate approaches, and negotiate standards of practice. Although some utilities adopted analytical, and later digital, computing machines to model power control, many still considered the existing networks to be the best platform for experimenting with new ideas and discerning problems emerging from more widespread integration. Some control issues were too subtle to detect until large numbers of companies moved large amounts of power in real time on the system. By the end of this period, members of the largest and most advanced power pools formed the North American Power Systems Interconnection Committee (NAPSIC) to aid in completing coast-to-coast interconnection.

The growing confidence of electricity experts belied the inherent fragility of this technology. From the industry's perspective, bigger networks moving more power were inherently robust. Utility leaders firmly believed that greater interconnections limited the likelihood that any service area would lose power during a local failure. The success of power operations in the United States garnered international attention, and industry experts traveled the globe to trade ideas. Yet, during the 1950s, system operators battled many unexpected faults on large networks. While the utilities averted blackouts, the engineers found themselves debating a complex problem with nuanced choices for using automatic control apparatus. Indeed, the potential for system failures only became evident once networks grew sufficiently large to test the sensitive settings on the apparatus. Further, while the experts engaged in debates until they reached consensus at one point in system development, years later they returned to the same set of issues as new aspects of operating larger and more complex grids re-opened the discussion.

While utilities actively promoted increased consumption during these years, especially by advertising the benefits of an all-electric society, a conservation discourse around waterpower, long-distance transmission, and interconnection continued. Although Progressive Era style conservation movements were fairly quiet during the mid-century, advocates for large federal dams still described the advantages to the public in terms of maximizing the use of every drop of water before it reached the sea. Similarly, politicians and utility leaders promoting giant transmission lines, such as the Northwest-Southwest Intertie that was first proposed in 1919, argued that the projects would allow the industry to alternate between energy sources based on availability, thus conserving both water and hydrocarbons. Engineers focused on interconnections in particular, and developed methods for improving energy efficiency through more exact load distribution and frequency control. In the 1964 Power Survey, Progressive Era conservation ideas dominated the proposals for this blueprint for national interconnection. The authors of the survey explicitly linked "conservation" with increased consumption. They also bragged that the power industry had taken a leading role in water pollution control and that interconnections would reduce air pollution.[7]

The grid developed along a fault-line between massive consumption and ecological damage. The Kennedy administration authorized the National Power Survey during a brief revival of Roosevelt-era conservation ideas in the public discourse. This had been a part of Kennedy's effort to woo western states during his presidential campaign. But by 1964, the public focus was already shifting to broader environmental concerns, as evidenced by the fleeting attention given to pollution in the power survey. The publication of Rachel Carson's *Silent Spring* in 1962, widespread concern about the fallout from nuclear bomb testing, smog in urban areas, and a growing popular understanding of ecology and the interrelationship of human technologies and changes in the natural world all contributed to a new environmental era. The stature of utilities and electricity experts, while high in 1964, was about to take a fall in the coming years.[8]

The 1964 National Power Survey embodied the accomplishments, shortfalls, and hubris of the power industry as a whole. The survey laid out a plan for interconnecting from coast-to-coast that would ensure ample power at a low cost for consumers across the country while conserving vital resources. The past progress of the power industry displayed the know-how of engineers, the sufficiency of regulatory structures, the capability of managers, and the public-mindedness of utilities. While the survey identified shortcomings in North America's programs of electrification, it expressed no doubt that the coming years would bring about solutions to problems both technical and non-technical. With NAPSIC in place,

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[7] Ibid.
[8] Melosi, "Environmental Policy."

treaties to guarantee the movement of power across the US/Canadian border, and just the right blend of government and private sector involvement, the electric future looked secure.

Bookmarked by the advent of war and the appearance of the National Power Survey, the years 1940 to 1965 were regaled as the heyday of electrification. The war prepared the industry to meet massive industrial and economic growth. Individual power companies still pursued a sustainability paradigm built around energy efficiency, resource conservation, and increasing consumption. Private producers formed ever-larger power pools to oversee interconnections and to share information about independent plans for growth. The creation of NAPSIC formalized the industry's approach to self-regulation. The National Power Survey declared, "There are no insurmountable obstacles to the successful operation of large interconnected systems."[9] This assessment came just before the first major blackout hit North America in November 1965, shattering the industry's confidence in the established system of interconnection.

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[9] Federal Power Commission, *National Power Survey: A Report*, p. 167.

Chapter 6. How War Shaped the Grid, 1940-1945

World War II, even more than World War I, brought industry and government together to advance the cause of interconnection in North America. During World War I, the power industry cooperated with the federal government to direct electricity to war industries. In the early 1940s, once again, the federal government, with the aid of utility executives, centralized coordination of power systems across the continent in order to maximize the electricity available for war production. By the time the United States entered combat, private utilities abandoned opposition to government oversight and complied with the orders issued by war agencies. Because lead times for construction of new generating facilities ranged from eighteen months to several years, both government and utilities used interconnections to access excess capacity and deliver it to industrial centers. Central governments also directed manufacturers to areas with known overcapacity in power systems.[1]

Following the war, engineers credited interconnections with allowing the United States to maintain industrial supremacy. Further, they credited the technical demands of the larger power pools with solidifying advances in power control technologies. As the chairman of the War Production Board reflected, "We never once had to slow down production because of any lack of electric power."[2] The power industry prided itself with meeting both war production needs and civilian power demands during the war years. The fraternity of technical experts added to the self-congratulations. The engineers and system operators

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[1] Federal Power Commission, *Twentieth Annual Report of the Federal Power Commission* (Washington, DC: Government Printing Office, 1941), p. 1.

[2] Donald M. Nelson, *Arsenal of Democracy: The Story of American War Production*, ed. Frank Frieidel, Da Capo Press Reprint Series (New York: Da Capo Press, 1973), p. 365. Donald M. Nelson served as director of priorities for the Office of Production Management from 1941-1942, then as chairman of the War Production Board from 1942 -1944, until it was replaced by the Office of Production Management.

advanced the technologies of automated control, improved techniques for sharing power across interconnections, and maintained stability on the newly enlarged power pools.[3]

Consolidating Central Control

During the early years of World War II, utility executives resisted efforts by the Roosevelt administration to commandeer power planning. The private sector expressed great confidence in its ability to match the anticipated rise in demand for electricity as the country geared up for war. Throughout 1940, industry leaders assured the public that the "government can count upon the availability of an adequate power supply for national defense without the need for expenditures or other special measures on its own account."[4] Utility leaders claimed, "Private power resources are equal to the demands of national defense and require no assistance from … government funds."[5] Industry had a "tremendous undisclosed" surplus of power that could be "brought in through interconnection."[6] Because holding companies and the federal government were still in the throes of untangling utility relationships under the 1935 Public Utilities Holding Company Act, utility owners took pains to clarify that physical integration would not equate to corporate integration.[7]

While utility leaders called power for arms ample, they failed to anticipate the effects of drought and regional power shortages on federal participation in power planning. Some analysts viewed the pre-war industry as unstable, and both physically and financially

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[3] Cohn, "Recollections of the Evolution of Realtime Control Applications to Power Systems."
[4] Thomas P. Swift, "Utilities Geared to Aid Defense," *The New York Times*, June 5, 1940; Swift, "Defense Is Theme of Utility Session," *The New York Times*, June 2, 1940; Swift, "Utilities Pledge Aid for Defense," *The New York Times*, June 6, 1940; "Defense of Nation in War Discussed," *The New York Times*, January 16, 1941; H. S. Bennion, "Electric Power in American Industry," *Military Engineer* 32, no. 186 (1940); M. W. Smith, "War Emergency Power from Present Systems," *Electrical World* 112, no. 3 (1939).
[5] "Sees Utilities Set for Defense Task," *The New York Times*, August 10, 1940.
[6] Ibid.
[7] Ibid.

unprepared when "confronted with new, and in some regions unprecedented, need for its highly essential product."[8] For example, on June 27, 1941, the Federal Power Commission (FPC) recommended curbing the use of electric energy in the southeastern states. With greater defense production than expected in the South, and a drought, the FPC urged citizens and utilities to limit nondefense uses. On the same date, the Commission issued seven orders for utilities in southeastern states to interconnect. Policy experts expected the federal government to flex even greater oversight both during and after the war to effect regional grids. Reluctant to depend entirely upon the intelligence and goodwill of the private sector, the Roosevelt administration took additional steps to assure some federal control over the electric power system.[9]

Various federal agencies had been actively preparing for war through the end of the 1930s. While the locus of government control remained unresolved through 1940 and early 1941, Leland Olds, Chairman of the Federal Power Commission (FPC) called a series of meetings with utility executives in June 1941 to assess the power situation. Olds held meetings in the Northeast, Atlanta, Chicago, Portland, and Denver. Describing a power emergency, Olds stated, "I cannot overemphasize the gravity of the present power situation."[10] Following the FPC meetings, the US Office of Production Management established a special unit, headed by James A. Krug, chief power engineer with the

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[8] Hunt, *The Power Industry and the Public Interest, a Summary of a Survey of the Relations between the Government and the Electric Power Industry*, p. 217

[9] "Power for Arms Is Called Ample," *The New York Times*, August 30, 1941; Federal Power Commission, *Opinions and Decisions of the Federal Power Commission, with Appendix of Selected Orders in the Nature of Opinions* (Washington, DC: United States Government Printing Office, 1943), pp. 990-999; "Utilities Are Seen Facing More Curbs," *The New York Times*, December 26, 1942.

[10] "Parleys to Weigh Power Emergency," *The New York Times*, June 2, 1941.

Tennessee Valley Authority (TVA), to "handle all defense power problems."[11] Krug announced plans to create giant power pools in the southeast and the New York/New England areas to supply major aluminum and magnesium production efforts. "The day of emergency is here," Krug explained, "Reserves long provided for such contingencies must now be called upon to the limit of their capacity."[12]

Roosevelt consolidated his administration's authority over power systems through 1941 and 1942. The TVA deployed engineers to New York to assist with interconnection between several very large private operations including Commonwealth Edison, the Niagara Hudson Power Corporation, and the Pennsylvania-New Jersey Power Pool. The Securities Exchange Commission acted in November 1941 to facilitate financing for private utilities seeking to interconnect, just before the United States formally joined hostilities.[13]

In January 1942, Roosevelt created the War Production Board (WPB), which subsumed the Office of Production Management and gained greater authority over private industry activities. In April, Roosevelt conferred additional authorities on the WPB, allowing it to allocate equipment for power development, determine supply and demand for war and civilian purposes, take over planning in districts with limited power supply, and work out arrangements to assure electricity would be available for war industries. The FPC would

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[11] W.H. Lawrence, "Power Unit Set up to Spur Defense," *The New York Times*, July 22, 1941.

[12] Funigiello, *Toward a National Power Policy; the New Deal and the Electric Utility Industry, 1933-1941*; Federal Power Commission, *Nineteenth Annual Report of the Federal Power Commission* (Washington, DC: Government Printing Office, 1940); Federal Power Commission, *Production of Electric Energy and Capacity of Generating Plants*, (Washington, DC: Government Printing Office, 1941); Federal Power Commission, *Twentieth Annual Report of the Federal Power Commission*; G. S. Lunge, "Carrier Telemetering with Metameter," *General Electric Review* 43, no. 8 (1940). Quote in Lawrence, "Power Unit Set up to Spur Defense."

[13] "Power Emergency Seen," *The New York Times*, December 17, 1941; Thomas P. Swift, "Pooling Speeded in Electric Grid," *The New York Times*, August 3, 1941; Hunt, *The Power Industry and the Public Interest, a Summary of a Survey of the Relations between the Government and the Electric Power Industry*; "Utility Program Speeded by SEC," *The New York Times*, November 9, 1941.

"make suggestions" to the WPB while continuing with its ordinary responsibilities, but only ordering interconnections after conferring with the WPB. During 1942, the FPC waived one of its key interconnection policies and allowed intrastate companies to join interstate pools without falling under federal regulatory control. In numerous orders approving emergency interstate interconnections, in particular many affecting Texas utilities, the FPC provided an exemption that would cease to be in effect ninety days after the end of the war. The FPC also began closer management of power sales across the US/Canada and US/Mexico borders. By December 1942, federal war agencies had already commandeered significant authority over power systems.[14]

The Dominion government of Canada likewise consolidated authority in the central government for power production during the war. Canadian involvement in hostilities officially began in September 1939. The Dominion government focused on accelerated development of hydroelectric facilities in order to meet war production demands for power. The Canadian power utilities shared a commitment to meeting war production needs, doing

[14] Exec. Order No. 9024, 7 FR 302, January 16, 1942; "Power Authority Received by WPB," *The New York Times*, April 30, 1942; "FPC Waives Policy on Power Connections," *The New York Times*, October 17, 1942. This policy shift proved significant for utilities in Texas. While many Texas utilities joined in one of the larger pools during the war years – the Southwestern Pool – that stretched north to Nebraska and east to the TVA, most withdrew after 1945. The private utilities preferred to avoid federal regulation for the long-term. In 2012, Texas continues to operate an independent power pool, beyond the reach of FERC regulation. Federal Power Commission, *Opinions and Decisions of the Federal Power Commission, with Appendix of Selected Orders in the Nature of Opinion*, 1943; Federal Power Commission, *Opinions and Decisions of the Federal Power Commission, with Appendix of Selected Orders in the Nature of Opinions*, (Washington, DC: United States Government Printing Office, 1944); Federal Power Commission, *Opinions and Decisions of the Federal Power Commission, with Appendix of Selected Orders in the Nature of Opinions*, (Washington, DC: United States Government Printing Office, 1946). In some cases, the Commission permitted companies on the Niagara River to divert more water for power than previously allowed. For example, Federal Power Commission, *Opinions and Decisions,* 1943, p. 1069. In others power sales were either curtailed or expanded in order to accommodate war production activities on either side of the border. See, for example, Federal Power Commission, *Opinions and Decisions*, 1944, pp. 615 and 637.

their "potent share for the allied cause."[15] In 1942, the central government passed the War Measures Act, establishing a prices and trade board. By that year, waterpower development had succeeded in meeting war needs with the installation of extra generating equipment, diversion for power production at Niagara, conversion of steam plants to electric plants, and continuation of daylight savings time. Transmission line extensions and interconnections further facilitated the exchange of hydroelectric energy in certain areas.[16]

By 1944, one third of Canada's waterpower installations provided electric power for war production. Interconnections also played a key role in moving energy from US power producers to Canadian centers of manufacture. Canadian power experts determined that the country's power program was "virtually completed" by 1944 and anticipated a post-war power system that would be well poised to aid in the development of new industries and "for the rebuilding of a happier world."[17] As had happened in the United States, Canadian power companies collaborated with government agencies to improve electrical production specifically for wartime needs. This resulted in rapid harnessing of the nation's waterpower resources. Canadians had improved access to the nation's energy wealth and was well on the road to turning those resources to domestic use. For Canada's government and utilities, the future offered the bright prospect of enormous reserves of yet undeveloped waterpower even after the war.[18]

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[15] D. C. Durland, "Electrical Industry Must Expand to Meet War Production Needs," *Electrical News and Engineering* 49, no. 1 (1940).
[16] A. E. K. Bunnell, "War Time Control of Utilities," *Engineering and Contract Record* 55, no. 17 (1942); "Hydro-Electric Power Development," *Modern Power and Engineering* 36, no. 4 (1942), p. 35.
[17] "Hydro 1944," *Modern Power and Engineering* 39, no. 3 (1945).
[18] W. R. Way, "Power-System Interconnection in Quebec," *Electrical Engineering* 61, no. 12 (1942).

Pooling Beyond "Mere Puddles"

Participants in both government and utility planning circles quickly understood that interconnection provided the only rapid route to essential power resources. While the utilities resisted direct federal control of their activities, they participated in planning activities. By 1939, the FPC, in cooperation with private utilities, had mapped out power supply areas for defense work, where to interconnect and exchange power, and how to protect against hostile acts. With modeling and testing provided by private utilities, the FPC "investigated the feasibility of a system of high capacity transmission interconnections … with a view to the more economical use of existing capacity and greater assurance against interruption of service in any one of the important centers of defense production."[19] The FPC also surveyed twenty-five geographically defined power supply areas essential to industrial defense production to assess the economic feasibility of interconnection and coordination.[20]

Interconnection offered multiple advantages for defense preparation. With interconnections, utilities avoided new plant construction by sending excess power from areas with low industrial activity, like New York City, to regions with intense war production, like upstate New York. Large power pools took advantage of diversity of types of generators, types of customers, time zones, and regional rainfall differences. Further, by avoiding new plant construction, the WPB could divert material resources and manpower to the construction needs of defense industries. Finally, interconnection allowed power pools to prepare for direct attacks, sabotage, or other causes of outages that might cripple defense producers. "If a plant is put entirely out of commission, the only immediate replacement can

[19] Federal Power Commission, *Twentieth Annual Report of the Federal Power Commission*, p. 6.
[20] Ibid.

come from interconnections."[21] While private utilities had created interconnected systems during peacetime to achieve operating economies, conserve natural resources, and increase reliability, these pools were "mere puddles" when compared with the power pools effected for national defense.[22]

Pooling took place both at the behest of the federal government and through private utility initiative. Between 1941 and 1944, the FPC ordered 52 interconnections, the majority during the first two years, many in the Northeast, the TVA area, Texas, and the Pacific Northwest. The southeastern United States served as the testing ground for accelerating interconnections. Over the prior decade, area utilities had built extensive interconnections, but did not generally practice regional coordination. Following a severe drought during the summer of 1941, the power branch of the Office of Production Management issued Limitation Order L-16, which directed interconnected utilities to maximize flow to areas serving defense industries in the Tennessee River Valley. This resulted in a forty percent increase in power availability in the drought-stricken region. Evidently, not all consumers appreciated the focus on military use of electricity over domestic use. They must have resisted requests to curtail residential electricity use because one utility in Tuscaloosa published ads to explain to customers the need for cutbacks even when there appeared to be

[21] "Defense of Nation in War Discussed." Quote from paper by Philip Sporn, read by H.S. Bennion to the American Society of Civil Engineers 88th annual meeting.
[22] P. W. Swain, "Power Teamwork for Victory," *Power* 86, no. 9 (1942), p. 63, 66; W. C. Heston, "Kilowatt-Hours Pooled for War," *Electrical West* 92, no. 3 (1944), p. 51; Swain, "Power Teamwork for Victory," p. 67. Heston, "Kilowatt-Hours Pooled for War," p. 51; "Defense of Nation in War Discussed"; "Utilities Ready for Raids," *The New York Times*, March 5, 1942; C. S. Lynch, "Southwest Power Pool," *Electric Light and Power* 20, no. 8 (1942), p. 41.

no shortage of local power. Interconnections followed in the northeastern corridor, in Texas, and between several Midwestern states in 1942.[23]

In some cases private utilities jumped ahead of federal agencies to facilitate electrification of war industries. For example, Arkansas Power & Light Company learned in May 1941 that Arkansas was under consideration for a large aluminum producing facility. The utility organized a pool with eleven neighboring companies in eight nearby states and proposed interconnection plans to the WPB, in direct competition with a similar proposal from the Rural Electrification Administration. Ultimately, the WPB approved a compromise plan that incorporated government and private entities. The War Production Board, however, curtailed some interconnections to conserve copper that would otherwise be used in transmission lines.[24]

In another example, Ebasco Services, Inc., a subsidiary of GE's Electric Bond and Share Company, proposed to the US government a comprehensive plan to link isolated and municipal plants into existing power pools and increase capacity for war production. The 1942 study amply illustrated the amount of additional power available from existing plants through improved load factor and greater economy in operations. Similarly, without a government push, the Nebraska Power Company and Kansas Gas and Electric Company interconnected in 1942. They built a 270-mile transmission line to aid in war production, increase operating economies in a 31-state power pool, and insure against interruptions. The

[23] Putnam, Israel. "Wartime Prices That Fell - Gas and Electricity." Public Utilities Fortnightly 40, no. 3 (1947): 151-62; "Why Power Curtailment Is Necessary." The Tuscaloosa News, November 5, 1941, 6; "Black-Outs Must Continue So Factories Can Run Full-Time." The Tuscaloosa News, November 26, 1941, 6.
[24] Lynch, "Southwest Power Pool."

public and private power sectors, despite expressions of distrust, worked with each other and federal agencies to increase available electricity.[25]

Big Pools Move Big Power

The interconnections built through federal and private sector cooperation proved critical to meeting defense power demands. All told, through interconnections and careful planning of operations, the government and private utilities together assured that hundreds of billions of kilowatt-hours of electricity traveled across roughly 200,000 miles of power lines to both defense and domestic users. With only a 25-percent increase of installed capacity from 1940 to 1945, the nation's power system generated nearly 60 percent more electricity during the war years. No peacetime era matched this phenomenal record. Only through close coordination of operations and rapid installation of new interconnections could the industry achieve such unusual gains in power production without new power plants.[26]

The Northwest Power Pool, for example, reported an impressive record of power delivery by late 1944. Six utilities created the pool in 1942 and WPB Order L-94 expanded the pool to include Bonneville and Grand Coulee Dams in 1943. Adding only interconnections, not generating facilities, the pool provided power for new defense industries along the Columbia River, including the secret Hanford nuclear facility. The pool linked generating plants across five states – Washington, Oregon, Montana, Idaho, and Utah – and capitalized on the combination of hydroelectric power, steam power, differing time

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[25] Thomas P. Swift, "Plan Is Devised to Increase Power," *The New York Times*, August 9, 1942; "Idle Electric Generating Capacity," *Edison Electric Institute -- Bulletin* 10, no. 7 (1942); L. Elliott, "Meeting Power Demand During War," *Mechanical Engineering* 64, no. 12 (1942); "New Power Line Set up in West," *The New York Times*, September 8, 1942.

[26] Federal Power Commission, *Twenty-Sixth Annual Report of the Federal Power Commission* (Washington, DC: Government Printing office, 1947), p. 1; Sporn, *Vistas in Electric Power*. Reprint of "A Plan for Maintaining Power Supply in a Destructive Emergency," presented to The Industrial College of the Armed Forces, Washington, DC, January 21, 1948, p. 955.

zones, and diverse customers to produce 4.5 million horsepower of capacity around the clock. This equaled the quantity needed "to build one 10,000 ton Liberty ship every day, or turn out (censored) [*sic*] Flying Fortresses a day, or to produce 275,000 pounds of aluminum every 24 hours."[27] Meanwhile, the Southwest Interconnected Power System reached from Nebraska to South Texas, and from Tennessee to New Mexico, an area covering roughly 800,000 square miles. This pool also periodically joined the East Central and Southeast pools to form a "superpool with over 21,000,000 kw of resources."[28]

Cooperation, coordination, and dedication to the defense cause proved to be the hallmarks of successful electrification during World War II. The private sector took pride in utility achievements. The year of peak demand during the war, 1944, "justified all the predictions which the electric utility industry has consistently made as to its ability to supply the war load of the United States."[29] Cooperative action allowed utilities to pool "regional capacity to carry local overloads."[30] Edward Falck, following James Krug as director of the WPB's Office of War Utilities, recognized that for the private sector, "the emphasis … was to assure the maximum co-ordinated use of existing facilities and to minimize the amount of additional generating capacity required."[31] At the same time, government agencies understood the "vital importance of power" and stepped in with "drastic action to bring about full co-ordination of the utility."[32] Falck explicitly noted that utilities arranged operations on

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[27] Heston, "Kilowatt-Hours Pooled for War," p. 51.
[28] Ibid; S. B. Morehouse, "Inter-System Power Coordination in Southwest Region," *Electric Light and Power* 23, no. 12 (1945); Lynch, "Southwest Power Pool." Quote in E. Falck, "Power Pooling During War," *Power Plant Engineering* 49, no. 10 (1945), p. 85.
[29] "1944 Electricity Production Measured Country's War Effort," *Edison Electric Institute -- Bulletin* 13, no. 5 (1945), p. 125.
[30] Swain, "Power Teamwork for Victory," p. 63.
[31] Falck, "Power Pooling During War," p. 84.
[32] J.M. Gaylord, "Integration of Power Systems," *Engineering and Science Monthly* 8, no. 6 (1945), p. 3.

their own to achieve policy directives set forth by the WPB. Engineers working for both utilities and the government "knew perfectly well that operating economies could be effected by cooperation and interchange between systems, and the impetus of a national emergency promptly over came the long-standing resistance to integrated operation."[33]

Bigger Pools, Closer Coordination, Increased Technical Integration

No one approach to interconnection dominated the nation's increasingly integrated power supply during the war years. Through the efforts of the War Production Board, the FPC, the SEC, and private utility executives, several new power pools organized and tackled the challenges of operating interconnected and at maximum capacity for defense production. Regional differences, historical experiences, and particular technical preferences determined how each pool functioned. In the aggregate, however, the utility industry and the engineering community gained significant insights into how to manage and control power exchanges among multiple entities across great distances. The lessons learned helped the industry respond to the post-war industrial boom and the advent of giant power pools in the 1950s.

Operating techniques varied across different regions of the country. Older power pools, like the Pennsylvania-New Jersey interconnect employed a central dispatching organization, that was "merely intensified" during the war. In several regions a "top operating committee," with multiple more localized sub-committees provided system oversight. Examples include the East central region, the Southwest Power Pool, and the Pacific Northwest region. The Wisconsin/Northern Illinois interconnection operated under mostly informal relations. In general, oversight committees provided regular co-ordination through scheduled meetings and weekly telephone conference calls. "Responsible executives

[33] Falck, "Power Pooling During War"; John P. Callahan, "Office Ends Today for War Utilities," *The New York Times*, September 30, 1945. Quote in Gaylord, "Integration of Power Systems," p. 3.

in each of the utilities working in co-operation with the Office of War Utilities were able to carry out the necessary co-ordination throughout the operating departments of their respective systems."[34] Actual power dispatching, however, took place in the control rooms of the participating utilities.[35]

System operators, of course, understood all too well the need for careful control of power exchanges to achieve maximum delivery of power for wartime purposes. "Control of some kind is necessary in order that the power transferred from one system to another over the interconnecting tie lines may conform to plans."[36] By the waning months of the war, automatic frequency control was "now almost universal, and automatic tie line control [was] becoming more and more extensively used."[37] Inadvertent (unscheduled) power exchange was the bogeyman of interconnected systems, resulting in regulating problems and wasted energy. System operators strove to maximize power allocation to war areas and minimize system waste, inventing approaches that later became industry standards.[38]

In the Southwest Interconnected Power Systems Group, the scheme for managing both scheduled and inadvertent exchanges presaged automatic control techniques adopted by the entire industry after the war. The Pool functioned as several discrete control areas, each with a central dispatcher responsible for that area's operations. The area dispatcher handled local load changes, allowing the pool as a whole to control frequency and load on a net interchange basis, a radical approach in the early 1940s. Using data from extensive field

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[34] Falck, "Power Pooling During War," p. 86.
[35] Ibid.; Morehouse, "Inter-System Power Coordination in Southwest Region"; Heston, "Kilowatt-Hours Pooled for War"; Lynch, "Southwest Power Pool." The East central region included Indiana, Ohio, West Virginia, Kentucky, western Pennsylvania, and Virginia.
[36] C. K. Duff, "Control of Load, Frequency, and Time of Interconnected Systems," *Electrical Engineering* 64, no. 11 (1945), p. 778.
[37] Ibid.
[38] The terms "inadvertent" and "unintentional" were both used to describe unscheduled power transmission across interties.

measurements, the technical staff analyzed trends and established generation plans for both intra-area and inter-area power dispatch. "Estimating loads, making units available, and scheduling interchange, are manual operations which require extensive communication."[39] Each area was equipped with telemetering apparatus and reliable communication equipment. With telemetering data that provided accurate information about actual system conditions, "more capacity was gradually assigned to regulation and coordinated results improved correspondingly."[40] Overall, the pool achieved greater and more economic use of available generating and transmission capacity, continuity of service without loss of facilities, less inadvertent interchange between areas, improved system frequency, improved economy at individual stations, and excellent cooperation among participants through a true "good neighbor policy."[41]

In a similar manner, the Northwest Power Pool organized as a single system with multiple operating units. Interconnections in this region dated back to 1915, when the municipal utilities of Seattle and Tacoma built a transmission line for mutual aid. By the early 1940s, the pool encompassed eleven utility systems, both municipal and investor-owned, and two of the world's largest dams, owned by the federal government. In addition to a top operating committee that included one representative from each pool member, a coordinating committee of four engineers conducted studies and supervised pool operations out of a central office. "Controlling the energy in a Goliath such as this super power pool requires high operating skill and expert dispatching along with careful scheduling of power

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[39] Morehouse, "Inter-System Power Coordination in Southwest Region," p. 65.
[40] Ibid., p. 67.
[41] Lynch, "Southwest Power Pool." Quote in Morehouse, "Inter-System Power Coordination in Southwest Region," p. 105.

exchanges."[42] The coordinating committee used historical data and network analyzers to simulate operating conditions and transmission line faults before scheduling interchanges. Automatic telemetering and tie line load and frequency control apparatus aided the process. Grand Coulee usually served as the frequency controller for the entire system. As a result, "variations in frequency [were] less for the pool as a whole than formerly under separate system operation."[43] The committee scheduled interchanges on an hourly basis, with a goal of net deviation from schedule, between operating units, of zero. While the Northwest Power Pool had not yet embraced frequency and tie line load control on a net-interchange basis, the participants moved in that direction.

The lessons of the new pool operating experiences included numerous unsolved challenges. While the systems achieved phenomenal improvements, "interconnected operations of many power systems throughout the country [were] still in the pioneering stage."[44] For example, the problem of inadvertent interchange, while partially resolved, continued to plague engineers and system operators. Both automatic control settings and manual control decisions could cause unscheduled power shifts. Engineers accurately predicted that larger power pools, including hundreds of units, would experience these problems on a magnified basis. By the end of 1945, systems experts defined a need for further study, modeling, and practice in the field of automated control. Nonetheless, the advances brought about by the exigencies of war hastened the development of net tie line bias control, the operating standard of the industry for the coming decades. As utility executive Robert Brandt described, "No scheme has been devised yet which will permit tie

[42] Heston, "Kilowatt-Hours Pooled for War," p. 59.
[43] Ibid.
[44] Morehouse, "Inter-System Power Coordination in Southwest Region," p. 68.

lines to be scheduled for loads as near to their operating limit as this one and this, of course, was extremely important during the war."[45]

Poised for Expansion

The concerted effort to integrate generating and transmission systems created an extraordinary situation for power producers at the end of the war, either they had overbuilt for a post-war economic bust, or they were underprepared for a post-war boom. Two issues had plagued utility executives as they addressed wartime electricity demands. First, although they had initially proposed expanding generating facilities by 10,000,000 kW, industry leaders feared finding the industry in a state of overcapacity as the war ended. The War Production Board limited planned expansion of generating plant to 5,500,000 kW, in 1942, but this did not completely eliminate the potential problem. Second, the strategy of relying on interconnections to increase available power for war production led directly to a drop in generating reserves. In the late 1940s, the industry operated with the lowest reserve capacity in decades, creating a high risk for blackouts and brownouts in the face of sudden high demand. In the end, greater capacity and extended interconnections, however, allowed utilities to meet an unprecedented and unexpected surge in domestic demand in the late 1940s.[46]

Amid the push for more power, utility executives waffled on the question of overbuilding. As noted in the 1942 Ebasco report, "utilities … usually tried to prepare for all expectable load … and a large number of power developments, aggregating millions of kilowatts, have been projected. … there is the possibility or even probability that large excess

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[45] Ibid. Quote in Brandt, "Historical Approach to Speed and Tie-Line Control," p. 8.
[46] Elliott, "Meeting Power Demand During War," p. 873.

capability will be available with the dropping off of war load."[47] In 1944, Philip Sporn acknowledged the possibility that "installed electric capacity immediately after the war may be anywhere from three to seven years ahead of the long-term trend."[48] Regional differences affected the engineers' assessment of capacity growth. Some Canadians saw the excess as an opportunity in general that, "in a reasonable time should become fully absorbed by reconversion."[49] In parts of Quebec, however, "an inordinate surplus may develop unless new uses for aluminum and adequate export markets" create demand, or "new industries employing heavy waterpower consumption can be attracted to the area."[50] In the Pacific Northwest, the additional capacity created through interconnection was "a war drama with peacetime implications that can have a far reaching influence on the industrial future of this region."[51] The Edison Electric Institute went so far as to congratulate the industry for approaching the end of the war "with no great overcapacity of generating plant."[52]

While utility operators feared the financial burdens imposed by excess capacity, they equally dreaded operating with insufficient reserves. Power producers historically relied on reserves to meet peak loads, to address incidents of unexpectedly high demand, to aid in emergencies, and to allow scheduled shutdowns for repairs and maintenance. Before the war, US utilities boasted a 26 percent generating reserve capacity. Because the War Department held expansion of generating capacity to a minimum, and the industry maximized the use of installed capacity through interconnections, operating reserves fell steadily. By 1943, the reserve had dropped to 13.2 percent, and after the war, hit an all-time low of under five

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[47] Ibid., p. 873.
[48] Sporn, *Vistas in Electric Power*. Reprint of "Realism in Post War Planning," *Electric Light and Power*, June 1944, p. 295.
[49] "Hydro 1944," p. 73.
[50] Ibid.
[51] Heston, "Kilowatt-Hours Pooled for War."
[52] "1944 Electricity Production Measured Country's War Effort," p. 126.

percent. Industry specialists preferred a reserve of at least 15 percent to assure adequate capacity to address all eventualities. In the post-war years, utility managers responded by carefully managing system operations and taking full advantage of interconnections while awaiting new and larger power plants.[53]

Advances in managing interconnections placed utilities in an excellent position to meet post-war demands with great flexibility. Experiences with large power pools in the Southeast, the Southwest, the Pacific Northwest, and the mid-west demonstrated that utility operators could control and deliver power on a timely basis to specific regions. The use of biased tie line and frequency control apparatus, and in some cases, the further use of early net-interchange procedures, allowed operators to manage power flow with a minimum of system interruption. Neither the central governments, nor the utility industry knew what to anticipate heading into the late 1940s. Power pools, control technologies, and war experiences, however, proved ready for the tasks of reconversion, and later, domestic industrial and economic expansion.[54]

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[53] Sporn, *Vistas in Electric Power*, Reprint of "A Plan for Maintaining Power Supply in a Destructive Emergency," Presented to The Industrial College of the Armed Forces, Washington, DC, January 21, 1948, p. 955; Walker L. Cisler, "Electric Power and National Defense," *Electrical Engineering* 67, no. 4 (1948). According to the Federal Power Commission, drops in reserves took place incrementally, from 26 percent in 1939 to 15.4 percent by the end of 1940 to 9.5 percent at the end of 1944. *Electric Power Requirements and Supply in the United States, 1940-1945: War Impact on Electric Utility Industry* (Washington, DC: Federal Power Commission, 1945); "Shortages of Reserve Capacity Tax Systems' Capabilities," *Electrical World* 128, no. 21 (1947); W. J. Lyman, "Determination of Required Reserve Generation Capacity," *Electrical World* 127, no. 19 (1947); H. W. Phillips, "Determination of Reserve Requirements for Interconnected System," *Edison Electric Institute -- Bulletin* 14, no. 4 (1946).

[54] Biased tie line and frequency control apparatus allows utilities to aid each other briefly when frequency varies from the standard of 60 Hz, but then acts to stabilize the system. Systems that operated on net-interchange acted to maintain constant frequency within a defined area, but not across the tie line to the next area.

Summary

The utilities provided a triumphal account of their role in winning World War II. Philip Sporn credited the companies with meeting the production demands of the war industries without ever shorting the domestic consumer. Experiences on the ground may have been different. The Tuscaloosa advertisements explaining the need for residential energy conservation suggest that power shortages frustrated utility customers when their region seemingly had plenty. When the REA competed directly with Arkansas Power and Light Company to provide electricity for a wartime aluminum factory, it was clear that public/private partnerships were not always congenial. Nonetheless, the physical evidence of expanded grid systems and a rapid increase in power production, without a matching increase in generating capacity, suggests that overall the utilities did accomplish a great deal.[55]

In fact, the private power companies and the federal government entered a phase of unprecedented cooperation during the war years. Although the utilities quickly dismissed the oversight of federal agencies by the late 1940s, they learned important lessons from the collaborative experiment. Through interconnection, utilities speedily expanded their power markets during the war, and they continued to employ this strategy to address the post-war industrial boom. Individual companies continued to share power while strategically planning new plant infrastructure in the late 1940s and 1950s. This allowed the companies to reap steady profits from rapidly increased consumption, even before they built larger and more efficient generators and tied into new federal dam projects. System operators moved closer to perfecting techniques for controlling load and frequency on fully operational tie lines. The utilities formed giant power pools in the 1950s to capitalize on interconnections, share

[55] Sporn, *Vistas in Electric Power*, p. 12; "Black-Outs Must Continue So Factories Can Run Full-Time," *The Tuscaloosa News*, November 26, 1941; "Why Power Curtailment Is Necessary," *The Tuscaloosa News*, November 5, 1941; Lynch, "Southwest Power Pool."

techniques for managing the grid, avoid government oversight, and retain autonomy over their own operations and profits.

The war experiences illustrated to both government and utilities the efficacy of centrally directed planning and highly coordinated power production and distribution. Private utilities, however, still commanded the vast majority of the electricity market, and quickly returned to independent operations and profit-seeking. Notably, of the forty-five emergency interconnections ordered by the FPC during the war, all but seven were abandoned by 1947. The war represented extraordinary times, and in ordinary times in North America, capitalist enterprises, even regulated monopolies, preferred minimal government interference. As a result, individual utilities expanded regionally, to address their separate market opportunities, whether or not those plans matched widespread trends. This is not to suggest that the utility owners operated in a vacuum. If anything, electricity experts shared information even more vigorously than they had in the past. Instead, this illustrates that what appeared to be an inevitable direction of growth was not pursued in a unified manner. Even though a 1946 map shows dense networks of electric transmission lines in the east and west, power companies expanded interconnections primarily to suit their own bottom line interests.[56]

During the war, power plant operators and engineers learned in greater depth the shortcomings of past approaches to automated power control and the capabilities of new techniques. Several of the large power pools experimented with the newest approaches to load and frequency management and demonstrated, for the larger industry, that distributed control worked. Entering the post-war years, engineers focused on making distributed control an industry standard. In addition, problems emerging from the operation of much larger

[56] Gray, Horace M. "The Integration of the Electric Power Industry." The American Economic Review 41, no. 2 (1951), p. 545.

power pools with greater quantities of electricity moving across the network defined the challenges that lay ahead. In addition to responding to an industrial boom with new power plants and power lines, the system operators and engineers would soon discover that this seemingly robust approach to growth revealed fragility within the system.

Chapter 7. Growing Interconnected: Expansion from 1945 to 1965

During the two decades following World War II, the power industry not only grew, and faster than the economy as a whole, but also grew interconnected. In other words, government and private utilities alike invested in more and higher capacity long-distance transmission lines, they linked those lines through interties, and they formed larger power pools to oversee operations. Further, the interties remained closed for greater periods of time as more power exchanges occurred. The industry again joined in promotions to increase electricity consumption. Interconnections permitted utilities to meet demand without pause. The emerging grid boasted improved reliability, greater resource conservation, and expanded capacity, all at the same time.

By the end of the war, the skeleton of high-voltage power lines crossing the continent offered a clear indication of the direction of future growth. (See Map C, p.237) If power companies continued to build interconnections, a coast-to-coast grid appeared inevitable. In fact, encouraged by the wartime experiences of providing more power through interconnection, utilities did choose to expand power pools. As had been the case through the previous decades of electrification, no central authority commandeered the process of building a grid. At the same time, there was no significant political or economic pressure to reverse the trend toward integration. Growth continued on a piecemeal basis, but at a very rapid pace. Utilities shared common goals in their expansion projects, including improved reliability, improved operating economies, and greater access to diverse markets and resources. These goals remained unchanged through the mid-century. But within different regions, power pools looked quite distinct from each other. This suggests that while the industry was moving toward a grid, the process was marked by individual choices unique to each power pool. In fact, industry experts did not begin to forecast coast-to-coast interconnections until the late 1950s.

During these years, utilities relied heavily on system operators and manufacturers to collaborate on techniques for managing power sharing. The interconnected systems grew to be very large and complex, and the older technologies for controlling power flow became obsolete. The fraternity of experts developed new and better apparatus for managing electricity interchanges. They adopted more sophisticated instruments, including digital computers, for analyzing and modeling system behavior. And they formed organizations through which they could share operating standards and techniques. Nonetheless, the nature of the failures taking place, particularly in the 1950s, indicated that interconnected power systems harbored underlying weaknesses. While there were no major blackouts, operators and engineers tackled an array of challenges to stable and reliable electricity. These same experts, nonetheless, touted their accomplishments and expressed great confidence in the future of interconnected power systems.

Power Systems Growth and Intensifying Networks

A brief post-war depression marked economic activity in North America, but electrification picked up even before new industrial growth could take place. In the United States, during a period of reconversion to peacetime economies, industrial production dropped in 1946 and did not reach wartime levels until 1948. Production fell again in 1949 and then began steady growth in the 1950s. By contrast, the pace of US power production slowed in the opening months of 1946, picked up speed by August, and exceeded the prior year's activity by December. Power production then exploded in 1947 and grew at an average rate of 44 percent increase every five years for the next two decades. Table 7.1

illustrates the percent change in power production compared to industrial activity and population growth in the United States during the post-war years. The growth in power production took place independent of the rise and fall of industrial activity, and the steady but slower growth in total population. The extra capacity for power production created during the war, especially through interconnections and extended operation of existing plants, met immediate post-war demand. Mostly residential customers, but some commercial customers as well, sought electricity for new appliances and for extended use of lighting and motors.[1] As economic activity accelerated, the power industry added momentum to electricity growth through active marketing. Promotions for all night illumination of restaurants, air conditioning of schools, and all electric kitchens added demand for both manufacturers and power producers. Utilities charged promotional rates to increase residential consumption. In the 1940s, over 200 companies adopted Reddy Kilowatt, an advertising slogan developed during the prior decade to advance the cause of electrification. General Electric began a "Live Better Electrically" campaign in the 1950s and identified "Medallion Homes" that married maximum electrical use to lower rates. For the utilities, bigger loads justified the

[1] Board of Governors of the Federal Reserve System Data Download Program, "G.17 - Industrial Production and Capacity Utilization," (Object Name Frb_G17), accessed March 14, 2012, http://www.Federalreserve.Gov/Datadownload/Choose.Aspx?Rel=G17; *Historical Statistics of the United States, Colonial Times to 1970, Bicentiennial Edition, Part 2* (Washington, DC: Government Printing Office, 1975); Federal Power Commission, *Twenty-Sixth Annual Report of the Federal Power Commission*. The Canadian experience differed. Industrial production dropped, by a smaller amount, in 1946, then rose well beyond wartime levels in 1947. Growth in Canadian power production followed industrial expansion throughout the next two decades. "Historical Statistics of Canada, Section A: Population and Migration; Section F: Gross National Product, the Capital Stock and Productivity; Section Q: Energy and Electric Power; Section R: Manufactures," Statistics Canada, last modified February 28, 2012, http://www.statcan.gc.ca/pub/11-516-x/3000140-eng.htm; Rose, *Cities of Light and Heat: Domesticating Gas and Electricity in Urban America*, p. 172; Nye, *Consuming Power: A Social History of American Energies*, p. 204.

construction of bigger power plants, and bigger power plants in turn encouraged greater interconnection.[2]

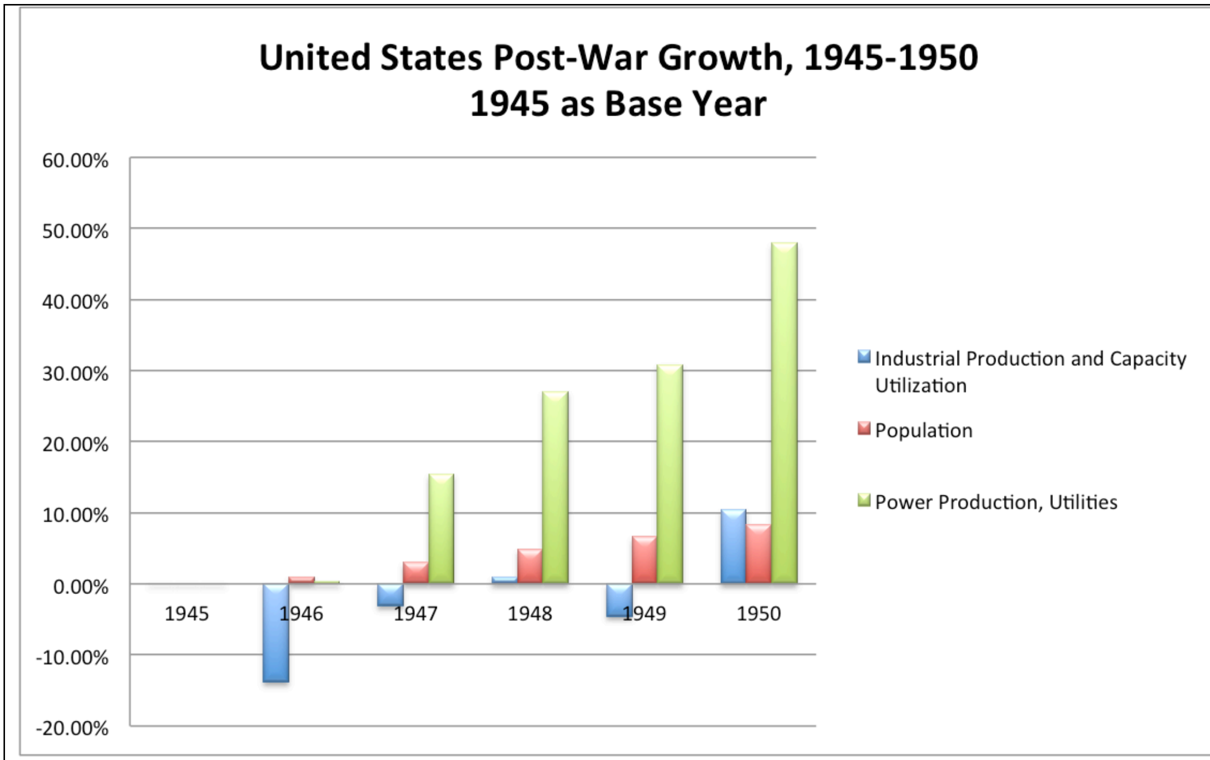

Table 7.1. United States growth in population, industry, and power production, 1945-1950. *Sources:* Data from Federal Reserve System Industrial Production and Capacity Utilization and Bureau of the Census, *Historical Statistics of the United States, Colonial Times to 1970*.

Increases in the size of transmission lines and the number of interconnections accompanied the economic expansion experienced by the United States and Canada between 1945 and 1965. In 1940, just below 3,000 miles of the highest voltage transmission lines (230 kV and 287 kV) crossed the United States. That number increased nearly nine-fold by 1965. Utilities installed ever-larger generating plants, federal agencies built huge dams, and ventures into nuclear power quickly scaled up from small plants to large. A century-long

[2] Rose, *Cities of Light and Heat: Domesticating Gas and Electricity in Urban America*, pp. 173-174; Hirsh, *Technology and Transformation in the American Electric Utility Industry*, pp. 48-51.

trend favoring economies of scale and mass production touched the power industry as well as most other industries in the United States.[3]

Transmission lines with voltages of 60,000 or above crossed the country like a virtual web by 1960. Map C (p. 237) makes the growth of the power network visually clear. At the end of the war, significant interconnections served industrial and urban centers. Fifteen years later, power lines nearly covered the entire country, with the exception of parts of the arid and sparsely populated western states. Not only did utilities spread their tentacles across long distances and at higher voltages, they also built interties allowing power sharing across larger regions. Federal Power Commission maps, reproduced in Map 7.2, suggest the extent to which utilities closed the gaps in parallel operations during the post-war years. It is telling to compare the 1939 map and the 1967 map. In 1939 many small, interconnected systems served various regions of the country, and large areas appeared to have no electric service. In 1967 there appears to be a single giant grid that reaches from coast-to-coast, excluding Texas and a corner of New Mexico. The shaded areas represent general regions in which systems operated interconnected, but parts of those regions were not integrated into the networks. Nonetheless, by the mid-1960s, most utilities could exchange power, at least in an emergency.[4]

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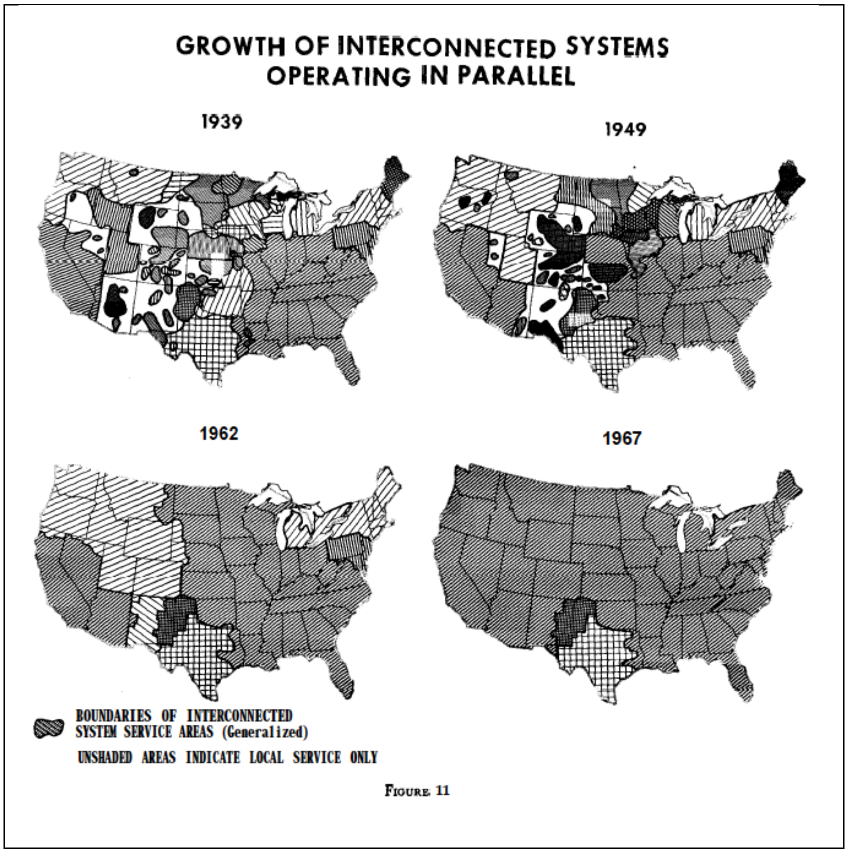
[3] Federal Power Commission, *Nineteenth Annual Report of the Federal Power Commission*. Before World War II, the majority of transmission lines operated at 161 kilovolts or below. The extra-high-voltage lines operating at 230 or 287 kilovolts were located primarily in the western states, transmitting power from hydroelectric dams across long distances to markets. A surge in construction of higher voltage lines began in the early 1950s to carry power in the West Virginia/Ohio area and on the Bonneville Power System. Federal Power Commission, *National Power Survey: A Report*, p. 149; Federal Power Commission, *Prevention of Power Failures: An Analysis and Recommendations Pertaining to the Northeast Failure and the Reliability of U.S. Power Systems; a Report to the President*, 3 vols. (Washington, DC: Government Printing Office, 1967); Hirsh, *Technology and Transformation in the American Electric Utility Industry*, p. 81.

[4] Federal Power Commission, *Prevention of Power Failures: An Analysis and Recommendations Pertaining to the Northeast Failure and the Reliability of U.S. Power Systems; a Report to the President*, p. 35.



Map 7.1 Areas of United States served by interconnected power systems. *Source:* United States Federal Power Commission, *Prevention of Power Failures,* 1967, P. 35.

By 1965, nearly 200 major systems or pools aggregated power from the vast majority of the 3,600 entities producing power in the United States. In fact, 97 percent of the power industry "to a greater or lesser degree interconnected in five large networks."[5] These networks served the Pacific Northwest; the Pacific Southwest; Texas and part of New Mexico; the Central states stretching from the Rocky Mountains in the west to the southeastern seaboard in the east; and the mid-Atlantic states, New England, and eastern Canada in the northeast. A few smaller grids served portions of the United States as well. While electricity reached most areas of the country through interconnections, numerous independent small power producers dotted the landscape and vast stretches had no electricity at all.

[5] Federal Power Commission, *National Power Survey: A Report*, p. 14.

Common Goals, Regional Differences

Utilities participating in the giant power pools shared key objectives in operating interconnected, but the development of each pool occurred along distinct lines that continued to reflect regional priorities, political preferences, and corporate differences. First, in all the pools, utilities agreed to provide emergency assistance. Second, with the exception of parts of Arizona, most utilities also agreed to exchange economy energy. In other words, utilities scheduled generation across the pool to use the most economical power sources first. Third, in most of the giant pools, the utilities shared "spinning reserve," back-up power available at any time, thus reducing the additional generating plant each system required to provide sufficient spinning reserve on its own.[6] Fourth, but less consistently, the pools provided participants with a forum for joint planning of future generating and transmission capacity. Engineers and utility operators identified all of these objectives as essential for obtaining the most energy efficient operations and for assuring reliability.[7]

Utilities further organized the pools to protect the autonomy of individual participants while sharing the energy efficiency and reliability objectives. Regardless of whether the pools operated under formal contracts or through looser agreements, this combination of shared management and divided authority prevailed. For example, the Southwest Power Pool was a "voluntary organization with a rigid network for maximum utilization of the resources

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[6] According to the NERC Glossary of Terms, "spinning reserve" is "unloaded generation that is synchronized and ready to serve additional demand." In other words, the power plants are generating extra power that is not being used at that moment to meet supply, but is instantly available for unanticipated demand.

[7] This section is largely drawn from the Edison Electric Institute's 1962 *Report on the Status of Interconnections and Pooling of Electric Utility Systems in the United States* (Washington, DC: Edison Electric Institute, 1962). The EEI acknowledged that the report primarily addressed investor-owned systems, but included discussion of government projects when they were part of interconnected systems. Before World War I, engineers sometimes described economy scheduling as a "conservation" practice as well as an economy practice. After the war, "conservation" all but disappeared from the lexicon of power systems operation.

of all for the common good."[8] In Florida, with no pool agreements in place, the utilities undertook close cooperation and constant power interchange even when nothing specific was scheduled. In the Illinois-Missouri Pool, each company retained complete autonomy, but members agreed to cooperate for the benefit of the entire pool. The Northwest Power Pool was a voluntary organization in which utilities made plans independently, but in harmony with each other.

The planning feature of the pools offers the clearest expression of the way in which these organizations allowed for both autonomy and unity. Whether corporations, municipal utilities, rural cooperatives, or government agencies, each participating entity built its own physical facilities. In some extraordinary instances, groups of utilities invested together in infrastructure for a common purpose. For example, in 1952, fifteen utilities in Ohio formed the Ohio Valley Electric Corporation to provide transmission lines and generating plants for an Atomic Energy Commission uranium enrichment plant. In general, however, power providers invested in their own new infrastructure, raising their own capital, and obtaining returns through their own regulated rates. The regional pools, whether formal or informal, went to great lengths to coordinate this investment, primarily to economize on a regional basis and additionally to maximize the opportunity for adding the largest and most cost-effective infrastructure.

The largest power pool, the Interconnected Systems Group (ISG), grew out of one of the earliest formal integration agreements. In 1928, eleven companies in western Pennsylvania, eastern Ohio, and part of West Virginia organized to operate in parallel. Despite early challenges in frequency control, this pool continued integrated operations, formally organized as the ISG, and by 1960 included 100 major companies in 31 states. The

[8] Ibid., p. 123.

ISG reached from Canada to the Gulf of Mexico and included interconnections into Mexico. The deliberate expansion of this giant pool included early experiments with automated control apparatus and computerized economic dispatch. Within ISG were multiple smaller pools, some of which had central coordinating offices. Within each sub-area, the utilities participated in integrated planning for increased capacity. For example, the Illinois-Missouri Pool had no central pool coordinator, yet the member companies participated in quarterly load review and planning, and then staggered construction. In the Iowa Pool, "usually the more deficient company installs the next unit required."[9] All the utilities in ISG, however, retained distinct corporate autonomy.[10]

While the mechanisms differed, the overall coordination of system expansions had the effect of creating an even more coherent network of power companies. Thus, with a wide variety of pools and interconnection agreements, the grid began to look more and more like a single entity. The operating committees that provided oversight of daily operations further provided a sense of integration and cohesion. Yet, individualism reigned. Some pools used automated load and frequency control. Others did not. Some pools operated only on scheduled and emergency interchange; others kept power flowing at all times without any schedules. Some operators fretted over inadvertent power exchanges, which caused problems for both frequency control and accounting. Others did not address inadvertent flow. The emerging nation-wide grid could best be described as a growing hodge-podge of public and private companies operating in locally determined fashions, yet maintaining a consistent flow of power to customers with very few significant interruptions.

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[9] Ibid., p. 107.
[10] See Chapter 5 for examples of early automated control experiments. American Gas & Electric Company (AGE) was one of the founding members of ISG.

Unity Within Variety: Standards, Autonomy, and NAPSIC

By the 1960s, as illustrated in Map 7.2 above, the grid appeared to function as a unified national network. The patterns of development in different regions revealed the grid to be, instead, an aggregation of disparate systems, with a wide variety of generating technologies, operating approaches, and local challenges and demands. In 1967 utilities closed ties between the eastern and western power pools to form a single interconnected system that included most of Canada, parts of Mexico, and the entire continental United States except Texas. These ties, however, were too small to allow for continuous parallel operations across the continent. In areas of both technical innovation and organizational refinement, the stakeholders in the North American power grid continued to advance along lines of shared management and divided authority. Two key examples, one a solution to a technical problem that led to failures on seemingly robust networks, and the other an attempt to rationalize grid operations, demonstrate the manner in which both autonomy and unity characterized grid development.[11]

During the 1950s, control engineers and system operators refined techniques for frequency and load control to bring about greater system stability. The engineers and operators together delineated both problems and solutions over the course of several years through a process of argument, collaboration, and voluntary adoption. At the same time, utilities pursued cohesion across multiple power pools through development of the North American Power Systems Interconnection Committee (NAPSIC). An examination of these two initiatives reveals the extent to which systems of shared management and divided authority became entrenched during these years. It is notable that this took place under

[11] The utilities closed the ties between the eastern and western systems in 1967, however these two major areas did not, and do not currently, operate in parallel continuously.

schemes of state and federal regulation established by the end of the 1930s and unchanged until the passage of the Public Utilities Regulatory Policy Act of 1978. State regulators attended to the rates charged and areas served by utilities within state boundary lines. Federal regulators addressed rates charged for interstate trades. Utilities themselves governed the stability of the interconnected power lines on a voluntary basis.

Argument and Collaboration: The Question of Bias

Within a network of systems, an obligation to maintain stability with near neighbors as well as distant operators bound disparate utilities together. The mechanisms for cooperation included enlightened self-interest, loose agreements, contractual commitments, and shared knowledge through technical societies. The latter method was historically critical to the progress of interconnections around the world and continued to hold sway through the post-war era. The fraternity of engineers and operators concerned with electric power aggressively provided and sought information through regional meetings, journals, correspondence, and through national and international conventions. Participants came from large privately owned utilities, federal power systems, small municipal companies, equipment manufacturers, regulatory agencies, and universities. When engineers alluded to proprietary information and trade secrets, competitors watched each other closely, critiquing shortcomings and honing their own approaches in order to gain industry-wide acceptance.

The process by which the industry converged on technologies and practices to maintain system stability can be seen in arguments over seemingly minute technical choices. By the 1940s, utilities industry-wide used "tie line bias frequency control" to regulate frequency across interconnected systems. This approach allowed generators to respond briefly on their own to frequency changes before control apparatus effected a system correction. In other words, an increase in demand for electricity from a consumer, also called an increase in "load," caused generators to respond naturally by slowing down. Similarly a drop in demand led to a natural generator speed up. Either action caused the frequency on the system to likewise slow down or speed up. This was often called "prevailing natural generation governing characteristic," or simply "natural governing response" or "natural characteristic."[12]

Interconnected power plants relied primarily on automatic controls to override the natural response of generators and keep systems at the established 60 Hz frequency. "They reallocate generation changes … because of schedules or agreements or understandings amongst the participants of an interconnection."[13] The most common approach involved a "bias" setting that allowed some natural response first, and an opportunity for one area to aid another with a load change, before the automated control took over. Over time, operators began to care deeply about fractional differences in bias settings. The eminent GE engineer, Charles Concordia, reflected in later years "… when the frequency changed by a tenth of a

[12]The term "bias" refers to "a value, usually given in megawatts per 0.1 Hertz, that relates the difference between scheduled and actual frequency to the amount of generation required to correct the difference." *Glossary of Terms Used in NERC Reliability Standards, Updated October 19, 2012*, (Atlanta, GA: North American Electric Reliability Corporation, 2012), p. 56. In fact, by 1953, use of automatic frequency and load control was common across the globe. C. Concordia and L. K. Kirchmayer, "Tie-Line Power and Frequency Control of Electric Power Systems," *American Institute of Electrical Engineers -- Transactions -- Power Apparatus and Systems* 72, no. Part 3, 6 (1953). This chapter will use the term "natural characteristic" as that was the term that appeared most frequently in the papers published in the 1950s. Today, all large generators are obligated to have automatic governor controllers as a condition of connecting to the grid and the industry is in general agreement for the bias setting. Walt Stadlin, personal communication, October 20, 2012; Nathan Cohn, *Control of Generation and Power Flow on Interconnected Power Systems*, 2nd ed. (New York: J. Wiley, 1967), p. 19; Nathan Cohn, "Some Aspects of Tie-Line Bias Control on Interconnected Power Systems," *AIEE Transactions Part III* AIEE Paper 56-670(1957), p. 2.

[13] Nathan Cohn, "A Step-by-Step Analysis of Load Frequency Control Showing the System Regulating Response Associated with Frequency Bias," in *Meeting of the Interconnected Systems Committee* (Des Moines, IA: Interconnected Systems Committee, 1956), p. 2.

cycle (or hertz) it was sufficient cause to establish a committee to study the problem for a year and a half."[14]

Early in the years of experiments with automatic apparatus on interconnections, operators and engineers had learned that overly tight automatic frequency control resulted in unwanted and uneconomical load shifts. The biased control had the benefit of minimizing the burden on single machines or single areas to handle all frequency changes on the interconnected system while maintaining scheduled load transfers and restoring the system to standard frequency quickly. Operators typically set the bias at a percent of the natural characteristic of the area under control. Some set the bias at precisely one percent of the natural characteristic; others chose settings above and below. For many years, the bias setting gained modest attention, but the effects on the systems during a disturbance were barely noticed. By the early 1950s, with the rapid expansion of interconnections, "large blocks of load or generation can now be suddenly lost, causing significantly large changes in frequency, but with the system still holding together."[15] These larger disturbances revealed, for the first time, the effect of bias settings on operations.

Trouble on the ISG Lines

The problems caused by inappropriate bias settings emerged during trouble on one of the largest and oldest interconnected systems in the country, the Interconnected Systems Group (ISG). During 1955, operators in several parts of the interconnection dealt with numerous outages that required frequency and load adjustments, often experiencing system instability for several minutes at a time. Luckily, none of these events resulted in a major blackout. Nonetheless, the automatic and human responses to loss of generating plant, loss of

[14] Letter to Cohn, March 28, 1972, Box 1, NC Papers, MIT.
[15] Cohn, "Some Aspects of Tie-Line Bias Control on Interconnected Power Systems," p. 2.

load, or other interruptions led to an investigation of causes and effects that became international in scale. Earlier challenges of frequency and load control contributed to the initial organization of ISG. At its founding in 1933, the operating executives of the utilities that became ISG met to address "the tremendous frequency control problem their system operating people had to contend with."[16] The ISG's Test Committee, formed at that initial meeting, served as the heart of the system's efforts to standardize operations across a rapidly expanding interconnection. ISG pioneered early methods of automated control and by the early 1950s provided recommended operating standards to over 70 participating utilities.[17]

The operating standards issued by ISG in the early 1950s reflected nearly two decades of experience in voluntary collaboration among engineers and operators across the interconnection. The Test Committee regularly performed trials of different types of controls and settings on interties, communicated through typed newsletters and meeting reports, and encouraged voluntary participation of member utilities in tests, surveys and reporting. In 1951, the Test Committee established that "bias settings are to be increased on all systems … to reflect approximately 1 percent of system load per 0.1 cycle frequency departure."[18] Because utilities participated in the interconnection on a voluntary basis, this standard was styled as a recommendation on a list of six "recommendations as to operation of the

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[16] Institute, "Report on the Status of Interconnections and Pooling of Electric Utility Systems in the United States," p. 58.

[17] Ibid; Miscellaneous Minutes, Standards, Newsletters, Reports, Correspondence of the Interconnected Systems Group, 1933-1938, North American Power Systems Interconnection Committee Papers, courtesy of North American Electric Reliability Corporation, Atlanta, GA. Hereinafter, manuscripts from this collection will be titled NAPSIC Papers, NERC. Information on the Interconnected Systems Group, 1961, NAPSIC Papers, NERC.

[18] Memorandum from J. R. Smith, Chairman, to All Members of the Northwest Regional Committee of the Interconnected Systems Committee, October 21, 1952, NAPSIC Papers, NERC. In other words, the bias would be set to one percent of an area's natural characteristic.

interconnection systems."[19] In other words, no individual utility was under an obligation to meet the standard, but all were encouraged to do so.[20]

"The Controversy Which is Raging"

Despite the widespread usage of tie line bias frequency control across North America, individual power pools elected to use different bias settings. Like ISG, most used one percent as the internal standard. As Nathan Cohn of Leeds & Northrup (L&N) reported in 1950, however, "operators are sometimes of the opinion that operating with a very small bias will minimize local generation changes."[21] The operators believed this lower setting improved the economies of the local system. As the scale of interconnections grew, disagreements about bias setting intensified. By 1954, a meeting on the subject left members of the ISG with "battle scars."[22] One year later, engineers were "well aware of the controversy which is raging throughout the power industry with regard to what bias should be used and how this bias should be calculated."[23] The ISG experience both exemplified the challenge facing utilities and unified the power system fraternity around a solution.

Large-scale problems began on the ISG network in 1955. On February 2nd the Tennessee Valley Authority (TVA) Shawnee power plant experienced trouble, causing part of the Illinois-Missouri power pool to disconnect, and resulting in interruption of the scheduled generation in multiple systems across Iowa, Missouri, Illinois, and Kentucky, all part of the Northwest Region of ISG. Evidently, a fault on a generator at the Shawnee plant initiated the trouble, and a combination of operator decisions, bias settings, and techniques

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[19] Ibid.
[20] "Miscellaneous Minutes, Standards, Newsletters, Reports, Correspondence of the Interconnected Systems Group."
[21] Cohn, "Power Flow Control - Basic Concepts for Interconnected Systems."
[22] Letter to Members of Northwest Regional Committee, June 24, 1955, NAPSIC Papers, NERC.
[23] Memo to S.B. Morehouse Regarding System Operations, September 22, 1955, Box 44, NC Papers, MIT.

for tie line control led to the small cascade of problems. Two weeks later, representatives from the largest affected utilities met to address how to operate during this and other types of emergencies. Participants agreed on the facts and calculations, but differed considerably as to the desired operation under each of the various emergencies.[24]

There were six additional disturbances on the ISG interconnection over the next three months, including one in March on the Ohio Valley Electric Corporation (OVEC) system. OVEC was formed by numerous utilities strictly to provide power to the Atomic Energy Commission's top-secret uranium enrichment plant in Ohio. Following this event, Howard Stites, an electrical engineer with Central Illinois Public Service Company, reported to the ISG Test Committee that the trouble lasted only four minutes and in this case "demonstrated that the frequency bias [of one percent] was satisfactory."[25] Stites provided few details, presumably because the system and its customer operated under the public radar. Stites reported on all seven disturbances at the May meeting of the ISG Test Committee, resulting in a decision to research the problem more thoroughly. The ISG held a "discussion on increasing bias obligation" during a full system meeting at the end of that month.[26]

Tackling the Bias Question

Separately, several of the affected utilities turned to the instrument manufacturers to help sort out the issues surrounding the faults and outages occurring on these larger interconnections. By this time, well over ninety percent of the utilities in North America used L&N tie line frequency and load control apparatus on their systems. Three of the ISG

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[24] Report from the Test Committee to the Interconnected Systems Committee, 1955, Box 4, NC Papers, MIT.
[25] Letter to W.T. Pavely, March 21, 1955, NAPSIC Papers, NERC.
[26] "Report from the Test Committee to the Interconnected Systems Committee"; Letter to Nathan Cohn, November 28, 1955, Box 4, NC Papers, MIT; "Information on the Interconnected Systems Group."

utilities, Union Electric Company, Central Illinois Public Service Company, and Illinois Power Company, invited Nathan Cohn of L&N to attend an April 8th meeting to discuss the February trouble. Cohn used the opportunity to clarify for the operators the two functions of bias: "1) Cause each area to do its share of frequency regulation; and 2) Match the area's … governing characteristic."[27] Addressing the February trouble, he noted that the bias settings were lower than the natural characteristic, resulting in improper control responses and exacerbating the unfolding problems. Cohn and his colleague, W. Spencer Bloor, recommended that the utilities adjust bias settings upward.[28]

Continued trouble on different parts of the vast ISG network led operators to actively address the growing problems. Following a June 21st disturbance, again on the OVEC system, the Northwest Regional Committee asked the Test Committee to undertake more detailed study of the bias setting question. Regional Committee Chair E.S. Miller suggested, "it may go a long way towards resolving the percent bias argument."[29] Study of the OVEC disturbance began in July, with a major goal of determining "the advisability of increasing our bias percent."[30] The Test Committee membership at that time included representatives from the TVA and from nine utilities based in eight states. The Test Committee regularly reported findings and recommendations to the full Interconnected Systems Group, comprised of 75 utilities and including some of the largest and most influential electric companies in

[27] "Some Aspects of Bias Control - Getting the Most from It During and Following Periods of System Disturbance," April, 1955, Box 4, NC Papers, MIT; Conference Minutes, April 9, 1955, Box 4, NC Papers, MIT.
[28] AIEE System Control Subcommittee, "Report on the Current Status of Load - Frequency Control Methods and Equiopment by the System Controls Subcommittee of the Committee on System Engineering," in *AIEE Fall General Meeting* (Chicago, IL: American Institute of Electrical Engineers, 1956), p. 2.
[29] Letter to L. V. Leonard, Chairman, Interconnected Systems Test Committee, June 24, 1955, NAPSIC Papers, NERC.
[30] Memo to Members of the Test Committee, July 7, 1955, NAPSIC Papers, NERC.

North America. A study by the Test Committee clearly held interest for the affected members, but also potentially influenced practice across the continent and perhaps around the world.[31]

The assessment of the causes of troubles and how bias setting might be addressed began with a survey of all ISG member utilities, not only those participating in the OVEC system. In August, the Test Committee sent a memo to the utilities asking for data, and considered the results during the following months. On October 25, 1955, the Test Committee issued a report that contended "the present frequency bias of 1 percent per .1 cycle of deviation is inadequate, unrealistic and detrimental to Interconnected System operation."[32] Although not involved in this phase of ISG investigations, Cohn and Bloor at L&N independently endeavored to clarify and quantify the method for calculating an ideal bias setting for a system.[33]

The Utilities Bring in the Manufacturers

The Test Committee continued to probe the question of bias settings. The October report summarized findings based upon survey responses, but committee members recognized that those responses had been incomplete and inadequate. At a December meeting, the committee decided to hold a special gathering early in the next year for "conducting additional research on the bias subject" and to formulate a plan for bringing the

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[31] E.S. Miller, "Letter to Members of Northwest Regional Committee"; L.V. Leonard, "Memo to Members of the Test Committee." Utilities represented on the Test Committee and the states in which they were headquartered included Arkansas Power & Light Co., Arkansas; Duke Power Company, North Carolina; Tennessee Valley Authority, Tennessee; Indiana & Michigan Electric Co., Indiana; Louisiana Power & Light Co., Louisiana; The Ohio Power Company, Ohio; Georgia Power Company, Georgia; Illinois Power Company, Illinois; Cleveland Electric Illuminating Co., Ohio; and Appalachian Electric Power Co., Virginia. Leonard, "Letter to Nathan Cohn"; Letter to Test Committee Members, Interconnected Systems, January 6, 1956, Box 4, NC Papers, MIT.

[32] "Report from the Test Committee to the Interconnected Systems Committee," p. 3.

[33] "Some Aspects of Tie Line Bias Settings," handwritten notes signed by Nathan Cohn and W. Spencer Bloor, August 18, 1955, Box 4, NC Papers, MIT.

issue to full ISG membership in the spring.[34] The "plan of attack … was to invite a representative from each of four (4) industries, which industries are associated with the problems of system regulation, to meet with the Test Committee."[35] The Chairman, L.V. Leonard extended invitations to representatives from L&N Company, General Electric Company, Westinghouse Electric Corporation, and Woodward Governor Company. Leonard also exchanged correspondence exclusively with Cohn of L&N, describing at length the make-up of ISG, the functioning of its four Regional Committees and the Test Committee, and the evolution of the decision to tackle the bias setting controversy.[36]

All four manufacturing companies had been competitors in the automated control field and the L&N team did not hesitate to exploit the coming meeting for marketing purposes. The correspondence from Leonard provided L&N with added insight into the utilities' concerns. Bloor met with John Donaldson, a TVA engineer and client, just a week before the planned Test Committee gathering, and discussed the TVA records regarding the 1955 failures. In the course of this meeting, Donaldson noted that only recently had they "been able to see this regulating effect since 1) the system didn't used to be strong enough to hold together and 2) only recently have they experienced such large load losses."[37] Both Bloor and Donaldson, like others in the industry, articulated the relationship between recent industry expansion, the growth in the size of electricity loads, and the mounting evidence that bias settings mattered a great deal to system stability. Before departing, Bloor ensured Donaldson had a full set of L&N publications on the topic of frequency and tie line control to read before the upcoming special Test Committee meeting.

[34] Leonard, "Letter to Test Committee Members, Interconnected Systems."
[35] Ibid.
[36] Leonard, "Letter to Nathan Cohn."
[37] Inter-Office Memo to N. Cohn Re: Bias-T.V.A.-Almond, February 7, 1956, Box 4, NC Papers, MIT.

The Test Committee convened in mid-February and the representatives from the four manufacturers made their presentations. Representing L&N, Cohn discussed the theoretical fundamentals of system regulation, the basic concepts of automatic control and operation, the priority of customer service, and the status of present control techniques. He addressed a number of questions about bias control, including the effect of different bias settings on tie lines after a fault occurs on a system. He outlined various scenarios and likely outcomes based on settings below one percent, at one percent, and above one percent. This set the stage for Cohn to argue to the Test Committee that the best outcomes occurred when the bias setting was equal to or greater than one percent of the system's natural characteristic. Following the presentations, the utility members met in private session to discuss the talks and decide how to proceed. The Test Committee evidently found the L&N presentation sufficiently compelling to ask only Cohn to address the full ISG committee later in the spring.[38]

Industry-Wide Interest

The elevation of the bias setting issue to the full ISG committee prompted industry-wide interest in the topic. On March 1st, Cohn accepted the invitation to meet with ISG at their Des Moines meeting at the end of April. One day later, the American Institute of Electrical Engineers (AIEE) Committee on System Engineering asked Cohn to turn the material into an AIEE paper to be presented at their summer general meeting in June. Cohn agreed to submit the paper to AIEE. In the meantime, he received a letter from Russ Purdy, senior executive with Commonwealth Edison and Vice Chairman of the AIEE Committee on

[38] Minutes of the Test Committee Meeting, February 15-16, 1956, Cincinnati, Ohio, February 15-16, 1956, Box 4, NC Papers, MIT. The approbation of individual utility members present at the meeting was reiterated in conversations with other L&N representatives during the weeks following the meeting, and shared with Cohn through internal memos. Green to Cohn, March 12, 1956; Bloor to Cohn, March 23, 1956; Bloor to Cohn, April 10, 1956, NC Papers, MIT.

System Engineering. Purdy outlined the lack of unanimity among system operators regarding increasing the bias setting. "I can state flatly that there is still a wide divergence of opinion within the group."[39] Purdy included himself among the skeptics, citing the lack of uniformity in apparatus used, the inadequacy of system telemetering across interconnections, and the capacity shortages that might inhibit generator responses under increased bias setting control. Cohn's reply underscored the autonomy of system operators in determining how interconnections should work. "We are always glad to discuss the theoretical aspects of this problem, but in the final analysis it is the operating people themselves who will want to determine what operating practices they will use."[40] Cohn met the submittal deadline for the paper and distributed it widely for comment in advance of the June AIEE meeting.[41]

Meanwhile, the April ISG meeting proved educational for members of that interconnection. Over 120 individuals representing the ISG membership gathered in Des Moines on April 26th – 27th. The schedule included two blocks of time, totaling nearly three hours, for Cohn's presentation. This was preceded by a report from the Test Committee. Earlier in the year, the Test Committee had distributed new surveys to the participant utilities and compiled more complete data regarding regional response to the disturbance of June 21, 1955. In the new report, the Test Committee concluded, "The data submitted … does indicate that the present 1 percent bias is too low."[42]

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[39] Letter to Nathan Cohn, April 9, 1956, Box 4, NC Papers, MIT.
[40] Letter to Russ L. Purdy, April 23, 1956, Box 4, NC Papers, MIT.
[41] Letter to A. L. Richmond, March 1, 1956, Box 4, NC Papers, MIT; Letter to Nathan Cohn, March 2, 1956, Box 4, NC Papers, MIT.
[42] Interconnected Systems Committee General Meeting Attendance List, April 26-27, 1956, Box 40, NC Papers, MIT; Interconnected Systems Committee General Meeting Agenda, April 26-27, 1956, Box 40, NC Papers, MIT. Quote in Report of Bias Analysis Survey for June 21, 1955, April 26, 1956, Box 4, NC Papers, MIT.

In his own talk, Cohn repeated his injunction against using theory as gospel, perhaps responding to the critique from Purdy. "I just can't emphasize too strongly that the bias setting problem is your problem and my analysis here is simply a theoretical one of how I think bias operates and does its regulation job."[43] Cohn walked the attendees through the underlying theory of bias control and the expected effects of bias settings above, below, and equal to natural characteristic. He explained that the setting should be determined by each system based on the degree to which the system can and will aid a neighboring system with a load change. In the most general terms, when the bias setting was below one percent, the area under control provided less help, the frequency moved further away from normal, and it took longer to return to stability. With the bias setting above one percent, the area under control provided extra help and the frequency moved toward normal, though to a lesser degree than the movement away under a low bias setting. Cohn again placed the responsibility squarely with the operators for determining their own settings, "For the function of responding to remote load change, the bias setting is very important. … simply ask your self the question: What do I want the bias regulators to do on the contribution function of responding to a remote load change."[44] In other words, how much did the operator want to help his neighbor at his own expense?

Cohn validated the autonomy of system operators as decision makers on a significant technical issue, at the same time expanding the theoretical basis for decision-making. He clearly leaned toward a bias setting no lower than one percent and enhanced mutual aid, but stopped short of advocating this as a standard. Both the chairman of the ISG and the chairman of the Test Committee reported to Cohn that his presentation "was exactly what we

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[43] Cohn, "A Step-by-Step Analysis of Load Frequency Control Showing the System Regulating Response Associated with Frequency Bias," p. 1.
[44] Ibid., p. 24.

wanted" and that "everyone has a much better understanding of the function of load regulating equipment than they have had heretofore."[45] During the meeting, ISG adopted the recommendation that "each system set its bias equal to its natural system characteristic."[46] Nonetheless, the final decision of bias setting rested with each system operator managing his own discrete sub-network on the interconnection.

Reaching Consensus at the AIEE Meeting

The presentation at the June AIEE meeting solidified the preeminence of L&N in the field of bias control, elevated the issue of bias setting to international status, and aggregated a solid professional community behind the changes Cohn advocated. Cohn's presentation at this meeting matched the April ISG talk, with greater attention given to mathematical models of his theory. Fifteen well-known and well-respected engineers, most from very large operating utilities in the United States and Canada, provided comment on Cohn's paper in advance of the meeting. One academic noted, "there have been many more, and unanimously very favorable discussion of this paper than of any other AIEE paper which I can remember."[47] Most concurred that the bias setting question, though seemingly minute, was timely and of great significance to the industry. As Purdy noted, in the past the bias setting was reached by "observation of system reaction in time of trouble by some calculation and considerable arbitration, which often included a sizable factor of ignorance," with the result that "the 1.0 percent bias became something of a standard."[48] Purdy emphasized the

[45] Letter to Nathan Cohn, May 10, 1956, Box 40, NC Papers, MIT; Letter to Nathan Cohn, June 5, 1956, Box 40, NC Papers, MIT.
[46] "Information on the Interconnected Systems Group."
[47] Letter to R.T. Purdy Re: Prize Paper, August 15, 1957, Box 41, NC Papers, MIT.
[48] Cohn, "Some Aspects of Tie-Line Bias Control on Interconnected Power Systems," p. 16.

importance of considering practical limitations as well as theory in determining a setting. Some favored Cohn's approach while others found reasons to dissent.[49]

In addressing the comments, Cohn clarified that the controversy rested on two potentially incompatible priorities: rapid restoration of system stability and economy. He noted that five commenters "call attention to the conclusion that bias ratios greater than one have correspondingly less effect on system parameters than bias ratios that are less than one."[50] Thus, if rapid restoration of stability was the top priority, a bias setting greater than one had a significant advantage. On the other hand, another commenter noted "that regulation would be minimized, and hence economy improved, when the bias ratio equals one" and if ties are fully loaded, systems "would prefer to have the bias ratio smaller than one" to realize greater economy.[51] In reminding operators that they held the final authority for determining bias setting, Cohn also pushed utilities to determine whether their first responsibility was to meeting stability obligations or economy goals. In the coming years, more sophisticated apparatus made this balancing act easier to achieve.

Leeds & Northrup focused on the success of Cohn's presentation. M.D. Leighty, from the company's San Francisco office, reported that Cohn "ran away with the show."[52] With respect to competitor companies, he carefully noted, "G.E. attempted to criticize the paper."[53] Leighty also reported in greater detail on presentations and comments at other sessions by GE engineers. The question of techniques and apparatus for achieving greater economy loading occupied engineers from L&N, GE, and numerous utilities. More significantly, the

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[49] Ibid., pp. 15-20.
[50] Ibid., p. 21.
[51] Ibid.
[52] Memo to T.W. Hissey, Subject: AIEE Meetings Held in San Francisco During the Week of June 25th, July, 1956, Box 5, NC Papers, MIT.
[53] Ibid.

bias setting discussion found its way into widely distributed publications following the June meeting. The journal *Electrical West* featured highlights of the conference in the July 1956 issue, including coverage of Cohn's talk. In January 1957, AIEE decided to elevate the paper from Conference status and include it, along with discussions and closure, in the printed Transactions. In addition, L&N produced reprints of both the ISG and AIEE talks for distribution to clients around the globe.[54]

In the ensuing years, utilities converged on a standard bias setting equal to or greater than the natural characteristic. Notably, like the question of frequency, the standard for bias-setting remained voluntary. Cohn's presentations had solidified support for bias settings that favored providing aid from one utility to another while rapidly restoring system stability rather than offering reduced aid in the interest of greater economy. In an internal memorandum at one utility, a Test Committee member reported, "While there was much controversy last year on the suggestion of bias equal to system characteristic, I was very pleased to find that there is now apparently complete agreement after a year's operation under that plan."[55] One engineer wrote in later years that the mid-1950s shift to the higher bias setting led to improved system frequency, closer adherence to tie line schedules, and a reduced regulating burden. In May 1957, the ISG Test Committee issued updated operating recommendations that stated "Each individual operating company should set the bias setting of its tie line load controller equal to or as close as possible to its natural system

[54] Memo to Nathan Cohn, Subject: Your Paper on Tie Line Bias Control, July 26, 1956, Box 41, NC Papers, MIT; Photocopy of page from *Electrical West*, Vol. 117, No. 1 attached. Memo to D. E. Moat, Subject: AIEE Paper 56-670; "Some Aspects of Tie Line Bias Control on Interconnected Power Systems," January 14, 1957, Box 41, NC Papers, MIT; Cohn, "A Step-by-Step Analysis of Load Frequency Control Showing the System Regulating Response Associated with Frequency Bias"; Cohn, "Some Aspects of Tie-Line Bias Control on Interconnected Power Systems."
[55] Memorandum from Mollman to Howell, Subject: Test Committee, May 22, 1957, NAPSIC Papers, NERC.

characteristic as estimated to apply to its system peak load (for the current year). … In no case should the bias be set at a value of less than 1 percent of estimated system peak load (for the current year) per .1 cycle change."[56] Operating recommendations issued in 1960 repeated this wording, as did the very first set of operating recommendations issued by the North American Power Systems Interconnection Committee (NAPSIC) in 1963. The newly created NAPSIC included utilities across the entire continent, suggesting that the standard for bias setting had gained universal acceptance in the power industry.[57]

When Cohn presented a paper to a NAPSIC group in 1970, titled "Bias Revisited," he reviewed the purpose of tie line bias control and the value of the industry standard. He noted that the argument about bias setting had returned, "we have had some suggestions in the last year or so that it might be better to use a bias equal to one-half beta."[58] He then argued that this suggestion was regressive, "since historically – prior to mid-1956 – the industry went through a long period of operation with such settings – with unsatisfactory results."[59] Cohn made the case in 1956 and again in 1970 that when operators chose a bias setting equal to or higher than the natural characteristic, this was "better for coordinated systems performance" and the operating industry seemed to agree.[60] Upon the occasion of Cohn's retirement from

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[56] Operating Recommendations for the Interconnected Systems Sponsored by the Test Committee and Approved by the Main Committee, May 1, 1957, NAPSIC Papers, NERC.
[57] Letter to Cohn, April 4, 1972, Box 1, NC Papers, MIT; Operating Recommendations for the Interconnected Systems Sponsored by the Test Committee and Approved by the Main Committee, April 22, 1960, NAPSIC Papers, NERC; North American Power Systems Interconnection Committee Minutes of Meeting January 15-16, 1963 - New Orleans, La., February 18, 1963, NAPSIC Papers, NERC.
[58] Nathan Cohn, "Bias Revisited," in *East Cetnral Systems Group of the North American Power Systems Interconnection Committee* (St. Joseph, MI: Leeds & Northrup, 1970), p. 10. Cohn cites a paper addressing this question: O.I. Elgerd and C.E. Fosha, Jr., "Optimum Megawatt-Frequency Control of Multiarea Electric Energy Systems." IEEE Transactions on Power Apparatus and Systems, Vol. PAS-89, No. 4, pp. 556-563, April 1970. In this paper, Cohn uses the term "beta" to refer to natural characteristic.
[59] Ibid., p. 11.
[60] Ibid.

L&N in 1972, Lou Mollman, formerly with Union Electric Company and a key participant in the ISG Test Committee during the 1950s, reflected that "few … agreed that the old fixed 1 percent bias was not doing the job and should be changed. … It took quite a time to get an acceptable rule … but we did. Your original literature and theory helped 'get it across.' The industry must thank you for that."[61]

Without a regulator, national standards group, or common owner to formally determine the solution, individual stakeholders pushed the discussion of bias setting through isolated companies, interconnection meetings, and professional associations. The initial problem, though confined to a small detail on a single apparatus, posed a serious threat to expanding interconnections. If left unattended, this inherent instability in grid operations would result in repeated failures like those experienced in 1955 and 1956, and might lead to major outages. The process of resolution, which took years, matched the grid itself. Engineers and operators cobbled together information and ideas to produce a coherent body of knowledge. While many shared a consensus about the right approach, all agreed that bias settings ultimately rested in the domain of individual system operators. The approach of ISG reflected the approach of the industry as a whole: "All changes are, of course, subject to approval by the main group, and they are always only recommendations to the members of the Group because the Group is a voluntary group."[62] The ideal solution provided interconnections with greater stability across the continent.

NAPSIC: Anticipating a National Grid

By the late 1950s, power systems engineers and operators contemplated the very real possibility of interconnection from coast-to-coast. While expanding systems, like ISG,

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[61] Letter to Nathan Cohn, August 15, 1972, Box 1, NC Papers, MIT.
[62] "Memorandum from Mollman to Howell, Subject: Test Committee."

addressed the difficulties of maintaining stability across a group of somewhat like power pools, the challenges of interconnecting between large systems appeared even thornier. Regional differences from the Pacific Northwest to the New England coast presented a variety of issues the power industry fraternity had not fully addressed. Within ISG, operators began discussing how to manage the next logical step in the growth of the power grid.

A narrow focus on the details of stable operations precipitated the creation of NAPSIC. ISG utility operators worried about the ramifications of interconnecting with other large systems. For example, in November 1959, anticipating "the possibility in future years of a coast-to-coast network," R.O. Usry, an engineer from Southern Services, Inc. recommended that ISG adopt "the same time for Interconnection operation."[63] Usry referred to the variety of time zones observed within different power pools. The Test Committee decided to establish standard on-peak and off-peak hours on a temporary basis for the purpose of conducting trials and surveying utilities. As in the case of bias setting, "discussion brought out that some companies may not agree to these times on a permanent basis."[64] At the next Test Committee meeting, in February 1960, the participants again considered that "ties with other Interconnections are possible to the east and west in the future."[65] This led to concern that "the operations of these Interconnections are not as good as ours."[66] The Test Committee decided to "invite key operating people outside of our Group to the St. Louis meeting."[67] For this meeting, the Test Committee planned to invite operators of utilities likely to later join ISG itself, breaking with the past tradition of keeping these meetings

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[63] Interconnected Systems Group Test Committee Meeting, Commonwealth Edison Building - Chicago, Illinois, November 19-20, 1959, Minutes, December 1, 1959, NAPSIC Papers, NERC, p. 7.
[64] Ibid.
[65] Interconnected Systems Group Test Committee Meeting, Sheraton-Jefferson Hotel - St. Louis, Missouri, February 18-19, 1960, Minutes, February 29, 1960, NAPSIC Papers, NERC, p. 2.
[66] Ibid.
[67] Ibid.

closed to outsiders. Thus began the process of forming an organization, potentially international in scope, to bring about stable operations should a coast-to-coast grid be realized.

This initial effort by the Test Committee to anticipate the ramifications of broader system interconnections paid off within two years, when operators from across the United States and Canada met to discuss coordination. At the instigation of ISG, and in conjunction with the Group's annual meeting, system representatives from Philadelphia to Los Angeles and from Texas to Oregon convened in Omaha on April 25, 1962 "to discuss the Future Operations of Systems."[68] At the meeting, representatives reported that with the recent or impending closures of ties between systems, "all systems in the United States except the Texas New Mexico Area, plus systems in Canada" will be operating in parallel.[69] Meeting participants expressed interest in developing "the most desirable operating organization to effect the parallel operation of all systems."[70] They formed a temporary Interconnection Coordination Committee Working Group, chaired, of course, by a representative of ISG, and agreed to hold follow-up meetings in June. In addition, those in attendance agreed to limit discussion to two areas: (1) the formation of an "informal voluntary association of operating personnel," and (2) questions of frequency regulation and time error correction, bias obligations or contributions, unintentional exchanges, and certain areas of accounting.[71]

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[68] Report on Progress on Interconnections and Summary of Meeting Held in Omaha on April 25, 1962 to Discuss the Future Operations of Systems, April 26, 1962, Box 1, NC Papers, MIT; Memorandum to System Representatives Re: Interconnection Coordination Committee, May 4, 1962, Box 1, NC Papers, MIT.
[69] Kleinbach, "Report on Progress on Interconnections and Summary of Meeting Held in Omaha on April 25, 1962 to Discuss the Future Operations of Systems."
[70] Ibid.
[71] Ibid. As mentioned in a previous note, "unintentional" and "inadvertant" both refer to electricity that crosses from one network to another outside of any planned power exchanges. In this case, Kleinbach used the term "unintentional" in his meeting report.

The working group quickly developed a plan. Following meetings in June and August, the group outlined the framework of a new organization that would provide coordination to all the participants in the rapidly emerging grid. The new entity, to be named the North American Power Systems Interconnection Committee (NAPSIC) would be informal, voluntary, and broadly representative. Ten operating areas or pools comprised NAPSIC: The Northwest Power Pool, Pacific Southwest Interconnected Systems, Rocky Mountain Power Pool, New Mexico Power Pool, Canada-United States Eastern Interconnection (CANUSE), Pennsylvania-New Jersey-Maryland Interconnection (PJM), and the four regions of ISG. Two representatives from each area or pool would serve on the committee. The working group addressed basic organizational details regarding officers, subcommittees and meeting schedule. More significantly, the committee listed the operating matters to be addressed by NAPSIC, primarily frequency and time error standards, bias settings, time error correction procedures, methods for handling unintentional energy, and how to respond to emergencies.[72]

While predictions of linking utilities across the continent were premature in 1962, the system operators were anxious to stay ahead of the curve. NAPSIC convened in January 1963, just months after the first meeting to consider the creation of this organization. NAPSIC's first chairman, W.S. Kleinbach from the PJM Interconnection Office, identified two priorities for the member utilities: economy and coordination. "There is much to be done nationally and internationally in the area of economic integration of power resources and in coordinating day-to-day operations including load-frequency and time control of all

[72] Interconnection Coordination Committee, Minutes of Meeting, August 28-29, 1962 - Denver, Colorado, September 12, 1962, NAPSIC Papers, NERC; Interconnection Coordination Committee, Minutes of Meeting, June 12-13, 1962 - Chicago, Illinois, June 22, 1962, NAPSIC Papers, NERC.

interconnected systems."[73] With that, NAPSIC set to work, adopting the organizational guidelines outlined by the Working Group as well as recommendations for tie line bias settings (identical to those used by ISG) and action in emergencies. The attendees also participated in a degree of coordinated planning, sharing details about upcoming interconnections and tie line closures, discussing interactions with the Federal Power Commission, and reviewing a variety of other issues including nuclear attack warning systems and the Edison Electric Institute Task Force on National Defense.

With the creation of NAPSIC, the power industry had finally established an entity that had eluded large utilities, politicians, and engineers for decades. The independent interconnected systems created NAPSIC without fanfare, publicity, political endorsement, or regulatory demand. NAPSIC served as the stability overseer for all the power companies, both public and private, that operated interconnected across the continent. In addition, NAPSIC provided a forum for a level of national grid planning unprecedented in the industry's history. Yet, through its very organizational structure, NAPSIC preserved the autonomy of government agencies, privately owned utilities, municipal companies, and rural cooperatives; and respected the wide variety of systems developing across the continent. NAPSIC was the embodiment of shared responsibility and divided authority, an approach to building the world's largest machine that was uniquely North American and that kept a potentially unstable technology operating, with few major interruptions, for decades.

Summary

During the post-war years, the collection of networks linking utilities across North America began to resemble a single grid, yet regional and organizational differences marked

[73] Canady, "North American Power Systems Interconnection Committee Minutes of Meeting January 15-16, 1963 - New Orleans, La.."

each power pool and system area. While power providers shared a common goal of increasing the number of interconnections, they still closely guarded their own economic interests. The composition of each power pool reflected the geography and energy sources endemic to the region, the political preferences of state and local governments, and the corporate objectives of participating utilities. Even when coast-to-coast interconnections appeared imminent, the international organization designed to smooth the process, NAPSIC, delineated a narrow set of shared concerns that would not impinge on utility autonomy.

A strong fraternity of engineers, manufacturers, and system operators collaborated on techniques for maintaining steady power delivery to customers, on demand. Arguments over technical details played out within power pool committees and across international boundaries in widely read publications. Through technical journals and societies, industry professionals vetted each other's ideas and often converged on recommended approaches to power control. Throughout, experts articulated a healthy respect for the autonomy of each utility in meeting its operating objectives. In some instances, as in the case of bias setting, operators voluntarily adopted standards that favored shared responsibility for system stability over the economic interests of the individual utility.

In the past, state and federal governments and politicians had tried and failed to commandeer the process of electrification. At the same time, no single utility fully dominated the industry, nor did private utilities as a group control systems across the continent. The development of the power grid continued piecemeal. Members of the industry fraternity shared an enormous body of knowledge that included both operating techniques and expansion plans. Yet federal agencies and private utilities constructed each new transmission line independently. With the extraordinary exception of the war years in the early 1940s, each power pool separately determined how and when to interconnect with neighboring systems. With interconnections crossing the United States, and strong ties linking power systems in the United States and Canada, the time appeared ripe for government oversight. Nonetheless, the utilities clung to systems of shared management and divided authority, and coopted federal incursions into system planning through the creation of NAPSIC.

Notably, as the power pools approached cross-continental interconnection, the potential fragility of the networks became evident. During the 1950s, engineers addressed detailed control problems that emerged only as systems grew fairly large. While the settings at stake were tiny, fractions of a percent in fact, the latent difficulties were significant. Unless a very large number of network participants adopted a standard setting that favored aiding the neighbor over aiding the individual company's bottom line, system operators faced the likelihood of handling frequent failures that could cascade into major blackouts. Ultimately, the fraternity of experts chose the standard that allowed stable automated operations and facilitated further expansion. But in the process, they learned that the reliability sought through interconnections might be undermined by small variations in the ways individual companies operated.

Chapter 8. Expansion, Conservation, and "The Look Within for Economy," 1945-1965

During the two decades following World War II, the trends framing the development of interconnected power systems came into high relief. By the early 1960s, the idea of coast-to-coast interconnections achieved forthright public consideration and was, indeed, deemed inevitable by many within the power industry. While discussion of a national grid in the United States, with connections into Canada, indicated a unified focus on interconnections, federal agencies carefully acknowledged that the autonomy of individual power companies would not be abrogated in the process. In fact, during this era, the power industry solidified systems of shared management and divided authority, particularly within power pools, while regulators at all levels refrained from changing the governance paradigm. Between 1945 and 1965, Progressive Era conservation ideology evolved into the roots of modern day environmentalism. At the same time, power industry experts focused internally on techniques for improving energy efficiency, while explicitly promoting increased consumption. At the end of 1964, government officials and industry leaders touted a formal plan to build "the grid." This plan would expand a robust electricity supply, conserve natural resources (in the Progressive Era sense of the word) and strengthen the power system against failures of all types.

In the early 1960s, the federal government assembled a National Power Survey that proposed a fully integrated power system by 1980. This project respected the systems of shared management and divided authority by suggesting that a unified power network could be accomplished through a coordinated effort on the part of existing entities. No new industry consolidation or regulatory restructuring was required. The plan expressed the confidence of both government officials and industry leaders in a history of power systems operations with minimal interruptions over the prior decades. Further, North American power system experts, and the technologies they used, enjoyed an international reputation for providing the leading edge of innovation in electrification. Private utility leaders in particular assured the public that the successes of the past insured a future of unified operations without significant restructuring of the industry.

During these two postwar decades, the power industry promoted consumption and responded to increased demand for electricity without hesitation. Progressive Era ideas about multiuse river development initiatives found expression in major federal projects, but these were typically promoted for their industrial and economic development benefits, not for resource conservation. While conservation ideology was not widely considered in the public discourse, particularly in the late 1940s and the 1950s, engineers and operators in the power industry still sought improved energy efficiency in their systems. This internal focus was captured in the idea of "the look within for economy," particularly with respect to exchanges of power on interconnections. The look within for economy aligned neatly with a revived opportunity for the grid to serve as a technology of conservation in the early 1960s. President John F. Kennedy promoted a conservation program from the beginning of his administration, with specific proposals concerning national interconnections and resource management. Engineers in the power industry, with their prominence on the international stage, their historical focus on energy efficiency, and the renewed status of interconnections as a technology of conservation, failed to grasp the magnitude of the environmental problems that would soon capture public attention. Instead, they saw themselves once again as the central agents in a unified effort to improve the lifestyle and well-being of North Americans.

The reputation of the industry as a whole was under attack by the end of this era. In the immediate post-war years, the industry was in ascendency because electricity was considered a key to economic recovery and growth. By the late 1950s, the industry was poised to play a dominant role in bringing about a new age of resource conservation through widespread interconnections and sophisticated, technology-driven movement of electricity across the continent. In 1965, the North American public began to lose faith in the industry and the grid following the first major blackout. Further, new advocacy groups were about to place electric utilities at the center of disputes about pollution, public safety, overconsumption, and ecological destruction. During the post-war era, the power industry reached its heyday, and was about to experience its come-uppance.

Conservation Trends

The New Deal left a legacy of federal programs that closely aligned with earlier Progressive Era ideals. Careful development of natural resources for the benefit of current and future generations served as the hallmark of the traditional conservation movement. After World War II, agencies like the Tennessee Valley Authority, the Bonneville Power Administration, and the Rural Electrification Agency continued the effort to build hydroelectric dams on the nation's rivers and to bring power to a broad consumer base. In the post-war years, however, these programs focused more on the potential for industrial and economic development in nearby regions and less on the potential to displace thermal energy with renewable waterpower. In addition, Dwight D. Eisenhower, president from 1953 to 1961, imposed a "no new starts" policy intended to slow federal investment in reclamation projects in particular, and natural resource development in general, in favor of private sector projects. Thus, by the 1950s, the federal government continued to invest in dams and transmission lines, but the projects no longer represented a conservation ethic at work.

In other ways, interest in traditional conservation values waned in the 1950s. While the federal government authorized eighty nine new National Park units during the 1930s, the number dropped to twenty one during the 1940s (most after the war ended) and dropped again to a mere sixteen in the 1950s. During the 1950s, soil conservation programs focused on productivity more than erosion control. Logging of national forests increased. The wartime practice of unrestrained natural resource extraction continued into the following decades to support the growing military-industrial complex, the rapid expansion of housing and suburban development, and the rising affluence and spending ability of the middle class. During these years, often described as the "boom era," productivity and consumption proceeded hand-in-hand while the concept of wise management of resources receded. Indeed, a new interest in environmental protection slowly appeared during the post-war years in direct response to the effects of aggressive consumption.[1]

During the 1950s, activists opposed federal dams, rallied against nuclear fallout, and sought cleaner air and water. Many issues and techniques of the modern environmental movement had roots in landmark moments during these post-war years. Both state and federal governments passed anti-pollution laws that preceded the much stronger environmental acts of the early 1970s. In 1954, the Sierra Club effectively halted construction of the Echo Canyon Dam and achieved preservation of Dinosaur National

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[1] "National Park System Areas Listed in Chronological Order of Date Authorized under DOI," National Park Service website, accessed August 28, 2012, http://www.nps.gov/applications/budget2/documents/chronop.pdf; Andrews, *Managing the Environment, Managing Ourselves: A History of American Environmental Policy*, pp. 179-183. Samuel P. Hays and Barbara D. Hays, *Beauty, Health, and Permanence: Environmental Politics in the United States, 1955-1985*, Studies in Environment and History (Cambridge; New York: Cambridge University Press, 1987).

Monument. Concerned about radioactive substances that found their way into the food supply, citizens protested nuclear fallout and gained a voluntary moratorium on aboveground nuclear testing in 1958. A new group of technocrats emerged, professionals at lower levels of government and in business who offered themselves as knowledgeable stewards of nature and development. Intellectuals and social critics rounded out the contributions to evolving environmental thought. They offered a critique of the industrialized economy that suggested science and technology together accelerated man's domination over nature, but not necessarily for the benefit of mankind.[2]

Not every set of activists organized to protect the environment. Some sought to protect regional private sector interests. For example, the groups arrayed against the federal Hells Canyon Dam project on the Snake River in the mid-1950s represented private utilities and states' rights conservatives as well as those seeking fisheries protection. Other activists sought greater access to outdoor amenities for their own consumption. For many, the opposition to nuclear testing on grounds of the challenges to human health was conflated with anxiety about the Cold War. Nonetheless, while the 1950s appeared to be a quiet phase

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[2] Brooks, *Public Power, Private Dams: The Hells Canyon High Dam Controversy*; Farmer, *Glen Canyon Dammed: Inventing Lake Powell and the Canyon Country*; Dalton, *Critical Masses: Citizens, Nuclear Weapons Production, and Environmental Destruction in the United States and Russia*; A. Costandina Titus, *Bombs in the Backyard: Atomic Testing and American Politics*, Nevada Studies in History and Political Science (Reno: University of Nevada Press, 1986). In the deal struck to preserve Echo Canyon, the Sierra Club sacrificed the equally as magnificent Glen Canyon. Adam Ward Rome, *The Bulldozer in the Countryside: Suburban Sprawl and the Rise of American Environmentalism*, Studies in Environment and History (Cambridge: Cambridge University Press, 2001); Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement*, p. 92. In 1947, California passed its first Air Pollution Act. Congress acted in 1948 to address water pollution and insecticides, fungicides and rodenticides. During the 1950s, Congress passed the Dingell-Johnson Act to protect fisheries (1951), the Watershed Protection and Flood Prevention Act (1954), and the Delaney Amendment addressing food additives and cancer (1958). In 1970, President Nixon signed the National Environmental Policy Act. In addition, Congress passed a stronger Clean Air Act, and responded to the Santa Barbara oil spill with the Water Quality Improvement Act. 1972 brought the Federal Water Pollution Control Act, the Federal Environmental Pesticide Control Act, and the Coastal Zone Management Act.

for conservation in the United States, interest groups continued to advocate for a variety of protections for nature and for society. These activities had minimal direct influence on the expanding power grid, but the results shaped the environmentalist discourse of the 1960s and that, accompanied by a brief Kennedy-era revival of traditional conservation activism, influenced the direction of electrification in the later post-war years.[3]

From Conservation Back to Economy

Within the electric power industry, the topic of conservation fell by the wayside after World War II. During the Progressive Era, engineers in the power industry positioned themselves as knowledgeable collaborators in the conservation movement. During the 1920s and 1930s, utility leaders and electrical engineers touted the benefits of hydroelectric power, long-distance transmission, and interconnection as elements of careful natural resource management and energy efficiency. Advanced technologies applied to interconnections were specifically designed to improve the economy of operations while reducing the per-unit usage of hydrocarbons. Interest in conservation as part of the war mobilization effort burgeoned again during the 1940s. As illustrated in Table 8.1, the use of the term "conservation" in the technical literature increased dramatically in the early 1940s. This reflected a war-driven concern for saving fuel and other material resources for war production rather than other domestic uses. Concern about resource conservation, use of the term, and reference to electricity as a resource-conserving alternative to other forms of energy notably declined in the 1950s. Engineers who worked for the utilities during the mid-

[3] Brooks, *Public Power, Private Dams: The Hells Canyon High Dam Controversy*; Hays and Hays, *Beauty, Health, and Permanence: Environmental Politics in the United States, 1955-1985*; Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement*, pp. 93-94.

century confirm in retrospect that resource conservation was not on the radar during this decade.[4]

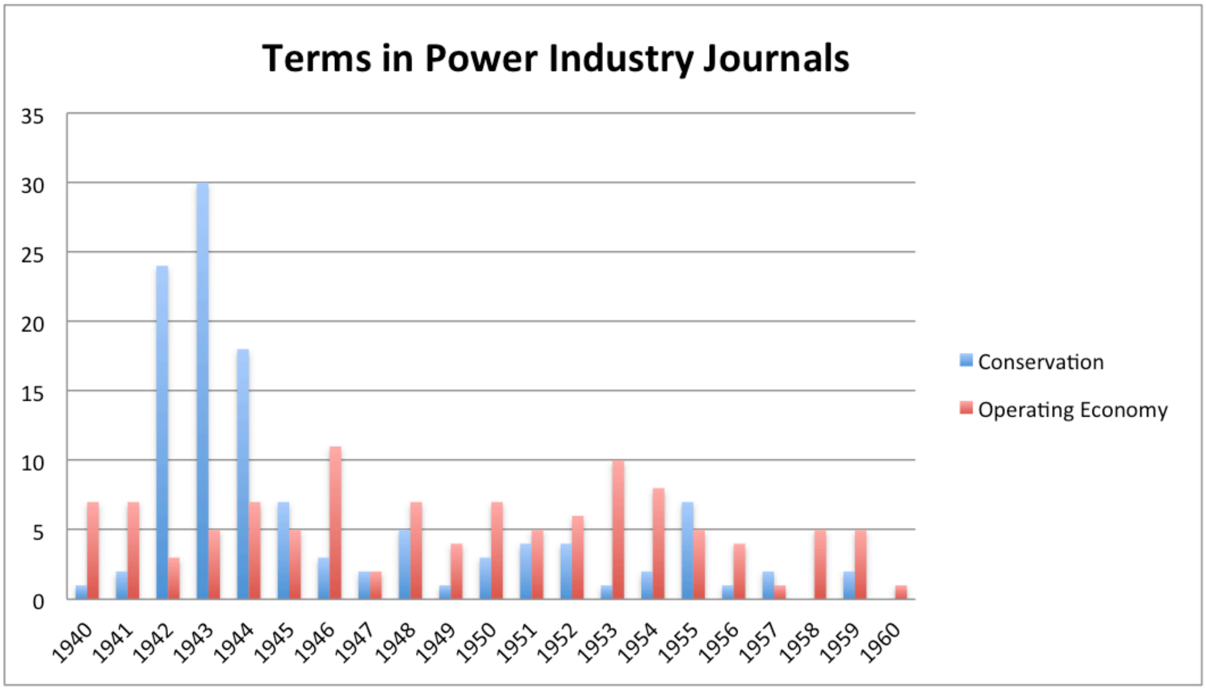

Table 8.1. Changed use of the terms "Conservation" and "Operating Economy" in journals specific to the power industry, 1940-1960. *Source: Engineering Village, Compendex Database.*

In the absence of a conservation ethic, and amidst rapid expansion and profit seeking, operating economy remained a priority for utilities during the post-war years. The utility industry invested heavily in improved economies of scale at the generating plant. As had been the historical trend, utilities installed larger and larger generators, which in turn used less and less fuel per kilowatt-hour produced. In the two decades following the war, thermal efficiency of power plants improved from an average of just above 20 percent to above 30 percent, with the best generating units achieving over 40 percent efficiency. The maximum capacity of generating units grew from just above 200 megawatts to above 1,000 megawatts, while the per-unit construction costs for the new, larger plants declined. During those same

[4] Walt Stadlin, Senior Principal Consultant, DNV KEMA Energy & Sustainability, James Resek, Executive Consultant, DNV KEMA Energy & Sustainability, and Dave Nevius, Senior Vice President, NERC, in discussion with the author, June 29, 2012.

years, the real price of electricity for the average residential consumer fell 70 percent. Of course, to reach consumers, utilities also invested in larger and longer transmission lines. Utilities realized greater efficiency and enormous operating economies at the generating end of the power systems, but there were concurrent losses of energy on the longer transmission lines.[5]

Economy Dispatch and the "Look Within"

System operators and control engineers joined the effort to improve the efficiency of power networks. As one engineer put it, "this era was highlighted by the adoption in many areas of 'a look within' … for economy."[6] In particular, the look within referred to the allocation of load among generators in order to achieve the lowest cost per kilowatt-hour delivered to the customer. "The most important tangible advantage is the fuel saving that can be realized by more exact economic load allocation."[7] Economic load-sharing had long been one of the primary goals of building interconnected systems. During the 1950s, as control engineers and operators wrestled with maintaining system stability on increasingly complex networks, the rapid growth of power networks led to "increased interest and emphasis on the overall problem of operating systems at optimum economy."[8] Directly related to this challenge, a new question emerged: should utilities adopt digital computing for system control?

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[5] Hirsh, *Technology and Transformation in the American Electric Utility Industry*, p. 4, 5, 9, 56,70. Electricity costs to consumers dropped from 35 cents per kWh to ten cents per kWh in 1986 cents.
[6] Cohn, "Developments in Computer Control of Interconnected Power Systems: Exercises in Cooperation and Coordination among Independent Entitites, from Genesis to Columbus."
[7] Co-Ordination of Desired Generation Computer with Area Control, Discussion By: F.H. Light, Senior Engineer, Economy Division, Philadelphia Electric Company, 1959, Box 3, NC Papers, MIT.
[8] E. E. Ward, "Analogue Computer for Use in Design of Servo Systems," *Institution of Electrical Engineers -- Proceedings -- Part A, Power Engineering* 99, no. Part 2, 72 (1952).

From the beginning, instrument manufacturers and system operators sought to maintain steady frequency on interconnections, without sacrificing the desired, and carefully scheduled, exchanges of power. Within increasingly complex interconnections, the calculation of economical load distribution likewise became much more difficult. Operators had to consider not only which generator or plant offered the next most economical unit of power, they also had to account for energy losses on the transmission lines and across interties. In the late 1930s, operators began to use network analyzers, which offered apt models of working power systems, to determine the effects of changing loads. With widely distributed telemeters on the systems, operators collected reams of data about demand and power flow. The next challenge involved incorporating transmission loss data into the calculations. In the 1950s, manufacturers started to produce more sophisticated analog computers to directly calculate economy loading, combining plant efficiency data with transmission loss data. Using the new computers, operators predicted economical distribution of load and adjusted the increasingly widespread automatic control devices to respond accordingly.[9]

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[9] C. W. Watchorn, "Co-Ordination of Hydro and Steam Generation," *American Institute of Electrical Engineers -- Transactions -- Power Apparatus and Systems* 74, no. 17, Part 3 (1955); L. K. Kirchmayer and G. H. McDaniel, "Transmission Losses and Economic Loading of Power Systems," *General Electric Review* 54, no. 10 (1951); P. E. Soper, "Review of A.C. Network Analyzers," *Beama Journal* 52, no. 99 (1945); E. E. George, "Principles of Load Allocation among Generating Units," *Electrical Engineering* 72, no. 6 (1953); W. R. Brownlee, "Co-Ordination of Incremental Fuel Costs and Incremental Transmission Losses," *American Institute of Electrical Engineers -- Transactions -- Power Apparatus and Systems* 73, no. Part 3, 12 (1954); C. A. Imburgia, L. K. Kirchmayer, and G. W. Stagg, "Transmission-Loss Penalty Factor Computer," *American Institute of Electrical Engineers -- Transactions -- Power Apparatus and Systems* 73, no. Part 3, 12 (1954); E. D. Early, W. E. Phillips, and W. T. Shreve, "Incremental Cost of Power-Delivered Computer," *American Institute of Electrical Engineers -- Transactions -- Power Apparatus and Systems* 74, no. 18, Part 3 (1955); E. D. Early, G. L. Smith, and R. L. Schroeder, ""Early Bird" Guides System Loading," *Electrical World* 143, no. 2 (1955); Cohn, "Developments in Computer Control of Interconnected Power Systems: Exercises in Cooperation and Coordination among Independent Entitites, from Genesis to Columbus."

By the mid-1950s, engineers argued about the merits of digital computing for application to power systems. Some in the technical fraternity clung to the analog systems. Analog computers had an enormous benefit for system operators because they responded to electric impulses in essentially the same way power systems responded. An analog dispatch computer provided a truly analogous match to a power system. There was added value for young engineers attempting to grasp how electric power networks functioned. The "newbies" modeled system behavior with the computers and felt confident that they understood how electricity flowed. Advocates persuasively argued that the analog computers saved utilities real money. In one case, for example, a utility saved $200,000 per year using an analog computer and a simple slide rule to calculate economy loading.[10]

On the other hand, advocates for digital computers rightly argued that these new machines offered much more rapid and accurate calculations and of much more complex equations. While the model built into a digital machine might not be a perfect analogy of an electrical network, the speed and power of the computer itself allowed rapid system response. In addition, as the technology advanced, digital computers could combine system-operating metrics with other types of data important to utilities, including information about finances and personnel. This offered utilities much more detailed productivity management. Manufacturers also offered a hybrid option called digital directed analog control, in which

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[10] Early, Phillips, and Shreve, "Incremental Cost of Power-Delivered Computer"; E. D. Early, R. E. Watson, and G. L. Smith, "General Transmission Loss Equation," *American Institute of Electrical Engineers -- Transactions -- Power Apparatus and Systems* 74, no. Part 3, 18 (1955); J. E. Van Ness and W. C. Peterson, "Use of Analogue Computers in Power System Studies," *American Institute of Electrical Engineers -- Transactions -- Power Apparatus and Systems* 75, no. Part 3, 23 (1956); R. B. Shipley, "Electric Analog Circuits for Exact Economic Dispatch," *AIEE -- Transactions* 76, no. Part 3, 33 (1957); W. Aspray, "Edwin L. Harder and the Anacom: Analog Computing at Westinghouse," *Annals of the History of Computing, IEEE* 15, no. 2 (1993). Stadlin, Resek, and Nevius in discussion with the author, June 29, 2012; A. H. Willennar and G. W. Stagg, "Penalty Factor Computer Teams with Slide Rule," *Electrical World* 143, no. 16 (1955).

both types of computers were used. By the late 1950s, the look within for economy included a glance ahead to the digital age.[11]

While experts disagreed about the best approach to sequentially loading power plants for the greatest economy, known as "economy dispatch," consensus was not necessary across the industry. Individual networks selected different approaches to control loads within their own areas and this had no ill effect on the neighboring network. Often the choice of digital or analog computing reflected the approach to power transactions and billing systems already in use. The search for effective automatic economy dispatch also resulted in new opportunities for manufacturers to enter the control apparatus market and for utilities to adopt a variety of techniques. Leeds & Northrup attempted to dominate this field as it had the automatic load frequency and control market, but without similar success. A 1970 survey of utilities illustrated that Westinghouse, General Electric, IBM, Honeywell, and L&N all found favor with utility operators. This survey forecast a future trend toward all digital controls, although many utilities and system operators used analog computers as late as 1990. Because systems looked *within* for economy, there was no pressure for uniformity of economy control apparatus *between* systems.[12]

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[11] J. B. Ward and H. W. Hale, "Digital Computer Solution of Power-Flow Problems," *American Institute of Electrical Engineers -- Transactions -- Power Apparatus and Systems* 75, no. Part 3, 24 (1956); S. B. Morehouse, "Automatic Economic Loading Practices on Interconnected Power Systems in U.S.A" (paper presented at the Conference Int. des Grands Reseaux Electriques a Haute Tension, Jun 8-18 1966, 1966); G. W. Bills, "Digital Computers to Speed Studies," *Electrical World* 143, no. 16 (1955); Federal Power Commission, *National Power Survey: A Report*, Volume I, p. 165; Morehouse, "Automatic Economic Loading Practices on Interconnected Power Systems in U.S.A."

[12] "Symposium on Scheduling and Billing of Economy Interchange on Interconnected Power Systems" (paper presented at the American Power Conference, Chicago, IL, March 26, 27, 28 1958); J. W. Lamont and J. R. Tudor, "Survey of Operating Computer Applications" (paper presented at the Proceedings of the American Power Conference, 21-23 April 1970, Chicago, IL, USA, 1970); Aspray, "Edwin L. Harder and the Anacom: Analog Computing at Westinghouse." Correspondence in the Nathan Cohn Collection discloses competition with Westinghouse to win major contracts for load control equipment, including economy loading computers. Leeds & Northrup went to some length to illustrate how a more complete and sophisticated system would ultimately save the utility

During these years of waning conservation fervor, the growing power grid hardly served as the technology that facilitated wiser use of natural resources. In fact, increased consumption occupied the attention of utilities. The fraternity of engineers and operators who concerned themselves daily with the operation of power systems, did, however, consider interconnections a locus for improved resource economy and energy efficiency. By advancing techniques for economy loading while preserving the stability of the network, these professionals realized real dollar savings for utilities. Those savings represented lower coal to kilowatt-hour ratios, and, for many consumers, lower rates. More significantly, the engineers viewed themselves as stewards of energy efficiency. During a coming revival of traditional conservation ideas in the political arena, the power systems engineers were well positioned to be conservation experts.

Conservation Revival

While John F. Kennedy is not remembered as an environmental president, his administration re-introduced traditional conservation ideas to the national discourse and explicitly linked power networks and resource protection once again. As one of his advisors said in later years, "if you look at the record, you'll find out the Kennedy administration

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money through more successful economy loading. Westinghouse underbid L&N every time. In the case of a Cleveland Electric Illuminating Co. project, for example, "we could not demonstrate a dollar savings at the coal pile to offset our price disadvantage." In this instance, Westinghouse underbid L & N by almost 60 percent. Memo from Kuhl (L&N Clevleand Office) to Balbirnis (L&N Philadlephia Office): Cleveland Electric Illuminating Co. Load Control Negotiations, October 1, 1958, Box 3, NC Papers, MIT; Letter to Mr. James R. Guy, The Cleveland Electric Illuminating Company, October 3, 1958, Box 3, NC Papers, MIT; Memo from Balbirnie to Hissey: Cleveland Electric Illuminating Company, November 28, 1958, Box 3, NC Papers, MIT; Memo from Hissey to Mackay, Patent Department: Competitive Activities - Load Frequency Control, Westinghouse Electric Corporation Entry into Field, November 19, 1958, Box 3, NC Papers, MIT; Memo from Nichols to W. G. Amey, Research: Simulation of Control Schemes Associated with Load Control Recommendations for Cleveland Electric Illuminating Company, July 17, 1958, Box 3, NC Papers, MIT.

really began this great concern over the environment and ecology."[13] In 1960, the young senator from Massachusetts, with no real affinity for the great out-of-doors, invoked the ideals of Teddy Roosevelt when campaigning for president in the western states. "The conservation and wise development of our natural resources - our water, land and air - is not a California problem. It is not a western problem. It is a national, indeed, a world-wide problem."[14] Giving speeches in Alaska, Arizona, California, Colorado, New Mexico, Wyoming, and Utah, Kennedy berated Eisenhower's "no new starts" policy and endorsed full waterpower development. He advocated for wildlife and forest protections and called for conferences on resource and mineral use. He decried a presidential veto that had blocked water pollution controls and called for a clean and healthy water supply. Indeed, Kennedy offered a mixed message, for example he also encouraged the full operation of steel mills and construction of highways. Nonetheless, once in office, Kennedy and his team advocated a conservation program.[15]

Kennedy's effort as president to create a conservation program began with a Special Message to Congress on Natural Resources, sent just one month after his inauguration. "We

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[13] Recorded Interview by William W. Moss, May 25, 1971, 1964, John F. Kennedy Oral History Collection, John F. Kennedy Presidential Library website, accessed August 14, 2010, http://www.jfklibrary.org/Research/About-Our-Collections/Oral-history-program.aspx. James K. Carr was Undersecretary of the Interior from 1961-1964.

[14] Senator John F. Kennedy, "Transcription of Remarks of Senator John F. Kennedy, Redding, California, September 8, 1960," John F. Kennedy Presidential Library website, accessed August 23, 2012, http://www.jfklibrary.org.

[15] Recorded Interview by Layne R. Beaty, 7/2/19764, 1964, John F. Kennedy Oral History Collection, John F. Kennedy Presidential Library website; Smith, "John Kennedy, Stewart Udall, and New Frontier Conservation"; "Transcription of Remarks of Senator John F. Kennedy at Edgewater Hotel, Anchorage, Alaska, September 3, 1960," "Transcript of Remarks of Senator John F. Kennedy at Phoenix, Arizona, April 9, 1960," "Transcript of Remarks of Senator John F. Kennedy at Cheyenne, Wyoming, September 23, 1960," "Transcript of Question and Answer Session with Senator John F. Kennedy at Mormon Tabernacle, Salt Lake City, Utah, September 23, 1960," "Transcript of Remarks of Senator John F. Kennedy at Western Conference, Albuquerque, New Mexico, February 7, 1960," "Remarks of Senator John F. Kennedy at Durango, Colorado, June 18, 1960," "Transcription of Remarks of Senator John F. Kennedy, Redding, California, September 8, 1960," John F. Kennedy Presidential Library website.

face a future of critical shortages," he announced, and a "wise investment in a resource program today will return vast dividends tomorrow."[16] He invoked Gifford Pinchot and Theodore Roosevelt as the founders of the progressive principles his administration embraced. Kennedy's message covered a wide range of conservation topics, including a set of proposals regarding electric power. Kennedy favored federal investment in dams and power lines that would assure equity of service, reach out to rural customers, minimize unfair monopoly controls, and extend interconnections. Within the year, Kennedy called for a White House Conservation Conference, the first to be held since 1908.

The brand of conservation activism promoted early on by President Kennedy and his secretary of the interior, Stewart Udall, adhered to a Progressive Era agenda, with only modest attention to emerging environmental concerns. Speaking to the White House Conservation Conference in 1962, Kennedy stated "I'm hopeful that we can move far faster in the more traditional kinds of conservation," referring specifically to wilderness preservation and careful resource development.[17] Udall told the conference that the administration sought a plan of "Rooseveltian proportions" to secure the country's resource base.[18] According to his aides, Kennedy viewed natural resource development as "a source of strength to the country" and a competitive edge in terms of international political power.[19] Within this message, he focused on the importance of science and research, and identified a

[16] Special Message on Natural Resources, 1961, JFK Speech Files 1961-1963/Box 67, Theodore C. Sorensen Papers, John F. Kennedy Presidential Libarary, Boston, MA. Hereinafter, manuscripts from this collection will be titled JFK Library.
[17] Remarks of the President to the White House Conference on Conservation, Undated, 1962, JFK Speech Files, 1961-1963, Box 38, President's Office Files, JFK Library.
[18] Address by Secretary of the Interior Stewart L. Udall at White House Conference on Conservation, May 24, 1962, Interior, Box 79a, President's Office Files, JFK Library.
[19] Cliff, "Recorded Interview by Layne R. Beaty, 7/2/19764"; First Draft, President Kennedy's Adress [Sic] to the Conservation Conference, Undated, 1962, JFK Speech Files, 1961-1963, Box 67, Theodore C. Sorensen Papers, JFK Library; Main Themes of the President's Conservation Speech, Undated, JFK Speech Files, 1961-1963, Box 67, Theodore C. Sorensen Papers, JFK Library.

clear and immediate economic development side to his conservation approach. As the Forest Service chief Edward P. Cliff noted, Kennedy "was interested in industrial uses; he recognized the importance of using resources in addition to just conserving them."[20]

Aides observed a mixed response to President Kennedy's conservation message. In May of 1961, Udall encouraged Kennedy to pursue an aggressive wilderness and recreation expansion program because this would bring broad support in Congress and across the country. One month later, he assured Kennedy that "there has been a steady upsurge of interest in conservation in this country …"[21] In contrast, however, when secretary of agriculture Orville Freeman called for a National Conference on Land and People, scheduled for January 1962, preservationists responded with frustration and hostility. For example, Sierra Club leaders accused the administration of excluding important Western conservationists from the meeting. Perhaps the Sierra Club representatives found fault with Freeman's position favoring "land use and not mummifying [*sic*] land in idleness."[22] Similarly, Kennedy's endorsement of new reclamation projects faced a variety of hurdles, in no small part because "conservationists had become more active in opposing dams."[23] The general public also offered a mixed response. During his western tours in 1962 and 1963, Kennedy's conservation message garnered little interest whereas his discussion of a "test ban

[20] Smith, "John Kennedy, Stewart Udall, and New Frontier Conservation." Quote in Cliff, "Recorded Interview by Layne R. Beaty, 7/2/19764," p. 13. Stewart Lee Udall lived from January 31, 1920 to March 20, 2010. He represented Arizona in Congress for three terms, after which he served as Secretary of the Interior under both President Kennedy and President Lyndon B. Johnson (1961-1969).
[21] A Report for the President on A Proposal for a Kennedy Administration Parks Conservation Program, 1961, Interior, Box 79a, President's Office Files, JFK Library.
[22] Letter to the President, January 25, 1962, Box # 642, White House Central Files, NR/MC White House Conference on Conservation, JFK Library.
[23] Orren Beaty Jr., "Recorded Interview by William W. Moss, January 9, 1970," John F. Kennedy Oral History Collection, John F. Kennedy Presidential Library website.

treaty and other things that affected peace" brought on "all kinds of enthusiasm."[24] The response to Kennedy's forays hinted at the imminent environmental movements, which expressed much broader concerns for ecosystem protection and public health.[25]

Conservation, Energy, and the Grid in the Kennedy Agenda

Udall, however, continued to push a wide-ranging conservation program for the Kennedy administration, while acknowledging the ideological shift underway. In a 1963 lecture at the University of California, Berkeley, Udall declared, "we are on the verge of the third wave" of conservation "high tides."[26] He touted a "changing conservation philosophy," "a new land ethic, and new forms of social control," in which "our environment should have parity with payrolls and profits."[27] Udall encouraged cooperation by multiple sectors to take on the "task of wise resource management." [28] The speech included a heavy emphasis on using advances in science and technology to further conservation goals.

Udall offered a special focus on energy resources, bringing attention to concerns of the power industry. He declared "Our supreme conservation achievement this century has been the discovery of a self-renewing source of energy … the fission of the atom has allayed our fears of fuel exhaustion."[29] He outlined a three-pronged federal effort to advance electric

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[24] Ibid.
[25] Letter to the President, 1961, Interior, Box 79a, President's Office Files, JFK Library; Udall, "A Report for the President on A Proposal for a Kennedy Administration Parks Conservation Program"; Letter to the President, January 9, 1962, Box # 642, White House Central Files, NR/MC White House Conference on Conservation, JFK Library; Freeman, "Letter to the President"; Letter to the President, January 29, 1962, Box # 642, White House Central Files, NR/MC White House Conference on Conservation, JFK Library; Letter to Mr. Pierre Salinger, Press Secretary, January 9, 1962, Box # 642, White House Central Files, NR/MC White House Conference on Conservation, JFK Library.
[26] Stewart L. Udall, "The Conservation Challenge of the Sixties, Horace M. Albright Lecture, Given at Berkeley, California, Aril 19, 1963," University of California, Berkeley, College of Natural Resources, http://nature.berkeley.edu/site/lectures/albright/1963.php.
[27] Ibid.
[28] Ibid.
[29] Ibid.

power: 1) accelerate nuclear power development, 2) quicken development of the renewable waterpower of rivers and tides, and 3) integrate electric power systems so that "region-to-region transmission lines … will soon add to the efficiency of our over-all electric plant."[30] The speech continued with an outline of the Kennedy "conservation-of-environment" program that covered a wide range of bills and projects covering everything from wilderness protection to pesticide research to pollution control.[31] Udall defined a new home for the power industry, and interconnections, within a comprehensive national effort to protect and carefully use the environment.

From the beginning of Kennedy's first year in office, his administration drew a connection between conservation and potential coast-to-coast interconnections. Initially, however, the administration broached the subject of a national grid "gingerly," as Udall explained to reporters in February 1961. He did say, "such interconnections might very well be, if handled as we would intend, on a common-carrier basis, to the benefit of both public and private utilities, for example, but we want to move slowly."[32] The Kennedy administration identified several elements of a new power policy: 1) revocation of the "no new starts" policy, 2) replication of TVA-type river development projects, 3) ratification of the Columbia River Treaty with Canada, 4) a variety of power expansion projects, and 5)

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[30] Ibid.
[31] Udall listed the following proposed and enacted efforts: A Wilderness Bill, The Land and Water Conservation Fund, state-level preservation of out-of-doors programs, acquisition of the "best seashores," wildlife refuges for endangered species, new national parks and recreation areas, Open Space Aid for Cities, Youth Conservation Corps, Preservation of Selected Rivers, System of Scenic Roads and Parkways, Wetlands Preservation Bill, new military land policies, full development of fresh water resources for species protection and recreation, all-out attack on water pollution, research into air pollution control, regulation of strip-mining, research unwise use of pesticides, combat pollution of oceans and estuaries, and address conflicting land uses.
[32] Department of the Interior Press Conference, The Honorable Stewart L. Udall, Secretary of the Interior, Tuesday February 14, 1961, AZ 372, Box 91, Folder 9, Press Conferences, Special Collections, University of Arizona Libraries, Tucson, AZ, p. 5.

movement toward a coast-to-coast grid. In 1961, Kennedy announced, "I have directed the Secretary of the Interior to develop plans for the early interconnection of areas served by that Department's marketing agencies with adequate common carrier lines; to plan for further national cooperative pooling of electric power, both public and private; and to enlarge such pooling as now exists."[33] Early in 1962, the Federal Power Commission (FPC), under the leadership of Joseph Swidler, initiated a national power survey, with a specific focus on interconnections. The fraternity of electric power specialists had already been considering the implications of national interconnection for a few years. Once again, from the power industry perspective, the grid took center stage as a key technology to effect the country's conservation goals.[34]

Interconnections and International Status

The Administration's push for greater integration of North American power systems married conservation interests and concern about international status. By 1960, major industrialized countries, including Great Britain, France, Germany, and Sweden, all operated national grids. "There was no question that we were not keeping up with other countries in the world," noted Kennedy's Undersecretary of the Interior, James K. Carr.[35] Beyond a desire to compete favorably with the friendly nations of Western Europe, both the power industry and the administration sought a position of technical superiority in the electricity

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[33] Kennedy, "Special Message on Natural Resources," p. 6.
[34] "Department of the Interior Press Conference, The Honorable Stewart L. Udall, Secretary of the Interior, Tuesday February 14, 1961," p.5; "FPC Chief Proposes New Study for Nation-Wide Power Network," *Wisconsin State Journal*, January 24, 1962; Letter to The President, March 20, 1962, FG 232 Box # 171, White House Central Files, Federal Power Commission, Executive, JFK Library. The Columbia River Treaty between the United States and Canada formed a crucial element in an overall scheme to develop fully hydroelectric power resources and flood control measures throughout the entire Columbia River basin and its tributaries. The Treaty also facilitated power trades between the Pacific Northwest and the southwestern region of the United States.
[35] Carr, "Recorded Interview by William W. Moss, May 25, 1971," p. 31.

field with respect to the Soviet Union. “They already had their grid system all the way from Siberia through the Urals and Moscow,” noted Carr.[36] This was a cause for consternation, because the USSR appeared to be ahead in some areas of electrification. But the USSR’s accomplishments also provided encouragement that a national grid in the United States was feasible.

An international community of power experts had worked across political and corporate boundaries for years to enhance the pool of technical knowledge. In addition to sharing technical publications around the world, engineers from France and the United States formed the International Council on Large Electric Systems (CIGRÉ) in 1921. CIGRÉ’s mission from the outset was “Facilitate and devlop [*sic*] the exchange of engineering knowledge and information, between engineering personnel and technical specialists in all countries as regards generation and high voltage transmission of electricity.”[37] CIGRÉ held meetings bi-annually in Paris, and was dominated by representation from the United States and other western countries. However, the organization included members from around the world and fostered significant information exchange on topics germane to power control on interconnected systems.[38]

Cultural and technical exchanges marked the friendly side of the Cold War. In 1958, the United States and the Soviet Union signed a two-year agreement of “the United States of American and the Union of Soviet Socialist Republics on Exchanges in the Cultural, Technical, and Educational Fields.” Among the first delegations from the United States, two included representatives from the utilities (in 1958) and equipment manufacturers (in 1959).

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[36] Ibid.
[37] “CIGRÉ-US National Committee,” History and Purpose, accessed January 20,2013, http://cigre-usnc.tamu.edu/history/.
[38] John Casazza, “History of the U.S. National Committee of CIGRÉ,” (Palo Alto, CA: Electric Power Research Institute, 2007).

Udall led a delegation to the USSR in 1962 specifically to examine electrical installations. By this time, the USSR reportedly operated some transmission lines at a higher voltage than US lines, and had one 800,000-volt direct current line under construction. In the United States, the highest voltage generally used was 345,000, and only on alternating current lines. Udall noted, "The entire Soviet-European and Siberian power systems will [soon] be interconnected and dispatched from a central location."[39] In fact, during Udall's visit, Soviet Premier Nikita Kruschev challenged the United States to an "energy race, the race to see which country can produce the most energy to drive its industrial machine."[40] Udall described the Soviet Union as a "formidable challenger in this important field."[41] The prominence of electric power interests in these exchanges underscored for engineers their own status on the international stage.[42]

The utilities and control engineers followed these developments closely. The Edison Electric Institute issued a lengthy report on the 1958 and 1959 trips, prompting extensive coverage in *Electrical World.* With the headline "The True Race with the Soviets," the *Electrical World* editor identified electric power and economic expansion as the keys to dominance between the competing nations. At this same time, control engineers from across the globe formed the International Federation of Automatic Control (IFAC). IFAC participants met yearly to discuss advances in control technologies for a wide range of fields including electric power systems. Soviet engineers participated in IFAC from the beginning

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[39] Report on Trip to the Soviet Union, August 17, 1962, 1962, Box 79A, President's Office Files, Interior, JFK Library, p. 43.
[40] Ibid., p. 67.
[41] Ibid., p. 67.
[42] Edison Electric Institute, *A Report on USSR Electric Power Developments, 1958-1959* (New York1960). The US/USSR agreement is also known as the Lacy-Zarubin Agreement, on January 27, 1957. Both government signed extensions of the agreement frequently throughout the Cold War.

and the third Congress took place in Moscow in 1960, further cementing the mutual interest of the two countries in matters related to interconnected power systems.[43]

Renewed Contests for Control

The elements of the Kennedy conservation program that touched the power industry also touched off disputes over system control. Since the 1930s, municipal and cooperative power companies enjoyed a preference arrangement that accompanied all federal investment in dams and transmission lines. Power from these federal systems was made available first to public distributors and customers, and later to private utilities. On the private sector side, utility managers grumbled but accommodated the public preference requirement. However, with a new push for coast-to-coast interconnections from the highest levels of the US government, both sides of the public-private power debate retrenched. Private utilities claimed they were well equipped to build and operate major transmission lines and objected to any increase in federal authority over the grid. Undersecretary of Interior Carr remembered that the utilities "reacted violently" to the national grid concept "because it interfered with their own little domain."[44] On the other side, associations of municipal companies and rural

[43] "Report Finds Soviet Sound on Power," *Electrical World* 153, no. 8 (1960); "The True Race with the Soviets," *Electrical World* 153, no. 6 (1960); "U.S. Power Team Answers: What's the Score on Russian Power?," *Electrical World* 153, no. 8 (1960); Edison Electric Institute *A Report on USSR Electric Power Developments, 1958-1959*; Stephen Kahne et al., *The American Automatic Control Council: AACC History and Collaboration with IFAC, 1957-2011*, (Troy, NY: The American Automatic Control Council, 2011), American Automatic Control Council website, accessed September 7, 2012, http://a2c2.org/sites/default/files/BookWithCover.pdf. Professionals in the power industry in both Eastern Bloc and Western countries continued these technical exchanges until the dissolution of the Soviet Union in 1991. Thereafter, technical exchanges endured, but without the overlay of Cold War politics.

[44] Carr, "Recorded Interview by William W. Moss, May 25, 1971," p. 31.

cooperatives lobbied for federal ownership of a common carrier transmission system, and protection of the preference requirement.[45]

Agencies within the Kennedy administration also vied for control. The FPC wrangled with the Departments of Interior and Agriculture over grants of rights-of-way to private utilities to build transmission lines across public lands. Udall and Freeman sought to restore a policy under which the two secretaries could make the grants if the utilities, in return, transmitted power from federal generating facilities when the capacity of the lines permitted. In essence, Interior and Agriculture would require the private transmission line owners to "wheel" public power. Under this policy, the rural and municipal power entities stood to gain greater access to low-cost federally generated power. "Wheeling" was anathema to the private utilities. The FPC's Swidler, however, asserted that this policy would give the secretary of the interior "unlimited and unreviewable discretion" to reject applications he thought conflicted "with the power-marketing program of the United States."[46] Swidler argued that this rule could interfere with plans for national interconnections, which fell under the domain of the FPC. Democrats in Congress, rural cooperatives, and public power

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[45] Power Pooling - A National Issue, Presentation to California Municipal Utilities Association, March 8, 1962, 1962, UT 2-1 Public Power, Box 993, White House Central Files, General, JFK Library; Letter to The President from the Edison Electric Institute, February 11, 1963, UT 2-1 Box 993, White House Central Files, JFK Library; Letter to Lee C. White from Commonwealth Edison Company, October 2, 1962, UT 2-1 Box 993, White House Central Files, JFK Library; Letter to The President from the National Rural Electric Cooperative Association, March 19, 1963, UT 2-1 Box 993, White House Central Files, JFK Library, Boston, MA; Letter to Lee C. White, with Attachments, September 23, 1963, UT 2-1 Box # 993, White House Central Files, Public Power, JFK Library; Letter to Honorable Clinton P. Anderson, Chairman, Committee on Interior and Insular Affairs, November 30, 1962, UT 2 Electricity, Box 993, White House Central Files, General, JFK Library. The first federal preference clause dates back to the 1906 Town Sites and Power Development Act. Numerous federal acts and amendments since then incorporated the preference idea, including the 1920 Federal Water Power Act, the 1933 Tennessee Valley Authority Act, the 1937 Bonneville Power Authority Act, and the 1954 Atomic Energy Act.

[46] Letter to Stewart Udall in Re: Proposed Regulations Governing the Granting of Rights-of-Way for Electric Transmission Lines across Public Lands, March 15, 1963, UT 2-1 Box # 993, White House Central Files, JFK Library.

advocates accused Swidler of parroting the views of the private utilities, and in addition threatening the traditional "yardstick" role of federal power agencies. In the end, Udall and Freeman issued the rule, but dropped the term "wheeling."[47]

Similar disagreements arose around other projects related to high voltage transmission lines and interconnection projects, including the Northwest-Southwest Intertie and a similar transmission line in the Midwest. The rural and municipal power companies consistently advocated in favor of federal transmission lines, wherever they might be built. They argued that the lines "are self-liquidating" and thus of no cost to the nation over time.[48] Further, private utilities could not be trusted to "provide the nation with a nationally-integrated power system" by any date certain.[49] The rural cooperatives and municipal power companies wanted greater access to inexpensive power, whether through the preference clause or through economic purchases from private generators. The private utilities, however, continued to build transmission lines and to sell power, while they lobbied for a minimum of federal interference and a maximum of independence.

Udall managed to navigate the public and private power interests in favor of advancing interconnections. The reluctance of advocates on any side of the power question to build duplicate facilities, especially the very costly extra-high-voltage transmission lines, helped the cause. With the new rule regarding private lines crossing public lands, municipal

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[47] Newspaper Clipping from *The Sacramento Bee*, "Udall, Freeman Undo FPC's Embarrassing Effect on Administration's Power Policy", March 29, 1963, FG 232 Box # 171, White House Central Files, Federal Power Commission, General, JFK Library; Letter to the President, March 19, 1963, UT 2-1 Box # 993, White House Central Files, JFK Library; Robinson Jr., "Letter to Stewart Udall in Re: Proposed Regulations Governing the Granting of Rights-of-Way for Electric Transmission Lines across Public Lands"; Beaty Jr., "Recorded Interview by William W. Moss, January 9, 1970," Interview Number 9.
[48] Ellis, "Letter to Honorable Clinton P. Anderson, Chairman, Committee on Interior and Insular Affairs."
[49] Ibid.

companies and rural cooperatives accessed more federal power. Power pools dominated by private utilities eventually interconnected with the new federal transmission lines. One of Udall's aides credited the secretary with developing "relative peace … between the public and private power interests during this period" and placed this at the top of the list of the secretary's conservation achievements.[50] The 1964 National Power Survey echoed the universal commitment to building interconnections, with a strong conservation justification.

An End to Development in "a Spotty Kind of Way"

In 1962, the FPC proposed to tie together the nation's power systems by 1980. With an investment of only $380,000, the FPC planned to survey the industry and determine where demand was growing fastest, which areas were importers or exporters of power, and what the capabilities and plans of existing companies might be. As the chair of the commission Joseph Swidler pointed out, "Development of the nation's power system has come 'in a spotty kind of way.'"[51] The commission hoped a thorough study and projection through 1980 would allow every utility, whether large or small, public or private, to make its own plans "keyed … to a national scale."[52] The project offered high hopes for a coherent strategy for power system growth across the country.

When completed, the survey defined lower rates and higher quality services for the American consumer as primary objectives. The survey set a target price for 1980 that would be 27 percent lower than the average 1962 price. In addition, proposed activities sought to reduce coal dependency through more efficient plant design by 45 million tons per year. American consumers stood to save a potential $11 billion if government agencies and

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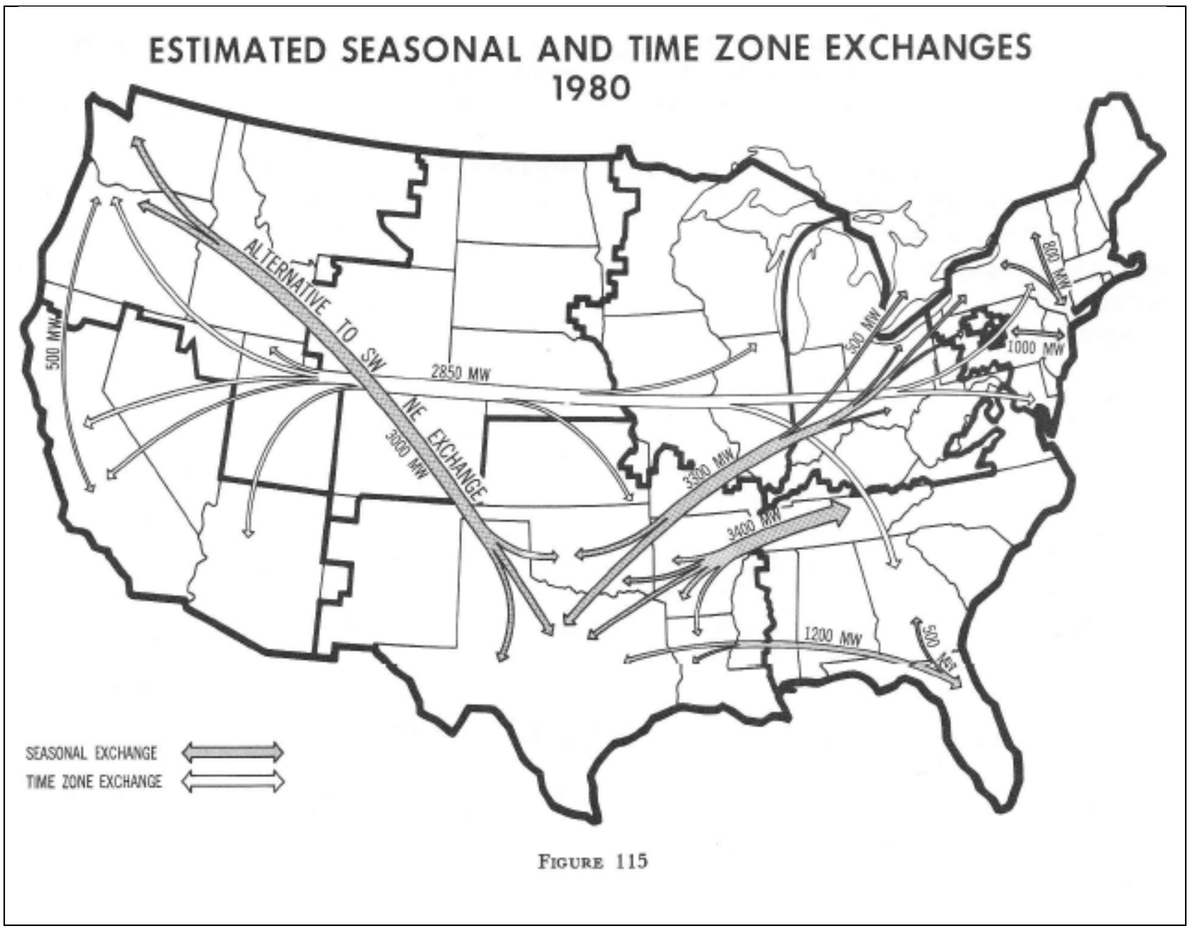
[50] Beaty Jr., "Recorded Interview by William W. Moss, January 9, 1970," Interview Number 9, pp. 202-206.
[51] Peter Braestrup, "National Power Survey Is Urged as Step to Cut Consumer Costs," *The New York Times*, January 24, 1962.
[52] "Swidler Asks Nation-Wide Power Tie-In," *The Washington Post, Times* Herald, January 24, 1962.

utilities followed the ideas outlined in the final report. The survey sketched out a plan for massive infrastructure expansion to meet anticipated demand in every sector of the country. One map, replicated in Map 9.1, projected a fully interconnected system that facilitated massive movement of electricity from east to west and north to south to take advantage of time zone and seasonal differences. These exchanges could result in reduced rates for regions currently burdened with high cost electricity.[53]



Map 9.1. Projected power exchanges in 1980. *Source:* 1964 National Power Survey.

The National Power Survey of 1964 enshrined the confidence and optimism of the power industry. The report of the survey opened with expressions of enthusiasm for a "new era of low-cost power", new technologies, larger machines, competitive nuclear power,

[53] Federal Power Commission, *National Power Survey: A Report*, p. 4.

economical extra-high voltage power lines, and interconnections across broad geographic areas.[54] In short, the power industry had the techniques, the know-how, and the public support to perhaps triple capacity for the anticipated demands of the relatively near future. Not only did the Survey predict growth in both demand and supply, the survey also practically guaranteed enormous savings through advances in technology and practices that resulted in maximum efficiency. In addition, the survey proposed that a national grid promised both equity of service and conservation of resources for the American public.[55]

Cutting Across Traditional Battlelines

As a relatively new chair of the Federal Power Commission in 1962, Joseph Swidler embarked on a politically fraught mission by introducing the power survey. Private utilities, rural cooperatives, and municipal power companies all maintained aggressive lobbying activities to mitigate federal actions that might infringe on their respective market sectors. Swidler attempted to bring together public and private support for the survey by noting that the United States is "probably the only civilized country in the world that does not have a coordinated national electric system."[56] He explained that a 1961 utility effort to produce an interconnection plan was "merely a consolidation of local and regional plans … limited by local interests and restrictions."[57] Private industry responded by noting that previous federal proposals for national grid systems had been a "prelude to nationalization of all utility

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[54] Ibid., p. 1.

[55] The Survey specifically addressed questions related to power supply and demand in the target year of 1980. While the Canadian public did not fall directly within the intended audience for the survey, the authors assumed the grid would also be international in scope, accessing the vast water resources of the northern part of the continent.

[56] "Swidler Asks Nation-Wide Power Tie-In."

[57] Braestrup, "National Power Survey Is Urged as Step to Cut Consumer Costs"; Institute, "Report on the Status of Interconnections and Pooling of Electric Utility Systems in the United States."

companies."[58] A *Wall Street Journal* editor further suggested that the utilities already had all the data the FPC sought, and the survey, therefore, was just "a Federal move in the direction of a nationalized power industry."[59] Swidler counteracted these objections by appointing a diverse advisory committee in March 1962. He reported to Kennedy, "The industry leaders, representing both private and public power, all agree that the national power survey is in the public interest."[60]

Over the next two years, a broad array of engineers, utility managers, fuels specialists, lawyers, and federal administrators collaborated to produce a report. Through twelve special advisory committees, individuals from the public and private sectors hammered out detailed reports on an array of topics ranging from power requirements to legal matters to distribution details to regional differences. During this time, the FPC weathered an array of controversies that repeatedly brought opposing views into the public spotlight. Whether the rural cooperatives challenged the FPC's intent to support private construction of extra-high voltage power lines, or the FPC took the industry to task over a lack of coordinated research efforts, the debates over the federal role in power development continued.[61]

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[58] Braestrup, "National Power Survey Is Urged as Step to Cut Consumer Costs."
[59] "How to Save the Taxpayers, $380,000," *Wall Street* Journal, February 6, 1962.
[60] "F.P.C. Establishes New Advisory Unit," *The New York Times*, March 9, 1962. Quote in Swidler, "Letter to The President." Kennedy appointed Swidler to the FPC in June 1961, and named him chair of the Commission in August. Swidler took up this post on September 1, 1961. "Swidler Nominated to Head F.P.C," *New York Times*, August 19, 1961.
[61] Federal Power Commission, *National Power Survey: A Report*. Volume I, pp. 293-29. Letter to Clyde T. Ellis, General Manager, National Rural Electric Cooperative Association, December 11, 1962, UT 2 Electricity, Box 993, White House Central Files, General, JFK Library; Julius Duscha, "Swidler Tells Electric Leaders to Generate New Power Uses," *The Washington Post, Times* Herald, June 5, 1963; Julius Duscha, "Power Commission Split by Licensing Proposal," *The Washington Post, Times Herald*, January 19, 1963; Ellis, "Letter to the President"; Ellis, "Letter to The President from the National Rural Electric Cooperative Association"; Radin, "Letter to Lee C. White, with Attachments"; Robinson Jr., "Letter to Stewart Udall in Re: Proposed Regulations Governing the Granting of Rights-of-Way for Electric Transmission Lines across Public Lands."

As the industry anticipated release of the report in late 1964, the news media focused on the potential for additional controversy. Gene Smith, a reporter for *The New York Times* who covered power issues closely, compared the report release to "D-Day" for US utilities. While Swidler reassured utilities that the survey would not be an attack on their independence, industry leaders expressed concern that the incoming President Johnson had a pro-public power record in Congress. As if to shore up their position, the utilities announced numerous new pooling agreements in the final weeks before Swidler presented the completed survey.[62]

With the release of the National Power Survey report in December 1964, controversy still revolved around the FPC's intentions, although widespread support for the plans soon emerged. In his initial coverage, Gene Smith noted a generally positive response from a limited sampling of industry, "battle lines between public and private power seemed to be broken."[63] The *Washington Post*, however, noted that private utilities "are voicing a mixed reaction."[64] On the public power side, skepticism prevailed. Clyde Ellis, representing the National Rural Electric Cooperative Association, claimed cooperation could be achieved "only through drastic change in the negative attitudes of the commercial power industry."[65] Alex Radin, speaking for the American Public Power Association, worried that local communities would lose the option of municipal service.[66] The *Wall Street Journal* was similarly caustic, suggesting the FPC's intentions were thinly veiled. "The industry's record

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[62] Gene Smith, "Dec. 14 Is 'D-Day' for U.S. Utilities"," *The New York Times*, November 16, 1964; Gene Smith, "Utilities Fear Power Policies New Government Might Adopt," *The New York Times*, November 29, 1964.
[63] Gene Smith, "F.P.C. Seeks Cut in Power Costs," *The New York Times*, December 13, 1964.
[64]"FPC Power Suggestion Finds Mixed Reactions," *The Washington Post, Times* Herald, December 15, 1964.
[65] Smith, "F.P.C. Seeks Cut in Power Costs."
[66] Ibid.

of past achievement hardly adds up to a solid case for sweeping new Federal powers to guide its future."[67] Are regulators "simply as preoccupied as ever with another kind of power?"[68] Even the executive advisory committee for the survey acknowledged that there were differences of opinion between individuals involved in the project and the published findings.[69]

As the different interest groups took time to study the survey report, they began to express support. In presenting the report, Swidler reiterated that the survey was not intended as a blueprint for development, that it would not trigger a legislative overhaul, and that the national grid was not "anything we'd build."[70] Within days, a utility spokesman concurred the survey "did not advocate a national Government-controlled grid. Instead it suggested a partnership within the industry."[71] The utilities found the survey proposals to be in line with their own plans for 1980. Swidler assured small utilities, municipal companies, and rural cooperatives that the FPC had no intent of increasing their regulatory burden. By expanding power interconnections, he claimed, "we're trying to get them in on the benefits of pooling, technology, and the like."[72] In January 1965, the FPC sent its annual report to Congress and highlighted the survey as a major accomplishment of the prior year. Gene Smith reported, "Strangely enough, the F.P.C.'s assessment of the industry seemed to cut across the traditional battlelines [*sic*] between public and private power and to call for continuing the

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[67] "Planning for Power," *Wall Street Journal*, December 18, 1964.
[68] Ibid.
[69] Smith, "F.P.C. Seeks Cut in Power Costs"; Eric Wentworth, "Federal Power Agency to Seek Controls over Growth of Electric-Utility Industry," *Wall Street Journal*, December 14, 1964.
[70] "U.S. Survey Sets Goal for Electricity Price Cut," *The Washington Post, Times* Herald, December 13, 1964; Julius Duscha, "Projection to 1980 Says Electric Rates Can Be Cut by 27%," *The Washington Post, Times* Herald, December 13, 1964; Smith, "F.P.C. Seeks Cut in Power Costs."
[71] Gene Smith, "Utilities Study National Power Survey and Relax," *The New York Times*, December 20, 1964.
[72] Smith, "F.P.C. Seeks Cut in Power Costs"; Smith, "Utilities Study National Power Survey and Relax."

cooperating between the Government's ratemaking body and the investor-owned segment as a strong means of achieving the goals of the survey."[73]

While sniping continued periodically, both among lobbying groups and within the press, the National Power Survey appeared to represent a consensus across the public and private sectors in favor of greater interconnection, larger power plants, closer coordination and planning, and a long-term goal of benefitting consumers. While public power advocates doubted the sincerity of private sector commitments to lowering rates, they embraced the notion of "a national power pool jointly owned by public and private utilities."[74] The private utilities, likewise, saw the survey as vindication of the plans they already had in place for extra-high voltage lines and giant power pools. Even better, with widespread participation in preparation of the survey report, the engineering and utility operations community found their ideas about efficiency, economy, and conservation happily endorsed on a national scale.

Conservation, but Not Environmental Protection

From the outset, the survey linked interconnection to resource conservation, although this was not the sole objective for the FPC. On January 24, 1962, FPC chair Joseph Swidler announced the agency's plan to conduct a survey of the nation's power resources. In endorsing this proposal, President Kennedy encouraged the creation of a "fully interconnected system of power supply for the entire country."[75] In the opening pages of the National Power Survey report, the Commission explained that the project fulfilled a directive of the Federal Power Act, to "… 'promote and encourage … interconnection and coordination' of electric utility systems for … 'the purpose of ensuring an abundant supply of

[73] Gene Smith, "A Powerful Year in U.S. Electricity," *The New York Times*, January 11, 1965.
[74] Wentworth, "Federal Power Agency to Seek Controls over Growth of Electric-Utility Industry."
[75] Federal Power Commission, *National Power Survey: A Report*, p. xxiii.

electric energy throughout the United States with the greatest possible economy and with regard to the proper utilization and conservation of natural resources …'"[76]

The report authors noted a longstanding goal of improved power system integration across the continent. For example, decades earlier, FPC staff "suggested that a future report 'of the highest public interest' should deal with 'improving the interconnection and coordination of existing power facilities.'"[77] With 3600 separate US power systems in 1964, the industry faced ample opportunity to achieve greater economies of scale, take better advantage of diversity, and lower rates to consumers through improved coordination and planning. This would lead to conservation of resources, but only in the Progressive era sense of "maximum economic use" for the greatest number of consumers over the long term.[78]

The survey report primarily addressed expansion of the power system to undergird the country's economic future, but delved briefly into concerns about environmental protection and pollution control. As outlined in the introduction, 13 chapters forecast demand, technology advances, and energy sources. Three explored strategies for expansion and interconnection, including regional differences and economic considerations. Chapter 9 alone was devoted exclusively to effects of power projects on the environment. Out of two volumes, over 700 pages of text and graphics, 17 chapters and 25 advisory reports, a mere 12 pages addressed air and water pollution. Environmental concerns had just barely begun to command the attention of electric power planners. However, the report writers did recognize that "environmental considerations will become increasingly significant factors in the location, design, and operation of future thermal-electric plants."[79]

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[76] Ibid., p. 1.
[77] Ibid., p. 3.
[78] Ibid., p. 4.
[79] Ibid.

The report considered only two types of pollution: thermal pollution resulting from both nuclear and fossil-fueled plant discharges to various water bodies, and air pollution from fossil-fueled plants. After sketching out the array of problems understood by the industry, the authors proposed six conclusions. First, both government and industry should give additional emphasis to pollution concerns as utilities build larger plants. Second, thoughtful planning should go into the design of larger plants. Third, available technology controlled pollution, but costs could be high and more information was needed. Fourth, more research on pollution damage was needed. Fifth, careful selection of plant sites could mitigate the economic and social effects of pollution (note that the authors did not address ecological effects of pollution). And finally, the potential for bringing down electricity rates could be somewhat reduced by pollution controls, but the "nation's capacity to produce needed electrical energy will not be impaired because of these environmental considerations."[80]

In these early years of the 1960s, the power industry and government alike trivialized the potential effects of environmental impacts on power system expansion. They similarly minimized the likelihood that new power projects would inflict serious environmental damage. Most significantly, they expressed great confidence that any potential problem could be mitigated through cost-effective technical innovation and careful siting decisions.

Confidence and Optimism

With a goal of coordinated growth across all power sectors, the survey optimistically outlined how coast-to-coast transmission benefitted systems large and small. "In short, interconnection is the coordinating medium that makes possible the most efficient use of

[80] Ibid., p. 147.

facilities in any area or region."[81] Technical innovations foreshadowed much higher capacity transmission lines, and the survey authors suggested that many of the benefits identified throughout the report depended on those lines. "In this context, the historical function of the electric transmission circuits has assumed new dimensions."[82] Although each section of the report detailed problems as well as opportunities for transmission and pooling, the survey authors expressed enormous confidence in the capabilities of the industry. "There are no insurmountable obstacles to the successful operation of large interconnected systems."[83]

Much of this confidence rested on the perceived ingenuity of engineers and operators in solving past problems. In enumerating the challenges of operating interconnected, the survey authors offered a triumphant status report on US systems. Because "difficult technical problems were solved as they arose," and thanks to automated control apparatus, frequency fluctuations in the United States were minimal.[84] Innovations in lightning arrestors, very high speed relays, circuit breakers, and other equipment "all played important parts in making present day interconnected system operation a reliable reality."[85] For economic dispatching, "modern computer programs have been devised," and also provide operators with current cost data, operating performance, and billing information.[86] Regarding safety, "the current state of the art is such that a satisfactory degree of reliability may be obtained with present hardware."[87] The survey touted the many applications of computers throughout system operations and predicted even more widespread uses by 1980, including a foreshadowing of

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[81] Ibid. Volume I, p. 27.
[82] Ibid. Volume I, p. 149.
[83] Smith, "Dec. 14 Is 'D-Day' for U.S. Utilities"."
[84] Federal Power Commission, *National Power Survey: A Report*. Volume I, p. 163.
[85] Ibid. Volume I, p. 164.
[86] Ibid. Volume I, p. 165.
[87] Ibid. Volume I, p. 166.

today's smart grid. "Remote monitoring of system loads, possibly down to the individual customer's service with all data feeding into a central computer, has been suggested."[88]

Drawing on the projections of the private utilities, the survey optimistically predicted national interconnection in the near future. "By 1980, it is expected that virtually full coordination will be completed both east of the Rockies and west, and that substantial interconnections between the east and west zones will be established."[89] This in turn would bring about the traditional conservation changes sought in previous eras. The low-cost energy transportation provided by long-distance transmission and interconnection was already "making all of the Nation's fuel and water power resources a common fund."[90] The future collateral benefits of interconnection included adding "measurably to the life of our limited low-cost fossil fuel supplies," relocating steam plants to reduce urban air pollution, allowing instant shutdown in instances of extreme pollution, and improving the use of hydropower with less wasted energy "sent to sea."[91]

As a means of reassuring different industry sectors, and expressing faith in the status quo, the FPC also predicted that full coordination "can be accomplished without altering existing patterns of ownership."[92] The survey called for the creation of 16 study areas in which all stakeholders would coordinate plans and investments to bring about greater efficiency and lower cost electrical service. With adequate contractual arrangements, and technologies to address the complexities of sharing power, "there seems to be no doubt but what the operation of the systems … can be coordinated both on an intra-area and an inter-

[88] Ibid. Volume I, pp. 165-166.
[89] Ibid. Volume I, p. 200.
[90] Ibid. Volume I, p. 4.
[91] Ibid. Volume I, p. 7.
[92] Ibid. Volume I, p. 199.

area basis."[93] The survey authors acknowledged that "certain freedoms of individual operation must be relinquished voluntarily" to achieve optimum operation of a pooled system.[94] They suggested, however, that operators historically recognized that the potential benefits outweighed the costs of coordination.

The achievements of the power industry to date, and the opportunities offered by full coordination, painted a rosy future for the nation's electrical system. The survey predicted and encouraged consumption, growth, expansion, cross-country interchanges of power, and full enjoyment of the benefits of electricity. With more interconnections, improved economy dispatch, greater flexibility of plant siting, full use of nuclear power, and improvements in air and water pollution controls, the country surely would enjoy cleaner, cheaper, and more efficient delivery of electricity everywhere it was wanted and needed. These improvements would slow the depletion of fossil fuel resources. Past development may have taken place in a "spotty kind of way," the United States might be the only civilized country in the world without a fully coordinated power system, yet the survey recognized the industry as "the largest and most efficient source of electric power supply in the world."[95]

In one particular way, the optimism and confidence contained in the survey was merely hubris. "The plans projected in the Survey for 1980 provide for a continually

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[93] Ibid. Volume II, p. 209

[94] Ibid. Volume II, p. 209. The survey did acknowledge that in some areas, "failure to interconnect [in the past] may reflect an attempt to avoid federal regulation rather than a decision based on engineering or economic considerations." Volume I, p. 209. A separate report by the Legal Advisory Committee delineated a number of issues related to power pooling, corporate status, antitrust issues, and rate regulation. The committee concluded that "there are no nationwide insuperable legal barriers to achieving the benefits of full coordination." Volume II, p. 354. Two members of the committee indicated in a footnote that they did not necessarily individually agree with every finding of the committee, particularly as the findings related to the potential impact upon rural electrification, but they concurred with the report as a whole because they agreed with its major conclusions. Volume II, p. 355.

[95] Ibid. Volume I, p. 2.

increasing interconnection of systems, thus rendering it more difficult to isolate a load from power. The greater interconnection of systems enhances survivability by decreasing the probability that a given service area would be totally without power. However, even today for most areas, interconnections are sufficiently numerous that this eventuality is very improbable."[96] The authors failed to recognize the potential fragility of such a large and complex system. The nation's first major cascading blackout hit the northeast less than one year after Swidler released the first completed US national power survey.

Summary

If long distance transmission lines and interconnections served as technologies of conservation before World War II, they clearly served as tools for growth and national pride in the post-war years. With new waves of industrialization, urban concentration, and suburban expansion, electricity provided a major economic engine during these years. Politicians and power engineers seldom discussed careful development of natural resources for current and future generations. Instead they focused on how to construct big dams, integrate nuclear power, and build extra high voltage power lines quickly and strategically. The utilities formed giant power pools in order to achieve both greater reliability and greater access to energy resources. The efforts of activists to ward off unnecessary damage to beautiful places, excessive air and water pollution, and over-exposure to radiation only occasionally interrupted the plans of the power industry and its advocates.

With a primary focus on economic success, managers within the power business also sought economies of scale and efficiencies of operations. Utility engineers and operators found energy savings in improved techniques for transmission and exchange of power. In

[96] Ibid. Volume I, pp. 224-225.

fact, with new automatic control devices, more sophisticated approaches to pooling, and the adoption of analog and digital computers, American utilities maintained a position at the cutting edge of innovation. Interconnections figured prominently in the public discourse as an element of national economic strength and international power. Through professional publications, international conferences, and diplomatic exchanges, American engineers established themselves as experts in controlling interconnected power systems and producing electricity with maximum economy. For the most part, consumers benefited from lower rates as a result.

When the Kennedy administration ushered in a new focus on conservation, followed by increasing interest in environmental protection, the engineers who designed and operated the interconnected power systems were well pleased to be in a position of authority. In multiple federal initiatives, a national grid figured prominently as the key tool for moving energy from areas of abundance to areas of need, for guaranteeing greater equity in access and rates, for assuring improved reliability, and for once again conserving natural resources. News reports, technical magazines, and politicians reflected a growing consensus in favor of coast-to-coast interconnection. This took place during a period of transition for conservation initiatives. During the 1950s, new public interest groups shifted the focus of the conservation discourse to quality of life issues, pollution control, excessive consumerism, and fear of nuclear fallout. In the early 1960s, with Stewart Udall's warning of a conservation crisis, and the influence of ecology on public understanding of the human influence on natural systems, the seeds of modern environmentalism began to take root. By the time Lyndon Johnson took office, in late 1963, the power industry operated in a new political context regarding care for the natural world.[97]

The individuals and organizations promoting the grid had only a minimal grasp of how expanded electric power production and distribution might impact the environment. They generally saw increased electricity consumption and a bigger network as net gains for the country, especially with greater use of hydroelectric power and nuclear power. A wide array of power system experts participated in drawing up the nation's first completed power survey, and offered a glowing report on the state of affairs and the potential for future growth. While poised for expansion, and confident about its strength and efficiency, the industry was ill-prepared to face the coming test of reliability: the 1965 Northeast Blackout.

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[97] Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement*; Hays, *Conservation and the Gospel of Efficiency: The Progressive Conservation Movement, 1890-1920*; Melosi, *Coping with Abundance: Energy and Environment in Industrial America*; Rome, *The Bulldozer in the Countryside: Suburban Sprawl and the Rise of American Environmentalism*; Thomas Raymond Wellock, *Preserving the Nation: The Conservation and Environmental Movements, 1870-2000*, The American History Series (Wheeling, IL: Harlan Davidson, Inc., 2007); Stewart L. Udall, *The Quiet Crisis*, 1st ed. (New York: Holt, 1963); Rachel Carson, *Silent Spring*, 40th anniversary ed. (Boston: Houghton Mifflin, 2002); Melosi, "Environmental Policy," pp. 187-209.

Part IV. Crisis and Closure: From Blackout to National Grid, 1965-1967

On February 7, 1967, a momentous event passed nearly un-noticed in North America: four tie lines connected 95 percent of the electric power systems across the continent. For the first time in history, a kilowatt of electricity generated on one coast could illuminate a light bulb on the other. For years, if not decades, engineers, politicians, and utility executives had been dreaming and scheming about a national grid, and at last it was in place. From Gifford Pinchot to John F. Kennedy, the merits of coast-to-coast interconnection had been extolled. Yet this moment was met with a collective shrug in the United States and Canada – why? The answer may lie in a less popular event that had occurred just over a year earlier. On November 9, 1965, the lights went out for 30 million North Americans in the worst power outage in history. This disaster was a real game-changer for the electric power industry, which had enjoyed over 80 years of celebrated, though not uncontroversial, growth and had approached expansion and interconnection with the enthusiasm and dedication of missionaries. The 1967 east-west intertie, and its quiet completion, is emblematic of what changed and what did not change as a result of the 1965 blackout.[1]

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[1] Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*; Melosi, *Coping with Abundance: Energy and Environment in Industrial America*; Kennedy, "Special Message on Natural Resources." Numerous scholars have described and analyzed the 1965 blackout, offering analyses of the social, technical, economic, and political implications of this event. For detailed discussions, see, Hirsh, *Technology and Transformation in the American Electric Utility Industry*; Hyman, Hyman, and Hyman, *America's Electric Utilities: Past, Present and Future*; Nye, *When the Lights Went Out: A History of Blackouts in America*; Pratt, *A Managerial History of Consolidated Edison, 1936-1981*; Schewe, *The Grid: A Journey through the Heart of Our Electrified World*. The website of "The Blackout History Project" (http://blackout.gmu.edu) provides a useful compendium of reports, essays, personal accounts, data, and images for both the 1965 blackout and later blackouts. "East-West Ties Hold; US Systems in Phase," *Electrical World* 167, no. 8 (1967); "East-West Closure Will Parallel 94% of US Capacity," *Electrical World* 166, no. 20 (1966); "Editorial - Thoughts About an East-West Closure," *Electrical World* 166, no. 20 (1966); "Electrical Week: Intertie," *Electrical World* 167, no. 7 (1967), pp. 49-51; C. Sulzberger, "History - When the Lights Went out, Remembering 9 November 1965," *Power and Energy Magazine, IEEE* 4, no. 5 (2006); "Huge Power Grid to Get Test

Chapter 9. Cascading Failure and Then Closure: The 1965 Northeast Blackout to the 1967 Intertie

The 1965 blackout shook the utility industry, revealed the fragility of interconnected electrical systems, and changed the perception of the grid for power producers and consumers alike. Until the big blackout, Americans had not contemplated a cascading failure of such enormous magnitude. Engineers and utility managers had confidence in a half-century of studying, evaluating, inventing, adjusting, and operating interconnected power systems. The technology was sound, the practices tried and true. From the general public to the most experienced stakeholders, most observers considered power pooling essentially beneficial in all respects. The interlinked transmission lines carried electricity to people, promised efficiency and economy, allowed more thoughtful use of energy resources, facilitated lower prices, and increased the profit margins of the utilities. The first major blackout in North America's history called into question the wisdom of building a giant network of power lines across the continent.

The blackout revealed the dark side of interconnection: those linked in success were also linked in failure. By 1965, 30 privately owned and government power companies shared power across the northeastern United States and into Canada. These utilities chose to interconnect in order to enjoy the benefits of greater operating efficiency and the reassurance of ready access to back-up power from neighbors. All experienced the repercussions of the blackout, from the minor inconvenience of separating from the network to the disastrous

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Feb. 7. U.S., Canada Plan to Link Major Systems," *New York Times*, January 26, 1967; "East-West Ties Hold; US Systems in Phase."

circumstance of full shut-down. Although individuals had questioned interconnections in the past, never before had the costs of sharing power been so starkly revealed.[2]

The United States was moving quickly and enthusiastically toward coast-to-coast power transmission in 1965. For national grid advocates, interconnection represented economic strength, international political power, technological know-how, and engineering derring-do. It also exemplified the very American value of equity in service by bringing power to every corner of the country. At the same time, as an odd jumble of federal installations, private transmission lines, and international links, the proximate national grid personified capitalist democracy at work. Investor-owned utilities time and again resisted government oversight of interconnections in favor of self-determination, but welcomed key transmission lines built by the federal government. Most significantly, the growing network of transmission lines represented the backbone of electrification. The blackout illustrated the weakness of that backbone. If one small error could leave 30 million people without power in a matter of minutes, what did the grid really represent?

The blackout pushed utilities and politicians alike to reconsider the feasibility of building a network in bits and pieces. For the prior fifty years, utilities vigorously protected their autonomy in the development of an interconnected system. Even the recently issued 1964 National Power Survey, produced by the federal government, offered only a suggested path for further growth. The 1965 blackout began with a flawed relay setting, but it manifested through varying approaches to automation and decision-making across the participating utilities. For engineers and system operators, the organic growth of the grid up to this point had been both challenging and manageable. But a massive failure suggested that

[2] Federal Power Commission, *Prevention of Power Failures: An Analysis and Recommendations Pertaining to the Northeast Failure and the Reliability of U.S. Power Systems, A Report to the President*, p. 8.

greater uniformity, and perhaps more authoritarian oversight, would insure a more reliable system.

The blackout further revealed the advantages and disadvantages inherent in systems of shared management and divided authority. With so many individuals and entities responsible for maintaining stable operations, the initial reaction to the blackout inevitably involved finger pointing. The follow-up studies of the blackout revealed a great lack of uniformity in installations, inspection programs, information flow, and monitoring techniques. Further, utilities adhered to settings, standards, and recommended emergency response procedures on a voluntary basis. By the same token, decades of collegial information exchange and collaborative problem solving engendered a sense of unity among most of the utilities sharing power in the northeast. Industry leaders immediately offered expertise, information, time, and staff support to the government agencies that investigated the blackout. The US Federal Power Commission (FPC) likewise worked hand-in-glove with state utility commissions and Canadian power authorities to determine precisely how the blackout had happened, where weaknesses lay, and how to best approach strengthening systems in the future.

The 1964 National Power Survey had once again elevated interconnected transmission lines as a technology of conservation, but the blackout immediately pushed conservation concerns into the back-ground as reliability became a top priority. In the aftermath of massive power failure, the public demanded explanations of how and why the breakdown occurred, as well as promises of greater security in the future. Americans expected ubiquitous and reliable electricity by this time, a sign of the power industry’s success even in the face of failure. In the past, the grid had offered the means of assuring that electricity flowed even if a generator failed or a power line went down. Now, consumers called into question the reliability of the grid itself. In fact, many asked if a grid was even necessary.

A brief tour of the events of the 1965 blackout will reveal how views of the grid changed as a result of this one event. As the blackout occurred, the frailty of the loosely organized interconnected system became obvious. In the immediate aftermath, the existence of a nearly national grid actually caught many by surprise, and the purpose of interconnections rose to the fore of national discourse. As investigations of the outage began, the system of shared management and divided authority – on both the operating level and the governance level – showed its strengths and weaknesses. The blackout raised many questions about the assumptions that formed the context of grid development. Just as engineers verged on tying the continent together into one giant machine, Americans in both the United States and Canada confronted the irony of growing interconnected.

The Power Industry in 1965

The 1964 National Power Survey provides a benchmark for the status of the power industry at the time of the Northeast blackout. As the survey reports, the United States used 40 percent of the electricity produced in the world and electric power businesses constituted the largest industry in the US economy according to several measures. As had been the case through the prior eighty years, a "gaggle" of entities electrified North America. There were 3600 power systems in the US at this time, a number of which crossed into Canada. Of those, 480 investor-owned utilities, or 13 percent, owned 76 percent of the capacity and served 79 percent of the consumers. In other words, the majority of the system was operated by a relatively small number of regulated monopolies. More than 3,000 much smaller municipal utilities and cooperatives operated a mere 11 percent of the system, providing power to 21 percent of the customers. The federal government owned 13 percent of the system, but provided no direct service to retail customers.[3]

Long distance transmission and interconnection were on the rise in the early 1960s. The industry operated 90,000 miles of transmission lines, 97 percent of which were interconnected across North America in five large networks. In 1964, a loosely organized pool called the Canada-United States Eastern Interconnection (CANUSE) served customers in New York, New England, Ontario, and Michigan. CANUSE shared power with the Interconnected Systems Group (ISG), which by this time stretched west to the Rocky Mountains and south to the Gulf of Mexico. CANUSE had also recently closed ties with the Pennsylvania-New Jersey-Maryland Interconnection (PJM). All three of these major pools were comprised of numerous smaller pools and operating groups. Within CANUSE, the interties were, in many cases, of limited capacity and normally used only for power exchange in emergencies. Map 9.2 illustrates the major interconnections across the United States. CANUSE and PJM covered the states stretching from Maryland and Delaware north to Maine and west to Michigan. The portion of CANUSE that extended into Canada is not shown in this image.[4]

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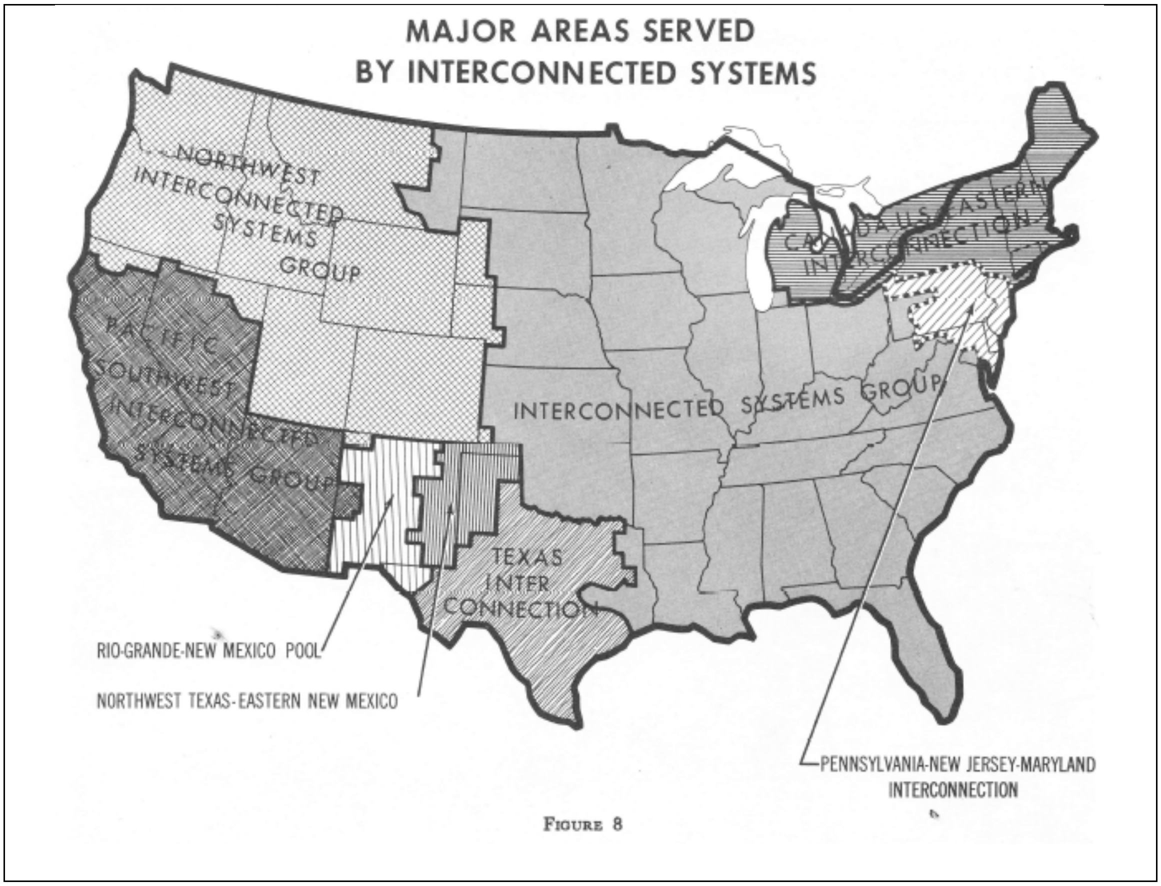
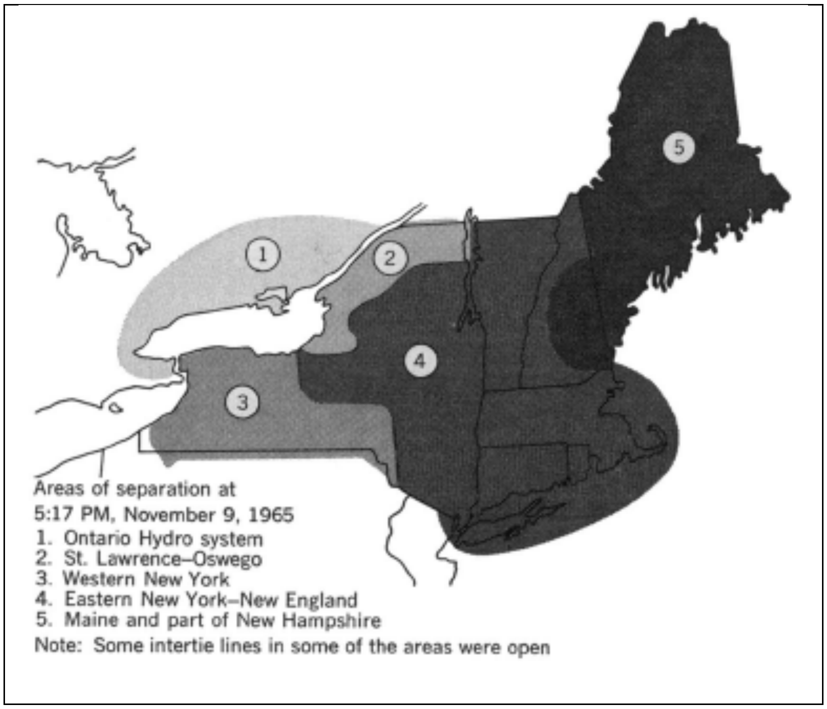
[3] Federal Power Commission, *National Power Survey: A Report*; Nye, *When the Lights Went Out: A History of Blackouts in America*, p. 164. Nye quotes the CEO of the PJM Interconnection speaking at hearings investigating the 2003 northeast blackout. "Yet, this industry was built, financed, and operated for over 80 years by a gaggle of over 4,000 different entities." See footnote on p. 256. "Blackout in the Northeast and Midwest," Hearing before Committee on Energy and Natural Resources, US Senate, February 24, 2004 (Government Printing Office, 2004), 22.
[4] Federal Power Commission, *National Power Survey: A Report*.



Map 9.2. Five large networks and three smaller networks identified by the Federal Power Commission. ***Source:*** **United States Federal Power Commission,** ***National Power Survey,*** **1964, p. 15.**

The area affected by the blackout, though geographically smaller than other major power pool areas, represented a significant portion of the continent's electrification. Map 9.3 indicates the portions of Canada and the northeastern United States affected by the blackout. The utilities within CANUSE generated nearly a third of the continent's power. Most of the northeast system was privately owned and operated. Within CANUSE, some of the pools, like the Connecticut Valley Electric Exchange (CONVEX), were highly coordinated. Other utilities maintained loose interconnections, as in New Hampshire and Vermont. Utilities in Maine operated in virtual isolation. In general, electricity rates varied greatly, reflecting regional energy costs, the costs of infrastructure, the presence of federal power sources, and the interplay between utilities and regulators in the rate-setting process. At the time of the blackout, fossil fuels provided 81 percent of the energy for power production, hydroelectric plants provided eighteen percent, nuclear plants provided less than one percent, and in that year the United States shipped a little bit of electricity to Canada. The cost of electricity was highest in the northeast, nearly 30 percent higher than the rest of the country.[5]



Map 9.3. Areas affected by the November 9, 1965 blackout, and further illustration of the separations that occurred in the first few seconds of the cascading failure. *Source:* Gordon D. Friedlander, "Northeast Power Failure – a Blanket," *IEEE Spectrum,* February 1966, p. 62.

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[5] The New England Pool included New England Electric Systems (NEES), Boston Edison, Eastern Utilities Associates, Connecticut Valley Electric Exchange (CONVEX), and Vermont Electric Power Co. The New York Pool covered three smaller pools, the Upstate Interconnected Systems, the Southeastern New York Power Pool, and the Michigan-Canadian Group with connections into New York. Consolidated Edison Co. of New York (Con Edison) was the major power provider in the Southeastern New York Pool. Ibid. The utilities in the northeast used primarily imported energy resources – natural gas and coal – to generate electricity, which contributed in part to the higher electricity rates. *Table 8.4b Consumption for Electricity Generation by Energy Source: Electric Power Sector, 1949-2011*, Energy Information Administration, US Department of Energy, Washington, DC, 2011, accessed March 5, 2013, http://www.eia.gov/totalenergy/data/annual/pdf/sec8_18.pdf;
Energy Information Administration, *Average Retail Price of Electricity to Ultimate Customers: Total by End-Use Sector*, US Department of Energy, Washington, DC, 2011, accessed March 5, 2013, http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_3. Electricity rates in 1965 were about 93 percent of rates today, in 2000 dollars.

Throughout the growth of the electric power industry, there had been many blackouts, and they had merited moderate concern. New York City alone had experienced major blackouts in 1935, 1938, 1959, and as recently as 1961. Overall, however, the public took reliable electricity for granted. The Edison Electric Institute, the New York Public Service Commission, and the FPC all acknowledged the reliability benefits of the grid, but touted economic and resource conservation functions when promoting national interconnections. Looking back on the 1965 blackout in 1991, a prominent utility executive tried to recapture the "1960s mindset" stating, "As we approached the mid-1960s, the reliability of electric bulk power supply was not the major issue, either within the electric utility industry or within its various publics."[6] No one expected a crippling blackout.

November 9, 1965, 5:16 p.m. – 5:28 p.m., Eastern Standard Time

It took only 12 minutes for one unanticipated relay response to bring down the nation's most intensely electrified region. On November 9, 1965, at 5:16:11 p.m. EST, a relay on the transmission line carrying power from Niagara Falls to Toronto "tripped" and stopped the flow of electricity. At an earlier date, this relay had been set to protect the line from a sudden influx of too much power. But the setting was lower than the amount of power the line could actually carry, and the load had been steadily increasing in prior months. This

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[6] Knowles, "Hydro-Electric Development and Water Conservation"; E.C. Stone, "The Interchange of Power between the Duquesne Light Company and the West Penn Power Company.," *Electric Journal* 14, no. 9 (1917); Cook, "The Future Power Station"; Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, p. 309.P.H. Chase et al., "Power Transmission and Distribution in the United States of America, Part I," *General Electric Review* 35, no. 8 (1932); "Northeast Power Pool Quickly Meets Emergency," *Electrical World* (1943). Public Service Commission, "Annual Report," (Albany, NY: State of New York Public Service Commission, 1962); G. S. Vassell, "Northeast Blackout of 1965," *Power Engineering Review, IEEE* 11, no. 1 (1991); James F. Fairman, "Hard-Head Engineering," in *Twenty Eight Annual Convention of the Edison Electric Institute* (Atlantic City, New Jersey: Consolidated Edison, 1960); "N.Y. Utilities Form Group for State-Wide Studies," *Electrical World* 153, no. 2 (1960); "EEI Task Force Study Reveals 1970 Pooling Plans," *Electrical World* 158, no. 5 (1962).

meant that the relay tripped when the load exceeded the relay setting, but was still well below the amount of electricity the line could carry. In other words, the amount of electricity on the line was not enough to threaten the stability of the line, but the relay behaved as if it was. With this line down, the load shifted to four additional power lines connecting Niagara to Toronto, and the relays on those lines tripped as well. In less than three seconds, excess power started flowing into New York State. In one more second, in accordance with predetermined operating procedures and automated responses, the CANUSE system broke into four isolated sections. Maine and part of New Hampshire separated as well and did not lose service. Each of these five areas is delineated and shaded in Map 9.3. There followed a series of events, described as a "cascading" blackout, which ultimately plunged the northeast into darkness by 5:28 p.m.[7]

On this cold November evening, in the midst of rush hour, demand for electricity was reaching its peak. In the moments before the relay tripped, the collection of twenty large utility companies and pools that served the majority of the northeastern United States and Ontario generated nearly 44,000 megawatts of electricity to meet the area's demand. As excess electricity flowed south, the interconnected system witnessed a variety of responses from individual utilities and pools. In some cases, automatic relays caused areas to separate, in others operators made decisions to remain connected and aid neighbors, or disconnect and protect their own generators and customers. In a system developed piecemeal and

[7] The four separate areas were: (1) the Ontario system; (2) an area around Niagara served by the Power Authority of the State of New York (PASNY); (3) a second area around Niagara with excess generation; and (4) the remainder of the pool extending east to Boston and south to New York City. NERC defines "cascading" as "The uncontrolled successive loss of system elements triggered by an incident at any locations. Cascading results in widespread electric service interruption that cannot be retrained from sequentially spreading beyond an area predetermined by studies." *Glossary of Terms Used in NERC Reliability Standards, Updated October 19, 2012*.

characterized by shared responsibility, but divided authority, lack of uniform response marked the sequence of events that followed the initial opening of a relay in Ontario.

Automatic Separation, Manual Control, Unpredictable Outcomes

Throughout the area affected by the blackout, varied system responses led to unpredicted outcomes. Some areas relied on automatic relays to separate at the first indication of trouble. Others relied on system operators to determine the best response to the unfolding situation. Neither approach guaranteed protection from the cascading power failure. Automatic response systems led to protection of certain areas, like New Jersey and most of Pennsylvania, and power loss in others, as in the province of Ontario. As a result of both conservative engineering and forward thinking, New Jersey, Maryland, and most of Pennsylvania avoided the effects of the blackout. The Pennsylvania-New Jersey-Maryland Interconnection (PJM), serving the majority of customers in those states, had a long history of stable operations within its original system, and exercised great caution when it intertied with CANUSE utilities. As one of the oldest power pools in the country, PJM took great pride in the reliability of service the pool provided. In the early 1960s, PJM and Con Edison began negotiations to build an intertie between the two systems. Not fully trusting the effects of major system trouble on the Con Edison side of the intertie, PJM engineers installed special relays at the New Jersey/New York boundary and at the Pennsylvania/New York boundary. The day after the blackout, Pennsylvania Power & Light Company, a PJM member utility, reported to its customers, “These ties are designed to disconnect when overloaded in order to prevent extension of any trouble that might arise. Such overloading did occur last night and these ties did disconnect as designed."[8] PJM customers did not experience any power failure.[9]

When Ontario separated from the rest of CANUSE, different regions experienced the cascading failures in different ways. Within one-half second of the loss of the five transmission lines from Niagara to Toronto, Ontario was operating on its own, and experienced a major deficiency of power. Actions within the province no longer affected New York and the other regions of CANUSE. The Hydro-Electric Power Commission of Ontario (HEPCO) networks automatically separated into three major sectors. The western sector of Ontario received assistance from Michigan and did not lose power. Throughout the other two sectors, major cities went dark within seconds of the start of the cascade. HEPCO restored service to the entire area by 8:30 p.m.[10]

Near the Canadian border in upstate New York, automatic separation protected a discrete group of economically significant power users. The Power Authority of the State of New York (PASNY) planned for automatic separation of its major hydroelectric plant in the case of trouble. Following the tripping of the five HEPCO power lines that initiated the blackout, lines connecting the PASNY plant to downstate New York and to New England also tripped out, as did five generators within the plant. The hydroelectric generating station

[8] Letter from Jack. K. Busby, President, Pennsylvania Power & Light Company to Customers, November 10, 1965, Box 39, NC Papers, MIT.
[9] The automatic response systems discussed here are different in kind from the automated tie-line and load control systems discussed earlier. Automatic tie-line and load control apparatus addresses normal operating conditions and causes adjustments that will allow interconnected power systems to operated in parallel. The relay trip that initiated the Northeast blackout caused such a large mismatch of demand and supply that automatic tie-line and load control mechanisms were overwhelmed. On the other hand, relays and governors designed to protect systems from exceptional changes in power flow did act automatically to separate transmission lines and generators from the network. For a simple explanation of this situation, see Nathan Cohn, "L & N and the Control of Electric Power Systems" (paper presented at the Leeds & Northrup Shareholders Meeting, Philadelphia, PA, September 14 1966); Jack Casazza Interview by Loren J. Butler, February 1 1994.
[10] Federal Power Commission, *Northeast Power Failure: November 9 and 10, 1965*, (Washington, DC: Government Printing Office, 1965).

now operated in isolation from the rest of the system and supplied electricity to nearby industrial loads. In this island of power, facilities owned by Aluminum Company of America, General Motors, Reynolds Metals Company, the City of Plattsburg, and Plattsburg Air Base all continued activities unaffected.[11]

Over the next several minutes, system operators on manual control throughout New England and New York faced difficult decisions. In the case of Con Edison, for example, the system operator observed rapidly switching inflow and outflow of power as other utilities separated from the pool. In keeping with the recommended emergency procedures of the North American Power Systems Interconnection Committee (NAPSIC), the operator attempted to provide aid to his neighbors by increasing generation. After a few minutes, however, this effort failed and the system physically disintegrated, leaving New York City in the dark. During this same period, operators at CONVEX and Long Island Lighting Co., among others, manually separated from neighboring systems, exacerbating the situation for Con Edison. In each case, the system operator had the authority to determine how to balance obligations to his own network and to his interconnected neighbors in order to address the growing crisis.[12]

CANUSE failed in 12 minutes in much the same way interconnections had been assembled over several decades. Each participating entity acted according to its own internal objectives as the system fell apart in pieces. While utilities shared responsibility for managing a stable network, they operated their own sub-networks with autonomy. Some were able to protect their customers from power loss by automatically separating. Others

[11] Ibid.
[12] Schewe, *The Grid: A Journey through the Heart of Our Electrified World*; "Northeast Power Failure: November 9 and 10, 1965." Schewe offers an entertaining, suspense-filled, and accurate account of the events unfolding in the Con Edison control room.

attempted to do the same through manual separation. Still others acted to meet their pooling obligations. With insufficient coordination, lagging communication between systems, and inadequate preparation for failure on this scale, they lost power nonetheless. The immediate effect of the blackout, in addition to causing major problems for millions of power customers, was to force the power industry itself to reassess the nature of the interconnected systems.

The Aftermath, November 9, 1965 – December 6, 1965

The 1965 blackout affected 30 million people across 80,000 square miles in nine states and in Canada. The power was out in some areas, including most of Manhattan, for more than half a day. It took hours to restore power across the blackout area, days to determine the cause, and weeks to inspect all of the affected generation and transmission equipment. The scale of this event prompted President Johnson to immediately call upon the Chairman of the FPC to investigate, and led ultimately to a multitude of reports by government and private sector entities documenting every nuance of the outage and its causes.[13]

Reporters looked to the industry and to governments to explain what had taken place. The earliest news briefs expressed palpable relief that no enemy attack had caused the trouble. The media quickly dismissed several other preposterous explanations, including the less likely possibilities of nuclear attack, UFOs, and a little boy in Massachusetts hitting a telephone pole with a stick. On November 10th, headlines across the country reported that the cause of the blackout was a mystery. One day later, headlines posited there had been a

[13] "Northeast Power Failure: November 9 and 10, 1965"; Pratt, *A Managerial History of Consolidated Edison, 1936-1981*, pp. 138-152; J.J. O'Connor, "Northeast Blackout Triggers Plans For ... Firm Power Supplies," *Power* 110, no. 1 (1966); Schewe, *The Grid: A Journey through the Heart of Our Electrified World*; Pratt, *A Managerial History of Consolidated Edison, 1936-1981*, pp. 138-152. "Northeast Power Failure: November 9 and 10, 1965," Cover Letter.

"quarrel" between generators, thus explaining that generators operating out of synchrony could bring down a power system. In fact, utility representatives understood quite quickly that there had been some sort of fault on the line near Niagara, but investigations lasted days before the public had a clear explanation. One week after the blackout, Ontario officials finally accepted responsibility for the relay action that initiated the cascading failures.[14]

As the popular press pondered the cause of the giant power failure, reporters also discussed what the grid was, why it existed, and whether or not it was a good thing. The public began to understand that behind the light switch lay "an immensely complex and interlocking network of men, machines, and wires that is not infallible."[15] One critic compared the grid to the skin of a ripe cantaloupe, vulnerable to failure. Another observer noted, "interest in power system controls has been literally hurled into the public

[14] "Editorial Comment - We Can Learn Vital Lessons in Adversity," *Electrical World* 164, no. 21 (1965); Charles G. Bennett, "City Scores Westinghouse, Con Ed, P.S.C. In Blackout," *New York Times*, June 21, 1961; James Doyle, "The Blackout All Started in a Little Ontario Relay," *Boston Globe*, November 16, 1965; "Ontario Admits It's to Blame," *Boston Globe*, November 16, 1965; Michael Posner, "Blackout Fault of Canada," *Chicago Daily Defender* November 16, 1965; "Blame Broken Relay for N. Y. Blackout," *Chicago Tribune* November 16, 1965; "Blackout Is Traced to Canadian Plant," *Hartford (CT) Courant* November 16, 1965; John M. Lee, "Ontario Accepts Blame for Blackout in Northeast," *New York Times*, November 16, 1965; Peter Kihss, "Ontario Station Cited at Outset," *New York Times*, November 16, 1965; "Power Row Stirred Up," *Batlimore (MD) Sun*, November 16, 1965; James MacNees, "Troubles Originated in Ontario Generating Plant, Panel States," *Baltimore (MD) Sun*, November 16, 1965; "Canada Line Failure Caused Blackout, Probers Say," *Batlimore (MD) Sun*, November 16, 1965; Howard Simons, "Great Blackout Is Laid to Pesky Canadian Relay," *Washington Post, Times Herald* November 16, 1965. A Google News search for the term "blackout" between the dates of November 9, 1965 and November 16, 1965 returned hundreds of articles from around the world documenting the power failure, most of which repeated wire service stories. For example, there were 97 articles calling the blackout a "mystery," 82 headlines asking for the cause of the blackout, 20 regarding President Johnson's plan for the Federal Power Commission to probe the blackout, and 17 explaining that the grid itself spread the blackout. "Google News," *Google*, Mountain View, California, accessed October 29, 2012, https://news.google.com.
[15] McCandlish Phillips, "Behind the Light Switch Lies Complex Power Network Covering Entire Northeast," *New York Times*, November 15, 1965.

consciousness."[16] The press delineated the inherent conflict of the grid: "The Northeast power system was considered the last word in sophisticated engineering and the product of computer science. Ironically, the interlocking grid system designed to assure a supply of electricity in an emergency helped spread the blackout over the huge area."[17]

The lack of immediate information about the sequence of events and the frightening first-hand experiences of sudden darkness and prolonged service outages shook public confidence in electric utilities and the notion of interconnection. On November 22nd, *Electrical World* conducted a spot survey of 200 customers of northeast utilities to determine whether the blackout had tarnished the industry's image. While respondents felt that their utilities did a reasonably good job of restoring service, nearly a third thought that their utility was to blame for the power failure. "At fault, of course, in the public's view, was the grid -- and everyone connected into it. As a Brooklyn housewife put it, 'They (electric companies) shouldn't put all their eggs in one basket that way. Why should we be in the dark because of something that happened in Canada? I've never even been to Canada.'" *Electrical World* noted in an earlier survey that the majority of North Americans never heard of the grid or thought it was a football field. With the blackout, consumers began to understand that the functioning of the living room light switch might be contingent on decisions made several states, or entire nations, away. Surprisingly, in the November 22nd survey, two thirds of respondents still believed interconnections were a good idea.[18]

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[16] "Large-Scale Federal Sale of Electricity in Northeast to Be Sought by President," *Wall Street Journal*, July 12, 1965.
[17] Lawrence J. Hollander, "The Big Blackout: Whooping Cranes & Power Failures," *The Nation* 202(1966). Quote in "The Great Blackout -- It's Still a Big Mystery," *St. Petersburg (FL) Evening Independent*, November 10, 1965.
[18] "Did Blackout Tarnish Utility Image?," *Electrical World* 164, no. 21 (1965); Pratt, *A Managerial History of Consolidated Edison, 1936-1981*. According to historian Joseph Pratt, the main criticism of Con Edison after the blackout was its long delay in restoring service. Ibid., p. 148.

Journalists, politicians, and government officials expressed their own concerns. In a special supplement published just days after the blackout, *Electrical World* posited that the massive shutdown "had been considered extremely improbable" before it happened.[19] As the supplement reported, from New York Governor Nelson Rockefeller to Texas Congressman Walter Rogers, many others shared this view. In a hearing called by Governor Rockefeller, utility executives began pointing fingers as they proclaimed their own systems were not at fault. The spokesman for the American Public Power Association noted that independent municipal electric companies, unlike the linked private utilities, did not lose power. Secretary of the Interior, Stewart Udall, urged stronger interties. The *New York Times* stated "the utilities are on trial. They must give a complete account of what went wrong. And they must see to it that the public will never again be faced with the helplessness that comes from a total power failure."[20] International reporting on the blackout also raised the question of whether the US approach to power networks aided or harmed the system. In most countries outside North America, governments owned and operated national grids. To these observers, the hybrid collection of public and private ownership characterized by CANUSE looked particularly unreliable following the blackout.[21]

Closer to home the blackout represented a chink in the armor of the power industry and the organic approach to growth and development that had dominated the twentieth century. Newspaper and magazine editors expressed concern about future blackouts. As reliability jumped to the top of the agenda, power experts offered differing views of interconnection. Joseph Swidler, Chairman of the FPC, repeatedly spoke in favor of the grid, and Robert Person, President of the Edison Electric Institute stated, "The principle of pooling

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[19] "Did Blackout Tarnish Utility Image?"
[20] "Paralysis of Power," *New York Times*, November 11, 1965.
[21] Murray Illson, "Blackout Is News All over World," *New York Times*, November 11, 1965.

and interconnection, as it has evolved over the years, is basically sound, as indicated by the fact that the kind of massive failure just experienced has rarely occurred."[22] Prominent engineer Philip Sporn, immediate past president of American Gas & Electric Company, part of the Interconnected Systems Group, backed away from the notion of a national grid in favor of more tightly organized regional pools. Other utility executives argued that interconnections weakened the power system, offering that the "entire nation could have been plunged into darkness in less than a second if a Federally proposed plan had been in effect."[23] Boston Edison's executive called for a thorough study before proceeding with a nationwide grid.[24]

The Report, December 6, 1965

While individuals and organizations debated North America's approach to electrification, the FPC conducted a detailed study of the power failure. With the aid of dozens of private sector utility representatives and several government agencies, the FPC sought to understand precisely what had taken place, how and when each link in the network failed, and what the implications were for future planning. The preliminary results of the investigation, released less than a month after the blackout, reinforced the industry commitment to grid development. The report concluded that the failure was not inevitable, and that interconnections added strength and reliability to electric power service. Following a detailed description of how the blackout occurred, the report identified measures to

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[22] Gene Smith, "Utilities Agree on a Prediction: Statewide Failures Can Recur," *New York Times*, November 11, 1965.

[23] Eileen Shanahan, "Blackout Inquiry Gets Underway," *New York Times*, November 11, 1965; Gene Smith, "Utilities Failed Major Test for Grid," *New York Times*, November 14, 1965; Smith, "A Nationwide Grid Termed Solution," *New York Times*, November 10, 1965; Smith, "Utilities Agree on a Prediction: Statewide Failures Can Recur."

[24] Hirsh, *Technology and Transformation in the American Electric Utility Industry*; "Northeast Power Failure: November 9 and 10, 1965"; Illson, "Blackout Is News All over World"; Smith, "Utilities Failed Major Test for Grid," p. 134 "Blackout Is Traced to Canadian Plant."

strengthen the grid and confine future outages. The FPC committed to carrying out further studies, and offered a set of specific recommendations to President Johnson, Congress, and the industry. With high praise for the industry representatives who assisted with the investigation, the FPC affirmed the strength of the power sector and the benefits of the path to interconnections previously chosen for increased electrification.[25]

The section of the report detailing the cascading failure illustrated the autonomy of each utility and pool in responding to a crisis. While indicating and explaining the instances in which relays tripped, transmission lines fell out of service, and generators slowed or stopped, the report dwelt on the decision-making at Con Edison. The FPC noted that individual systems generally followed the recommendation of NAPSIC to maintain parallel operations if at all possible in order to render "maximum assistance to the system in trouble and … prevent cascading of trouble to other parts of the system."[26] At the same time, however, the NAPSIC guidelines also suggest that a system should disconnect if an "intolerable overload" threatens the equipment.[27] Beyond these potentially conflicting guidelines, the on-duty Con Edison operator had no specific instructions concerning what particular circumstances should trigger load shedding in order to save the remainder of the system. This individual had full authority for making a decision, but insufficient information to act quickly and in the best interest of his utility's own customers. The FPC further

[25] "Northeast Power Failure: November 9 and 10, 1965." Ironically, systems in Texas and New Mexico experienced a brief power outage on December 3rd, just days before President Johnson, then at his "Texas White House," expected to receive the report. The following paragraphs summarize key points covered in the report.
[26] Ibid., p. 16.
[27] Ibid., p. 16.

explained that each company faced a similar problem, particularly those that were not automatically disconnected by an emergency relay trip.[28]

To remedy this situation, the FPC called upon the utilities to reexamine the extent of planning and coordination in place for their interconnected systems. As the report explained, equipment failures must be expected, but system failures can be prevented. Noting the great variety among the "power grids of the nation," the FPC called for several specific measures to minimize the likelihood of a repeat blackout. Among the list of 19 "partial and tentative" recommendations, the agency highlighted closer coordination between the US and Canada, both at the government level and at the operating level. Further, the agency called for independent power companies to join power pools, for the creation of planning and operating entities with sufficient responsibility to require close coordination within pools, more studies of how to ensure stable operations, more frequent checks of relay settings, and increased reserve capacity in both transmission lines and generators. The FPC also encouraged widespread use of more advanced automated controls, and reconsideration of load shedding under emergency conditions. For the most part, the FPC looked to industry to proceed as it had in the past, only more so. The nineteenth recommendation, however, called for greater regulatory authority at the federal level.

One week later, speaking to a US House subcommittee investigating the blackout, Joseph Swidler expanded on the nineteenth recommendation. Swidler declared that interconnections, at the heart of continuity and reliability in the bulk power supply, were a matter of national interest. He acknowledged that new legislation should "leave upon the

[28] Load shedding refers to the practice of disconnecting a customer or collection of customers from the generating system in order to reduce the total load on the network.

shoulders of management" primary responsibility for reliability.[29] But, he sought authority for the FPC to set minimum standards for system design and operation and for intersystem coordination. He requested that legislation encourage additional and more fully coordinated interconnection. He urged Congress to establish legislation that covered all entities in the power industry. The press focused on the call for new and stronger regulatory authority at the federal level.[30]

The Response: Industry, Politicians, and The Public, 1965-1967

The press provided widespread coverage of the FPC blackout report, opening further questions about federal authority and the benefits of interconnection. Wire service stories appeared across the country outlining the findings and focusing on the FPC's quest for more regulatory power. Taking a different tack, Eileen Shanahan, writing for the *New York Times*, highlighted the FPC's claim that "more, rather than fewer interconnections … were needed to provide electrical service."[31] She noted, "Since the blackout, there have been some assertions in Congress and elsewhere that the interconnection system itself is a bad idea, inasmuch as it permits the wide spreading of power failures."[32] She returned to this theme four days later, "What was more startling to many people was the vigor with which the Government and industry experts who worked on the report reaffirmed their belief in the whole concept of

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[29] *Northeast Power Failure, November 9, 10, 1965 Hearings before the Special Subcommittee to Investigate Power Failures of the Committee on Interstate and Foreign Commerce, House of Representatives, Eighty-Ninth Congress, First and Second Sessions ... December 15, 1965; February 24, 25, 1966*, Eighty-Ninth Congress, 1st and 2nd Sessions (Washington, DC: Government Printing Office, 1966).
[30] Shanahan, "F.P.C. Asks Right to Set Electric Power Standards," *New York Times*, December 16, 1965; "Chairman Urges More Authority for FPC," *St. Petersburg (FL) Times*, December 16, 1965; "Laws Called Answer to Power Losses," *Toledo(OH) Blade*, December 16, 1965; "Legislation Held Need in Power Problem," *Lexington (NC) Dispatch*, December 16, 1965.
[31] Shanahan, "F.P.C. Criticizes Power Systems in Nov. 9 Failure," *New York Times*, December 7, 1965.
[32] Ibid.

interconnecting power systems."[33] Reflecting the uncertainty of many across the country, Shanahan found it confusing to hear on the one hand that a failure of interconnecting systems led to the blackout and on the other that strengthened interconnections offered the answer.[34]

In the weeks following the FPC report, the US Senate and House of Representatives conducted their own investigations of the blackout. The Senate Committee on Commerce requested information from federal agencies, emergency relief groups, the utility industry, and state and municipal officials. The Senate released the report in March 1966, including correspondence from the constituencies surveyed. All seemed to concur that "this country has the technical talent and facilities available … to upgrade the power systems of this country so that power failures of this severity will be extremely improbable."[35] All shared faith in interconnections for both reliability and economy. Witnesses before the Senate Committee on Commerce upheld a belief in technology and the capability of power systems experts to maintain a growing and stable power supply.[36]

The executives of several private utilities extolled the strength of their own pooling arrangements to the Senate Committee. Commonwealth Edison boasted the regional power system in the Middle West "can achieve a degree of reliability that will practically rule out a widespread electric shutdown."[37] Florida Power Corporation offered that excellent

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33 Shanahan, "F.P.C. Asks Right to Set Electric Power Standards."
34 A Google News search for the term "Federal Power Commission" produced 58 news articles published in early December 1965. Representative headlines from December 6th and 7th include the *Milwaukee Journal*: "Blackout Study Asks New Regulations," the *Spokane Daily Chronicle*: "Change Asked in Power Act," and the *New York Times:* "FPC Indicates New Legislation," accessed November 3, 2012, https://news.google.com.
35 Response from Rural Electrification Administration administrator Norman Clapp, *Responses to Inquiries About the Northeast Power Failure November 9 and 10, 1965; Interim Report of the Committee on Commerce, United States Senate on the Northeast Power Failure, March 22 (Legislative Day, March 21), 1966*, Eighty-Ninth Congress, 2nd Session (Washington, DC: Government Printing Office, 1966), p. 3.
36 Ibid.
37 Ibid., p. 161.

coordination among that state's utilities minimized the chance of a cascading failure. Pennsylvania Power & Light Co could not "conceive of the occurrence on PJM of a power failure similar in cause and scope to the Northeast power failure."[38] Pacific Gas & Electric Co. assured the Senate that California systems were inherently less vulnerable to major outages, although the executive from Southern California Edison offered some humility, "we want to be as certain as we can be that we are not overconfident in our self-appraisals."[39] The longstanding overconfidence of the industry, however, was in evidence throughout most of the responses to the Senate Committee.

Industry executives responded with caution to Swidler's request for increased FPC oversight of the interconnected power systems. The President of Northern States Power Co., operating in the Upper Mississippi River basin, expressed his belief that responsibility for coordination should remain with local utility operators. The president of Virginia Electric & Power Co. likewise discouraged legislation that would increase controls on utility companies. He offered that the highly specialized competence of utility engineers "is the only reason there has never been a shortage of electric energy in this great Nation."[40] The chief of the American Electric Power Co. strongly objected to a national grid on the grounds that it would add unmanageable complexity to planning and operation of power systems. The utilities clung tightly to their operating autonomy while extolling their ability to coordinate reliable service between themselves.[41]

Government officials and representatives from public utilities were less sanguine. For example, the Missouri Basin Systems Group, comprised of preference customers of the

[38] Ibid., p. 180. Ironically, the PJM system experienced a cascading failure on June 5, 1967, just over a year later.
[39] Ibid.
[40] Ibid. Response from A.H. McDowell, Jr., Virginia Electric & Power Co., p. 197.
[41] Ibid. Response from Donald C. Cook, President, American Electric Power Co., Inc., p. 147.

Bureau of Reclamation, reported to the Senate Committee that joint planning with private utilities left much to be desired. Despite effective relations with the Bureau of Reclamation, which built the transmission grid in this area, the rural cooperatives and municipal power companies found the private utilities and large generation and transmission cooperatives to be less forthcoming. They encouraged more federal intervention in the planning process. In the area more directly affected by the blackout, the Mayor of New York reported efforts to gain local jurisdiction with the state over Con Edison's operations, while the Governor of Vermont claimed the blackout indicated a regulatory vacuum. Amid the consensus favoring continued interconnection, there was great diversity of opinion whether the grid should be "national," how governments should be involved, and how much leeway should be enjoyed by the private sector utilities.[42]

The House Committee on Interstate and Foreign Commerce Special Subcommittee to Investigate Power Failures echoed the findings of the Senate. The Subcommittee held hearings on December 15, 1965 and February 24-26, 1966 and solicited responses from each of the fifty states.[43] The report included the hearing testimony, the full text and exhibits of a Stone and Webster study commissioned by utilities in northeastern states, and correspondence from thirty two states. The responses reflected regional and political differences from across the country. In many states, the regulatory commissions took exception to the pronouncements of the utilities or the FPC, although in several states, commissioners praised regional preparedness for emergencies.

Commissions in areas unaffected by the blackouts generally praised their own exceptional systems and doubted that they would suffer similar outages. They appeared to

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[42] Ibid. Response from James L. Grahl, Basin Electric Power Cooperative, p. 153.
[43] *Northeast Power Failure, November 9, 10, 1965 Hearings before the Special Subcommittee to Investigate Power Failures of the Committee on Interstate and Foreign Commerce.*

self-consciously protect systems of shared management and divided authority. They detailed their own long histories of operating interconnected without major power interruptions, their strong interties and agreements, their effective use of automated controls, their access to more stable energy supplies, and their better plans for responding to emergencies. Many noted that they were already implementing enhanced digital computing systems to evaluate their networks and plan for future contingencies. From Georgia to Idaho, numerous state utility regulators opposed increased federal oversight and resisted the completion of coast-to-coast interties. In contrast, several states sought greater oversight and improved coordination through interstate ties. Regional variation proved to be the rule rather than the exception in defining the state of power systems across the nation.[44]

The More Things Change … The Final FPC Report, July 1967

The power industry responded to the 1965 blackout by renewing a commitment to the path it had been following for decades. Through a combination of public expressions of confidence in the system, investment in technology, increased interconnection, and formation of entities that fostered voluntary adherence to reliability standards, electric utilities managed to sidestep the challenges to the status quo brought about by the blackout crisis. The earliest statements from utility executives reflected the hubris of the engineers who had developed the complex, intertied power system. As *New York Times* reported Gene Smith remarked,

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[44] Ibid. The utility commission in Florida expressed a preference for remaining autonomous from FPC jurisdiction, p. 189. The Georgia public service commission expressed concern that more interties would lead to greater system complexity, and future cascading blackouts, p. 195. Idaho lauded it's own regional coordination and opposed "unnecessary rigid restrictions" imposed by a federal regulator, p. 198-199. Nevada argued that the FPC "invaded and deteriorated intrastate utility regulation" with the preference clause, p. 386. The Virginia State Corporation Commission expressed faith in state level regulation to "see that service is reliable," p. 464. Notably, Nebraska laws restricted power service to government owned utilities and cooperatives, yet the Nebraska Power Review Board found that "on the administrative and planning levels, coordination was found to be sadly lacking," p. 376.

before the blackout “the top executives of the utilities ... would certainly have denied that any blackout such as the one that did occur could ever occur in so vast an expanse of the United States. ... they would also have argued that it was inconceivable that an area extending from New York City to Quebec to North Bay to the outskirts of Detroit and back to New York City could ever be blacked out short of an enemy attack in wartime.”[45] Over the longer haul, the utilities played to their strengths, focusing on technical and organizational solutions to the question of grid instability.[46]

Within months of the blackout, utilities, and particularly those in the northeast, had made a number of technical improvements to the interconnected power system. Advances included improved communications systems, updated displays in control centers, increased use of automated control technologies including automatic load shedding devices, new system monitoring equipment, backup generators for control centers, and even new turbines. Utilities debated the merits of automatic load shedding versus on the spot decision-making, yet the industry touted the greatly increased use of technology to separate segments of the power system that were experiencing failures. According to the FPC "... the best insurance against a major power failure is sound planning plus a well-designed and -operated bulk power supply system. ... automatic controls are essential." Even more important than more sophisticated instruments and devices, however, was the move towards tightened pooling agreements and shared central control facilities.[47]

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[45] Smith, “Utilities Failed Major Test for Grid.”
[46] “Northeast Power Failure: November 9 and 10, 1965”; PE Clarence Paulus, “Questions Engineeers' Courage,” *Electrical World* 165, no. 6 (1966), p. 5; Gordon D. Friedlander, “Prevention of Power Failures: The FPC Report of 1967,” *Spectrum, IEEE* 5, no. 2 (1968); Pratt, *A Managerial History of Consolidated Edison, 1936-1981*.
[47] State of New York Public Service Commission, *Annual Report*, (Albany, NY1966); C. Girard Davidson, “Report to the City of New York's Consumer Council on Reliability of Service, Adequacy of Future Power Supply, and Rates to Consumers Provided by Consolidated Edison Company,”

Eighteen months after the big blackout, the FPC issued a thorough statement on how to prevent future blackouts. With 34 recommendations, the report outlined a path to greater reliability of the power grid. Most of these recommendations addressed expanding the size and strength of the transmission network, improving coordination between participating entities, and upgrading the technologies used for studying and operating the grid. As in the case of prior FPC reports, the Commission relied heavily on participation and input from industry representatives. More than 75 individuals from across the country, representing private utilities as well as cooperatives, municipal companies, and federal agencies, aided in preparation and review of the two-volume report, thus insuring that the FPC findings reflected a very broad range of perspectives.[48]

The report called for the creation of coordinating entities to oversee implementation of report recommendations, much in line with the types of organizations the industry had already created over the prior decades. Just before releasing the report, the FPC had asked Congress to consider a proposed "Electric Reliability Act of 1967" that would enshrine this approach in federal law. The power industry was already moving in the direction of the report's recommendations, but resisted the FPC's push for greater regulatory authority. Shortly after the blackout, the affected utilities in the northeast formed the Northeast Power Coordinating Council to strengthen planning and operations of the interconnected pools. By

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(Washington, DC: Davidson, Sharkey & Cummings, 1968); Friedlander, "Prevention of Power Failures: The FPC Report of 1967"; Hirsh, *Technology and Transformation in the American Electric Utility Industry*.

[48] *Prevention of Power Failures: An Analysis and Recommendations Pertaining to the Northeast Failure and the Reliability of U.S. Power Systems, A Report to the President*; Friedlander, "Prevention of Power Failures: The FPC Report of 1967."

the end of 1966, an additional eight regional coordinating councils appeared across the country.[49]

Efforts to Legislate Reliability

The FPC and supporting legislators introduced eighteen bills during the 90th Congress to implement the proposals for electric reliability, including the controversial Electric Reliability Act of 1967. The Senate Committee on Commerce attempted to garner widespread input on the proposed legislation. The Committee held a series of hearings, beginning in Washington, D.C.in August 1967 and continuing in the Pacific Northwest in December 1967 and in Salt Lake City in April 1968. The testimony was heavily weighted toward representatives from western states, although representatives from national entities also participated. A definite trend opposing federal legislation emerged, although some offered remarks backing greater oversight from the FPC.[50]

At the initial hearing, several federal agencies and legislators presented testimony in support of the Act, arguing that the severity of recent blackouts called for greater central control and oversight at both planning and operating levels. In addition to the FPC, the Committee heard from the Office of Emergency Planning, the Department of Transportation, the Bonneville Power Administration, and the Assistant to the President for Consumer Affairs – all favoring the bill. Senators from Montana, California, Maryland and Maine also expressed support. The Hearing record included editorials from a wide range of publications,

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[49] *Hearing before the Committee on Commerce on S. 1934 Amending the Federal Power Act and Related Bills, S. 683, S. 1834, and S. 2227, August 22, 1967*, Ninetieth Congress, 1st Session (Washington, DC: Government Printing Office, 1967).

[50] Ibid; *Hearing before the Committee on Commerce on S. 1934 Amending the Federal Power Act and Related Bills, S. 683, S. 1834, and S. 2227, Part 2, December 20 and 21, 1967*, Ninetieth Congress, 1st Session (Washington, DC: Government Printing Office, 1968); *Hearing before the Committee on Commerce on S. 1934 Amending the Federal Power Act and Related Bills, S. 683, S. 1834, and S. 2227, Part 3, April 26 and 29, 1968*, Ninetieth Congress, 2nd Session (Washington, DC: Government Printing Office, 1968).

from the *Pittsburgh Post-Gazette* and the *Washington Post* to *Life Magazine* offering further endorsement of legislative action. As the editor of *Public Utilities Fortnightly* remarked, "The FPC produced a bill it believes will help insure the nation against future blackouts and yet one which it thinks the electric industry will be able to live with."[51]

An interesting collection of public interest organizations joined the side supporting new laws. The National Rural Electric Cooperative Association, numerous individual municipal utility districts, environmental and conservationist groups, sportsmen's associations, and several Indian Tribal Councils further argued in favor of increased federal authority. These entities sought to defend their own interests in the process of strengthening transmission grid planning, location, construction, and operations. A stronger FPC offered this solution. In addition, the California Public Utilities Commission acted as the lone state regulator in favor of greater federal oversight.

These favorable testimonials contrasted sharply with the opinions of investor-owned utilities, the majority of state regulatory commissions, and active power pools. For the most part, presenters from the private sector, including Commonwealth Edison, Pacific Gas & Electric Company, and even the very small Nevada Power Company, documented the extent to which cooperation marked the industry's practices. These individuals noted that their systems suffered very few outages, stayed on top of current technical innovations, and offered superior service to customers. In like fashion, representatives of interconnected systems, including the Northwest Power Pool, the California Power Pool, and Western Energy Supply and Transmission Associates, offered strong arguments in favor of continuing with voluntary coordination and planning. These entities detailed the history of their

[51] *Hearing before the Committee on Commerce on S. 1934 Amending the Federal Power Act and Related Bills, S. 683, S. 1834, and S. 2227, August 22, 1967,* p. 113.

interconnections and outlined the nature of their cooperative relations. Many introduced actual contracts and written agreements into the hearing record.

The delicate balance of power between state and national governments figured in the unfolding dispute. Several state utility commissioners defended the autonomy of their regulatory authority and expressed dismay at the possibility that federal regulators would intrude on local sovereignty for protecting reliability and consumer interests. Other voices joined the opposition, including *Electrical World* and a handful of daily papers; several federal agencies including the Department of Interior, the Tennessee Valley Authority, and the Rural Electrification Administration; the Los Angeles Department of Water and Power; the United Mine Workers of America; and the International Brotherhood of Electrical Workers. While every one of these hearing witnesses agreed that the industry should move toward greater reliability, all concurred that the federal role should continue to be advisory, along with voluntary industry cooperation on a regional basis. One even went so far as to say, "The legislative proposal, in my opinion, would adversely affect reliability and the future vitality of the electric utility industry."[52]

Protecting the Regulatory Status Quo Within a New Environmental Discourse

While the hearings unfolded, the industry moved in 1968 to establish the North American Electric Reliability Council (NERC), a totally voluntary organization. Floyd L. Goss, the newly elected chairman of NERC explained to the press that "the primary purpose of the council will be to continue improvements in reliability of bulk-power supply through exchanging and disseminating information on regional coordination practices; to review,

[52]Ibid., p. 135. Memorandum of Lelan F. Sillin, Jr., President and Chief Executive Officer, Central Hudson Gas & Electric Corporation, concerning The Federal Power Commission's Proposed Electric Reliability Act of 1967."

discuss, and resolve matters affecting inter-regional coordination; and to provide an informed and responsible means of communication with the public, as well as with regulatory and governmental authorities in regard to the reliability of electric power."[53] Unlike other national power organizations, NERC offered a wide umbrella to all classes of electric utilities and explicitly included at least two representatives from each sector, including federal agencies, investor-owned utilities, rural cooperatives, and state and municipal companies. Further, NERC invited the chairman of the FPC to send an observer to every meeting. The utilities formally announced the creation of NERC at a press event in June 1968, two months after the third of the Senate Committee hearings. According to Goss, the group did not represent an attempt to circumvent pending legislation, yet in the same news conference, he confirmed that legislated reliability controls would now be unnecessary. Goss claimed that the industry had begun developing this national planning group as early as 1965, long before the FPC formulated the proposed Electric Reliability Act.

As NERC gained prominence, the proposed reliability legislation lost traction. The Senate Commerce Committee held no additional hearings on this topic in 1968 and held none in 1969. In January 1970, the Committee on Commerce's new Subcommittee on Energy, Natural Resources, and the Environment convened a hearing on Federal Power Commission Oversight, but by this date the focus had shifted away from reliability to growing demand and the health of the environment. In fact, at this hearing, the FPC dwelt at some length on the significance of the recently signed National Environmental Policy Act and the need for state and federal regulators to expand consideration of environmental issues when addressing the power industry. Reliability held limited interested during the hearing, despite the fact that

[53] Gene Smith, "Electric Utilities Form Group," *New York Times*, June 12, 1968.

blackouts continued to plague utilities and pools around the country. Instead, the FPC repeatedly offered legislative solutions, all of which languished in Congress.[54]

The new focus on environmental concerns marked a complete shift away from traditional conservationism for the power industry. The 1964 National Power Survey couched plans for industry expansion in terms of resource conservation, and gave fleeting attention to emerging environmental concerns such as air and water pollution and plant siting. The survey described pollution issues in terms of technical challenges soon to be solved by engineers. After the 1965 blackout, the industry focused on expanded interconnections as a path to greater reliability, to the exclusion of resource conservation and, to some extent, operating economy. Congressional hearings specifically addressing interconnections from 1965 to 1968 ignored the question of resource conservation altogether. When the Senate returned to consideration of FPC oversight and interconnections in 1970, attention had shifted again, away from reliability and toward environmental protection.

Apart from the power industry's negotiation of control over expanding interconnections, North Americans witnessed the emergence of new environmental movements. Beyond protection of scenic beauty, local pollution problems, and resource conservation, advocates pressed on several fronts for greater environmental controls at federal and state levels, and conservation at the consumer level. Groups sought preservation of ecosystems; limits on pollution of the air, water, and ground; constrained nuclear power development; and a slower pace of natural resource development. Once a tool for achieving resource conservation and energy efficiency, the grid now represented the path by which very large electric generating plants delivered more and more power to consumers. Regardless of the energy source – falling water, hydrocarbons, or nuclear energy – giant power plants and

[54] Gene Smith, "Reliability Plea Made to Utilities," *New York Times*, June 5, 1968.

the transmission lines that linked them embodied the concerns of modern environmentalists. The fraternity of technical experts who had previously taken on the role of designing economical and efficient power systems, now found themselves at the bewildering center of controversy.[55]

By 1970, new federal laws and a new public discourse shaped the context of electric power system expansion. Following the embarrassment of the 1965 blackout, the power industry faced opposition to nuclear power, opposition to dams, opposition to water storage projects, opposition to the siting of extra-high voltage power lines, opposition to the use of coal in generating plants, and opposition to rising utility rates, in sharp contrast to decades of praise for bringing modern technology to citizens across the land. Further, Congress enacted laws that placed more aggressive controls on the development of new power plants to protect the environment. The FPC produced a second National Power Survey in 1970, developed in the shadow of the blackout and in response to the blackout reports. This time around, the survey praised interconnections for contributing to the reliability of power supply. "Thus, today it is reliability more than economy that provides the thrust for … complete and better interties."[56] The survey opened with a bleak description of the future for electric power – strained power supply in some areas; recurrent and spreading shortages; conditions slowing orderly development; and rising prices due to environmental protection efforts, market pressure on fossil fuels, and inflation. As the survey authors saw it, the core problem for the nation is to "... ensure an adequate and reliable power supply without undue adverse impact

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[55] Rome, "Conservation, Preservation, and Environmental Activism: A Survey of the Historical Literature"; Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement*; Andrews, *Managing the Environment, Managing Ourselves: A History of American Environmental Policy*.
[56] Federal Power Commission, *The 1970 National Power Survey [of the] Federal Power Commission* (Washington, DC: Federal Power Commission, 1970).

upon the environment."[57] Environmental protection, not reliability or even resource conservation, figured prominently throughout the survey.[58]

During this period, the utility sector moved quickly to strengthen its position as a self-regulated, well-coordinated industry. Utilities regularly announced the formation of new power pools and the expansion of existing interconnected networks, frequently touting the increased reliability sure to result. NERC took on the task of planning a reliable network across the continent. NAPSIC focused on operating a stable system. Both entities encouraged voluntary reliability compliance by all types of power producers, transmitters, and distributers. Through regional pooling agreements and participation in national associations, the industry retrenched behind the idea of shared management and divided authority. The reluctance of state utility regulators to cede authority to the federal government aided the investor-owned utilities in blockading the FPC's legislative moves. Greater public interest in the environmental impact of specific projects than in the stability of the entire system, even in areas affected by the big blackout, further dulled the FPC's efforts. Beyond that, the mere

[57] Ibid.
[58] Brooks, *Public Power, Private Dams: The Hells Canyon High Dam Controversy*; Hirsh, *Technology and Transformation in the American Electric Utility Industry*; Lifset, "Storm King Mountain and the Emergence of Modern American Environmentalism, 1962--1980"; Melosi, *Coping with Abundance: Energy and Environment in Industrial America*; Pope, *Nuclear Implosions: The Rise and Fall of the Washington Public Power Supply System*; Wellstone and Casper, *Powerline: The First Battle of America's Energy War*; The Wilderness Act of 1964 authorized permanent protection of wilderness lands. The 1965 Water Quality Act provided for federal standards to prevent water pollution. The Air Quality Act of 1967 introduced explicit federal authority over stationary sources of air pollution. In 1967, the *Storm King v. Federal Power Commission* decision affirmed the right of environmental groups to have standing in environmental lawsuits. In 1970, President Richard Nixon signed the National Environmental Policy Act into law, launching a series of follow-on legislation that strengthened federal control over environmental policy across the country. The 1970 Clean Air and Water Quality Acts followed. Andrews

fact that the lights stayed on nearly all the time reduced the perceived importance of proposed federal reliability oversight.[59]

Through the remaining decades of the twentieth century, the industry worked through a system of voluntary compliance to maintain and expand the interconnected power grid. In 1980, NERC absorbed NAPSIC, combining the planning and coordination functions of the former, and the operating standards and guidelines of the latter under a single entity. Individual power companies, both public and private, had the option of voluntarily complying with NERC operating criteria. During the period of deregulation in the 1990s, NERC itself determined that it was time for federal legislation to bring about mandatory compliance with reliability standards. Congress finally passed reliability rules in 2005. In 2006, the Federal Energy Regulatory Commission (FERC), successor agency to the FPC, certified NERC as the official organization responsible for enforcing reliability compliance. Forty years after the first major cascading blackout in the United States and Canada, national law provided for oversight of the power grid. Yet, the process by which the law is enforced mimics the historical structure of the industry and reflects the shared management and divided authority that characterized a century of power system development.[60]

In the aftermath of the 1965 blackout crisis, the power companies regrouped around tried and true techniques for operating interconnected. They shared information about expansion plans, devised agreements for interties, vetted technology through professional

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[59] Claude Koprowski, "Pepco Signs Regional Pact to Help Prevent Blackouts," *Washington Post, Times Herald*, January 4, 1968; "Expansion Set by Big Utility," *New York Times*, October 13, 1968; "T.V.A. And Southern Map Power Protection Accord," *New York Times*, March 11, 1968; Gene Smith, "Utility Goal: A Shoehorn for Volts," *New York Times*, February 23, 1969; "Electric Utilities Form Five Regional Councils," *New York Times*, October 31, 1969; "T.V.A., Utilities Set Power Deal," *New York Times*, September 14, 1969.
[60] "About NERC: Company Overview: History," North American Electric Reliability Corporation, last modified 2012, http://www.nerc.com/page.php?cid=1%7C7%7C11; The Energy Policy Act of 2005, Pub. L. No. 109-58, 119 Stat 594 (2005) Title XII – Electricity addresses reliability standards.

associations and well-publicized trials, and coordinated operations and maintenance through power pools and regional councils. At the same time, individual utilities, cooperatives, and government agencies maintained economic autonomy and avoided federal regulation of transmission grid reliability. And every few years, but not terribly often, the public experienced cascading power failures. Table 9.1 offers a partial list of failures significant enough to affect at least 1,000 people for more than one hour and to cause over 1,000,000 person-hours of disruption.[61]

Partial List of Major North American Power Outages	
Year	**Locale**
1965	Northeast
1967	Pennsylvania-New Jersey-Maryland
1971	New York City
1976	Utah, Wyoming
1977	New York City
1981	Utah
1982	California
1989	Quebec
1991	Iowa to Ontario
1991	Quebec, New England
1996	Western North America
1998	San Francisco
1998	Ontario and North Central United States
1999	Northeast
2003	Northeast
2011	Southern California, Arizona, Mexico
2012	New York and New Jersey

Table 9.1 Partial List of Major Power Outages, 1965-2012. *Sources:* US Department of Energy, "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations" and "List of Power Outages," *Wikipedia.*

[61] U. S.-Canada Power System Outage Task Force and Energy United States, "Final Report on the August 14, 2003 Blackout in the United States and Canada Causes and Recommendations," US Department of Energy, http://purl.access.gpo.gov/GPO/LPS47061. List of Power Outages, *Wikipedia,* accessed December 9, 2012, http://en.wikipedia.org/wiki/List_of_power_outages.

Drifting Lazily into Synchrony, A National Grid at Last

As the Northeast Blackout captured local and international attention, engineers, utility operators, and government officials continued the quest for a national grid. From the early decades of the twentieth century, power systems experts and eager politicians had envisioned a coast-to-coast transmission network. Some advocated for a centrally planned and constructed system. Others endorsed private sector development of interconnections. Still others puzzled over the technical ramifications of building such a large and complex electrical network. For more than fifty years, discussions about linking the east and west coasts with power lines ebbed and flowed. Presidents and cabinets argued over provenance, Congress considered and rejected proposals for federal authority, and individual utilities stood on both sides of the question, some hoping to dominate large geographic sectors of the country through interconnections, others demanding local autonomy and control. While the 1965 blackout raised the question of whether interconnected systems offered greater reliability or risk, the technicians pursued tying together the giant eastern and western power networks.

In the early 1960s, President Kennedy gave new life to the idea of a national grid as a tool for achieving greater efficiency and resource conservation, and the industry took the proposition to heart. The 1964 National Power Survey illustrated the opportunities for saving energy by moving electricity across the Rocky Mountains to take advantage of seasonal demands and resource availability. Not long after the Survey appeared, power pools in the northern and southern states west of the Rocky Mountains shared power, reducing the number of grids serving North America from five to four. By early 1965, representatives of public and private utilities began working on plans to achieve coast-to-coast power transmission. In addition to the potential conservation benefits of this truly giant grid, engineers relished the challenge of bringing numerous very large systems into parallel and operating them without serious mishap. The Soviet Union had built the only other power system comparable in scale to North America's, but this had been achieved under central command and control that greatly contrasted with the "gaggle" of interconnected companies operating in the capitalist west. A successful closing of the North American ties represented a technical, organizational, and political accomplishment that was international in scope.[62]

The US Department of the Interior Bureau of Reclamation, working with the East-West Intertie Closure Task Force (the Task Force), moved steadily ahead on closing the ties. The Task Force included representatives from the Bureau of Reclamation and several utilities based in states directly affect by the project. During 1965 and 1966, in spite of blackouts, discussions of the value of interconnections, FPC and state investigations and reports, and Congressional hearings, the planning and technical installation continued apace. In November 1966, Secretary of the Interior Stewart Udall distributed a press release announcing the plan to test the closure the following February. The announcement was met with a small flurry of news reports, mostly neutral, although the *Chicago Tribune* accused Udall and the Bureau of Reclamation of "empire-building."[63] The *Tribune's* editor suggested that the linkup was of interest only to the Interior Department, which sought to co-opt private power markets in the central part of the country. By contrast, *Electrical World* offered praise

[62] Kennedy, "Special Message on Natural Resources"; Federal Power Commission, *National Power Survey: A Report*; "East-West Closure Will Parallel 94% of US Capacity"; "East-West Power Intertie Closure Test Scheduled February 7," *United States Department of the Interior News Release*, January 26 1967. The four grids included Texas, Quebec, everything else east of the Rockies, and everything else west of the Rockies.

[63] "U. S.-Canadian Power Hookup Set for Feb. 7," *Chicago Tribune*, January 26, 1967; "Mr. Udall's Empire Grows," *Chicago Tribune*, November 16, 1966; "Giant Power Intertie for U.S., Canada to Be Tested Early in 1967," *Wall Street Journal*, November 14, 1966; "U. S.-Canada Power Grid Trial Set," *Chicago Tribune*, November 13, 1966; "Coast-Coast Power Link Due in 1967," *Washington Post, Times Herald*, November 13, 1966.

for the "history-making interconnection of systems east and west of the Rockies."[64] *Electrical World* cautioned that this should not be interpreted as the completion of a "fully integrated, monolithic power grid," but rather another phase in a process that has been underway for years. The project quickly faded from public view as the year drew to a close.[65]

Udall piqued public interest again in late January 1967 with a lengthy press release detailing the date of the first major test of closure. He highlighted the cooperation between industry and government, and suggested that east-west links would both improve the operating economy of power systems and grant greater reliability from coast to coast. The Bureau of Reclamation planned to close four tie lines in northeastern Montana; south-central Montana; Gering, Nebraska; and North Platte, Nebraska on February 7, 1967. With this announcement, a handful of newspapers offered brief reports, primarily listing details of the coming event. The *New York Times* did counter the *Chicago Tribune's* earlier claim that the closure represented a power grab, no pun intended, on the part of the Bureau of Reclamation. The *Times* noted that this event "has long been sought by engineers," and by former FPC chair Joseph Swidler. The report further offered that most in the utility field expected a full national grid to "do much towards avoiding" future major blackouts.[66]

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[64] "East-West Closure Will Parallel 94% of US Capacity"; "Editorial - Thoughts About an East-West Closure"; "Pooling Changes Planning and Operating Patterns," *Electrical World* 166, no. 20 (1966).
[65] "Editorial - Thoughts About an East-West Closure." Task force members represented the Bureau of Reclamation offices in North Dakota, South Dakota, and Colorado; The Consumers Public Power District, Nebraska; Pacific Power & Light, Oregon; Public Service Company, Colorado; Idaho Power, Idaho' Utah Power & Light Company, Utah; Iowa Power & Light Company, Iowa; Montana Power Company, Montana; and Iowa Public Service Company, Iowa. East-West Tie Closure Task Force Meeting Agenda, July 27, 1967, 1967, Record Series 1206-13. Box 3, Folder 10, Seattle City Light Regional Power Management Records, Record Series 1206-13. Box 3, Folder 10, Seattle Municipal Archives, Seattle, WA.
[66] "East-West Power Intertie Closure Test Scheduled February 7"; "U. S.-Canadian Power Hookup Set for Feb. 7"; "Huge Power Grid to Be Formed," *Hartford (CT) Courant*, January 26, 1967; "Huge Power Grid to Get Test Feb. 7," *New York Times*, January 26, 1967; "Power Pool Planned for February 7," *Baltimore (MD) Sun*, January 26, 1967; "Huge Power Grid to Get Test Feb. 7. U.S., Canada Plan to Link Major Systems."

In line with the hope that the larger interconnections would minimize blackouts, the Task Force took care to prepare for closure-related problems. Task Force chair, and Bureau of Reclamation Power Systems Operation Officer, Frank Lachicotte distributed a four-page document delineating steps to take in case of automatic separation. Of note, the eastern system was about four times larger than the western system, each carrying 170,000 mw and 45,000 mw of capacity respectively. By comparison, the interties could carry only a small fraction of that capacity. The potential for severe power swings between the two areas was significant. Engineers in the broader industry shared heightened concern about the results of linking these two systems, and further wondered what the effects of trouble on one coast would have on the other. In anticipation of problems, the participating utilities and power pools agreed that any prolonged or serious difficulties would lead to opening of the ties until the problems were resolved. The Task Force arranged for all participating utilities affected by the closure to receive information during the February 7th test, and to receive operating data and analyses in the ensuing weeks. Leeds & Northrup Company (L&N) engineers, with deep interest in the process of managing interties and the physical control apparatus involved, participated as observers of the test.[67]

The big event, soon to be hailed by power engineers as "Driving the Golden Spike," approached quietly. On February 7, 1967, at 9:49 a.m. Mountain Standard Time, the North American grid was born. "Actually, the East-West closure itself was almost without unusual incident," announced Lachicotte. "After a 19-minute delay during which the two massive power interconnections lazily drifted into synchronism, the connecting circuit breakers were

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[67] Frank W. Lachicotte, "Emergency Action after Automatic Separation and Normal Opening Poitns for Prolonged Separation," (unpublished: Bureau of Reclamation, 1966). Walt Stadlin, personal communication, December 6, 2012; "East-West Power Intertie Closure Test Scheduled February 7."

closed … establishing the tie."[68] Lachicotte directed the closure from the Watertown, South Dakota office of the Bureau of Reclamation. One trade magazine editor in attendance described the scene: "All we got on film was intent expressions on the faces of twelve men gazing at a group of electrical meters which recorded nothing at all unusual."[69] For the occasion, L&N set up a special frequency recorder in Philadelphia to observe and report the oscillations between the systems as they came into parallel. As the image in Figure 9.1 illustrates, power systems experts followed the event closely, using both traditional means of communication (the telephone) and the most modern data collection and recording techniques (graphing recorders). The event seemed to bring a sense of somber anticipation to those observing, and enormous relief when the ties held.

Figure 9.1. Leeds & Northrup engineers witness closing of the ties, February 7, 1967. "On the occasion of the closing of the East-West Ties, Leeds & Northrup set up a special ultra narror [*sic*] range frequency recorder in their R & D center to observe and report to utility operators what they saw. In photos are Nathan Cohn (on phone), S.B. Morehouse (with watch), and others." ***Source:*** **Private Collection Courtesy of North American Electric Reliability Corporation.**

[68] Frank W. Lachicotte, "The East-West Tie Closure, Staff Information Letter, February 27, 1967," (Washington, DC: Bureau of Reclamation, Office of Chief Engineer, 1967).
[69] Ibid.

Walt Stadlin, a power engineer present at the L&N observation locale, shared some recollections of the significance of the closure. The observers were especially concerned with frequency fluctuations as the two giant grids came into synchrony. The lower recorder in Figure 9.1 measured the frequency on the eastern connection. The upper recorder may have been tracking the difference between eastern and western frequencies. Nathan Cohn was likely talking on the phone to a colleague on the west coast who was likewise measuring the frequency of the western connection and the two shared information. The engineers were vitally interested in the viability of the largest ac network in the world. Stadlin recalls, "Since this was a 'proof-of-concept,' everyone was hoping for the best, but was prepared for the unknown and potential accompanying problems that need to be resolved."[70] Stadlin recalled that the results of the test led to quick recognition that weak ac interties were limited, and could not support the exchange of large trades of power from coast to coast without affecting system stability.

News reports captured the sentiments of power engineers, utility operators, and government officials. Lachicotte shared a sampling of headlines and highlights with employees of the Bureau of Reclamation in an internal newsletter: "An unprecedented accomplishment of public and private power groups working cooperatively together" … "two massive power interconnections consisting collectively of over 209 public and private electric systems in Canada and the United States joined into one big system for the first time" … "94% of the nation's electrical might now be joined into one vast interconnected power network" … "a culmination of longtime dreams of engineers" … "the Golden Spike

[70] Walt Stadlin, personal communication, December 7, 2012. This paragraph paraphrases comments provided by Mr. Stadlin.

operation, connecting East and West."[71] The popular press hailed this event as the test of a huge grid intended to prevent blackouts. *Electrical World* offered the utility perspective that this was a successful process of coordination, built upon past attempts in 1957, 1962, and 1963. Two days of connecting and disconnecting different regions, sending power east to west, then west to east, and changing up the schedule of electricity trades proved that the concept of integration across the continent was, indeed, sound. In the past, generators delivered electricity through networks and pools and grids, now electricity flowed through a single grid.[72]

While the moment of closure brought great delight to the participating institutions and individuals, operations over the ensuing months proved problematic. Lachicotte reported to colleagues that he opened the ties on July 20th at the request of three western companies. Both instability on the network and large inadvertent interchanges of electricity proved onerous to local and regional operations, and consumers experienced several power outages. All but one of the problems occurred on the western portion of the grid. The Task Force took on the job of testing the system, determining what to change, and where to make changes. Lachicotte hoped to reclose the ties by mid-August, in part to protect the prestige of the industry. The Task Force developed a set of nine recommendations and enlisted the Western Systems Coordinating Council, one of NERC's signatory regional councils, to persuade the

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[71] Lachicotte, "The East-West Tie Closure, Staff Information Letter, February 27, 1967."
[72] "Electrical Week: Intertie"; "East-Eest Ties Hold; US Systems in Phase," *Electrical World* 167, no. 8 (1967); "U.S.-Canada Power Grid Passes Test," *New York Times*, February 8, 1967; "North American Grid Put Together to Test Blackout Prevention," *Wall Street Journal*, February 8, 1967; "Power System Is Tested for Blackout Guard," *Washington Post, Times Herald*, February 8, 1967; "Closing Circuits," *Christian Science Monitor*, November 13, 1967; Neal Stanford, "Nationwide Power Net Nears," *The Christian Science Monitor*, February 7, 1967; "East West Tie," *The Lamplighter Newsletter, Black Hills Power and Light Company* 17, no. 3 (1967).

utilities to cooperate. The Bureau of Reclamation finally reclosed the ties on December 3, 1967, with new operating guidelines and monitoring apparatus in place.[73]

Until the 1980s, when high-voltage direct current (HVDC) ties replaced the original alternating current ties, North America's grid operated with very weak links between east and west. As one observer ruefully remembered in 2000, "We … had some fancy, brilliant schemes to close the East-West ties. But there were problems with them. If something would happen on one side or the other, you wound up tripping the lines."[74] Stadlin explained, "The solution to the interconnection problem (in all large countries) has been to interconnect the ac networks by means of high capacity HVDC interties that have very fast controllability, in order to maintain the maximum power exchange and stability of the overall grid in each country or region."[75] Nonetheless, the symbol of a single network carried far more significance than the challenges of maintaining stable links between the two major eastern and western systems. From this time forward, the interconnected power systems of North America have been referred to as "the grid."[76]

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[73] Letter from Nathan Cohn to Frank Lachicotte and Attached Documents, April 24, 1967, Box 38, NC Papers, MIT; "Swings Force Systems to Open East-West Ties," *Electrical World* (1967); Minutes of East-West Tie Closure Task Force Meeting, July 27, 1967, Record Series 1206-13. Box 3, Folder 10, Seattle City Light Regional Power Management Records, Seattle Municipal Archives, Seattle, WA; Letter from Frank W. Lachicotte, Chairman, East-West Task Force to R. P. Marean, Chairman, Western Operations Committee, August 31, 1967, Record Series 1206-13. Box 3, Folder 10, Seattle City Light Regional Power Management Records, Record Series 1206-13. Box 3, Folder 10, Seattle Municipal Archives, Seattle, WA.

[74] *Serving the West: Western Area Power Administration's First 25 Years as a Power Marketing Agency*, available from the Western Area Power Administration Website, http://ww2.wapa.gov/sites/western/about/history/Pages/25Years.aspx (Lakewood, CO: Western Area Power Administration, US Department of Energy, 2002), p. 33.

[75] Walt Stadlin, personal communication, December 7, 2012.

[76] Walt Stadlin, James Resek, Dave Nevius, personal communication, June 29, 2012. With direct current ties, it was no longer necessary to keep the two systems operating in parallel. Walt Stadlin, personal communication, December 6, 2012.

Summary

Despite the profound achievement represented by the closure of ties between east and west, the general public essentially paid no attention to this landmark event. Like electric service itself, the grid had become essential, yet invisible. Over the course of two years, North Americans discovered both the promise and the perils of a true coast-to-coast interconnected power system. From the tribulation of the Northeast Blackout of 1965 to the triumph of closing the East-West intertie, the power industry itself faced the hard reality of electricity. When the system failed, the public outcry was loud and long-lasting. When the system reached record heights, there was barely a shrug of recognition. Although “the grid” arrived with the closure of the east-west interties, the challenges of operating interconnected continued to grow with increased production and demand, ever more complex power trades, and the eventual restructuring of the industry.

The fraternity of power system specialists fought hard to maintain control of the grid. Through both technical failures and political attacks, industry representatives and engineers repeated a refrain extolling the virtues of interconnection and the system of voluntary coordination in place among power companies. Before Congressional hearings and to the press, the industry offered a multitude of examples and assurances that successfully halted new national legislation to regulate the grid. Even as FPC commissioners, Senators, and advocates for public power testified in favor of reliability controls, the industry organized a self-regulating entity that included every corner of the continent and every type of electricity provider. In less than eighteen months after the blackout, the economic, political, and technical systems of shared management and divided authority had reasserted themselves. In the meantime, the technicians effected a closure of ties between east and west that proved the viability of a national grid comprised of the broadest variety of institutions and operators.

Despite the technical marvels of grid development during this period, the utility industry and power system engineers lost the shine of public admiration. In addition to blackouts, power systems produced air and water pollution, nuclear plants threatened human health and safety, power lines disturbed attractive scenery, and activists pushed for more environmentally sensitive development of the nation's energy systems. Electric power experts no longer touted the grid as a means of achieving greater resource conservation. Instead, the grid retained value as a means of assuring reliable power operations, but it shared some ignominy with power plants that marred the landscape. The industry shared that tarnish as electricity rates rose, and advocacy groups succeeded in halting high profile power projects. The heyday of power development had ended and the remaining decades of the twentieth century promised massive change for the industry that operated the world's largest machine.

Conclusion

Without a central plan, without a full appreciation for the complexity, without full concurrence across the industry, utilities and governments built a grid that carried power across nearly all of North America. It took 85 years, two wars, and much negotiation to accomplish this feat. At the same time, extensive cooperation, and a common mission of providing stable electric service to an eager paying public, kept engineers and executives working together to achieve this accomplishment. In 1882, Thomas Edison offered the vision of a networked electrical world. In 1967, engineers closed the ties that linked the east coast to the west coast, Canada to Mexico, in a single machine. The significance of the grid changed over time, from a technology that aided both resource conservation and profitability, to a technology that facilitated exceptionally rapid growth, to a technology that could be at once the source of stability and the cause of failure. Today, nearly all North Americans still rely on the grid utterly, and rather casually, for the majority of every-day activities. With a history of how the grid grew, perhaps the ramifications of operating this large machine will inform the energy choices of the future.

Thomas Edison, Nikola Tesla, George Westinghouse, and others too numerous to list, offered the technologies and vision that ultimately comprised the grid. Central station service, regional systems, long-distance alternating current transmission: these formed the primary building blocks for coast-to-coast interconnection. Later, electric clocks, automatic frequency and load control apparatus, telemeters, analog and digital computers perfected operations of power networks. Major wars spurred the construction of interconnected systems. Political and economic trends influenced how and when companies interconnected. Power producers also addressed geography and local preferences when expanding and linking systems. A fraternity of technical experts responded to challenges with apparatus and operating techniques that facilitated expansion. For most of the twentieth century, the public regarded the power industry with respect, as well as a bit of suspicion. The 1965 Northeast blackout caused the first major setback experienced by power producers and advocates of the grid. Two years later, utilities triumphantly, and with little fanfare, tied together the power lines of the eastern and western sides of North America, proving that the grid was operationally viable, if not universally approved.

Across the decades, politicians, utility owners, and segments of the public repeatedly rebuffed efforts to centralize authority over the grid. The choice to continue development on a piecemeal basis by a variety of entities reflected the government structures and capitalist economy unique to North America. In both Canada and the United States, federalist governments resisted nationalizing enterprises that were essentially capitalist at the start. Instead, states and provinces developed the approach of regulating privately owned utility monopolies, a system that appeared to benefit investors and consumers alike for decades. Governments built and financed major electrification infrastructure as well, facilitating expansion into rural areas and promoting industrial development in certain regions. By the time the US Bureau of Reclamation and the utilities closed the ties between the eastern and western power networks, a "gaggle" of entities owned and operated the world's largest machine. Multiple sectors negotiated policy choices that framed the development of the North American grid.

As a result of these policy choices, the American grid is different in kind from grids in other nations. Countries like France, England, and Germany, devastated by World War I, nationalized their transmission networks to assure that expansion took place when and where needed for economic and industrial recovery. This process intensified after World War II, when many took the next steps to nationalize power generation and delivery systems as well. In socialist countries, like the Soviet Union, grid development took place under systems of central command and control. In North America, prior to the 1965 blackout, arguments favoring and opposing centralized control of grids revolved around the politics and economics of control. For example, public power systems and rural cooperatives favored government control because they did not trust the private utilities. The distrust encompassed questions of when and where private utilities might build transmission lines and whether public entities would have access to affordable power from those transmission lines. On the other side, opponents argued that central control of the transmission network equaled a major step toward a socialist government. Across nations, however, engineers and operators assumed that interconnections under all varieties of organizational schemes added reliability to power systems. The experiences of the decades after 1965 suggest that centrally controlled grids function with fewer cascading failures than the North American grid. While it may be ahistorical to look back to the years before 1965 and suggest that countries like England, France, and the USSR acted to protect system reliability by centralizing control of the grid, it is important when looking ahead to understand the advantages of this approach.

On one level, technical choices followed economic and political choices. Once utilities sought to interconnect, technical experts followed by designing apparatus and operating strategies that accommodated the relationships of the entities involved. On another level, an early technical choice, favoring alternating current (ac) over direct current (dc), defined the opportunities and challenges for developing a large interconnected system. The preference for alternating current grew out of the economic and physical limits imposed at the time by the direct current technologies available in the nineteenth century. Utility operators quickly discovered that they could expand their markets with ac central station service. With ac, utilities built very large networks at a speed and price that rendered dc systems unappealing, at least in the United States and Canada. In the process, electrification transformed North American life on an unprecedented scale.[1]

While the choice of alternating current allowed power producers to build a coast-to-coast electrical grid, the grid itself is extraordinarily fragile. Interconnected systems using alternating current are inherently unstable, in the sense that electricity is constantly moving back and forth. For multiple generating networks to stay interconnected, they must operate in perfect synchrony. Without highly observant and fast-acting human controllers, or sensitive and high-tech automatic controllers, the oscillations of alternating current on large systems will lead to outages. Over the course of several decades, as interconnections grew larger and more complex, operators and engineers developed advanced control techniques to keep systems stable. However, small problems can still cause large blackouts. Luckily, cascading failures occur infrequently.

The economic and political choices that framed the North American grid also affect system fragility. Shared management and divided authority mean that no one agency or

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[1] As noted in Chapter 2, several countries in Europe employed dc systems invented by engineer Rene Thury in the early 1900s. The Thury systems transmitted power over long distances on dc lines with generators in series. These systems experienced significant energy loss, required a great deal of maintenance, and were subject to power failures. If one segment failed, all the subsequent segments had no power. J. Arrillaga, *High Voltage Direct Current Transmission*, 2nd ed., Iee Power and Energy Series (London: Institution of Electrical Engineers, 1998). Inventors and engineers abandoned dc systems in favor of the less expensive, and more flexible ac technologies available for expanding power networks at that time. In the absence of affordable and practical technologies for building ac networks it is possible that innovators would have developed technologies for dc networks, which may have been more or less stable than ac networks. Likewise, it is possible that full development of dc technologies would have led to affordable, reliable, and completely disaggregated networks. These are possibilities in the imagination only and not useful for further discussion of the existing systems of electrification.

company exerts control over the entire network. When all the operators of power plants on a network answer to a single central controller, as is the case in most other parts of the world, maintaining stability is simplified. For example, the Russian power network, the largest centrally controlled grid in the world, experienced no major blackouts for over 30 years because the controlling authority required technical and operating uniformity across the system.[2] Multiple owners of different sizes and types of power networks introduced a wide variety of technologies and approaches into the North American power networks. Extraordinary coordination between many entities on both the engineering and operating fronts is required in order to maintain stability across the system. And, with such a variety of systems interlinked, failure on one small segment of the grid can cascade into an enormous outage with huge economic impact, immediate challenges for millions of people, and longer-term consequences for restoring and shoring up the system.

The innovations introduced by the fraternity of technical experts allowed multiple organizations to coordinate successfully and achieve mostly stable operations in North America without government oversight. Operations depended on delicately calibrated apparatus and extensive information sharing between independent system operators. Through informal channels, technical societies, power pool meetings, and voluntary associations, system operators and engineers did share ideas and introduced standards that allowed for stable operations. When it became obvious that power pools would soon interconnect across

[2] Between 1975 and 2005, there were no major blackouts on the centrally controlled Russian electric power network. Y. V. Makarov et al., "Blackout Prevention in the United States, Europe, and Russia," *Proceedings of the IEEE* 93, no. 11 (2005); Yu V. Makarov, N. I. Voropai, and D. N. Efimov, "Complex Emergency Control System against Blackouts in Russia" (paper presented at the IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century, PES, July 20, 2008 - July 24, 2008, Pittsburgh, PA, United states, 2008); Hyunsoo Park, "The Social Structure of Large Scale Blackouts Changing Environment, Institutional Imbalance, and Unresponsive Organizations" (3434847, Rutgers The State University of New Jersey - New Brunswick, 2010).

the entire continent, the private sector utilities took the initiative to form a national organization to set standards and oversee operations (The North American Power Systems Interconnection Committee - NAPSIC). Participation and compliance was entirely voluntary. After the 1965 blackout, when politicians and the Federal Power Commission moved to institute federal regulation of grid reliability, those same private utility groups formed another national organization, this time including government representation, to provide voluntary regulatory oversight (The North American Electric Reliability Council - NERC). The 2005 Energy Policy Act provisions for grid reliability essentially enshrined the system of cooperation, information sharing, and self-regulation that the industry had developed over the prior century.

Policy makers addressing energy choices in the twenty-first century would do well to consider this exploration of electrification through most of the twentieth century. History offers some useful explanations for why North Americans have an interconnected power system, how it was built, and what it now is. The heavy participation and influence of private companies in a public and essential service has framed the role of governments in determining power policy. The opportunities and challenges presented by the technology and this form of energy likewise frame the choices worth seriously considering for the coming years. The interests and demands of consumers shift over time, as does the influence of producers, and this will further augment policy discussions about power. There are many questions to be answered going forward, for example how much electricity will we use and will we, finally, address conservation in the most modern terms? Which energy sources will we use and in what proportion? Will integration or disaggregation of networks best serve the combined challenges of reliability, fragility, economics, international security, and environmental effects? How will governments address the aging grid infrastructure; what will be repurposed, abandoned, replaced; and how will those pieces be linked with new technologies? Who will pay for reconfiguration of the transmission networks? Looking back, it is clear that some of these decisions will be negotiated over decades, some will be reoriented by technical innovation, some will be influenced by fashion, some will be limited by larger political issues, and many different challenges and questions will arise along the way. Most significantly, the existing grid, with all its oddities, ingenious inventions, robust qualities, inherent fragility, and multiple stakeholders will definitely play a central role in the next generation of electricity choices.

This study of the grid adds to several fields of historical inquiry. Electrification has long held the interest of historians of technology. In this field, scholars have debated the proper approach to understanding how technological change fits into the overall process of historical change. Fascination with individual artifacts, the creative genius of inventors, and the possibility that technical innovation determined the course of human development characterized early histories of technology. Historians drew distinctions between technical, social, cultural and political aspects of technological development. Over time, however, historians have sought to study technological development as it is embedded in the social, political, and economic context in which it took place. Rejecting technological determinism as a theoretical approach, historians have sought to reframe the discussion in terms of system theory and social constructs. Within these approaches, historians have wrestled with determining the proper role of the expert in the narrative, the degree to which technological innovation is central to or dependent upon larger socio-economic trends – especially industrialization – and what technical advance and modernization means to society.

In this study, choices were of key importance. Engineers, managers, politicians, investors, and consumers all made choices that framed the development of the electric power grid. Several factors influenced the options individuals and organizations considered over a century of electrification. The qualities of electricity itself, particularly the twin facts that it is extremely difficult to store electrical energy and electricity is useful only if it is available at the instant of demand, figured heavily in technical inventions. The culture of capitalist enterprise encouraged private sector development of electric power systems. The federalist structure of North American governments framed a tendency for policy-makers to shy away from central control. The abundance of falling water available in certain regions and the abundance of coal available in other regions led power producers to select technologies best suited to the geography in which they operated. Local political sentiments were reflected in legislative choices, for example in Nebraska, to favor all public power systems, and utility choices, for example in Texas, to avoid interconnecting across state lines. The overall trend favoring the development of regulated monopolies enabled individuals working for utilities, who would otherwise compete, to instead choose to share innovations as they experimented on their own power systems.

Many of the technical, economic, and political choices made in the earliest years resulted in legacy technologies that have been difficult to abandon. A preference for ac systems, chosen for the economic advantages it conferred, narrowed the options for later interconnected power systems. Engineers worked around the challenges of alternating current in order to link multiple power networks across the continent. Similarly, the fragmentation within the power industry limited system operators to technical fixes for improving reliability because no single entity could require participants on a network to fall in line with central organizational controls. While early choices for interconnection did not determine that the North American power industry would ultimately build a grid, the legacy technologies, and the legacy political and economic trends, did frame the process in which individual entities elected to link with each other. Federal agencies, rural cooperatives, provincial power commissions, and private utilities tied the continent into a single grid in 1967, but only after many decades of trial and error on the part of entities operating autonomously and without an overarching plan.

In the area of environmental history, the dissertation addresses the relationship between the power industry and conservation movements across the twentieth century. Environmental historians have studied electric power projects with respect to how they affected human health, urban and rural development, ecosystems, and economies. These projects tend to offer a narrative of decline, for example revealing the ways in which a major project, be it a hydroelectric dam or a major power line, advantaged certain economic interests while ruining surrounding areas. With a focus on the effects of electrification on the environment, historians have rightly highlighted the relationship between technological and industrial advance and negative ecological and human results. On the other hand, without examining the industry itself, and the power experts' concepts of conservation and stewardship, environmental historians miss an important piece of the twentieth-century puzzle. In the electric power industry, what might be termed a sustainability paradigm for economic stability led engineers and system operators to focus on legitimate environmental concerns. Indeed, their perspective was narrowly focused on how to produce electricity with minimum use of non-renewable resources and maximum use of the presumed inextinguishable supply of waterpower. The experts did in fact reduce the per kilowatt usage of hydrocarbons as they advanced power producing and transmitting technologies. While it is necessary to address the broader questions of how electrification changed the environment, it is worthwhile to consider the industry's own understanding of how they managed energy resources over the first six decades of the twentieth century.

The research for this study suggests that this one energy industry operated with a long-term economic horizon. Profitability depended upon access to energy sources while the investors amortized the capital costs of generating plants and transmission lines. For that reason, careful development and use of natural energy resources was critical to the early twentieth century power companies. In twenty-first century terminology, this was an industry concerned with sustainability. The Progressive Era conservation movement likewise was concerned with careful development of natural resources for both current and future use. For many years, system engineers and utility managers prided themselves with working toward the same goals as conservationists. Later conservation movements redefined the cause, and in later eras, the utilities found themselves at odds with the activists.

The irony for modern environmentalists, and for the industry itself, is that interconnected power systems offered the opportunity to use energy resources more efficiently, but only if consumers used more and more power. It is reasonable to construe the early interconnections as technologies of conservation, but only in the sense of Progressive Era conservation. From the 1950s onward, interconnected systems were technologies of consumption. Yet, power industry experts continued to focus on improving energy efficiency by tightly controlling the flow of electricity across interconnections. System engineers saw themselves as conservationists in the sense of improving the rate at which energy resources were used to generate electricity. Environmental historians should recalibrate the relationship between industry and conservation movements in light of the lessons offered by the power industry. At different points, the industry itself focused on conservation as a goal harmonious with growth and profit-making.

The relationship of the grid to the environment opens up an entirely different line of questions. With the grid, utilities were able to make massive physical changes to the terrain. From coal mines to river basins to sprawling urban areas, the electrification of North American equaled the restructuring of the continent's landscape. This dissertation barely touches on the way in which the grid was a technology of environmental change. The ramifications of building giant, interconnected power systems demand greater attention from environmental historians, particularly those interested in energy history. From local stories to national and international projects, a myriad of matters deserve investigation. While it was not the purpose of this project to pursue this research, this biography of the grid should raise some scholarly interest in deepening the understanding of the relationship between energy and the environment, and particularly the role of the interconnected electric power system.

In the field of energy history, the story of the power grid poses a paradox. The grid was used to promote consumption and conservation at the same time. With interconnections, power users accelerated the depletion of coal reserves, dammed rivers, and experimented with potentially dangerous energy sources. At the same time, the grid facilitates the efficient use of energy sources for human purposes. With electrification, it is possible to deploy energy to build a strong economy, brighten homes, and ease farm work. Unlike other energy networks, the power grid depends upon cooperation between companies, the use of highly advanced control technologies, and second-by-second guesses about the market. Utilities gain no benefit from producing extra electricity. Unlike coal or gas, electric power cannot be easily stockpiled. Nor can power companies "clear the inventory," because they can sell only as much power as is demanded at the moment. While the market responds somewhat to pricing, the economy as a whole is so dependent upon electricity, and demand is so time specific, that fluctuating electricity rates have less effect on usage than fluctuating prices of other energy resources might. Electricity differs in another significant way from other energy systems. Outages can occur suddenly and with widespread and devastating effect. An oil spill may be more environmentally disastrous, but the immediate effects are far more localized. The story of the power grid asks energy historians to consider electrification within the matrix of energy systems in use in modern society, but to recognize that it is different in kind technically, organizationally, and in the way it functions in the economy.

The development of the North American power grid offers insights in the fields of business and regulatory history. The power industry began as a capitalist enterprise. While the very earliest customers were wealthy individuals and businesses, the industry itself pushed to make electrification a necessity. Within a few short years of the introduction of central station service, many sectors treated electricity as a service rather than a commodity. Under the emerging schemes of local and state regulation, competition took place between government-owned and investor-owned utilities more frequently than between private power companies. In addition, the long-term economic horizon of the power business created an opportunity for even the privately-owned utilities to put quality of service ahead of immediate profits, to consider resource conservation as an element in profitability, and to share information with competitors. Thus, the power business developed along very different lines from other industries. It was understood to be the most highly-capitalized industry of North America, it was the darling of investors through many decades, it was reviled by some during the Depression and the late twentieth-century, and it was regarded as an essential service-provider for a strong economy.

The history of the grid is marked by the contest for control. This contest took place in terms of regulatory oversight, ownership, and the physical management of electricity itself. Over time, utility owners and government leaders negotiated systems of shared management and divided authority. Federal and state governments shared responsibility for protecting consumers from excessive rates and overly aggressive market development, yet they explicitly divided responsibilities for different portions of the electric business. The utilities themselves shared in this responsibility by regulating network reliability. This was done through agreements and voluntary arrangements that protected the economic autonomy of individual companies on the network. This approach worked well when operators maintained a stable and steady supply of electricity to customers at a reasonable rate, without causing excessive air, water, or scenic pollution. The limits of this approach became evident when there were disruptions in the power supply, excessively expensive rates, opposition to projects on the basis of health, safety, or environmental damage, and when it is time to make decisions about the energy future. In systems of shared management but divided authority, it is possible to achieve terrific cooperation and technical advance, but it is also easy to point fingers, shift responsibility, and avoid progress.

For industry engineer, and my father, Nathan Cohn, and many others like him, the history of the power grid was the story of deep challenges and modest triumphs that together brought an interconnected system into being. It was also the story of connecting the disparate parts of the continent: northeast to southeast to Midwest, across the Rocky Mountains, from the Columbia River basin to the Mexican Baja. A century of tinkering, investigating, collaborating, and competing brought about an exceptional network. North America's grid is a testament to the passion certain individuals had in their very technical work. It is a tribute to visionaries who foresaw industry, homes, and farms linked in economic expansion. It is an admonishment to the hubris of mere mortals who believe that human technologies and human practices can perfectly control the rules of physics. It is a warning to policy makers to consider the potential for unanticipated consequences when solving last year's problem with this year's approach. It is a technology for rapidly developing, using, and depleting energy resources, causing environmental damage at the same time. It is a reminder that technical projects undertaken in this part of the world may be conceptually like similar projects elsewhere, but they will be uniquely shaped by the political and economic realities of North America. This biography of the grid should offer some insights into the composition, organization, and operation of a legacy technology that will inevitably play a role in decisions about our energy future.

List of Abbreviations

AGE	American Gas & Electric Company
AIEE	American Institute of Electrical Engineers
AT&T	American Telegraph & Telephone
BPA	Bonneville Power Administration
CANUSE	Canada-United States Eastern Connection
CIGRÉ	The International Council on Large Electric Systems
CONVEX	Connecticut Valley Electric Exchange
EIA	US Energy Information Agency
FERC	Federal Energy Regulatory Commission
FPC	Federal Power Commission
FTC	Federal Trade Commission
GE	General Electric Company
HEPCO	Hydro-Electric Power Commission of Ontario
IBM	International Business Machine Corporation
IEEE	Institute of Electrical and Electronic Engineers
IFAC	International Federation of Automatic Control
ISG	Interconnected Systems Group
L&N	Leeds & Northrup Company
LADWP	Los Angeles Department of Water and Power
NAPSIC	North American Power Systems Interconnection Committee
NDPC	National Defense Power Committee
NELA	National Electric Light Association
NEPCo	New England Power Company
NERC	North American Electric Reliability Council (later Corporation)
NPPDC	National Power Policy and Defense Committee
OVEC	Ohio Valley Electric Corporation
PASNY	The Power Authority of the State of New York
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PNJ	Pennsylvania-New Jersey Interconnection
PUHCA	Public Utilities Holding Company Act
PWA	Public Works Administration
REA	Rural Electrification Administration
SEC	Securities Exchange Commission
TVA	Tennessee Valley Authority
USGS	US Geological Survey
USSR	United Soviet Socialist Republic
WIB	War Industries Board
WPB	War Production Board

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Chicago Tribune
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Hartford (CT) Courant
Lexington (NC) Dispatch
New York Times
St. Petersburg (FL) Evening Independent
St. Petersburg (FL) Times
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