Santa Ana River No. 1: A Pioneer in Hydro Generation, Power Transmission

The 3-MW Santa Ana River No. 1 hydro plant had two claims to fame in 1899: it featured the longest-distance, highest-voltage transmission line carrying alternating current in the U.S., and it was the country's largest high-head hydroelectric plant.

By Thomas T. Taylor

When the 1999 Hydro Hall of Fame inductee—Southern California Edison's Santa Ana River No. 1 hydro plant—was built in 1899, it featured the longest-distance, highest-voltage transmission line carrying alternating current in the U.S. at the time. And, the facility was the largest high-head hydroelectric plant to be constructed in the country. The plant's development was closely tied to the early growth and technological advances of the state of California.

The Switch from DC to AC: Moving Power Longer Distances

In the 1880s—the first decade of electrical power development—electrical systems were used for lighting and running small motors, and employed direct current (DC). However, at the time, DC power could not be transmitted long distances economically. The transmission losses at the low generation voltages used by early equipment were too great. Therefore, DC power only could be used where the generation source was located near the load, in city centers.

In the late nineteenth century, hydropower offered the most practical source of fuel for power plants in southern California. Water was abundant, and the power generated was less costly than electricity produced by burning fuel. But, the hydro sites often were located far from the load centers. The solution to this dilemma lay in the development of alternating current (AC) power systems.

AC power differs from DC in that it is generated in pulses that reverse or alternate direction at regular intervals or cycles. The voltage of AC power can be changed (and safely controlled) by induction transformers, enabling the generation of power at low voltages and then stepping up—transforming—the power to high voltages for long-distance transmission. At high-transmission voltages, line losses are reduced. Then, at the user's end, the voltage can be stepped down again to low, safe levels. Owing to the need posed by geography for long-distance power transmission from hydroelectric generation sources to electrical load centers, southern California became the testing ground for AC power development.

Three Important Contributors

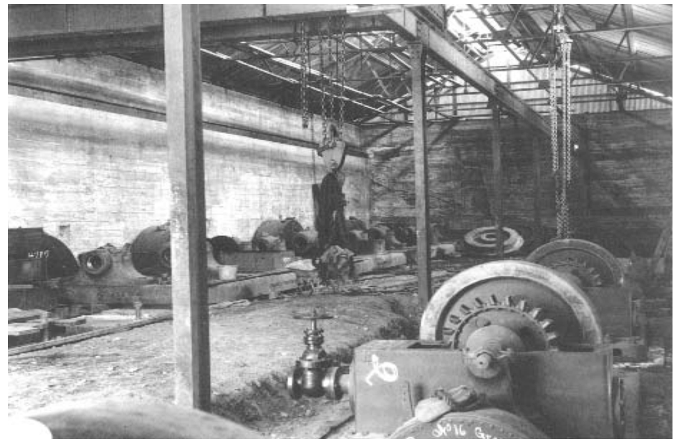
Pioneering AC power developments occurred at three hydro facilities in southern California during the 1890s: the 120-kW Pomona Plant in the San Gabriel Mountains, and the 500-kW Mill Creek No. 1 and the 3-MW Santa Ana River No. 1, both located in the San Bernardino Mountains. The technological advancements demonstrated at the Pomona and Mill Creek No. 1 plants served as stepping stones for the development of Santa Ana River No. 1.

In 1892, the San Antonio Light and Power Company built the Pomona plant, which was designed by a young electrical engineer named Almerian Decker. This facility was the first to use AC step-up/step-down transformer technol-

Construction of the Santa Ana River No. 1 powerhouse was completed in 1899. It featured the longest-distance, highest-voltage transmission line carrying alternating current in the U.S., and it was the country's largest high-head hydroelectric plant.

Tom Taylor is a senior archaeologist in the Environmental Affairs Division of Southern California Edison Company. In this position, he is responsible for company archives, including the historical records of the Santa Ana No. 1 project.

In 1898, the Edison Electric Company of Los Angeles (predecessor of Southern California Edison Company) began construction of the Santa Ana River No. 1 powerhouse. This photograph shows crews pouring concrete for the south side wall and part of the east and west end walls of the powerhouse.



Impulse turbines were installed in the Santa Ana River No. 1 powerhouse in 1898. The Pelton turbine units in the right corner of the photograph would be placed in the foundations under construction along the north wall of the powerhouse (in the left corner of photo).

ogy to transmit electricity over high voltage (10-kV) transmission lines. Electricity was transmitted 14 miles to Pomona and 29 miles to San Bernardino.

Decker also was employed by Redlands Electric Light and Power Company to design the electrical components for a plant on Mill Creek. Redlands Electric Light and Power was incorporated in 1892 to provide electrical illumination to the city of Redlands, and to supply power to the Union Ice Company of Mentone for a 150-horsepower refrigeration motor that would produce the ice needed to ship local orange crops to market. The directors of utility envisioned an electrical market that could include supplying power to street cars in Redlands and other electric rail lines connecting Redlands with Riverside and San Bernardino.

To address these goals, Decker proposed the use of then experimental three-phase AC equipment. Decker found that AC electric motors functioned more efficiently when three-phase power was used. Also, three-phase motors could start independently, whereas single-phase AC motors had to be started at the same time as the generator.

The Mill Creek plant further advanced power technology by the installation of two generating units instead of the single unit common to previous plants. To synchronize the two generators, General Electric developed a visual method using flashing lights. This method later became commonly used for synchronizing generators to grids served by multiple power plants.

The Santa Ana River No. 1 powerhouse was rewired and a marble switchboard was installed in 1914. The powerhouse was designed to hold six turbine-generator units, yet only four units were installed. The additional units would have occupied space at the west end of the building, shown in the foreground of this photo.

Buoyed with the success of the Mill Creek venture, the Redlands investors formed the Southern California Power Company in 1896 to develop hydroelectric energy on the Santa Ana River. The investors planned to build a hydropower plant, which they named the Santa Ana River Plant, and to sell the power generated by the plant to Los Angeles and other cities in southern California, in addition to Redlands.

The Edison Electric Company of Los Angeles, a direct predecessor of Southern California Edison, most likely provided the crucial impetus to the Santa Ana River Plant by agreeing to buy the excess power. From the beginning, the designs for the Santa Ana River Plant included a high-voltage transmission line to Los Angeles. Work began on the plant, now known as Santa Ana River No. 1, in the spring of 1897. In 1898, with construction half-complete, the Edison Electric Company of Los Angeles acquired the Southern California Power Company. And, by 1902, Redlands Electric Light and Power Company was absorbed into the Edison Electric Company as well.

A Closer Look at Santa Ana River No. 1

Water for Santa Ana River No. 1 is diverted from Bear Creek and the Santa Ana River well upstream from the powerhouse, which is located at the confluence of Keller Creek and the Santa Ana River. Water is conveyed through a series of tunnels and flumes to a regulating forebay above the powerhouse. From the forebay, water is dropped approximately 735 feet through a

Technical Information

Santa Ana River No. 1

General Information

Location: The San Bernardino Mountains of southern California, upper Santa Ana River watershed, approximately 80 miles east of Los Angeles

Owner: Southern California Edison Company

Prior Ownership: Construction began in 1897 by Southern California Power Company of Redlands; ownership transferred to the Edison Electric Co. of Los Angeles (predecessor of Southern California Edison Co.) in 1898

Type of Project: Run-of-river

Static Head: 726 feet

Maximum Diversion: 93.3 cfs

Capacity: 3 MW originally; upgraded to 3.8 MW during the 1946-48 rewind to 60-cycle operation

Average Annual Generation: 12,351 MWh

On-Line Date: January 9, 1899

Equipment

Turbines (4)

Impulse type

3 Pelton wheels, 1 Doble wheel

300 rpm, 1,000 horsepower

74-inch-diameter runner

Generators (4)

20-pole, revolving-field

750 kW, 578 amps

Manufactured by General Electric

Originally produced 3-phase 50-cycle alternating current at 750 volts/578 amps; Rewound to 800 kW, 2,400 volts during the 1940s 60-cycle changeover

Governors

Original:

Lombard Type F

30-inch gate-type shutoff valves

Present:

Speed-control system with simple trip devices

Construction

Water Conveyance

18 5-foot-wide by 6.5-foot-high concrete-lined tunnels (11,765-foot total length)

18 5-foot-wide by 5.5-foot-high wooden flumes set at 9.5-foot-per-mile grade (2,697-foot total length)

Penstocks (2)

30-inch diameter steel

No. 10 (British wire gage) at top

9/16-inch thick at bottom

Laid in trenches; buried in earth

Intakes

2 concrete structures

6-foot-high, 40-foot-long concrete diversion dam on Santa Ana River

5-foot-high, 29-foot-long rubble concrete diversion dam on Bear Creek

Powerhouse

Poured concrete

Corrugated-iron roof supported by steel trusses

Single story

36.5 feet wide by 126 feet long

Transmission

Original:

33-kV double-circuit transmission line running 83 miles from plant to Edison Electric Company of Los Angeles' Second Street Substation

Present:

Line runs approximately 17.5 miles to Cardiff Substation in San Bernardino

pressurized pipe to the turbines.

Constructing the Santa Ana River plant was difficult owing to its remote location and the rugged terrain. Men and materials had to be hauled by horse-drawn wagon up the canyon, and then up a series of hoists to the job site. Approximately 80 percent of the water conveyance is tunnel, and because of the fractured nature of the local granite, these tunnels had to be dug using compressed air drills—and without the benefit of dynamite. The tunnels were lined with concrete from the Mount Slover mine in Colton in order to minimize hydraulic losses and seepage.

The project was designed to contain six generating units, each with its own individual tailrace. However, only four units were ever installed in the plant. Each generator, configured with the then new design of an internal revolving-field alternator, was capable of producing 750 kW, for a total powerhouse capacity of 3 MW.

The turbine runners were Pelton-impulse type, 82 inches in diameter, each weighing 12,500 pounds. Fitted into each wheel was a Type F Lombard water wheel (runner) governor believed to be the first manufactured with that name. The Type F Lombard governors, designed by James Lighthipe and manufactured by the Lombard Governor Company of Ashland, Massachusetts, controlled the output by directing the aim of the nozzle at the buckets on the runner.

Beyond Generating the Power

Another feature of the Santa Ana River No. 1 development was the double-circuit transmission line consisting of two three-wire circuits (one wire for each phase of the three-phase current) that connected the plant to Edison's Second Street substation on the west side of Los Angeles, 83 miles away. It was the longest and, at 33 kV, one of the highest-voltage transmission lines in the U.S. However, the unprecedented length and a voltage three times of that used at the Mill Creek and Pomona plants revealed problems. The solutions developed to address these problems would usher in the era of modern high-voltage electrical transmission.

The first problem faced by the engineers was that of insulators. The best available insulators on the market in 1890 were manufactured for use in telegraph and telephone applications. Typically made of glass, these insulators performed poorly at the high voltages of AC transmission. During the 1890s, porcelain insulators became the norm for high-voltage electrical transmission because of their greater strength. Still, the available designs for porcelain insulators performed poorly on voltages above 10 kV. The solution was a new insulator designed specifically for the Santa Ana-Los Angeles transmission line by engineer O.H. Ensign. The successful model was called the "Redlands" insulator. It was white-glazed porcelain, about 6 inches tall, with a shape that included three successive flares called "petticoats."

When the transmission line was first tested, it was found that the 33-kV current created an electromagnetic field or "corona" around the wires. This caused static noise in nearby telephone lines, including the important communication line between the Los Angeles switching station and the plant, which was located on the transmission line poles just a few feet below the conductors. The solution was to transpose the transmission line wires along the route at regular intervals, thus focusing the electromagnetic field created by the transmission line into a narrow cone. This solution also reduced line losses due to induction. The three wires of the north circuit were spiraled one-third of a rotation every 41 poles; the three wires of the south circuit were spiraled in the opposite direction every 88 poles. The spiraling was arranged so that the two circuits were never transposed on the same pole.

Several other adjustments to the transmission line were required. The most critical was a short-to-ground that was discovered to be caused by two wires that had been transposed incorrectly near Ontario and were only 1 inch apart. When the line was energized, the local citizens were treated to the spectacle of a great electric arc running up and down the line where the wires were in close proximity!

With the major transmission line problems solved, all units in the plant were put on line January 1899. Although it was not a problem that required solving, the transmission line experienced electrical "leakage" from its bare copper wires during rainy and foggy weather.

Holding Its Place in History

The Santa Ana River No.1 plant's equipment remained largely unchanged over the years. The biggest change came in 1946-48, when the equipment, which originally ran at 50 cycles, had to be rewound to conform to the new industry standard of 60 cycles. The rewinding permitted interconnection of the Southern California Edison system with the systems of adjacent utilities already running at 60 cycles. The plant also was upgraded from to 3.8 MW from 3 MW.

The Santa Ana River No. 1 plant remained Edison Electric's premier hydro facility until 1907, when the 20-MW Kern River No. 1 hydro facility began operating. Kern River No. 1 used the three-phase technology pioneered at Mill Creek No. 1 and, on a considerably larger scale, at Santa Ana River.

Today, the company, now called Southern California Edison, owns 36 hydro plants with an annual generating capacity of 1,150 MW. The present 3.8-MW Santa Ana River No. 1 plant makes a small contribution to the company's overall energy supply. However, the advances pioneered at the plant 100 years ago played a key role in laying the foundation for today's power industry technology. ■

Mr. Taylor may be contacted at Southern California Edison Company, 2244 Walnut Grove Avenue, P.O. Box 800, Rosemead, CA 91770; (626) 302-9540.

Changes in Santa Ana Canyon

Santa Ana River No. 1—1999 inductee into the Hydro Hall of Fame—is located at the top of the Santa Ana Canyon in the San Bernardino Mountains in southern California. Far from being a quiet place where a 100-year-old plant resides, the canyon has been bustling with construction activity.

The finishing touches are being put on the 550-foot-high Seven Oaks Dam, under construction by the U.S. Army Corps of Engineers to provide flood control for San Bernardino, Orange, and Riverside counties. Construction of the dam has affected two of Southern California Edison's existing hydro plants in the canyon, Santa Ana River Nos. 2 and 3. As a result, the utility is decommissioning these two plants, and building a new facility at the bottom of the canyon. Because Santa Ana River No. 1 is located at the top of the canyon above the flood zone, it is unaffected by construction of the dam.

The Santa Ana River No. 2 plant is being decommissioned because it would have been inundated with water when the Seven Oaks Dam reservoir begins filling. In reviewing options for replacing the 1.5 MW of generating capacity from the No. 2 plant, the utility decided to also decommission the original 1.7-MW Santa Ana River No. 3 plant, and to build a new 3.1-MW facility.

The new plant is located at the same site as the original No. 3 powerhouse, and also is named Santa Ana River No. 3.

The operating head at the new facility is 680 feet, and the average streamflow is 41 cubic feet per second. A 33-kV transmission line runs from the plant approximately 100 feet to the Santa Ana River No. 3 substation.

C.A. Rasmussen served as general contractor for project construction; Harza Engineering Company was consulting engineer. The powerhouse contains one horizontal Pelton turbine manufactured by Bouvier Hydro, and one horizontal synchronous 4,160-volt generator manufactured by Ideal Electric. A series of tunnels and flumes that served the original Santa Ana River No. 3 was replaced with a 15,000-foot-long penstock supplied by Ameron. ABB Power Generation Inc. provided switchgear, station service, direct current equipment, spare parts, and commissioning services.

Construction of the new plant was scheduled for completion in July 1999.

—Cathy Swirbul