# When the Grid Was *the Grid*: The History of North America's Brief Coast-to-Coast Interconnected Machine

By Julie Cohn

From 1967 to 1975, a single, giant, interconnecting machine linked together the vast majority of power users in North America. Called *the grid*, this collection of generators, transmission lines, substations, and related infrastructure operated in near-perfect synchrony to deliver electricity across the continent. Many had envisioned a coast-to-coast grid for decades, but the project was hindered by cost, competing jurisdictions, a wide array of stakeholders with nonaligned interests, and especially technological barriers. Building this machine was an engineering accomplishment of the highest order.[1] But operating the machine was another matter. Though brief within the now long history of electrification, this eight-year period marked a pinnacle of achievement for American engineers and system operators and a phase of instability for the machine itself.

When North Americans talk about *the grid*, they are usually referring to the backbone of the power system—a collection of power plants and transmission lines that ensure delivery of electricity across the continent at the flick of a switch. But conceptions of what comprises the grid are fuzzy, with some including every piece of equipment from a hydroelectric dam to a homeowner's meter, and others carefully delineating only certain groupings of power plants and high-voltage transmission lines. *Grid* is the informal term used for the formally defined *bulk power system:* "facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof); and electric energy from generation facilities needed to maintain transmission system reliability."[2] Note the term *interconnected*, which specifically means the synchronous operation of all parts of the linked system. In other words, on an alternating current (ac) interconnected network, every piece of equipment from the generating plant to the customer's wall outlet must operate at exactly the same frequency.

The idea of a single grid is also misleading, as there are now four major interconnected systems in North America and a few small

This article provides a compelling look at an eight-year period in American history of a single grid connecting the vast majority of electricity networks. The article traces the grid's development, its performance, and its eventual devolution into four North American grids ten years later.

[1] The National Academy of Engineering named electrification as the number one engineering achievement of the 20th century. "Greatest Engineering Achievements of the 20th century," National Academy of Engineering website, accessed October 22, 2018, http://www.greatachievements.org/, 2018.

[2] Federal Power Act, 16 U.S.C. §824.

Digital Object Identifier 10.1109/JPROC.2018.2880938

ones. The Eastern Interconnection serves customers east of the Rocky Mountains from Canada to Florida. The Western Interconnection likewise reaches from Canada to the Mexican Baja, and west to the Pacific coast. The Texas Interconnection serves exclusively Texas customers (but not all Texans). And the Quebec Interconnection operates only within the province of Quebec. All of these ac networks are internally synchronized and are linked to each other only through direct current (dc) ties.[3] This allows these giant networks to share power while operating out of synchrony with each other. For eight rocky years, however, a single system reached east to west and north to south (excluding Texas and Quebec) and was known as *the grid*. This paper will revisit the story of this "longtime [*dream*] of engineers" and help elucidate why our power system is no longer *the grid*.[4]

## I. THE HISTORY OF HISTORIES

A growing body of literature explores the making of North America's power system.[5] Perhaps the best-known history, *Networks of Power* by Thomas P. Hughes compares the early decades of electrification in the United States, England, and Germany, concluding that large technological systems like power systems evolve in similar and predictable ways.[6] Importantly Hughes avers that the development of large interconnected networks became the expected path for growth by 1930. Indeed, a series of maps published by the Edison Electric Institute strongly suggests that a pattern begun in 1908 forecasts increasingly dense and interconnected power lines throughout the century. A sampling of these maps is shown in Fig. 1. Other historians focus especially on power systems before the 1930s, or pick up the story after World War II, seeming to suggest that once conceived, a continental grid was inevitable.[7]

The difficulty of actually operating interconnected systems disappears from view across these narratives. To highlight how problematic this challenge was, consider that engineers and politicians in the United States first imagined a national grid in the 1910s.[8] Before the vision could be realized, however, power system experts had to gain an understanding of the behavior of electricity on ac networks and develop strategies for controlling it. The notion of a national grid reappeared periodically throughout the mid-century. Yet, it was not until the 1950s that engineers considered coast-to-coast interconnection potentially feasible and a serious likelihood. And the completion of such a network finally took place in 1967.

From a twenty-first century perspective, a path from a local generating station lighting up 100 brand new street lamps in the late 1800s to a giant network powering homes and factories in the late 1900s looks both logical and likely. A closer examination of the process leading to the 1967 closure of eastern and western interconnected systems, and the relatively quick decision to abandon those ties just eight years later, underscores how complex power networks really are.[9] It was perhaps this very complexity that disguised the challenges of building networks when historians traced the more exciting political, economic, and environmental developments underway and the compelling personalities of prominent company managers and inventors who propelled the stories.

## II. THE DREAM OF A COAST-TO-COAST GRID—FROM CONCEPTION TO REALITY

The path to giant power networks originated in the nineteenth century. Independent power companies began building links for the purpose of sharing electricity late in the 1890s.[10] The earliest systems appeared in California, Utah, and near Niagara Falls, all areas with abundant falling water located at a distance from centers of power consumption. As companies realized cost savings, coal savings, fuller use of hydroelectric plants, and greater reliability, system operators enthusiastically discussed the benefits of these connections. In 1904, for example, the editor of the widely read journal *Electrical World* offered:

> Today with the resources of electrical power transmission at hand, enabling half a dozen plants to be linked together and utilized as a unit, and allowing power to be economically transmitted a hundred miles or more, every [*falling water power source*] has a potential far greater than ever before. A little skillful storage and the interlinking of stations so as to distribute the load in the most

[3]The industry uses the terms *tie*, *inter-tie*, *intertie*, *tie-line*, and *tieline* to refer to a connecting link between two power systems.

[4]Quote from a newspaper headline included in F. W. Lachicotte, "The East-West Tie Closure, Staff Information Letter, February 27, 1967," (Washington, DC: Bureau of Reclamation, Office of Chief Engineer, 1967).

[5]For a recently compiled list of works, see the Selected Bibliography in J. Cohn, *The Grid: Biography of an American Technology*. Cambridge, MA, USA: MIT Press, 2017, pp. 303–310. This article is based in part on *The Grid*, with additional research focused on the 1967 East-West closure.

[6]T. Parke Hughes, *Networks of Power: Electrification in Western Society, 1880–1930*. Baltimore, MD, USA: Johns Hopkins Univ. Press, 1983.

[7]Examples include R. F. Hirsh, *Technology and Transformation in the American Electric Utility Industry*. Cambridge, U.K.: Cambridge Univ. Press, 1989; C. F. Jones, *Routes of Power: Energy and Modern America*. Cambridge, MA, USA: Harvard Univ. Press, 2014; D. E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880–1940*. Cambridge, MA, USA: MIT Press, 1990; H. L. Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880–1930*. Chicago, IL, USA: Univ. Chicago Press, 1991. For an exception, see P. W. Hirt, *The Wired Northwest: The History of Electric Power, 1870s–1970s*. Lawrence, KS, USA: University Press of Kansas, 2012.

[8]For example, "Economic limitations to aggregation of electrical systems," *Electrical World* vol. 57, no. 8, p. 468, 1911.

[9]The term *closure* is used to mean that the links between systems are operational.

[10]C. Hering, "83 miles of power transmission," *Electrical World*, vol. 34, no. 20, p. 750, 1899; "Transmission system of the Bay Counties Power Company, California," *Electrical World*, vol. 37, no. 7, pp. 273–274, 1901; "San Gabriel Electric Company," *Engineering*, pp. 781–783, 1899.

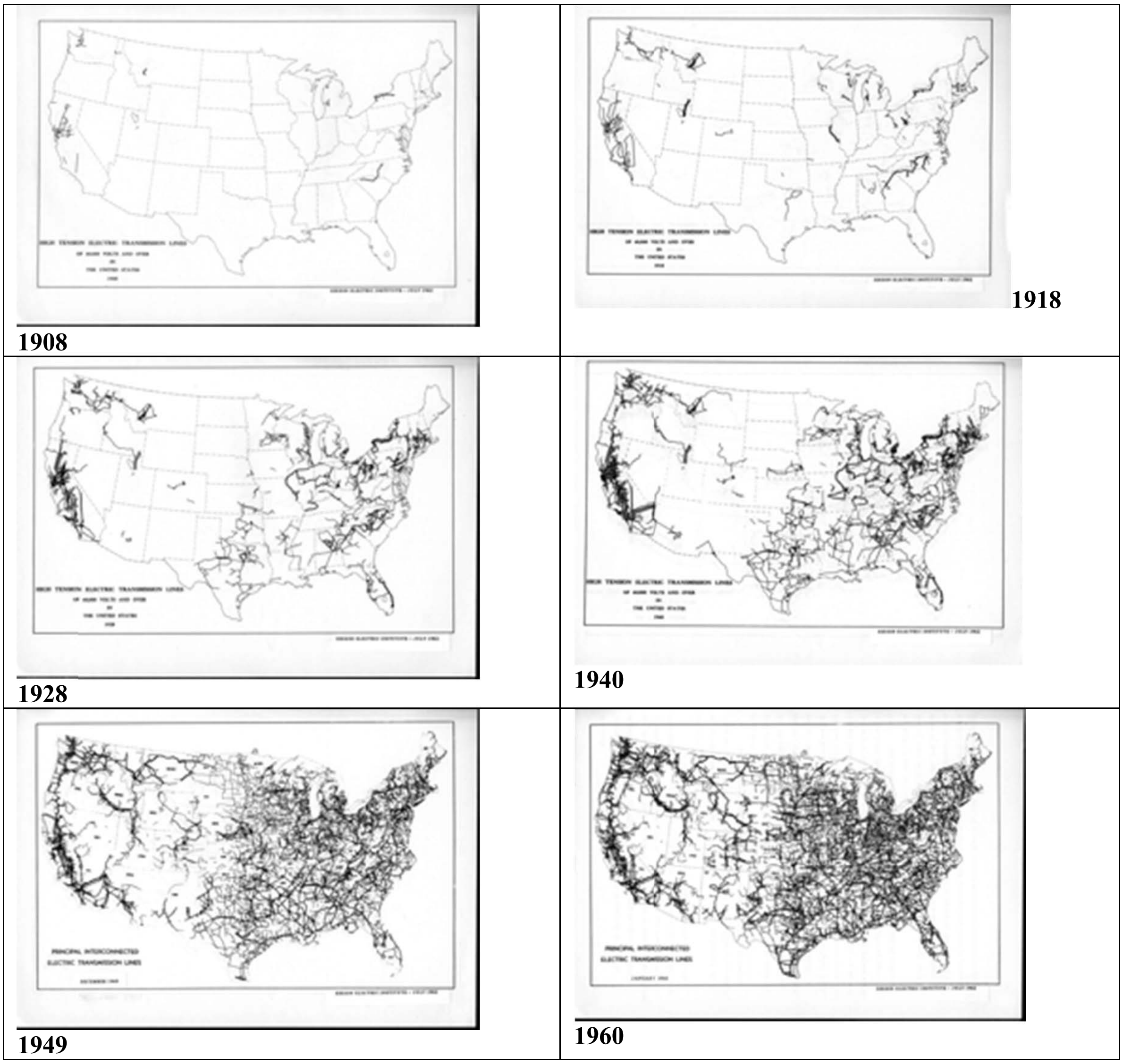


**Fig. 1.** *Maps showing high-tension electric transmission lines in continental United States, multiple years. (Source: Report on the Status of Interconnected Power Systems, Edison Electric Institute, 1962).*

> advantageous way work wonders in the economy of transmission as a whole. The art is young yet, spanning scarcely a decade, and there are many things to learn, not the least of which is the economical employment of water.[11]

Power system experts used the term *interconnection* for links between companies operating ac systems. Interconnection implied the possibility of moving power to and from multiple generators and also the possibility of expansion. By 1911, Robert A. Philip, an electrical engineer with Stone & Webster Engineering ventured, "The interconnection of two systems forecasts future connection with a third and fourth. Such extension carried on indefinitely leads to the conception of a single vast system which may be built up in the future." Philip further offered, "Continued, indefinite extension is desirable and inevitable if possible."[12] Commenting on this presentation, American Institute of Electrical Engineers president Dugald C. Jackson suggested that Philip was addressing the challenges of a future "nation-wide network."[13] These comments mark some of the early musings on the possibility of building an integrated power network reaching across the continent.

During World War I, R. J. McClelland, chief engineer of Electric Bond and Share Company, lamented the state of electrification in the United States. Like Britain and France, war industries in the United States experienced an energy supply emergency. But, "in Great Britain plans far

[11] "The value of water storage," *Electrical World*, vol. 44, no. 20, pp. 810–811, 1904. (Author emphasis.)

[12] R. A. Philip, "Economic limitations to aggregation of power systems," *Trans. Amer. Inst. Electr. Eng.*, vol. 30, no. 1, p. 602, 1911.

[13] "Economic limitations to aggregation of power systems."

more comprehensive than anything even talked of here are being laid years ahead for increasing, interconnecting and centralizing the supply of electrical energy."[14] In the early 1920s, competing interests promoted Super Power, Giant Power, and other regional plans to build large-scale interconnected systems.[15] At the same time, private interests pushed ahead with their own networks. Eleven companies in three eastern states, for example, formed a power pool called the Interconnected Systems Group in 1928, and this became the kernel of the largest network on the continent, eventually reaching customers east of the Rocky Mountains from Ontario to Florida.[16] Despite no explicit calls for a national grid, North American power industry leaders and politicians were surely aware of the advances in centralized integration on the other side of the Atlantic. In Britain's case, Parliament voted to establish the Central Electricity Board in 1926 in order to standardize electrical supply and oversee the creation of a fully interconnected national transmission network.

In the mid-1930s, as the federal government became increasingly involved in electrification, President Franklin Roosevelt ordered the Federal Power Commission (FPC) to undertake a national power survey. Though incomplete, the FPC's 1935 report did anticipate a push to coast-to-coast integration. The FPC predicted that a return to normal activity following years of economic depression would result in a "demand for power . . . at least 4 000 000 kW in excess of that which existed in 1929," while "the capacity of existing plants is 2 325 000 kW less than the demand that will exist ..."[17] The FPC stopped short of calling for a national grid but did warn that federal planning and supervision of new plants and transmission lines was necessary for the safety and wellbeing of the nation. The utilities also clearly kept in mind Britain's advances in the formation of a national grid. In a 1938 paper about interconnection, Philip Sporn, then Vice President of the American Gas and Electric Company, explicitly compared the scale of American interconnections (much larger) to those of Britain (fully integrated within the country).[18] Sporn included the map reproduced in Fig. 2 that made these differences vividly clear. Utility executives like Sporn evidently wanted colleagues to understand that the trend toward interconnection in the United States was well underway despite the lack of formal government oversight.

Through the war years, engineers and system operators focused primarily on building large integrated networks that could deliver power to defense industries in particular locations. These initiatives pushed the power system experts to operate their networks closer to the margin of reliability yet improve reliability at the same time. Power pools expanded across large regions of the country. The newly organized Northwest Power Pool, for example, included federal hydroelectric dams, rural cooperatives, municipal power companies, and private generators in five states with an installed capacity of 4.5 million horsepower (more than 33 million kW).[19] With both technical and operating innovations and newly enlarged power pools, the industry came out of the war primed to continue expansion.

By 1950, electrical engineer Nathan Cohn speculated, "a grid approaching country-wide extent is not too fantastic a contemplation for the future."[20] Colleagues repeated those musings later in the decade, forecasting coast-to-coast interconnections in the near future.[21] As the likelihood of a national or continental grid increased, the industry organized to prepare for the operating challenges ahead. In 1962, 10 power pools, comprised primarily, but not exclusively, of investor-owned utilities, formed the North American Power Systems Interconnection Committee (NAPSIC) to plan for coordinated operation between giant power pools.[22]

In 1962, President John F. Kennedy called for a new and thorough national power survey that would "suggest the broad outline of a fully interconnected system of power supply for the entire country."[23] Joseph Swidler, chair

[14]R. J. McClelland, "Electric power supply for war industries," *Electrical World*, vol. 72, no. 3, p. 101, 1918

[15]J. Christie, "Giant power: A progressive proposal of the Nineteen-Twenties," *The Pennsylvania Magazine of History and Biography*, vol. 96, no. 4, pp. 480–507, 1972; T. Parke Hughes, "Technology and public policy: The failure of giant power," *Proc. IEEE*, vol. 64, no. 9, pp. 1361–1371, 1976.

[16]"National Power Survey: Principal Electric Utility Systems in the United States, Power Series No. 2," Washington, DC, USA: Government Printing Office, 1936, x.

[17]P. Sporn, "Interconnected electric power systems," *Electr. Eng.*, vol. 57, no. 1, pp. 16–25, 1938; *Report on the Status of Interconnections and Pooling of Electric Utility Systems in the United States*. New York, NY, USA: Edison Electric Institute, 1962.

[18]Sporn, "Interconnected electric power systems."

[19]W. C. Heston, "Kilowatt-hours pooled for war," *Electr. West*, vol. 92, no. 3, p. 51, 1944.

[20]N. Cohn, "Power flow control—Basic concepts for interconnected systems," *Electric Light and Power*, vol. 28, p. 82, 1950. Nathan Cohn (1907–1989) was an electrical engineer active in the development of electric power control instruments and procedures and was also the author's father. Mr. Cohn was a Life Fellow of the IEEE and served for many years on numerous committees including the History Committee. He received the IEEE Lamme Medal in 1968 and the IEEE Edison Medal in 1982.

[21]Usry, R.O. 1959. Interconnected Systems Group Test Committee Meeting, Commonwealth Edison Building—Chicago, Illinois, November 19–20, 1959, Minutes, box 3, folder 7, Electric Power Systems Records, Hagley Library.

[22]The ten groups included the Northwest Power Pool, Pacific Southwest Interconnected Systems, Rocky Mountain Power Pool, New Mexico Power Pool, Canada–United States Eastern Interconnection, Pennsylvania–New Jersey–Maryland Interconnection, and the four regions of the Interconnected Systems Group. The Tennessee Valley Authority, a federal agency, was part of one of the latter power pools. The National Electric Reliability Council, now the North American Electric Reliability Corporation (NERC), was founded in 1968 to promote system reliability across the country. In 1980, NAPSIC joined NERC as an operating committee, thus integrating work on system reliability and system planning within one organization. See "History of NERC," North American Electric Reliability Corporation website, updated August, 2013, accessed June 15, 2018, https://www.nerc.com/AboutNERC/Documents/History%20AUG13.pdf, August, 2013.

[23]"Special Message to Congress on Conservation, March 1, 1962," Papers of John F. Kennedy, Presidential Papers, President's Office Files, Subjects: Conservation, John F. Kennedy Presidential Library and Museum.

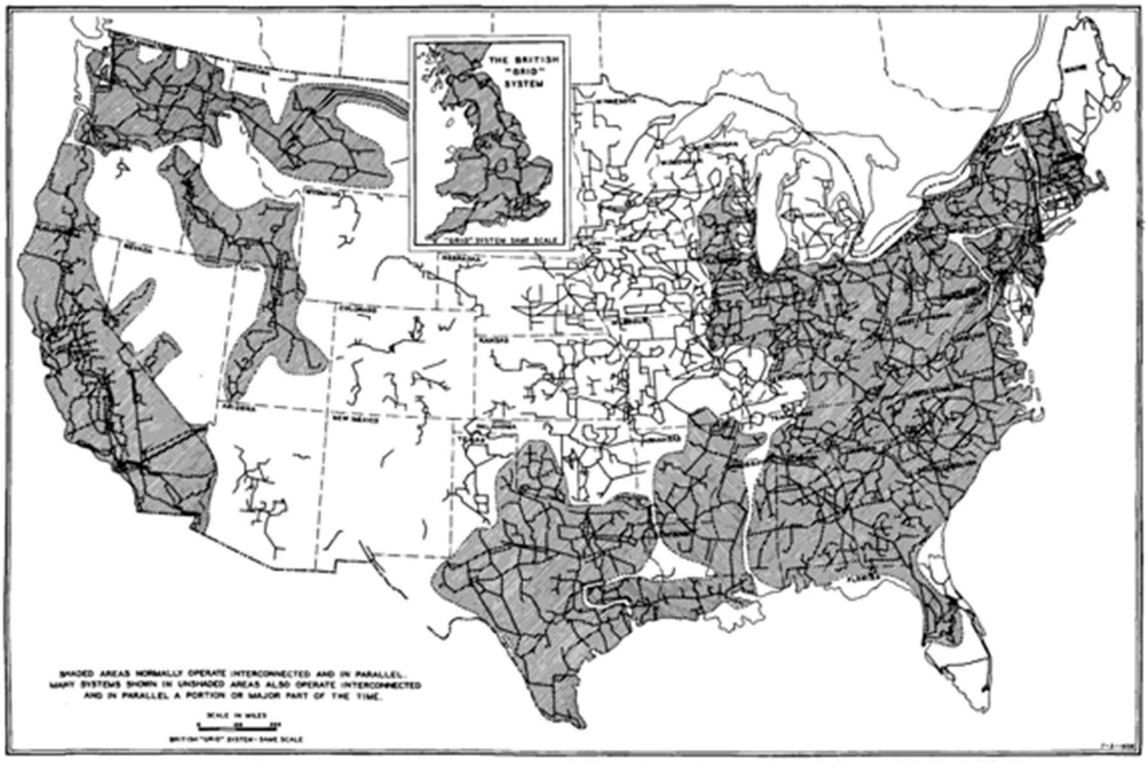


**Fig. 2.** ***Map comparing U.S. and British power networks. (Source: Philip Sporn "Interconnected Electric Power Systems," Electrical Engineering, January 1938).***

of the FPC, noted at that time that the United States was "probably the only civilized country in the world that does not have a coordinated national electric system."[24] The commission published the survey in 1964 and outlined how coast-to-coast interconnections might function to improve energy efficiency, conserve resources, and save power customers money. As evidenced by the map in Fig. 3, not only would power companies integrate networks across the continent, they would ship power east and west, north and south to achieve conservation goals as they were understood in the early 1960s.

Less than one year later, the Northeast Blackout of 1965 hit the power industry hard. Beginning at 5:16 P.M. on November 9th, more than 30 million people in 11 states and parts of Canada experienced the continent's first major power failure.[25] The blackout lasted minutes for some and as long as half a day for others. Afterward, interconnections became the focus of public interest. Reporters, customers, and even some power industry leaders questioned the wisdom of building large networks to supply American power, when they could be so easily and thoroughly disabled. At the very same time, the vast majority of engineers, system operators, and utility managers redoubled their commitment to interconnected power systems. During the aftermath of the blackout, the Bureau of Reclamation and representatives of numerous utilities formed a NAPSIC task force to plan for complete coast-to-coast interconnections.[26] Called the East-West Intertie Task Force, this small group quietly engineered the establishment of the world's largest interconnected machine. The group worked in relative obscurity, perhaps to avoid questions from a public and press that still doubted the efficacy of interconnections. During these years, municipal power companies and rural cooperatives continued the debate over who should own, operate, and control electrification in North America. In November 1966, when Secretary of the Interior Stewart Udall finally announced plans to test an east/west closure, the *Chicago Tribune* accused him of both a literal and figurative power grab.[27]

On February 7, 1967, Homer Loutzenheuser, general manager of the Platte Valley Public Power and Irrigation District operated a switch that completed ties between the

[24] "Swidler Asks Nation-Wide Power Tie-In," *The Washington Post, Times Herald* (1959–1973) 1962, A12.

[25] D. Nye, *When the Lights Went Out: A History of Blackouts in America*. Cambridge, MA, USA: MIT Press, 2010; J. Pratt, *A Managerial History of Consolidated Edison, 1936–1981*. New York, NY, USA: Consolidated Edison Co. of New York, 1988.

[26] "Changing Patterns of Power Pooling," *Electrical World*, vol. 166, no. 20, p. 102, 1966.

[27] "East-West Power Intertie Closure Test Scheduled February 7," U.S. Department of the Interior News Release, January 26, 1967, attached to Letter from Nathan Cohn to Frank Lachicotte, April 24, 1967, Box 38, Nathan Cohn Papers MC 317, Institute Archives and Special Collections, MIT Libraries; "Mr. Udall's Empire Grows," *Chicago Tribune*, November 16, 1966, p. 20.


**Fig. 3.** *Projected power exchanges in 1980. (Source: National Power Survey: A Report by the Federal Power Commission, 1964).*

eastern and western systems to create North America's first ever coast-to-coast grid.[28] In effect, Loutzenheuser, along with his counterparts in Gering, Nebraska, and at the Yellowtail and Fort Peck dams in Montana, created a giant machine. All the moving parts worked in synchrony to generate, transmit, and deliver electric power. The lights in an apartment in Los Angeles, California, for example, were physically connected to a generating plant in, say, Boston, Massachusetts. This was an engineering accomplishment of the highest order, first envisioned in the early twentieth century, touted by politicians and contemplated by engineers for decades, and finally achieved—nearly undetected by the American public—in 1967.

## III. WHAT TOOK SO LONG? THE TECHNICAL CHALLENGES

The interties functioned pretty well at first, but instability soon plagued the network, which then led to a return to the proverbial drawing board. Following a pattern established in the early years of electrification, the system experts had enlarged the power system, then discovered nuances and exaggerations of the natural behavior of ac. The challenge of operating interconnected ac power systems dates back to the early 1900s. Then, as now, system operators had to ensure that the amount of electricity generated at any given moment closely matched demand, deliver the quantity needed in an instant, and maintain steady frequency and voltage on all parts of the system. This meant—and continues to mean—that the generators, transmission lines, lights, motors, and other elements of the network all worked at the same speed—that is, the same frequency.[29]

Even before power companies first built ac links, the frequency was an issue. On a one-generator system, every time a customer flipped a light switch or a factory conveyer belt started up the frequency changed. Consider the simple analogy of a horse pulling a load. If weight is added to the load, the horse will slow down, at least briefly; and if weight is removed, the horse will likely speed up. Likewise, as a load was added to or subtracted from a power system, the generators slowed down and sped up. This meant that the frequency was constantly fluctuating across a system. Since the time of Edison's first experiments with electric lighting, power system builders installed governors on their generators to detect changes and bring the generators back to the desired frequency—and this is a requirement of all generators on North America's power systems today. While continuous frequency changes may not have mattered to the nineteenth-century customer using an incandescent light bulb, a manufacturer producing fine textiles would have noticed serious variations in the resulting goods. Furthermore, large frequency variations could, and still can, cause system instability, even system failure. As utilities then experimented with ac links in the early twentieth-century, operators noted that when demand changed on any part of a network, all the generators on the network responded.

By the 1920s, manufacturers offered devices such as frequency recorders with connected controllers and electric clocks to hold the frequency across a system to 60 Hz. But, as one engineer explained it, several devices on the same system have a tendency to "fight."[30] Once engineers resolved this problem, they found that they could control the frequency on a network very closely. This, however,

[28] "Switch Thrown," *North Platte Telegraph*, February 7, 1967, 1.

[29] By 1920, most electricity producers in North America adopted a voluntary standard of 60 Hz. P. Mixon, "Technical Origins of 60 Hz as the Standard AC Frequency in North America," *IEEE Power Eng. Rev.*, vol. 19, no. 3, pp. 35–37, 1999.

[30] "Development Committee Misc. Report 180, 2-6-28," Accession 1110, Reel 7, Leeds & Northrup Company Records, Hagley Museum and Library.

simultaneously upset the division of the customer load among generating plants, and therefore, among different companies. This behavior undermined the financial and operating agreements established between independent companies. As Robert Brandt, with New England Power Company explained, "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 tieline. From this, it appears that it may be necessary to incorporate with straight frequency controllers some sort of tieline load control."[31] These two consecutive examples illustrate the process of iterative problem identification, design, and testing—directly on the power network—that occupied power system experts through the twentieth century. As networks grew larger, the problems magnified.

For the next several decades, engineers, system operators, and instrument manufacturers wrestled with the load and frequency control conundrum. Through the 1930s, operators experimented with both centralized and distributed control strategies, frequency controllers and load controllers in different combinations, and many types of apparatus. And new challenges emerged. During World War II, demands for large amounts of electric power in certain locations intensified frequency and load control problems and framed a half-decade of experimentation. In the Northwest Power Pool, for example, the Grand Coulee hydroelectric dam provided frequency control for many interconnected utilities. As a result, "variations in frequency [*were*] less for the pool as a whole than formerly under separate system operation."[32] Elsewhere, operators increasingly noted the problem of unintended power exchanges between networks—called *inadvertent interchanges*. Engineers working with the Southwest Interconnected Power Systems pool designed techniques and acquired new apparatus specifically to minimize inadvertent exchanges on a network that served critical aluminum-producing factories.[33] In the late 1950s, the industry widely adopted the frequency and load-control method and standards in use today. Referred to as *automatic generation control*, this approach relies on an algorithm for calculating the net of unplanned power exchanges between control areas.[34] With each enlargement of a power pool and the further revelation of system behavior, manufacturers offered increasingly sophisticated computing and controlling devices, and the iterative process of testing and identifying new concerns continued.

[31] R. Brandt, "Automatic frequency control," *Electrical World*, vol. 93, no. 8, p. 387, 1929.

[32] Heston, "Kilowatt-hours pooled for war," p. 59.

[33] S. B. Morehouse, "Inter-system power coordination in Southwest Region," *Electric Light and Power*, vol. 23, no. 12, pp. 62–68, 70, 105, 1945.

[34] R. Brandt, "Theoretical approach to speed and tie line control," *Trans. Amer. Inst. Electr. Eng.*, vol. 66, no. 1, pp. 82–92, 1947; Cohn, "Power Flow Control—Basic Concepts for Interconnected Systems"; *Glossary of Terms Used in NERC Reliability Standards*, NERC website, updated July 3, 2018, www.nerc.com/files/glossary_of_terms.pdf.

In 1965, just prior to the Northeast Blackout, investor-owned utilities dominated the industry, as illustrated in Fig. 4. Regulation of these entities was dispersed. The FPC regulated wholesale power transactions, while nearly every state regulated retail rates and determined the boundaries of individual systems. In Texas, some cities, including Houston and Dallas, regulated investor-owned utilities, while others, such as Austin, operated their own power companies.[35] Nebraska allowed only public entities to operate power systems within the state. Through the work of NAPSIC, all of these entities had opportunities to discuss technical concerns, share experiments and results, and examine the potential benefits of coordinated operating techniques. Although each maintained autonomy in terms of financial goals and expansion plans, most agreed to adopt standards that would allow harmonious and reliable operation of interconnected systems.

## IV. THE "GOLDEN SPIKE OPERATION"

Industry experts considered the February 7, 1967 closure a major test of both the technologies and the social practices of power system control on the largest network ever created. The eastern system was nearly four times larger than the western system, and the interties could carry only a fraction of the power generated on each.[36] The potential for severe power swings between the two areas was significant. Two spinning balls side by side offer an analogy. To successfully link the balls, without causing either one to spin out of control or come to a stop, both must spin at exactly the same speed and in the same direction. In addition, the device linking the balls must either spin along with them or have connectors that work like swivels at each end. The eastern and western systems were equivalent to the spinning balls, but one ball was significantly larger than the other, and the connecting devices, that is, the interties, were quite slender. James Movius, an engineer with Public Service Company of Colorado at that time, described the linked systems as "elephants doing the ballet": the "trunk to tail" connections were weak.[37]

Utilities had attempted three previous smaller-scale east-west closures: in 1957, 1962, and 1963. The 1957 closure revealed that the frequency and load control approach used by the Northwest Power Pool—flat-frequency control—was incompatible with the technique used in the east—frequency-tieline bias control.[38] The test lasted just under 6 minutes. With new apparatus, utilities in the Pacific Northwest revised their approach to load frequency control and in 1962 the longest of

[35] The Texas legislature enacted utility regulation in 1975.

[36] F. Lachicotte, "Emergency Action After Automatic Separation and Normal Opening Points for Prolonged Separation," Box 1, Folder 15, Electric Power System Records, Hagley Museum and Library.

[37] J. Movius, telephone interview with author, August 11, 2017. James Movius was an engineer with Public Service Company of Colorado in the months preceding the closure.

[38] "Changing patterns of power pooling," pp. 102–103.

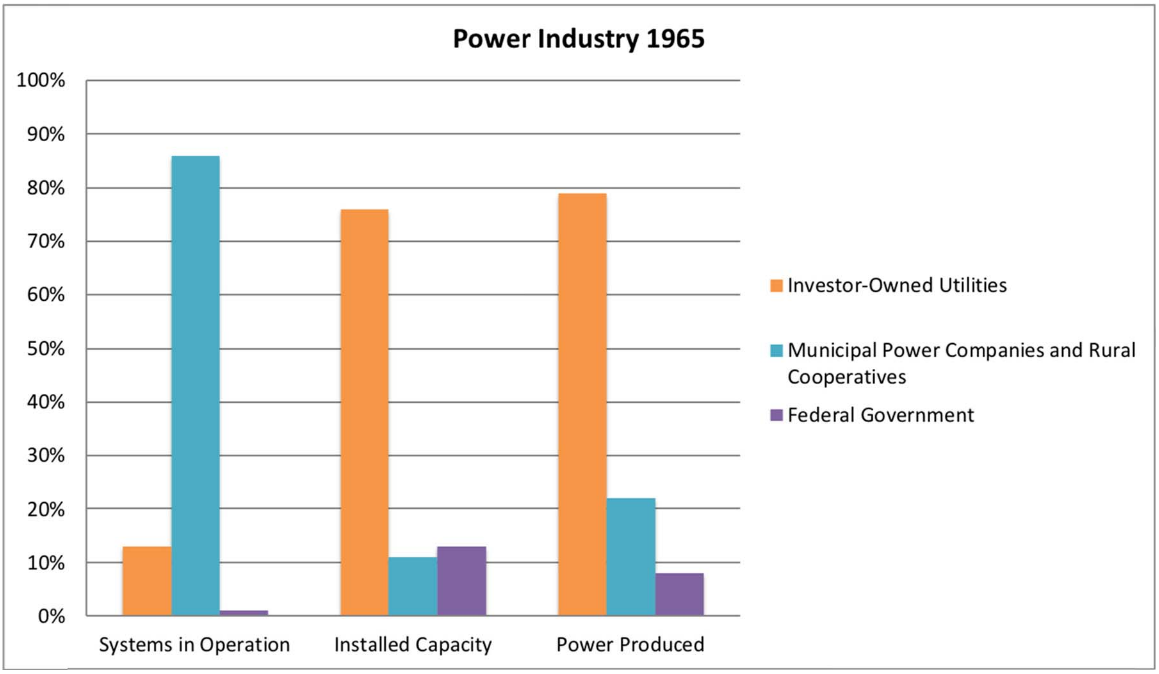


**Fig. 4.** ***Comparison of sectors of the power industry in 1965. (Source: National Power Survey: A Report by the Federal Power Commission, 1964).***

nine test closures lasted for 2 hours. Telemeter trouble interrupted the process. In 1963, inadequate telemetering likewise plagued closure experiments, with the longest of 11 tests lasting 2 hours and 5 minutes. Surveying the experience, writers for *Electrical World* reported that improved techniques and more interties were needed for "satisfactory East-West parallel operation."[39] For the 1967 closure, the task force planned to activate four interties, two in Nebraska and two in Montana.

Shortly before the 1967 East-West closure, utilities in the western states linked their northern and southern systems for the first time. While utilities in the east maintained very close frequency, the western utilities experienced frequent, poorly understood oscillations. The western interconnection, unlike the eastern, had a predominance of hydroelectric plants and very long transmission lines. Movius worked with a group casually known as the "blackout planning committee" to model behavior of the western system.[40] This was one of several task groups established by NAPSIC to prepare for another closure attempt.[41] Big outages in the west signaled potential problems for a coast-to-coast interconnection.[42] Movius, like other engineers and operators active at the time, viewed the project as a "grand experiment."[43] He remembered being optimistic beforehand that the east-west ties would work, but acknowledged that engineers knew the links were fragile.

[39]Ibid., p. 103.

[40]Movius, telephone interview with author.

[41]"Changing patterns of power pooling," p. 103.

[42]Letter from F. 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, Seattle Municipal Archives.

[43]Movius, telephone interview with author.

In anticipation of some of the difficulties that might emerge, the East-West Closure Task Force installed relays at each of the intertie sites. The task force used commercially produced apparatus at three locations and an experimental relay at the Yellowtail tieline.[44] As Bureau of Reclamation engineers explained, four characteristics of system behavior could cause east and west to operate out of synchrony with each other, making it "advantageous, if not eventually imperative, that [*all interties*] be opened simultaneously" rather than sequentially:

1) inadvertent interchange either from failure or error of tieline control apparatus in any area;
2) inadvertent interchange from imperfect coordination of schedule changes;
3) sudden system changes such as loss of load, generation, or a principal transmission line;
4) system oscillation.[45]

All of these conditions could occur on any part of any interconnected system in North America in 1967, and the western system was especially prone to significant oscillation. The engineers custom-designed the test relay at Yellowtail to effect simultaneous disconnection at all four locations. As part of this experiment, they used sensitive

[44]F. R. Schlief *et al.*, "A swing relay for the East-West Intertie," *IEEE Trans. Power Apparatus Syst.* vol. PAS-88, no. 6, pp. 821–825, 1969.

[45]Ibid., p. 821.

**Fig. 5.** ***Senior Leeds and Northrup engineers Stephen B. Morehouse (left) and Nathan Cohn (right) watch instruments recording system behavior during the closure. (Source: Electric Control Systems Records, Hagley Museum and Library).***

relay settings so that the machine's oscillograph would, in effect, "monitor its own performance."[46] In addition, Frank Lachicotte, Bureau of Reclamation power systems operation officer and task force chair, distributed a four-page list of steps to be taken in the event of automatic separation.[47] Power system experts from across the industry shared the deep interest in the results of the closure, wondering what the effects of trouble on one coast would have on the other.[48]

On February 7, equipment manufacturers, system operators, and engineers at participating utilities and the Bureau of Reclamation observed the test from multiple locations, tracking the behavior of different parts of the power system on recording instruments and keeping in close touch on dedicated telephone lines and an early "conference call."[49] The photograph in Fig. 5 captures the intent focus of the witnesses to the closure, in this case from a control room in Philadelphia. Lachicotte directed the process from Watertown, South Dakota. That office of the Bureau of Reclamation maintained telephone, teletype, and other communication links to multiple points east and west. The journal *Electrical World* provided a minute-by-minute account of a "tension-packed silent period" during which a task force spokesman gave instructions from Watertown, operators at Yellowtail monitored instruments, and then operators proceeded to "lock . . . east and west systems into synchrony" sequentially through each of the four interties.[50] Once all four interties were closed, the task force spent days sending power east to west and west to east and varying the schedule of trades. Happily, the task force recorded no significant frequency changes during this portion of the test. As reported in a local paper, "officials . . . said the 209 private and public power systems hooked into the national grid retained control over their areas and that the closure could be opened in minutes if major troubles developed."[51]

Lively news reports following the closure used words such as "unprecedented" "massive" and "vast" to describe the new network and called it "the Golden Spike Operation."[52] Papers around the nation ran wire service stories, and the industry journals followed up with detailed reports

[46]Ibid.

[47]F. Lachicotte, "Emergency action after automatic separation and normal opening points for prolonged separation."

[48]W. Stadlin, personal communication with the author, December 6, 2012; D. Schaufelberger, personal communication with author, September 11, 2017. Walt Stadlin was an engineer with Leeds & Northrup Company at the time of the closure and later served as a consultant to the industry. Mr. Stadlin is a Life Fellow of IEEE. Mr. Schaufelberger retired as the President of Nebraska Public Power District in 1989. At the time of the closure, he worked for Consumers Public Power District.

[49]"East-West Power Intertie Closure Test Scheduled February 7"; "East-West Ties Hold, U.S. Systems in Phase," *Electrical World*, vol. 167, no. 8, pp. 49–51, 1967.

[50]"East-West Ties Hold; U.S. Systems in Phase,"

[51]"Power grid is humming along," *North Platte Telegraph*, Feb. 8, 1967, p. 4.

[52]Lachicotte, In-House Newsletter, Box 1, Folder 15, Electrical Power Systems Records, Hagley Museum and Library.

on the project.[53] More locally, in the towns housing the four interties, reporting was scant. *The Glasgow Courier* in Montana offered one very short story, and the *North Platte Telegraph* in Nebraska printed a front-page photo and two accompanying articles.[54] Donald Schaufelberger, of Nebraska Public Power, reflected that for the locals, the closure was no big deal. "As long as their lights were on, they did not care much what was happening. They did not understand. Even newspapers did not really understand the significance of it."[55]

Minimal local interest and relatively brief national coverage reflected the lack of material changes experienced by power customers. But the closure did offer modest economic benefits to regional utilities and rural cooperatives. The East-West intertie, for example, would "permit more efficient utilization of water and hydropower, both seasonally and on a day-to-day basis."[56] According to Schaufelberger, it also resolved projected generation shortages and high coal costs for certain cooperatives within Nebraska. The closure further promised, but did not deliver, more significant reliability benefits to the larger industry. As *The New York Times* noted, "an official said the intertie would mean that 'generating plants from coast to coast will respond to power system emergencies in any part of the nation,'" but that it would not have helped in the case of the 1965 Northeast blackout.[57] The more in-depth reporting of industry publications indicated the fulfillment of engineering ambitions that had lasted half a century. As an article in *Power Engineering* reported, "A technical achievement without precedent, [*the closure*] culminates the power-pooling process which began in earnest in the 1920's."[58]

## V. ''SOME FANCY BRILLIANT SCHEMES''

As a test, the closure failed after a few months. System engineers described "relatively serene" operations through the spring, but this did not last. Two types of problems afflicted the network.[59] First, as feared, oscillations on the western system upset operations, despite experiments in closing and opening certain north/south interties and reliance on Grand Coulee to control frequency.[60] Second, there had been large inadvertent exchanges, reflected in significant fluctuations over the interties.[61] During July alone the task force recorded 24 incidents of oscillations, inadvertent flows, automatic opening of the relays, overloads, trips, and system break-ups.[62] As had been agreed upon in advance, the utilities exercised their right to request that Lachicotte open the ties, which he did in late July, so that they could resume more stable operations. During the ensuing weeks, members of the task force encouraged quick reclosing of the ties, arguing that open ties equaled economic loss "to the USBR, CPP, and BHL&P," represented a waste of the large investments already made, and tarnished the "prestige of an electrical industry accomplishment."[63] This discussion took place amongst individuals from public power districts, investor-owned utilities, and the Bureau of Reclamation, all of whom had a stake in the project. Nonetheless, the ties remained open.

During August, the task force developed nine recommendations for both operating and technology improvements on the western system to prevent ongoing system outages.[64] As the task force noted, inadvertent flows caused overloading of transmission facilities, major system breakups, and reduced capacity on transmission lines for scheduled flows. The task force called for modification of control settings to be adopted voluntarily by individual systems. The task force also recommended acquisition of a wide area teletype communications network by all major load control centers in the west to give system operators dedicated pathways for communication about planned outages, system emergencies, and other unusual conditions. Other proposed changes included designation of central coordination centers, training for dispatchers and plant operators, and review of a number of operating techniques that might be improved. In addition, the engineers who had engineered the test relay at Yellowtail used the pause in east-west operations to refine the relay.[65]

Lachicotte reclosed the interties on December 3, 1967. The improved relay at Yellowtail did a better job of anticipating oscillation problems than it had before. Over the next eight months, the relay triggered 381 separations between eastern and western systems at all four intertie locations.[66] As disturbing as this sounds, it represented the

[53] "Closing circuits," *The Christian Science Monitor*, Feb. 7 1967, p. 1; "U.S.–Canada power grid passes test," *New York Times*, Feb. 8, 1967, p. 61; "North American grid put together to test blackout prevention," *Wall Street Journal*, Feb. 8, 1967, p. 11; "Power system is tested for blackout guard," *Washington Post, Times Herald*, Feb. 8, 1967, p. 1-D7; "East-West ties hold; US systems in phase," 49; "East West Tie," *The Lamplighter Newsletter, Black Hills Power and Light Company,* vol. 17, no. 3, 1967; Schlief *et al.*, "A swing relay for the East-West Intertie."

[54] "World's largest electrical system completed February 7," *Glasgow Courier*, February 9, 1967, p. 1; "Switch thrown," *North Platte Telegraph*, February 7, 1967, p. 1; "Nationwide system: Final switch thrown here to complete huge network test," *North Platte Telegraph*, Feb. 7, 1967, p. 1; "Power grid is humming along."

[55] D. Schaufelberger, telephone interview with the author, September 11, 2017.

[56] East-West Ties Hold; U.S. Systems in Phase.

[57] "U.S.–Canada power grid passes test," p. 61.

[58] "Status of power pools—Part I," *Power Eng.,* vol. 71, no. 5, p. 63, 1967.

[59] Schlief *et al.*, 821.

[60] Cohn to Lachicotte, April 24, 1967, Nathan Cohn Papers.

[61] Ibid.

[62] "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.

[63] Ibid. "USBR, CPP, and BHL&P." refers to U.S. Bureau of Reclamation, Consumer's Public Power, and Black Hills Lighting and Power respectively.

[64] Lachicotte to Marean, August 31, 1967, Seattle City Light Regional Power Management Records.

[65] Schlief *et al.*

[66] Ibid.

desired outcome for interconnected operations between the two giant systems. East and west functioned as one machine for an additional eight years, delivering electricity to 95 percent of customers in the United States and parts of Mexico and Canada. In their professional papers and presentations, engineers began to refer to a single transmission system serving most of North America, and colloquially called it *the grid*.[67]

Looking back on the eight years of coast-to-coast interconnection, engineers reflected on the challenges of maintaining parallel operations between the mismatched networks. Thomas Weaver, a former executive with the Western Area Power Administration described the east-west interties as "some fancy brilliant schemes ... [*but*] if something would happen on one side or the other, you wound up tripping the lines. The people who lived right along the ties were not happy campers, because their voltages were going up and down."[68] Engineer Walt Stadlin observed that "power system engineers quickly recognized the limitations of weak ac tielines. Under these conditions the exchange of large amounts of power between East and West was not viable, from a market point-of-view or a national stability point-of-view."[69] Donald Schaufelberger recalled that the ac interties were useful, but not reliable. He and other engineers learned a lot about what needed to be done. But when they changed to dc ties, it really "started the ball rolling because it worked so well."[70] The utilities permanently opened the four east-west interties in 1975. No longer interconnected, and no longer operating in parallel, the two systems no longer functioned as a single machine.

By the 1970s, innovations in dc transmission looked promising to North American power companies. Although most North American utilities had abandoned dc systems in the early twentieth century, the Swedish company Allmanna Svenska Elektriska AB continued to develop devices that allowed for the use of high-voltage dc transmission lines to link ac systems. Revisiting the spinning ball analogy, a dc tie between two ac systems worked as a link with swivels at each end. The first North American HVDC lines went into service in Vancouver in 1968 and in California in 1970.[71] With these lines, large ac power networks shared power, but did not have to maintain synchronous operations—they were connected, but not interconnected.

In 1977, Tri-State Generation and Transmission Association, an organization of rural cooperatives, commenced operation of a high-voltage dc transmission intertie in Stegall, Nebraska—the first dc link between the eastern and western systems. By 1987, the utilities had effectively replaced all four east-west interties with additional dc ties in Eddy County, New Mexico; Miles City, Montana; and Sidney, Nebraska. Today, there are six dc ties linking the eastern and western networks, and several others providing connections to Texas and Quebec. Technically, four grids operate across the continental United States and Canada, and parts of Mexico. Engineers are careful to identify the separate systems that serve each region. Yet, the concept of a single grid remains as a cultural artifact.

## VI. THE CYCLE OF INNOVATION CONTINUES

During the period of coast-to-coast interconnection, power system experts continued the decades-long process of iterative innovation as they attempted to resolve seemingly intractable problems. In 1942, inadvertent exchanges had been "the cause of the principal regulating problems on interconnected power systems."[72] Throughout the 1950s and early 1960s, engineers experimented with various approaches to calculating, assigning responsibility for, and mitigating inadvertent exchanges. Yet, large inadvertent exchanges were partly responsible for the instability of the east-west interties. Bureau of Reclamation engineers introduced a new fix—a specialized relay—and the system limped along. Similarly, engineers had observed oscillations on interconnected systems from the earliest experiments linking ac networks.[73] It was in the 1950s and 1960s, however, that oscillations on very large interconnected systems became problematic. In anticipation of the east-west closure, NAPSIC organized a committee to address known oscillation problems in the western region. Although engineers modeled the network and how it might function following the closure, oscillations proved to be a recurring cause of failures. In fact, following re-opening of the interties, western utilities continued to struggle with oscillations, which were responsible in part for a major 1996 blackout that affected 7.5 million customers in seven states, two Canadian provinces, and part of Mexico.[74]

These two examples highlight a salient feature of North America's power system. To control the extremely complex behavior of electricity, particularly in the form of ac, engineers and system operators have spent a century experimenting with, learning from, succeeding at, and failing on expanded networks. For much of that time, the testing took place directly on the power lines delivering electricity to paying customers, in real time. From links between two separately owned power stations in the late 1890s to the world's largest interconnected machine, realized in 1967, the system experts have engaged in a process of collaborative, iterative invention. Each expansion led

[67]Cohn, *The Grid*, pp. 204–209

[68]As quoted in *Serving the West: Western Area Power Administration's First 25 Years as a Power Marketing Agency*. Lakewood, CO, USA: Western Area Power Administration, 2002, p. 33.

[69]Stadlin, personal communication with the author.

[70]Schaufelberger, telephone interview with the author.

[71]"Existing HVDC Projects Listing, Prepared for the HVDC and Flexible Transmission Subcommittee of the IEEE Transmission and Distribution Committee," University of Idaho Electrical and Computer Engineering Department website, March 2012, http://www.ece.uidaho.edu/hvdcfacts/Projects/HVDCProjectsListing2013-existing.pdf.

[72]Morehouse, "Inter-system power coordination in Southwest Region," 63.

[73]G. Rogers, *Power System Oscillations*. New York, NY, USA: Springer Science + Business Media, 2000, pp. 1–6.

[74]Ibid.

to new discoveries about how electricity behaves and new techniques for managing those behaviors. But as this tale cautions, time and again, the experts met limits to their ability to control electricity on interconnected systems. *The grid* is now four grids and the experts continue to discover new aspects of power system control, devise new techniques in response, and, albeit with outstanding digital models to forecast results, test their approaches on our electric power lifelines.

The history of infrastructure and networks includes an inference that growth represents progress and inevitably links to success. But the 1967 case illustrates that failure resulted in a true termination for one type of expansion, and an opening for a different approach. The stakeholders could no longer tolerate an unstable grid and thoroughly abandoned the notion of a single interconnected North American power system. With a different technology and different types of links between systems, the stakeholders accomplished a connected group of networks. This allowed for the desired power sharing, if not the technological achievement touted at the outset. It also allows for the continued popular idea of *the grid*, a conceptual network of power, but not a true interacting machine. ■


## Acknowledgments

The author would like to thank A. Magoun of the IEEE History Center for encouraging this project. She would like to thank several engineers for discussing the control challenges of twentieth-century power system operations and the 1967 closure, especially W. Stadlin, J. Preston, D. Schaufelberger, and J. Movius. She would also like to thank D. Hounshell for bringing to her attention the recent work on power system oscillations and the three anonymous reviewers who read the initial draft of this article and provided helpful and insightful recommendations.


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