Underground Electric Transmission Lines

Introduction

This overview contains information about electric transmission lines which are installed underground, rather than overhead on poles or towers. Underground cables have different technical requirements than overhead lines and have different environmental impacts. Due to their different physical, environmental, and construction needs, underground transmission generally costs more and may be more complicated to construct than overhead lines. Issues discussed in this pamphlet include:

- Types of Underground Electric Transmission Cables
- Ancillary Facilities
- Construction and Operation Considerations
- Costs
- Repairs

The design and construction of underground transmission lines differ from overhead lines because of two significant technical challenges that need to be overcome. These are: 1) providing sufficient insulation so that cables can be within inches of grounded material; and 2) dissipating the heat produced during the operation of the electrical cables. Overhead lines are separated from each other and surrounded by air. Open air circulating between and around the conductors cools the wires and dissipates heat very effectively. Air also provides insulation that can recover if there is a flashover.

In contrast, a number of different systems, materials, and construction methods have been used during the last century in order to achieve the necessary insulation and heat dissipation required for undergrounding transmission lines. The first underground transmission line was a 132 kV line constructed in 1927. The cable was fluid-filled and paper insulated. The fluid was necessary to dissipate the heat. For decades, reliability problems continued to be associated with constructing longer cables at higher voltages. The most significant issue was maintenance difficulties. Not until the mid-1960s did the technology advance sufficiently so that a high-voltage 345 kV line could be constructed underground. The lines though were still fluid filled. This caused significant maintenance, contamination, and infrastructure issues. In the 1990s the first solid cable transmission line was constructed more than one mile in length and greater than 230 kV.

Underground Transmission in Wisconsin

There are approximately 12,000 miles of transmission lines currently in Wisconsin. Less than one percent of the transmission system in Wisconsin is constructed underground. All underground transmission lines are 138 kV lines or less. There are no 345 kV lines constructed underground, currently in Wisconsin.

Types of Underground Electric Transmission Cables

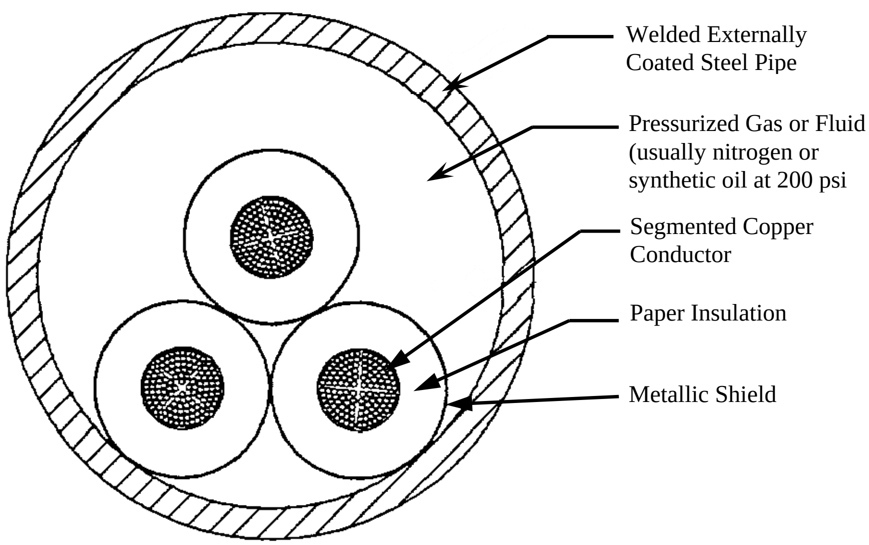
There are two main types of underground transmission lines currently in use. One type is constructed in a pipe with fluid or gas pumped or circulated through and around the cable in order to manage heat and insulate the cables. The other type is a solid dielectric cable which requires no fluids or gas and is a more recent technological advancement. The common types of underground cable construction include:

- High-pressure, fluid-filled pipe (HPFF)
- High-pressure, gas-filled pipe (HPGF)
- Self-contained fluid-filled (SCFF)
- Solid cable, cross-linked polyethylene (XLPE)

High-Pressure, Fluid-Filled Pipe-Type Cable

A high-pressure, fluid-filled (HPFF) pipe-type of underground transmission line, consists of a steel pipe that contains three high-voltage conductors. Figure 1 illustrates a typical HPFF pipe-type cable. Each conductor is made of copper or aluminum; insulated with high-quality, oil-impregnated kraft paper insulation; and covered with metal shielding (usually lead) and skid wires (for protection during construction).

Figure 1 HPFF or HPGF Pipe-Type Cross Section



Inside steel pipes, three conductors are surrounded by a dielectric oil which is maintained at 200 pounds per square inch (psi). This fluid acts as an insulator and does not conduct electricity. The pressurized dielectric fluid prevents electrical discharges in the conductors' insulation. An electrical discharge can cause the line to fail. The fluid also transfers heat away from the conductors. The fluid is usually static and removes heat by conduction. In some situations the fluid is pumped through the pipe and cooled through the use of a heat exchanger. Cables with pumped fluids require aboveground pumping stations, usually located within substations. The pumping stations monitor the pressure and temperature of the fluid. There is a radiator-type device that moves the heat from the underground cables to the atmosphere. The oil is also monitored for any degradation or trouble with the cable materials.

The outer steel pipe protects the conductors from mechanical damage, water infiltration, and minimizes the potential for oil leaks. The pipe is protected from the chemical and electrical environment of the soil by means of a coating and cathodic protection.

Problems associated with HPFF pipe-type underground transmission lines include maintenance issues and possible contamination of surrounding soils and groundwater due to leaking oil.

High-Pressure, Gas-Filled Pipe-Type Cable

The high-pressure, gas-filled (HPGF) pipe-type of underground transmission line (see Figure 1) is a variation of the HPFF pipe-type, described above. Instead of a dielectric oil, pressurized nitrogen gas is used to insulate the conductors. Nitrogen gas is less effective than dielectric fluids at suppressing electrical discharges and cooling. To compensate for this, the conductors' insulation is about 20 percent thicker than the insulation in fluid-filled pipes. Thicker insulation and a warmer pipe reduce the amount of current the line can safely and efficiently carry. In case of a leak or break in the cable system, the nitrogen gas is easier to deal with than the dielectric oil in the surrounding environment.

Self-Contained, Fluid-Filled Pipe-Type

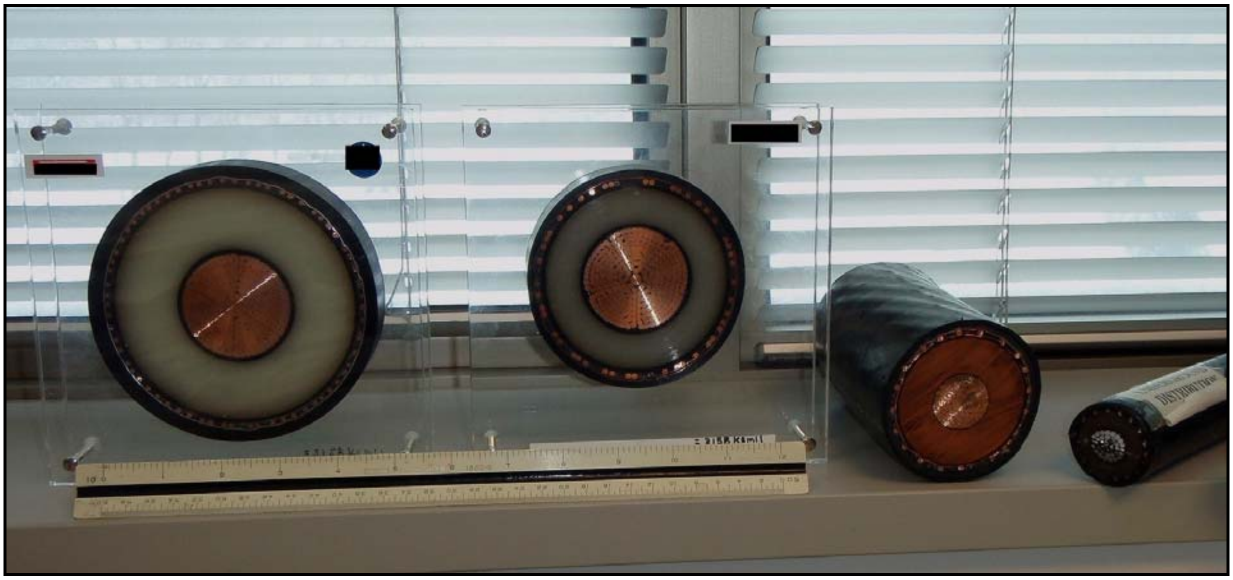
The self-contained, fluid-filled (SCFF) pipe-type of underground transmission is often used for underwater transmission construction. The conductors are hollow and filled with an insulating fluid that is pressurized to 25 to 50 psi. In addition, the three cables are independent of each other. They are not placed together in a pipe.

Each cable consists of a fluid-filled conductor insulated with high-quality kraft paper and protected by a lead-bronze or aluminum sheath and a plastic jacket. The fluid reduces the chance of electrical discharge and line failure. The sheath helps pressurize the conductor's fluid and the plastic jacket keeps the water out. This type of construction reduces the risk of a total failure, but the construction costs are much higher than the single pipe used to construct the HPFF or HPGF systems.

Solid Cable, Cross-Linked Polyethylene

The cross-linked polyethylene (XLPE) underground transmission line is often called solid dielectic cable. The solid dielectric material replaces the pressurized liquid or gas of the pipe-type cables. XLPE cable has become the national standard for underground electric transmission lines less than 200 kV. There is less maintenance with the solid cable, but impending insulation failures are much more difficult to monitor and detect. The diameter of the XLPE cables increase with voltage (Figure 2).

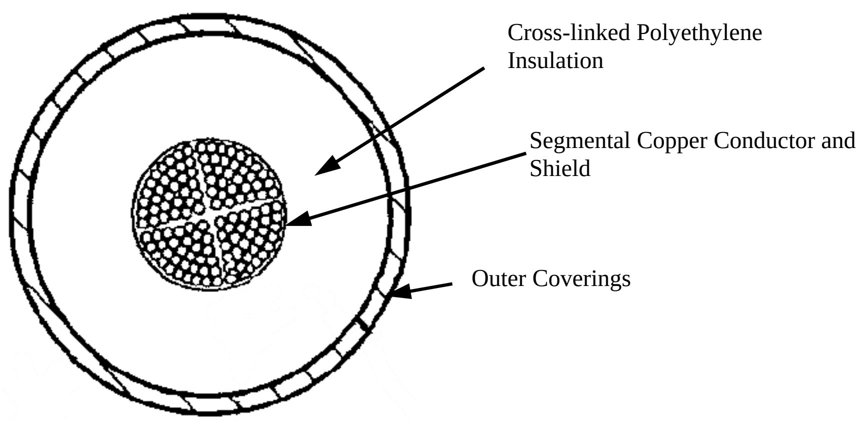
Figure 2 XLPE Cables with Different Voltages



Underground XLPE cables left to right: 345 kV, 138 kV, 69 kV, and distribution

Each transmission line requires three separate cables, similar to the three conductors required for aboveground transmission lines. They are not housed together in a pipe, but are set in concrete ducts or buried side-by-side. Each cable consists of a copper or aluminum conductor and a semi-conducting shield at its core. A cross-linked polyethylene insulation surrounds the core. The outer covering of the cable consists of a metallic sheath and a plastic jacket (Figure 3).

Figure 3 XLPE Cable Cross-Section



For 345 kV XLPE construction, two sets of three cables (six cables) are necessary for a number of reasons, primarily so that the capacity of the underground system matches the capacity of the overhead line. This design aids in limiting the scope of any cable failure and shortens restoration time in an emergency situation. Most underground transmission requires increased down time for the repair of operating problems or maintenance issues compared to overhead lines. The double sets of cables allows for the rerouting of the power through the backup cable set, reducing the down time but increases the construction footprint of the line.

Ancillary Facilities

Different types of cables require different ancillary facilities. Some of these facilities are constructed underground, while others are aboveground and may have a significant footprint. When assessing the impacts of underground transmission line construction and operation, the impacts of the ancillary facilities must be considered, as well.

Vaults

Vaults are large concrete boxes buried at regular intervals along the underground construction route. The primary function of the vault is for splicing the cables during construction and for permanent access, maintenance, and repair of the cables. The number of vaults required for an underground transmission line is dictated by the maximum length of cable that can be transported on a reel, the cable's allowable pulling tension, elevation changes along the route, and the sidewall pressure as the cable goes around bends. XLPE cable requires a splice every 900 to 2000 feet, depending on topography and voltage. Pipe-type cables need a splice at least every 3,500 feet. The photos in Figure 4 show examples of vault construction.

Vaults are approximately 10 by 30 feet and 10 feet high. They have two chimneys constructed with manholes which workmen use to enter the vaults for cable maintenance. Covers for the manholes are designed to be flush with the finished road surface or ground elevation. Vaults can be either pre-fabricated and transported to the site in two pieces or constructed onsite. Excavations in the vicinity of the vaults will be deeper and wider. Higher voltage construction may require two vaults constructed adjacent to each other to handle the redundant set of cables.

Figure 4 Vault Construction

Left: 345 kV XLPE project – Cement vault visible with two chimneys extending up to be level with the future road surface.
Right: 138 kV XLPE project – Bottom half of pre-constructed vault positioned in trench.

138 kV XLPE project – Pre-fabricated top half of vault being lowered into trench.

Transition Structures

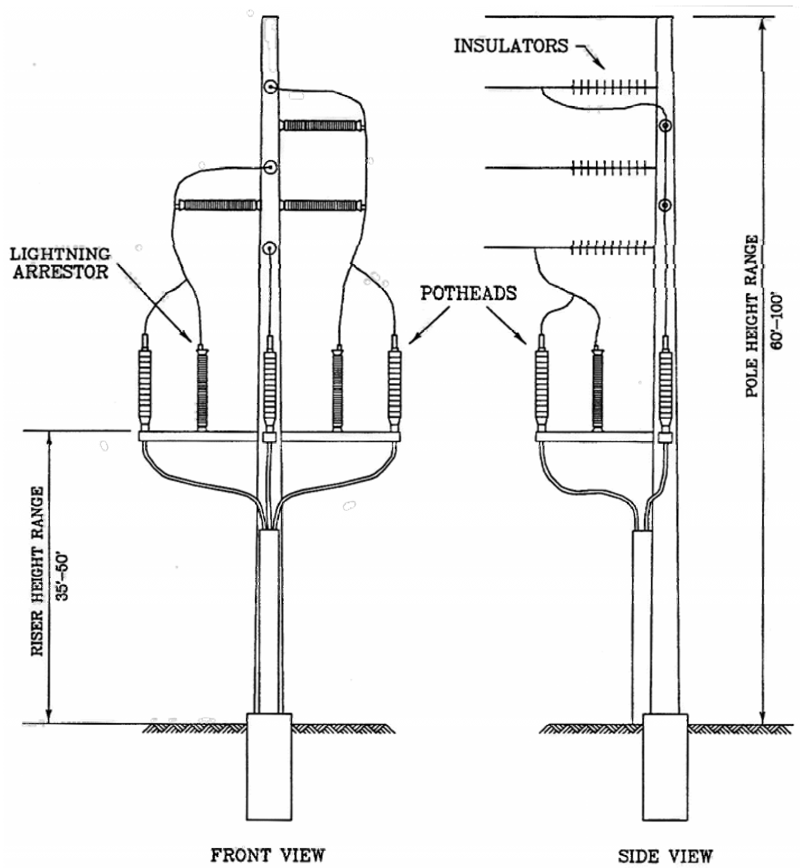
For underground cables less than 345 kV, the connection from overhead to underground lines require the construction of a transition structure, also known as a riser. Figures 5 and 6 depict sample transition structure designs. These structures are between 60 and 100 feet tall. They are designed so that the three conductors are effectively separated and meet electric code requirements.

The insulated conductor of the overhead line is linked through a solid insulator device to the underground cable. This keeps moisture out of the cable and the overhead line away from the supporting structure.

Figure 5 138 kV Underground to Overhead Transition Structures

Lightning arrestors are placed close to where the underground cable connects to the overhead line to protect the underground cable from nearby lightning strikes. The insulating material is very sensitive to large voltage changes and cannot be repaired. If damaged, a completely new cable is installed.

Figure 6 Diagram of a Typical Transmission Riser Structure



Transition Stations

High voltage (345 kV or greater) underground transmission lines require transition stations wherever the underground cable connects to overhead transmission. For very lengthy sections of underground transmission, intermediate transition stations might be necessary. The appearance of a 345 kV transition station is similar to that of a small switching station. The size is governed by whether reactors or other additional components are required. They range in size from approximately 1 to 2 acres. Transition stations also require grading, access roads, and storm water management facilities. Figure 7 is a photo of small transition station.

Figure 7 Small Transition Station

Pressurizing Sources

For HPFF systems, a pressurizing plant maintains fluid pressure in the pipe. The number of pressurizing plants depends on the length of the underground lines. It may be located within a substation. It includes a reservoir that holds reserve fluid. An HPGF system does not use a pressurizing plant, but rather a regulator and nitrogen cylinder. These are located in a gas-cabinet that contains high-pressure and low-pressure alarms and a regulator. The XLPE system does not require any pressurization facilities.

Construction of Underground Transmission

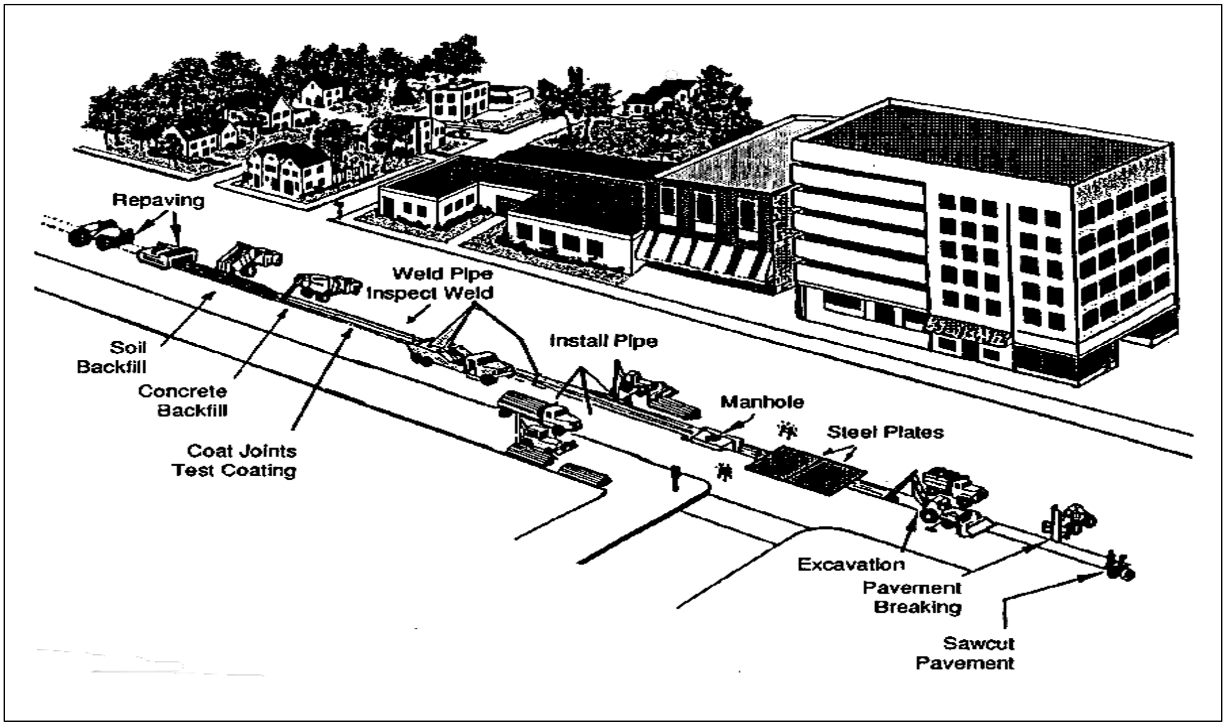
Installation of an underground transmission cable generally involves the following sequence of events: 1) ROW clearing, 2) trenching/blasting, 3) laying and/or welding pipe, 4) duct bank and vault installation, 5) backfilling, 6) cable installation, 7) adding fluids or gas, and 8) site restoration. Many of these activities are conducted simultaneously so as to minimize the interference with street traffic. Figure 8 shows a typical installation sequence in a city street.

Right-Of-Way Construction Zone

Similar to overhead transmission construction, underground construction begins by staking the ROW boundaries and marking sensitive resources. Existing underground utilities are identified and marked prior to the start of construction.

If the transmission line is constructed within roadways, lane closures will be required and traffic control signage installed. Construction activities and equipment will disrupt traffic flow. On average, several hundred feet of traffic lane are closed during construction. When materials and equipment are delivered, additional lengths or lanes of traffic may be closed. Construction areas need to be wide and level enough to support the movement of backhoes, dump trucks, concrete trucks, and other necessary construction equipment and materials. Undeveloped portions of the road ROW may require excavation or fill deposited on hillsides so that the surface is leveled and compact enough for support of the construction equipment. Construction areas in road ROWs are typically 12 to 15 feet wide with an additional 5 to 8 feet for trench construction.

Figure 8 Typical Work Sequence for Pipe-Type Installation in an Urban Area



If the transmission line is to be constructed in unpaved areas, all shrubs and trees are cleared in the travel path and in the area to be trenched. Temporary easements would be necessary during construction and permanent easements for the life of the transmission line.

Trenching and Blasting

Most commonly, a backhoe is used to dig the trench (see Figure 9). The excavation starts with the removal of the top soil in unpaved areas or the concrete/asphalt in paved areas. Large trucks haul away excavated subsoil materials to approved off-site location for disposal, or if appropriate, re-use. In accordance with OSHA requirements, trenches of a certain depth may require additional shoring. Trench size will vary depending on the cable type and the line's voltage. Most commonly, trenches are at least 6 to 8 feet deep to keep cables below the frost line. The trench dimensions will be greater in places where vaults are located. In many instances, groundwater will be encountered during the trenching. In accordance with DNR permits, groundwater may be pumped from the excavation to a suitable upland area or pumped directly into a tanker truck for transport to a suitable location for release.

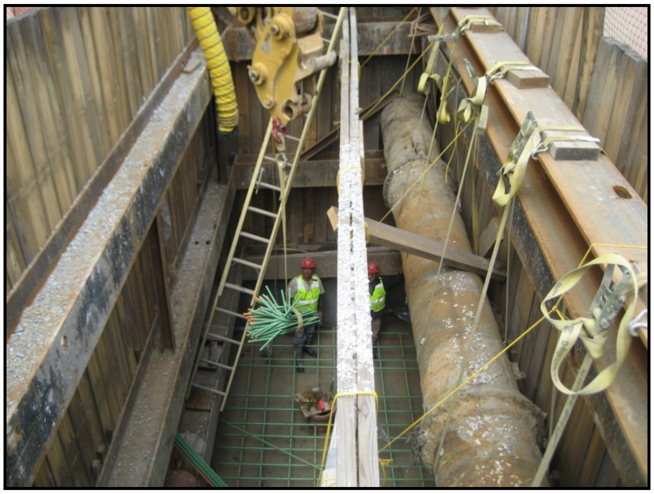
Figure 9 Examples of Trench Construction

Urban road ROWs often contain a wide variety of underground obstacles, such as existing utilities, natural features, topography, major roadways, or underpasses. The dimensions of the trench might need to be deeper and wider to avoid underground obstacles. Every effort should be made to prevent impacts to existing utilities such as making minor adjustment to the alignment of the duct bank, relocating the existing utility, or putting the duct bank below the existing infrastructure.

When trenches are excavated deeper than anticipated, the width of the trench must be widened for purposes of stability. Figure 10 shows a greatly enlarged trench so that the transmission cables and could be located below the exposed storm sewer (sewer located along the right side of the photo).

When bedrock or subsoils primarily consisting of large boulders are encountered, blasting may be required.

Figure 10 Example of Trench with Storm Sewer Obstacle



Jack and Bore

Jack and bore construction is used in areas where open trench construction is obstructed by existing features such as railroads, waterways, or other large facilities or utilities. It can be used for most types of underground cable construction. Entrance and exit pits are excavated to accommodate the boring equipment and materials. Typical boring pits are around 14 by 35 feet, and deep enough to accommodate the boring equipment. An auger is used in the entrance pit to excavate a hole and remove spoils. A jack pushes a reinforced pipe in sections behind the auger head. When the pipe is installed, the conduit is surrounded by bore spacers and the conduit is pushed into the casing pipe. The casing pipe is then backfilled with a material that optimizes thermal radiation. Lastly, the entrance and exit pits are restored to their original condition.

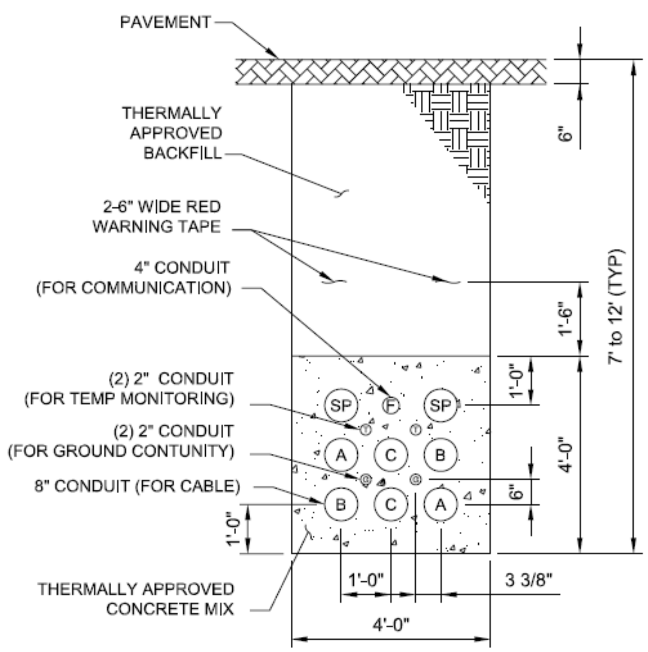
The amount of disturbed construction area required for a jack and bore is usually proportional to the diameter of the bore, its maximum depth, and the length of the bore. Typically construction lay down areas are equal to the length of bore to facilitate the welding of the pipe that is installed into the bore hole. The bore entry site may be as much as 150 feet long to handle the drilling equipment and management of the slurry.

Conduit Assembly for XLPE Construction

The assembly of conduits and direct-buried method of XLPE construction are illustrated in Figures 11, 12, and 13. Underground XLPE cable systems can be direct-buried or encased in concrete duct banks. For duct bank installation, the trench is first excavated a couple hundred feet. Then the duct bank is assembled using polyvinyl chloride (PVC) conduit and spacers. Even though using concrete duct banks is more expensive than direct-bury, it is the most common method of installation for higher voltage lines. This is because the construction technique provides more mechanical protection, reduces the need for re-excavation in the event of a cable failure, and shorter lengths of trench are opened at any one time for construction and maintenance activities.

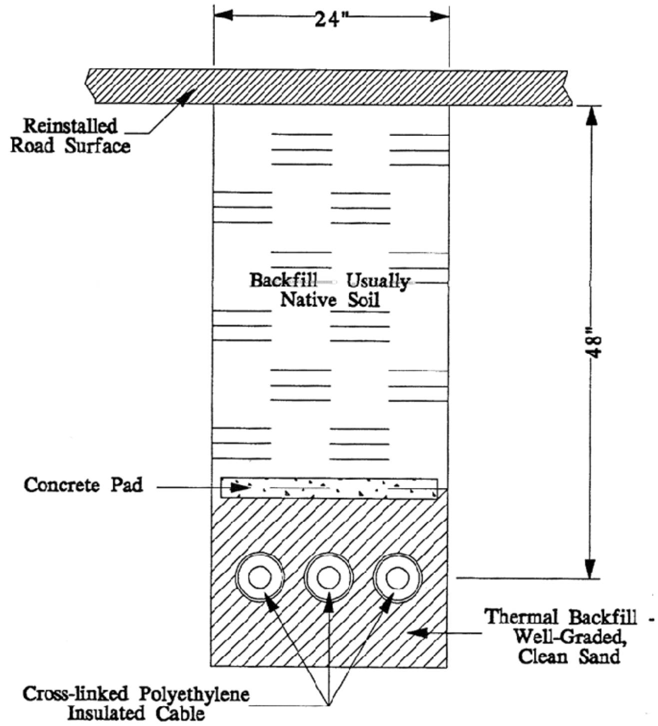
Figure 11 Examples of XLPE Conduit Assembly

Figure 12 Sample Configuration of an XLPE Duct Bank



TYPICAL CONCRETE ENCASED DUCTBANK
W/ 1 FIBER, 2 CONTUNITY, AND 2 TEMP MONITORING
CONDUITS FACING UP STATION
NOT TO SCALE

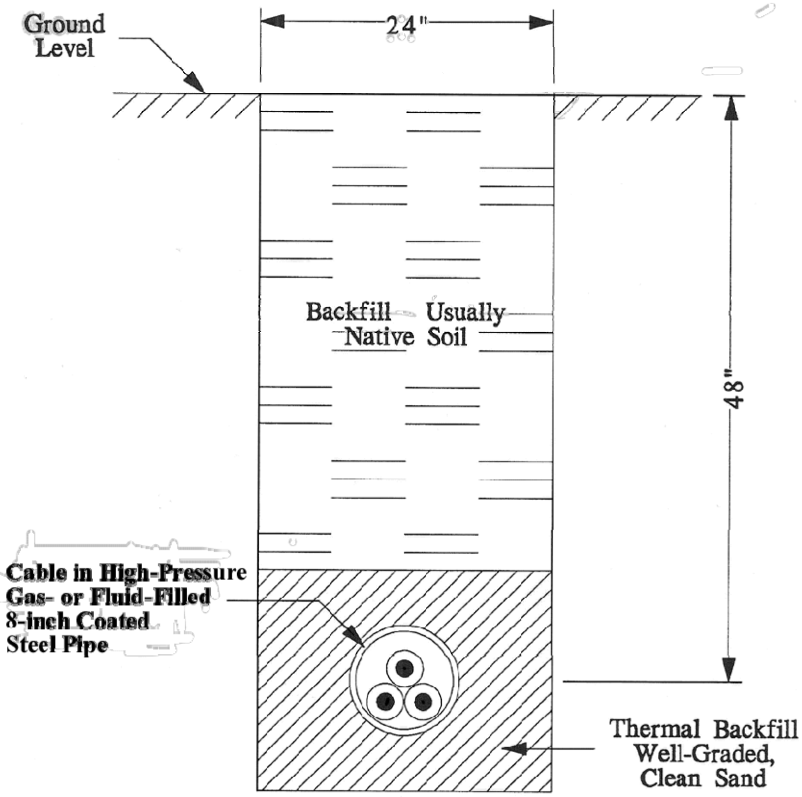
Figure 13 Installation of XLPE Underground Cable Directly Buried



Pipe Installation

HPFF and HPGF pipe-type installation requires the construction of welded steel pipe sections to house the cables. The welding of pipe sections takes place either in or over the trench. Pipe welds are X-rayed, and then protected from corrosion with plastic coatings. When the pipe is completely installed, it is pressure tested with either air or nitrogen gas. It is then vacuum-tested, vault to vault, which also dries the pipe. Figure 14 show the cross-section for an HPFF or HPGF pipe-type underground transmission line.

Figure 14   Installation of HPFF or HPGF Pipe-Type Underground Cable



Cable Installation

Cable pulling and splicing can occur any time after the duct banks and vaults are completed. Prior to installation of the cable, the conduit is tested and cleaned by pulling a mandrel and swab through each of the ducts. A typical setup is to lace the reel of cable at the transition structure or at one of the vaults and the winch truck at the next vault (see Figure 15). The cable is then pulled from the transition structure to the nearest vault. Direction of pull between vaults is based on the direction that results in the lowest pulling and sidewall tensions. Cable lengths are spliced within the vaults.

Figure 15   Cable Pulling

Backfilling

Pipe-type conductors operate at about 167 to 185 °F with an emergency operating temperature of 212 to 221 °F. XLPE conductors operate at about 176 to 194 °F with an emergency operating temperature of about 266 °F. Heat must be carried away from the conductors for them to operate efficiently. The air performs this function for overhead lines. The soils in and around the trench do this for underground lines.

All of the heat generated from direct buried cables must be dissipated through the soil. The selection of backfill type can make a strong difference on the capacity rating. Different soils have different abilities to transfer heat. Saturated soils conduct heat more easily than for instance, sandy soils. For this reason, the design needs to determine the type of soil nearest the line. A soil thermal survey may be necessary before construction to help determine the soil's ability to move heat away from the line. In many cases, a special backfill material is used instead of soil in the trench around the cables to ensure sufficient heat transfer to the surrounding soils and groundwater.

Site Restoration

Site restoration for underground construction is similar to overhead transmission line construction restoration. When construction is completed, roadways, landscaped areas, and undeveloped areas are restored to their original condition and topography (Figure 16). Highway lands and shoulders are re-constructed so as to support road traffic. Roadside areas and landscaped private properties are restored with top soils that was previously stripped and stockpiled during construction or with new topsoil. Any infrastructure impacted by the construction project such as driveways, curbs, and private utilities are restored to their previous function, and yards and pastures are vegetated as specified in landowner easements. Similar to overhead lines, all landowner protections listed in Wisconsin statute (Wis. Stat. § 182.017(7)(c)) must be met.

Figure 16   Backfilling and Street Restoration

Underground Construction Considerations

Underground construction could be a reasonable alternative to overhead in urban areas where an overhead line cannot be installed with appropriate clearance, at any cost. In suburban areas, aesthetic issues, weather-related outages, some environmental concerns, and the high cost of some ROWs could make an underground option more attractive.

Underground transmission construction is most often used in urban areas. However, underground construction may be disruptive to street traffic and individuals because of the extensive excavation necessary. During construction, barricades, warning and illuminated flashing signs, are often required to guide traffic and pedestrians. After each day's work, steel plates will cover any open trench. All open concrete vaults will have a highly visible fence around them. When the cable is pulled into the pipe, the contractor should cordon off the work area. There may be time-of-day or work week limitations for construction activities in roadways that are imposed for reasons of noise, dust, and traffic impacts. These construction limitations often increase the cost of the project.

The trenching for the construction of underground lines causes greater soil disturbance than overhead lines. Overhead line construction disturbs the soil mostly at the site of each transmission pole. Trenching an underground line through farmlands, forests, wetlands, and other natural areas can cause significant land disturbances.

Many engineering factors significantly increase the cost of underground transmission facilities. As the voltage increases, engineering constraints and costs dramatically increase. This is the reason why underground distribution lines (12 - 24 kV) are not uncommon; whereas, there is just over 100 miles of underground transmission currently in the state. There are also no 345 kV underground segments in Wisconsin.

Construction Impacts in Suburban and Urban Areas

The construction impacts of underground lines are temporary and, for the most part, reversible. They include dirt, dust, noise, and traffic disruption. Increased particles in the air can cause health problems for people who live or work nearby. Particularly sensitive persons include the very young, the very old, and those with health problems, such as asthma. If the right-of-way is in a residential area, construction hours and the amount of equipment operating simultaneously may need to be limited to reduce noise levels. In commercial or industrial areas, special measures may be needed to keep access to businesses open or to control traffic during rush hours.

Construction Impacts in Farmland and Natural Areas

Most underground transmission is constructed in urban areas. In non-urban areas, soil compaction, erosion, and mixing are serious problems, in addition to dust and noise. During construction, special methods are needed to avoid mixing the topsoil with lower soil horizons and to minimize erosion. The special soils often placed around an underground line may slightly change the responsiveness of surface soils to farming practices. Post-construction, trees and large shrubs would not be allowed within the right-of-way due to potential problems with roots. Some herbaceous vegetation and agricultural crops may be allowed to return to the right-of-way.

Costs

The estimated cost for constructing underground transmission lines ranges from 4 to 14 times more expensive than overhead lines of the same voltage and same distance. A typical new 69 kV overhead single-circuit transmission line costs approximately $285,000 per mile as opposed to $1.5 million per mile for a new 69 kV underground line (without the terminals). A new 138 kV overhead line costs approximately $390,000 per mile as opposed to $2 million per mile for underground (without the terminals).

These costs are determined by the local environment, the distances between splices and termination points, and the number of ancillary facilities required. Other issues that make underground transmission lines more costly are right-of-way access, start-up complications, construction limitations in urban areas, conflicts with other utilities, trenching construction issues, crossing natural or manmade barriers, and the potential need for forced cooling facilities. Other transmission facilities in or near the line may also require new or upgraded facilities to balance power issues such fault currents and voltage transients, all adding to the cost.

While it may be useful to sometimes compare the general cost differences between overhead and underground construction, the actual costs for underground may be quite different. Underground transmission construction can be very site-specific, especially for higher voltage lines. Components of underground transmission are often not interchangeable as they are for overhead. A complete in-depth study and characterization of the subsurface and electrical environment is necessary in order to get an accurate cost estimate for undergrounding a specific section of transmission. This can make the cost of underground transmission extremely variable when calculated on a per-mile basis.

Underground Operating Considerations

Post-construction issues such as aesthetics, electric and magnetic fields (EMF), and property values are usually less of an issue for underground lines. Underground lines are not visible after construction and have less impact on property values and aesthetics.

Apart from cost and construction issues, there are continued maintenance and safety issues associated with the right-of-way. The right-of-way must be kept safe from accidental contact by subsequent construction activities. To protect individual ducts (for SCFF and XLPE lines) against accidental future dig-ins, a concrete duct bank, a concrete slab, or patio blocks are installed above the line, along with a system of warning signs ("high-voltage buried cable").

Additionally, if the cables are not constructed under roads or highways, the ROW must be kept clear of vegetation with long roots such as trees that could interfere with the system.

Cable Repairs

Repair costs for an underground line are usually greater than costs for an equivalent overhead line. Leaks can cost $50,000 to $100,000 to locate and repair. A leak detection system for a HPFF cable system can cost from $1,000 to $400,000 to purchase and install depending on the system technology.

Molded joints for splices in XLPE line could cost about $20,000 to repair. Field-made splices could cost up to $60,000 to repair.

A fault in a directionally drilled section of the line could require replacement of the entire section. For example, the cost for directional drilling an HPGF cables is $25 per foot per cable. The cables in the directional drilled section twist around each other in the pipe so they all would have to be pulled out for examination.

The newer XLPE cables tend to have a life that is one half of an overhead conductor which may require replacing the underground every 35 years or so.

Easement agreements may require the utility to compensate property owners for disruption in their property use and for property damage that is caused by repairing underground transmission lines on private property. However, the cost to compensate the landowner is small compared to the total repair costs. Underground transmission lines have higher life cycle costs than overhead transmission lines when combining construction repair and maintenance costs over the life of the line.

Potential Fluid Leaks

Although pipe-type underground transmission lines require little maintenance, transmission owners must establish and follow an appropriate maintenance program, otherwise pipe corrosion can lead to fluid leaks.

Both HPFF and SCFF lines must have a spill control plan. The estimate for potential line leakage is about one leak every 25 years. Soil contaminated with leaking dielectric oil is classified as a hazardous waste. This means that contaminated soils and water would have to be remediated. The types of dielectric fluid used in underground transmission lines include alkylbenzene (which is used in making detergents) and polybutene (which is chemically related to Styrofoam). These are not toxic, but are slow to degrade. The release and degradation of alkylbenzene could cause benzene compounds, a known carcinogen, to show up in plants or wildlife.

A nitrogen leak from a HPGF line would not affect the environment, but workers would need to check oxygen levels in the vaults before entering. Fluid leaks are not a problem for solid dielectric cables.

Electric and Magnetic Fields

Electric fields are created by voltage. Higher voltage produces stronger electric fields. Electric fields are blocked by most objects such as walls, trees, and soil and are not an issue with underground transmission lines. Magnetic fields are created by current and produced by all household appliances that use electricity. Magnetic field strength increases as current increases so there is a stronger magnetic field generated when an appliance is set on "high" than when it is set on "low". Milligauss (mG) is the common measurement of magnetic field strength. Typically, a hair dryer produces a magnetic field of 70 mG when measured one foot from the appliance. A television produces approximately 20 mG measured at a distance of one foot.

The strength of the magnetic field produced by a particular transmission line is determined by current, distance from the line, arrangement of the three conductors, and the presence or absence of magnetic shielding. Underground transmission lines produce lower magnetic fields than aboveground lines because the underground conductors are placed closer together which causes the magnetic fields created by each of the three conductors to cancel out some of the other's fields. This results in reduced magnetic fields. Magnetic fields are also strongest close to their source and drop off rapidly with distance (Table 1). Pipe-type underground lines can have significantly lower magnetic fields than overhead lines or other kinds of underground lines because the steel pipe has magnetic shielding properties that further reduce the field produced by the conductors.

Table 1 shows sample magnetic field measurements at different distances from underground and overhead lines. Maximum magnetic field strengths of underground transmission lines typically do not exceed a few mG at a distance of 25 feet.

Table 1 Sample Magnetic Field Strength of Various Transmission Lines

Voltage	Construction	Amperes	Distance	mG
69 kV	Underground - XLPE	252	Centerline at surface	34.20
			50 feet from Centerline	0.90
69 kV	Underground - Pipe-type	204	Centerline at surface	0.80
			50 feet from Centerline	0.10
69 kV	Overhead	167	Centerline	23.00
			40 feet from Centerline	7.00
138 kV	Underground - Pipe-type	467	Centerline at surface	0.21
			50 feet from Centerline	0.05
138 kV	Overhead	710	Centerline at surface	190.00
			50 feet from Centerline	46.00

Heat

Heat produced by the operation of an underground transmission cable raises the temperature at the above the line, a few degrees. This is not enough to harm growing plants, but it could cause premature seed germination in the spring. Heat could also build up in enclosed buildings near the line.

Transmission routes that include other heat sources, such as steam mains, should be avoided. Electric cables should be kept at least 12 feet from other heat sources, otherwise the cable's ability to carry current decreases.

Reliability of Service

In general, lower voltage underground transmission lines are very reliable. However, their repair times are much longer than those for overhead lines.

Repair Rates – Pipe-Type Transmission Cables

For pipe-type lines, the trouble rates historically, for about 2,536 miles of line correspond to about:

- One cable repair needed per year for every 833 miles of cable.
- One splice repair needed per year for every 2,439 miles of cable.
- One termination repair needed per year for every 359 miles of cable.

These trouble rates indicate that there would be, at most, a 1:300 chance for the most common type of repair to be needed in any one mile of pipe-type underground line over any one year.

Repair Rates - XLPE lines

There is less available documentation regarding XLPE trouble rates and very little information for 345 kV transmission lines. However, the following estimates are generally accepted.

- One cable repair needed per year for every 1,000 miles of cable.
- One splice repair needed per year for every 1,428 miles of cable.
- One termination repair needed per year for every 1,428 miles of cable.

These trouble rates indicate that there would be, at most, a 1:1,000 chance for the most common type of repair to be needed in any one mile of XLPE underground line over any one year.

Outage Duration

The duration of outages varies widely, depending on the circumstances of the failure, the availability of parts, and the skill level of the available repair personnel. The typical duration of an HPGF outage is 8 to 12 days. The duration of typical XLPE outages is 5 to 9 days. The repair of a fault in a HPFF system is estimated to be from 2 to 9 months, depending on the extent of the damage.

The outage rate would increase as the number of splices increases. However, the use of concrete vaults at splice locations can reduce the duration of a splice failure by allowing quick and clean access to the failure. The outage would be longer if the splice were directly buried, as is sometimes done with rural or suburban XLPE lines.

To locate a leak in a pipe-type line, the pipe pressure must be reduced below 60 psi and the line de-energized before any probes are put into the pipe. For some leak probes, the line must be out of service for a day before the tests can begin. After repairs, pipe pressure must be returned to normal slowly. This would require an additional day or more before the repaired line could be energized.

To locate an electrical fault in an underground line, the affected cable must be identified. To repair a pipe-type line, the fluid on each side of the electrical failure would be frozen at least 25 feet out from the failure point. Then, the pipe would be opened and the line inspected. New splices are sometimes required and sometimes cable may need to be replaced and spliced. Then, the pipe would be thawed and the line would be re-pressurized, tested, and finally put back in service.

In contrast, a fault or break in an overhead line can usually be located almost immediately and repaired within hours or, at most, a day or two.

One problem that increases emergency response time for underground transmission lines is that most of the suppliers of underground transmission materials are in Europe. While some of the European companies keep American-based offices, cable and system supplies may not be immediately available for emergency repairs.

Line Life Expectancies

While the assumed life of underground pipe-type or XLPE cable is about 40 years, there are pipe-type cables that has been in service for more than 60 years. Overhead lines in northern Wisconsin last 60 plus years. There are some overhead lines that have lasted more than 80 years.

Choosing Between Underground and Overhead

There are different advantages and disadvantages for underground transmission lines. When compared with overhead transmission lines, the choice to build an underground transmission line instead of an overhead line depends on a number of factors.

The most non-debatable reason for choosing underground is in highly urban areas, where acquiring ROW that meets National Electrical Safety Code requirements is difficult or impossible. This makes the added cost of undergrounding acceptable to not being able to route the new line at all.

Choosing underground for reasons of aesthetics, may be justified because it is assumed that following the disruption of construction, the entire line would be out-of-sight. However, considerations must be made for the disruption caused by the trench construction and the ancillary facilities that would be above ground, such as transition structures (risers), pressurizing stations, and transition stations.

In general, underground lines are significantly more expensive than overhead lines. There are operational limitations and maintenance issues that must be weighed against the advantages. For some projects only a portion of a line may be constructed underground to avoid specific impacts. Every project must be assessed individually to determine the best type of transmission line for each location segment.

Role of the Public Service Commission

For most large underground or overhead transmission lines, the utility must apply to the Public Service Commission (PSC) for approval prior to building the line. An applicant must receive a Certificate of Public Convenience and Necessity (CPCN) from the Commission for a transmission project that is either:

- 345 kV or greater; or,
- Less than 345 kV but greater than or equal to 100 kV, over one mile in length, and requiring new right-of-way (ROW).

All other transmission line projects must receive a Certificate of Authority (CA) from the Commission if the project's cost is above a certain percent of the utility's annual revenue. The requirements for these certificates are specified in Wis. Stat. §§ 196.49 and 196.491.

The Public Service Commission of Wisconsin is an independent state agency that oversees more than 1,100 Wisconsin public utilities that provide natural gas, electricity, heat, steam, water and telecommunication services.

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