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Developments in Electricity and Bodie’s Long Distance Transmission Line

By
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Introduced to Bodie in 1893, electric power was an important innovation in the remote mining community, where an economic revival was badly needed. But, Californians had been experiencing electricity’s marvels for more than two decades. Beginning in 1871, demonstrations of arc lighting by a professor at Saint Ignatius College periodically illuminated a section of Market Street facing the San Francisco campus. In 1878 city residents gazed upon an exhibition of electric lighting at the Mechanics Pavilion, made possible by manufacturers who displayed arc lamps and generating dynamos. These early novelties were put to practical use in September 1879, when the newly organized California Electric Light Company erected a small steam-powered generating plant in San Francisco to furnish downtown subscribers with arc lighting.

San Francisco’s introductory displays of electricity, like others across the country, employed arc lamps, whose glaring brilliance, smoking carbon electrodes, and hissing arcs, restricted their use to outdoor areas or spacious interiors. Through the 1880s, arc lamps were most often purchased for city streets, where they were mounted on colossal masts or towers, some soaring more than 100 feet, to light entire blocks. A nearby steam-powered plant generated electricity for the lamps. Otherwise, large stores, hotel lobbies, or factories lighted their interiors with arc lights, powered by a steam engine and dynamo on the premises.

In 1882 Thomas A. Edison responded to the cry for more practical interior lighting by using the incandescent light bulb of his invention to build the country’s first electric network intended to serve individual customers. His Pearl Street Station in New York City (preceded seven months earlier by London’s Brighton Station) used six dynamos, each connected to a coal-fired steam engine, to supply electric current to the most promising segment of the lighting market: the multistory apartment, office, and hotel buildings in Manhattan’s financial district, where improved lighting devices were sought to replace gas and kerosene lamps. Edison quickly met demand with numerous centrally-located generating stations, each powering lights within a limited area of distribution. Edison soon lit major urban centers by dotting them with central stations. By the mid-1880s, electricity was equally familiar on the West Coast, where steam-generating systems supplied major city boulevards with arc lamps and residential or commercial customers with incandescent lighting.

The next impressive advancement in electrical engineering supplied motive power to urban transit vehicles. Expanding population centers, slow speeds, and sanitation concerns led to a search for alternatives to horse-drawn vehicles. Working with electric motors, Frank J. Sprague combined earlier technical developments to build a pioneering electric streetcar line in

Richmond, Virginia. Regarded as the first successful large city electric street railway, Sprague's 1888 achievement was followed in American cities by a rapid multiplication of electric-powered trolley systems, an increase in number almost as great as the profusion of electric lighting networks that preceded it. By 1889, the California cities of Los Angeles and San Jose boasted electric street railways. As with Edison's neighborhood lighting systems, dynamos run by steam engines in central stations generated power for vehicles traveling within a restricted area.

American industry, however, was slow to accept the new form of power. In furnishing motive power to factories, electricity did not enjoy the same conspicuous advantages over water and steam power as it did over horse-drawn public transit vehicles and gas or oil lighting devices. During electricity's development, manufacturers in particular chose to stay with their long-proven and well-established water wheels and steam engines. Although historians have paid little notice, the one heavy industry that quickly recognized the advantages of electric power was mining. The obvious need for underground lighting, the inefficiencies of piping compressed air or steam to the far reaches of a mine, and the difficulties associated with placing steam engines and boilers below ground (heat, vapor, smoke, ventilation, and transporting copious amounts of fuel through shafts and tunnels), established a ready market for electric power.

A procession of improved motor designs inspired manufactures to adapt them to mining machinery. Demands placed on streetcar motors (heavy loads, frequent stops and starts, abrupt accelerations and decelerations, and exposure to water and dirt) were identical to the harsh conditions encountered in mining. By 1888, manufacturers fulfilled underground requirements with motorized machines, such as hoists, air compressors, locomotives, fans, and pumps. A wide range of auxiliary equipment quickly followed, including lights, signaling devices, telephones, detonators, and rock drills (though electric percussion drills never achieved the degree of acceptance necessary to replace pneumatic drills).

Possessing cheap and abundant fuel, coal mines readily took advantage of electrical devices arriving on the market. Coal-fired boilers, steam engines, and dynamos on the surface generated electricity for equipment inside the mine. Slender copper wires were all that were needed to convey power anywhere underground. In the fuel-starved West, however, boilers that produced steam for electricity offered no relief from energy costs. Transporting expensive fuel over long distances and rugged terrain (usually uphill) cost so much that many remote mines and mills were desperate for cheap power.

Capitalizing on free water as an energy source, small hydroelectric systems began appearing about 1887 in the mountainous regions of California and Colorado to run existing stamp mills and hoisting works with electric motors. One innovative hydroelectric plant in 1888 drove preexisting technology at the 60-stamp Nevada mill, the last Comstock stamp mill built for the Washoe Pan Process. Water from a mountain reservoir above Virginia City plunged 1,630 feet down the Chollar Mine's incline shaft through two pipes to drive six Pelton wheels in an underground chamber. Each water wheel ran a dynamo from which copper wires conducted electricity up the shaft and across country to the newly-constructed mill. Spent water from the subterranean power plant discharged through the Sutro Tunnel.

Early electric lights and motors ran on direct current (DC) produced at a nearby generating facility. Transmitting DC power over a substantial distance, however, presented certain problems. Much of the electricity dissipated from the wires before it reached distant customers. Raising the voltage could deliver functional current at the far end of the line, and manufacturers marketed equipment capable of producing 5,000 volts, but the generating machines possessed a fatal flaw. Their weak link was the commutator, a spinning device with sparking brushes that wore out quickly when running continuously at high voltage. Moreover, high voltages exceeded the capacity of incandescent lights placed along the route. These restrictions limited DC systems to fairly low voltages. Low-voltage loses over long distance could be reduced by thicker wires, but the high price of copper forced early electrical engineers to minimize its use. Generating plants, therefore, produced voltages low enough for practical use, and small, affordable wires determined that power stations had to be close to their customers. Direct current proved most effective in densely populated downtown areas, where the radius of distribution could be held to about three miles or less.(1)

At Bodie, Superintendent Thomas Leggett sought to improve the Standard Company’s economic condition by reducing milling expenses. Cordwood to fuel the mill was costing the company $22,000 per year, and he recognized that free hydroelectric power would substantially decrease operating costs. If Leggett was going to replace the Standard mill’s steam engine with an electric motor, his primary dilemma was its isolation, as Bodie possessed no source of waterpower, and delivering DC electricity from far away would be burdened with problems, if not impossible. A resolution came with the emergence of alternating current.

George Westinghouse, inventor of air brakes for trains, recognized that alternating current (AC) could make the transmission of electric power commercially feasible over long distances. He hired Nikola Tesla, who held patents for AC generators, motors, and other vital components. Tesla understood that the key to overcoming problems associated with conducting electricity beyond the reach of central stations was the ease with which AC voltage could be increased or decreased with a simple device, containing no moving parts, known as a “transformer.” Alternating current could be generated at low voltage, transformed to high voltage for transmission through thin, economically sized wires over long distances, then transformed to a suitably low voltage near the point of use. Because there existed no DC equivalent to the AC transformer, high voltage transmission over long distances would forever be restricted to alternating current systems. As might be expected, the initial demand for AC called for lighting, and Westinghouse cornered the market in rural areas with inexpensive systems that stepped up the voltage for transmission to isolated towns, then stepped it back down for distribution to customers. Because alternating current addressed the critical issues of wire size and the cost of copper, Westinghouse earned a reputation for building far-reaching electrical installations at more reasonable expense than Edison could with DC.

Based on the advantages of AC power, worldwide advances in transmitting electric power over long distances became so frequent during the three years following 1890 that it is difficult to reconstruct the progression. Several milestones, however, were recorded: Willamette Falls to Portland, Oregon, completed in 1890, a distance of 14 miles; Lauffen Falls to Frankfurt, Germany, completed in 1891, 105 miles(2); Hochfelden to Oerlikon, Switzerland, completed in 1892, 14 miles; River Gorzente to Genoa, Italy, completed 1892, 18 miles; San Miguel River to Telluride, Colorado, completed in 1892, 8 miles; Tivoli to Rome, Italy, completed in 1892, 18 miles; Tariffville to Hartford, Connecticut, completed in 1892, 11 miles; San Antonio Canyon to Pomona, California, completed in 1892, 14 miles; San Antonio Canyon to San Bernardino, California, completed in 1892, 29 miles.

These developments were watched closely in western mining regions, where high fuel costs and abundant mountain streams focused attention on the relative ease with which distance could be spanned by transmission lines. In the West, worldwide advances inspired a rapid progression of lengthening wires that energized individual mining operations: San Miguel River to the Gold King mill, Telluride, Colorado, completed in 1891, 3 miles; Rock Creek to the St. Lawrence Mine, El Dorado, California, 1891, 6 miles; San Miguel River to the Bear Creek mill, Telluride, Colorado, 1892, 10 miles.

Leggett recognized that Bodie's closest source of reliable water power were streams in the Sierra foothills, more than a dozen miles away. He approached General Electric, the successor of Thomas A. Edison's pioneering company, but its engineers had not solved the problem of transmitting DC electricity over extended distances. Leggett and his consultant rejected GE's proposal, concluding that Westinghouse Electric & Manufacturing Company's AC plan was more likely to succeed. To generate electricity for the Standard mill, Leggett selected Green Creek, a stream with adequate fall that coursed some 12-1/2 miles from Bodie. Seven miles due south of Bridgeport, on the northern slope of Castle (now Dunderberg) Peak, lay an abandoned ditch from earlier mining activity that would divert Green Creek 4,570 feet across the mountain face to a point directly above an excellent site for a generating plant.

Between August and October 1892, workers enlarged and cleared the ditch, fabricated a penstock, pipe, water gates, and weirs, and erected a powerhouse with materials from the recently abandoned Bulwer-Standard mill. In November they set in place an assembly from San Francisco containing a generator and four Pelton waterwheels. Meanwhile, work progressed on a transmission line that traversed the sagebrush-covered hills between Green Creek and Bodie. Wooden poles spaced 100 feet apart supported two copper wires that surveyors ran almost perfectly straight—minimizing the line's length to increase the odds of success and to reduce the amount of copper. The wires entered Bodie from the hill above the cemetery, crossed Main Street just south of the brick post office, then angled through an open field before turning northward near the intersection of Green and Wood streets to follow Wood into the Standard mill's new motor room. A telephone line traced existing roads to provide voice communication between the mill and powerhouse.(3)

Winter weather hampered work and slowed the arrival of key components, delaying completion beyond the scheduled December 1, 1892, startup date. Other worrisome setbacks prevented the contractor from finishing until July 1893. After a required 30-day test run, the Standard Company disconnected its mill's boilers and steam engine, and Leggett's vision became reality. "The familiar toot of the Standard mill whistle is no longer heard," remarked one correspondent, "Many a miner will miss its sound in the morning and will have to rely upon other means of waking up in time for work." (*Mining and Scientific Press* 22 July 1893, 61)

To power the Standard mill, water from Green Creek flowed nearly a mile through the ditch before entering a penstock and plunging 1,571 feet (355 feet vertically) through an 18-inch diameter pipe to the powerhouse. Eight nozzles shot high-pressure water against four Pelton waterwheels spinning on a common axle with a Westinghouse 120-killowatt AC generator. Spent water discharged into the creek bed, eventually joining the East Walker River. The generator produced 3,530 volts of AC power, conducted 12.46 miles to Bodie. After losing some potential, the 3,100 volts arriving at the Standard mill drove a 120-horsepower motor that turned the belts, shafts, and gears that ran 20 stamps, 4 concentrators, 8 pans, 3 settlers, and 1 agitator. A transformer at the mill provided 100-volt current to light the building's interior and adjoining offices.(4)

So far, the Standard mill was the only building at Bodie with electricity. Because AC motors ran at constant speed, they were unsuited for hoisting, which required starting and stopping under changing loads. Therefore, the Standard works atop the hill continued operating under steam at a cost of $11,000 per year for wood. Likewise, other area mines and mills continued as best they could with their old steam engines. Not until late in 1910, when a commercial power network made electricity available across the region, did Bodie's dwellings and downtown businesses receive the new form of energy.(5)

Due to Thomas Leggett's persistent promotional efforts, Bodie's 1893 contribution to electrical engineering probably received more attention than it deserved. A paper he presented in February 1894 to the American Institute of Mining Engineers gave an unusually detailed description of the 12-1/2-mile transmission system. As a practical guide, his report was reprinted with only introductory changes in pamphlet form and as articles in at least five scientific and trade journals.(6) Other than Leggett's account, Bodie was rarely mentioned in technical literature of the day. His autobiographical sketch for *Who's Who in Engineering* (1925) held that he had erected the "first long-distance electric transmission for power purposes in [the] U.S." This assertion has become a staple for uncritical Bodie writers, even though it conveniently ignores greater distances previously achieved for power purposes in Europe and longer transmissions in the United States for urban lighting, a distinction rarely recognized at the time. It also downplays the significance of lighting entire cities by overemphasizing his feat of running a single motor.

Bodie's record—if one really existed—was short-lived. Green Creek was one of many ever-lengthening electric power transmissions; so numerous that Bodie's claim, as with others that preceded or followed it, is almost entirely overlooked by electric-power historians. Instead, an enormous hydroelectric project concurrently under construction became recognized as an engineering triumph of the nineteenth century. While work progressed on the little power plant at Green Creek, an installation of monumental scale at Niagara Falls, New York, so thoroughly captured the imagination of the scientific community and the public at large that it overshadowed Leggett's humble accomplishment at Bodie.(7) Completed in 1896, the facility at Niagara Falls carried 11,000 volts AC 26 miles to Buffalo, New York, and its status as a definitive milestone in power engineering trivialized every previous landmark including a 22-mile transmission to Sacramento that preceded it by a year. Bodie's new power system was significant mostly to locals, who longed for an economic revival. Beyond Mono County, a reporting bias toward eastern achievements obscured Bodie's fleeting moment of importance and prevented widespread recognition.

NOTES

1. This shortcoming is specific to transmitting electricity at voltages high enough for power and lighting purposes. Successful long distance telegraph and telephone systems had been in existence since 1851 and 1885, respectively.

2. The International Electric Exhibition at Frankfurt, Germany, demonstrated that AC power could be transmitted over tremendously long distances, but its cost was five times that of electricity produced locally by steam.

3. Local folklore asserts that the transmission line had to be "absolutely straight, no angles, no curves, which might cause the power to jump off into space." (Cain 1956, 49) This delightful anecdote is not upheld by technical literature of the period, nor does it account for vertical curves (hills and valleys) that the line traversed. "The line crosses extremely rough country," wrote Leggett in his paper to the American Institute of Mining Engineers, "not 500 yards of which is level beyond the town-limits. Most of the ground is very rocky, over 500 pounds of dynamite being used in blasting the pole-holes." (Leggett 1895, 328)

4. Oddly, step-up and step-down transformers were not used, except to reduce the 3,100 volts arriving at the mill to 100 volts for incandescent lights.

5. After the Standard's steam-powered hoisting works on High Peak burned down in August 1894, Leggett placed a DC hoist deep inside the mine. A dynamo, belted to the Standard mill's AC motor, generated DC current for the hoist and other company motors.

6. For Leggett's description of the Standard's electric power system and its operation, see Thomas Haight Leggett, "A Twelve-Mile Transmission of Power by Electricity." *Transactions of the American Institute of Mining Engineers* 24 (New York, NY: A. I. M. E., 1895): 315-338., or his other works cited in the bibliography.

7. At the same time, Westinghouse Electric & Manufacturing Co. underbid General Electric to illuminate the Columbian Exposition—the Chicago World's Fair of 1893. The fair became the glittering showcase for the new age of electricity, based on alternating current. At Chicago, AC electricity lit up some 180,000 incandescent and arc lights and powered hundreds of motors, pumps, displays of the latest electrical products, and towering water fountains—plus a huge Ferris wheel. Machinery Hall, housing electrical and mechanical exhibits, also featured the fair's central station power plant comprising the latest oil-fired boilers that powered 13 steam engines running 14 alternators. See, John Patrick Barrett, *Electricity at the Columbian Exposition* (Chicago, IL: R.R. Donnelley & Sons, Co., 1894), 79-84; Trumbull White and William Igleheart, *The World's Columbian Exposition, Chicago, 1893* (Boston, MA: John K. Hastings, 1893), 139-160, 301-330.

BIBLIOGRAPHY

Bailey, Ronald H. “Tesla: The Wizard Who Electrified the World.” *American History*, June 2010: 52-59.

Cain, Ella M. *The Story of Bodie*. San Francisco, CA: Fearon Publishers, 1956.

Coleman, Charles M. *P. G. and E. of California: The Centennial Story of Pacific Gas and Electric Company, 1852-1952*. New York, NY: McGraw-Hill Book Co., 1952.

Hasson, W. F. C. “Electric Transmission of Power Long Distances.” *Transactions of the Technical Society of the Pacific Coast* 10, no. 4 (May 1893): 49-72.

Hunter, Louis C. and Lynwood Bryant. *A History of Industrial Power in the United States, 1780-1930, Vol. 3: The Transmission of Power*. Cambridge, MA: M I T Press, 1991.

Leggett, Thomas Haight. *Electric Power Transmission Plants and the Use of Electricity in Mining Operations*. Sacramento, CA: Superintendent of State Printing, 1894.

________. “An Electric Power Transmissions Installation—In the Mining District of Bodie, in California.” *Practical Engineer* (London), 2 November 1894.

________. “Electric Power Transmission.” *Mining and Scientific Press* (San Francisco, CA), Part 1, 30 March 1895: 196-197; Part 2, 6 April 1895: 212-213.

________. “A Twelve-Mile Transmission of Power by Electricity.” *Cassier’s Magazine* (New York, NY), 7, no. 5 (March 1895): 355-368.

________. “A Twelve-Mile Transmission of Power by Electricity.” *Engineering News and Railway Journal* (New York, NY), 26 July 1895: 74-77.

________. “A Twelve-Mile Transmission of Power by Electricity.” *Transactions of the American Institute of Mining Engineers*, 24, New York, NY: A. I. M. E., 1895: 315-338.

________. “Electric Power Transmission Plants and the Use of Electricity in Mining Operations.” *Twelfth Report of the State Mineralogist, Two Years Ending September 15, 1894*. Sacramento, CA: Superintendent of State Printing, 1894: 413-435.

Myers, William A. *Iron Men and Copper Wires: A Centennial History of the Southern California Edison Company*. Glendale, CA: Trans-Anglo Books, 1983.

Passer, Harold C. *The Electrical Manufacturers, 1875-1900: A Study in Competition, Entrepreneurship, Technical Change, and Economic Growth*. Cambridge, MA: Harvard University Press, 1953.

Rickard, T. A. *Interviews With Mining Engineers*. San Francisco, CA: Mining and Scientific Press, 1922.

Williams, James C. *Energy and the Making of Modern California*. Akron, OH: University of Akron Press, 1997.