MSCE Energy Infrastructure Brief on the Electrical Grid

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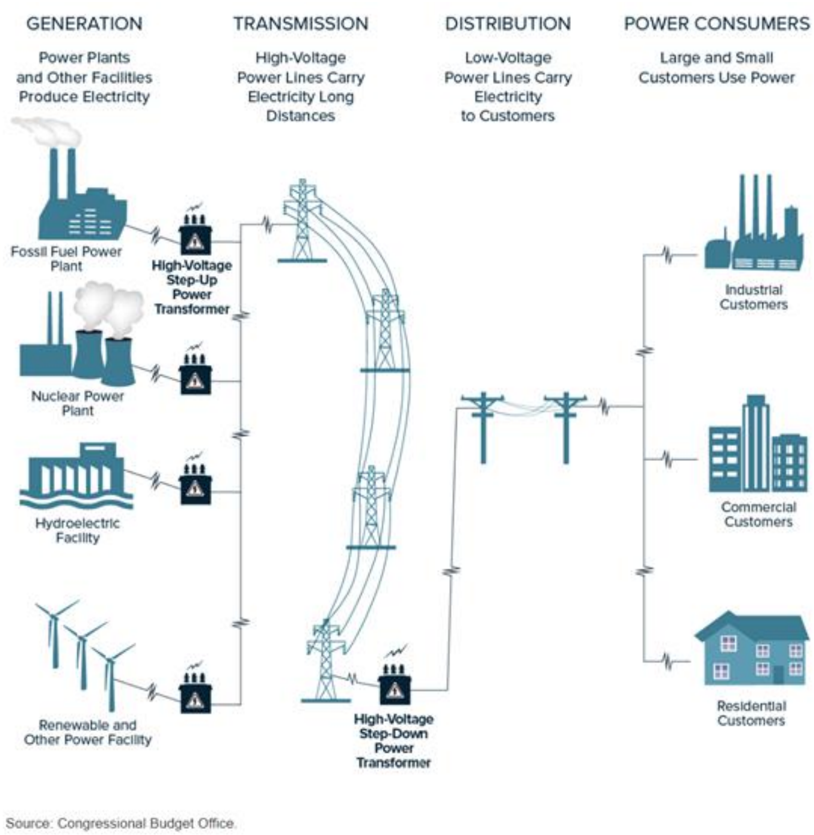
Introduction and Terminology

The electrical grid is illustrated below. It shows the four primary elements which are: (1) generation, (2) transmission, (3) distribution, and then (4) power consumers. As the electricity departs the power plants, the voltage is increased for transmission. Transmission lines move the electricity to the vicinity of users. The electricity voltage is then stepped down by transformers to enter a lower voltage set of power lines. These lower voltage lines constitute the distribution system which delivers electricity to specific customers.



Main Elements of the Electrical Grid

Source: Congressional Budget Office, “Enhancing the Security of the North American Electric Grid,” March 2020

The US electrical grid consists of more than 7,000 power plants (the number of plants can be much larger…depends on which plants are included), nearly 160,000 miles of high-voltage transmission lines, and millions of low-voltage distribution lines and transformers, which serves about 145 million customers. An analogy between electricity and transportation, the transmission grid is equivalent to Interstate highways and the distribution system similar to lower volume rural roads.
[Energy Information Agency, https://www.eia.gov/todayinenergy/detail.php?id=27152]

Most of this Brief on the electrical grid will focus on transmission and distribution grids associated with the traditional "macrogrid." However, you should be aware that there is an additional grid descriptor which implies a different scale and function—a microgrid. Both definitions follow.

- **Macrogrid:** Typically referred to as the "grid." It connects homes, businesses, and other buildings to central power sources such solar, wind or fossil fuel power plants.
- **Microgrid:** A microgrid is typically a smaller grid with local control, which means it can disconnect from a large grid and operate autonomously.

There are numerous standards and regulations that govern reliability of the power sector. Here they are reduced to four and apply to the full system…not just the grid:

- Power generation and transmission capacity must be sufficient to meet **peak demand** for electricity.
- Power systems must have adequate flexibility to address **variability and uncertainty** in demand (load) and generation resources.
- Power systems must be able to maintain steady **frequency**.
  If frequency deviates significantly from 60 Hz, it could damage machines and electronics.
- Power systems must be able to maintain **voltage** within an acceptable range.

[Source: Maintaining Reliability in the Modern Power System, DOE, December 2016.
https://www.energy.gov/sites/prod/files/2017/01/f34/Maintaining%20Reliability%20in%20the%20Modern%20Power%20System.pdf]

Transmission Grid

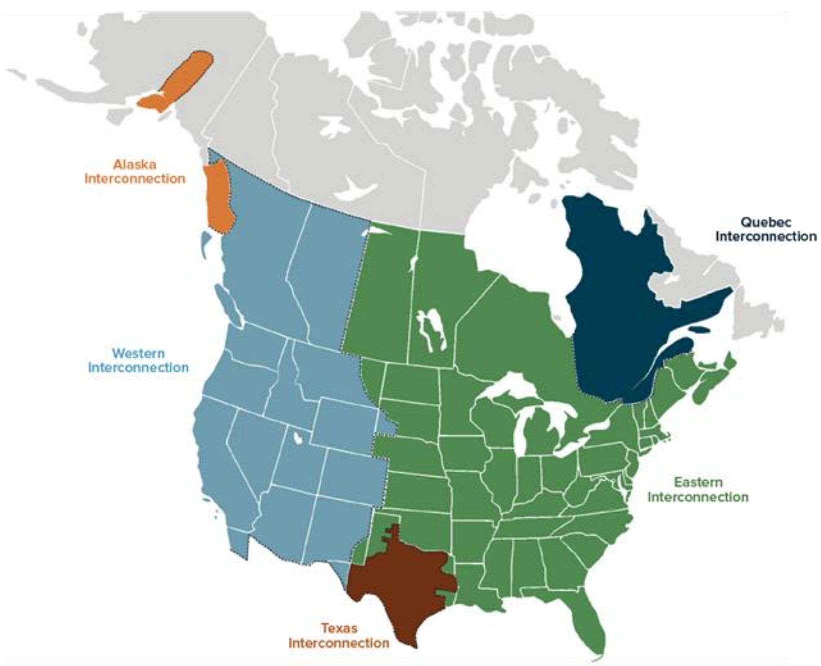
The capacity needs in electricity markets has expanded transmission grids … in part due to a wide variety of generation. The transmission grid was originally built to interconnect neighboring utilities but now is used as a "superhighway." This can result in congestion which is a primary reason grid upgrades required.

How is the grid managed? There are two levels you should be aware of: (1) the interconnection of major grid areas and (2) balancing authorities. Discussions of both follow.

Interconnection Regions. The electrical grid is composed of two main networks, or interconnections which are largely electrically separate from other power regions, and three smaller interconnection networks for Texas, Quebec, and Alaska. Hawaii, Puerto Rico, other island territories, and portions of Canada operate separate grids. The network structure of the interconnections helps maintain the reliability of the grid by providing multiple routes for power to flow and allowing generators to supply electricity to numerous load centers (electricity users). This redundancy helps prevent transmission line or power plant failures from occurring. The three primary interconnection networks in the US are:

- The **Eastern** Interconnection encompasses the area east of the Rocky Mountains and a portion of northern Texas. The Eastern Interconnection consists of 36 balancing authorities: 31 in the United States and 5 in Canada.
- The **Western** Interconnection encompasses the area from the Rockies west and consists of 37 balancing authorities: 34 in the United States, 2 in Canada, and 1 in Mexico.
- The **Electric Reliability Council of Texas (ERCOT)** covers most, but not all, of Texas and consists of a single balancing authority. This system has limited connections with the Eastern and Western Interconnections largely to preclude federal oversight of ERCOT.

[After Energy Information Agency, https://www.eia.gov/todayinenergy/detail.php?id=27152]



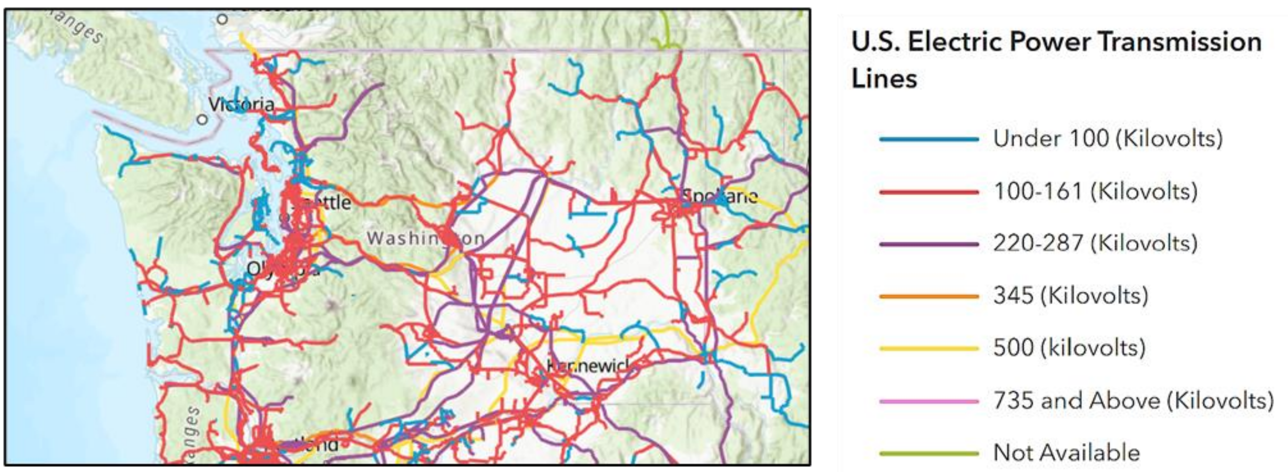
Interconnection Regions

Source: Congressional Budget Office, "Enhancing the Security of the North American Electric Grid," March 2020

Balancing Authorities. The regional grids describe the large-scale management and structure of the grid. The regional operation of the electric system is managed by **balancing authorities** whose primary job is to ensure that **electricity supply constantly matches power demand**. Most of the balancing authorities are electric utilities that fulfill balancing responsibilities for a specific part of the power system.

Transmission Voltages. The earliest transmission lines in the US (about 1896) were a maximum of 11 kV. Today transmission lines can have voltages up to 765 kV_{AC}. The importance of higher transmission voltages is straightforward—they allow longer transmission distances. This has increased in importance with the need to move large amounts of renewable generation to urban markets.

The voltage classes for transmission lines include both AC (voltages generally range between 230 to 765 kV) and DC (250 to 500 kV). The illustration below shows how the transmission grids are viewed as to voltages—in this case for Washington State. The maximum transmission line voltages for Washington are typically 500 kV but mostly less.



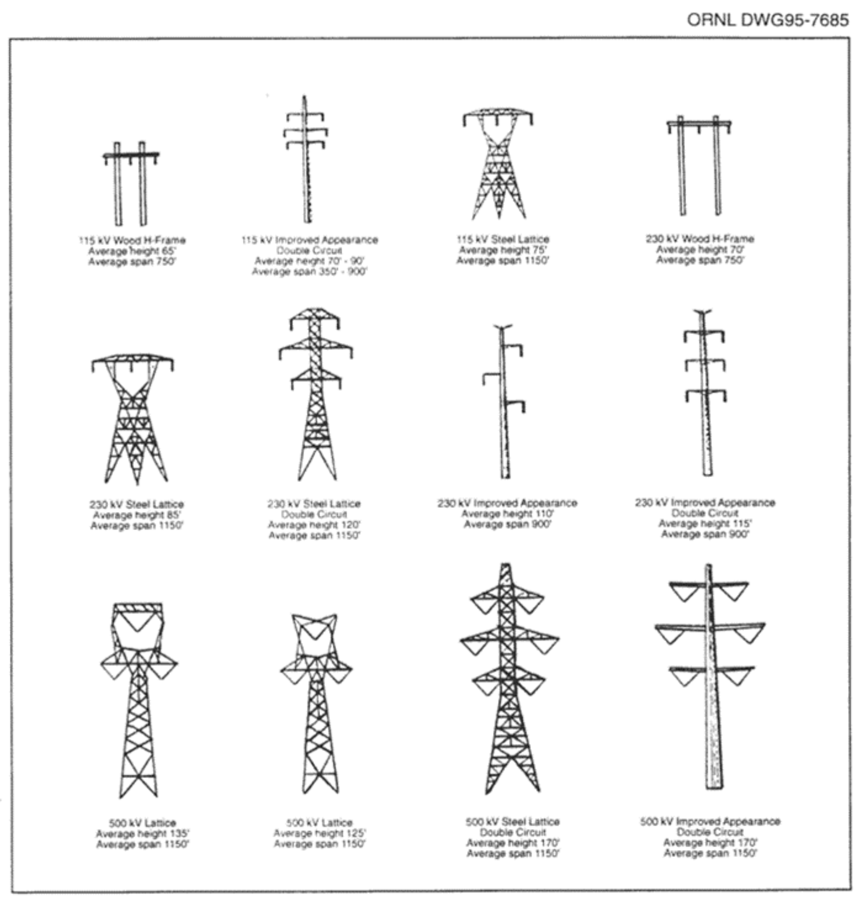
Source:https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=d4090758322c4d32a4cd002ffaa0aa12]

Since transmission lines can be energized as either AC or DC, which is best? Major additions or changes to transmission lines can require extensive permitting, it may be best to use the existing type of delivery system—typically AC. However, DC lines have several positive features including narrower right-of-ways for its towers, two primary wires between towers instead of three for AC since it does not have phases, a 0 Hz frequency, and may be less expensive.

Transmission Grid Reliability. There are two types of electricity deviations which affect how a transmission grid operates … voltage and frequency … as noted earlier. Voltage deviations are typically associated with uncontrolled brownouts (excessively low voltage on the grid), and voltage surges (more likely to occur when electrical services are being restored). Second, for the US, the AC transmission line frequency operates at 60 Hz. Most other countries operate at 50 Hz. Regardless of the frequency used, transmission frequency is tightly controlled. If that is not the case, then generators or transmission lines can trip offline. What can cause this to happen?

(1) sudden supply or demand imbalances, and (2) short circuits (largely due to transmission line or equipment failures) or line faults (line faults are commonly caused by lightning).

Transmission Structures. Transmission lines can be supported by wood frames, steel lattices, single steel poles, or placed underground. Above ground heights as shown in the figure below range from 65 ft. up to 170 ft. As the height increases so does the span (distance between supports). Since most transmission lines are aluminum, temperatures must be considered to limit line sag.



A range of above ground transmission structures

Source: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437/v1/fig005.gif

Distribution Grid

Handoff from the transmission grid to distribution lines occurs at a substation (refer to the figure on p.1 and the portion "Distribution" and "Power Consumers"). The substations take high voltages and step them down for the local distribution system. A small transformer near homes or apartments reduces the voltage further to 120 V/240 V.

Distribution lines typically have two broad descriptors: (1) distribution and secondary voltages; and (2) above or below ground placement. The focus for this section is above-ground installations, the most common and least expensive to construct.

Distribution Voltages. Distribution lines run from substations to homes and businesses and generally fall into four voltage classes:

- 4 to 5 kV
- 12 to 15 kV
- 20 to 25 kV
- 30 to 35 kV

For residential connections, which are called secondary circuits, the typical voltage from the distribution line is stepped down to 120/240 V. As for the larger electrical grid, the voltage for secondary circuits must be maintained within a range that does not damage customer equipment.

Distribution Structures (poles). Typically, wood power poles are used in the US for distribution. These can last up to 30 years (a range is typically 25 to 50 years). Some locations go with prestressed concrete poles which generally last > 50 years and better resist moisture, insects, and high winds. Some countries do not have easy access to wood poles and thus use concrete poles). Other material possibilities include steel and composites. The following figure shows a typical treated wood pole with transformer allowing connection with electrical loads.

Following major wind storms, such as hurricanes, the major outages are largely due to damage to the distribution system with the principal issues falling trees and branches impacting the lines.

Useful Websites

- DOE, "Transmission Division," https://www.energy.gov/gdo/transmission-division
- Wikipedia, "North American Electric Reliability Corporation," https://en.wikipedia.org/wiki/North_American_Electric_Reliability_Corporation
- UW MSCE Energy Infrastructure, https://www.energy-infrastructure.uw.edu/