The War of the Currents

Thomas Edison

Courtesy U.S. Dept. of Interior, National Park Service, Edison Natl. Historic Site

Nikola Tesla

Courtesy Nikola Tesla Museum

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Most of us don't give a second thought to where our electricity comes from, how it gets to the outlet, or the fact that it arrives as alternating current (AC). In fact, it's hard to believe that a battle was ever waged over whether to use AC or DC (direct current) electricity—why not just choose the best form? However, at the turn of the twentieth century, two powerful inventors battled over the future of electrical transmission. The outcome led to the interconnected power system we rely on today.

Early Electric Generation

First pioneered at the turn of the nineteenth century, the earliest sources of continuous electrical energy were batteries—DC devices. However, these batteries did not produce enough energy to economically run bright lights or powerful motors for any useful length of time.

In 1831, Englishman Michael Faraday invented the first electromagnetic generator or dynamo. But it wasn't necessarily these rotating machines (see the sidebar on opposite page) that sparked the revolution in widespread electricity generation and distribution. Rather, it was the simple need for light. In the early 1800s, homes and businesses relied on light from candles and kerosene lamps.

DC vs. AC

Direct current (DC) electricity comes from sources such as batteries, photovoltaic (PV) modules, and DC generators. DC voltage doesn't change polarity—the positive pole always has a positive voltage with respect to the negative pole. Since charges flow from a higher potential (voltage) to a lower potential, DC provides a constant, unidirectional flow.

Alternating current (AC) electricity is produced from rotating generators and can now be synthesized by inverters and variable-speed motor drives. The familiar AC voltage takes the form of a sine wave, with the voltage's magnitude constantly changing and reversing polarity. The current also changes constantly and reverses direction each cycle. (For more information about AC and DC electricity, see the two-part article in *HP52* and *HP53*, "Basics of Alternating Current Electricity," and *Word Power* in *HP85* and *HP86*.)

Later on, gas lamps, which used coal gas for illumination, gained popularity, especially in cities. However, gas lamps were dirty and smelly, and posed a fire risk.

Illuminating Inventions Lead the Way

Inventors had been working for more than 50 years trying to invent a successful incandescent lamp. In 1802, Sir Humphry Davy caused a platinum filament to glow when he connected it to the most powerful battery built in that time. Englishman Joseph Swan had some success by 1860, but eventually gave up on the project since his lamps burned out within a few minutes.

American inventor Thomas Edison also faced similar problems. He experimented with more than 1,600 different filament materials, including platinum, but his lack of success with the platinum filament did not stop him from telling reporters in 1878 that there was "no doubt" that he had already discovered a successful light. He showed reporters his platinum filament light, being careful to usher them out of the room before it burned out. "When I'm through, only the rich will be able to afford candles," said Edison.

A year later, in December of 1879, Edison was able to get a carbonized-thread-filament bulb to burn for 13.5 hours. In 1880, after a worldwide search for a more durable filament, Edison started manufacturing carbonized bamboo filament lamps that lasted 1,000 hours.

Edison realized, though, that to sell his lamps to the public he needed an entire system of electricity generation and distribution. So he bought an old building on Pearl Street in New York City and turned it into a power plant, filling it with coal-fired steam turbines and dynamos. On September 4, 1882, 800 lamps at the Drexel-Morgan Building, the *New York Times* headquarters, and other establishments were illuminated by Edison's power plant. After this remarkable success, the Edison General Electric Company was formed to build and sell electric power stations to cities and towns across the United States.

By 1887, Edison's DC system of generating electricity had become the industry standard, with more than 120 Edison power stations delivering DC electricity to its customers. But this method of producing and distributing electricity was not without its challenges. The low-voltage energy (240 V) could only be sent a short distance—usually one mile or less—before the electricity began to suffer extreme losses in voltage. Because of this, power plants had to be built close to users, which was a costly endeavor. And, to carry the high currents required

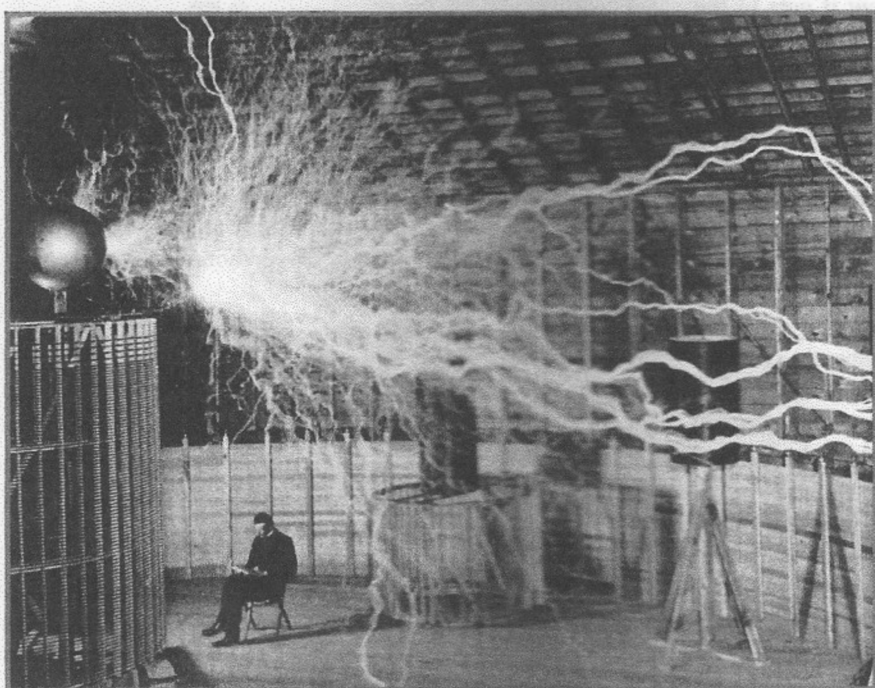
How DC & AC Generators Work

Both DC and AC generators use Faraday's principle of induction, which says that when a conductor moves through a magnetic field, a voltage is induced. A rotating loop of wire (armature) cuts and stretches the magnetic lines of force, as the conductors pass the field face, generating voltage.

At other times during the rotation, when the loop is traveling parallel to the magnetic lines of force, no voltage is generated. The polarity of the voltage induced in the left and right segments depends on whether they are traveling down through the field, and then traveling up a half-turn later. With each rotation, the voltage reverses, generating one cycle of AC.

When scientists first sought to generate electricity from machines, they wanted the same steady flow that batteries provided. American blacksmith Thomas Davenport invented the commutator, a mechanical device to make an alternator's current unidirectional. The commutator acts like a high-speed switch, switching the load just as the generator's voltage drops to zero, ensuring that the load's current and voltage do not reverse. Practical DC generators use many armature windings and commutator segments to minimize ripple in the output voltage.

A huge Tesla coil, part of Nikola Tesla's transatlantic experimentation in wireless communication and electricity transmission.



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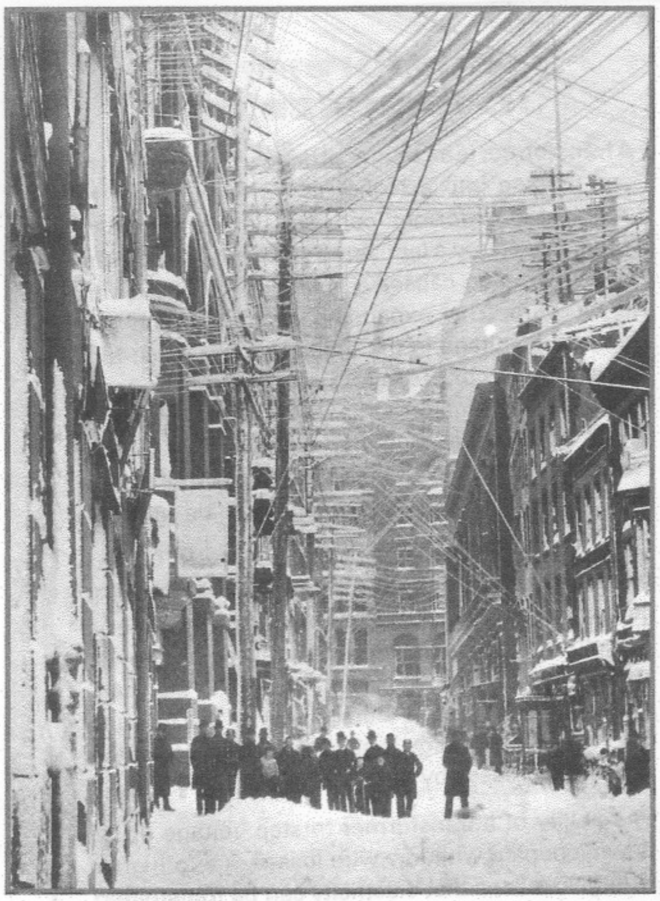


Edison buried his electrical lines due to the tangle of wires overhead.

to meet the demand of distributed load, expensive, large-diameter copper wire had to be used for cables and lines carrying the electricity.

Foreign Competition

Meanwhile in Europe, Serbian inventor Nikola Tesla was developing a different system. As a young man, he examined the early DC machines and decided that there was a way to eliminate the sparking commutator and just use AC directly. Tesla understood that a rotating magnetic field could be produced in a motor by two or more alternating currents of the same frequency, but which were out of step with each other. By this method, commutation was unnecessary. His idea was not only brilliant, but stunningly simple.

In 1884, Tesla arrived in the United States and went to work for Edison, although it was not the harmonious meeting of the minds that Tesla had envisioned. With little scientific training, Edison relied on his laborious trial-and-error approach to inventing. Tesla, by contrast, had great academic and engineering skills.

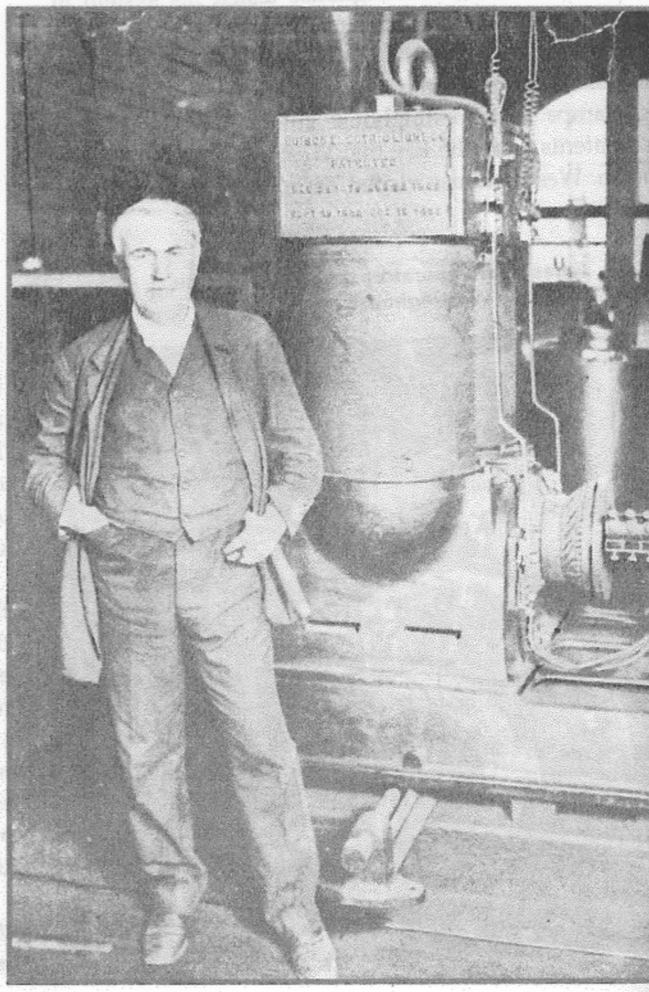
Given their very different personalities, conflicts arose. Edison brusquely told Tesla that he was not interested in AC—he asserted that there was no future in it and said that anyone who dabbled in it was wasting his time. Edison also believed that AC was deadly—he was convinced that people would be killed by the high voltages that can be produced with transformers and AC. Many historians speculate that part of Edison's opposition to AC may have come from the grudging realization that the Serbian genius who was working for him had designed a system that made his own DC system obsolete.

Tesla Takes Another Tack

In 1887, after parting ways with Edison over a bonus dispute, Tesla founded the Tesla Electric Company and began working on his AC alternators day and night. During this period, he not only constructed the machines, but he also formulated the basic mathematical theory and basis for our modern electrical system. His original version, developed in Belgrade, Yugoslavia, was two-phase electricity—two identical voltage waveforms separated by 90 degrees. While this system produced the rotating magnetic field he desired, it required four wires.

He progressed from this system to the three-phase system—three voltage waveforms, 120 electrical degrees out of phase with each other. This system requires only three wires, and was electrically balanced, since the voltages add up to zero. In 1883, Tesla had built his first working AC motor, producing motor rotation for the first time without a commutator.

Edison's inventors improved the early dynamo designs.



By 1891, he had acquired more than 40 patents for his "polyphase" system. Unlike Edison's DC system, in Tesla's system, voltage could be generated at two- or three-phase, stepped up for transmission, and then stepped down again to run lights and his polyphase motors.

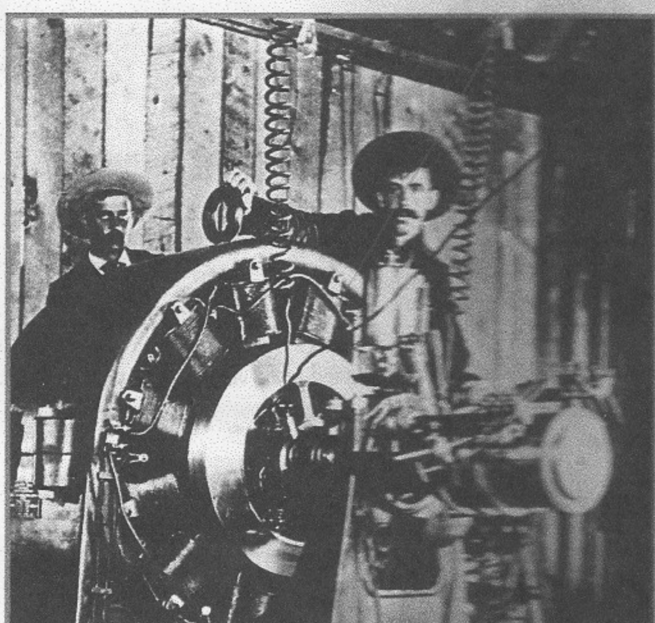
Westinghouse Transforms the Industry

Intrigued by the emerging electrical energy business, business magnate George Westinghouse had identified significant flaws with Edison's DC system. Due to the need for the rotating commutator, Edison's systems could not generate at high voltages, and due to voltage drop, his plants could only deliver energy over a radius of about one mile.

Westinghouse understood that a transformer would allow stepping up the generator voltage to high voltage and low current, permitting longer range transmission with low losses. With this in mind, he bought patent rights to the transformer invented by Frenchman Lucien Gaulard and Englishman John Gibbs, and hired American engineer William Stanley to improve the primitive design into one that was economical to manufacture. By using transformers, power plants would no longer have to be located in city centers. Instead, they could generate electricity where hydro or coal power was abundant, deliver the energy with low loss by high-voltage transmission lines, and step the voltage down to low voltages at the point of consumption.

In March of 1886, Westinghouse tested his system in Great Barrington, Massachusetts. A generator produced 500 volts AC, which was stepped up to 3,000 volts for transmission, and then stepped down to 100 volts to power electric lamps. But Westinghouse still had no AC motor. Tesla's patents were the key that Westinghouse needed for his vision. Westinghouse visited Tesla's lab and purchased his patents.

Ames Hydro operators gather around the **big Westinghouse** generator.



Courtesy Deep Springs College Archives, Dyer, NV

Transformers & Transmission

A transformer is an electrical device that transforms one voltage into a higher or lower voltage. The simplest transformer consists of two windings wrapped around a laminated steel core. AC current in one winding causes a changing magnetic flux in the core. This expanding and collapsing flux induces a voltage in the other winding. Each turn of the primary or secondary winding has the same voltage. The transformer is reversible—if there are more turns on the secondary winding, the voltage will be stepped up; if there are fewer turns on the secondary winding, the voltage will be stepped down.

A transformer does not produce electricity—it just changes the current and voltage levels. For a transformer, power in approximately equals power out (minus efficiency losses). Power ("P"), current ("I"), and voltage ("V") are given by the formula $P = I \times V$. If the voltage is stepped up ten times, the current decreases by the same factor of 10.

The ability of a transformer to step voltage up or down, coupled with low wire losses due to higher voltages, means that electricity can be transmitted and distributed over long distances. On average, the electricity you use at your household socket may have traveled as far as 300 miles (483 km) and passed through four to five transformers.

The Executioner's Current

By 1889, Westinghouse had built 870 central lighting stations, cutting into Edison's sales and profits. Edison was furious at the Westinghouse-Tesla encroachment into the business he had pioneered. His fortune was threatened and his personal pride was wounded. In retaliation, Edison Electric Light Co. published a book predicting the dire consequences if AC were used to generate electricity. And then, much to his delight, Edison was handed an opportunity to discredit AC.

The governor of New York appointed a commission to find an alternative to the gallows. When first approached by the commission, Edison was opposed to the idea of using electricity for capital punishment. But in a fit of inspired revenge, he changed his mind, telling the commission that 1,000 volts of AC from a Westinghouse machine would work well. To demonstrate AC's killing capacity, Edison's associate Harold Brown traveled from town to town, publicly killing old dogs, cows, or horses with AC. He even killed Topsy, a three-ton elephant.

Tesla also campaigned, but instead of leaving a trail of charred animals in his wake, he relied on dazzling demonstrations to counter fears of alternating current. One of his more outlandish demonstrations of AC's safety was to pass high-frequency current through his body to light a fluorescent lamp.

Despite Edison's efforts, the AC campaign continued. In 1891, Westinghouse built his first AC hydroelectric power plant for long-distance transmission of electricity in Ames, Colorado, sending electricity 2.6 miles (4.2 km) to power the Gold King mining camp. This was the longest distance that electricity had been transmitted in the United States.

The next year, Westinghouse won the bid to light the 1893 Chicago World's Fair—the first all-electric fair. Westinghouse had underbid General Electric by half, with much of the savings realized from using less copper. At night, 27 million attendees witnessed the illumination of 100,000 incandescent lamps—the most spectacular lighting display the world had ever seen.

The End of the Current War

In 1890, the International Niagara Commission had sponsored a contest to harness the energy of Niagara Falls. World-famous scientist Lord Kelvin chaired the Niagara Commission, which investigated proposals from around the world. Initially opposed to AC, he changed his mind after visiting the Chicago Fair, and awarded Westinghouse the contract in October of 1893. Kelvin recognized the advantages of the lower costs of an AC system and AC's ability to transmit energy over long distances.

When the power plant was successfully inaugurated in 1895, it was the largest electrical engineering project to date. To add insult to injury, Edison General Electric had to license the Tesla patents from Westinghouse to install the transmission and distribution lines from Niagara Falls to Buffalo, New York. After finally abandoning Edison's DC system, General Electric eventually removed Edison's name from the company's title.

And so the war was won. With the ease of long-distance AC energy transmission, four major highly interconnected grids evolved, with interstate transmission lines connecting many different utility systems. Today, we enjoy—and sometimes suffer—from this long-distance generation. Although most of the time our electricity is delivered to us quietly and without fanfare, brownouts and blackouts serve as reminders that a system of widespread distribution is still not without its own limitations.

Access

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Edison: A Biography, by Matthew Josephson, 1992, Paperback, 528 pages, ISBN 0471548065, US$24.95 from Wiley, 10475 Crosspoint Blvd., Indianapolis, IN 46256 • 877-762-2974 • Fax: 800-597-3299 • www.wiley.com

Tesla: Master of Lightning, by Margaret Cheney, 1999, Hardcover, 184 pages, ISBN 0760710058, US$20 from Barnes & Noble Books • 800-843-2665 or 201-272-3651 • www.barnesandnoble.com