ESSAY

Power grid? What is that?

by Raymond E. Floyd

The electric grid that exists today, frequently called the *power grid* and serving millions of homes and businesses in North America, began its existence in the late 1800s. Unless you are an engineer—more specifically, a power engineer—it is doubtful that you have ever given a single thought to what is behind the switch whenever you turn on lights, televisions, radios, or other electrical devices. The normal expectation is that, when the switch is thrown on, the lights will come on—every time and always. Outstanding availability and reliability are expected of the system.

History

One of the first patents, U.S. Patent 0,223,898 (the original patent number was 223,898, issued 27 January 1880, but it was modified with the addition of a leading zero to maintain consistency with patents issued after 1976 for search purposes), was issued to Thomas Edison for the incandescent light bulb, a carbon filament-based light. It operated on a dc power source with a supply voltage of approximately 100 V.

That patent was followed by many more, with two being U.S. Patents 0,251,551 ("System of Electric Lighting") and 0,263,142 ("Electrical Distribution System"), which provided a description and basis for a dc power distribution system. This offered an easy way to supply power to homes, businesses, and cities. It did have a number of limitations, including that it typically offered only 110-V power; had major problems in operating consistently; and was restricted in its distribution range, with the limit being fewer than 2 mi from the source to the outer bounds of the system. To go beyond that range was not possible with then-current technology, so, as the demand increased, additional power plants had to be built to supply the local market.

In that same time frame, Westinghouse and Tesla were advocating the use of ac power systems for general distribution and use. The current dc systems had a limited application range, but, through the use of transformers, which do not work with dc power, ac voltages could be stepped up or down to allow distribution across far more distant applications. In what is described as the "War of Currents," Edison and Westinghouse argued back and forth as to which was the "ideal" form of electrical distribution. In the end, Westinghouse won out, and ac became the de facto standard—but the debate is not yet over.

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The structure of the grid

Going back to the original discussion, just what is beyond that switch that is being turned on? The entire system begins at the power producing station, which may be a hydroelectric dam, fossil fuel-fired power plant, land- or offshore-based wind generator farm, solar panel farm, nuclear plant, or geothermal generator. Regardless of the source, each plant will generate electric power, typically in the 5,000–15,000-V three-phase output. When selected to become part of the grid power system, that output is stepped up through the use of transformers, with typical voltages ranging from about 100,000 V to more than 700,000 V to feed the transmission network over large distances.

Most people will recognize the transmission network as the tall electric poles running along a highway, mile after mile. Periodically, there is a fenced area with cables running from the transmission lines down into the enclosed equipment. These facilities are referred to as *substations*, and they use transformers to step-down the high voltage

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from the transmission lines to, typically, 35,000–100,000 V. The output of the substation then feeds a series of distribution lines, carrying power to consumers.

Once in the vicinity of a consumer or consumers, the electric lines enter another level of distribution substation, where the line voltage may be reduced further to 6,000–35,000 V. At the industry level, this output is input to local transformers to reduce the voltage to 500–600 V for commercial use or, via pole/pad-mounted transformers, to a household level of 120–240 V.

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In the United States, there are almost 200,000 mi of distribution wiring, with more than 500 power-generating stations involved. The interesting point is that there is not a "single" grid but a number of primary and smaller grids. The grid systems are illustrated in Fig. 1. It might be asked why Mexico is not included in the North American grid system. At one time, there was an interconnect between the Mexican and Texas grids, but it is no longer in use.

There are two major wide area distribution grids, the Eastern and Western Grids. The former covers the area from the Atlantic Ocean to the eastern edge of the Rocky Mountain range, with the exception of Texas and Québec, Canada. The Québec Grid does tie into the Eastern Grid but is isolated for control purposes. The Western Grid covers the area across the Rockies, including the U.S. states and Canadian provinces. Beyond the two major grids, there are smaller ones, including the Texas, California, and Alaska Grids (actually two independent grids). The Alaska Grids are unique in that, because of the nature of the state, there is a need for two independent grid operations. Even with such grid availability, many remote villages or island communities must have local diesel power operations for their electricity.

High-voltage dc systems

Where loads and limited distance were problems in the systems of the 1800s, those limitations have been overcome in modern high-voltage dc (HVdc) systems. Today, long distances—in excess of 1,200 mi—can be achieved with voltages in the 800,000-V range (with plus and minus polarity lines achieving a capacity of 1.6 million V).

There are some problems noted with HVdc systems, with the primary ones being maintenance and availability. HVdc systems have an availability typically

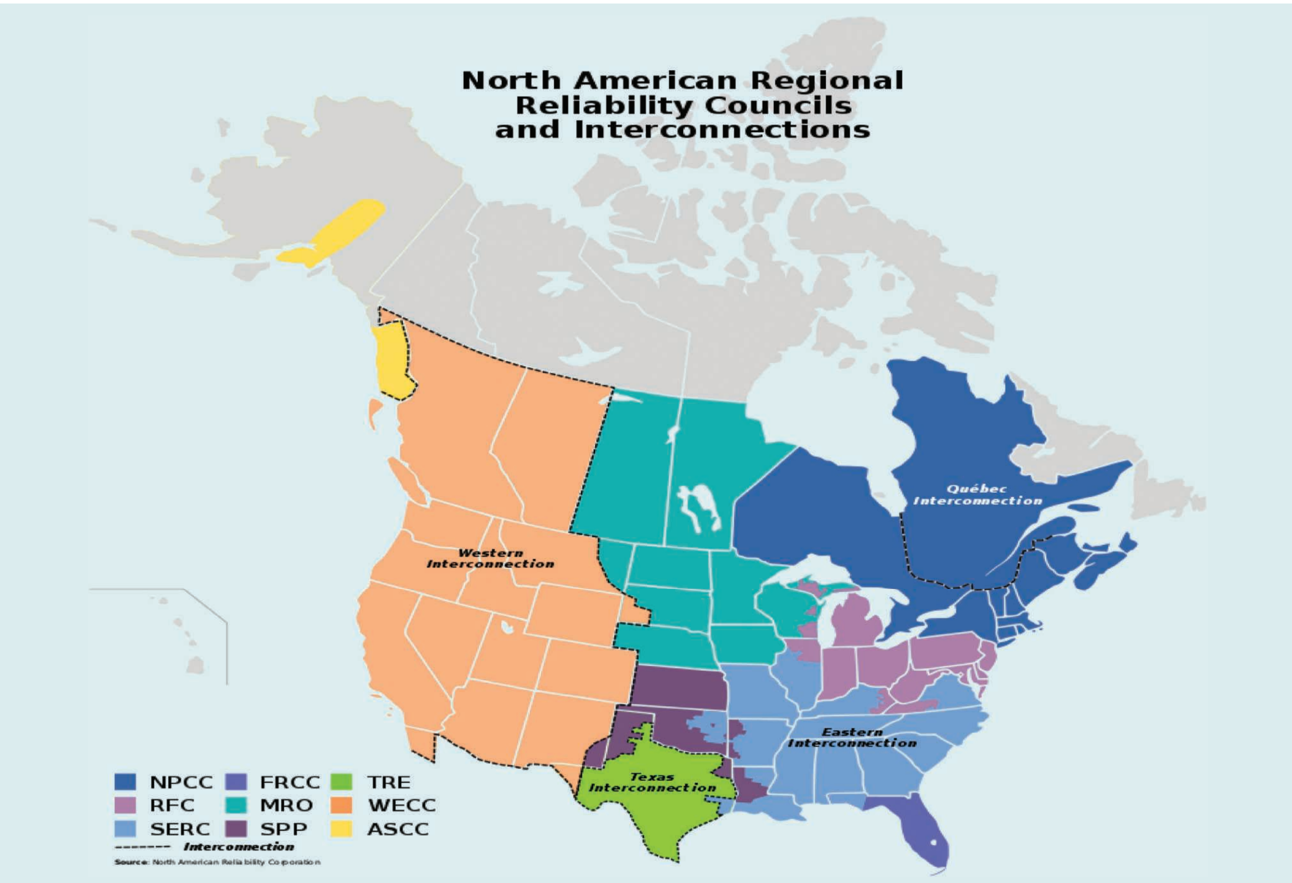

FIG1 The U.S. grid. (Source: Wikipedia, 2020.) NPCC: Northeast Power Coordination Counsel; RFC: Reliability First Counsel; SERC: SERC Reliability Counsel; FRCC: Florida Reliability Coordination Counsel; MRO: Midwest Reliability Organization; SPP: Southwest Power Pool; TRE: Texas Reliability Entity; WECC: Western Electricity Cooperative Counsel; ASCC: Alaska Systems Cooperative Counsel.

in the 97–98% range, when compared to ac distribution grids operating in the 99+% range. With the rectification, switching, inversion, and other control elements required, there is simply more equipment failure to be considered.

Another problem is that manufacturers of dc power equipment have not standardized to the same level that those of ac power equipment have. There are specific applications where dc systems are the better choice. For example, underwater lines powered by dc are more efficient than those with the equivalent ac power due to capacitive losses suffered by the ac system. Similarly, where there are long lines with no intermediate access taps, dc lines are more effective and cheaper.

There have been a number of large HVdc grids installed over the past 10 years, with the majority in China and European countries (England, Scotland, France, Spain, and The Netherlands). Typically, an HVdc line suffers less transmission loss, ranging from 30% to 50% less, thereby enabling longer distances for power transmission.

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The next time you turn on the light, the stove, or some other electrical appliance, take a moment and imagine where that power originated. How far did it travel? What kind of power generators were involved? It is an impressive highly technical, solution for your use in everyday operations.

Read more about it

- T. K. Grose, “Power play – The re-current rivalry,” PRISM, Feb. 2016.
- “Applications for high voltage direct current transmission technologies,” U. S. Dept. of Energy (DOE), Arlington, VA, 2013.
- J. Jones, *Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World*. New York, NY, USA: Random House, 2003.
- “HCDC vs. HVAC transmission”, Electriceasy, Feb. 2016. http:www.electricaleasy.com/2016/02/hvdc-vs-hvac.html
- E. Wolf, D. Kahn, and Z. Coman, “Texas and California built different power grids, but neither stood up to climate change,” Politico, 2021. https://www.politico.com/news/2021/02/21/texas-california-climate-change-power-grids-470434
- “North American power transmission grid,” Wikipedia, https://en.wikipedia.org/wiki/North_American_power_transmission_grid (Accessed: Apr. 27, 2022).
- “Alaska’s energy infrastructure,” Renewable Energy Alaska Project (REAP). alaskarenewableenergy.org/ppf/alaskas-energy-infrastructure (Accessed: Apr. 27, 2022).
- S. W. Blume, *Electric Power Systems Basics for the Nonelectrical Professional (IEEE Press Series on Power and Energy Systems)*, 2nd ed. Hoboken, NJ, USA: Wiley, 2016.

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Raymond E. Floyd (r.floyd@ieee.org) earned his B.S.E.E. degree from the Florida Institute of Technology, Melbourne, Florida, USA, in 1970, his M.S.E.E. degree from Florida Atlantic University, Boca Raton, Florida, in 1977, and his Ph.D. degree in engineering management from California Coast University, Santa Ana, California, USA, in 2009. He spent 26 years with IBM, Armonk, New York, USA, retiring in 1992 as a senior engineer. He is a Life Senior Member of IEEE, life senior member of the Society of Manufacturing Engineers and member of the Society of Petroleum Engineers and American Society for Engineering Education, and he holds four patents. He has served as a program evaluator for the Engineering Technology Accreditation Commission of the Accreditation Board for Engineering and Technology for 25 years and is a corresponding editor of *IEEE Potentials*. He is currently a visiting lecturer at Northwest College, Powell, Wyoming, 82435, USA, where he teaches a variety of engineering- and computer-related courses.