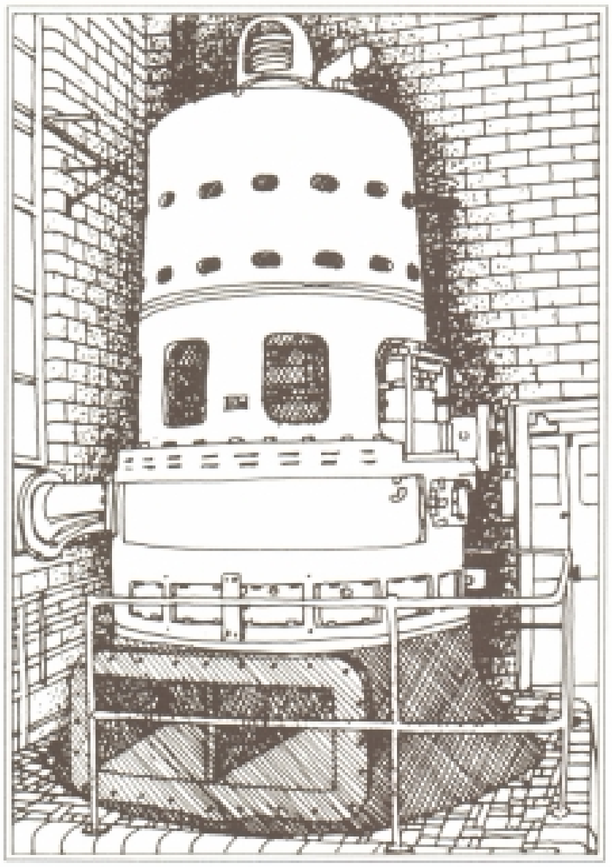
The First 500-Kilowatt Curtis Vertical Steam Turbine

Placed into Commercial Service
in Newport, Rhode Island,
February, 1903



An International Historic Mechanical
Engineering Landmark
July 23, 1990

Indianapolis Power & Light Company
E.W. Stout Generating Station
Indianapolis, Indiana

The American Society of
Mechanical Engineers

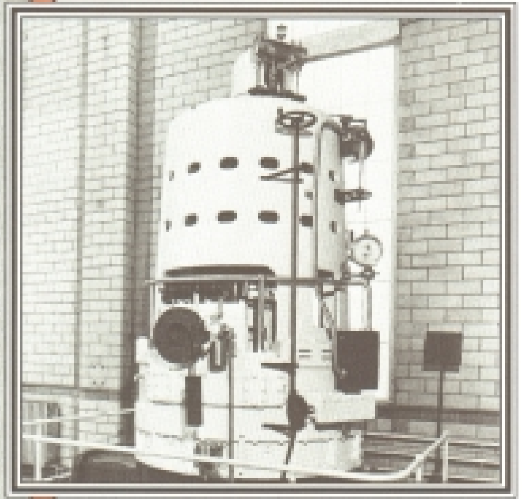
345 East 47th Street, New York, NY 10017

Curtis Vertical Steam Turbine Recognized as an Engineering Milestone

In the 1880s, streetcars were pulled by mules. Horses and buggies were everywhere. Lighting was provided by gas, kerosene and candles. Heat came from coal, wood and kerosene.

But within the primitive confines of this early life-style were the beginnings of some of the world's greatest discoveries -- discoveries that would radically change the course of history.

In New York, September 1882, Thomas A. Edison opened the first central electric - light power plant in the world--the famous Pearl Street plant. Alexander Graham Bell had just a few years earlier said, "Watson, come here. I want you," the first message transmitted by electric waves and distinctly heard by an assistant. And in Germany, engineers Karl Benz and Gottlieb Daimler completed automobiles with internal combustion engines, vastly accelerating the development of the modern day automobile.



The first vertical Curtis turbine placed in commercial service is now on permanent display at IPL's E.W. Stout Generating Station in Indianapolis.

It was during this inventive period, in 1896, that Charles Gordon Curtis (1860-1953) patented two turbine concepts (Curtis 1896 a,b) that would eventually lead to the commercial production of low-cost, single-cylinder turbines to provide the electricity so much in demand in America during the early 1900s.

According to Euan F. C. Somerscales, associate professor of mechanical engineering at Rensselaer Polytechnic Institute, and chairman of the American Society of Mechanical Engineers' National History and Heritage Committee, "The Curtis vertical steam turbine was the vehicle by which the electric power supply system grew at an astonishingly rapid rate during the first two decades of the twentieth century. It is difficult to believe that any contemporary turbine of any other type or form could have supported this growth rate."

Remarkably, the first vertical Curtis turbine placed in commercial service survives. Because of the historic interests of Harry T. Pritchard, a former president of Indianapolis Power & Light Company (IPL), the first Curtis vertical steam turbine was moved to Indianapolis for preservation. At the time of the move, Pritchard was an officer for a number of electric utilities, including the Newport Electric Corporation where the first Curtis turbine produced power from 1903 until 1927. He recognized the engineering significance of the vertical Curtis turbine as a major milestone in the technology of electrical generation. And, after the turbine had served its purpose powering the streetcar operations of the Newport and Fall River Company, Pritchard had the machine placed on permanent display in Indianapolis in 1931. It can be seen at IPL's E.W. Stout Generating Station, 3700 South Harding Street, in Indianapolis, and every year hundreds of visitors to the station view the Curtis vertical steam turbine and are educated about its historical significance. It serves as a monument to the engineers who built the machine and to the thousands of electric utility employees who dedicated their hard work and time to make electricity for a growing America.

Development of the Curtis Vertical Steam Turbine Was a Long and Arduous Process

It began, as all inventions, with the initial idea and then steadily evolved into a practical and cost-efficient model with commercial applications that would revolutionize the generation of electricity.

Charles G. Curtis patented his turbine designs some 13 years after Swedish engineer Gustav de Laval (1845-1913) first demonstrated a simple turbine design in 1882. Curtis' patents overcame many of the limitations of the de Laval turbine. And one of the two new designs offered a radically different concept, now known as velocity compounding. In velocity compounded steam turbines, the steam speed, not the pressure, decreases in steps as it passes through the turbine from inlet to outlet.

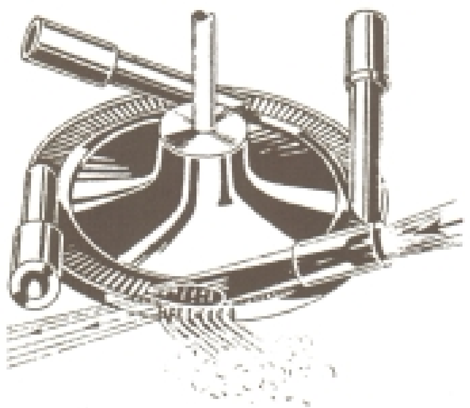


Illustration of Gustav de Laval's 1882 turbine design.

Source: Encyclopaedia Britannica, 1968.

This type of turbine requires far fewer wheels and therefore a shorter shaft than earlier turbine models. It also was somewhat less efficient than earlier turbine designs. Curtis, recognizing that limitation, placed two or more turbines in a series.

With patent in hand, the construction of a practical, commercially viable machine was still some years off. Curtis knew that the engineering challenges of his turbine concept were great. Because of the speeds, temperatures and pressures that the machinery would be exposed to, substantial resources would be required to develop the project.

Curtis proposed his ideas to several companies with no success, until he met E.W. Rice (1862-1935), vice president of manufacturing and engineering for General Electric (GE). Rice was interested in Curtis' turbine, and in 1897 an agreement was reached by Curtis and General Electric. Curtis would receive the necessary facilities and personnel to develop the turbine for commercial use, and General Electric would have the rights to manufacture the turbine.

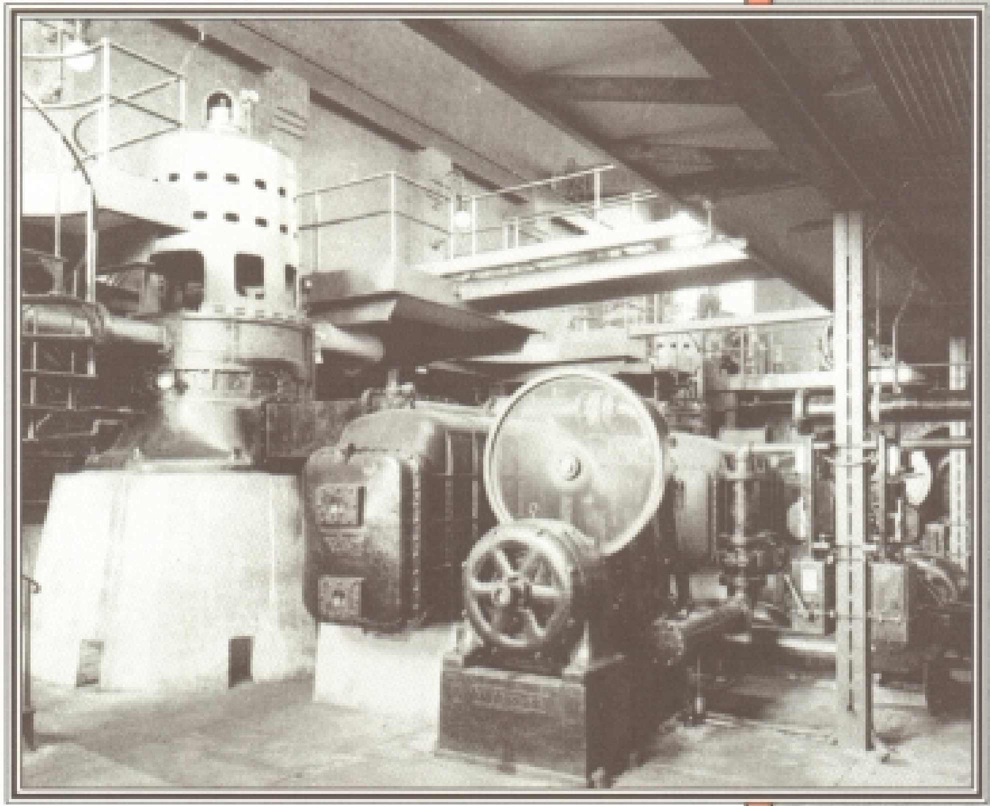
Development began that same year at General Electric's Schenectady Plant in New York. Experiments were observed by GE representative John Kruesi, one-time manager of the factory in Schenectady. From 1897 until 1901, three horizontal shaft experimental turbines were constructed: a 50-kilowatt unit; a two-stage, 200-horsepower machine; and a two-stage machine designed for flexibility in testing. Specially designed water brakes were used to provide a generator-like load, since there were no generators available at that time capable of operating at the speeds attained by the turbines.

By 1901, many tests had been completed, but reports submitted by Kruesi and other General Electric representatives were not very optimistic. Despite skepticism by Kruesi and the others, Rice still believed the Curtis turbine had a great deal of merit, both commercially and technically. As a result, Rice asked W.L.R. Emmet (1859-1941), who at that time was in charge of the General Electric Lighting Department, to review Curtis' work. Emmet submitted a favorable report and, as a consequence, Rice placed Emmet in charge of development. Curtis severed his direct connection with the experiments.

Shortly thereafter, Emmet create the first production turbine. a 500-kilowatt machine, that consisted of a horizontal shaft and two multiple row wheels in separate casings connetted by a pipe that ran beneath the floor. This machine was used to generate power for the Schesectady plant. A similar machine was built in 1902 for use at the Lynn, Massachusetts, location of the General Electric Company. Commercial production began soon thereafter, and a 1,500-kilowatt, horizontal turbine was delivered to the Port Huron Power and Light Company in 1902.

Even though commercial production of the horizontal steam turbine was well underway, Emmet decided to shift the design of the turbine to a vertical configuration. Emmet believed, despite objections from Curtis, that turbines with a vertical shaft had a number of advantages over the conventional horizontal turbine. He asserted that there were two distinct advantages: first, the machines would occupy less floor space than a horizontal turbine, and second, the positions of the moving and stationary parts would be more definitely fixed by the step bearing at the base of the machine.

Emmet's decision was based on the experimental testing he had done with vertical shaft turbines driven by the waters of Niagara Falls. In these vertical machines, the weight was carried on a footstep bearing lubricated by oil under pressure.



Basement view of the Newport and Fall River Company Generating Station.

Thus, production began on the Curtis vertical steam turbine, and manufacturing of the horizontal steam turbine was discontinued.

In February 1903, the first vertical Curtis turbine, a 500-kilowatt unit, was supplied to the Newport and Fall River Company in Newport, Rhode Island. Because there is no record of a prototype machine being built for shop testing, this may have been the first vertical Curtis turbine completed. It certainly was the first machine shipped for commercial use. The machine supplied power power to the Newport and Fall River Company's streetcar operations for 24 years, until June 1927

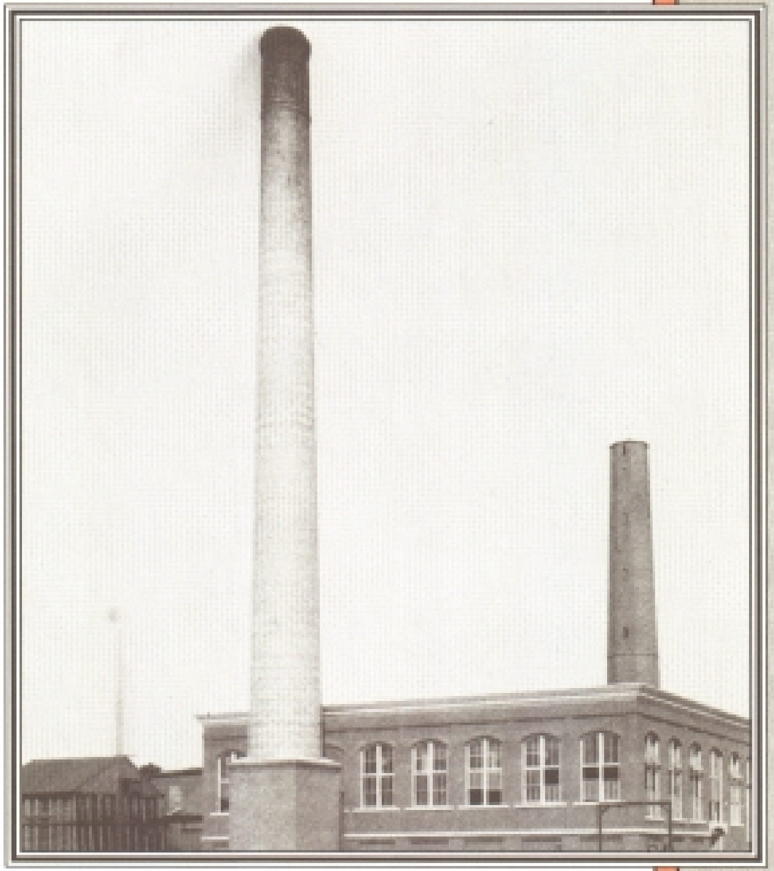
Over the next ten years, an estimated 1,000 Curtis vertical steam turbines were produced and sold to companies in the United States.

Interestingly, a predecessor company of IPL, the Marion County Hot Water Heating Company, purchased the first two turbo-generators in Indianapolis -- two 2,500-kilowatt vertical steam turbines in 1903 for use at its plant at 18th Street and Mill Street in Indianapolis. It is believed these turbines were of the Curtis design, but no record of that has yet been found. Later, the Indianapolis Light and Heat Company (which evolved from the Marion County Hot Water Heating Company in 1905), purchased two 5,000-kilowatt vertical steam turbines, which we know to be Curtis, one in 1909 and the other in 1911, again for the Mill Street Generating Station.

The Curtis steam turbine made the more commonly used reciprocating steam engines obsolete almost overnight for large power generation Curtis steam turbine had tremendous capacity in a small space. The machine was lower in cost than its competitor, the Parsons turbine, and because it was shorter than the Parsons turbine, it was less susceptible to distortion of the central shaft. Finally, it could operate at lower rotational speeds, so lower grade materials could be used in the construction of the internal buckets and wheels.

During the decade following the completion of the first Curtis vertical steam turbine, technical advances were rapid, For instance, the first 5,000-Kilowatt machines shipped to Commonwealth Electric Company in Chicago in 1903 were about half as efficient, in terms of kilowatt produced per pound of steam pressure as the Curtis vertical turbines in use at commonwealth Electric in 1909. The difference was so striking that Samuel Insull (1859-1938), president of the Commonwealth Electric Company, described the first turbines "as pipes that passed steam."

Despite these technical advances, General Electric decided sometime in



Newport and Fall River Company Generating Station, Newport, Rhode Island.

1908 to produce horizontal turbine, and in 1913 production of the vertical steam turbine was abandoned. Turbine speeds had increased radically from the 500 revolutions per minute (rpm) in the early 5,000-kilowatt turbines to 1,800 rpm in the later vertical turbines. Speeds as high as 3,600 rpm were considered, but these higher speeds required a stiffer structure, which could not be provided by the vertical turbines without additional lateral support from the power station building itself. Also, at the time of the changeover, steam turbines were getting longer as their power output increased and as more expansion stages were added to improve efficiency.

In addition to the Curtis vertical steam turbine at IPL's E.W. Stout Generating Station, there are seven other Curtis vertical steam turbines still in existence. All are located in the United States.

The first 5,000-kilowatt turbine produced, which generated electricity from 1903 until 1909 at the Fisk Street Generating Station of Commonwealth Electric Company (later Commonwealth Edison Company), is now on display in front of the Steam Turbine Generator Product Development Laboratory at the General Electric Plant in Schenectady, New York.

There are three Curtis vertical turbines -- 15,000 kilowatts each -- which are located in the South Boston Station of the Massachusetts Bay Transit Authority. These turbines were taken out of service in 1950.

The Georgetown Generating Plant in Seattle, Washington, has two well-preserved Curtis vertical steam turbines -- a 3,000-kilowatt and an 8,000-kilowatt version -- which were in use as late as 1964 and remained on standby status until 1977 as part of a regional power reserve for emergency situations.

Finally, the youngest of the surviving Curtis vertical steam turbines is a 15,000-kilowatt unit at the L Street Station of the Boston Edison Company. The L Street Station ceased operations in 1967, but this 15,000-kilowatt unit, originally installed either in 1913 or 1914, was retained as a landmark in the history of electric power generation.

Although the life of the Curtis turbine was short lived, its impact on the electric utility industry was immense. Indeed, many historians believe the electric utility industry was revolutionized by the Curtis steam turbine.

The Curtis Steam Turbine Technical Background

The simplest form of steam turbine was demonstrated by the Swedish engineer Gustav de Laval about 1883. It was constructed with a single rotating wheel attached to a shaft. Steam under high pressure passed through a number of nozzles directed at "blades," "buckets" or "vanes" attached to the outer circumference of the wheel. In passing through the blades, which were specially shaped to achieve this objective, the steam caused the wheel to turn. This type of steam turbine was actually less efficient than contemporary steam engines, but that was not of particular concern to de Laval who wanted to spin a cream separator at a very high speed. His steam turbine did just that; under conditions of maximum efficiency the turbine wheel rotated at speeds between 20,000 and 25,000 revolutions per minute. In most situations where a steam turbine would be useful, particularly in driving electrical generators, such high speeds could only be used by arranging a speed-reducing gear box between the steam turbine and the generator that was being driven by the turbine. However, gear boxes are not one hundred percent efficient. Their efficiencies at the time that de Laval would have been interested in using his turbine for electrical generation were far less than today. Even so, the invention of a suitable steam turbine with the potential to rotate at much lower speeds and having a better efficiency than the de Laval turbine was not long delayed.

In 1884 British engineer Charles A. Parsons (1854-1931) designed a steam turbine, now called a reaction turbine, with a number of bladed wheels arranged along the length of the turbine shaft. Steam admitted at the inlet to the turbine had to pass through each wheel before it left the turbine. In this way the pressure decreased from the inlet to the outlet in small steps in each one of the wheels. Stationary blades were arranged in rows around the inside of the cylindrical turbine case, with each such stationary row between a pair of rotating bladed wheels. The stationary blades were designed so that some of the pressure drop occurred both in them and in the blades attached to the rotating wheels. Arranging for the steam pressure to decrease in small steps, rather than one large step (as in de Laval's turbine), resulted in a significant improvement to the turbine's energy efficiency and practicality.

Experience soon showed that for the best efficiency the Parsons turbine had to have many wheels attached to its shaft. As new turbines were built with higher steam pressure to increase the turbine power output, the number of wheels increased. The turbine shaft had to likewise increase in overall length with the result that, if a slight bend occurred in the shaft, the outer end of the blades on the rotating wheel could rub the turbine casing and destroy the machine.

Another major participant in the development of the turbine was A.C.E. Rateau (1863-1930) who, independently of Parsons, designed a turbine in which the pressure drop also occurred in small steps. He, however, designed his turbine in such a way that the pressure drop only took place in the stationary blades attached to the turbine case. This small, but significant, difference simplified turbine design and operation because it avoided the efficiency-reducing leakage around the rotating wheels, which is a problem in the Parsons turbine. The Rateau turbine today is known as a pressure-compounded turbine.

A key event in the development of the turbine came when Charles Curtis patented two concepts that, like the inventions of Parsons and of Rateau, overcame the comparatively poor efficiency of the de Laval turbine, but also avoided the very long shaft that was required in the Parsons turbine. Curtis' first patented design was essentially the same as the idea behind the Rateau turbine, but his second patent dealt with a radically different concept, known as velocity compounding. In a velocity compounded steam turbine it is the steam speed, rather than the pressure, that decreases in steps as it passes through the turbine from inlet to outlet. This type of turbine requires far fewer wheels, and hence a shorter shaft, than the Parsons turbine. Also, because Curtis designed the turbine so that the steam only decreases in pressure in the nozzle where it enters the turbine, there is no need to worry about the leakage problem that occurs in the Parsons turbine around the outside of the rotating wheels. In spite of these advantages, the Curtis turbine is not as efficient as the Parsons and Rateau turbines, but it is mechanically much simpler and significantly more rugged.

Curtis undoubtedly recognized at the time he conceived it that his velocity compounded turbine was potentially not as efficient as the Parsons turbine, so he arranged for two of them to be connected together. The steam from the first turbine was then supplied to the second. The turbine shafts were also connected together end-to-end. This arrangement was known as pressure compounding, and the earliest designs of the Curtis turbine all used both velocity compounding and pressure compounding in the same machine. As an example, the 500-kilowatt Newport turbine has two stages of pressure compounding, each consisting of three velocity compounded stages. This means that six rows of blades rotated on the periphery of turbine wheels when the machine was operating.

Development of the Curtis vertical turbine, both to increase its power output, as well as its efficiency, occurred at a hectic pace after the completion of the first machine -- the 500-kilowatt turbine that was shipped to Newport, Rhode Island. Very little information is available on the exact nature of the technical improvements, but considering both the meager published data and the later history of the steam turbine, it seems likely that the next significant advances were connected with reducing the fluid friction and turbulence, as well as generally "smoothing" the flow of steam through the turbine. In particular, it was found that reducing the number of stages of velocity compounding was beneficial. When it reached its final form, the Curtis vertical turbine employed up to six stages of pressure compounding (the number depended on the power output of the turbine), with two stages of velocity compounding in each pressure stage. To cut down friction between the rotating wheel and the steam, the two rows of rotating blades forming a single velocity-compounded stage were attached to the periphery of a single wheel (for obvious reasons this was called a double-row wheel).

While the previous paragraphs have described the technical advantages and disadvantages of different types of steam turbines, it is undoubtedly true that another, and possibly more important, incentive for designing different forms of turbines was to allow individ-

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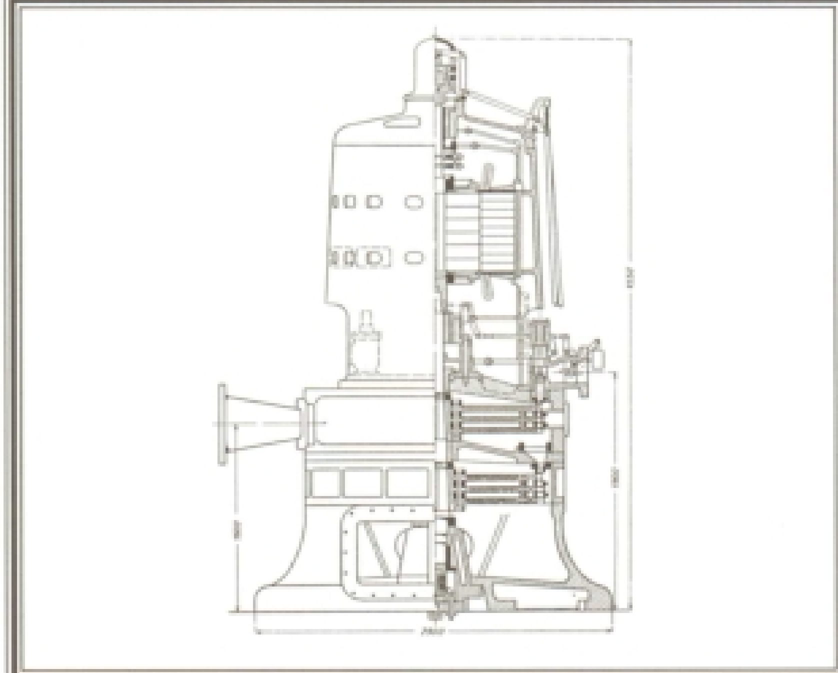
consequence of their holding patent rights or exclusive licenses. From this point of view, it is clear that the invention and patenting of the Curtis turbine allowed the General Electric Company to enter the turbine field in the United States. The field had been dominated by Westinghouse Machine Company, which held the U.S. manufacturing rights to the Parsons turbine. As the various steam-turbine patents expired, the different manufacturers incorporated the best features of each type of turbine into their designs. Consequently, the modern steam turbine, regardless of manufacturer, is a hybrid using concepts originally invented by de Laval, Parsons, Rateau and Curtis.



Vertical section through the 500-kW vertical Curtis steam turbine supplied by the General Electric Company to the Newport and Fall River Company (later the Bay Street Railway Company) for installation in the Newport station in May 1903. The turbine has two pressure compound stages, each consisting of a nozzle, two rows of stationary guides and three rows of moving, buckets attached to individual wheels.

Specifications of the 500-kW Curtis Vertical Steam Turbine

Type:	**2 stages of pressure compounding, 3 stages of velocity compounding per pressure stage.**
Power Output:	500 kW
Speed:	1800 rpm
Steam pressure:	150 psig
Steam temperature:	350 F°
Exhaust pressure:	28.5 - 29 in. Hg.
Frequency and phase:	60 Hertz, 3 phase
Voltage:	2300

Wording of the Plaque designating the 500-kW Curtis Vertical Steam Turbine Generator as an ASME International Historic Mechanical Engineering Landmark.

International Historic Mechanical Engineering Landmark
500-kW Curtis Vertical Steam Turbine Generator
Indianapolis, Indiana
1903

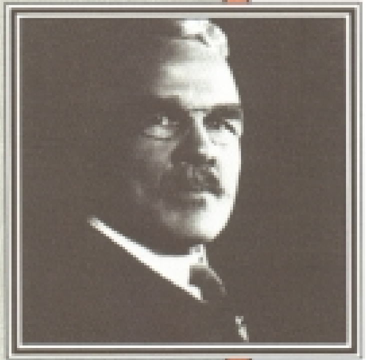
This, the first Curtis vertical turbine built, was constructed by the General Electric Company for the Newport & Fall River Street Railway Co. It operated in the Newport, R.I., generating station unitil June 1927. To preserve this historic machine, it was transferred for display to the Indianapolis Power & Light Company's E.W. Stout Generating Station.

Charles G. Curtis (1860-1953) - Inventor
W.L.R. Emmet (1859-1941) - Designer and Developer

American Society of Mechanical Engineers-1990

Biographies of Charles Gordon Curtis, William Le Roy Emmet and Edwin Wilbur Rice

Charles Gordon Curtis was born April 20, 1860 in Boston, Massachusetts. He graduated from Columbia University with a civil engineering degree in 1881. He also studied law at the New York Law School and graduated in 1883. For several years, Curtis was a patent lawyer, but decided to give up his practice in 1891 to organize the C & C Electrical Motor Company to manufacture electric motors and fans.



Charles Gordon Curtis
(1860 - 1953)

In 1896 Curtis patented two concepts of the steam turbine, and in 1899 he patented the first American gas turbine. This was recognized by the American Society of Mechanical Engineers in 1948 when he received the first annual award of the Gas Turbine Division. During the 1920s, Curtis studied the scavenging — the removal of burned gases from cylinders — of two-stroke diesel engines and patented the Curtis system of scavenging in 1930. Historians also credit Curtis with inventing the propulsion mechanism used in certain naval torpedoes.

Curtis died at Central Islip, New York, on March 10, 1953.

The practical development of the Curtis turbine is due to **William Le Roy Emmet.** Born July 10, 1859 on Travers Island, New York, Emmet graduated from the United States Naval Academy in 1881. Emmet served during the Spanish-American War as a navigator and during World War I as a member of the Naval Consulting Board.

William Le Roy Emmet
(1859 - 1941)

From 1883 until 1891 Emmet worked at various jobs related to the expanding electrical industry. In 1891 he joined Edison General Electric Company (a predecessor of the General Electric Company) in Chicago. When the General Electric Company was formed in 1892, Emmet was moved to Schenectady, New York, where he spent the rest of his career.

Emmet began working with Charles Curtis and the steam turbine around 1901 and is credited with making Curtis' ideas work in the production of electricity.

He died in Erie, Pennsylvania, on September 26, 1941.

Edwin Wilbur Rice was born on May 6, 1862 in Lacrosse, Wisconsin.

After moving in 1870 to Philadelphia, Rice attended Central High School and was graduated in 1880.

One of his teachers, Elihu Thompson, later became a scientific advisor and inventor of electric apparatus and Rice became his assistant. Together, they manufactured arc lamps and dynamos at the American Electric Company in New Britain, Connecticut. Rice remained with the company as it changed its name to the Thompson-Houston Company where he was promoted to plant supervisor, and then later to the General Electric Company in a merger with Edison General Electric Company.

Edwin Wilbur Rice
(1862 - 1935)

At General Electric, Rice climbed the corporate ladder from technical director to vice president. It was at this time that Rice met Charles Curtis.

Interested in Curtis' ideas, Rice drew up the initial agreement between General Electric and Curtis. In 1913 Rice became president of General Electric Company and was later made an honorary chairman of the company's board of directors. Rice has more than 100 patents to his name. He died November 25, 1935.

Acknowledgements

Special thanks to Euan F. C. Sommerscales, associate professor of mechanical engineering at Rensselaer Polytechnic Institute, and chairman of the American Society of Mechanical Engineers' National History and Heritage Committee. Most of the information contained in this brochure comes from his research paper, "The Curtis Vertical Turbine," presented in the History and Heritage session at the Winter Annual Meeting of ASME in Chicago, Illinois, November 28-December 2, 1988. Additional text also was written for the technical section of this brochure. Thanks also to Ruth Shoemaker of the Hall of History Foundation for her assistance in locating photographs.

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The ASME History and Heritage Recognition Program began in September of 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee, initially composed of mechanical engineers, historians of technology and (ex-officio) curator of mechanical engineering at the Smithsonian Institution. The Committee provides a public service by examining, noting, recording and acknowledging mechanical engineering achievements of particular significance. The History and Heritage Committee is part of the ASME Council on Public Affairs and Board on Public Information. For further information, please contact the Public Information Department, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, (212) 705-7740.

ASME Book HH0690

Designation

The 500-kilowatt Curtis vertical steam turbine is the 30th International Historic Mechanical Engineering Landmark to be designated. Since the ASME Historic Mechanical Engineering Recognition Program began in 1971, 137 Historic Mechanical Engineering Landmarks, five Mechanical Engineering Heritage Sites and two Mechanical Engineering Heritage Collections have been recognized. Each reflects its influence on society, either in the immediate locale, nationwide, or throughout the world.

An ASME landmark represents a progressive step in the evolution of mechanical engineering. Site designations note an event or development of clear historical importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

The ASME Historic Mechanical Engineering Recognition Program illuminates our technological heritage and serves to encourage the preservation of the physical remains of historically important works. It provides an annotated roster for engineers, students, educators, historians and travelers. It helps establish persistent reminders of where we have been and where we are going along the divergent paths of discovery.

Turbine testing department at the Schenectady Works of the General Electric Company circa 1904. (Photograph courtesy of General Electric Company)

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J.E. Housley (right), while president of the American Institute of Electrical Engineers, congratulates H.T. Pritchard, then president of Indianapolis Power & Light Company, for preserving the first 500-kilowatt Curtis vertical steam turbine used in commercial service.