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PowerSouth's World Record Breaking 115kV HDD Installed Underground Transmission Line Feeding Orange Beach, Alabama
Part 3 of 3 - 115kV Cable Design, Selection and Installation

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115kV Cable Design

With a feasible Horizontal Directional Drill (HDD) concept developed, the next major project challenge was to develop an acceptable cable design. The cable design not only had to meet PowerSouth's 300MVA load capability requirements at 115kV, but also had to be manufactured in continuous 6,500-foot lengths, tested, transported to site, installed and terminated. The largest 115kV cable copper conductor available from any manufacturer is limited to 5,000 Kcmil (i.e. approximately 2.5 inch diameter copper conductor). Unfortunately even this massive conductor would not be sufficient to support the approximately 1,500 amps required to carry a 300MVA load at 115kV without "out of the box" thinking and development of a unique cable design. The largest previously manufactured cable incorporating a 5,000 Kcmil copper conductor was used in the 2004 cable crossing under the Mississippi River. However, this crossing only required approximately 3,600-feet of continuous cable with a 1,400 amp capacity compared with Wolf Bay's 6,500-foot continuous length, 1,500 amp capacity requirements. Also the Mississippi River cable weighed 42.5 pounds per foot which would have made PowerSouth's 6,500-foot cable weigh over 138 tons and installation in the 6,131-foot duct impossible. Pulling forces for this cable design would have exceeded the mechanical pulling capability of the cable

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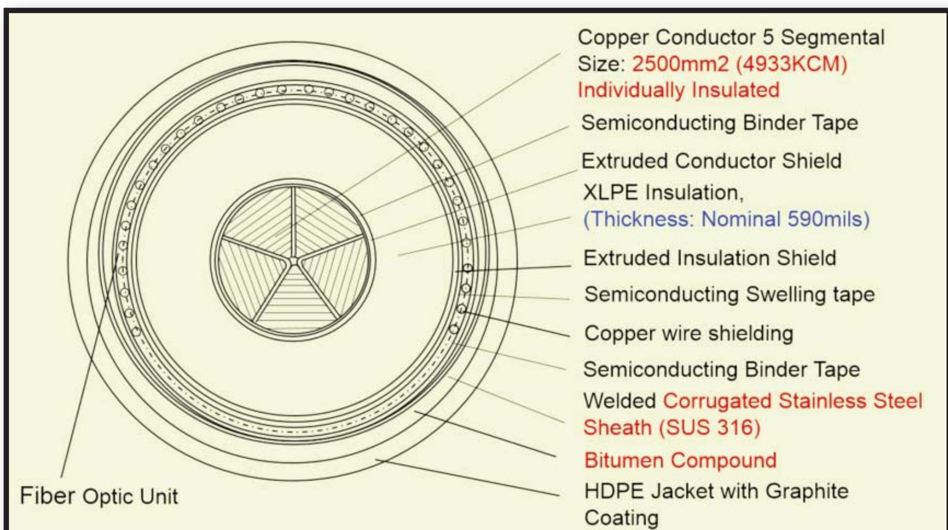
(i.e. the cable would mechanically fail during installation). Obviously for the PowerSouth crossing to be successful, a significantly lighter cable design was required, along with an increase in cable ampacity, while at the same time limiting the design to the maximum 5,000 Kcmil copper conductor available from any of the cable manufacturers.

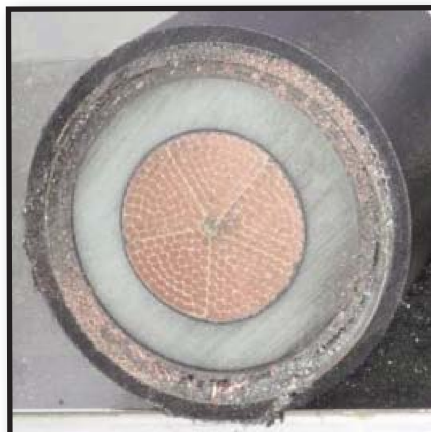
J-Power Systems, a world class cable manufacturer that provided the Mississippi River cable crossing, initially stated the Wolf Bay crossing was impossible. Similar comments were provided by all cable manufacturers contacted. Fortunately, J-Power was willing to provide assistance and help develop solutions to what initially seemed like impossible cable requirements, and they contributed greatly to the success of this project.

The first challenge was to develop a cable design that was significantly lighter than the lead sheathed Mississippi River crossing cable. A metal sheath is required as part of the cable design to completely block water ingress, but a metal lighter than lead had to be found that would not only significantly reduce cable weight but also not adversely affect cable ampacity due to induced currents in the cable sheath under heavily loaded conditions. The lead sheath typically used in many HV cable designs is an excellent choice for many reasons. However, weight eliminated lead as an option, so both aluminum and stainless steel were studied as possible replacements for the typical lead sheath. After significant study and research, stainless steel was selected as the best option for the sheath design. Stainless steel properties not only allowed the sheath to be much thinner than the equivalent aluminum sheath, it also reduced eddy currents, increasing cable ampacity by approximately 10 percent over an aluminum sheath design. The increased corrosion resistance properties of stainless steel were also a positive considering cable proximity to the heavy salt laden atmosphere near the Gulf of Mexico. Cable flexibility of the stainless steel design was addressed by corrugation of the stainless steel sheath.

The stainless steel sheath design not only reduced cable weight from 45.2 pounds per foot for a lead sheath cable design to 24.3 pounds per foot but also increased cable ampacity approximately 10 percent over an equivalent aluminum sheath designed cable. At only 53 percent of the Mississippi River crossing cable's weight using the same copper conductor, it appeared we had a cable design that could be installed in the 6,131-foot duct. Cable weight was further reduced during installation in the duct to 14.5 pounds per foot using Archimedes' principle and filling each duct with water causing the displaced water to further offset cable weight. This further reduced frictional forces between the cable and the HDPE duct wall during installation.



The 300MVA cable capacity required each cable to carry slightly more than 1,500 amps at 115kV. Unfortunately the approximate 10 percent increase in cable ampacity gained through a stainless steel sheath wasn't enough to reach the required current rating. Alternating Current (AC) tends to flow near the surface of each conductor creating a phenomena known as "skin effect". Therefore, to increase the effective surface area of the 2.5-inch diameter copper conductor and further increase conductor ampacity, a number of the three-hundred and five (305) individual copper strands forming the 2.5-inch diameter conductor were coated with an insulating enamel, preventing uninsulated strands from touching and effectively increasing overall surface area of the copper conductor. This process further increased cable ampacity by approximately another 10 percent and finally created a cable design that could not only be installed but also meet Power South's ampacity requirements.



In order to monitor actual cable temperatures during operation, fiber optic glass fibers were included as part of the cable design. This allowed use of a Distributed Temperature Sensing (DTS) system during operation. These fiber optic glass fibers are sensitive to temperature changes which affect "light scattering" and the resultant back-scattered light reflected back to an injected laser source at one end.

This principle allowed the DTS

system to provide:

- Real Time monitoring of the cable surface and conductor temperatures.
- Identification of hot spots.
- Prediction of actual transmission capacity.

Without a DTS system, conservative thermal resistance and cooling capacity estimates would be used for calculating cable ampacity and provide ampacity limits below actual cable capability.

The final 115kV cable design not only met the 300MVA capacity requirements, but also provided an emergency current rating capacity of 370 MVA, 1,858 amps for 100 hours. It also made cable installation through the 6,131 foot duct feasible. Unfortunately, cable design was only one of many significant cable related challenges that had to be resolved. Project success also required manufacturing a cable never previously attempted in this size and length, transportation to the site, installation, restraining the cable in a way that allowed thermal cycling, termination and finally commissioning for long term service.

Cables loaded on Barge from Cable Factory in Osaka Japan

Cable Manufacturing and Testing

Four 6,513-foot long, 115kV cables were manufactured by J-Power in their Sumitomo Power Cable Plant located in Osaka, Japan. Each of these four cables were spooled on specially designed cable reels measuring 29.5 feet long by 15.75 feet high and 14 feet wide, weighing over 100 tons each. These cable reels created a formidable transportation challenge from Japan to the construction site. However, before the reels could be transported complete factory acceptance testing was performed on each cable.

115kV Cable Transportation from Japan to Orange Beach

Once the cables successfully completed factory acceptance testing, each cable reel was prepared for the long journey from Osaka, Japan to Orange Beach, Alabama.

Cable Preparation for HV Testing

Note: 160kV was applied between the cable conductor and the cable metalic shielding for 30 minutes with no breakdown as part of the factory acceptance testing.

The first leg of this journey required loading each reel to a barge docked next to the Sumitomo Osaka Works factory. This barge then transported the cables on a short trip to a local deep-water port where they could be transferred from the barge to an ocean going ship. Each reel was then offloaded from the barge and loaded on the BBC England where the cables would make their way through the Panama Canal and eventually to the Port of New Orleans, Louisiana.

After approximately 5 weeks at sea, the BBC England arrived in New Orleans where the cables were then offloaded to another barge for the final water portion of their journey. These cables were then transported from New Orleans through the Intracoastal Canal to Orange Beach, Alabama.

A docking site in Orange Beach was identified approximately three miles from the Florida Avenue construction site. This allowed the cables to be offloaded from the barge by crane and placed onshore on stands for the final leg of their journey to the construction site. A Goldhofer heavy equipment mover was used to transport each cable reel approximately 3-miles down Alabama Highway 180 to a staging area located on Orange Beach Boulevard very close to the Florida Avenue substation construction site.

The Goldhofer is a self-propelled, 80 wheel heavy equipment mover, with computerized electronic steering controlled by an operator with a wireless remote control.

Cables offloaded from Barge to Oceangoing ship, for transportation through Panama Canal to the Port of New Orleans.

Cables loaded on Ocean-going ship (BBC England) in Japan

Each wheel of the Goldhofer is controllable allowing counter steering, diagonal steering (crab steering), carousel steering or 90° transverse steering which would be required to place the cable reels at the construction site in a location suitable for cable installation. The Goldhofer not only allowed the cable reels to be transported from the barge offloading site approximately three miles to the Florida Avenue Substation, but also allowed easy navigation down a winding driveway and exact reel placement required for cable installation at the construction site. The Goldhofer would simply roll under a stand-mounted cable reel, elevate the transporter bed and transport the cable reel from the storage site to the construction site. At the final location, the Goldhofer would then hydraulically lower its bed and drive away leaving the cable reel for future relocation as required.

115kV Cable Installation and Racking

Temporary scaffolding was installed to support cables from the cable reel to the duct entrance at the Florida Avenue site and from the Sapling Point duct exit to a cable winch.

With duct entry/exit cable installation preparations complete, roller bearings were added to the cable reel, and it was moved into place with the Goldhofer. The roller bearings were then hydraulically lifted allowing the cable reel to rotate and minimize pulling forces required to "pull" the cable off the reel during installation. Frictional brakes were also added to the reel to prevent excess cable payout that could have kinked and failed the cable if pull rates varied or stopped during the installation process and the cable reel continued to turn.

At the Florida Avenue site, cable haulers were placed between the cable reel and duct entrance. These cable haulers had the capability of "holding back" or "pushing" on the cable throughout the installation. Since the first leg of the duct was at a negative 13° slope, there was a concern that the weight of the cable would tend to pull cable from the reel. In fact during cable installation, the cable haulers were required to "hold back" on the cable during the initial downward slope of the duct installation to maintain control of the cable. Without the haulers holding back on the cable during this part of the installation, the risk was that gravitational forces created by the cable "sliding" down the duct may pull cable off the reel at an uncontrolled rate. This would possibly allow the cable to over payout and kink,

BBC England offloading cable to barge at the Port of New Orleans

Goldhofer cable transportation from barge offloading site located near Orange Beach, Alabama to Florida Avenue Substaton construction site.

Florida Avenue Cable Installation Preparation

Sapling Point Cable Installation Preparation

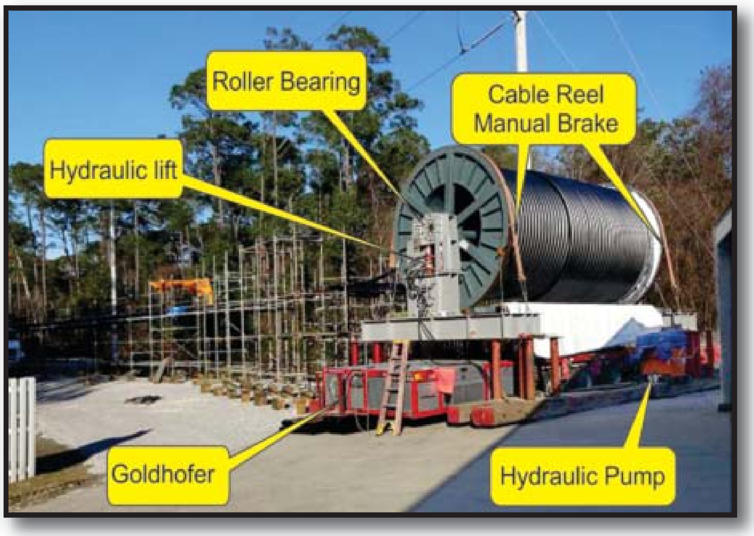
failing the cable with only the cable reel brakes to control cable payout. However, once the cable stopped "sliding" into the duct from gravity, the cable haulers started pushing on the cable, not only preventing any back pressure at the entry point, but also assisting the Sapling Point cable winch further minimizing cable pulling tensions throughout the installation.

The cable pulling forces required were further reduced by filling each duct with water and coating each cable with a wax based cable pulling lubricant upon entrance at the duct. Water displacement during cable installation reduced its weight on the bottom of the duct by the weight of the displaced water. Installing the cables in water filled ducts reduced cable weight from 24.3 pounds per foot in air to 14.5 pounds per foot in water. The reduced cable weight, due to displaced water (Archimedes' principle) along with wax lubricant and a graphite coated cable significantly reduced frictional drag between the cable and the duct contributing to its successful installation.

The next challenge that had to be resolved for a successful installation was managing the cable as it exited from the duct. When pulling cables, the maximum installation force occurs with a maximum length of cable located behind the pulling head, just before the installation is complete. Cable design and installation methods as described above maintained the pulling forces well below the allowable 38,580 lbs for the cable design. However, maintaining cable sidewall pressures below the allowable maximum of 1,008 lbs/ft. upon exit also needed to be considered. As the cable exited the duct and transitioned from a 13° slope to horizontal, a method was needed to keep cable sidewall pressure below the allowable 1,008 pounds per foot. Rollers couldn't be used to make the transition to horizontal since the concentrated point loads on each roller would exceed the allowable sidewall pressure ratings of the cable risking cable failure upon duct exit. The solution to excessive sidewall pressure was identified in a specially designed pulling "shoe" that gradually made the transition from 13° to horizontal and spread the load on the cable throughout the shoe length maintaining sidewall pressures well below cable ratings.

Once the cables were pulled, it was time to coil and prepare them for termination. The coiling of cables within the structures is known as cable "racking" and was designed to address several concerns. The first concern addressed by cable rack-

Cable Haulers

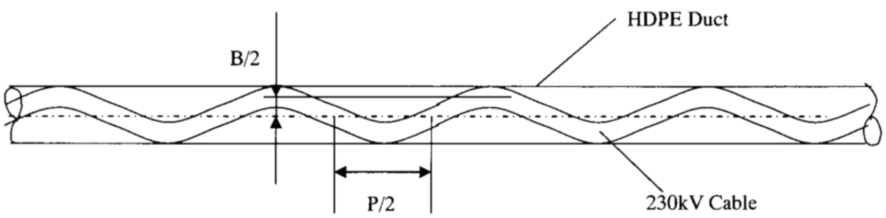


Florida Avenue Cable Installation Setup

Cable Winch Truck Located at Sapling Point

Pulling Shoe

ing was to provide sufficient extra cable should re-termination ever be required. The second concern addressed by racking was to allow cable movement due to thermal cycling. The calculated cable movement at each end due to thermal cycling exceeded 2 feet between no load and full load operation. The cable racking system design had to accommodate this movement along with a tendency for the cable to "snake" in the duct throughout the life of the installation. Snaking is a thermo-mechanical phenomenon that occurs when cable gradually slides down the angled portion of the duct aided by gravity during the cooling portion of cable thermal cycling expansions and contractions. During the heating portion of cable thermal cycling, the force of gravity exceeds the frictional force between the cable and the duct in part due to our efforts to make this frictional force as low as possible to make cable installation feasible. As the cable "slides down the duct" during thermal cycling, cable is pulled into the duct resulting in a permanent displacement that continues until the entire length of cable has taken a "snake" shape within the duct. Therefore, the cable racking design had to accommodate not only the excess of a 2 foot thermal expansion but also over 9 feet of cable contraction within the duct due to the thermo-mechanical phenomenon known as snaking.



Cable Snaking in Duct

Cable expansion and contraction considerations are typically not an issue in most cable racking designs because limited cable movement can typically be accommodated between duct exit and cable clamping, allowing the cable racking system to accommodate these movements. Unfortunately designing a racking structure to accommodate these expansions and contractions would exceed available Florida Avenue real estate for the

Cable Racking

Note: Cable movements absorbed between duct exit and cable clamps

Cable Ratcheting Device

Cable Preparation for Termination

Sand Blasting to Remove Strand Insulation

termination structure. Clearly another solution was required.

115kV Cable Termination

Accommodating the significant cable expansions and contractions was found in a cable clamping device called a "cable ratcheting system". Cable ratcheting systems are not commonly used in the States, but have been successfully applied in Japan by Sumitomo for more than 30 years. This clamping device allowed 200 percent of the maximum calculated cable thermal movements, while at the same time prevented the cable from sliding into the duct during the cooling portion of the thermal cycle. This device allowed the cable racking design to not only consider thermal expansion, but also significantly reduce rack size and create a practical solution for the termination structure design.

After all cables were "racked", it was time to terminate each conductor. A crane was used to lift each cable end, which was then secured to temporary scaffolding providing support and access to each cable for termination.

One interesting aspect of the cable design is that many of the conductor copper strands were insulated with enamel to increase the current carrying capacity of the cables due to skin effect as discussed earlier. However for the cables to be terminated, this enamel had to be removed. This was accomplished by spreading and sand blasting the separated strands until all the insulating enamel had been removed. The spread ends were then rewoven into their original shape and the termination was completed.

With cable terminations complete the dead-end termination structures were installed allowing connection to PowerSouth transmission lines at Sapling Point and the substation at Florida Avenue, completing a very challenging and successful project.

Completed Terminations

Florida Avenue Substation
Termination Structure

Sapling Point
Termination Structure

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