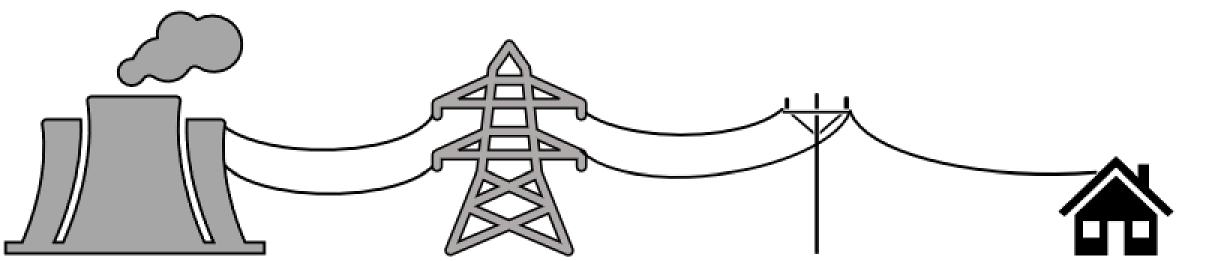
MISO 101 Primer: Part 2
Electric Grid Basics

Composition of the US power grid

From illuminating our homes to serving businesses and industry, the electric grid (figure 1) has long supported American progress by powering our nation. Sometimes called the most complex machine in the world, four general components make the grid today.

Figure 1: Components of the electric grid



Generation resources (power plants) are the sources of electricity for the grid. Electricity can be generated from many sources, including fossil fuels (coal, natural gas, and petroleum), nuclear power plants, and renewable sources (solar panels, wind turbines, and hydroelectric dams).

Transmission lines transport high-voltage electricity over long distances between generation facilities and energy consumption centers like cities and manufacturing zones. The transmission system is an interstate network of lines. Because the transmission network facilitates interstate commerce, it is subject to federal oversight.

Distribution lines carry electricity over short distances at lower voltage levels from substations to end consumers. The key difference between transmission and distribution lines is the voltage level and resulting capacity to carry electricity. This difference is why the transmission grid—rather than the distribution grid—transports electricity across state boundaries.

Load is instantaneous power demand on the grid and is generally measured in kilowatts or megawatts (energy consumption over time is generally measured in kilowatt-hours or megawatt-hours).

The fundamental physical properties of the grid require generation and load to be perfectly balanced every minute of every day to prevent outages. Costs and capabilities for wind, solar, batteries, and other energy technologies are changing rapidly. With those changes, the way grid system operators plan and operate the grid will also need to change to maintain reliability and affordability.

Concurrent changes in the grid

The grid is undergoing a rapid transformation spurred by technological advancements and cost declines, the decommissioning of aging power plants, and shifts in public policy. The pace of these changes has accelerated dramatically in the last ten years. It is likely to accelerate further with the passage of the Infrastructure Investment and Jobs Act in 2021 and the Inflation Reduction Act in 2022.

Power plant retirements

Since 2002, approximately 100 gigawatts of coal-fired generation capacity has retired in the US. An additional 59 gigawatts (over a quarter of the remaining coal-fired generation capacity) are expected to retire by 2035.[1] These retirements are driven by both the age and condition of older power plants as well as market economics. Low natural gas prices resulting from the US shale gas boom that started in the mid-2000s have put economic pressure on coal-fired power plants across the US.

Growth of renewable energy and distributed energy resources

LARGE-SCALE RENEWABLE ENERGY

Since the early 2000s, capital costs of wind and solar generation have rapidly declined, leading to increasing rates of adoption. Unlike some conventional generation technologies, in which fuels such as coal can be transported to a power plant, renewables are location constrained. They can only be built where there is a sufficient natural resource supply, meaning that the grid must be built out to connect them.

DISTRIBUTED ENERGY RESOURCES

Distributed energy resources (DERs) are an emerging technology class that connect at the grid's distribution component or on the customer side. Customer-side DERs are often referred to as "behind-the-meter" technology. DERs include residential and community-scale solar and wind generation, demand response (voluntary customer load reductions), consumer-scale batteries, electric vehicles, and more.[2] These resources have the potential to dramatically change the way power flows across the grid, possibly changing a system built for one-way flow of electricity to a two-way flow system.

Electrification

Historically, load was largely uncontrolled but was also predictable. Today, electrification of buildings, vehicles, and industrial processes is adding load to the grid and changing daily and seasonal electricity demand patterns. This new load growth could present reliability and cost risks if it requires vast amounts of new grid infrastructure to reliably meet that load. However, if this new load is controllable and coordinated, it could help reduce costs for all customers by more fully utilizing the existing grid.

Adapting to changing conditions

To adapt to the changes discussed above, grid planners and operators are developing new systems, processes, and metrics to ensure that the grid stays reliable. Grid reliability needs generally fall into three broad categories: resource adequacy, energy adequacy, and grid stability.

Resource adequacy

Each year, grid planners evaluate whether the amount of installed generation capacity is sufficient to reliably serve projected peak electricity loads. **This process answers the question, "Do we have enough electric generation capacity, and if not, how much do we need to build?"**

The answer to this question was once straightforward: Planners measured the annual peak load (which usually occurs on a hot summer day) and added in a "reserve margin requirement" to account for the probability of power plants tripping offline. But aging power plants, increasing impacts from extreme weather events, and the growth of variable renewable resources are changing how this process works, leading to the need to also evaluate energy adequacy.

Energy Adequacy

Energy adequacy is the grid's ability to provide sufficient energy to meet demands during every hour of the year. If every megawatt of installed generation capacity could run at full output every hour of the year, energy adequacy would not be a concern. But power plants need to take maintenance outages, sometimes for months or longer, and renewables are variable in nature.

The ability to provide sufficient energy in every hour of the year requires coordination and collaboration among utilities, grid operators, and grid planners to ensure that generation resources are adequately orchestrated to maintain sufficient availability.

Grid Stability

Frequency and voltage level are the two primary physical characteristics grid operators focus on to maintain grid stability and, therefore, reliability. The US grid operates at a frequency of 60 hertz. Voltage levels vary throughout the grid based on power-carrying capacity needs. If either frequency or voltage varies outside of acceptable levels, parts of the grid may automatically shut down or disconnect to prevent damage and widespread outages.

Conventional power plants with large spinning turbine generators provide both frequency and voltage support, or stabilization, as a byproduct of the physics of electricity generation. As aging power plants retire and are replaced by inverter-based resources like solar and batteries, voltage and frequency support will no longer exist as a simple byproduct of electricity generation.

Several technologies are available to address grid reliability needs, including, in some cases, the inverter-based resources themselves. As these changes become more widespread with the resource mix transformation underway, grid operators will need new approaches to ensure grid reliability. Certain reliability attributes that used to come inherently with the generation fleet will also have to be explicitly procured.

For questions, comments, and feedback, please contact Matt Prorok, senior policy manager, Great Plains Institute, at mprorok@gpisd.net.

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[1] David Fritsch, *Today in Energy: Of the operating U.S coal-fired power plants, 28% plan to retire by 2035, (*US Energy Information Agency, December 15, 2021, https://www.eia.gov/todayinenergy/detail.php?id=50658.

[2] *How Microgrids Work,* (US Department of Energy, accessed September 21, 2022), https://www.energy.gov/articles/how-microgrids-work.