Chapter 8: Electricity

Overview

Electricity can be defined generally as a form of energy involving the flow of electrons (negatively charged particles) from one atom to another. This flow of electrons, or electric current, occurs when the balancing force electrons is upset, allowing atoms to gain or lose electrons. The balancing force may be upset by the application of an external force, such as that derived from a chemical reaction or from a magnetic field moving across a conductor, to name two examples.[1]

Alternating current (AC), which is the type of current used in the North American electricity industry, reverses its direction at regularly recurring intervals.[2] AC results from the movement of a conductor, a material that conducts electricity easily (such as copper or aluminum), within an electromagnetic field. Direct current (DC) results from a chemical reaction, such as that occurring in a battery (also in a solar photovoltaic panel or in a fuel cell). Electronic circuits can also convert AC to DC and back.

Electricity travels in closed loops, and an electrical circuit can be defined a closed, conducting pathway through which an electric current travels. If the circuit is open, as when a light switch is turned off, the electrons cannot flow; flipping the switch "on" closes the circuit and electrons flow through the wires and the wire filament (within a conventional bulb), producing light.

The basic components of the electric industry are generation, transmission, and distribution. Generation refers to the source—for example, power plants, hydroelectric dams, wind turbines—where other forms of energy are converted to electricity. Transmission is the high-voltage system of wires that transports electricity over long distances. Distribution is the low-voltage system of wires that delivers electricity to customers. The network of power plants and interconnected electrical lines is often called the electric grid.

Electric generation—Generators are devices that convert mechanical energy into electrical energy. Most U.S. electricity is produced in steam turbines (which convert the kinetic energy of moving fluids, liquid or gas, to mechanical energy). Generating electricity in steam turbines involves the following steps: (1) water is heated (either in a boiler or in a nuclear reactor) to produce steam, which is contained to produce high pressure; (2) the pressure from the released steam spins a turbine (an array of blades as on a fan), which is connected to a shaft that rotates as a turbine spins; (3) the spinning shaft turns a magnetic rotor inside the generator; and (4) as the rotor magnetic field spins past stationary coils of wire mounted inside the generator, AC electricity is produced on the wires. Whether produced by fossil fuels or the fission of uranium, the resulting steam turns the turbine blades that turn the shaft of the generator to produce electricity.

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[1] Unless otherwise noted, this information is derived from (1) a PowerPoint presentation entitled "Introduction to the technology, institutions, and history of the electric industry, by Douglas Gegax, Professor of Economics and Director, Center for Public Utilities, New Mexico State University, May 19, 2007; and (2) Electricity—A Secondary Energy Source, Energy Information Administration (EIA), Energy Kid's Page: http://www.eia.doe.gov/kids/energyfacts/sources/electricity.html. Professor Ward Jewell, Wichita State University reviewed this draft and provided helpful comments.

[2] Energy Information Administration (EIA), 2008, Glossary: http://www.eia.doe.gov/glossary/glossary_a.htm

Other ways to "spin the turbine" include water falling down a dam, water running downstream, wind turning a wind turbine, or fossil fuels firing a combustion turbine (similar to a jet engine). Combustion turbines are designed to start quickly and are normally fueled with natural gas (or sometimes low-sulfur fuel oil). As in a jet engine, combustion turbines draw in air at the front of the unit, compress it, mix it with fuel, and ignite it; the hot combustion gases then expand through turbine blades connected to a generator. In a different process, the combined-cycle process, natural gas is ignited to spin a combustion turbine generator, and the hot-gas exhaust heat is transferred to a waste-heart recovery steam boiler that produces electricity by running a second steam-turbine generator.

While a small amount of electric energy is stored in pumped-hydroelectric plants, almost all is used the instant it is generated. Generating units must be equipped to generate and "dispatch" electricity at any give time to meet the system's load (instantaneous demand).[3] As the table below suggests, the various (conventional) generation technologies differ in terms of their capital and operating costs as well as in their start-up times (that is, the time it takes for them to begin generating electricity after being switched on).

Generation Technology	**Capital Costs**	**Operating Costs**	**Start-up Times**
Hydroelectric	High	Very Low	Quick
Nuclear	Very High	Very Low	Slow
Coal	High	Low	Slow
Combined-cycle Gas Turbines	Medium	Medium	Medium
Simple Gas Turbines ("Peakers")	Low	High	Quick

Power plants that are used to meet the minimum or "base load" of the system are referred to as base-load generating units; they are run continuously and operated, in general, so as to produce electricity at a constant rate, and typically include nuclear facilities, coal-fueled power plants, and sometimes hydroelectric plants (though many of these are operated as peaking units because they have a limited amount of water to use and, thus, cannot run continuously).[4] Base-load units are generally the cheapest to operate and the most expensive to build. Peak-load units, also called "peaking plants," are used to meet the system's peak load, and are typically gas-fired turbines that can be turned on quickly. Peaking plants are typically the expensive to operate and relatively inexpensive to build. Intermediate units are used to meet the system requirements between base and peaking load.

Transmission—Once electricity is generated, it needs to be delivered from that plant to population centers or other utilities, which are often located many miles away. To counter problems (line losses) associated with sending electricity over long distances, electricity produced by a generator is sent to a nearby substation, where transformers "step up" the voltage before transferring it to high-voltage transmission lines, which can carry electricity efficiently over long distances.

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[3] As economics change and new technologies advance, electricity storage may prove feasible; see, for example, Dan Rastler, 2008, New Demand for Energy Storage, Energy Power Research Institute (EPRI), September/October 2008 Energy Perspectives: http://www.eei.org/magazine/editorial_content/nonav_stories/2008-09-01-EnergyStorage.pdf.
[4] Of course, any unit can be operated to meet the base load, as long as it provides firm, dispatchable energy.

Distribution—Before the high-voltage electricity can be delivered to end users, it is transferred to a second substation, called a distribution substation, where the voltage is stepped down.[5] From here the electricity is sent to local medium-voltage distribution lines, commonly buried underground in newer housing and commercial developments, before it passes through one final transformer, which steps down the voltage once more before it reaches the end user.

Utilities must constantly monitor both the status of transmission lines, to insure current capacities are not being exceeded, and the local distribution systems, to ensure that a constant voltage is maintained. Moreover, they must balance the amount of power coming into the service area with the amount of being taken out by use and line losses. Therefore, within a utility's service area, a utility must monitor electrical supply to each distribution system, making sure that it matches electrical demand at every instant (two second intervals) in time. This process is called load balancing, as the utility "balances" electrical loads with available capacity.

[5] Transmission lines throughout the United States have varying maximum voltages they can sustain. Because of this, an electrical current may actually pass through several transmission substations before reaching a distribution substation. These transmission substations work in the same fashion as other substations, adjusting voltages as needed to comply with the characteristics of different transmission lines.