Electric Power Generation

A Nontechnical Guide

Table of Contents

Figures List

Tables List

Chapter 1
From Frogs Legs to Microwaves

"Everything I told you is a lie."

— Alan A. Jones, Ph.D.
Chair, Chemistry Department, Clark University

The history of science does not change even as engineers and scientists add historic breakthroughs at an ever-increasing pace. Maybe that increasing pace is the reason why high school and even college science courses mainly teach the history of science, rather than actual science. To a new generation born in the third millennium, the incredible technological advances of the Twentieth Century may blur together with the series of scientific discoveries that occurred earlier with the exploration and colonization of planet Earth by European countries. Change is not politically correct.

Atoms are not little plastic beads that snap together into molecules like a child's toy. Atoms are often described as mainly empty space, the hydrogen atom nucleus compared to a baseball at home plate, with a lone tiny electron a third of a mile away. With this image in mind, it is easy to believe the comic book hero Flash could vibrate his molecules past those be recharged, they cannot be!

Recharging these batteries also releases hydrogen gas that may cause them to rupture. The gas is flammable. The current generation of low-cost zinc chloride batteries have a longer shelf life than the ones you used to get free with your Radio Shack battery card, but like other primary batteries—including lithium, silver oxide and zinc-air—they really are not rechargeable. Trying to recharge any of these types may cause burns or rupturing of the cases and they will not provide reliable power. If you use a lot of batteries, rechargeable batteries and a charger pay for themselves after about five charging cycles.

Rayovac ran afoul of the letter of environmental law when it introduced "renewable" alkaline batteries. Federal regulations required that all rechargeable batteries be recycled. Even though the Rayovac batteries did not contain mercury or cadmium, etc., were safe in the domestic waste stream, and were designed to do their part to reduce that waste stream, they did not meet federal requirements.

It is not where you draw the line, but how you draw the line. Apparently the difficulties have been ironed out and the product is not only successful but recommended for use by government agencies and available to them through the General Services Administration!

Beyond batteries

While theoretical physics is well beyond the scope of this primer, within their limitations analogies serve us well for how electricity behaves. The analogy to water works on several levels. Atoms and subatomic entities, such as electrons, sometimes behave like the marbles we have been taught to imagine. Just as often (going back to the water analogy) they behave like waves.

All analogies have significant limitations. Water must ultimately travel in a complete cycle—from sky or stream to a reservoir, or from a well through pipes to point of use and then through septic or sewer systems into the ground or ocean—to eventually replenish the source in order to perform useful work. Electric currents must *immediately* pass through a complete circuit from one terminal of the battery or generator, through a conductor to the load, and then back through an associated conductor to

Scientists make it known, engineers make it work

As this century marched toward World War I, formally trained engineers began to reinforce the progress started by academics, curious amateurs, inventors, and tinkerers. Western Massachusetts native Vannevar Bush, who earned his Ph.D. and served as a professor and later dean of engineering at the Massachusetts Institute of Technology, invented the differential analyzer, a predecessor of the analog computer.

In 1948, Bell Telephone Laboratories' scientists John Bardeen, Walter Brattain, and William Shockley invented the transistor. Like the electron tube, the transistor could amplify signals by varying the bias current on the base electrode, much as high pressure water flows may be controlled by turning the handle on a faucet, or act as an electronic switch. In 1956, they received the Nobel prize in physics.

John Presper Eckert and John W. Mauchly, later in association with John von Neumann, designed ENIAC, EDVAC, and UNIVAC, the first digital computers, built between 1946 and 1958. Their machines used upwards of 18,000 electron tubes and were not available in notebook models. ENIAC had a fixed program for calculating ballistic trajectories. EDVAC's programming could be readily changed as needed. UNIVAC was the first commercially available general-purpose computer. Herman Hollerith's (1860-1929) rectangular punch cards, first invented for the 1890 U.S. census, were used to program computers through the 1970s. Hollerith's tabulating machine company grew into IBM.

Subsequent generations of computers used transistors, integrated circuits, and ever faster and more powerful microprocessors. They evolved from mainframe computers to personal computers (PCs), which then became networked to servers and connected to the World Wide Web. Moore's Law stipulates computing power doubles every 18 months—a 10 billion fold increase since the vacuum (VAC) tube computers of 1950 and an increase of a trillion since the gear-driven fire-control computers of World War I. As the cost of computing power decreases, futurists project microprocessors to be everywhere and in everything from clothing to paper.

Electrons in the large numbers used in today's electric circuits remain as predictable as the outcome of an election with 1% of the vote counted.

It takes energy to convert energy

Just as "It takes money to make money," it takes energy to convert energy. The gasoline engine in your car not only moves the vehicle, but also rotates the crankshaft that operates the oil and water pumps, valves and timing belt, directly or indirectly turns the radiator fan and fuel pump, and, via the alternator, energizes the computer, fuel injectors, gauges, and ignition. Once the engine is running, the alternator also charges the battery—storing enough potential chemical energy to start the vehicle the next time and powering the defroster, lights, radar detector, rear window defogger, and the stereo.

If the primary purpose of an automobile is transportation and that of an electrical generating plant is converting one form of energy into electricity, then the energy requirements of the vehicle itself would be comparable to station service in the generating plant.

Those are the useful drains on the energy produced. Exploding air and fuel inside the cylinders creates heat. Some of that heat expands the resulting gases to move the pistons, rotate the crankshaft, and so on. But only a small fraction of that heat can be utilized. Overall efficiency of an automobile engine is about 15%. Most of the energy is unavoidably wasted as heat. Fossil-fired steam plants are much more efficient, with gas turbine, combined-cycle plants nearing 60% efficiency. Hydroelectric and most alternative energy plants use "free" fuel. Nuclear steam plants are so efficient, fuel costs are relatively minor compared with the expenses of continuously and vigilantly meeting environmental, safety, and security requirements.

If your car has a manual transmission, you might get by without the battery by parking on hills or putting your passengers to work push-starting the car, but you would not want to stall in traffic.

Similarly, for startup and running, all generating plants require energy. Even hydroelectric plants need power to operate the controls, lamps, motors, pumps, relays, etc., to bring the plant on-line.

It's ALL solar

Parents lead their children into the planetarium, shushing them and trying to decide where the best seats might be with three or four together.

the water level is high enough to do so.

Demand for electric energy grew steadily from the 1880s, and following World War II, it at least doubled every 10 years. In the early 1970s, the Organization of Petroleum Exporting Countries (OPEC) oil embargo, dire warnings from environmentalists, economics, and world politics impacted demand. Since then, it has increased steadily but not in geometric progression (Table 3-1).

Year	Steam	Internal Combustion	Gas Turbine	Nuclear	Hydro-electric	Other	Total
1950	48.2	1.8	0	0	19.2	-	69.2
1960	128.3	2.6	0	0.4	35.8	-	167.1
1970	248.0	4.1	13.3	7.0	81.7	0.1	336.4
1980	396.6	5.2	42.5	51.8	81.7	0.9	578.6
1990	447.5	4.6	46.3	99.6	90.9	1.6	690.5

Table 3-1: Net Summer Generating Capacity (millions of kW) Source: DOE

Water

Fossil-fired steam or hydropower drove the first commercial dynamos and generators. Both require large quantities of water—the first for steam and cooling, the second as the prime mover. While the water for steam generators may be pumped out of lakes, reservoirs, or tanks as part of the station service energy requirements, obviously the hydroelectric generator must be located directly below the water supply. The greater the pressure "head" in a hydroelectric plant, the more energy may be extracted from the falling water.

While fresh water must be treated to remove debris, fish, organic matter, minerals, and rocks—material that can clog pipes, increase wear on pump seals and valves, and reduce heat transfer—saltwater presents challenges that make its use in boilers uneconomical except where it is the only choice. Salt water from Cape Cod Canal is routed to two conventional fossil-fired steam units at Southern Energy's Canal Power Generating Facility plant in Sandwich, Massachusetts. This once-through cooling system removes waste heat via heat exchangers to avoid contaminating the highly purified water used in the steam loop. The salt water cools in long, nessing alternative energy requires innovative solutions. Despite the fact the world's largest geothermal generating complex is at the Geysers north of San Francisco U.S.A., alternative energy still seems like an oddity in this country. In Iceland, geothermal energy directly heats 65% of homes.

Wind

Before rural electrification, many farms in the U.S. had small windmills to pump well water into cisterns. Intermittent winds perform this task adequately, but are of little use for generating lighting or manufacturing purposes. The gusting and wind shear caused by hilly or mountainous terrain create maintenance problems and frequent failures. As with other forms of generation, large-scale plants are more efficient. Hill and mountaintops do not have the acreage for large-scale generation. Therefore, plains with frequent, moderate, steady winds suit wind farms best.

Geothermal

Geothermal energy may only be harnessed practically where the earth's crust is thin enough to allow surface or groundwater to be superheated by molten rock (or magma) beneath the earth's surface. (Once magma reaches the surface in flows or volcanoes it is called lava.)

This suggests the biggest problem with geothermal energy: few areas of the world where geothermal energy is available are seismically or volcanically stable enough to permit its exploitation. Relatively few people live on the volcanic atolls of the Pacific Ocean because of the risk of eruptions, therefore there is neither market nor capital available to build geothermal generating plants. Iceland and some areas of the Scandinavian countries have stable geothermal resources, a market for this energy, and have invested to develop geothermal technology. U.S. geothermal electricity production has been estimated at 2.2 gigawatt (GW) for the year 2000.

Tidal

The relentless ebb and flow of tides cry out to be used as an endless source of electric energy. There are approximately two high tides and two