UNDERGROUND RISING

Some of the finest work your local electrical utility is doing today is going unseen and unnoticed — because it's going underground.

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INTRODUCTION

By **James R. Dukart, E-Books Editor, T&D World**

James R. Dukart

Some of the finest work your local electrical utility is doing today is going unseen and unnoticed — because it's going underground.

Varied economic and demographic factors or issues — both population growth/density and physical geography — are driving this, as are customer preferences for as much power delivery underground and out of sight as can be feasibly done.

And while undergrounding distribution cable (and, increasingly, transmission cable) looks to be a foreseeable trend well into the future, going subterranean carries with it its own set of unique and interesting challenges to utilities.

In this e-Book, we look at how utilities have addressed these underground challenges with dutiful and proficient engineering and field work, resulting in ultimate success.

Our first article, on the burying of a section of 230-kV cable in northern New Jersey, highlights both improvements in technology and work practices that are being developed in undergrounding. PSE&G, working with cable supplier Southwire, laid some 7.1 miles of high-voltage cable in a densely populated area in just a few months and with minimal traffic disruptions and no safety or workplace incidents whatsoever.

Our second article, "Where Innovation Meets the Road" discusses Dominion Energy's use of a mobile substation connecting to 230kV underground cable in Virginia. While the anticipated use of the mobile substation is for emergency preparedness and outage restoration, Dominion was successful in its first-ever use of this substation-on-wheels in a partial line rebuild of a 115-kV transmission line; fed by underground 230-kV cable, the mobile substation allowed the line to remain online and in service for four full months in 2016 during the line rebulid.

In our third piece, we look at riser tower issues AltaLink, an Alberta, Canada-based transmission line designer, faced when moving transmission underground. Among the takeaways from the article are to pay close attention to riser structures and bushing connections — the substation intersection of overhead and underground lines, in many instances.

The justification for including undergrounding in a utility's toolbox, particularly in urban areas, is rather eloquently stated in this quote from that article:

"As the areas in and around cities and substations become more congested with buildings and existing infrastructure, a moderate amount of underground sections can make the grid more reliable, especially in critical areas where a full rebuild or reconfiguration is not possible."

We then wrap up this e-Book up with a story any engineer should love — the tale of some of the engineering and planning that went into an underground 500-kV transmission line laid in Southern California by Southern California Edison from 2014 through 2016.

The underground portion of this line, running for 3.7 miles directly underneath the city of Chino Hills, California, was the first installation of 500-kV XLPE cable in North America and the first-ever use of this cable in duct and manhole systems (as opposed to tunnels) anywhere in the world. We don't want to give away the good parts — you should scroll down and read it yourself — but the project presented unique and vexing challenges around the thermal-mechanical performance of high-voltage cable operating in a seismic zone that no one had seen before, and probably very few, if any, have since.

From an engineering perspective, it is fascinating to read how the engineers and workers on the project managed to address and solve these issues on this first-of-its-kind endeavor.

We hope you will enjoy this T&D World e-Book on Undergrounding, and as always, we welcome your feedback and suggestions for future e-Book topics.

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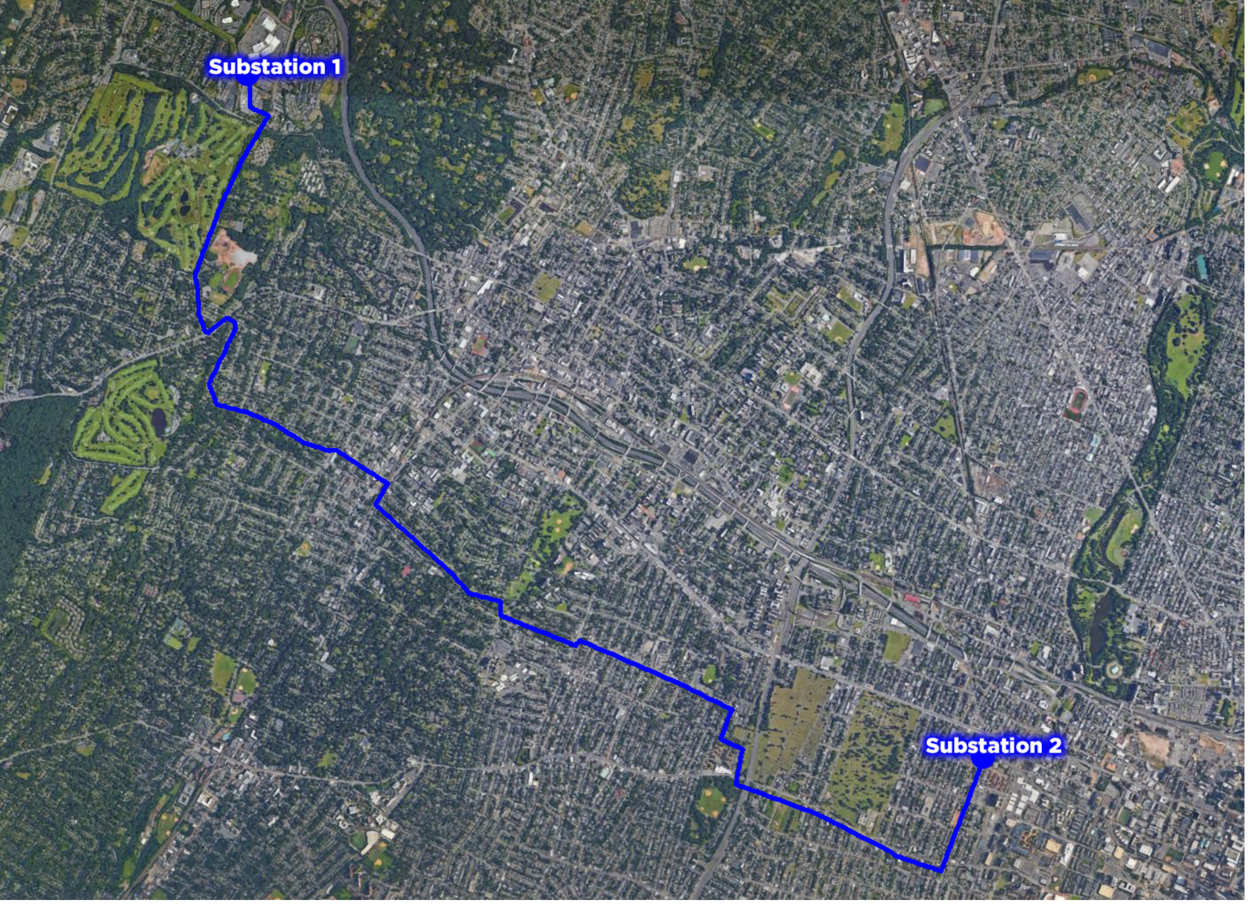


Figure 1: The location of the route required significant and ongoing coordination between and among PSE&G, local communities, and county and state police for installation. Several sections along the route required night operations for pulling cables to avoid disruption of local traffic; every effort was made to do as much work as feasible in lighter-traffic times of day, including overnight and mid-morning to mid-day hours.

GOING UNDERGROUND TO SOLVE A TRANSMISSION CHALLENGE IN NEW JERSEY

Electric utilities serving bustling urban areas today face a dilemma regarding existing transmission networks

By James R. Dukart, T&D World, and Randy Denmon, Southwire Company, LLC

With crowded cities and busy streets filled with constant vehicle and pedestrian traffic, increasingly cramped — if any — overhead rights-of-way and growing construction and urban development, how does the utility improve reliability, relieve transmission overloads and provide back-up to other critical circuits along transmission lines?

At PSE&G in Newark, New Jersey, the answer, in at least one case has been to go underground. In late 2017 and into the first two months of 2018, PSE&G installed new underground cable on its West Orange-to-Newark transmission line.

The 7.1 mile-long circuit is comprised of 112,470 feet of cable, 54 joints and 6 outdoor terminations, along with ancillary material, such as ground continuity conductor, grounding boxes with bonding cable and splice racking for supporting and clamping of the cables. In addition to the 230kV cable system, distributed temperature sensing (DTS) and communication fiber optic cables were simultaneously installed in the same duct bank.

The cable provided for this project consists of 3500kcmil copper segmented conductor to meet the ampacity of the circuit, 906 mils of XLPE insulation, concentric copper wire shield and a copper laminate moisture barrier with an outer HDPE jacket. The use of a thin moisture barrier reduces the weight and diameter of the cable versus other moisture barriers such as lead or corrugated metallic sheaths. The cable was manufactured at Southwire's

Huntersville HV/EHV cable production facility.

The circuit was PSE&G's first use of 230kV extruded dielectric cables for an underground transmission circuit. The route weaved its way through Essex County, NJ, crossing through five municipalities.

The location of the route required significant and ongoing coordination between and among PSE&G, local communities and county and state police for installation. Several sections along the route required night operations for pulling and splicing of cables to avoid disruption of local traffic; every effort was made to do as much work as feasible in lighter-traffic times of day, including overnight and mid-morning to mid-day hours.

In addition, work along public streets requires notification of local authorities, as well as affected homeowners, including no parking notifications for residents and visitors.

Cable installation work was coordinated with PSE&G's schedule to take best advantage of the weather in New Jersey. Delivery of cable to the project storage yards began in August 2017 and was completed by December 2017. Cable pulling began in August as well. It was common that the pulling subcontractor was able to perform two cable pulls in a day, which required very good coordination of labor and equipment around the various sections of the circuit. Simultaneous to cable pulling, cable splicing work began in September 2017 and was completed in February 2018. The commissioning test was performed on February 28, 2018, and all crews were demobilized the following week.

To maintain the project completion schedule, multiple splicing crews worked simultaneously in vaults where cable pulling had been completed, as well as at the substation termination points. Cable splicing and terminating work requires labor that is highly skilled and certified with the accessories installed as part of the cable system. Southwire's experienced cable splicers were up to the challenge and, along with their subcontractors, not only performed a high-quality installation but completed the work with zero safety incidents.

As previously mentioned, cable splicing requires highly skilled labor trained in proper use of the tools required to prepare the cable, as well as an understanding of the fitting instructions of the specialized splices and terminations installed on the cable. Pictures 3 through 5 are steps for cable prep, splice body assembly and final support.

Both ends of the circuit terminated in a substation and picture 6 is a completed set of terminations in one of the substations.

The completion of this circuit was a first for PSE&G, as it is their first extruded insulation cable in a circuit outside of their typical substation circuits. It also is part of PSE&G's


Cable endprep


Splice body assembly


Splice support

constant efforts to improve reliability.

"This was a new circuit between two substations," noted Ronald Shute, Director of Outside Plant Engineering & Construction for PSE&G and the project manager throughout the job. "If you know anything about northern New Jersey, you know this is a pretty densely populated area with a lot of existing underground infrastructure, so the shortest distance between any two points wasn't exactly the most constructible."

"This was also our first XLPE transmission circuit," Shute continued. "Up until this particular circuit, all of our underground was pipe-type cable, or HPFF [High Pressure Fluid Filled]. XLPE came along in the 1980s and 1990s and now it has really matured and shown itself to be something that is reliable and available and a very nice technology. There is no dielectric fluid needed to cool it, so you can get larger diameter cables and larger load using XLPE."


Substation terminations

From its completion and commissioning in February of 2018 through today, this particular section of underground 230kV transmission cable has contributed to the electric reliability of homes and businesses, and powered the lives of the residents, in this bustling area of New Jersey — a true win-win scenario for the utility and its customers. TDW

We asked Randy Denmon, P.E., Director of Underground Transmission Solutions in the Power Systems and Solutions Group of Southwire, what his group looks at on underground cable jobs. He provided us the following list:

CONSIDERATIONS FOR ALL UNDERGROUNDING JOBS:

Consideration	Items to Consider
System Requirements	Current / Voltage / Short Circuit / Emergency
Installation Type	Submarine / Direct Bury / Duct Bank / Shaft / Trough / Tray / Pipe
Installation Environment	Soil Type / Soil Resistivity / Ambient Temperature / Soil Temperature
Cable Elements	Conductor Material / Insulation Material / Water Barrier and Screen Type / Jacket Requirements
Circuit Measurements	Total Length / Limits on Minimum and Maximum Segment Length / Number of Splices
Installation Location	Natural Barriers / Site Accessibility / Transportation Limitations / Environmental Restrictions / Labor Laws / Permits
Accessories	Type of Accessories / Number of Accessories / Available Space / Technology
Testing Requirements	Routine and Commissioning Testing — Specific to Job
Monitoring Requirements	Specific to Job

In addition, Denmon offered the following as additional considerations for each and every underground install:

- Safety
- Overhead to Underground transition - riser pole, substation, work area?
- Unloading and staging large steel reels of cable – located close to project site, use of cranes to unload reels from trailers
- Splice vault locations and work area – city street, existing OH ROW, etc.
- Cable pulling tension calculations
- Weather conditions for cable pulling, terminating and splicing
- Industry standards such as AEIC CG4-97

SOURCE: Southwire

The Cartersville Mobile Substation Installation was energized in August 2016.

WHERE INNOVATION MEETS THE ROAD

A unique mobile substation application delivers power during a wreck-and-rebuild project

By Bobby Rich and Angelita Gardner-Kittrell

When it was time to rebuild a portion of the 115-kV radial Bremo-Cartersville transmission line in Cumberland and Fluvanna counties, Virginia, U.S., Dominion Energy immediately equated the rugged terrain — specifically a steep bluff — with a costly temporary line, right-of-way access challenges and safety concerns for its crews. However, Dominion Energy is no stranger to innovation, especially when it comes to serving more than 2.6 million customer accounts in Virginia and northeastern North Carolina, U.S. The utility is accustomed to thinking creatively about electric transmission projects because of the diverse conditions found in the region: coastal areas, mountains, rural communities and densely populated cities.

After considering the options for the Bremo-Cartersville line, Dominion Energy decided to use a 230/115-kV mobile substation to feed the load using a parallel 230-kV transmission line at the adjacent Cartersville substation. Coined the Cartersville Mobile Substation Installation, this solution was the first 230/115-kV mobile installation of its kind in North America. This project was different because it was a transmission-to-transmission application and featured self-contained gas-insulated substation (GIS) bays. This was the first time 230-kV underground cable had been used for temporary work. The rebuild project also involved underground cable connections: GIS to GIS and GIS to air-insulated bus (AIB).

It took four months to set up the Cartersville Mobile Substation Installation. The scope included grading work, as well as the installation of gravel, a ground grid, a security fence and five mobile trailers on a 3-acre (1.2-hectare) parcel in Cumberland County. The equipment included a 230-kV mobile switch, a 245-kV mobile GIS bay, three single-phase 230/115-kV mobile transformers, a 138-kV mobile GIS bay, a 115-kV mobile switch, and 138-kV and 230-kV underground cables. The mobile substation installation was energized and de-energized exactly as planned. No safety or human performance incidents occurred, thanks to detailed work plans.

This inside view of the 115-kV mobile GIS trailer shows the AC and DC distribution panels, SF6 gas DILO cart and track-mounted crane.

EMERGENCY PREPAREDNESS

Dominion Energy purchased the mobile substation as part of its resiliency strategy for responding to cyber-attacks, physical breaches, extreme weather and other such events. With hurricanes posing a real threat to the area, the mobile substation is a valuable asset. It allows the utility to re-establish service within seven days of an incident inside existing substations. Depending on the circumstances, without the mobile substation, the complete loss of a substation transmission transformer could take two months or more from which to recover.

The Bremo-Cartersville rebuild project presented the perfect opportunity for using the mobile substation. The project saw the installation of the mobile substation adjacent to the Cartersville substation. It provided the opportunity to vet procedures and associated checklists, as well as to test equipment.

VIABILITY AND RELIABILITY

The Cartersville Mobile Substation Installation carried the Bremo-Cartersville load 24 hours a day, seven days a week from Aug. 2, 2016, to Dec. 2, 2016. The success of the installation demonstrates the mobile substation's viability for unplanned restoration efforts and future transmission construction projects. One benefit of the mobile substation is its ability to integrate with the current line protection, providing the same reliability in a temporary connection as a permanent one.

The mobile substation also is separable and can be used individually. For example, a breaker failure or loss of a three-phase transformer can be resolved in 48 hours to 72 hours using only the breakers or single-phase transformers of the mobile fleet.

The underground cable links enable a large array of connections to be made, minimizing the need for disruptions to the surrounding environment as well as maximizing safety to personnel and the public. The underground cable links greatly reduce the installation time.

With the butterfly doors open on the 115-kV mobile GIS trailer, the GIS breaker, disconnects and ground switches can be seen. In this trailer, the 115-kV cable is not installed in this picture. However, the photo on the right shows 115-kV cables inside another 115-kV mobile GIS trailer.

While Dominion Energy is used to working with GIS breakers in standard substation configurations, the GIS breakers in the mobile configuration are mounted inside self-contained trailers. The breakers can be used for bypassing transmission switches while eliminating line outages for maintenance or replacement.

The 230-kV underground cable going into the 230-kV line connection.

A TEAM EFFORT

Tremendous coordination occurred across the electric transmission organization. During the Cartersville Mobile Substation Installation, biweekly meetings turned into weekly meetings. The installation was non-standard, and field engineering was ongoing throughout the duration of the project.

A 19-acre (7.6-hectare) parcel was rented from a local property owner, of which 3 acres were used for the mobile substation. Located in Cumberland County, the parcel was adjacent to Dominion Energy's Cartersville substation and another substation owned by Central Virginia Electric Cooperative (CVEC). After the mobile substation was dismantled, the parcel was restored to its original condition.

Dominion Energy met with Cumberland County early on to discuss the project. Because the substation was designed and built to be temporary, the county did not require a permit. However, the site was included in the state storm water permit acquired for the overall line rebuild project.

Dominion Energy worked with seven suppliers from three continents: Mitsubishi Electric, Alstom (now GE), Pfisterer, Southwire, Okonite, HICO and Trail King Industries. Because the equipment was non-standard, it was difficult to find willing suppliers capable of completing the technical engineering designs and then warranting their work. Simply put, this posed a unique challenge to suppliers.

Dominion Energy also worked with three contractors to support the mobile substation installation.

The 115-kV cable to 115-kV overhead line connection with arrestors.

LEADING-EDGE TECHNOLOGY

The concept of Dominion Energy's mobile substation was based on tried-and-true transmission substation knowledge. However, engineers applied the technology in a new and innovative way to create a mobile substation that is best in industry. From the beginning, Dominion Energy had a unique design for its mobile substation in mind. Engineers attended industry forums and conferences to learn more about the technology available in the market. They were thinking outside the box and looking for suppliers to do the same with their engineering concepts.

Dominion Energy opted for a plug-and-play concept while applying underground cables and special socket connections manufactured by Pfisterer. This approach reduces the amount of time it takes to install mobile substations, while not requiring the typical overhead support structures and added installation spacing.

The cables consist of 230-kV cross-linked polyethylene (XLPE) insulation manufactured by Southwire and 138-kV ethylene propylene rubber (EPR) insulation manufactured by Okonite. The cables are installed along the ground and plugged directly into the mobile GIS bays and transformers. Pfisterer helped to educate and assist engineers and contractors with the cable terminations as well as the installation.

The 138-kV GIS bay was manufactured by Alstom (now GE), shipped to Spain for integration into the mobile trailer, fully tested and then shipped to the U.S. The 230-kV GIS switchgear was manufactured by Mitsubishi Electric and then integrated into the mobile trailer in the U.S. by AZZ Manufacturing. Road tests were conducted on the unit at the Honda test track in the U.S.

Each mobile GIS bay consists of one gas circuit breaker, line-side and load-side disconnect and ground switches, a potential transformer that can be used for station service, gas-handling equipment, station batteries with a charger, and protection and control relays.

One of the innovations associated with this project was the ability to perform a high-voltage withstand test on the 138-kV GIS bay by backfeeding through the voltage transformer on the switchgear, using test equipment and reactor modules provided by OMICRON. This presented a significant time and cost savings over the normal testing method, which would have required transporting a test transformer to the site.

The three 230/115-kV single-phase transformers were manufactured by HICO and then integrated into the mobile trailer. HICO optimized the transformer design to meet all the technical requirements and arrived at a 195-MVA loading capacity. The specified high-voltage-rated Pfisterer socket terminations were applied to accept the underground cable connections. HICO worked with Trail King Industries to develop and manufacture low-boy trailers around critical weight distribution requirements and tight tolerance interfaces while also meeting all the required roadway transport limitations.

The 115-kV and 230-kV connections are going into the single-phase transformer.

LESSONS LEARNED

The Cartersville Mobile Substation Installation was not without challenges. The biggest challenge was designing roadworthy trailer-mounted mobile substation equipment that met all the required technical and reliability requirements. The final products had to be eligible for Virginia's and North Carolina's Department of Transportation blanket highway permits, which required close attention to ensure the trailer weights, heights, widths and lengths were well within the specified limits. This was extra challenging with the transformers and associated trailers, as they were the largest pieces of equipment. The cable reels had to be designed with removable flanges to make them more easily transportable.

The 3-acre parcel selected for the mobile substation had a slope that required extensive grading to avoid issues with water drainage and oil containment. It was important for the transformers to be installed on level grade with minimal tilt.

The maneuverability of the cables was challenging, as well. The 138-kV EPR cables are more flexible than the 230-kV XLPE cables, and the XLPE cables are much heavier. Since the cables had to be recoiled and used for future mobile substation installations, the cables were uncoiled carefully. Once the cables were down, other items within the substation could not be moved for risk the cables would be damaged. As part of the demobilization plan, a special reel stand was ordered to roll up the 230-kV cable and transport it to a storage facility.

The 230-kV cables in the foreground are going into the 230-kV mobile GIS trailer, while the 115-kV cables in the background are going into the 115-kV mobile GIS trailer. The inset shows the covers Dominion Energy designed to keep animals and other elements out of the 230-kV mobile GIS trailer.

FUTURE APPLICATIONS

The Cartersville Mobile Substation Installation was a success. By choosing the mobile substation instead of a temporary overhead line for the Bremo-Cartersville rebuild project, at least six months of construction was avoided. In addition, the one-time cost of the mobile substation was approximately 30% of the total cost of a temporary overhead line. This savings accounts for almost 40% of the total cost of the equipment. The equipment will pay for itself with one more application, planned or unplanned.

While it may not be ideal for every project, the mobile substation does have a permanent place in Dominion Energy's tool kit. TDW

The 230-kV cables in the foreground are going into the 230-kV mobile GIS trailer, while the 115-kV cables in the background are going into the 115-kV mobile GIS trailer. The inset shows the covers Dominion Energy designed to keep animals and other elements out of the 230-kV mobile GIS trailer.

Underground cable layout showing cable loops in the direct buried section between the duct bank and riser structure.

THE NAVIGATION OF AN UNDERGROUND PROJECT

The design and construction of riser structures provides unique challenges for transmission designers in Alberta, Canada.

By **Andrew Rees** and **Kishor Kumar**

In Alberta, Canada, most of the transmission grid consists of standard overhead transmission lines. While some underground transmission projects have been built—in looking at the percentage of the grid that is underground in southern Alberta—these underground additions are few and far between. So, when a project with underground is approved, it can provide some excitement compared to the standard overhead project. This type of project also can make the design challenging for those used to overhead lines, but it allows creativity to be combined with tried and proven standard construction practices. That is exactly what happened when AltaLink began looking at a different solution for a new transmission improvement project.

In recent years, multiple projects were investigated to improve the transmission grid in southern Alberta. Some of the areas AltaLink identified for improvement were congested either because of multiple transmission lines and buildings or because of proposed, new development plans. Overhead transmission is always the first option considered for economical reasons. However, because of reliability concerns and the geographic area, final approvals from the system operator included the go-ahead for some short underground sections of transmission line. These underground sections were added for various reasons, including overhead congestion and to avoid major long-term outages on existing lines.


During underground cable pulling the caisson foundations are exposed which is an important factor to consider during design.

In one project, underground designs were approved for use in three separate areas:

- Substation reconfiguration—A key substation was in a congested area with multiple transmission lines and surrounding buildings, new developments and a rail line. The transmission lines had to be reconfigured to improve reliability.
- New power plant—A new power plant was being built. The best place for the transmission lines to connect the plant to the grid was on the opposite side of a road, which itself was on the far side of an existing utility corridor already supporting multiple lines.
- Trail reclamation—An existing lattice-tower line passing through a downtown area was being upgraded with a higher-capacity rebuild. For future use of the area—residential, commercial and recreational purposes—it was decided a section of the new transmission line should be underground.

PROJECT REQUIREMENTS

After the need for an underground solution was identified, this solution was then approved by the Aberta Electric System Operator (AESO). The next step was to decide what types of structures to use for the connection. Because of the lack of available riser pole design experience at the time, no options were ruled out immediately. Extensive discussions were necessary to find the right choice to meet all the project's requirements.

The structure type had to satisfy overhead transmission standards used for all previously designed transmission lines in the project portfolio, including the Canadian Standards Association, the Alberta Electric System Operator and Alberta Electrical Utility Code, plus all applicable client standards. Standards outside the normal practice for overhead lines became part of the design work because of the need to include a small ground grid at some structures, together with a fenced enclosure.

The team performed checks and calculations normally done for systems inside substations. Once all requirements were identified for the projects, the final structure design proceeded with only minor design changes during the process because of new restraints that arose later.


The entire transmission utility corridor (TUC) showing the new circuits transitioning to underground on the far left, a rebuilt circuit in the center, and an existing lattice circuit on the right.

The entire transmission utility corridor (TUC) showing the new circuits transitioning to underground on the far left, a rebuilt circuit in the center, and an existing lattice circuit on the right.

DESIGN PROCESS

Before deciding on the geometry, the team considered multiple designs with feedback from the cable manufacturer and in consultation with the client. In the end, the preferred structure type was custom steel monopoles with a single-level bushing platform. This design would enable easy access for maintenance personnel and be customizable enough to limit aesthetic impact by adjustment of the platform height.

At one location, because of the number of visitors to the surrounding businesses and their proximity to the poles, it was decided the riser area should be completely enclosed with a fence. In this area, four circuits were attached to four poles before transitioning to underground. By restricting access, the fence allowed the support platforms to be significantly lower, which helped to improve the aesthetic for surrounding businesses.

Once the design concept was decided, the next step was to evaluate any available cost savings as well as additional special requirements and requests from the client at each specific location. One of the riser locations had extra, available right-of-way owned by the client, so a light-duty option was created, spreading the phases over multiple guyed light-duty steel poles. All other locations ended up requiring custom steel monopoles with appropriate height bushing platforms based on surrounding land use.

DESIGN CHALLENGES

Designing a riser structure has many similarities to standard transmission structures designed every day. However, they also come with many challenges that sometimes require looking outside transmission standards, which can make the design quite unique. Riser structures have loads from overhead and underground cables, which can interact differently from other overhead line structures where loads

Outer bushing casing being lowered over the prepared underground cable. Once bushing has been completed it will allow the safe transition between overhead conductor and underground cable.

are mainly from overhead wires. Understanding the performance of the underground cable and its termination to the bushing is important.

The bushing is the insulator that enables the transition between the overhead wire and underground cable. The overhead wire terminates at the connection on the top, usually by a National Electrical Manufacturers Association (NEMA) pad. Prepared specially, the underground cable is inserted and connected into the bottom. This connection point between the bushing and underground cable can be highly sensitive to any movement or forces, which can make this connection the weakest point, having the highest chance of failure between the overhead and underground systems.

When designing the riser structures, the interaction between the cable and bushing supplier is crucial. The cable supplier should provide details of the longitudinal movement of the cable during operating scenarios, so the structure support can be designed accordingly. Bushing support tolerance should be well-defined by the bushing supplier, so the support is rigid enough to keep the cable termination and bushing intact.

Another important aspect of the riser structures is hardware. Hardware for riser structures needs to terminate the overhead and transition to underground. For the long-term health of the cable, all cable manufacturer requirements should be established from the beginning, including hardware, deflection of supports, and unique loading criteria.

Underground cable emerging from the duct bank on the substation side during final stages of backfilling.

CONSTRUCTION METHODS

How the cable will be installed in the ground can affect construction methods significantly. Some of the major points for consideration are foundation design limitations, backfill material consistency and grounding.

With the underground cable being buried next to the riser structure, the foundations of the structure were specially designed. The custom steel monopoles required large caisson foundations. Because the cable was installed after pole erection and to accommodate possible cable repair or replacement, the top section of the foundation was designed to take loads without lateral support from the soil, but with minimal deflection all the same.

Backfill material consistency can be vitally important because of the specific temperature requirements to ensure the long-term health of the underground cable. Heat generated by the cable can have severely detrimental effects on performance, short and long term, if it cannot be regulated properly. With a consistent material surrounding the entirety of the underground system and known thermal properties, especially thermal conductivity, heat dissipation can be calculated to ensure the cable will operate at desirable temperatures during peak load. For the area requiring a concrete duct bank, a special concrete mix was required along with laboratory testing to have a reliable understanding of the thermal properties.

Because of the dimensions of riser structures, the risk of touch potential can be high depending on the type of grounding system used. Working with the cable manufacturer to satisfy any of its requirements for the cable, while also performing the necessary checks to ensure public and utility worker safety, is key to ensuring an appropriate grounding system has been chosen. Some of the riser areas needed localized ground grids because of the extended dimensions of the underground cable ground transition.

Finished riser area enclosed in a fence where 4 circuits transfer from overhead to underground to travel under the adjacent circuits to connect the new power plant to the grid.

THE CASE FOR UNDERGROUND

Even though designing riser structures is outside the normal practice for most transmission engineers, adding underground to transmission lines can help to mitigate several costly factors under unique circumstances. As the areas in and around cities and substations become more congested with buildings and existing infrastructure, a moderate number of underground sections can make the grid more reliable, especially in critical areas where a full rebuild or reconfiguration is not possible.

Working closely with the cable manufacturers and hardware suppliers ensures everyone is concentrating on the importance of safety and effective coordinated design. This helps to reduce costly redesigns mid-project when something simple, which could have been discussed and caught early, ends up needing extensive extra engineering hours or material changes. TDW

ENGINEERING A 500-KV UNDERGROUND SYSTEM

Southern California Edison realizes project success through collaboration with key organizations.

The 500-kV Tehachapi Renewable Transmission project in Southern California, U.S., will deliver renewable energy from Kern County, south through Los Angeles County and then east to the city of Ontario in San Bernardino County, a distance of more than 170 miles (274 km). The project, which replaced many of Southern California Edison's (SCE's) existing 220 kV lines with 500 kV, was all overhead except for 3.7 miles (6 km) of the line passing through the city of Chino Hills. While that portion represented only 1.5% of the total project, it created unprecedented engineering and construction challenges.

Although this project included just one circuit with two cross-linked polyethylene (XLPE) cables per phase initially, the final build-out can accommodate two circuits with three cables per phase for each circuit, or a total of 18 cables. SCE enlisted Black & Veatch as the engineer of record to handle detailed design, procurement and construction support to resolve the daunting electrical, mechanical and civil engineering challenges this project presented. Throughout the engineering, procurement and construction process, the SCE/Black & Veatch team worked closely and collaboratively with the various stakeholders, including Power Delivery Consultants and MPR Associates, as each new project decision arose.

This SCE underground project is the first installation of 500 kV XLPE cable in North America and the first time this type of cable was used in duct and manhole systems anywhere in the world. All previous installations were either in tunnels or direct-burial systems. None required the construction of duct structures on terrain with slopes between 30% to 40% in some areas, horizontal directional drilling (HDD) 150ft (46 m) below the ground surface; 42 64ft (19.5 m)-long cable splice vaults, or several miles of temporary and permanent access roads.

CABLE SUPPLIER

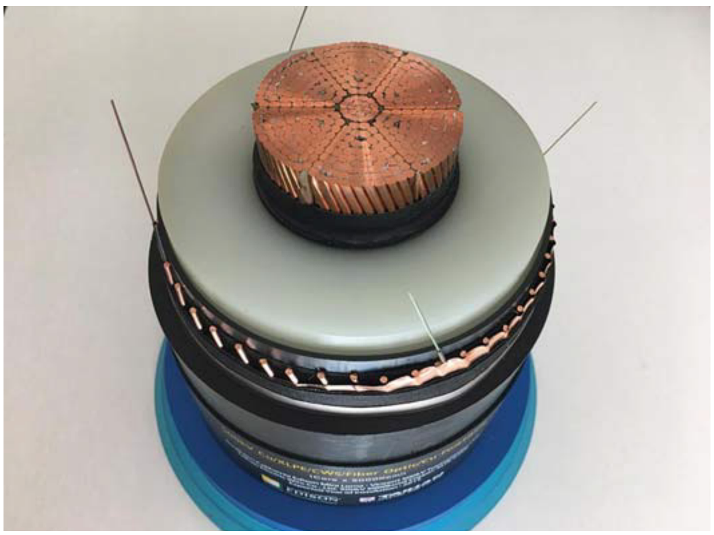
There were no cable standards in the U.S. or abroad that addressed the specific requirements of this project. Therefore, one of the project team's first responsibilities was to generate underground cable specifications to present to potential cable vendors. Nothing was off the shelf, not even the cable specifications. The International Electrotechnical Commission (IEC) standard covers cable up to 500 kV, but it is only for normal steady-state operations, or cable conductor temperatures up to 90°C (194°F).

The IEC does not incorporate emergency operating requirements. For this installation, in planned emergency operations, the cable could operate at a conductor temperature of 95°C (203°F), which is 5C° (9F°) higher than the normal steady-state operation temperature. While the Association of Edison Illuminating Companies (AEIC) standard includes emergency requirements for operating temperatures above 90°C, they are only for cable up to 345 kV.

Black & Veatch and SCE engineers had to massage and blend elements of the two existing standards to come up with a cable specification that met the requirements of the project. Initial studies determined the cable system needed to have a minimum 5000 kcmil conductor with XLPE insulation; beyond this, SCE looked to the cable vendors to develop the final design.

The cable system needed to handle the circuit ampacity of 2000 A for normal operation and up to 3500 A for emergency operation, and capable of operating in extremely hilly terrain at depths of more than 100 ft (30 m) and in duct banks. The design also needed to incorporate integrated distributed temperature monitoring system of all the cables and a real-time partial-discharge monitoring system.

Once the project cable specification was finalized, a request for proposal was issued. SCE received up to six viable, but different, proposals from cable vendors all over the world. During the ensuing evaluations, many factors were considered beyond the technical evaluation of the cable system. These factors included prequalification and type test record, manufacturing and installation experience, manufacturing capacity, commercial evaluations, installation plans, safety and environmental plans. In the end, Taihan Electric Wires from South Korea was awarded the bid.



PROTECTING THE CABLE

The team worked with Taihan to finalize the cable design. Many design issues needed to be addressed, including the thermal-mechanical forces the system would experience. This issue quickly became a central component of the entire design. SCE was familiar with these forces in lower-voltage circuits it had designed and installed, but at much smaller cable sizes. The cable specifications for this 500 kV line had an outer diameter of more than 6 inches (152 mm) and would weigh approximately 26 lb/ft (3.6 kg/m).

The design of a cable support system for a cable of this size would take some innovative engineering analysis; the XLPE cable system was modeled using a finite element analysis (FEA) approach based on work performed by the Electrical Power Research Institute. For simplification of modeling, the multi-layered cable core was modeled as a beam with material properties directly derived from mechanical tests Taihan performed in its factory. The results of the analysis would be used as a comparative check on the cable support system designed independently by Taihan engineers.

The team performed the FEA in three phases to determine the preferred design for the cable support system, which restrains the cable and splices inside the vaults and at the termination location in the transition station. Phase 1 focused on analyzing the cable thermal expansion and contraction without restraints. In phase 2, cable racking design information provided by Taihan was added to phase 1 results and a sensitivity analysis was performed on different cable system design parameters. With this information, engineers could determine the effect of different design and installation parameters on overall cable system operation, which, in turn, enabled them to develop an optimal design. Phase 3 focused on investigating the seismic effect on the thermal-mechanical performance of the cable system. Results indicated cable expansion during a seismic event would be unlikely to exceed the maximum allowable cable movement incorporated in the design of the proposed racking system.

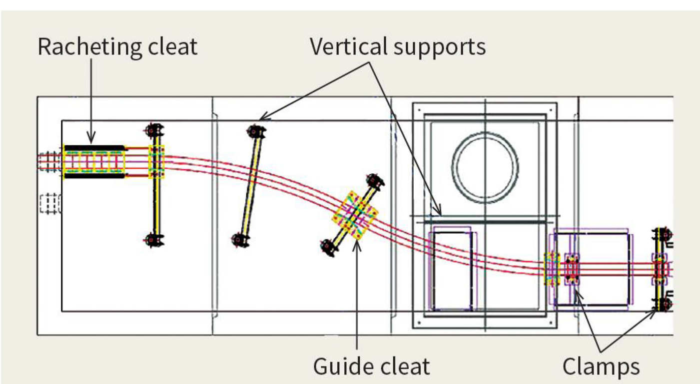
The need to build in such rigor on the cable support system was driven by the unknown forces the cable system would experience, because thermal-mechanical loading criteria were not well understood or addressed. Put simply, the cable system was not viewed as a static component but rather a moving object with a copper core that expands and contracts with changes in temperature.

When installed, the cable would be at an ambient temperature of approximately 20°C to 30°C (68°F to 86°F). However, during operations, the copper core itself could regularly see temperatures as high as 95°C (203°F). This large temperature delta creates large linear expansion in the cable and, in turn, potentially large forces on the cable support system. To address this concern, the project team integrated a cable restraint system that enabled the cables to lengthen as much as 16 inches (406 mm) into each splice vault with the use of a flexible restraint system.

The cables would be trained into the vaults through an S-bend that effectively would function as a spring, enabling the cables to expand and contract with changes in temperature. The amount of growth and forces the expanding cables might produce were modeled in the FEA to help validate the extent of the S-bend and the strength of the cable support system.

Restraining the cables along the route where they traverse steep hills also required special attention. Because of the flexible restraint systems in the vaults, the splices were not capable of restraining cables to fight gravity and slide downhill. Therefore, at six locations along the route, purposely built restraint vaults were designed to anchor the cables from movement.

The restraint vaults were filled mostly with cable cleats designed to grip the cables. The splice vaults then were free simply to handle the cable splicing function without additional cable loads. Another innovation incorporated into the splice vaults were spring-loaded cleats attached to the end walls of the vaults. The purpose of these cleats was to restrain the cable's growth partially into the vaults and provide additional load to force the cables back out of the vaults.



The design of the splice vaults themselves was another significant challenge. The project team had to add significant length to the vaults because the flexible restraint system incorporated the S-bend as the cables enter on one end and leave out the other. Unfortunately, this design detail was not developed before the final order was issued to the concrete vault fabricator. The original vault lengths were only 32 ft (9.8 m) long, but the final vault length grew to 64 ft (19.5 m) long. However, this additional length could be incorporated into the final design because of an innovative tunnel-section design used.

Early in the design process, the team realized the final vault lengths would be difficult to determine because the cable vendor had not been chosen yet. To address this unknown, the team incorporated a universal-design methodology wherever variability in cable criteria could impact other project components, such as the splice vault dimension. The vaults were designed as modular tunnel sections that would be assembled on-site. This provided flexibility for the vaults to be lengthened depending on the requirements of the selected cable vendor. The modular design also aided in delivery logistics, as a single tunnel section weighed significantly less than the fully assembled vault.

ACCESS ROADS AND DUCT BANKS

While the cable engineering and testing was underway, Black & Veatch and its subcontractor, Webb & Associates, began the civil engineering portion of the project. Permanent roads were required for access to all splice and restraint vaults, in addition to miles of temporary roads, which were needed immediately to build the duct banks and provide down-line access for construction equipment.

In all, the project required some 17,000 linear ft (5180 m) of duct bank, which consisted of 7.5 ft-deep by 7.5 ft-wide (2.3 m by 2.3 m) trenches into which crews set 12 8 inch (203 mm)-diameter conduits for the XLPE cable (two layers of six). All the cable conduits — for power, ground, fiber-optic telecommunication cables and wires for partial-discharge monitoring — were held in place by cable spacers until the entire assembly was encased in thermal concrete.

HORIZONTAL DIRECTIONAL DRILLING

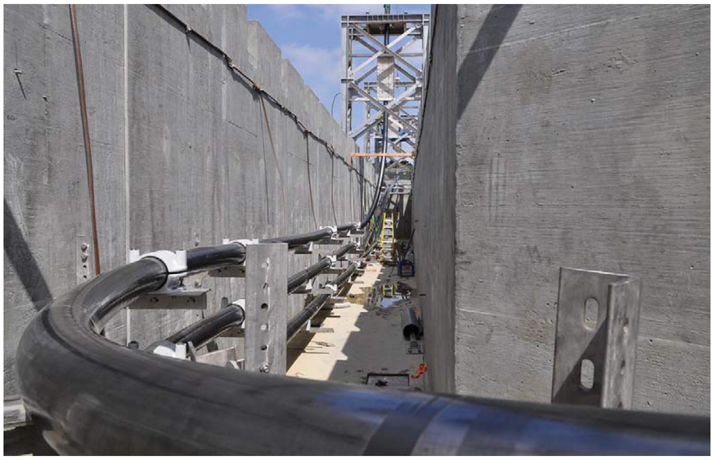
At two locations along the transmission line corridor, Black & Veatch engineers decided to employ HDD to install the conduit system under existing structures and topographic features. In all, the team designed a total of nearly 3 miles (4.8 km) of 36 inch (914 mm)-diameter HDD runs at two locations along the narrow transmission corridor. The first location crosses under a 60 ft (18.3 m) hill and a flood-control channel. The HDDs paralleled each other in a 3 wide by 2 tall configuration. This is expected to be the thermal chokepoint for the entire underground circuit, meaning the cables would run hottest in these HDDs. The second location also crosses under a flood-control channel.

The work, which began in late 2014 and continued through December 2016, required design considerations related to the following:

- Cable ampacity. Because the cables were designed to run at a steady-state temperature of 90°C throughout their 40-plus-year lifetime, the mutual heating of cables in six parallel HDDs in a relatively confined space became a key design consideration. As such, the engineering team performed extensive cable ampacity calculations to design a drill path for the HDDs that would meet the line rating requirement without the addition of an expensive forced cooling system.
- Drilling tolerances. If a drill bit wandered 5 ft (1.5 m) off the design path, the engineering team needed to know how that would affect ampacity.
- Grouting the bores. The engineering team also needed to know whether HDD bores should be grouted to prevent their collapse and the resulting surface settlement, and to provide the cables with a thermally favorable environment. Grouting the HDDs would alter the design and increase the complexity dramatically. The team decided there was no significant value in grouting.
- Alternative drilling paths. Determine whether another path would be available if the drillers were unable to complete an HDD and had to start over.

TRANSITION STATIONS

The two transition stations, each about 3 acres (1.2 hectares) in size, constituted major civil engineering work on their own. Because of the hilly terrain, the Western Transition Station required approximately 170,000 cubic yards (130,000 cubic m) of cut and 60,000 cubic yards (45,000 cubic m) of fill. The Eastern Transition Station involved the demolition of old buildings and hazardous contamination remediation. Key features of both stations are the cast-in-place concrete cable trenches, which were designed to relieve mechanical stress in the cable terminations by enabling the cables to expand freely into the trenches.



SUCCESS

Throughout the three-year engineering design process, the team made all decisions with a strict emphasis on safety, constructability, schedule, maintainability and electrical performance. With input from numerous stakeholders, the overall project was so successful because of the collaboration from the various organizations involved. They have much to be proud of in building this first-of-its-kind transmission line. TDW

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Video: Southwire's Huntersville High-Voltage Cable Production Facility

In operation since 2012, the Huntersville Facility became a member of the Southwire family in 2015. The plant currently fulfills orders for 69-400 KV transmission cable.

https://www.youtube.com/watch?v=E677QAzlXSI

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