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POWER VS. ENERGY
Power is the instantaneous flow of electricity, or current – that is, the rate of electricity production, transfer or demand. Under the International System of Units, it is measured in watts. Energy is the amount of power consumed over time, which is measured in watt-hours.

ENERGY = POWER X TIME
For example, if a generator produces 100 megawatts (MW) of power for two hours it creates 200 megawatt-hours (MWh) of energy. The average household consumes about 900 kilowatt-hours (kWh) per month.

PHYSICAL CHARACTERISTICS OF ENERGY

INTRODUCTION

Electricity is the flow of electrical charge. It occurs naturally, but must be created and distributed in particular ways to make it useful to people. The physical fundamentals of electricity define how we build and use electric infrastructure to ensure reliable service to customers.

The vast majority of electricity in the United States is generated by large power plants and transferred to customers through the "grid." The grid, or transmission system, is a network of power lines and equipment used to transport electricity in bulk from power plants to communities. At the local level, distribution lines and equipment transfer power from the transmission system to end-use customers. Increasingly, customers also generate electricity on-site to meet some or all of their needs, most commonly through rooftop solar panels.

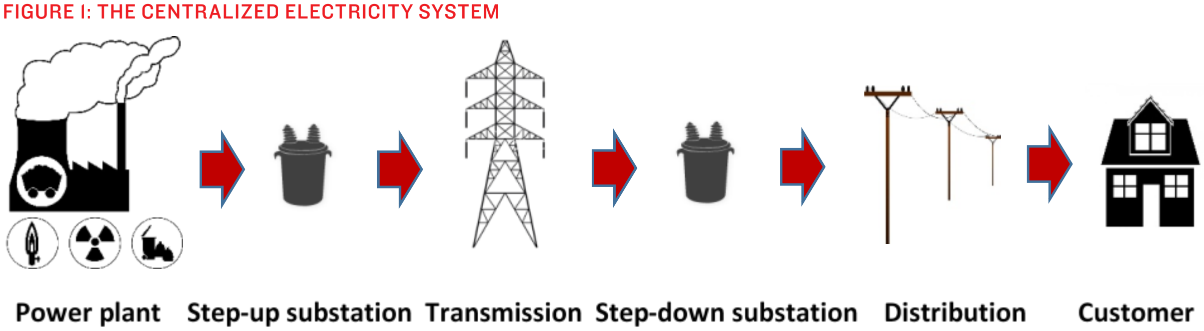
Electricity is a secondary energy source derived from a primary source. Primary sources include chemical energy stored in fossil fuels and biomass; kinetic energy from wind or solar; nuclear energy stored in the nuclei of atoms; or gravitational energy stored at an uphill dam. This energy converts to mechanical energy that spins or rotates magnets around wire coils, which thus induce electrical currents and voltages.

Voltage is a measure of the electromotive force of electricity. This can be thought of as the "pressure" of electricity, similar to the pressure in a waterline. A substation "steps up" the voltage of electricity generated in power plants to transport it via high-voltage transmission lines. Higher-voltage lines transfer power more efficiently over long distances. The bulk or "wholesale" transmission system operates lines that range in capacity from a few thousand volts to as much as 750,000 volts. This system delivers power to retail distribution systems, where other substations "step down" the voltage for local distribution to customers on low-voltage wires.

SYSTEM OPERATION

To maintain reliability, the U.S. electric system seeks to keep the system frequency near 60 hertz, but imbalances in supply and demand cause deviations from that target. Severe

FIGURE 1: THE CENTRALIZED ELECTRICITY SYSTEM



deviations can cause problems in the quality and reliability of electric service, such as brownouts and blackouts. This challenge is exacerbated by the practical limits to storing electricity in a cost-effective way. Thus, the system must balance generation and demand simultaneously, which requires generation output to be adjusted constantly to match fluctuations in demand.

There are a variety of operational limitations that generation facilities face which constrain their ability to match changes in demand. Generators vary in how quickly they can adjust their output. For example, natural-gas-fired generators generally can alter their output more quickly than coal-fired generators. Generators also have a limited "dispatch range," which refers to the difference between their maximum and minimum output. Most fossil and nuclear units require hours or even days to start. Generators also may be limited in how frequently they can start and stop within one or several days. Units with better operational abilities provide more supply flexibility to match fluctuations in demand. For example, natural-gas combustion turbines can start in a matter of minutes and be turned on and off multiple times a day.

Electricity demand, or "load," fluctuates within each hour, varying considerably based on the time of day and weather patterns. Demand also varies greatly by location. The geographic dispersion of generation facilities and demand, along with transmission-system limitations, results in transmission congestion. Transmission congestion limits the ability to dispatch generation to meet demand in constrained areas. This often occurs in high-demand areas, such as cities, where transmission constraints limit the ability to import power from far away.

Balancing the electricity system involves coordinating generators' dispatch to meet demand. This requires anticipating demand, a process known as "load forecasting." To prepare for changes in demand, a grid operator must pre-position generators (i.e., turn them on and schedule their operation) hours or even days in advance, based on their operating characteristics and location. Real-time adjustments become necessary to correct for unanticipated developments, such as load-forecast errors or system contingencies. Reserve generation resources can address major contingencies, like a sudden mechanical failure at a generation facility or loss of a transmission line. The rise of wind and solar resources, whose output varies with weather conditions, introduces a challenging supply-side variable to balancing the grid.

SYSTEM PLANNING

Maintaining a reliable system requires long-term planning to ensure future demand can be met adequately. Large generation and transmission facilities take three or more years to build. Planning requires determining the appropriate size of generation, transmission and distribution facilities to meet the maximum amount of power consumers will demand at any given point in time. Specifically, this requires sufficient generation capacity, or maximum output, to meet peak load, plus a reserve in the event of a system contingency.

Planners use long-term load forecasting to provide an estimate of peak demand. Demand-side management programs, such as promoting weatherization and high-efficiency lighting, can reduce the need to invest in generation and transmission. Transmission and distribution system planning must also provide for sufficient transfer capability to accommodate electricity flows at peak periods in all locations.

Electric-system planning must address both the expected and unexpected. Changes in technology, policy and demand are difficult to predict. Planners must account for risks and uncertainties, such as economic shifts that affect load growth, changes in regulatory requirements and the rise of disruptive technologies that affect load or customer self-generation. For example, policies that promote wind and solar generation may create the need for additional flexible-generation services, such as quick-start and fast-ramp capability. Future unknowns, combined with the long-term nature of electricity infrastructure, amplify the importance of risk and uncertainty management in electricity planning.

POWER PLANTS ARE LIKE SPRINTERS

Power plants' abilities can be analogized to those of elite athletes:

- How fast a sprinter runs is akin to a plant's "dispatch," or level of output.
- How quickly a sprinter accelerates is akin to "ramp," or the rate of change in output.
- A sprinter's top speed is akin to a plant's capacity, or maximum output.
- An athlete's responsiveness is similar to the time a plant needs to begin producing power.
- The short- and long-term performance of both athletes and power plants depends on conditioning (e.g., equipment maintenance).
- The performance of both athletes and power plants can be sensitive to weather conditions (e.g., high heat lowers the output of many plants).

CONTACT
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