Cooke Hydroelectric Plant
Cooke Dam Road at the Au Sable River
Oscoda Vicinity
Iosco County
Michigan

HAER No. MI-98

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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Mid-Atlantic Regional Office
Department of the Interior
143 South Third Street
Philadelphia, PA 19106

HISTORIC AMERICAN ENGINEERING RECORD

COOKE HYDROELECTRIC PLANT

HAER No. MI-98

Location: Cooke Dam Road at the Au Sable River
Oscoda Vicinity
Iosco County, Michigan

UTM: 17:295470:4927560 (NE point) 17:295560:4927280 (SE point)
17:295410:4927200 (SW point) 17:295340:4927320(SW point)
Quad: Sid Town, Mich., 1:24,000

Dates of Construction: 1909-1911

Engineers: William G. Fargo, Fargo Engineering Company, Jackson, Michigan (civil and hydraulic engineer); and
James B. Foote, Consumers Power Company, Jackson, Michigan (electrical engineer)

Present Owner: Consumers Power Company, 212 West Michigan Avenue, Jackson, Michigan

Present Use: Hydroelectric generating plant

Significance: The Cooke Hydroelectric Plant on northeastern Michigan's Au Sable River was the beginning of an interconnected power system throughout that state's Lower Peninsula. When Cooke went on line in 1912, the plant produced electrical energy that was used 125 miles to the south, in the growing industrial city of Flint. This marked the greatest distance commercial electrical power had traveled in the state. An even more remarkable achievement was the voltage of Cooke's transmission: its 140,000-volt pressure surpassed that of any other line in the world. The 140,000-volt line would become the "backbone" of Consumers Power Company's system, which supplied power to the greater part of lower Michigan.

Project Information: This documentation was prepared by Consumers Power Company (CPCo) in conformance with its Cultural Resources Management Plan for the Au Sable River Hydroelectric Projects (July 1995). The plan stipulated the recordation of the entire Cooke Hydroelectric Plant (according to the standards of the Historic American Engineering Record) as mitigation for the planned rehabilitation of the plant's concrete spillway. The documentation was completed in 1996 by Hess, Roise and Company of Minneapolis under contract with CPCo. Jeffrey A. Hess served as Principal Investigator and Cynthia de Miranda as Project Historian. Project photography was completed under a subcontract with Hess Roise by Clayton B. Fraser of Loveland, Colorado.

OVERVIEW

The Cooke Hydroelectric Plant was the first facility built by entrepreneur William Augustine (W.A.) Foote as part of his larger plan to develop the hydroelectric potential of northeastern Michigan's Au Sable River. The plant, under construction from 1909 through 1911, was erected twenty-two river miles west of the river's mouth at Lake Huron. The Au Sable, with its steady flow and infrequent floods, was an ideal tributary for hydroelectric development. It was the river's unfortunate location—the sparsely populated northeastern part of the state's Lower Peninsula—that made it appear a poor investment in the early days of hydroelectricity. Little profit lay in selling power locally to so few people.

Foote's plan, however, was to generate power on the relatively isolated river and send the electrical current down long-distance transmission lines. The lines would feed into cities and industrial sites in the Lower Peninsula's more densely populated southern region. When Cooke went on line in 1912, the plant produced energy that was used 125 miles away in factories in the industrial town of Flint, Michigan. This was a remarkable transmission distance at the time, especially in the Midwest, where power plants were customarily located near population centers. Even more staggering was the voltage, or pressure, of Cooke's transmission: its 140,000-volt pressure surpassed that of any other line in the world.

SITE DESCRIPTION

An earthen embankment impounds water at Cooke for use in generating hydroelectric power. The dam and power plant meet at an angle in the river channel, forming a "V"-shaped impediment to water flow and creating a 1,627-acre impoundment. The base of the "V" points upstream (west), and the entire north arm is a section of the dam known as the North Embankment (HAER No. MI-98-A).[1] This 572'-0"-long earthen dam is reinforced on its upstream side by a 12"-thick concrete corewall. The top of the embankment is 12'-0" wide; from the apex, both the upstream (west) and downstream (east) sides descend at a slope of 2:1. On the upstream side, the descent is interrupted after about 3' by an 8'-3" wide berm, created when Consumers Power Company raised the height of the embankment in 1925. The concrete corewall forms the upstream side of the berm. Below it, the embankment's slope descends toward the riverbed at a 4:1 grade. The grade of the downstream side also changes from 2:1 to a more shallow 4:1 about 14' from the top of the dam. Grass covers the embankment above the water level, and a wooden staircase just north of the spillway serves as a canoe portage.

At the southern end of the North Embankment is the Spillway (HAER No. MI-98-B), which is controlled by three Tainter gates. The Spillway gates, designed to prevent the dam from overtopping, are only opened to pass flood waters. The normal river flow is directed through

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[1] While the base of the "V" more accurately points southwest, this description is written to reflect approximate full cardinal points for the sake of clarity.

the Powerhouse (HAER No. MI-98-C), a steel-framed, brick-clad structure situated immediately south of the Spillway in the southern arm of the "V". The gable-roofed building stands on a massive concrete foundation in the middle of the river's natural channel. It shelters three horizontal, direct-connected, 3,000 KW generating units, each producing current at 2,500 volts on three-phase, 60-cycle alternating current generators. The turbines for each unit are located in an open penstock situated behind (west of) the Powerhouse and sheltered by a concrete slab deck. Water flow is controlled by a Tainter gate at each penstock entrance. Upon passing through the turbines, the water exits the Powerhouse through draft tubes leading to a partially concreted, 120'-long tailrace. Adjacent to the southeast corner of the Powerhouse sits the outdoor Substation (HAER No. MI-98-D). A small concrete pad supports transformers and other equipment, and chain-link fencing encircles the entire yard. Three transformers step up the current to 46,000 volts for transmission to the Iosco-Loud line, 150' to the southwest. The Substation also includes a 4,800-volt distribution circuit.

Between the Powerhouse and the south river bank is another stretch of earthen dam known as the South Embankment (HAER No. MI-98-E). Like its counterpart to the north, this 90'-long embankment has a 12"-thick reinforced concrete corewall on its upstream side. The South Embankment's slopes match those of the north, excepting the 3:1 grade from the corewall to the riverbed on the upstream (west) side.

A wood-frame, front-gabled Storage Shed (HAER No. MI-98-F) sits on the south riverbank, on the downstream (east) side of the Powerhouse. The single-story structure, sheathed in board-and-batten siding, has double cargo doors on the main (west) facade. The doors slide on an overhead track, and a personnel door has been cut into the left cargo door leaf. Wood sash windows punctuate both the north and south walls. The exterior is papered with sheets of green asphalt, and the battens and other trim are painted white. The building's size and appearance indicate that it is probably a relic from the construction camp that was erected while the hydropower facility was being built.

On a hill south of the Powerhouse stands a two-and-a-half story, gable-roofed, wood-frame Attendant's House (HAER No. MI-98-G), so named because it once served as a dwelling for the plant operator. The front-gabled house has enclosed front and back porches and a dormer window on its south side. Another house, nearly identical, and a dormitory building provided additional lodging until they were removed from the site in the 1970s. The entrance to the plant site was once marked with iron gates in fieldstone Gate Posts (HAER No. MI-98-H). The posts were topped with domed lights, similar to some once used to illuminate the Powerhouse. Only the posts remain.[2]

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[2] This description is based on a site survey completed by the authors on 27 July 1995; engineering articles detailing the complex during construction; current planning documents produced by Consumers Power Company; and interviews with individuals familiar with the site. See "Highest-Voltage Transmission System in the World," *Electrical World* 59 (13 April 1912): 795-796; "The Design and Methods Employed in

HISTORY OF THE COOKE PLANT

FOOTE'S EARLY ACTIVITIES

William Augustine (W.A.) Foote (1854-1915) was the eldest of six children born to Augustus and Sarah Foote in Adrian, a small town in southern Michigan. Upon finishing public school in Adrian, Foote embarked upon a career as a flour miller, travelling to Minneapolis in 1878 to study a new grinding process involving steel rollers. Foote returned to Adrian around 1885 and purchased a mill with the financial backing of family friend James Berry.

An ambitious entrepreneur, Foote installed stone rollers in his new mill rather than the standard steel versions in an attempt at innovation. The venture was not the success Foote had hoped it would be. To supplement his income, Foote rented space in his flour mill to an electric power company. The company set up a small, Thompson-Houston electric generator, running it off the mill engine in the evenings to provide power for street lights. Foote found himself as fascinated by the generator as he was discouraged by his mill.

Inspired by the evening activities taking place in his flour mill, Foote signed the mill over to Berry and built a small hydroelectric plant in Adrian with a Thompson-Houston six-light generator. Foote recruited his younger brother James Berry (J.B.) Foote, who had been named for the family friend, to act as his bookkeeper. The younger Foote, not yet twenty years old and without any professional engineering training, quickly demonstrated a natural aptitude in electrical engineering that would prove invaluable to his elder brother's vision.[3]

In 1886, a year after establishing himself as a "utilities man" in his hometown of Adrian, W.A. Foote sold his plant and moved to Jackson, a growing town about halfway between Adrian and the state capitol of Lansing. Although Jackson was already home to two electric companies, the downtown district was still lit by gas lamps. The Foote brothers managed to get a franchise to

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Constructing the Cooke Water Power Plant on the Au Sable River in Michigan," *Engineering and Contracting* 37 (5 June 1912): 639-643; "Water Power from the Au Sable River," *Engineering Record* 66 (31 August 1912): 246-248.; "Au Sable River Hydroelectric Projects—Bidders Cover Sheets, December 1988," Historical Files, Civil/Mechanical Engineering Projects, Engineering and Construction, Consumers Power Company, Parnall Road, Jackson, Michigan; and "Application for New License for Major Project—Existing Dam—Cooke Project—Exhibit A," Hydro Operations, Consumers Power Company, Cadillac, Michigan.

[3] The story of W.A. Foote's entry into the field of power generation has been told in a number of manuscripts and publications. See George Bush, *Future Builders: The Story of Michigan's Consumers Power Company* (New York: McGraw-Hill Book Company, 1973); E. Hardy Luther, "Song of Service," unpublished history of Consumers Power Company, historical files, System Operations, Consumers Power Company, Parnall Road, Jackson, Michigan; and various newspaper clippings in the "Foote Family" vertical file, Minter-Van Orman Reference Room, Jackson Public Library, Jackson, Michigan. For more on J.B. Foote's career, see "Obituary—James Berry Foote," *Au Sable News* 10 (May 1924): 3; "Pioneers—James Berry Foote," *Au Sable News* 9 (June/July 1923): 2-8; and John William Leonard, *Who's Who in Engineering 1922-1923* (New York: John Leonard Corporation, 1922), 454.

illuminate downtown Jackson with arc lighting, as had been done in other Michigan cities like Grand Rapids, Flint, and Bay City. They accomplished this task with great success. Within the next two years, W.A. Foote would establish or gain control of electric companies in Battle Creek, Albion, and Kalamazoo.

ELECTRIFICATION IN THE LATE NINETEENTH CENTURY

In the 1890s, power supply in Michigan was a fully local operation. Electricity could be transmitted only a few miles at most from the point of production to the site of use. The reason for this limitation is known as "line loss." All electric current experiences resistance on a transmission wire, and the farther the current has to travel, the more resistance it encounters. This results in a loss of power sent over the wire. In the late nineteenth century, Michigan power companies usually generated at less than a few thousand volts. The effects of line loss on the current were devastating after a few miles. Many communities burned coal to produce steam as an electrical power source because steam plants could be located virtually anywhere, unlike hydroelectric plants. But coal was expensive and sometimes difficult to obtain. While hydroelectric plants had no fuel cost, only a few fortunate cities, like Battle Creek and Albion, both on the Kalamazoo River, were near rivers suitable for hydroelectric development.

Outside the Midwest, power companies were experimenting with ways of sending electric current over many miles of wire. As early as the late 1880s, Westinghouse Electric Company demonstrated that long-distance transmission was possible with alternating current (AC). Unlike direct current, the industry standard at the time, AC could be passed through a transformer to increase, or "step-up," its voltage, thus compensating for line loss. Higher voltages allowed power utilities like the Willamette Falls Electric Company in Willamette City, Oregon, to send current thirteen miles away to Portland in 1889. In 1895, at the Niagara Falls Hydroelectric Station in New York, Westinghouse used a fully integrated system to send electric current over twenty-six miles of transmission lines to Buffalo. This feat established AC as the new industry standard.[4] Electrical engineers now concentrated on ways to make such transmissions more efficient. At the turn of the century, long-distance transmission lines in Western states could accommodate current pressure as high as 40,000 volts.[5]

HIGH-VOLTAGE TRANSMISSION COMES TO THE MIDWEST

In 1899, W.A. Foote introduced long-distance, high-voltage transmission of electricity to the Midwest with the Kalamazoo River's Trowbridge Dam and Powerhouse. That facility, situated

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[4] For more on early AC achievements, see Jeffrey A. Hess, "Hydroelectric Generating Facilities in Minnesota, 1881-1928," National Register of Historic Places Multiple Property Documentation Form, 1989, 4-5; and Duncan Hay, *Hydroelectric Development in the United States, 1889-1940* (Washington, D.C.: Edison Electric Institute, 1991), 16-20.

[5] Donald Conrad Jackson, "A History of Water in the American West: John S. Eastwood and 'The Ultimate Dam' (1908-1924)," Ph.D. diss., University of Pennsylvania, 1986, 217.

four miles below the confluence of Pine Creek and the Kalamazoo, sent power to a 22,000-volt transmission line, which carried the current twenty-four miles to the city of Kalamazoo.[6]

Trowbridge was Foote's first visible step toward realizing his plan to develop hydroelectric power and send it to communities once thought to be beyond a hydro plant's reach. Foote also proposed, at least two years prior to Trowbridge's opening, to consolidate the power companies of Kalamazoo, Battle Creek, Albion, and Jackson under one control and management.[7] Such a plan would allow the communities to "share" power plants, resulting in lower operating costs and a more efficient distribution of electricity. In 1899, a similar plan went into effect in California when surplus electricity from Yuba Power was sold and transmitted to the Sacramento Power and Light Company on a sixty-two-mile line.[8] Five years later, Foote did consolidate power companies from Jackson to Kalamazoo into a single firm known as Commonwealth Power Company.

RELATED DEVELOPMENTS

Foote was eager to apply his achievements at Trowbridge on the Kalamazoo to other parts of the state with more dramatic results. He was particularly interested in the Manistee and Au Sable Rivers, two extremely stable-flowing streams located in the northern part of Michigan's Lower Peninsula. Uniformly flowing rivers had value as hydropower sites because an even stream flow obviates the need for expensive water storage facilities. Foote hired William G. Fargo, a civil and hydraulic engineer based in Jackson, to conduct a survey of the Lower Peninsula's rivers. Fargo's conclusions showed "the Au Sable to be the best power stream therein. Of all these rivers it has the greatest total power in annual KWH [kilowatt hours], most uniform runoff with the exception of the Manistee River, most clay foundation soil for dams . . . and [is] second only to the Manistee in total fall available for power."[9]

Through the course of acquiring riparian lands near the Au Sable, Foote discovered that a great deal of river frontage was already in the possession of Edward F. Loud and his three brothers, who once ran a lumber business in the area. When that industry went bust, the brothers attempted to develop the area for hydroelectricity. The Louds teamed up with Foote and his growing business to develop the river, but financial backing fell through on their initial try. Eventually, Edward Loud found his way to another utilities holding firm, Hodenpyl, Walbridge and Company, which specialized in gas operations. Loud and Hodenpyl scheduled a meeting in New York. Foote attended the meeting as well, and the eventual result of that encounter was

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[6] Hay, 32.

[7] Luther, "Song of Service," 57-59.

[8] Hay, 107.

[9] Fargo's survey resulted in an unpublished study known as the "Report on Michigan Rivers." See section "#2 Au Sable River," February 1913, Corporate Archives, Consumers Power Company, Bridge Street, Jackson, Michigan.

the reorganization of three firms—Foote's Commonwealth Power Company; Hodenpyl, Walbridge and Company; and the financiers E.W. Clark and Company—into Consumers Power Company, a utilities holding company formally organized in 1909.[10]

The Foote brothers, meanwhile, had not let financial setbacks on the Au Sable project keep them from pursuing other power developments. They continued to build dams and powerhouses to convert Michigan's flowing water into power, work which often yielded valuable technological advances in addition to electricity. In 1906, while erecting a hydro facility at Croton on the Muskegon River, J.B. Foote happened to discover that engineers at General Electric in Schnectedy, New York, were developing new insulators for connecting transmission cables to towers. An insulator's task is to prevent current from electrifying the towers themselves. Turn-of-the-century pin-type insulators (glass or porcelain disks cemented onto wooden or steel pins) limited transmission voltages because they could not accommodate much more than 70,000 volts.[11]

The General Electric engineers had developed "suspension" insulators, porcelain disks that hung from transmission towers. After some initial tests, J.B. felt certain that the new insulators would enable breakthrough transmission voltages, perhaps nearly double the pressure then possible, and he proposed to his company's board of directors that Croton be the first dam on their system to test the new, high-voltage insulators. The board agreed, and when Croton went on line in 1908, it transmitted power forty miles at an unprecedented 110,000 volts.[12]

The technological advances at Croton practically guaranteed that W.A. Foote's old plan to send power generated on the Au Sable River to Michigan's southern markets, or load centers, would work. By 1909, with the formation of Consumers Power Company, Foote finally had the land and the financial backing to try it. The success of the system, which was originally conceived with dams at three sites, depended entirely on the delivery of power to markets as many as 200 miles away.[13] Otherwise, the lack of sufficient load in the north would render the entire Au Sable system uneconomical.

CONSTRUCTION AT THE COOKE SITE

The Cooke Hydroelectric Plant was the first of the Au Sable facilities to be completed. The site was suggested by, and subsequently named for, Andrew Cooke, a financier who accompanied the Foote brothers on survey trips. J.B. Foote served as electrical engineer and William G.

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[10] Bush, 123-137.

[11] E. Hardy Luther, "Early Developments in High Voltage Transmission," *Michigan History* 51 (Summer 1967): 103.

[12] J.B. Foote, "History of the Evolution of the High Voltage Tower Transmission Lines of the Consumers Power Company," *Au Sable News* 7 (September 1921): 10-11.

[13] "The Au Sable River Transmission," *Au Sable News* 23 (April-May 1937): 19-22.

Fargo, the engineer who surveyed the Lower Peninsula's rivers, as civil and hydraulic engineer for the Cooke facility. Fargo had been erecting small-to-medium, low-head hydro plants in the Midwest for fifteen years and built his first dam for the Foote brothers at Trowbridge in 1898.[14] He designed a semi-hydraulic, earth-fill dam to span the river at the Cooke site.

Work began in 1909, when a large construction camp was established on the river's south bank. A tract of land was subdivided into lots that were made available to men working on the dam. The camp was laid out like a village with streets, alleys, and a sewer system, and laborers built tiny cottages on their lots. Bunkhouses, storage buildings, and offices also populated the site, and a large wood-frame, gable-roofed, temporary steam plant with a monitor running nearly the length of the roof ridge provided power for the construction equipment. Most of these buildings were simple, gable-roofed structures sheathed in board-and-batten siding with asphalt-shingle roofing. One small Storage Shed (HAER No. MI-98-F), presently located east of the Powerhouse, survives from the period and exemplifies the type of temporary construction that was seen throughout the camp. The Storage Shed appears to have been moved to this location from some other part of the camp.

A two-and-a-half-story, gable-roofed Attendant's House (HAER No. MI-98-G) south of the Powerhouse (HAER No. MI-98-C) also dates from the construction era. Two houses were originally erected as homes for the plant's future operators. During construction, however, the homes probably served as lodging for engineers or for visiting power company executives. Between the houses and the plant stood a simple, white, two-story bunkhouse.[15] Only the southernmost house survives at the site. No longer associated with the power plant, it now serves as a private residence.

After erecting the camp, workers diverted the river flow to a back channel and excavated the natural riverbed, preparing the site for construction. Crews worked northward from the south bank, where they built the concreting plant. They began by erecting wooden trestles to aid in delivering materials to the excavated river channel. By August 1910, much of the formwork and reinforcing bars were in place for the penstocks, Powerhouse foundation (HAER No. MI-98-C) and Spillway Tainter gate piers (HAER No. MI-98-B). Two months later, that phase of concreting was complete, and the river was redirected to flow through temporary gates installed in the base of the Spillway. By the following February, the trestle for the North Embankment was in place.

[14] Charles K. Hyde, "Croton Hydroelectric Plant," HAER No. MI-81, 1994, Historic American Building Survey/Historic American Engineering Record Collection, Library of Congress, Washington, D.C.

[15] The demolished bunkhouse was identified in a 1933 Consumers Powers Company description: "Known as the Sears House—was moved from [the town of] Au Sable in 1910 and used as a staff house for foremen and office help. It is two stories high and approximately 30' x 70'." The name may indicate that the building was purchased from Sears, Roebuck and Company.

The corewalls for the South and North Embankments (HAER Nos. MI-98-E and MI-98-A) were poured next. Upon their completion, workers could begin sluicing earthen fill into place, burying the trestles as they built up the dam. At the same time, the steel gates were installed in the Spillway and in the penstocks, and the generating equipment was put in place. Finally, the Powerhouse was erected to shelter the machinery.[16]

Upon the plant's completion, each of the three horizontal generating units produced current at a pressure of 2,500 volts. In preparation for the anticipated 125-mile transmission, three transformers standing in the southern end of the Powerhouse stepped up the current to the unprecedented transmission level of 140,000 volts. The higher voltage was made possible by a further advance in insulator design. Manufactured by the Ohio Brass Company, the suspension insulators selected for Cooke used a new connection between the porcelain insulator disk and its metal cap. The "O-B insulators," as they were known, included a gasket between the disk and cap. This helped overcome thermal stresses, previously a common cause of insulator failure. The change resulted in a stronger insulator.[17]

Transmission towers were also refined. The early metal structures were of a tripod design similar to windmill towers. The three legs converged at an apex, and arms extended horizontally to carry transmission wires. Cooke's towers were designed so that the inclining legs did not run to a peak. Rather, vertical members, spaced 4' apart and braced horizontally, extended from the legs to form the top of the tower. This design both stiffened the structure and increased the distance between the cables hung from it. The towers were spaced ten to a mile with cables hanging at least 40' above the ground.[18]

Cooke's transmission lines, outfitted with the more resilient insulators and suspended from newly designed towers, ran eighty-five miles in a southwesterly direction to a substation at Zilwaukee, where power would be stepped down for use in nearby Saginaw and Bay City. The line then proceeded another forty miles to the southeast toward Flint, the initial, temporary terminus of the Au Sable line. Plans dictated that the line would extend to Battle Creek, 250 miles from the Au Sable River, once the other hydro facilities were completed on the river.[19]

Cooke Dam and Powerhouse went on line in February 1912, successfully transmitting power to Flint at 140,000 volts, as planned. Cooke's record-breaking transmission level attracted considerable attention from the engineering press. One journal reminded readers that the

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[16] For more on the plant's erection and on the construction camp, see "Design and Methods Employed," 643. Historic photographs of the construction site offer additional views; see the following historic views appended to this report: HAER No. MI-98-5 and HAER No. MI-98-6.

[17] *Milestones of Transmission Line Construction* (Mansfield, Ohio: Ohio Brass Company, [1929?]), n.p.

[18] Foote, 7.

[19] "Water Power from the Au Sable River," *Engineering Record* 66 (31 August 1912): 246.

"140,000-volt achievement . . . is but the culmination of a series of pioneering advances in high-tension transmission made under the same direction, in the course of which the Michigan systems identified with the Commonwealth Power Company, of Jackson, have been the scene, successively, of the first 72,000-volt, 110,000-volt and now 140,000-volt line ever built or operated."[20] These advances were the direct result of W.A. Foote's efforts to harness power from the Au Sable River, despite its isolated location. "In order to develop the resources of the Manistee and Au Sable Rivers," wrote Foote's engineer-brother J.B., "it was necessary to employ a considerably higher voltage."[21]

Six hydroelectric facilities eventually churned out power from the Au Sable's flow: Cooke, Five Channels (completed in 1912), Mio (1916), Loud (1918), Foote (1918), and Alcona (1924).[22] Consumers Power continued to expand its long-distance electric power lines, creating an interconnected system that combined power from hydro plants and steam plants to supply electricity to most of the municipalities in central Michigan. Only a decade after the record-breaking work at Cooke, company officials could boast in an *Electrical World* article that "the territory served by the [Consumers Power] system covers a large portion of the richest industrial district in the state. The ten largest cities in the state outside Detroit are included in the territory." The "backbone" of that system was 600 miles of 140,000-volt transmission line, the line that began at Cooke.[23]

W.A. Foote died suddenly in 1915, just three years after Cooke's success proved that his dream was possible. "Mr. Foote began his water power development with one great purpose in mind," wrote the *Jackson Citizen Patriot,* "to unite the generation of hydroelectric power with the market and the need of that power. . . . But of far greater consequence are the profoundly valuable and lasting benefits to the industrial and social life for the State still accruing and multiplying from the work that this man began."[24]

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[20] "Highest Voltage System," 795.

[21] Foote, 6.

[22] "Bidders Cover Sheets," n.p.

[23] Percy P. Mooney, "Hydroelectric Plant Operation," *Au Sable News* 8 (May 1922): 9; Harry J. Burton and William W. Tefft, "Michigan a Leader in Interconnection of Hydro and Steam Plants," *Electrical World* 79 (18 February 1922): 329; Allen M. Perry, "Operating a Fully Interconnected System," *Electrical World* 86 (26 September 1925): 657-662.

[24] "Beautiful Memorial to W.A. Foote Unveiled in Woodland Cemetery, Jackson," *Au Sable News* 10 (January-February 1924): 3-4. This article was reprinted from the *Jackson (Mich.) Citizen Patriot.*

CHANGES AT THE COOKE PLANT

The Cooke Hydroelectric Plant has experienced few changes since it went on line in 1912. A 2'-0" concrete cap was affixed to the tops of the corewalls and fill was added to the embankments in 1925, allowing for an increase in the height of the impoundment headwater elevation. The height of the Spillway Tainter gates was increased accordingly. Also in 1925, the original monitor that adorned the roof of the Powerhouse was removed. The Powerhouse interior has seen some alterations, including a switching station installed in the northeast corner and an enclosed, air-conditioned office built around the switchboard near the downstream (east) wall of the building. The date of these changes is unclear.

Functionally, the plant has undergone more substantial alterations. Cooke no longer sends power directly to southern Michigan, nor does it transmit at its record-breaking voltage level. The plant now delivers its electricity at a much more modest 46,000 volts to an Iosco-Loud transmission substation, situated only 150 yards southwest of the new, outdoor Substation (HAER No. MI-98-D). The outdoor Substation, adjacent to the Powerhouse at the south end of the building's main (east) facade, appears to have been built in the late 1940s. Cooke's original transformers were removed from the south end of the power house in 1957.[25] The original electrical generating equipment is still essentially intact and operating well, however, and the overall appearance of the plant is largely unchanged.

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[25] For changes to the facility see the following engineering drawings in Consumers Power Company's Corporate Archives at Bridge Street, Jackson, Michigan: Commonwealth Power Corporation for Consumers Power Company, "New Roof—Cooke Development, 1925," Drawing M28-F1007; "Layout of Bus Run from Switch Structure, 1925," Drawing M28-G28 Sheet 1, updated through 1993; "Cooke Dam—Raise Head, Corewall, etc., 1925," Drawing M28-F1005; and Consumers Power Company, "General Design—Exhibit F2, 1994," Drawing No. 28, Sheet F2.

SOURCES OF INFORMATION

ENGINEERING DRAWINGS

Commonwealth Power Corporation for Consumers Power Company. "New Roof—Cooke Development, 1925." Drawing M28-F1007. Corporate Archives, Consumers Power Company, Bridge Street, Jackson, Michigan.

———. "Layout of Bus Run from Switch Structure, 1925." Drawing M28-G28, Sheet 1, updated through 1993. Corporate Archives, Consumers Power Company, Bridge Street, Jackson, Michigan.

———. "Cooke Dam—Raise Head, Corewall, etc., 1925." Drawing M28-F1005. Corporate Archives, Consumers Power Company, Bridge Street, Jackson, Michigan.

Consumers Power Company. "General Design—Exhibit F2, 1994." Drawing No. 28, Sheet F2. Corporate Archives, Consumers Power Company, Bridge Street, Jackson, Michigan.

Fargo, William G. "Plans for Attendant's Houses—Cooke Site, Au Sable River, 10-23-09." Drawings 1605A and 1606A. From the homeowner, 1201 Cooke Dam Road, Oscoda, Michigan.

HISTORIC VIEWS

Cooke Hydroelectric Plant construction and overview photographs. Historical files, Hydro Operations, Consumers Power Company, Cadillac, Michigan.

INTERVIEWS

Hicks, David, 1201 Cooke Dam Road, Oscoda, Michigan. Interviews by Jeffrey A. Hess and Cynthia de Miranda, Hess Roise and Company, Minneapolis, Minnesota, 27 July and 8 November 1995.

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"Application for New License for Major Project—Existing Dam—Cooke Project—Exhibit A." N.d. Hydro Operations, Consumers Power Company, Cadillac, Michigan.

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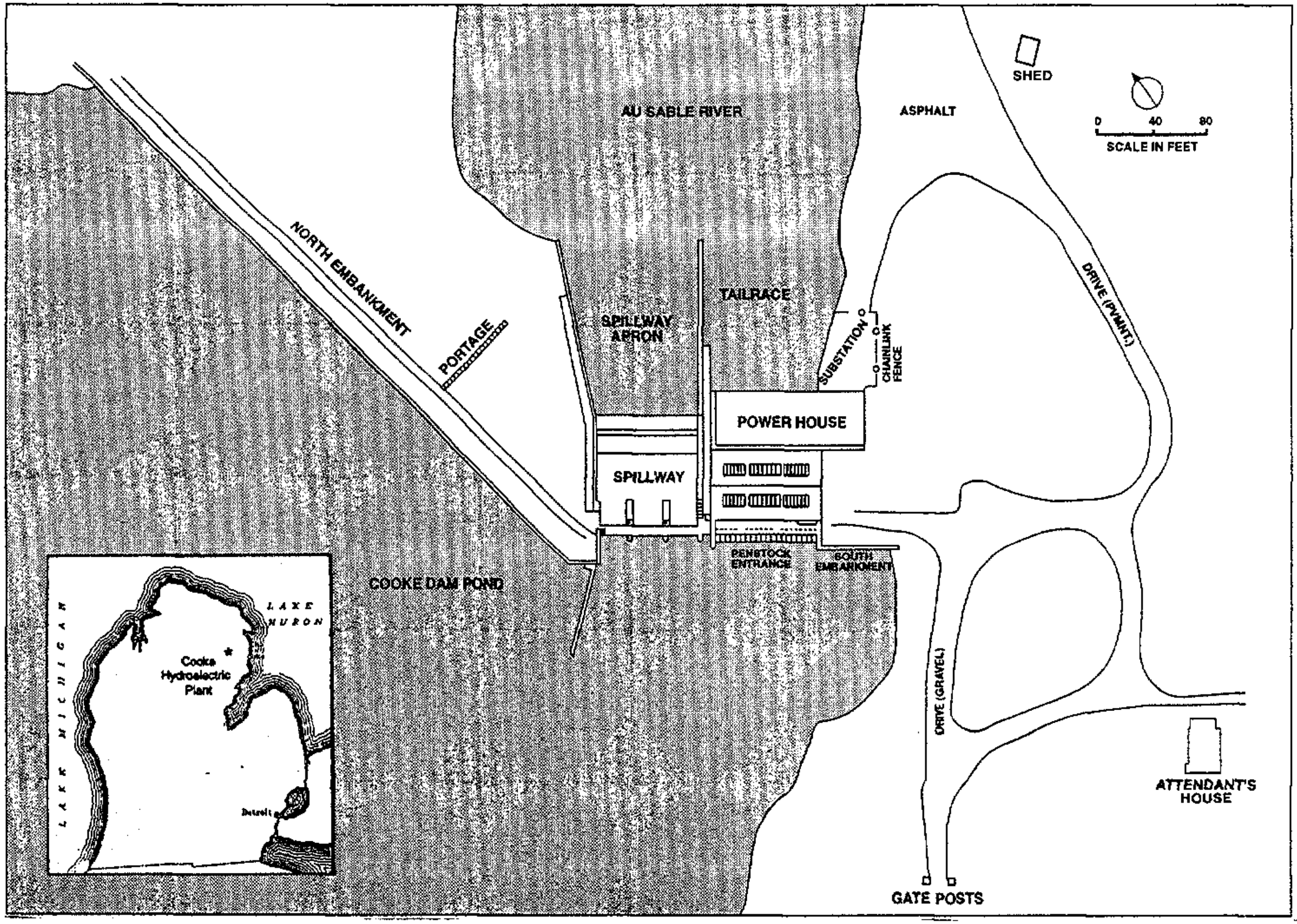

Figure 1 *Cooke Hydroelectric Plant—General Site Map and Regional Map (insert)*

North Embankment	HAER No. MI-98-A	South Embankment	HAER No. MI-98-E
Spillway	HAER No. MI-98-B	Storage Shed	HAER No. MI-98-F
Powerhouse	HAER No. MI-98-C	Attendant's House	HAER No. MI-98-G
Substation	HAER No. MI-98-D	Gate Posts	HAER No. MI-98-H

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NEW YORK, SATURDAY, APRIL 13, 1912.

CONTENTS.

TRANSMISSION AT 140,000 VOLTS.

It is with great pleasure that we are able to describe in the current issue a transmission system which marks another step forward in the utilization of high voltage for electric-power transmission. Transmission at 140,000 volts represents a long step forward, since it almost cuts in half the amount of copper required for transmission at the highest voltage previously attained. As our readers will remember, the maximum voltage utilized hung for very nearly a decade in the region around 50,000 or 60,000 volts. The number of plants operated at such voltage was steadily increasing, but the movement forward was temporarily checked. There was good reason for this, for at about the point mentioned the practical limit of insulation by means of pin-type insulators seems to have been reached. Such insulators, although they had been greatly improved over those used at lower pressures, became unwieldy and troublesome as attempts were made to adapt them to higher and higher voltages, and finally the time came when the danger limit was near. Considering the various contingencies of practical use, it has proved unsafe to operate transmission line insulators with a factor of safety below 2.5 or 3. Even at 50,000 volts working pressure this factor was impaired when the weather conditions were bad. It is doubtful whether any pin-type insulator yet manufactured can be trusted to stand up at 100,000 volts, under spray equivalent to what may be encountered in practice, with any degree of certainty. In most cases even the most carefully designed insulators will frequently spill over under test below this pressure. These conditions do not justify the use of working voltages much in excess of 60,000 volts, although this figure was now and then under fairly favorable circumstances exceeded. The great step forward was made with the advent of the suspension insulator, which itself has been steadily improved. By the use of such insulators the factor of safety could be increased to almost any extent necessary, and the immediate result of the introduction of this type was a jump forward in voltage to the vicinity of 100,000—a pressure quite adequate for most transmissions even of the kind which would now be classified as long-distance. The step forward to 110,000 volts was made on the Michigan system with which the plant here described is affiliated and was soon followed by others. Once the mechanical details of suspension insulation had been worked out, it was obviously only a question of a little time before the voltage would pass above the 100,000-volt mark to almost any point which economic considerations demanded.

The Au Sable transmission seemed to offer a favorable opportunity for another advance in voltage, although in point of fact the distance was in itself one which could comfortably be spanned without going to extremes; but modern practice tends more and more to the building up of networks covering huge territory, and as these develop, increase of working pressure is a logical necessity even though the first linkages in the network may not absolutely require it. It was therefore determined to go forward and the great step was taken. The system went into operation about a month ago over the first 125 miles of a line ultimately to be 100 miles longer, and has been in entirely successful service since then.

The point of greatest interest, of course, is the line itself. It is carried on steel galvanized towers of the tripod construction of 40 ft., 50 ft. and 60 ft. on the lowest conductor, spaced about 500 ft. apart. Two conductors are carried on one side of the tower and one on the other, each supported by a string of 10-in. disk insulators occupying a vertical space of 5 ft. 3 in. The two conductors on the same side of the tower are 12 ft. apart vertically, while the other two sides of the triangle are 17 ft. 4 in. The conductors themselves are No. 0 equivalent, medium hard-drawn stranded copper, and under ordinary conditions seldom show coronal discharge even at the full working pressure of 140,000 volts. This pressure is pretty near to the critical coronal pressure, however, so that when operated, as it happens to be just at present, with a heavy rise in voltage due to the capacity reactance, the losses by discharge toward the receiving end of the line rise to a considerable magnitude. The charging power required is in the vicinity of 80 kva per mile, and when the receiving transformers are disconnected the open line carries about 3000 kw dissipated as coronal and leakage loss in one form or another as the voltage rises. Load at the receiving end may actually diminish the line current as the power-factor moves toward unity. With the load for which the transmission is designed, some 25,000 kw, the added inductance should pull the power-factor near to unity and keep the voltage down to a point where the coronal losses will become comparatively trivial. At the present time, with a heavy lagging load of 4000 kw at the end of the line, the power-factor at the generators has been found as high as 85 per cent, leading, so that a very heavy load is obviously necessary to pull down the power-factor to a reasonable point. It still remains a question whether, in view of heavy real coronal losses and the difficulties of regulation induced by the extremely high capacity reactance, so high a voltage as this is justifiable for the amount of energy delivered. With considerably larger conductors, corresponding to a very much greater load transmitted, this difficulty would be in part offset.

The interesting thing, however, is that the difficulties of operation do not depend on any question of insulation strength, since the line has actually performed as steadily and peacefully as if worked at much lower voltage, but rather upon the extreme magnitude of the reactance factors. It would seem that much remains to be done in the way of controlling these before the use of so high a voltage as 140,000 can be undertaken on a large scale. The difficulties are certainly not insuperable. They may be greatly reduced by judicious installation of inductive load at the substations along the line, by dropping the frequency, using the smoothest attainable wave-form and applying various other remedies which will promptly suggest themselves to the engineer.

HIGHEST-VOLTAGE TRANSMISSION SYSTEM IN THE WORLD.

Plant of the Au Sable Electric Company, Supplying Electricity to Bay City, Saginaw and Flint, Mich.

Special 140,000-Volt Oil Switches, Lightning Arresters and Transformers. Details of Line Construction and Wall Inlets—Operating Characteristics and Provisions for Tests.

ANOTHER long stride in the advance of transmission potentials is marked by the use of 140,000 volts pressure on the Au Sable Electric Company's newly built 235-mile system connecting its Au Sable River water-power sites with Bay City, Saginaw, Flint and, later, Owosso, Lansing and Battle Creek. The present 125 miles of 140,000-volt line has already been in successful and uneventful service more than a month, and on test has been carried to a potential of 145,000 volts as measured at the power house, with a corresponding pressure at the substation end of 170,000 volts, due to the condensive reactance of the long line. The conductors are supported on suspension insulators composed of ten 10-in. disks, each disk tested to withstand 80,000 volts continuously or 125,000 volts momentarily, and all high-tension insulation and clearance are designed with a wide margin of safety beyond the normal 140,000-volt operating potential. Special designs of standard high-voltage equipment were required to fulfil the 140,000-volt conditions for oil switches, lightning arresters and transformers. The three last-mentioned units have their high-tension windings delta-connected, imposing the full 140,000-volt pressure across the coils, and in several cases transform down, in a single step, to minor 370-volt secondaries, a ratio of nearly 400 to 1.

Over the 140,000-volt line, hydroelectric energy from the 9000-kw Cooke plant, developing a 40-ft. head on the Au Sable River in the wilds of Iosco County, is now being transmitted 85 miles to the Zilwaukee substation, which supplies Bay City and Saginaw, and 40 miles further to Flint, where with a steam-turbine auxiliary a large industrial load is served. The Cook development is but the first of several water-power sites on the Au Sable River, whose output will be delivered over the new transmission line. A second site at Five Channels, 8 miles above Cooke, is now under development and will be operating before the close of the year. By June the 140,000-volt transmission will be in use as far as Owosso and Lansing, later tying in to the associated transmission systems at Battle Creek, a distance of approximately 250 miles from the power site on the Au Sable River.

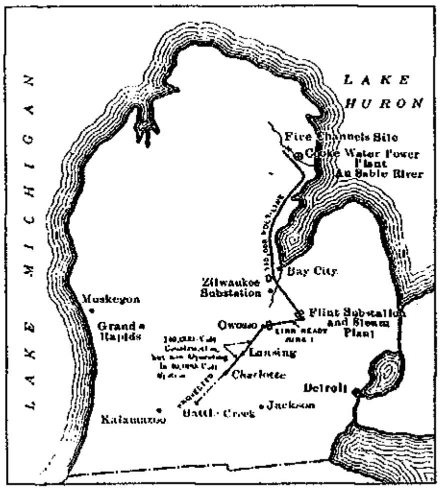


Fig. 2—Map of 140,000-Volt Transmission Line.

This present 140,000-volt achievement, the reader should be reminded, is but the culmination of a series of pioneering advances in high-tension transmission made under the same direction, in the course of which the Michigan systems identified with the Commonwealth Power Company, of Jackson, have been the scene, successively, of the first 72,000-volt, 110,000-volt and now 140,000-volt line ever built or operated.

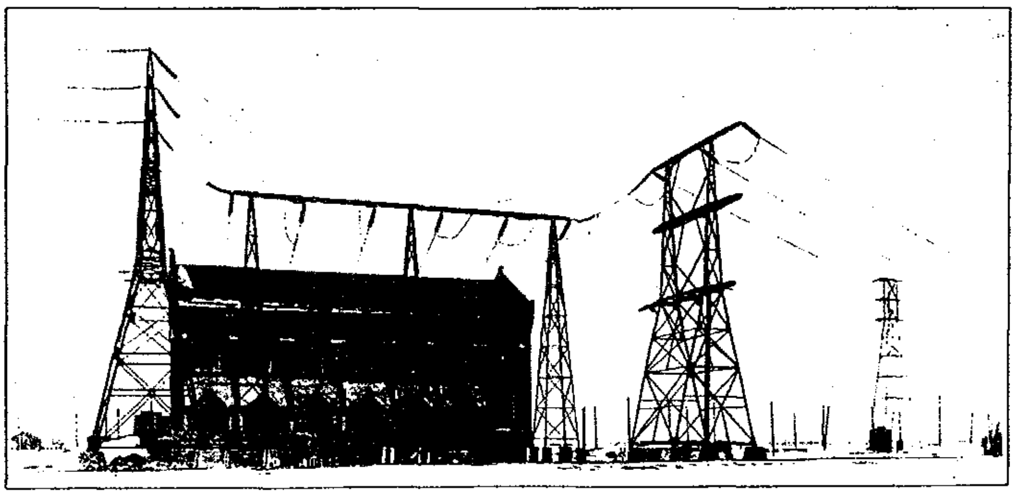


Fig. 1—140,000-Volt Entry Towers and Substation at Zilwaukee.

AU SABLE RIVER AND COOKE PLANT.

Unusual uniformity of flow marks the Au Sable River, the run-off of which at flood has rarely reached more than three times its minimum flow, 1100 cu. ft. per second, as shown by the records of ten years. Springs emerging from the clay strata which underlie the sandy surface of this part of the peninsula are believed to account for this regularity of flow, for the stream is fed by but two insignificant tributaries of a few second-feet each in its whole length of 60 miles from the power sites to the confluence of the three streams which form the main river.

The Cooke plant is located about 16 miles from the mouth of the Au Sable, and at approximately the same distance from the nearest towns, Au Sable and Tawas City. It is a dozen miles from any human habitation and can be reached only by driving 18 miles across country, or by a narrow-gage logging railroad from Au Sable. The development comprises a 40-ft. concrete dam and power house and concrete-core wall inclosed in earth embankment, creating a pond 2000 acres in area and making available a head of 40 ft.

The power house measures 67 ft. by 116 ft., with massive concrete foundations and molded water passages, the upper building walls being of red brick with truss-supported roof. Between the power house and the spillway section is a 6-ft. log sluice. A free spillway length of 72 ft. is provided by three 24-ft. by 13-ft. Tainter gates, which will be operated by a 7½-hp motor controlled from the gatehouse above.

The same Tainter construction is also applied to the 20-ft. by 25-ft. headgates which admit water to the turbine chambers, as shown in an accompanying illustration. This use of Tainter gates for penstock control is probably the first application of its kind in American hydraulic design, although the idea has been used abroad. Later it is planned to control these gates from the switchboard so that the amount of gate opening will be under the hand of the operator.

The hydroelectric equipment comprises three 4150-hp

Fig. 3—Tainter Headgate and Interior of Turbine Chamber.

Allis-Chalmers four-runner water turbines driving 3000-kw General Electric 2500-volt, 60-cycle, three-phase alternators at 180 r.p.m. The waterwheels are controlled by Allis-Chalmers oil-pressure governors of a newly improved type, driven through double belts and having their fly-ball settings adjustable from the switchboard. Each main generator has its individual 32-kw interpole 125-volt exciter mounted on its shafts, all three exciters being connected to a common direct-current bus. A grease gun provides forced lubrication to eight bearing points on each water turbine.

In the south end of the generator room are grouped the 140,000-volt transformers and oil switches. The station

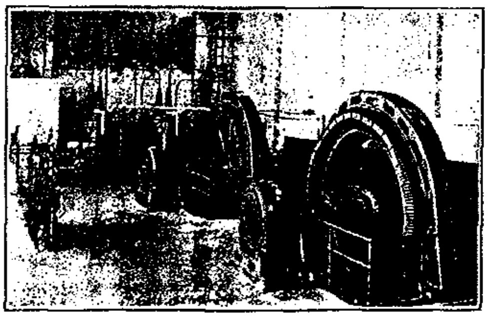


Fig. 4—Generators and 140,000-Volt Exit at Cooke Plant.

switchboard is mounted opposite the middle generator, all connections and auxiliary equipment being located in the basement. Inclosed in conduit the 2500-volt generator leads are brought up to the General Electric K-12 15,000-volt type oil switches, which connect to the station bus through hook switches. A 2500-volt aluminum-cell lightning arrester protects the station bus. This 2500-volt bus is thence extended directly to the delta-connected transformer primaries, through air-break disconnect switches mounted on the transformer cases.

The switchboard at Cooke comprises three generator panels and one regulator panel. The latter carries a twelve-section Tirrill regulator, which is supplemented by an excess-voltage relay, designed to reduce the generator pressure in case the voltage passes beyond the control of the Tirrill regulator. Besides the standard complement of switchboard instruments, there are a synchroscope, a frequency indicator, a curve-drawing wattmeter and a recording frequency meter. The last mentioned, built by the Lombard Governor Company, comprises a small synchronous motor driving a fly-ball governor, the amplitude of whose arms is recorded, through a sliding collar, by a stylus marking on a clock-driven paper ribbon. The generator oil switches are operated from switchboard levers and are equipped with time-limit relays set to open in five seconds at 1200 amp, the tripping coils being energized from the direct-current bus. Series and shunt instrument transformers, field rheostats and the station-service transformers are all mounted in the basement bus compartment.

140,000-VOLT TRANSFORMERS.

Three 3000-kw General Electric oil-insulated water-cooled transformers step the generator pressure, 2500 volts, up to the 140,000-volt transmission potential, both low-tension and high-tension windings being delta-connected. These huge transforming units measure 11 ft. by 5 ft. in section and 14 ft. 6 in. to the top of their cases, or 19 ft. 6 in. to the tips of the high-tension terminals. When shipped the tanks had to be laid obliquely in gondola cars to meet the railroad clearances. Each tank weighs 17,000 lb. and its core 34,000 lb., making the total weight per transformer, filled with oil, nearly 43 tons. The composition-filled 140,000-volt terminals measure 4 ft. in height and taper in diameter from 20 in. to 10 in., being fitted with twenty 3-in. pressboard leakage rings to increase the surface path between conductor and case. A center distance of 5 ft. is provided between terminals on the transformers, and this minimum distance between 140,000-volt conductors and ground is preserved everywhere about the high-tension structures.

except for the oil-switch terminals, which are separated only 4 ft. The transformers are themselves installed at center distances of 11 ft. Before shipment a factory test of 280,000 volts, or double rated pressure, was given these units.

Ordinary ¾-in. iron pipe is used for the 140,000-volt buses and connections, all high-potential parts being either supported on the transformer oil switch or entry insulators or suspended from regular 10-disk line insulators. All turns are made by bending the pipe, and for exposed joints couplings are used cut with extra threads for backing out one side so that the conductors can be dismantled without the use of unions, whose sharp points would give rise to corona effects. Where the use of unions has been necessary, and also where taps are made to the overhead buses or these are supported by the insulator hangers, hollow brass balls inclose the irregular and sharp points of the fittings, eliminating corona discharges. A minimum clearance distance of 5 ft. between conductors and ground has been preserved in all high-tension construction, although much wider spacing is used wherever possible.

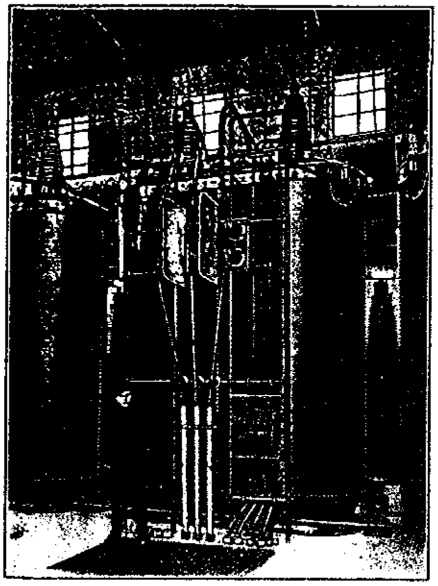


Fig. 5—3000-kw, 140,000/22,000/370-Volt Transformer.

Behind the transformers in the Cooke power house are installed the 140,000-volt General Electric K-10 oil switches, designed to break 100 amp per phase, the full-load current of the 9000-kw transformer group being, however, but 21.4 amp. The oil-switch tanks measure 8 ft. by 4 ft. in plan and 12 ft. to the top of the terminals, which are generally similar to those on the transformers. One of the stationary contact elements and terminals is shown in Fig. 7, the circuit being completed between two such contacts by a lower moving bridge element, which has an 18-in. travel and thus in its open position interposes a double break totaling 36 in. of oil path between the terminals. These oil switches are hand-operated and wholly non-automatic, being controlled from a hand lever in the high-tension pit. They have been tested by actually rupturing pressures up to 500,000 volts and are believed to be capable of breaking any current which may occur in the line.

Both switch and transformer tanks can be drained of their oil by 6-in. pipe lines discharging into a pair of steel tanks with a combined capacity of 9000 gal., equal to that of one transformer tank. A motor-driven pump is provided for returning the oil to the apparatus tanks after repairs have been made. Provision is also made for continuous sampling and filtration of the oil in any transformer without removing the unit from service. Through taps at the top and bottom of the transformer case the oil is withdrawn and filtered by forcing it, at 200-lb. pressure, through a series of thirty filter sections, each containing five 8-in. by 8-in. filter papers, making a total thickness of about 0.75 in. of paper. The paper filters the oil and removes all moisture, returning it to the case dry and clean. With the filter equipment provided for each tank of 140,000-volt transformers, 300 gal. of oil can be filtered per hour. In starting up the transformers, the entire contents of each tank were passed through the filter three times. The oil will be filtered again as needed, when its moisture tests show the need of further drying out. All circulation water lines for the 140,000-volt transformers are heavily lagged with a 1-in. asbestos covering on both the entry and discharge sides. No special provision is made for grounding the transformer and switch tanks except through the usual oil-pipe and water-pipe connections.

HIGH-TENSION WALL INLETS AND LIGHTNING ARRESTERS.

Much interest attaches to the method of bringing the 140,000-volt conductors out through the walls of the building. In all cases on the Au Sable line these inlets are entirely closed and weatherproof, the construction being best explained by the illustrations, showing the entry insulators placed at 11-ft. centers. The entry insulators used for the indoor portions are similar to the filled terminals on the 140,000-volt apparatus, while for the outdoor sections a 6-ft. petticoated porcelain type is employed corresponding to those on the outdoor lightning arresters. From tip to tip these entry insulators thus measure 10 ft., 6 ft. of which is outside. The entry insulators are seated in iron ring castings supported on the 45-deg. angle framing, the middle panels being of sheet metal made removable so that the entry insulator can be slipped out of place if desired. The other parts of the entry boxes are of plastered "Hy-Rib," supported on steel framing. A 3-ft. gable protects each line wire from the roof drippings. The entry box steel work

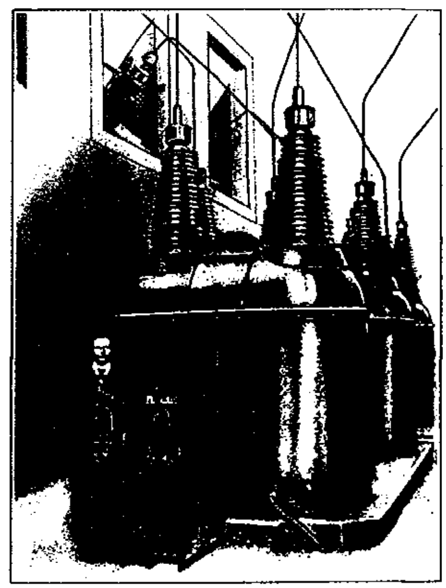


Fig. 6—140,000-Volt Oil Switches in Zilwaukee Substation.

is not specially grounded, except through the natural moisture in the brick wall. The entry wall openings measure 9 ft. by 11 ft., with 9-ft., 45-deg. canopy roofs, and are placed at 11-ft. center distances.

Connection between the entry jumpers and the dead-ended line wires is made through removable clip contacts,

Fig. 7—Terminal Bushing and Contact of 140,000-Volt Oil Switch.

which can be disconnected in case of emergency. These special contact clips are provided with funnels to guide into place the threaded caps of 18-ft. treated hard-maple sticks. After screwing the pole end into position a further twist opens the contact springs and releases the clip. This disconnect feature is intended only as an emergency expedient to be used to isolate the station apparatus while the potential is off the line, but as it is now designed it is believed that the full 140,000-volt pressure might be interrupted in this way, using a grounded stick, without danger to the operator.

Tapped into the line wires just outside the entry jumpers will be the connections for the 140,000-volt General Electric outdoor aluminum-cell lightning arresters. These huge units have been delivered to the system, but in the haste of starting up the line have not been installed during the winter months. Each tank measures 6 ft. by 3 ft. and is arranged with 9-ft. porcelain line terminals and 6-ft. center terminals.

TOWER-LINE CONSTRUCTION.

The transmission conductors are of No. 0 medium hard-drawn stranded copper cable, made up of seven No. 8 wires drawn upon specifications of the power company by the American Brass Company. At 140,000 volts the line wires, 3/8 in. in diameter, are practically without a visible corona or brush discharge, except during unusual atmospheric conditions when a slight discharge can sometimes be noticed on a dark night. The charged conductors do, however, produce a readily audible buzz or hum that can be heard for several hundred feet.

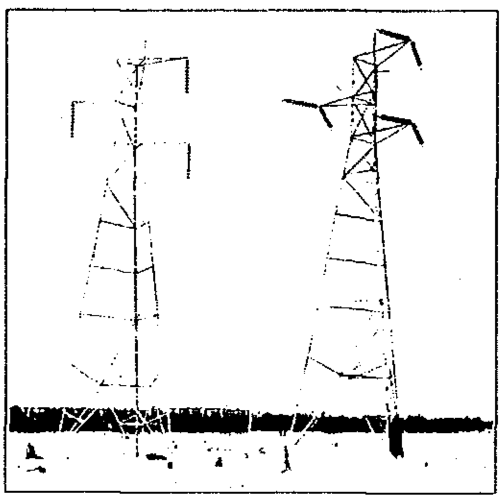
Tripod steel galvanized towers measuring 40 ft., 50 ft. and 60 ft. to the lowest conductors, built by the Aermotor Company, are erected at intervals of 500 ft., 865 towers being used in the transmission from Cooke to Zilwaukee and 420 towers from Zilwaukee to Flint. These towers are foundationed on 3-in. by 3-in. by 3/16-in. steel anchors spaced by means of a template, and are raised and bolted into place after being assembled at the site. The standard "40-ft." tower, measuring 54 ft. over all, which is used under ordinary conditions, has 3-in. by 3-in. by 3/16-in. angle steel legs, and 3-in. by 3-in. by 1/4-in. angle cross-arms, each arm being braced by a 5/8-in. round rod.

Each string of ten 10-in. disk insulators measures 5 ft. 3 in. from mast-arm to conductor. These insulators, made by the Ohio Brass Company, are designed to stand a continuous potential of 80,000 volts per disk and have been subjected to a momentary "kick test" of 125,000 volts per disk. On the tower line the three conductors form a triangle with sides respectively 17 ft. 4 in., 17 ft. 4 in. and 12 ft., the last being the vertical distance between the two conductors on the same side of the tower. The conductors were strung with the aid of a dynamometer, being pulled up to a tension of 1200 lb. each, allowing for approximately a 12-ft. sag in the 500-ft. spans.

On tangent stretches simple suspension construction is used, but wherever the line turns through more than a few degrees the strain-type construction illustrated in Fig. 9 is employed. In this case the same type of 10-disk insulator is used, the spans being dead-ended in special side-pass clamps supported by the insulators and the conductor then extended to the opposite strain insulator on the same arm, forming a 12-ft. loop which must clear the arm and all grounded parts of the tower by at least 6 ft.

The 140,000-volt, ten-disk insulator line is now completed from the Five Channels site past Cooke to Flint and the line from Flint to Owosso is nearing readiness for operation. The 50-mile line from Owosso to Charlotte was erected two years ago, using eight disks per insulator, and is now operating at 40,000 volts awaiting the delivery of Au Sable water-power. The ten-disk insulators will be added before 140,000-volt operation begins.

Various different heights of towers have been used to conform to the contour of the country through which the line passes. In one place an earth bank had to be excavated to clear the wires on a special span. Two 167-ft. steel towers (Fig. 13) support the 600-ft. span across the Saginaw River near the Zilwaukee substation. These towers also carry the 11,000-volt and 22,000-volt lines from the Zilwaukee substation into Saginaw, the minimum span height being 135 ft. The erection of the structures in-



Figs. 8 and 9—Standard Tower and Corner Tower Respectively.

cluded the solution of an unusual foundation problem, for the ground at this point is made from the slab and log refuse of years of sawmill operation. After cutting through many feet of this material a firm footing was finally reached.

Other features of this transmission system will be described in a following issue.

HIGHEST-VOLTAGE TRANSMISSION SYSTEM IN THE WORLD—II.

The Au Sable Electric Company, Supplying Electrical Energy to Bay City, Saginaw and Flint, Michigan.

Hydraulic Features and Construction Details of Cooke Water-Power Plant—Operating Characteristics of 140,000 Volts—Substations with Specially Designed Apparatus.

THE first instalment of this article, printed last week, gave a general description of the transmission system of the Au Sable Electric Company and details of hydroelectric equipment, 140,000-volt transformers, high-tension wall inlets, lightning arresters and tower-line construction. The present instalment, which concludes the article, deals with other construction and operating details.

ZILWAUKEE SUBSTATION.

Eighty-five miles from the Cooke water-power plant is the Zilwaukee 140,000-volt substation, located about midway between Bay City and Saginaw, into each of which it delivers 11,000 and 22,000-volt energy. As shown in the exterior view of the Zilwaukee substation (Fig. 1), the 140,000-volt line (which extends southward to Flint) is looped through the substation buses from which is taken the supply for the three 3000-kw Zilwaukee transformers. Three sets of high-tension oil switches, like those at Cooke, are provided here, for the incoming and outgoing lines and station transformers respectively.

This interesting substation at Zilwaukee is a concrete foundationed structure, 88 ft. by 49 ft. in plan, with red brick walls and green tile roof. The Cooke line, coming in through the north entries, is led through a set of 140,000-volt oil switches and thence to the substation 140,000-volt buses, made of 1.25-in. iron pipe suspended on line insulators. The group of oil switches for the Flint line and for the Zilwaukee transformers are interspersed at 5½-ft. centers, or 11 ft. between elements of the same group. These non-automatic switches are similarly hand-operated from lever panels, and the construction of bus connections, etc., is in general similar to that already described at Cooke.

The three 3000-kw Zilwaukee transformers have 140,000-volt delta-connected primaries and secondary windings comprising a 2750-kw, 22,000-volt coil, with 50 per cent or 11,000-volt taps, and two 125-kw, 370-volt secondaries for rotary-converter supply. The 300-kw, 500-volt railway rotary seen in Fig. 11 affords an interesting comparison of the hugeness of the 140,000-volt oil switches and transformers.

Fig. 10—140,000-Volt Entries at Zilwaukee Substation.

From the transformer secondaries the 22,000-volt and 11,000-volt lines are carried through a casting-covered floor trench to the oil-switch and busbar room behind the switchboard seen in Fig. 12. Here are located the oil switches controlling the circuits leading to Saginaw and Bay City, the instrument transformers and the 22,000-volt and 11,000-volt aluminum-cell lightning arresters. The simple and compact construction of all this 22,000-volt apparatus is no less interesting than the more spectacular equipment on the opposite side of the station. As might be expected in a 140,000-volt system, pressures of 22,000 to 11,000 volts are treated something like "low tension," and the greatest simplicity consistent with completeness is displayed in the selection and disposal of this distributing line apparatus. The secondary lines leave the substation on the side opposite the 140,000-volt entries and are carried on separate tower lines with three disk suspension insulators into their Bay City and Saginaw terminals.

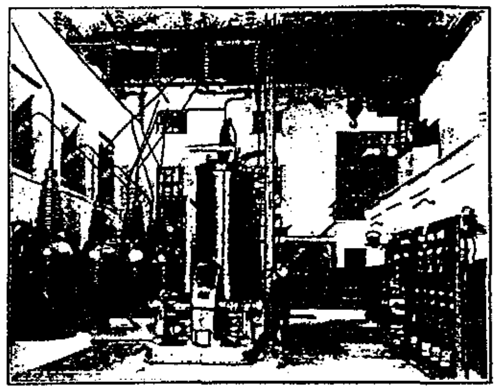


Fig. 11—Interior of Substation, Showing 140,000-Volt Switches and Transformers and 300-kw Rotary Converter.

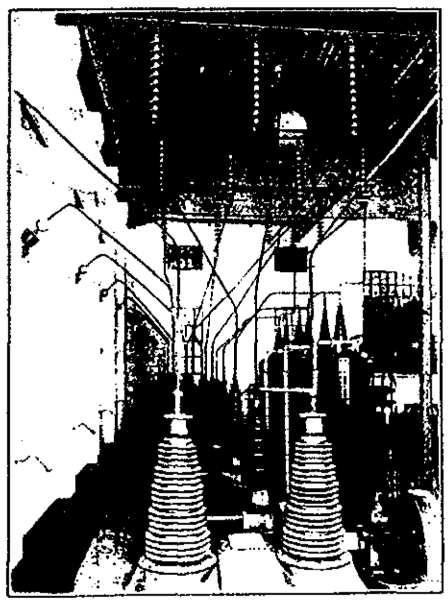


Fig. 12—140,000-Volt Bus Construction in Substation.

FLINT STEAM RELAY STATION.

At the Flint steam-turbine plant, 40 miles from Zilwaukee and 125 miles from Cooke, is the present terminus of the 140,000-volt line. The 30-mile link to Owosso (see map, Fig. 2) is, however, now nearly completed, while from Owosso to Lansing and Charlotte a 50-mile section of eight-disk insulator line has been erected two years and is

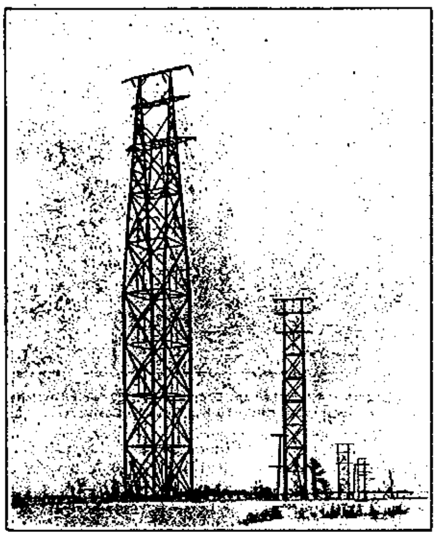


Fig. 13—140,000-Volt Line Crossing Saginaw River on 167-ft. Towers.

at present in use on the 40,000-volt system. While now a terminal substation, Flint will thus later become a switching point like Zilwaukee. For 2 miles before entering the Flint station the Zilwaukee and Owosso lines share a double tower line, at the end of which will be built a switch house adjoining the Flint plant.

A large industrial load, including several automobile factories, is supplied at Flint, for which purpose the present steam-turbine station was hastily built two years ago, pending the arrival of Au Sable hydroelectric energy. This modern steam plant contains six 600-hp Stirling boilers and one vertical and one horizontal 3000-kw Curtis-General Electric turbo-generator set. The 140,000-volt oil switches and transformers are installed at the north end of the turbine room. The high-tension entries here differ from those at Cooke and Zilwaukee in having the insulators set vertical in a horizontal shelf which forms the ceiling of a niche chamber, 30 ft. by 25 ft. and 12 ft. deep, in the building wall. The oil switches are spaced at 8-ft. intervals and the transformers at 9-ft. centers. At Flint the three 3000-kw transformer units have 22,000-volt, 5560-volt and 370-volt secondaries and are arranged for oil draining and continuous filtration in the way already described.

The Flint turbine station thus becomes the steam relay plant for the 140,000-volt system and, in case of any interruption to service from the Cooke water-power, can be called upon to transmit back through the line to Bay City and Saginaw as well as to serve the cities along the new extension. The substation at Owosso was originally erected for 140,000-volt operation and is installed complete ready for service at that pressure as soon as the link from Flint is completed.

OPERATING CHARACTERISTICS AT 140,000 VOLTS.

From the day the full tension was first impressed on the Cooke transmission line its operation has been so wholly uneventful that the men in charge of the stations declare they notice no difference between operating at 140,000 volts and 40,000 volts. The utmost care had been exercised in erection and preparation and every contingency was so fully anticipated that on starting up the system everything worked exactly as planned.

As is customary when putting pressure for the first time on any new high-voltage line, both the charging kilovolt-amperes and the energy consumed by the unloaded line were rather large during the first half hour, but stable conditions soon followed and the apparent power taken to charge the line then fell off to about 80 kva per mile. The No. 0 conductors of this line, it must be remembered, are operated very near to their critical corona point, 142,000 volts. With 140,000 volts on the generator and the Flint transformers connected but not loaded, pressures 17 per cent higher, or nearly 164,000 volts, are read at Flint, due to the capacity reactance of the line. With the receiving transformer primaries disconnected, the end voltage of the open line probably rises to 190,000 volts, although no measurements have been taken. Of course, the excessive rise above the corona point in the distant sections causes leakage losses in those portions which may run quite high. With receiving transformers disconnected, the open line is found to consume or leak about 3000 actual kw, dissipated as corona loss in the distant sections when the voltage is high. With additions of load at the receiving end the line current remains practically the same or even diminishes, depending on the inductive character of the demand, while the power factor, of course, rises. With a 4000-kw 65 per cent lagging inductive load at Flint, the power-factor at the generators has been observed to be 85 per cent leading. With accession of further inductive load and the completion of the Owosso link, it is expected to be possible to move the point of unity power-factor back to the generating station. No tests have thus far been made on the corona power loss of the line running at normal 140,000-volt pressure, but this loss is believed to amount to about 3 kw per mile. The transmission is designed to convey about 25,000 kw, and as the point of economic loading is approached its condensive reaction will be offset, a more uniform voltage maintained from end to end, and its efficiency increased. Like any large piece of apparatus, a 140,000-volt line must be operated within the magnitude of its capabilities.

Experience at Au Sable proves at any rate that transmission at 140,000 volts is a practical and economical procedure, but it should be made clear that such a pressure is justified only where the distance and the quantity of power to be transmitted are such that conductors of sufficient sec-

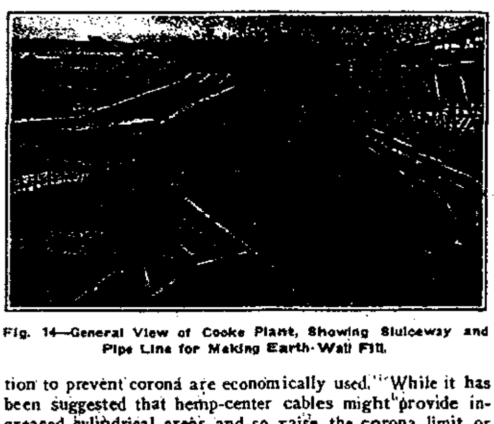


Fig. 14—General View of Cooke Plant, Showing Sluiceway and Pipe Line for Making Earth-Wall Fill.

tion to prevent corona are economically used. While it has been suggested that hemp-center cables might provide increased cylindrical areas and so raise the corona limit or decrease the copper investment necessary with a desired high voltage, the fact remains, according to the experience of the Au Sable Electric Company's engineers, that such hemp-center cables show a higher corona loss than equivalent all-copper conductors. This is attributed to the hemp fibers extending out through the cable strands and to the little nodules formed by the pitch used to lubricate the strands, both of which provide discharge points for the occurrence of corona loss.

CONSTRUCTION OF COOKE PLANT.

Many of the construction methods employed during the building of the Cooke water-power plant were novel and interesting. Direct-current and alternating-current motors were used for every possible operation. The river formerly flowed in a bed now occupied by the power house. While the concrete structures were being built the stream was diverted through a new channel under the trestlework marking the future core wall and fill.

After the power house and spillway structure were completed, a cofferdam was erected behind the trestle and the river then discharged through sluicegate openings beneath the main Tainter gates of the spillway. All of the material for the fill or dike was sluiced from a 135-ft. hill adjoining the power site. For construction purposes a temporary steam plant was erected at Cooke, containing a Corliss engine which, through line shafts, drove two sluicing pumps, delivering 200 lb. per square inch through 6-in. discharge lines; one 200-kw alternator for supplying lamps and motors, and one 200-kw, 500-volt direct-current machine operating the gravel-train locomotive and pile-driver. Four 2-in. nozzles of the hydraulic giant type were used to loosen the material on the 125-ft. hill. The sand, clay and gravel thus dislodged under the impact of these 200-lb. streams was shunted into 20-in. semi-circular No. 8 steel troughs, carried on timber trestle over the core wall of the dike, the earth protection of the latter being compacted out of sand and clay in this way. Small portable dams were used to deposit the material where wanted, pools being formed in which the suspended matter was precipitated, while the water was drained off through spouts embedded in the dam material. An area of the hilltop six or seven acres in extent was cut down in places 18 ft. in this way, some of the material being delivered a total distance of 1500 ft. The dike wall was carried to a flat top 45 ft. above the tailwater level. After completion the buried timbers were left in place in the compacted clay and sand.

This sluicing work done on the earth fill revealed some interesting results concerning the quantity of material which water in motion can transport. The slope angle of

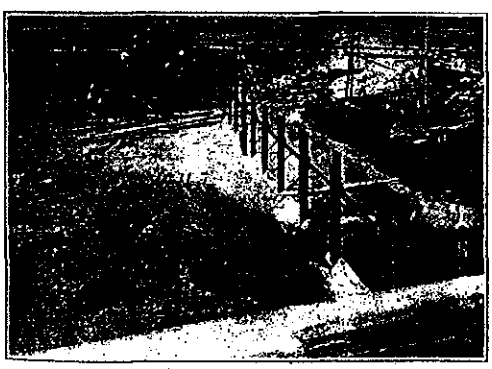


Fig. 15—Racks for Test Wires in Tailrace.

the trestled sluiceway varied between 6.5 and 8 per cent, and a careful log, with readings taken at fifteen-minute intervals, was kept of the material removed and the water used. In July 38,000 cu. yd. of sand was handled, representing 65 per cent of the weight of the water required to move it. In June and August, when sand was also handled, the ratio of solids to water was 55 and 49 per cent respectively. In September the ratio for clay was found to be 16 per cent. A total of 150,000 cu. yd. of material was moved in this way.

The earth fill measures 490 ft. in length and is approximately 45 ft. high with a 20-ft. flat top and sides laid at a

Fig. 16—24-ft. by 13-ft. Tainter Gate at Cooke Plant.

two to one slope. On the water side of the fill, so placed that it forms a wash wall extending 2 ft. above the earth at the water level, is a 12-in. concrete core wall, reinforced with ⅝-in. bars. This wall extends the full length of the fill, 490 ft., and is carried several feet below the clay at an average depth of 53 ft. from the top of the wall.

Gravel for the cement plant was handled by a 54-hp electric locomotive, equipped with two 500-volt railway motors. A 15-hp alternating-current motor hoisted cement up the incline, while two 25-hp motors operated the 1½-ton cube mixers. The mixtures of the various batches were adjusted to meet the conditions where the material was placed. Two 35-hp pumps operated the elevators and there were two triplex pumps for general supply, their output being delivered to an overhead tank.

During the time work was in progress about 300 men lived in camp on the site of the work. The employees' camp was located on the hilltop across the river from the offices and storerooms. Boarding houses and sleeping quarters were provided for the unmarried men, while men with families were offered the free lease of 50-ft. by 25-ft. lots on which to build their own shacks, being required in return only to sign agreements to keep the premises clean. Nearly seventy-five of these individual shacks were erected in street formation. Each street was drained by an 8-in. tile sewer, opening into a common main. At the upper end of each sewer line there was installed an automatic flushing barrel, pivoted just below its center and so arranged that two or three times daily it would overbalance, discharging its contents suddenly into the sewer. These flushing barrels were adjusted to operate twice or more during the daytime and at least once with the diminished water pressure available at night. Sanitary toilets were constructed by setting up 12-in. tiles over the sewer lines.

All machinery for the plant had to be delivered to Au Sable, a town on the Detroit & Mackinaw Railroad, since wiped out by a forest fire, and there transferred to the Au Sable & Northwestern Railroad, a narrow-gage road which runs near the Cooke site. From the narrow-gage spur the heavy machines were unloaded and skidded down the side of the 135-ft. hill which furnished the material for the wing-wall fill. For transporting passengers and supplies to the plant in good weather a gasoline rail-car has been improvised from the chassis of a 40-hp automobile. This conveyance is fitted with narrow-gage flanged wheels and makes good time over the tracks of the lumber railroad, whose own train schedule hardly suits passenger convenience.

TESTS OF COOKE WATER-POWER PLANT.

The Cooke water-power plant includes several unusual permanent features contributing to the convenience with which hydraulic tests of any unit or all of them can be carried out. Thrown across the 108-ft. tailrace, 134 ft. below the power-house wall, is a row of permanent H-section weir posts extending 8 ft. above the concrete and braced by double 3-in. by 3-in. by ¼-in. V-pieces like sash. Frame plates can be inserted in the channels of the uprights, which are set on 7-ft. 6-in. centers, water-tight joints being made by 5-in. felt strips asphalted to the frames, which are held against the bearing plates by the water pressure. Across the top of the weir sections an accurately leveled sill is made possible by gage-plate sections bolted under slotted holes so that the whole sill can be accurately leveled when the weir is installed for a test. At equal distances on a line 20 ft. behind the weir posts are four permanent water-

Fig. 17—140,000-Volt Transformer During Erection.

level wells, communicating through 2-in. pipes laid in the concrete with cisterns in observers' pits just outside the tailrace walls. Hook gages in these cisterns enable the height of water over the weir sill to be observed with accuracy, so that the water discharged by the turbines under test can be calculated. The test weir subtracts a fall of 4 ft. from the total 40-ft. head on the plant, connections being made for this difference in hydraulic pressure in computing the turbine performance.

At the time the Cooke plant was put into operation a complete acceptance test was made on the turbines, occupying the time of twenty-five observers for a week. All the observing stations were connected by an electric bell circuit, so that at the signal all readings could be taken simultaneously. An artificial load was provided by a water rheostat in the tailrace.

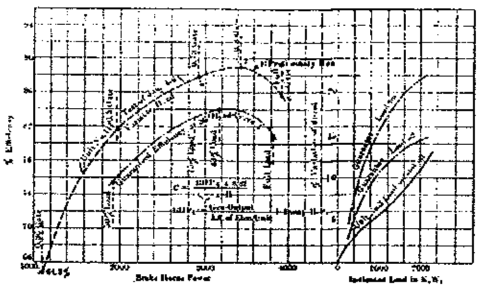


Fig. 18—Test Results of 4150-hp Turbine and Governor.

As shown by the accompanying curves, the actual performance of both turbines and governors exceeded expectations. At 3400-bhp load the efficiency of the turbines whose record is reproduced herewith reached 89 per cent, operating under 36-ft. head. The accompanying governor curve of the corresponding unit also shows that the regulation of this apparatus was practically identical whether the load was being taken on or off and was much better than had been specified originally.

No part of the construction has been by contract, all work being done within the owners' organization. The executive committee is composed of Mr. W. A. Foote, of Jackson, Mich., and Messrs. W. M. Eaton and B. C. Cobb, of the firm of Hodenpyl, Hardy & Company, 7 Wall Street, New York City, all practical and experienced men.

Mr. W. G. Fargo is hydraulic engineer for both the completed Cooke development and the Five Channels development under construction. A topographical survey of the entire basin of the Au Sable River was made by his force of engineers in 1908 and 1909, and studies are now being made for a third development. Mr. J. B. Foote, in addition to his many other official obligations to electric properties in Michigan, is general manager and electrical engineer and is responsible for the design, construction and operation of the unusual electric installation herein described.

AUTOMATIC FEATURES OF BOOSTER.

The 75-kw battery-charging motor-generator booster in the McComb Street substation of the Detroit Edison Company includes a number of automatic protective features. This unit is used in connection with the 11,000 amp-hr., eighty-cell storage battery and consists of a 110-hp motor driving a 55-volt generator designed for 1300 amp. The motor panel is arranged with an automatic overload trip, as well as a no-voltage-release coil inserted in its field circuit. The generator is similarly protected, its trips being interlocked through a back contact with the motor circuit-breaker. Operation of the motor circuit breaker for any cause will also open the generator switch, preventing the battery from discharging back through the generator. If the generator circuit is overloaded or interrupted the operation of its switch opens the motor circuit. Similarly, any interruption of the field circuit automatically removes the unit from service.

ADDENDUM TO:
COOKE HYDROELECTRIC PLANT
Cook Dam Road at Au Sable River
Oscoda vicinity
Iosco County
Michigan

HAER MI-98
HAER MICH,35-OSCO.V,1-

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240-0001