



## **IMPORTANT FACTORS AFFECTING UNDERGROUND PLACEMENT OF TRANSMISSION FACILITIES**

AEP's Operating Companies are occasionally asked to place sections of their transmission lines underground. (Transmission lines differ from distribution lines by virtue of their much higher voltage capacity – generally above 40,000 volts.) The reason given for such requests relates to aesthetics in most instances. This paper outlines the various factors that govern decisions about the placement of transmission lines and whether they are built overhead or underground.

### ***Background***

Electric transmission facilities form the backbone of the bulk electric power network. Generally, power lines of 69 kilovolts (kV) to 765 kV are considered to be transmission level voltage. Underground transmission involves a construction technique that encapsulates the conductor in an insulating material before burying it beneath the ground surface.

Due to the different electrical characteristics of underground construction, the actual amount of power a buried line can carry is significantly lower than the amount of power an overhead line can deliver. Underground lines physically store a significant amount of electrical charge, which means that a larger portion of the line is required to carry the power flow. As a result, underground transmission lines must be relatively short or use expensive methods, like shunt compensation, to improve the flow of power.

Generally, underground transmission is used in urban areas due to the lack of usable rights of way for overhead transmission. Construction in this environment usually entails installations under sidewalks or under roadbeds. This increases the amount of labor needed to cut roads/sidewalks, trench, refill the trench and repair the surface.

To date, 500kV has been the highest voltage transmission cable successfully placed in underground operation worldwide. The highest in the U.S. is 400kV. A prototype PPP-insulated 765 kV HPFF (High Pressure Fluid Filled) cable system successfully completed long term qualification tests at the Electric Power Research Institute Waltz Mill Test Facility, but has not been commercially deployed as yet.

### ***Cost Issues***

Underground cable system costs depend strongly upon the specific design and installation conditions. It is not appropriate to simply state a “standard” cost ratio of underground to overhead. Cost ratios have ranged from 1/1 (because of very expensive overhead construction in urban area, with many angle structures) to more than 20/1 (rural areas, inexpensive overhead construction).



Note that the ratio often depends more on the denominator (overhead costs, such as line construction) than the numerator. Underground cables are always going to be more expensive because every foot of the route must be excavated and restored. In some cases where the ratio has been low, the utility has been faced with acquiring extremely expensive right-of-way for the potential overhead line.

### ***Evaluating the Pros and Cons of Underground Transmission***

Beyond the aesthetic value of underground transmission lines, typical forced outage rates are lower than those for overhead lines. This is because underground lines are not exposed to storms and trees.

However, the combined effects of forced outage rates and repair times must be taken into account when comparing the overall reliability or availability of both types of transmission. When this is done, the availability of overhead lines is typically higher than those for underground lines (see Table 1 below).

**Table 1 – Typical Reliability Statistics for 138 kV HPFF Cable and 138 kV Overhead Lines**

	Overhead	Underground
Forced outage rate (outages/yr./mi.)	0.005	0.00165
Mean repair time (days)	0.375	21
Mean time between failures (yr.)	200	606
Unavailability (hours/year)	0.045	0.832

Although a narrower right of way is typically needed for underground transmission, the entire right of way must be cleared to allow access and visibility. Short growing vegetation is sometimes allowed in overhead rights of way.

Material lead times, especially the underground cable and splices, are significant. This is due generally to the low amount of demand and the ability of the manufacturer to gear up to a particular cable. This causes the utility to keep a significant amount of inventory in case of emergency or risk a multi-month circuit outage. Due to this fact, multiple redundancy is often built into underground circuits by laying parallel circuits for emergency, therefore, increasing cost.



### ***Reliability Issues***

Outages on underground transmission cables are primarily caused by dig-ins (i.e. cable damage due to excavation in the vicinity of the underground line). Consequently, the damaged cables must be located, and then exposed and time-consuming repairs must be completed before the cables can be returned to service. Typical repair times for underground transmission forced outages are one to three weeks or longer, months, in some cases.

Outside of physical damage due to excavations, underground splice failure is the leading source of transmission underground cable failures. Splicing is a labor intensive, manual process that joins segments of underground transmission cables. Besides introducing a source of electrical resistance, this connection point also increases the chance for moisture to migrate into the conductor allowing for an electrical short to occur.

Protecting underground systems is also a challenge. Because most cable faults are direct shorts (not induced by transients, i.e., lightning), reclosing on cables is rarely done automatically. This means that any protective equipment operation will lead to a sustained outage on the cable circuit until a comprehensive inspection is done of the visible parts of the cable or a non-destructive electrical test is done on the cable prior to returning power to the line.

As a result of the much longer repair times for underground transmission lines, it is relatively common practice to design cable circuits with 100 percent redundancy. That is, two parallel cable circuits are often installed with each of the two cables having sufficient capacity to carry the rated load of the circuit for the duration of contingency (typically the mean repair time). This obviously increases the cost of new transmission construction.

### ***Insulating Underground Cables***

All power cables must be insulated from the ground to achieve meaningful power flow. This is achieved by encapsulating the aluminum or copper power line, with an insulator. This insulator can take several forms; from fluids (most common, i.e., insulating oil) to solids (non-conducting dielectric polymer) to gas (sulfur hexafluoride -- SF<sub>6</sub>). Each has characteristic benefits and flaws.

There are significant differences in the maximum ampacity (current-carrying capacity in amperes) and power transfer ratings of the different types of transmission cables.

### **Oil/Gas-Cooled Underground Cables**

High Pressure Fluid Filled (HPFF) underground transmission systems with system voltages of 69kV to 345kV have been in commercial operation for over 70 years. HPFF cable systems with rated system voltages up to and including 765kV are commercially available and have passed long-term qualification tests.



High Pressure Gas filled (HPGF), is similar in construction but the dielectric fluid is replaced by 200 psig nitrogen. HPGF cable systems are not commercially available for system voltages above 138kV.

Gas Insulated Transmission Lines (GIL) have been used in applications where high power transfer capabilities are required, such as short dips in overhead lines or relatively short substation connections to overhead lines. GIL generally utilizes SF<sub>6</sub> gas as the insulating medium.

Compressed-Gas transmission cables have significantly higher ampacity ratings (5 kA and higher) than the other cable system types because:

1. The relatively low insulating strength of gases (compared to solid and laminar fluid filled electrical insulations) means that the diameters of the high voltage conductor and aluminum enclosure must be large. Therefore, the current ratings are also large because of the large cross section of the high voltage conductor and enclosure.
2. Dielectric losses, which are losses of energy that cause a rise in the temperature of the gases (nitrogen and SF<sub>6</sub>), are extremely low compared to most solid and laminar insulating materials. As a result, compressed-gas cables have increased ampacity ratings.

Self-cooled HPFF and HPGF transmission cable systems with very large conductors (3500 thousand circular mills -- kcmil) typically have power transfer capabilities of 1200 amperes or less, which is significantly less than self-contained, fluid-filled (SCFF) cable systems. This is due to the following reasons.

1. Magnetic losses in the magnetic steel pipe, like eddy current and hysteresis, are comparable to the losses caused by heat in the high-voltage conductors. The pipe losses significantly decrease the ampacity rating of the cables inside of the pipe.
2. Losses of energy, resulting in the rise in heat of laminar, fluid-impregnated insulation are significantly higher than for XLPE extruded dielectric insulation.

#### Dielectric (non-conducting) Polymers

The first major domestic 345kV solid dielectric transmission systems were installed in Connecticut, Long Island and Chicago in the past several years. Elsewhere, hundreds of miles of 230 kV solid dielectric cable systems have been installed in numerous countries around the world and tens of miles of 400 kV solid dielectric cables have been installed



in Europe. Japan completed installation of the first sizeable (two circuits, 25 miles long) 500 kV cross-linked polyethylene (XLPE) transmission cable system in late 2000.

XLPE-insulated cables have a significantly higher power transfer capability than pipe-type systems because of the lower dielectric losses, absence of pipe losses, and greater separation among phases. Large conductor size cables can have ratings greater than 2000 amperes.

The ampacity rating of XLPE transmission cables are higher compared to the same conductor size SCFF cable system because of the lower dielectric losses and charging current of the XLPE cables.

### ***Safety/Environmental Issues***

Most accidents involving underground transmission lines occur while digging and excavating in areas near underground cables. Most accidents with overhead lines involve ladders, cranes, truck mounted lifting devices, and other machinery that come too close to overhead lines. Downed overhead power lines can pose a potential public hazard, though transmission lines are designed to shut off if they fall.

Some scientific studies have suggested that electric and magnetic fields (EMF) from overhead power lines may contribute to increased cancer rates. However, there is no biological evidence to support this claim. EMF radiates from all energized conductors and/or equipment. Placing power lines underground does not shield magnetic fields. Magnetic fields are difficult to block and will continue to pass through the ground. At the center of an underground transmission line, fields from a buried line can actually be higher than those from an overhead line. These EMF levels will drop off quickly as distance increases.

Underground construction is not necessarily a better choice for the environment as well. Placing transmission lines underground requires extensive trenching and installation of vaults and duct banks. This construction typically has much greater environmental impact than installation of overhead transmission structures. Specifically, a 16-foot wide trench must be dug 6.5 feet deep to accommodate the line and prevent cave-ins during construction. In addition, manholes seven feet deep and 14 feet long are necessary every 2,000 feet for cable pulling and splicing.

This extensive trenching has more impacts on natural resources, such as wetlands and wildlife habitat. In contrast, an overhead line can be built to span (and avoid directly impacting) many sensitive resources. Additionally, oil filled transmission lines can leak and contaminate ground soil and components from underground lines are harder to recycle.



### *Summary Conclusions*

- The cost to place transmission facilities underground is, at a minimum, 2-3 times more than the comparable overhead option. In some situations, the cost difference can be 10 times more.
- Utility commissions typically allow electric utilities to include in the rates charged to all its customers, only the *reasonable* costs of facilities necessary to provide safe and reliable service. In most cases, this would be the cost of overhead lines. Thus, unless there are extenuating circumstances that dictate the use of underground facilities in lieu of overhead facilities, AEP would not be able to recover the premium paid to place facilities underground.
- The time and cost required to isolate and repair a problem with underground transmission lines is normally much greater than for overhead lines. Circuit outage times will almost always be greater, too, thus raising the reliability risk of operating the system without all lines in service, and raising the potential for customer dissatisfaction with lengthy outages.
- Underground transmission lines pose a significant safety hazard to non-electric utility construction personnel who do not follow proper protocols/laws/rules and accidentally dig into these lines.

Because of these issues, AEP is willing to consider requests to install transmission facilities underground under the following set of conditions.

- If the entire cost premium between the overhead option and placing transmission facilities underground is borne by the entity making the request; or
- If the underground option is more cost effective than overhead placement of the lines.