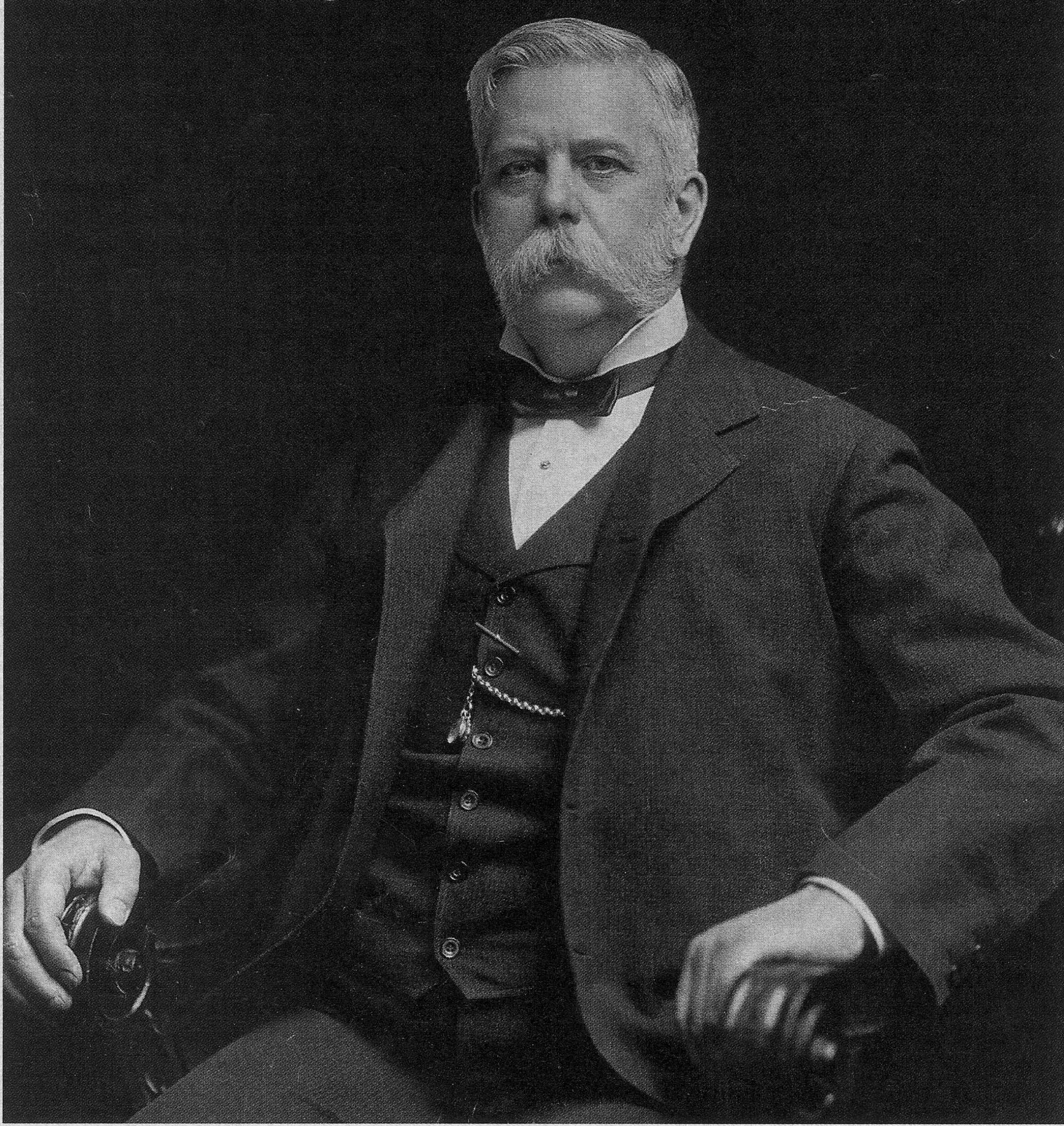
How George Westinghouse changed the world

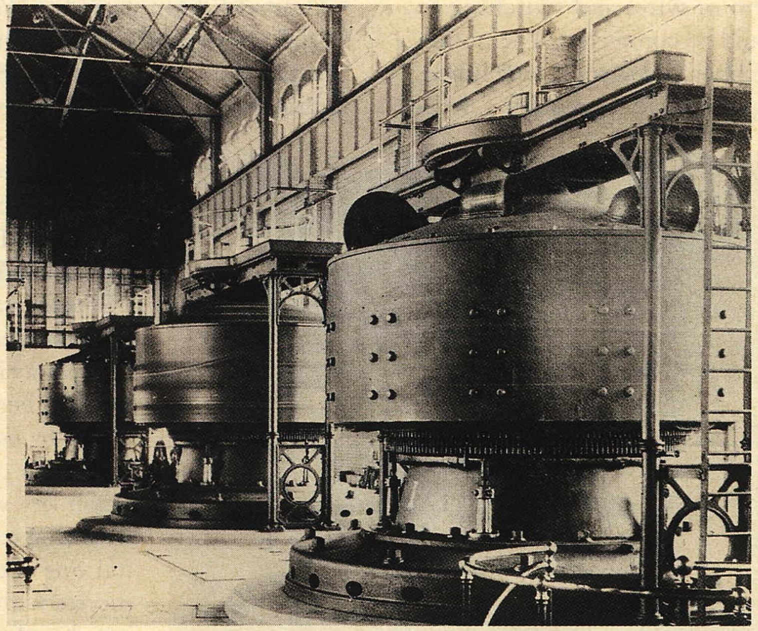


PHOTOGRAPHS COURTESY OF WESTINGHOUSE MUSEUM, WILMERDING, PA.

One of the greatest engineers of his day, George Westinghouse modernized the railroad industry and revolutionized the electric power system.

By Frank Wicks

The name of Westinghouse is familiar throughout the world, thanks to the myriad products and the manufacturing and communications companies that carry it, but the remarkable life and achievements of George Westinghouse, Jr., are less well known. Born 150 years ago, on Oct. 6, 1846, he became one of the greatest engineers, industrialists, and inventors of his time. He was also an Honorary Member of ASME, and in 1910 served as president of the Society. During his lifetime, Westinghouse received 360 patents and started 60 companies that had a total of 50,000 employees. At his peak, he was the largest private employer in industrial history.


Harnessing the power of Niagara Falls with these three 5,000-horsepower generators for transmission 25 miles to Buffalo, N.Y., a feat many thought impossible, was a crucial step in demonstrating the practicality of Westinghouse's ac system.

Westinghouse's vision and his technical and management skills were well demonstrated by his pioneering work with railroads and electric power systems. Although these are two very different technologies, during his lifetime he did more than anyone to modernize both of these developing industries.

A Fascination with Trains

Westinghouse's railroad work started while he was still in his teens. He had run away from home at 15 to join the Union Army with two of his brothers, one of whom was killed in action. (Another brother, Herman, became a mechanical engineer and, in 1904, vice president of ASME.) Later George served as a shipboard engineering officer in the Union Navy, where he used the ship's machine shop to develop a better engine.

In 1865 the 18-year-old veteran returned to his Schenectady, N.Y., home, where he had earlier learned the disciplines of design, manufacturing, invention, personnel management, and marketing in his father's factory, which made threshing machines and other agricultural equipment. He began to study engineering at Union College in Schenectady while he pursued his vision of an improved rotary steam engine. Like most young people, Westinghouse had a fascination with trains, which was intensified by Schenectady's railroad tradition and its growing locomotive-manufacturing industry.

Railroad travel in those days was unreliable, and railroad work was dangerous. Up to 30,000 people died each year from derailments and from brakemen jumping between cars to turn the hand-operated mechanical brakes. Westinghouse himself observed a train derailment and concluded that it took too long to get the train back on track. He invented and began to manufacture an improved car replacer to remount a car on the rails.

Soon after, Westinghouse saw two trains colliding because the brakemen could not respond to the engineer's whistle signal fast enough with separate hand-operated brakes on each car. This suggested the need for a fast, reliable braking system that could be operated by the engineer in the locomotive. All previous attempts at devising one, however, using methods such as chains and steam had proved unsuccessful. Westinghouse responded by inventing a compressed-air system that was centrally operated and fast, though not yet fail-safe. He later invented a reverse-acting fail-safe system that remains standard on railroads, trucks, and buses throughout the world today.

One success led to another. In 1868 Westinghouse

Frank Wicks is a professor of mechanical engineering at Union College in Schenectady, N.Y.

traveled to Pittsburgh to test his air brake, and eventually he made the city his new headquarters. The air-brake business and his growing reputation provided a base for the invention and manufacturing of automatic railroad signal and switching equipment, as well as improved car couplers that provided both spring and friction for shock absorption and vibration damping.

Oil had been discovered north of Pittsburgh in 1859, but there was no technology for recovering natural gas from the wells. During his first decade in Pittsburgh, Westinghouse pioneered technologies to transmit natural gas safely and efficient after he accidentally discovered gas while drilling for water at his new home. He subsequently invented and manufactured an apparatus for better drilling: a dual pressure system, with high pressure for efficient transmission and low pressure for safe use, via compressors and reducing valves, safety valves, techniques for leak detection and containment, and flowmeters to measure consumption.

Around this time, Alexander Graham Bell was demonstrating his newly invented telephone, which created a need for an efficient system of wires and switching so that any two telephones could be connected. The notion of a central telephone switchboard was soon established, but this meant that all telephones would require a dedicated wire to the central switchboard. By 1879, Westinghouse had devised a solution: a system of substations with automatic switching within the local exchange and with only a limited number of wires required to the central exchange for longer-distance calls.

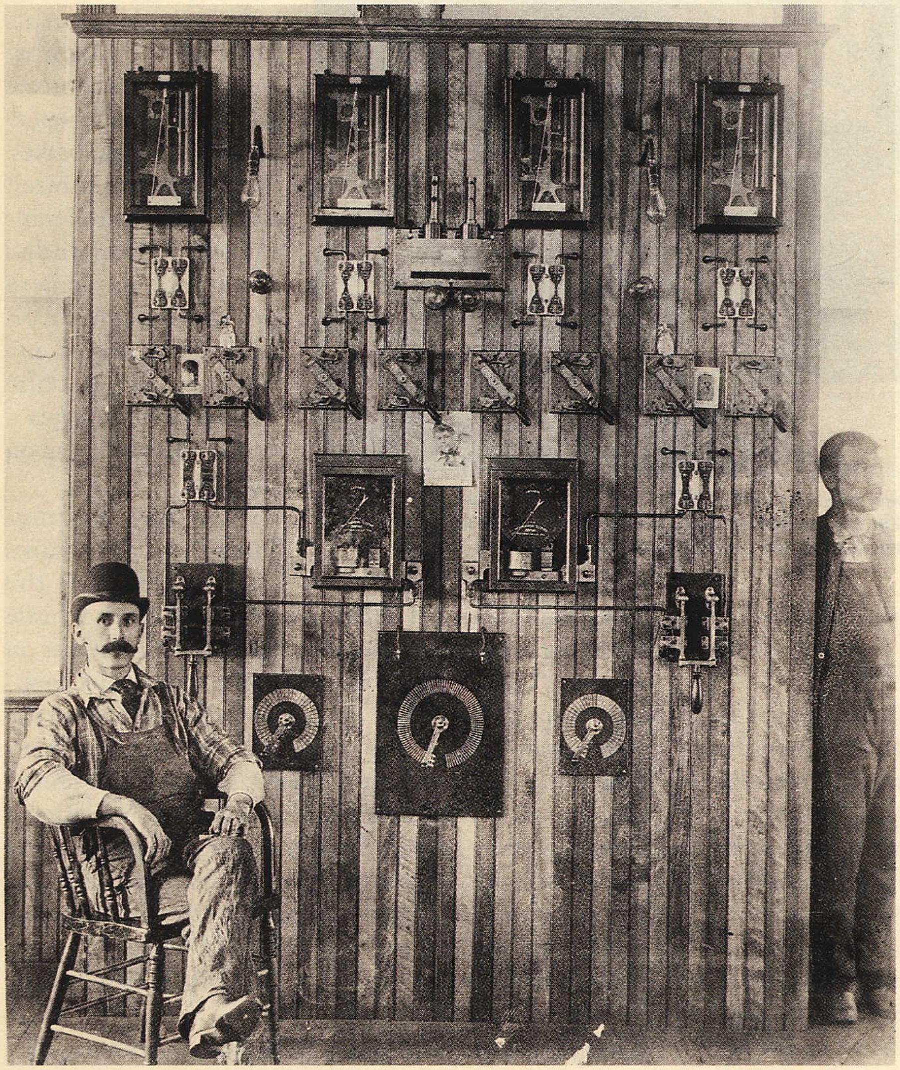
The Battle of the Currents

There were many great pioneers in the electrification of the world, but our existing power system owes more to the vision and work of Westinghouse than to anyone else. His knowledge of electricity was self-taught and initially quite limited. He seemed able to gain a working understanding of electricity through analogies to his earlier work in fluid and mechanical systems—such as compressed-air production, distribution, control, and end use; natural-gas pipelines and flowmeters; and signaling and automatic mechanical switching of rail tracks—and on his telephone switchboard. In general, Westinghouse would first define a problem or limitation of existing practice, then search for the appropriate technology and educate himself in the underlying engineering and scientific principles.

Thomas Edison provided Westinghouse with both an initial opportunity and his greatest challenge in their "Battle of the Currents." In 1877 the 30-year-old Westinghouse was a well-established inventor, engineer, and industrialist. Edison, four months younger, was still unknown, but he also aspired to be an inventor, proclaiming, "I'll never give up, for I may have a streak of luck before I die."

Edison was having limited success with his ideas for putting multiple signals on a single telegraph wire. He also had been trying to put speech on a wire by using the voice to make and break the circuit rapidly like a telegraph key when Bell succeeded with an analog technique rather than a digital one. Edison responded to Bell's success with the telephone by inventing the phonograph, which allowed the pressure variations of sound to be converted to mechanical vibrations by an analog process and stored on a wax cylinder for later replay. This sensational invention, for which there was no prior art nor expectation, made the previously obscure Edison instantly famous.

He followed up on the phonograph with his 1878 invention of the incandescent light bulb. He then conceived, constructed, and on Sept. 4, 1882, inaugurated the world's first electric utility system. His central electric generating plant on Pearl Street in New York City provided 110-volt direct current to 59 customers in the surrounding blocks of lower Manhattan.

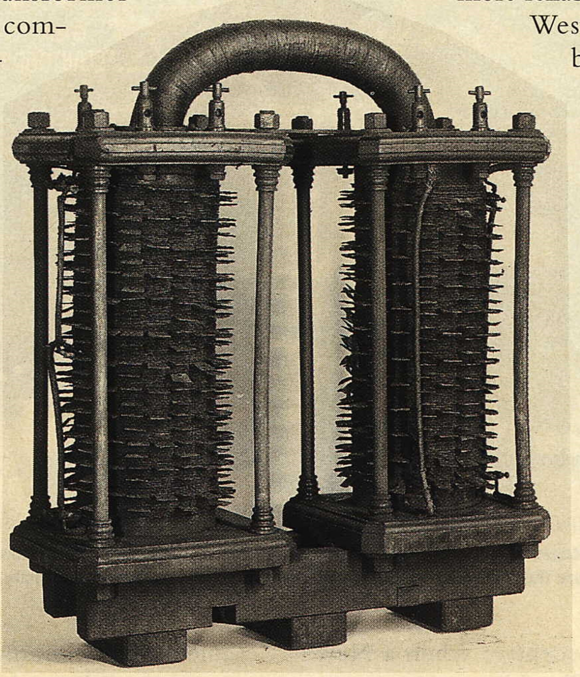


Control panels such as this one were used to regulate Westinghouse's new electric system.

Westinghouse studied the Edison system and concluded that it was good but had a fundamental problem. The low voltage required high current, which resulted in large transmission losses. What was needed was a much higher voltage for efficient transmission over large distances and a low voltage for safe use. The problem was analogous to that of increasing pressure for efficient transmission and reducing pressure for safe use in Westinghouse's natural-gas pipelines.

However, there was no practical method of changing the voltage of a dc system. A transformer could both step up voltage like a compressor and decrease it like a reducing valve, but electric transformers only operated on alternating current. While small transformers had been demonstrated for scientific purposes, none could continuously step up and down the very large amounts of power required for an electric utility system. There was also no practical method for winding the wires around such a large transformer or understanding of the amount of power loss involved in the transformer.

Westinghouse bought the rights to the Gaulard and Gibbs transformer, which had been demonstrated in London in 1881. He rapidly grasped the electrical principles of the magnetic circuit and the manufacturing problems of the device and redesigned it, going from using two windings on separate legs to a configuration with both the primary and secondary windings on the central core. The resulting transformer was more efficient and could be wound on a lathe, similar to most modern transformers.



The Gaulard and Gibbs transformer, first demonstrated in 1881 in London, was adapted by Westinghouse for use in a large-scale system.

Westinghouse then worked with William Stanley, who proceeded to develop further important features of the transformer, such as the technique for isolating and independently grounding the primary and secondary windings. In 1886 they installed the first multiple-voltage ac power system in Great Barrington, Mass. A hydroturbine drove a 500-volt generator; the electricity was transformed to 3,000 volts for transmission over a distance of 4,000 feet, then back to 100 volts for street lighting, with surprisingly low losses in the transformers.

Within a year, 30 such ac lighting systems were installed, but their practicality was limited because there was no ac electric meter, and no existing electric motor could operate from an ac power supply.

Westinghouse recognized that an electric meter should look like a gas meter, using gears and dials to integrate a flow rate into consumption. In 1888, his engineer Oliver Shallenger developed one. In this meter, still in use today, the driving torque on a Faraday disk is proportional to power flow, and the braking torque is proportional to speed, so the disk speed is proportional to the rate of power flow.

An ac motor was the remaining missing link. The solution was suggested by the previously little-known Nikola Tesla, who had worked for Edison. In 1888 he demonstrated the polyphase ac induction motor. This remarkable device operated on principles that were much harder to understand than those of existing dc motors, but it would ultimately prove simpler to manufacture and more reliable.

Westinghouse met with Tesla and bought the patent rights for the induction motor, even though it was not yet practical. He retained Tesla for one year of consulting service, during which the modern three-phase power system was defined as a technique for developing a more effective rotating magnetic field, rather than oscillating one, for motors. The 60-cycle standard was established—a frequency high enough to prevent lights from flickering and low enough to limit the reactance in the ac transmission lines that causes the current to lag the voltage.

The subsequent competition between Edison's dc systems and Westinghouse's ac systems became legendary. Edison argued that ac's high voltage was dangerous and initiated legislative efforts in many states to limit transmission to 800 volts. Westinghouse answered that all things are potentially dangerous, but safeguards and protective measures could make high voltage safe, and he continued to receive orders for new high-voltage ac power systems.

The Electric-Chair Charge

The New York state legislature inadvertently provided Edison with one last opportunity to destroy Westinghouse's ac system by negative advertising. In the fall of 1887, it had established a commission to search for a more humane method of capital punishment than hanging and asked Edison his opinion about using electricity.

Edison first replied that he wanted nothing to do with execution. He questioned the right of the law to kill, thought society could protect itself in some other way, and declared he would join heartily in an effort to abolish capital punishment.

However, Edison's low voltage and inefficient dc systems were continuing to lose out. Most cities and villages were beginning to purchase or plan their first electric systems, and Westinghouse was getting most of the new orders. Edison's best hope to preserve his inferior dc system was to dramatize the dangers of high-voltage ac

A dramatic early demonstration of the advantages of ac power was provided at the World's Columbian Exposition, the World's Fair held in Chicago in 1893, where the American public was introduced to the wonders of electricity.

more effectively. Thus he was receptive when a New York engineer, Harold Brown, offered his services to simultaneously demonstrate the dangers of ac and investigate its applicability for executions.

Edison now had a chance to dramatize the dangers of ac without personally involving himself. After Brown proceeded to use ac to kill 50 dogs and cats, a calf, and a horse, he pronounced ac a perfect medium for execution. Working through an agent, Brown procured three Westinghouse ac generators and devised an electrical cap and shoes, which he sold to the state for $8,000.

In August 1890, after two failed attempts, a convicted burglar named William Kemmler became the first person to be executed by electricity. A competition was held to name this new execution technology. "Electromort" and "electricide" were suggested. Edison proposed "Westinghoused."

Westinghouse was outraged. He responded that the state could have done the bungled job better with an ax, and defended the safety of ac and its ultimate benefits to society eloquently and effectively in public journals.

As a result of the limited performance of his dc systems, Edison was soon forced out of the electric industry he had created. In 1886 Edison had moved his electric-equipment manufacturing to a site in Schenectady adjacent to where, 30 years earlier, George Westinghouse, Sr., had founded his agricultural-equipment-manufacturing business. In 1892, the site became the headquarters of the General Electric Co., formed from a merger of the Edison facilities in Schenectady with other electric-equipment-manufacturing companies. The new company converted to the manufacture of ac equipment and, for a century, has been a prime competitor of Westinghouse.

The next dramatic demonstration of the Westinghouse ac system was to provide power and lighting for the 1893 World's Fair in Chicago. This was soon followed by the successful harnessing of 15,000 horsepower from Niagara Falls and the 25-mile transmission of this power for use in Buffalo, N.Y.

The Niagara Falls project was especially important. Before the introduction of electric power systems, power had to be used at the site where it was produced. Accordingly, most cities and villages were located on the fall lines of creeks and rivers, where water power could be captured by water wheels.

Westinghouse had become a good friend of Lord Kelvin, a great scientist who was also an engineer with varied practical achievements. Kelvin had been named to the commission to study the feasibility of harnessing the Falls, and technologies such as compressed air were being considered. Kelvin initially rejected the Westinghouse proposal of an ac power system as not feasible for such amounts of power over such a distance. Later, he happily admitted that he had been wrong.

Developing a High-Speed Turbine

At the beginning of the electric power industry, the two sources of mechanical power were falling water and the reciprocating piston-and-cylinder steam engines that Westinghouse had encountered as a boy in his father's shop and on the ships of the Union Navy. He found the idea of reciprocating motion cumbersome and wasteful. In fact, his very first invention was a rotary steam engine, which was not yet practical nor particularly necessary at the time. Later, however, the rapidly growing electric power system and Westinghouse's demonstration of high-voltage ac to transfer large amounts of power brought about a need for larger yet more efficient and compact engines that would rotate at high speeds and allow for more-compact generators.

In England, Charles Parsons had been experimenting with steam turbines, starting with a 10-horsepower machine in 1884. While the turbine had much potential, it still needed work, just as the Gibbs and Gaulard transformer had. Much more development would be required to make such a high-speed machine practical, depending as it did on jets of steam directed toward buckets, rather than expanding steam in a comparatively leakless cylinder and piston.

In 1895 Westinghouse bought the rights to the Parsons turbine and began his own development. Although others were highly skeptical of any favorable results, by 1898 Westinghouse had successfully demonstrated a 300-kilowatt machine as a replacement for reciprocating engines in his air-brake factory. By introducing radical new design features, he made history a year later by successfully installing a 1,500-kilowatt, 1,200-rpm turbine for the Hartford Electric Light Co.

The next challenge for steam turbines was the efficient propulsion of naval and merchant ships. The problem here was that the turbine operated efficiently at high speeds of about 3,000 rpm, while propeller efficiency required low speeds of about 100 rpm. The advantage of a turbine were nonetheless so great that some ships, such as the *Lusitania*, had been fitted with direct-drive turbines despite the inefficiency involved.

A reduction gear that decreases speed and increases torque is the mechanical analog of an electrical step-up transformer. While gearing is one of the oldest mechanical techniques, there were well-defined problems, and no prior experience, related to reliably gearing down a high-speed 3,000-horsepower turbine. Anything less than exact alignment would be fatal.

Westinghouse and others designed a novel automatic alignment system and successfully demonstrated it on a naval ship. It was then uprated to 5,000 horsepower, providing a new technique for much higher efficiency and lower-weight propulsion of all ships.

On the Westinghouse Trail

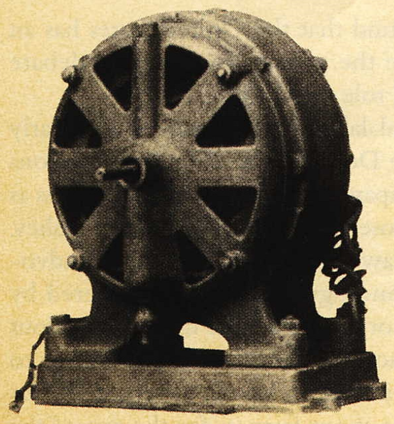
IN AN ERA in which employee relations typically meant ruthless exploitation and neglect of workers' health and welfare, George Westinghouse was a concerned and caring employer. Remembering his own long hours in his father's factory, he was the first to shorten the work week by introducing the Saturday afternoon holiday.

In appreciation, 60,000 Westinghouse employees contributed $200,000 for a magnificent memorial that was unveiled in Pittsburgh's Schenley Park in 1930. The central figure is a sculpture of Westinghouse flanked by figures of an engineer and mechanic, with six adjacent panels depicting his outstanding achievements. Completing the memorial is a figure of a youth drawing inspiration from the inventor.

The George Westinghouse Museum is in nearby Wilmerding, a town that he founded as a planned community to be integrated with his factories. Housed in a castlelike building that once contained Westinghouse's offices, the museum features educational demonstrations and artifacts. Union College in Schenectady, N.Y., is also preparing a sesquicentennial exhibit to be displayed in the Nott Memorial on campus.

AN EXPERIMENTER TO THE END

Both Edison and Westinghouse preferred to rely on experiment rather than on some vaguely defined theory. They did not always succeed, but they persevered in the face of failure. After unsuccessfully trying more than 1,000 filaments for an incandescent light bulb, for example, Edison proclaimed that he had not failed but rather that he had learned 1,000 things that did not work.



Nikola Tesla's ac motor was a key to the success of Westinghouse's ac system.

Westinghouse displayed similar resolve and determination. He was concerned that the growing use of electric power was consuming increased amounts of fuel, and that the Earth is a finite fuel reservoir and would eventually become depleted of coal, oil, and natural gas. He was also intrigued by an early paper written by his friend Kelvin, who had done much to define the second law of thermodynamics. Kelvin had suggested that heat for buildings could be extracted from air with a power-driven thermodynamic cycle more efficiently than it could be produced with passive heating systems.

Westinghouse recognized that the air contained energy in the form of the random motion of molecules. He asked Kelvin to review his ideas for using a series of thermodynamic engine and refrigeration cycles to extract more mechanical power from the air than the system put in. Kelvin diplomatically advised him that such a system would violate thermodynamic principles. Westinghouse answered that Kelvin might be right, but he was going to perform the experiment anyway. If his idea failed to harness power from the air, his apparatus could still provide a more efficient method of heating and cooling buildings. He proceeded to design and demonstrate compressor-driven air conditioning and heat pumps.

The introduction of the automobile by Henry Ford and others, along with the generally terrible condition of the roads, offered new challenges, and Westinghouse responded with the development of compressed-air vehicle-supporting devices, which combined spring and damping action.

Westinghouse, a friend of presidents and kings, was widely regarded as the world's greatest living engineer in 1910, when he was elected to serve as ASME president. When he died on March 12, 1914, at the age of 67, the Civil War veteran was buried, along with his wife Marguerite, in Arlington National Cemetery.

Throughout his life, George Westinghouse demonstrated a consistent high character, a concern for fairness as shown by his treatment of other inventors, and a commitment to making the world a better place. On the marker at his birthplace in Central Bridge, N.Y., the inscription reads: "If someday they say that in my work I have contributed something to the welfare and happiness of my fellow men, I shall be satisfied." ▪