The Future of Transmission

As Southern California Edison builds infrastructure to bring wind power to population centers, it is fulfilling environmental requirements that may be a glimpse of things to come.

By Don Johnson, Southern California Edison; and Ken Gerling, PE, Burns & McDonnell

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California has a strong appetite for electricity. And its residents increasingly favor a supply produced through renewable resources such as wind.

Southern California Edison (SCE) is one of the utilities that leads the pack toward meeting state mandates for renewable sources of power, having put contracts in place for more than 20 percent of delivered power to come from renewable sources. A big part of SCE’s effort is the Tehachapi Renewable Transmission Project (TRTP), which will deliver wind power to customers in Southern California.

The Tehachapi Wind Resource Area is in Kern County, north of Los Angeles. The route from the wind farm area to the electrical grid traverses a range of land uses from urban residential to rural farmland. The terrain varies from flat, high desert to rugged mountains. Much of the construction for the TRTP takes place in remote, inaccessible locations. Critical segments cross the Angeles National Forest.

To construct a 500-kV transmission line in California and across land managed by the U.S. Forest Service, SCE and its owner’s agent, Burns & McDonnell, faced a level of scrutiny not experienced when most existing lines were constructed 20 or more years ago. The environmental measures required to permit and begin construction on the line may be a harbinger of things the electrical transmission industry must be prepared to manage as upgrades to the grid are made across the country in the coming decades.

**Functionality and Aesthetics**

“The three initial segments of the TRTP required an unconventional approach to overhead transmission line design,” says Jason Weller, Burns & McDonnell engineering lead for TRTP segments 1-3. “The project is a true representation of the design principle ‘form follows function.’”

The design had to account for many environmental factors specific to the region and required by the California Public Utilities Commission (CPUC). Additionally, the varying terrain and weather zones presented numerous design challenges.
The engineer-procure-construct (EPC) contractor, PAR Electrical Contractors Inc., partnered with Dashiell Corp. as the design engineer; both companies are owned by Quanta Services Inc. This partnership allowed the construction contractor and design engineer to incorporate the construction methodologies for various project areas into the design. As the owner’s agent, Burns & McDonnell provided engineering design reviews, field engineering, construction management, quality assurance/control, project scheduling, document control and environmental monitoring services.

“One challenge in Segment 1 was accommodating construction along approximately 14 miles of mountainous terrain through the Angeles National Forest,” Weller says. “Inaccessible sites and restrictions on work within the forest boundaries meant that foundation installation and lattice tower erection was largely completed using helicopters.”

Dashiell worked with PAR to develop tower splice designs that accounted for helicopter load carrying capacities.

Additionally, subsurface investigation reports guided the selection of tower sites, reducing potential slope instability amid rugged terrain and potential landslide zones.

A visual specialist from the CPUC analyzed the project to determine what structure types, colors and finishes would be required to minimize the visual impacts in all project areas. Lattice steel towers were the primary choice for segments 1 and 2. Three colors were used. In Segment 2, for example, the new line parallels an existing lattice steel structure line, so the selected design and color reduces visual complexity.

Tower aesthetics also factored into the selected design for Segment 3B, which traverses several of the wind farms producing the power to be transmitted by the TRTP. The CPUC visual specialist requested a modified tubular steel pole design that mimics the form of a modern wind turbine mounted on a monopole. This Y-shaped configuration, developed by Thomas & Betts Inc., meets both aesthetic and loading requirements. This segment is also likely to experience the greatest wind and ice loading in the Tehachapi Mountain area, so structural integrity was critical.

“One challenge in Segment 1 was accommodating construction along approximately 14 miles of mountainous terrain through the Angeles National Forest.”
Outside Factors

“Despite Southern California’s reputation as a weather paradise, climatic conditions vary through the diverse geographical areas and dramatic elevation changes from one end of the project to the other,” Weller says. “An intensive meteorological study, ordered by SCE, assisted in designing to ensure future reliability.”

Data from weather stations in the project area was summarized, including wind speeds and icing conditions. In addition to SCE and General Order 95 loading conditions, 15 separate loading zones were identified, each factoring in wind, ice and wind on ice design loads. In spans where loading zones changed, the more conservative loading scenario was incorporated into the design.

The TRTP crosses numerous extra-high-voltage transmission lines owned and operated by SCE as well as other utilities. Reliability is critical through those corridors. One critical crossing in Segment 1, known as Haskell Canyon, was a 2,632-foot span crossing a 1,000-kV DC line, four 230-kV lines and two 115-kV lines. Segment 2 had eight 220-kV crossings over SCE-owned lines, four 220-kV crossings over the FPL Energy-operated Sagebrush line, and two 500-kV crossings. Segment 3A crossed 11 220-kV lines and one 1,000-kV DC line.

A Final Challenge

Subconductor oscillation became an issue during TRTP construction. The phenomenon occurred during periods of moderate to strong steady winds perpendicular to the line. The wake from one subconductor induced vertical motion in the other subconductor of the same phase bundle, which

The Flight Factor

Helicopter use for constructing electrical transmission lines is not uncommon. But few projects, if any, rely on helicopters to the level of the TRTP. When working in the Angeles National Forest, nothing goes in or out on the ground. Equipment. Supplies. Crew. Inspectors. Portable toilets. That’s right, nothing.

Flights into and out of construction sites in the forest were staged from three fly-yards to minimize flight time. From the fly-yards, six helicopter operators — Summit, Heliquest, Winco, Mountain Air, Swanson and Erickson, using models ranging from the MD250, MD530F and the AS350 to the K-Max and the Aircrane — ferried passengers, light materials and heavy equipment and materials to each tower site.

The challenges for helicopters working the project were amplified by the incessant winds that gust through the mountainous terrain. Pilots were on call to respond to time-sensitive material deliveries and urgent personnel evacuations.

Helicopter use enabled construction in an otherwise impossible region by keeping the construction footprint small. As new transmission infrastructure goes up across the U.S., helicopter support is likely to be an integral part of more projects.
caused uncontrolled oscillation of the bundle with peak amplitudes as high as six feet. This is most common in smooth areas, unobstructed by trees and other obstacles, but in this instance it also occurred in mountainous terrain. Segment 2, although not smooth throughout the alignment, experienced conductor oscillation shortly after installation. A quick design solution prevented potential significant wear or fatigue damage to conductors, spacers, dampers and support hardware. Design engineers stepped subconductors of the horizontal bundle approximately 6 inches. This horizontal bundle design modification mitigated the oscillation. Segment 3A, which crosses mostly flat terrain, was stepped over the entire length of the alignment as a proactive measure.

**Starting Out**

Once permitting was complete but before construction could begin, detailed mitigation, monitoring and compliance plans were required. The necessary level of planning required to receive approval to begin construction took nearly nine months for the portion of Segment 1 that was outside the Angeles National Forest. Approval to build within the forest was nearly two years in coming.

The mitigation, monitoring and compliance plans demonstrated how the construction teams would manage all aspects of the project, including complying with all CPUC regulations and U.S. Forest Service requirements. Factors considered included sensitive plant species, the protected California condor and migratory bird species.

**Plant Species**

As is the case in much of California, the Angeles National Forest is home to many sensitive plant species. Construction monitors worked to avoid disturbing a species of mariposa lily found in the forest. If the plant was found in the construction zone, it was avoided or transplanted to a safe area.

Construction crews also prevented the migration of weed species onto forest property via vehicles or supplies. All vehicles and equipment were washed and free of seeds.
and plant materials before being moved into the forest, and temporary soil stockpiles were weeded before transport to construction sites.

Protecting the Condor

“The California condor is a state and federally listed endangered species with habitat in the project area. The condors are curious creatures, attracted to colorful bits of plastic and wire or shiny bolts and nuts, known as microtrash on job sites,” says Chad Richardson, Burns & McDonnell environmental monitor lead for the TRTP Segments 1-3. “When the birds swallow these things, it can interfere with their digestive system or they take the material back to chicks in the nest, where the chicks can ingest them. In either case, a death is likely.”

Microtrash patrols were instituted in tower assembly yards and tower sites to remove all materials that fell to the ground during tower assembly or construction. To further protect the condor in selected canyon crossings, the project team installed swan flight diverters on static wires to make them more visible, helping avoid mid-air collisions with the wire.

SCE and Burns & McDonnell developed special environmental measures including microtrash patrols to help protect the California condor and other federally protected species during construction of TRTP segments 1-3.

Migratory Birds

Nearly all bird species in the U.S. are protected by one or more federal or state laws, especially the federal Migratory Bird Treaty Act, which prevents the capture or harm of most species. Active nests, defined as a nest with eggs or young in the nest, are included in the scope of the law.

“During nesting season, generally mid-February through mid-August, nests are often found on partially erected towers, near tower sites or wire-pulling locations, or on construction equipment,” Richardson says. “An active nest has the potential to shut down work at a tower site or could cause cranes or wire-pulling equipment to be unusable until the young birds fledge.”

For the TRTP, nest surveys performed using both ground and helicopter methods in advance of construction helped identify and deal with nesting birds in the project area. Construction was delayed at times during the nesting season. To mitigate these concerns, site monitors surveyed sites for several days before crews were scheduled to move in, relocating nests that were not yet active. In other cases, construction was halted for weeks until access and work on the sites were cleared with the appropriate agencies.

Making It Happen

For the 87 miles of TRTP segments 1-3, as many as 15 to 20 biological or environmental monitors were active at one time, conducting clearance surveys before crews could move onto a site, monitoring nests and spot-checking crews.

“The condors are curious creatures, attracted to colorful bits of plastic and wire or shiny bolts and nuts, known as microtrash on job sites.”
“The constantly changing environment was challenging, but no shutdowns were required for environmental non-compliance, other than self-imposed measures to ensure the project stayed in compliance with all regulations,” Richardson says. “Close coordination with a single point of contact for the U.S. Forest Service allowed efficient resolution of environmental and construction issues on the Angeles National Forest.”

During construction, the Forest Service determined daily whether work could proceed the following day and what type of work was allowed. This Project Activity Level primarily served to minimize the potential for fires, but it did make construction planning a challenge.

To maximize the construction team’s ability to manage the entire TRTP effort, enterprise construction management software — Primavera’s P6 and Contract Management suite — were selected for the project. The Burns & McDonnell OneTouchPM® geospatial project dashboard was implemented to enhance that tool set.

“Biological observations, including the potential presence of active nests and protected plant species, are tracked in OneTouchPM®. Biological monitors collect coordinate locations for observations using a handheld global positioning system (GPS) device,” says Dave Smith, Burns & McDonnell information management director for the TRTP segments 1-3. “The data is aggregated, reviewed and delivered to a Burns & McDonnell analyst, who makes the data available on maps and by OneTouchPM®.”

**The Safety Factor**

Building transmission lines through rough terrain like the Angeles National Forest requires unconventional methods. Many tower sites within the forest were remote. Construction of the initial segments had to be done either without building access roads or the roads had to be removed upon

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**How It Works: OneTouchPM®**

Device carried by construction worker receives a signal from the global positioning system (GPS) satellites to determine its location.

The device relays its serial number and the position coordinates to a commercial satellite.

The commercial satellite sends information to a data processing center, which delivers the information to Burns & McDonnell by email or file transfer protocol.

Burns & McDonnell translates the information into Google Earth symbols that are tracked by OneTouchPM®.

For more information on OneTouchPM®, visit www.burnsmcd.com/onetouchpm.
The completion of construction. That made helicopters the primary mode for bringing equipment, crews and materials to each job site.

Construction safety plans must factor in the rapidly changing weather and wind in the region. Crews able to get on-site for the day have no guarantee of being able to get back out. Sites have all necessary provisions for overnight stays, including food, equipment and first aid kits. Crews receive survival training to prepare for the threat of sudden weather changes or forest fires in the area. All personnel had to be capable of recognizing and responding to the presence of varied wildlife, including mountain lions and rattlesnakes.

All crews were prepared to handle weather issues from snow and fog to high winds and dust. High winds, in particular, made it impossible at times for helicopters to construct tall towers and string conductor. It was also difficult to retrieve crews. Crews on several occasions had to hike out of the forest because helicopters were grounded by high winds.

"The OneTouchPM® tool was customized to integrate satellite tracking of crew members," Smith says. "Each crew member is outfitted with a satellite transmitter, similar to what hikers use. OneTouchPM® interfaces with Google Earth Enterprise software to enable live tracking of each person's location."

### Moving Forward

Before beginning construction on segments 4-11, SCE evaluated the methods and programs that enabled segments 1-3 to remain in compliance with all regulations.

In meeting California's goals for renewable power, SCE is breaking new ground to comply with environmental controls that are unprecedented in the industry. As the electrical transmission industry nationwide moves to upgrade an aging infrastructure and accommodate wind, solar, biomass and other renewable sources, utilities and their partners are likely to see a similar regulatory environment.

Development of programs and procedures to manage the complex planning and execution of these projects will be the challenge of all.

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**Don Johnson** is Manager, Third-Party Interconnection Projects at Southern California Edison, an Edison International (NYSE:EIX) company and one of the nation's largest electric utilities, serving a population of nearly 14 million in a 50,000-square-mile service area. He was project manager for TRTP Segments 1-3. He has more than 27 years of diverse project management, engineering and design experience in the transmission, substation and distribution business. Johnson earned his Bachelor of Science in electrical engineering from the University of Alabama and completed the project management certification program at the University of California at Irvine.

**Ken Gerling** is an associate project manager at Burns & McDonnell and was the project manager for the Southern California Edison Tehachapi Renewable Transmission Line Project segments 1-3. He has also worked on major scale transmission line programs for Northeast Utilities, San Diego Gas & Electric and Vermont Electric. His expertise is in project planning, design management and construction management from project inception through closeout. Gerling has a Bachelor of Science in civil engineering from the University of Missouri and a Master of Science in engineering management from the University of Kansas.
Foundation Design Minimizes Environmental Impact

By Chih-Hung Chen, PE, Burns & McDonnell, and Nick Salisbury, Crux Subsurface Inc.

For construction within the Angeles National Forest, the U.S. Forest Service requires minimal disturbance of the land. An unconventional design and construction solution helped SCE gain approval from the U.S. Forest Service.

Micropile foundations, a high-capacity version of solutions sometimes known as pin piles or mini piles because of their small diameter, also provided cost and schedule advantages over other designs because of restrictions imposed by working within the forest.

Design Selection

The initial design for the TRTP included a typical drill shaft foundation, which would require miles of access roads for drilling and construction equipment. Within the forest, access roads were not approved. Hand-digging would be a high-cost, inefficient method for the shafts, which would range from 42 to 72 inches in diameter and 15 to 30 feet in depth. Hand-dug excavations create worker safety hazards that are difficult to mitigate in the eyes of contractors and the Occupational Safety and Health Administration. Explosives were not an option because of fire risk and environmental disturbance.

The use of micropile foundations enables the construction of transmission towers with a smaller overall footprint, disrupting less of the sensitive forest environment.
Several alternatives, including prestressed or post-tensioned rock anchors and micropile foundations, were considered. Rock anchor foundations, which use anchors to resist uplift and utilize bearing between concrete cap and rock to resist foundation rotation, compression, and shear loads, were deemed impractical because of the highly variable near-surface rock and soil conditions.

Micropile foundations were proposed by the general contractor, PAR Electrical Contractors, as the preferred foundation alternative. Foundations were designed by Crux Subsurface and its subconsultant and reviewed and approved by Burns & McDonnell and SCE. The foundation system was constructed by Crux and PAR.

Micropiles combine the uplift resistance consistent with a rock anchor foundation and the compression and lateral bending resistance of a drill shaft foundation. Because micropiles typically range from 4 to 12 inches in diameter, lightweight drill rigs can be configured to install the small, high-capacity deep foundation members that can be transported by helicopter and assembled at each site.

Beyond environmental advantages realized by the elimination of road building, the lightweight materials and construction equipment create benefits including a significant reduction in spoils, elimination of fluids commonly used in drilled shaft construction, reduced emissions compared to conventional equipment, and a smaller foundation footprint. These combine for an overall reduced impact on the environment, which contributed to the approval of the Forest Service.

On the TRTP, micropile diameters range from 5.5 inches to 8.625 inches at depths between 25 and 51 feet. Groups of three to 12 micropiles per tower leg are constructed, depending on the tower type and soil condition.

A geotechnical report for the project served as a basis for identifying soil type and condition. The Federal Highway Administration Micropile Design and Construction Guidelines Implementation Manual and the Post Tensioning Institute’s Recommendations for Prestressed Rock and Soil Anchors were used for initial assumptions of soil strength.

The micropile design was advantageous because it could be adapted to accommodate individual site conditions.
Several sacrificial preproduction micropiles were tested to evaluate the ultimate grout-to-ground bond stress before construction began. A licensed geologist characterized the soil on-site for each tower footing during construction.

The micropile design was advantageous because it could be adapted to accommodate individual site conditions by varying the pile length and/or adding additional piles to address anomalies that were not identified in the more general geotechnical investigation. The 224 micropile foundations (four per tower) installed were grouped into three tower families. The number of piles and length of each upper cased section and lower bond section were installed to meet a minimum criteria for a variety of soil and rock conditions. After micropile installation, proof load tests were conducted at each tower site to confirm that piles met factored design loads.

**Technical Challenges**

Micropile foundations utilize the complex interaction of numerous components including rock or soil, steel micropile reinforcement and casing, cast-in-place concrete and steel lattice stub angles. Comprehensive design of the entire foundation system is essential to ensure long-term tower performance.

Micropiles are inherently slender, flexible members. SCE required that the foundations meet stringent deflection criteria and have built-in safety factors to minimize stress buildup in the stub angle transferred up the tower leg and adjacent bracing member. Compliance with the desired deflection criteria was achieved by the arrangement of the piles within the group.

Environmental factors such as wind, fog, and dry, hot weather that increased fire risk all had impacts on this helicopter-supported project. Scheduling of critical items such as placement of concrete and micropile grout, each within a specified time of batching, enhanced the need for project planning and execution.

In the end, helicopter-supported micropile installations provided foundations that could meet strict design criteria, minimize ground disturbance and environmental impact, and provide scalability to adapt to varying ground conditions without downtime for further design or agency review.
For more information about Burns & McDonnell services to the electrical transmission and distribution industry, contact Mike Beehler, 816-822-3358, mbeehler@burnsmcd.com.