Thomas J. Blalock and Craig A. Woodworth

25-Hz at Niagara Falls

end of an era on the Niagara Frontier, part I

AT 8:53 PM ON 12 OCTOBER 2006, a 66-kV circuit breaker tripped and locked out at the Harper Substation in Niagara Falls, New York, due to downed transmission conductors near Buffalo, New York. That event marked the end of over 111 years of 25-Hz alternating current (ac) electric power service on the American side of the Niagara Frontier.

Early History

The story of the development of hydroelectric power at Niagara Falls has often been chronicled in detail. Part 1 of this article summarizes how the 25-Hz frequency came to be so entrenched in western New York State.

In the middle of the 19th century, a canal known as the "Hydraulic Canal" was dug through the town of Niagara Falls, New York. The original purpose of this canal was to provide water power for the mechanical operation of various mills in the area. The canal was fed from the Niagara River at a point above American Falls and terminated at the crest of a high bluff overlooking the gorge below the falls. In 1877, the canal was purchased by businessman Jacob F. Schoellkopf who then organized the Niagara Falls Hydraulic Power and Manufacturing Company to supply water power for the operation of mills located on the bluff above the gorge.

The age of electric power generation at Niagara began in 1881 when a hydroelectric plant was constructed by

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The harnessing of Niagara Falls to provide electric power to both Canada and the United States, beginning over a century ago, remains the most famous early North American hydroelectric power development. This article discusses a significant aspect of this project, the once widespread production of 25-Hz ac power for use in large areas of western New York State. Part 1, presented here, describes hydroelectric developments at Niagara Falls in the late 19th and early 20th centuries and details the establishment and growth of 25-Hz power on the United States side of the Niagara Frontier. Part 2, in the March/April 2008 issue, will cover subsequent developments and the gradual decline and final demise of 25-Hz power just over one year ago.

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Craig Woodworth holds a B.E.E. degree from Rensselaer Polytechnic Institute. His career with the Western Division of Niagara Mohawk Power Corporation, from summer employment during high school and college through 34 years of full-time employment to consulting work since his retirement in 1987, spans a total of 63 years. Craig served as underground engineer in charge of services to large buildings in downtown Buffalo, New York. He was also responsible for special cable projects, including over 20 mi of 230-kV cable in the Buffalo area. He later worked in overhead transmission and retired as lead transmission design engineer. Craig is a Life Member of the IEEE.

—Carl Sulzberger
Associate Editor, History

Schoellkopf's company at the top of the bluff to operate 16 arc lights in the village of Niagara Falls. This plant, known as Station No. 1, contained three direct current (dc) generators that were rope driven from waterwheels and had a total capacity reckoned as 2,000-hp. This station operated until 1904 when it was abandoned.

25-Hz Power Established

The 25-Hz era was ushered in by the most documented early hydroelectric development at Niagara Falls, the construction of two powerhouses by a company organized in 1886 that eventually came to be known as the Niagara Falls Power Company. Figure 1 shows the first powerhouse completed. These two powerhouses (eventually to be named the Edward Dean Adams Stations for the president of the Cataract Construction Company, the parent of the Niagara Falls Power Company) were located on opposite sides of a short canal upriver from the entrance for the early Hydraulic Canal. Water from this new canal operated vertical turbines located at the bottom of a deep wheel pit and was then discharged into the gorge below the falls by means of a 1-1/4 mi (2 km) long tunnel. Early plans for the development of an unprecedented 100,000 hp at this site considered the production of power by means other than electricity. These means included the distribution of hydraulic (water) power, mechanical (rope or cable) drives, and compressed air.

A major objective of this development was the transmission of power to the industrial city of Buffalo, about 20 mi (32 km) to the south. The construction company established an International Niagara Commission to investigate the state-of-the-art power generation and distribution in North America and abroad. A total of 14 proposals for the Niagara Falls development were received, but only four of these involved the transmission of electric power. Two advocated the use of dc and two the use of ac (one suggesting single-phase and the other polyphase ac). At that time, the use of dc was strongly advocated by Thomas Alva Edison, while George Westinghouse (using the patents and services of Nikola Tesla) advocated the use of polyphase ac power. By the summer of 1891, the power company had decided that local distribution would utilize dc, while the transmission of power to Buffalo would utilize compressed air. However, a decision to use ac electric power for both purposes was made in May of 1893. This followed the highly successful demonstration of the versatility of ac power which had been provided by the Westinghouse Company at the Colombian Exposition in Chicago in that year. In that exhibition, rotary converters were used to convert ac to dc power.

The first three turbines for the powerhouse were rated at 5,000 hp each and had been designed to operate at a speed of 250 rev/min. Thus, the ac generator frequency would be limited to multiples of 8-1/3 Hz (such as 16-2/3 Hz, 25 Hz, 33-1/3 Hz, and 41-2/3 Hz). Prof. George Forbes, a British

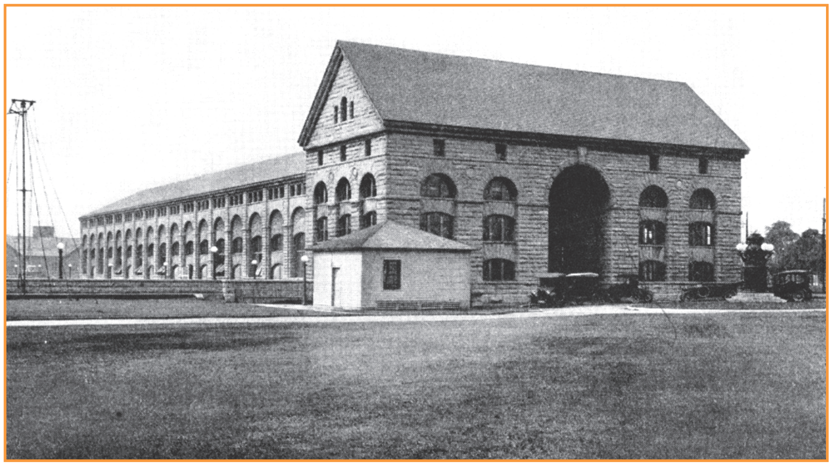

figure 1. Powerhouse No. 1 of the Niagara Falls Power Company, circa 1910 (from E.D. Adams, *Niagara Power*, 1927).

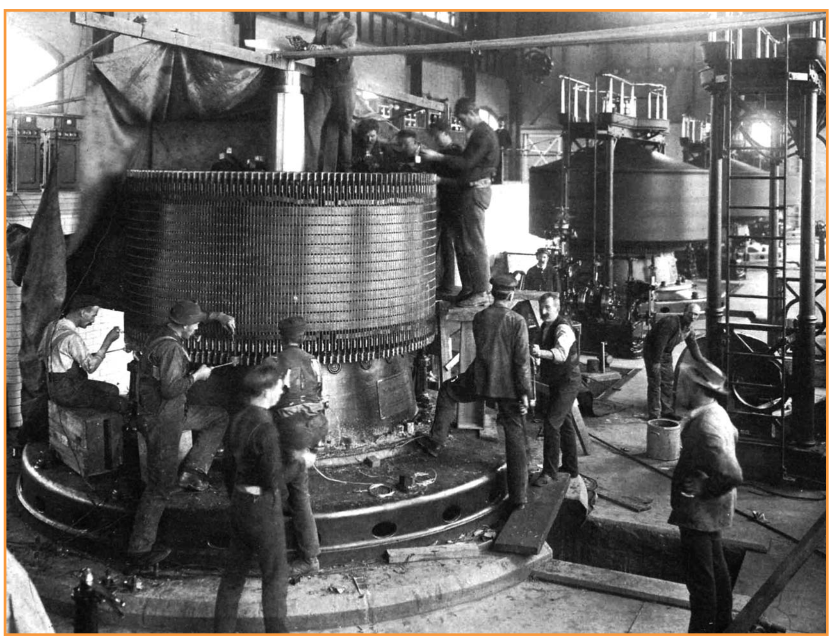

figure 2. Generator being assembled in Powerhouse No. 1, circa 1898 (photo courtesy of the Niagara Mohawk Power Corp. archives).

consultant for the power company, recommended the use of 16-2/3 Hz because he was of the mistaken opinion that commutator-type ac motors would become commonplace. A very low frequency (essentially closer to dc) would have been advantageous in this case. However, the common ac motor came to be Tesla's induction motor instead. Westinghouse refused to guarantee the operation of such huge generators for a frequency less than 30 Hz. That frequency had been used at the Colombian Exposition, and it was exactly one-half the 60-Hz frequency chosen by Westinghouse for general ac lighting use. This two-to-one relationship would simplify the design of rotating machines (frequency changers) operating between these two frequencies. However, 30 Hz could not be generated at a speed of 250 rev/min. The General Electric Company had recommended the use of 41-2/3 Hz and, eventually, a compromise of 25-Hz was finally selected. Figure 2 shows the assembly of one of the first Niagara project generators.

One additional reason for the selection of 25-Hz generation at Niagara was the intended use of this power for conversion to dc.

The initial generator designs submitted by General Electric and Westinghouse did not satisfy the mechanical requirements set down by the turbine manufacturer, including angular momentum and limited weight. The final generator design was based on a patent by Prof. Forbes that used a fixed armature surrounded by a rotating field assembly of the umbrella type. Two-phase generation was selected because it was expected that most of the local load would be single phase. In this arrangement, two-phase, four-wire distribution consists of two isolated single-phase circuits.

One additional reason for the selection of 25-Hz generation at Niagara was the intended use of this power for conversion to dc. During this era, the most efficient means for accomplishing this was by the use of rotary converters, and early rotary converters did not function well if designed for frequencies as high as 60 Hz. The Pittsburgh Reduction Company, later the Aluminum Company of America (ALCOA), had a need for large quantities of dc power for the reduction of aluminum ore. Also, Buffalo (as was true for most other large cities at that time) had an extensive dc distribution network for general purpose light and power. The choice of 25 Hz as the frequency to be generated by the Niagara Falls Power Company's Power House No. 1 established the use of this frequency at Niagara Falls for decades to come.

The design of ac power stations was still so new and unfamiliar at this time that the only dc exciters included in the first powerhouse were in the form of rotary converters operating from the outputs of the generators. It was quickly realized that there was no way to start up the station. Fortunately, an old steam-engine-driven dc generator that had been used during the construction of the powerhouse was still in place in a shack nearby. Temporary wires were run from it to the newly completed station to provide excitation for the first generator to be started up. The powerhouse was originally equipped with 2,200-V ac resistance units to provide heat during the winter. However, it was found that these were only needed until a sufficient number of generators were in operation such that the waste heat created by their electrical losses was enough to heat the station.

Two-phase, four-wire, 2,200-V, 25-Hz ac power was first commercially delivered on 26 August 1895 to the Pittsburgh Reduction Company. Power House No. 1 eventually contained a total of ten 5,000-hp, 25-Hz generators. This pioneering hydroelectric generating station was named an IEEE Milestone in Electrical Engineering in June 1990.

By this time, it was generally understood that three-phase ac power was the most efficient system to use for long distance transmission. A special connection of two single-phase transformers (the "Scott" connection) was used to step up to a transmission voltage of 11,000 V, three-phase to Buffalo. In

figure 3. Powerhouse No. 2 of the Niagara Falls Power Company, circa 1905 (from E.D. Adams, *Niagara Power*, 1927).

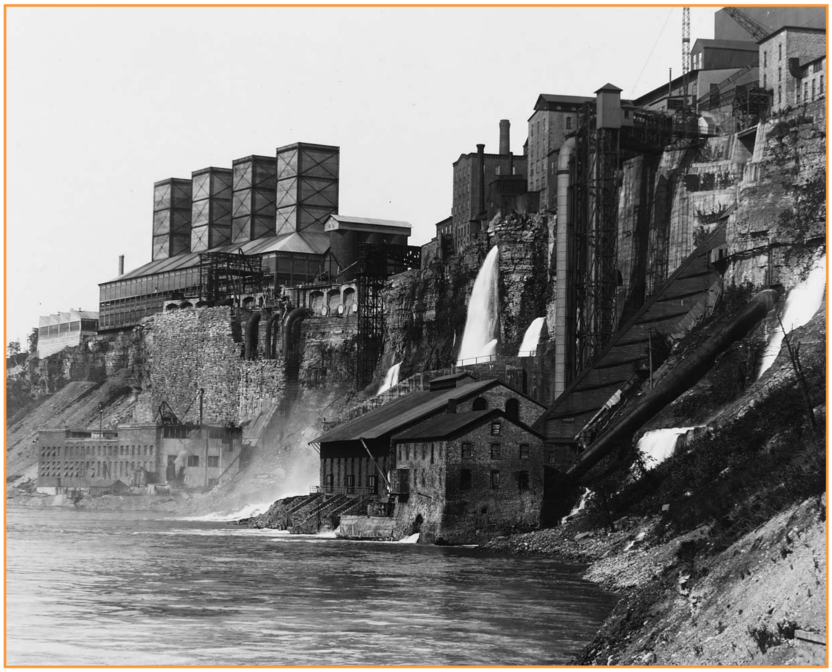

figure 4. Hydraulic Power Company Stations No. 2 (center) and 3 (far left), both at waterline, circa 1910 (from D.M. Dumych, *Images of America—Niagara Falls, Vol. II*, Arcadia Publishing, 1998, www.arcadiapublishing.com).

November 1896, the street railway company in Buffalo was the first customer for this power. Rotary converters were used to provide 550-V dc power, and these rotary converters were operated in parallel with the trolley company's existing steam engine driven generators. The overhead portion of the Niagara Falls to Buffalo transmission system was converted to 22,000-V operation in 1900.

Also in 1900, construction began on the Niagara Falls Power Company's Powerhouse No. 2 (see Figure 3). As completed in 1904, this powerhouse contained a total of 11 generators very similar to those already in operation at adjacent Powerhouse No. 1, except that the last five Powerhouse No. 2 generators were designed with internal revolving fields. An interesting event occurred on 31 May 1902 when Powerhouse No. 1 had to be shut down to remove a bulkhead in the tailrace tunnel leading to the new Powerhouse No. 2. To provide minimal service to important customers, the Niagara Falls-to-Buffalo transmission system was operated in reverse. Available 550-V dc power from the Buffalo street railway company energized the rotary converters and transformers that provided 11,000-V ac power for local use in Buffalo and for transformers at the Buffalo Terminal House that energized the line to Niagara Falls at 22,000 V. Then, at Niagara Falls, the Scott-connected transformers provided 2,200-V two-phase power for local distribution there.

figure 5. Hydraulic Power Company Station No. 3A, May 1913 (from D.M. Dumych, *Images of America—Niagara Falls,* Arcadia Publishing, 1996, www.arcadiapublishing.com).

The Schoellkopf Stations

Following the 1881 Station No. 1, the Schoellkopf company constructed its Station No. 2 in the gorge below the falls. This latter station was completed in 1898, and it operated until 1921 when it was abandoned. It was demolished in 1925. During the early years of its operation, the station generated dc as well as single-phase ac at a frequency of 125 Hz (then referred to as "15,000 alternations") and three-phase ac at a frequency of 30 Hz. The dc power was needed during this era due to the large numbers of dc motors in use in various industries. The higher ac frequency would have been used for general lighting purposes to avoid lamp flicker, and the lower frequency would have been used for large, slow-speed industrial induction motors.

At the peak of its operation, the capacity of this station's various generators totaled nearly 34,000 hp. Of this total, 90% was dc, however, and the remaining 10% was 25-Hz ac (the earlier frequencies having been abandoned by this time).

figure 6. Schoellkopf Stations No. 3B (three generators in the background) and 3C (three generators in the foreground), circa 1930 (from D.M. Dumych, *Images of America—Niagara Falls,* Arcadia Publishing, 1996, www.arcadiapublishing.com).

An unfortunate event occurred in 1904 when a huge icicle, estimated to weigh between 30 and 40 tons, fell from the cliff face above and crashed through the roof of the station destroying four of the generators.

In 1904, at the Schoellkopf site in the gorge near Station No. 2, construction began on Schoellkopf Station No. 3 (eventually to be known as Station No. 3A, see Figures 4 and 5). It was completed in 1914 and contained 13 10,000-hp turbines that were supplied with water from an enlarged Hydraulic Canal. Five of these turbines each drove pairs of 3,500-kW dc generators that were owned by the Pittsburgh Reduction Company. These dc generators were replaced with 60-Hz generators in 1946. Each of the remaining eight turbines in the station drove a 10,000-hp, 25-Hz generator.

In 1906, the U.S. Congress passed the Burton Act that limited the amount of water that American hydroelectric plants could divert from the Niagara River above Niagara Falls and limited the amount of power that could be imported from Canadian power plants. In 1917, the War Department issued a permit to the Hydraulic Power Company (the successor to the original Hydraulic Power and Manufacturing Company) that increased its authorized water diversion. Then, in 1918, construction began on what would become Station No. 3B at the Schoellkopf site. It contained three large, 25-Hz, three-phase generators with a total capacity of 112,500 hp. Water was still supplied via the Hydraulic Canal, which had been further enlarged.

In early 1918, the U.S. government determined that conditions resulting from World War I (as well as the national welfare) required utilization of water diverted from the Niagara River at an increased efficiency. This led to the consolidation of the two existing power companies to form a new Niagara Falls Power Company.

Following this consolidation, the two original Niagara Falls Power Company powerhouses were renamed Adams Stations No. 1 and 2, and the stations in the gorge became Schoellkopf Stations No. 3A and 3B. Then, in 1921, construction began on adjacent Schoellkopf Station No. 3C. This was completed in 1924 and contained three 25-Hz generators with a total capacity of 210,000 hp (see Figure 6). Because the Hydraulic Canal could not be enlarged further, the water for this new station was supplied via a new pressure tunnel running along nearly the same route as the Hydraulic Canal above it. Station No. 3C then utilized the water allotment for the Adams Stations, which were shut down and placed in reserve. The Schoellkopf Stations in the gorge were more efficient due to their greater

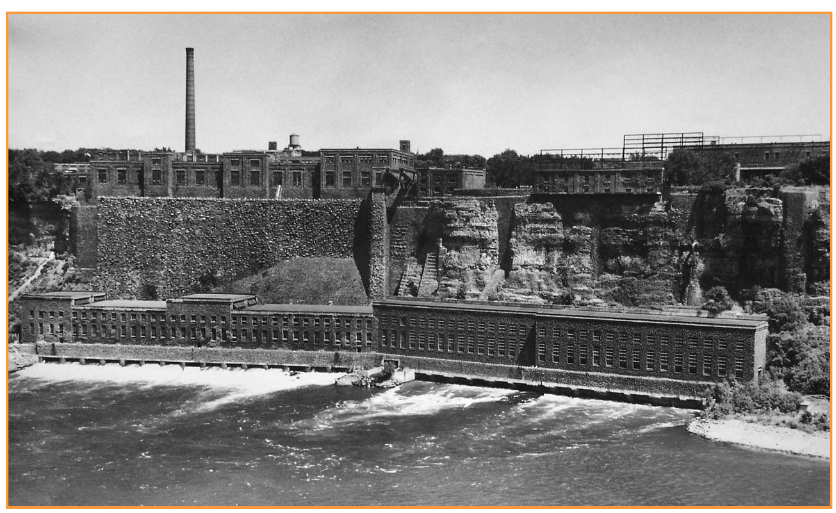

figure 7. Schoellkopf Stations No. 3A, 3B, and 3C, June 1955 (photo courtesy of the Niagara Mohawk Power Corp. archives).

available hydraulic head of 210 ft (64 m) as compared to only 135 ft (41 m) for the Adams Stations. This was due to the slope of the tailrace tunnel for the Adams Stations. Figure 7 shows Stations No. 3A, 3B, and 3C in 1955.

figure 8. Rankine Station of the Canadian Niagara Power Company, 1913 (from E.D. Adams, *Niagara Power*, 1927).

The Schoellkopf station complex eventually met with a very unusual fate. In 1956, it was almost completely destroyed by a massive rockslide from the towering cliff above. Following this catastrophe, 11 of the generators in Station No. 3A were rebuilt for 60-Hz operation, but Stations No. 3B and 3C were completely abandoned.

Canadian Powerhouses

In 1901, the Canadian Niagara Power Company (which was a subsidiary of the Niagara Falls Power Company) began construction of a powerhouse located just above Horseshoe Falls on the Canadian side of the Niagara River. This powerhouse was similar in design to the Adams Stations on the American side, and it was later named the Rankine Station in honor of William Birch Rankine who was instrumental in the early history of the power company (see Figure 8). This station began operating on 1 January 1905 and, when fully completed in 1924, contained 11 25-Hz generators with a total capacity of 121,000 hp.

In 1902, the Ontario Power Company began the construction of a powerhouse below Horseshoe Falls. When completed, it contained 15 25-Hz generators with a total capacity of slightly more than 205,000 hp. The configuration of this installation was somewhat unusual in that the generators were horizontal rather than vertical, and the turbines were double horizontal units.

In 1903, the Electrical Development Company began construction of a powerhouse upstream of the Rankine Station. This company was actually formed for the purpose of transmitting electric power from this location, and, in 1908, the station was leased by the Toronto Power Company. When fully completed in 1915, the station contained 11 25-Hz generators with a total capacity of 157,000 hp. The tailrace (water discharge) tunnel from this station ran beneath the Niagara River to a point located behind Horseshoe Falls. The tunnel was constructed in segments that were designed to break off as erosion caused the falls to recede upstream over the following decades.

Later, in 1917, the Hydroelectric Power Commission of Ontario began construction of the Queenston-Chippawa Development located on the Canadian side of the river at the Niagara Escarpment, several miles downstream from Niagara Falls near the town of Queenston, Ontario. Water for this station originated at Chippawa, upstream of the falls. This location was the mouth of the Welland River, and the flow of that river was actually reversed so as to feed water to a hydraulic canal that then conveyed the water downstream to the station. By locating the plant downstream of the lower rapids of the Niagara River, an effective head of 300 ft (91.4 m) could be utilized. When completed in 1925, this station contained nine 25-Hz generators with a total capacity of 507,000 hp. Eventually, this station was named Sir Adam Beck No. 1 in honor of a former mayor of the City of London, Ontario, and chairman of the Hydroelectric Power Commission of Ontario.

For Further Reading

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