

Underground Electric Transmission Lines



This Overview contains information about electric transmission lines which are installed underground, rather than overhead on poles or towers.¹ Underground lines have different technical requirements than overhead lines and have different environmental impacts. Due to their different physical, environmental, and construction needs, underground lines generally cost more than overhead lines.

This Overview describes types of underground electric transmission lines, the impacts of siting and operating them, how they are built, how reliable they are, and how their cost compares to overhead lines. Electricity consumers, landowners, and state and local government officials who are concerned about a transmission line project in their area may find this information helpful.

Introduction

An electric transmission line is defined by the regulations (Wis. Admin. Code § PSC 112.02(8)), as any line over 40 kilovolts (kV). Electric power lines or conductors move electricity over long distances. Most transmission lines have three conductors. Aboveground conductors are uninsulated bundles of wire separated by about 5 to 24 feet from each other, depending on the line voltage and suspended on poles or towers. Open air circulating between and around the three conductors cools the wires and dissipates the heat that's generated by transferring electricity. The air also prevents power from flashing over to ground.

Because the air space can be accidentally intruded upon, the Wisconsin State Electric Code and the National Electric Safety Code require the conductors to be a certain distance above the ground, away from buildings and other structures, and away from each other for safety and reliability. Some transmission lines in Wisconsin have been constructed underground, in pipes, in ducts, or directly buried in the earth. They are generally placed four to five feet underground, but the distance between the conductors is much less. Instead of wide spacing and natural air circulation, other methods are used to insulate the conductors from each other and their surroundings and to dissipate heat.

¹ Much of the information used in this publication was obtained from the Electric Power Research Institute (EPRI), primarily its [Underground Transmission Systems Reference Book](#), 1992 Edition, and from educational and project materials supplied by Power Delivery Consultants, Inc. of Ballston Lake, New York.

Underground Transmission in Wisconsin

Less than one percent of the transmission system in the eastern Wisconsin area is underground. While esthetically pleasing, the construction, operation and maintenance are more costly and take a much longer time periods to repair if damaged. In some situations the three conductors can be placed underground in pipes with special material surrounding them. The construction of the cables requires special insulating materials to allow the cable to be within two inches of grounding material.

Another major issue with underground transmission is the lack of capability to remove the heat when in the ground. The ability to remove heat underground is limited and reduces the flexibility of the system operations. The underground area must be safe from accidental contact by construction equipment and vegetation must be managed to avoid roots from interfering with the system and potentially removing soil moisture that's needed to help cool the cables.

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 following issues will be addressed in this Overview

- Types of underground electric transmission lines
- Accessories required for all underground lines
- Right-of-way requirements
- Cooling
- Construction
- Costs of underground transmission lines
- Siting impacts: construction, repair, obstacles
- Operating impacts: magnetic fields, heat, leaks, safety
- Reliability of service: repairs, outages, life expectancies, overhead vs. underground lines

Types of Underground Electric Transmission Lines

There are several types of underground transmission lines. They are classified by whether they require pipes and their type of insulation. The main types are:

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

Fluid-filled (HPFF) types are the most common in the United States. Self-contained (SCFF) types are the least common and least likely to be used in Wisconsin due to climate. This Overview focuses on the two pipe-type lines (fluid-filled and gas-filled) and the cross-linked polyethylene (XLPE) types of underground transmission.

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). The conductor and its wrappings are often referred to as “cables.” The cables are surrounded by a dielectric oil that is maintained at 200 pounds per square inch (psi). This fluid acts as an insulator and does not conduct electricity.

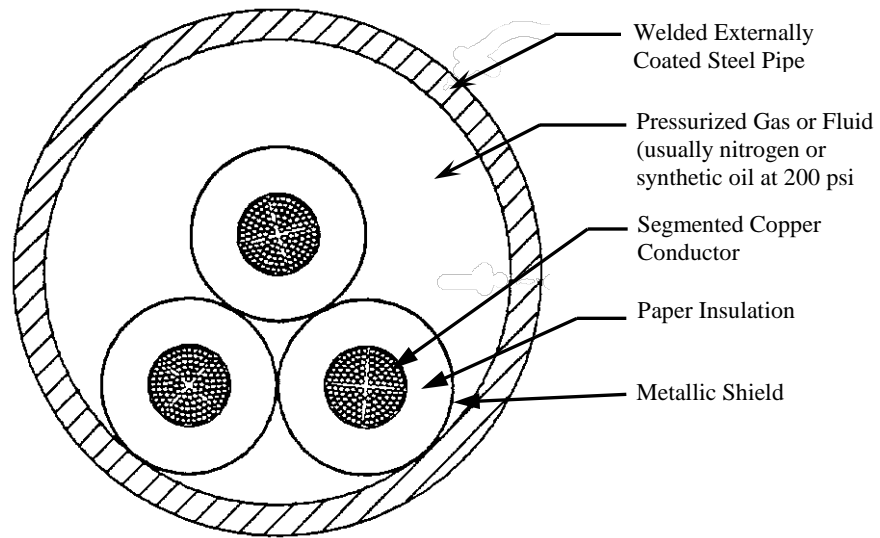
The steel pipe protects the conductors from mechanical damage and water infiltration and prevents fluid leaks. The pipe is protected from the chemical and electrical environment of the soil by means of a coating and cathodic protection.

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.

High-pressure, gas-filled pipe-type cable

The high-pressure, gas-filled (HPGF) pipe-type of underground transmission line is a variation of the HPFF pipe-type described above. Instead of a dielectric fluid, pressurized nitrogen gas insulates 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. However, this type of line operates well in Wisconsin’s low winter temperatures. Figure 1 is an illustration of either an HPFF or HPGF pipe type of cable.

Figure 1 High Pressure Fluid- or Gas-Filled Pipe Basic Design



Self-contained, fluid-filled pipe-type

The self-contained, fluid-filled (SCFF) pipe-type of underground transmission line is often the choice for underwater transmission lines. 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.

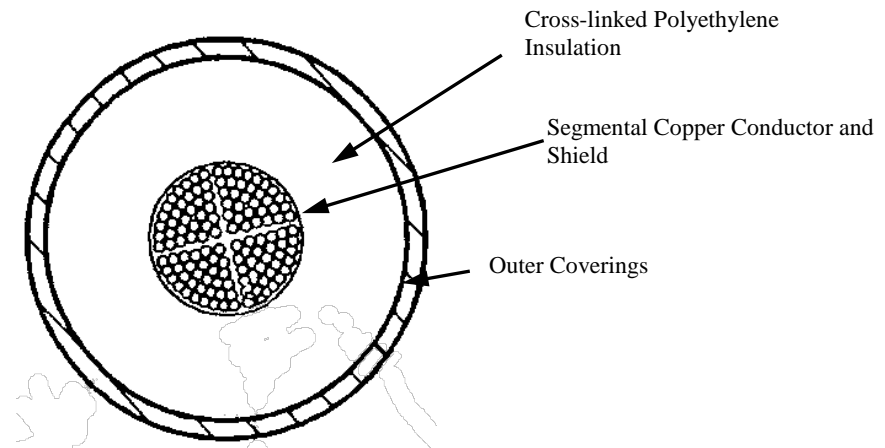
Each cable consists of the fluid-filled conductor insulated with high-quality kraft paper and protected by a lead-bronze or aluminum sheath and a plastic jacket. The fluid reduces the chance of electrical discharge and line failure. The sheath helps pressurize the conductor's fluid and the plastic jacket keeps the water out.

Cross-linked polyethylene

The cross-linked polyethylene (XLPE) underground transmission line is often called “solid dielectric”. The XLPE type is becoming the national standard for underground electric transmission lines. This type of line relies on high-quality manufacturing controls to eliminate any contaminants or voids in the insulation that could lead to electrical discharges and breakdown of the line from electrical stress. The solid dielectric material replaces the pressurized liquid or gas of other types of cable. Figure 2 illustrates the XLPE in cross-section.

This type of construction has three independent cables. They are not housed together in a pipe, but are set in concrete ducts or buried side-by-side directly in specially prepared soil. Each cable consists of a copper or aluminum conductor, a semi-conducting shield, a cross-linked polyethylene insulation, and an outer covering consisting of another semi-conducting shield, a metallic sheath, and a plastic jacket. The insulation is about twice as thick as the oil insulation used in other types of cable.

Figure 2 Cross-Linked Polyethylene Basic Design



Accessories

The following structures are called “accessories,” because they are a part of all types of underground electric transmission lines. They are also responsible for 90 percent of all underground line failures.

Splices

Splices join separate pieces of conductor. Splices are needed because there is a limit to the amount of cable that can be put onto a spool for shipping and there is a limit to the amount of tension a cable can withstand as it is pulled through a pipe. The length that works best also depends on the number of bends and dips in the line. XLPE type lines need a splice every 900 to 2000 feet. Pipe-type lines need a splice at least every 3,500 feet.

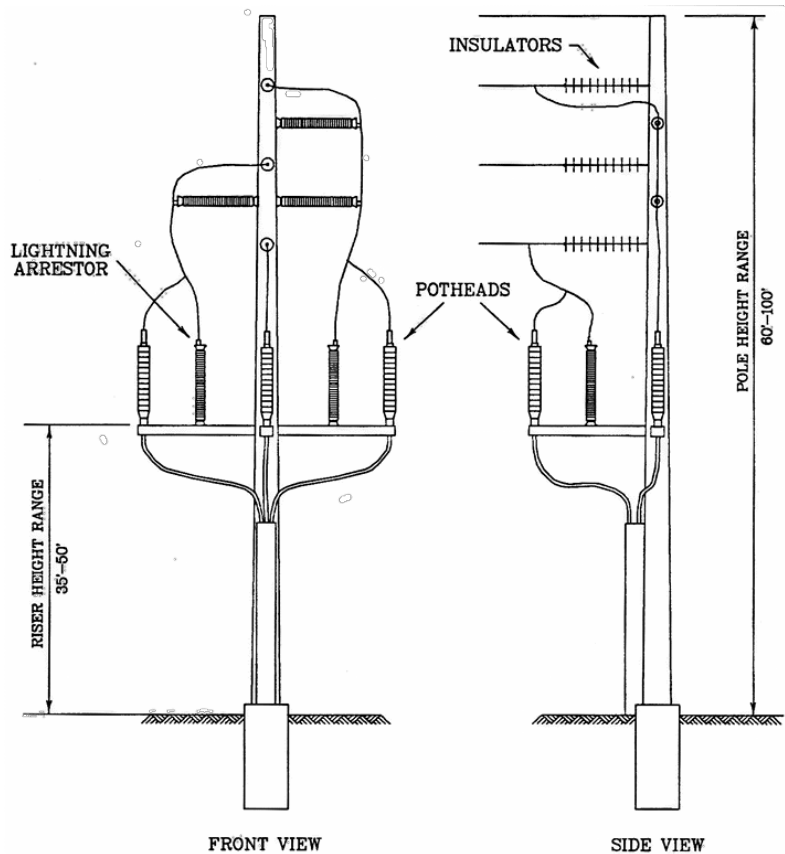
Pipe-type lines require a concrete work vault to hold each splice. While the connecting piece is only about 7.5 inches long, the materials needed to reduce the electrical stress results in a joint about 63 inches long (over 5 feet). This means that the vault must be at least 135 inches long (over 11 feet). Typically, the hole dug for a vault is over 15 to 20 feet long and about twice as wide as the trench for the pipe. There are typically one or two “chimneys” or vents to the surface that are closed with steel covers. The strength of the concrete must withstand the load of overhead traffic. Vaults are generally not located under sidewalks or within 125 feet of street intersections. About two-thirds of XLPE splices are in permanent concrete vaults and one-third are constructed in temporary vaults. Temporary vaults are not lined with concrete but filled in after construction. When XLPE is installed in concrete ducts, all splices are constructed in permanent, concrete vaults.

Terminations

Underground lines terminate (connect to overhead lines or to substations) by means of “risers,” which are fastened to above ground structures. Three spread arms (the “spreaderhead”) carry the underground line aboveground and separate the three conductors so that they meet electric code requirements for the spacing of overhead conductors. If spreaderheads are placed underground, they are called “trifurcators” and may be placed in a concrete vault. Porcelain insulators or housings, contain the actual connections between the in-earth and in-air portions of the line. These housings are often called “potheads.” Terminations keep moisture out of the underground system. An example of a termination is shown in Figure 3.

Lightning arrestors are placed close to the terminations to protect the underground cable from over-voltage damage that can be caused by near by lightning strikes. The insulating material is very sensitive to large voltage changes and cannot be repaired. Typically a completely new cable is pulled into place a lightning damaged cable.

Figure 3 Diagram of a Typical Transmission Riser Structure



Pressurizing sources

For HPFF systems, a pressurizing plant maintains fluid pressure in the pipe. The pressurizing plant is located at one end of the line, usually within a substation fence. 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. Sometimes, a longer SCFF line that varies in elevation has equipment approximately every mile at splice points to maintain equal pressure throughout its length. The XLPE system does not require any pressurization.

Construction Issues

Right-of-way requirements

The installation of underground transmission lines in urban environments requires construction equipment that can temporarily disrupt traffic. Figure 4 shows a typical installation in a city street. A minimum 20-foot right-of-way (ROW) is required to construct or repair an underground line in

an urban or suburban situation (Figure 5). Support work may require occasional use of additional lanes of traffic. Concrete vaults also require more than the minimum ROW. In open country, a wider 30- to 50-foot ROW is necessary (Figure 6). However, in areas where the ROW is constricted, a 20-foot ROW is possible for short distances (Figure 7).

Figure 4 Typical Work Progression for Underground Pipe-Type Installation in a City Street

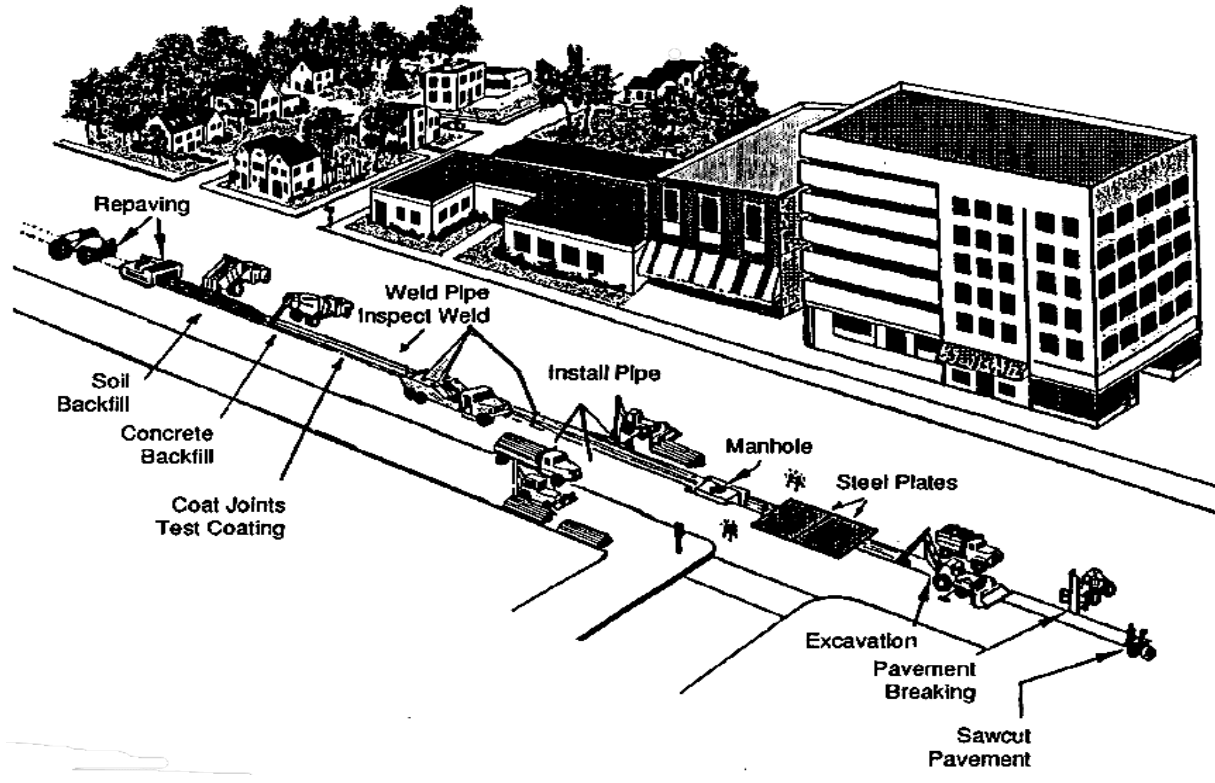
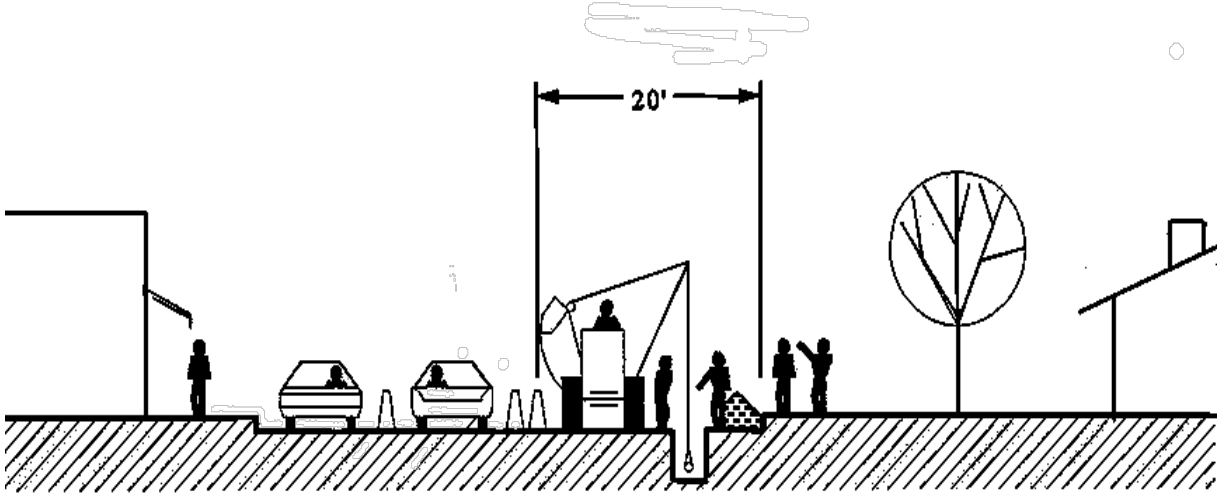


Figure 5 Minimum ROW for Underground Construction in Urban and Suburban Areas



The ROW is maintained free of trees or large shrubs, which could interfere with the underground line directly (with their roots) or indirectly (by removing soil moisture that is needed to adequately cool the conductors). Buildings are also prohibited in the ROW, since they would interfere with maintenance and repair work.

Figure 6 Typical ROW Needs for Underground Construction in Unpaved Areas

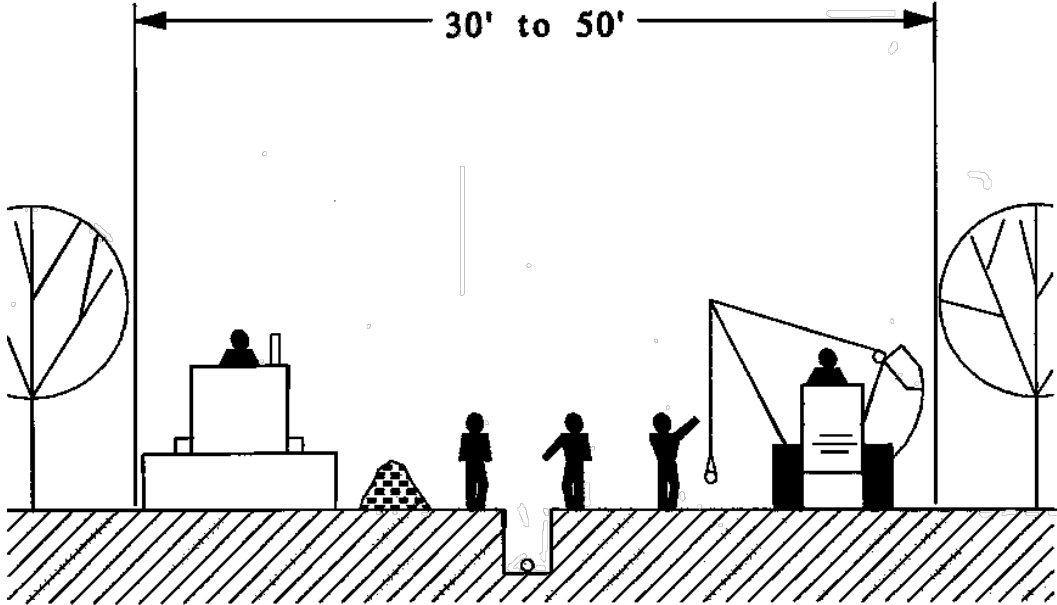
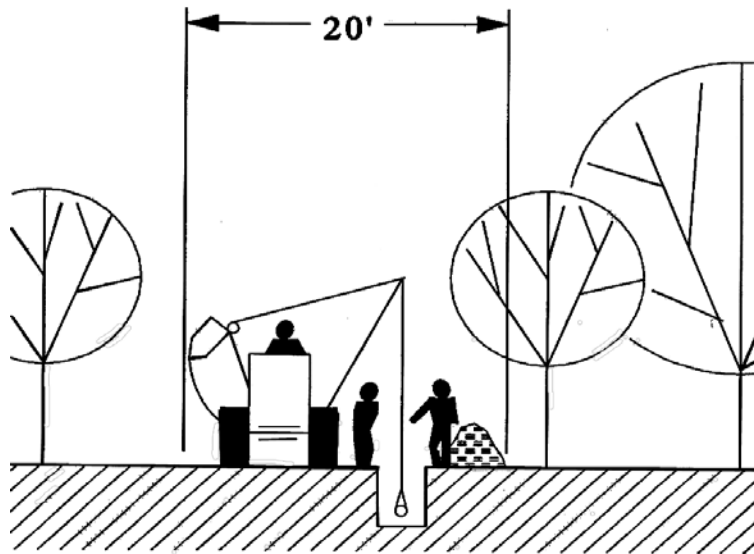


Figure 7 Minimum ROW for Underground Construction in Unpaved Areas



Cooling

Electrical conductors produce heat. 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 selective backfill makes a strong difference on the capacity rating. Different soils have different abilities to transfer heat. Saturated soils conduct heat more easily than soils with air pockets or dry places. For this reason, the soil nearest the line must not be allowed to dry out. A soil thermal survey may be necessary before construction to help determine the soil's ability to move heat away from the line. For many lines, a specially prepared backfill material is used instead of soil in the trench around the line to ensure a good heat transfer to surrounding soil or groundwater. The backfill material is specifically designed to move heat away from the line. The thermal survey and special backfill material add to the cost of the project.

Construction methods

Installation of an underground transmission line primarily involves: 1) trenching; 2) laying and welding pipes or pouring concrete conduits; 3) replacing soil and closing the trench; 4) pulling cable between vaults; 5) splicing cables; and 6) adding fluids or gas. Testing and evaluation are done throughout the process. If water is encountered, special pumping procedures are used. Figure 4 shows the flow of the construction process. Table 1 shows how long, on average, trenches remain open during the construction process. Table 2 shows typical clearances from other underground facilities that are accepted as good engineering practice.

Table 1 Open Trench Characteristics

Line Type	Approximate Length of Open Trench at Any One Time (Feet)	Average Length of Time Trench is Open	Notes
Pipe-type	600	5 work days	Cables are pulled from vault to vault after the pipes are installed.
HPGF	600	2 to 3 work days	Uses 40-foot pipe lengths and fluidized backfill.
XLPE, in concrete ducts	600	6 to 7 work days	Requires laying and curing concrete ducts.
XLPE, direct buried	1,000 to 2,000	10 work days	Limited to urban or suburban areas. Temporary vaults are backfilled.

Table 2 Clearance Requirements for Trenching

Facility	Required Clearance if Parallel (Feet)	Required Vertical Clearance if Crossing (Feet)
Storm sewer	1	1
Water	1.5	1.5
Natural gas	1	1
Electric distribution duck bank	10	2
Telephone distribution duct bank	1	1
Steam	10	4

The absolute minimum clearances for overhead electric transmission lines are described in the Wisconsin State Electric Code (Wis. Adm. Code ch. PSC 114), but pipe-type cable systems are not specifically addressed. The practical clearance requirements in Table 2 are based on accepted good engineering practice. Underwater lines have special construction needs and impacts that are not addressed in this Overview.

A line would normally be buried 3.5 to 4.0 feet beneath the surface. However, if the frost line is at or below that depth, burial might be deeper. Trenches for pipe-type, XLPE in duct, and XLPE directly buried, are illustrated in cross-section in Figures 8, 9, and 10.

A self-propelled, pneumatic-tired crane is used in most underground line construction. Some companies use side-boom crawlers, which are slower and not as versatile in city streets. The welding of pipe sections takes place either in or over the trench. A municipality may or may not allow

on-site storage of construction materials or excavated soil along city streets. Sometimes, a transport trailer is left at the site to provide a storage place and work platform.

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 8 Installation of HPFF or HPGF Pipe-Type Underground Cable

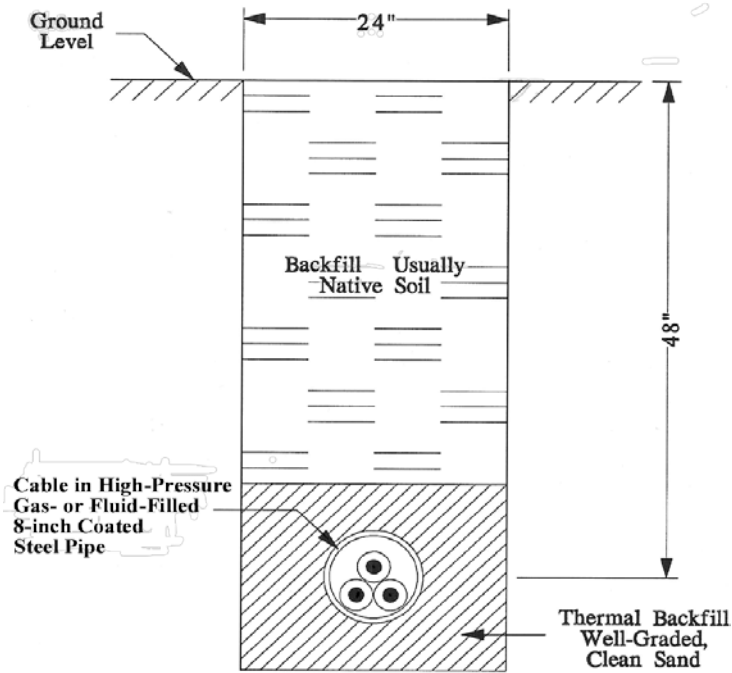
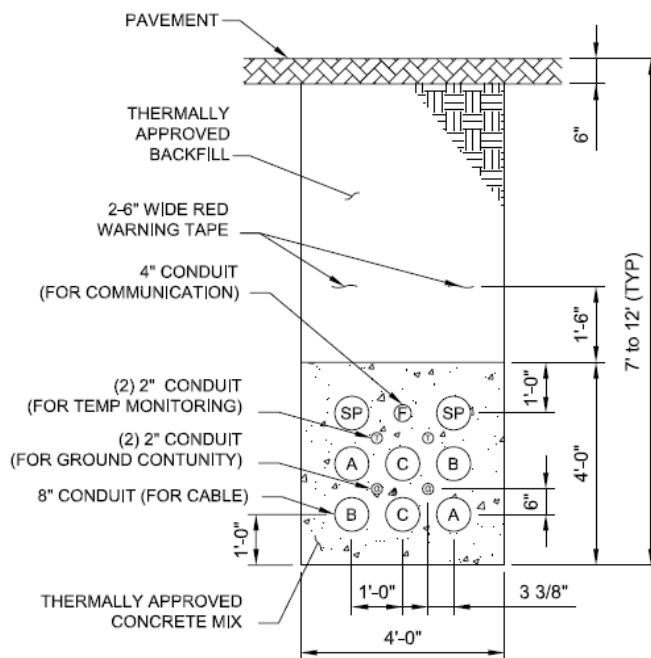
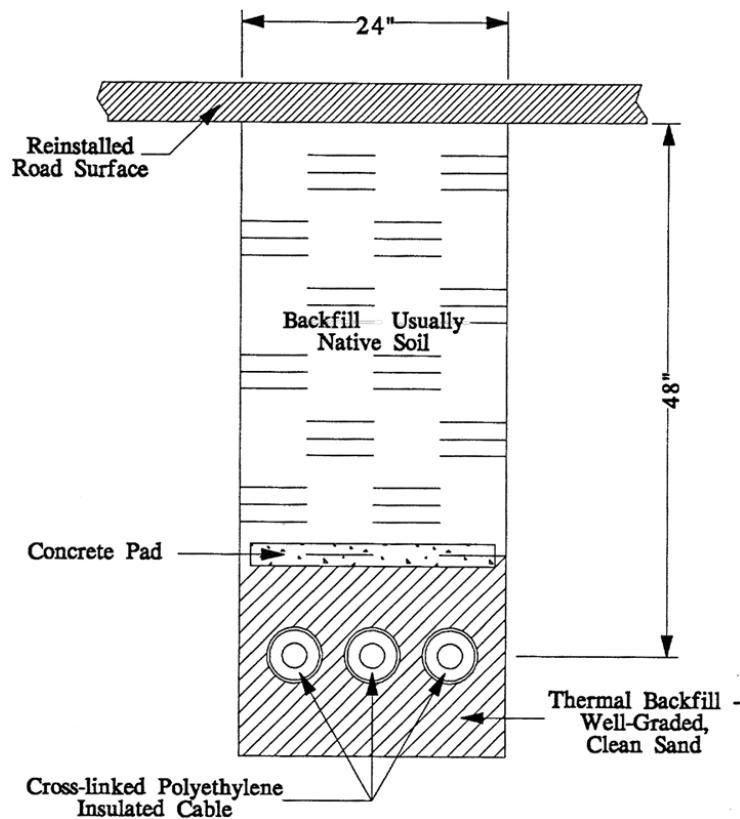


Figure 9 Installation of XLPE Underground Cable in Ducts



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

Figure 10 Installation of XLPE Underground Cable Directly Buried



Directional Boring

Directional boring can be used to avoid many surface features, such as rivers, roads, or landfills. However, expertise is needed to avoid covering the landscape with mud or grout pushed up through weak seams in the rock. Directional boring requires an extensive construction area on each side of the bore. The amount of space is proportional to the size of the bore, the maximum depth, and distance of the bore. Typically construction lay down areas are equal to the length of bore to facilitate the welding of the pipe to be placed in the bore hole. The bore entry site would be approximately 150 feet on each side to handle the drilling equipment and the slurry that cools the drilling head and removes the cuttings.

Site and route considerations

Underground construction could be a reasonable alternative to overhead in an urban area where an overhead line cannot be installed with appropriate ROW 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. An underground line might allow a shorter route to be used. Or, an underground line along a road corridor could reduce the land needed for easements.

The shortest route might not always be the lower cost route. Fewer obstructions or less traffic may make a longer route more appropriate. Timing problems may increase costs. For instance, restrictions on construction in the street or across a street might be appropriate during the morning or evening rush hours. There might be noise limitations that prohibit construction noise in the late evenings and night times. These restrictions could increase the time it takes to install a line.

Obstacles

Costs increase with the number of obstacles that need to be crossed by excavating underneath or be avoided by routing around the obstacle. Common obstacles are streams, railroads, other utilities, sanitary and storm sewers, streets, and highways. There may be numerous underground obstructions within urban areas (see Figure 11). Some areas have bedrock near the surface that would require blasting or directional boring. Hazardous waste sites might require the additional cost of remediation. Special measures would add to the project cost.



Figure 11: Subsurface obstructions

There are few obstacles that would prohibit the construction of an underground line. However, the cost of avoiding these obstacles or the potential for adverse environmental effects can often make the underground option not feasible.

Costs

Costs of installation and materials

The installation of underground transmission lines costs more per foot than most overhead lines. Costs of underground construction can range from four to ten times as much as an equivalent length of overhead line. However, generalized cost ratios of underground to overhead options should not be used because costs are site-specific.

A typical new 69 kV overhead single-circuit transmission line costs approximately \$285,000 per mile as opposed to \$1.5 million per mile (without the terminals) for a new 69 kV underground line. A new 138 kV overhead line costs approximately \$390,000 per mile as opposed to \$2 million per mile (without the terminals).

A 2006 Virginia Joint Legislative Audit and Review Commission report estimated that constructing underground transmission lines ranges 4 to 10 times more expensive when compared to overhead lines of the same voltage.

The cost of constructing underground transmission lines is determined by the local environment and the distances between splices and termination points. Other issues that make underground

transmission lines more costly than overhead lines are right-of-way access and maintenance, 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.

Repair costs

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.

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.

Siting Impacts

The impacts of underground transmission lines differ from those of overhead transmission lines during construction and afterwards. Underground lines generally cause greater soil disturbance due to trenching requirements, while overhead lines disturb the soil primarily at the location of the transmission poles. Trenching an underground line through farmlands, forests, wetlands, and other natural areas causes significant land disturbances. The ROW for underground transmission lines must be kept clear of trees and bushes, while small trees and bushes are allowed within the ROW under overhead lines. Post-construction issues such as aesthetics, concerns regarding 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.

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 ROW is in a residential area, construction hours and the amount of equipment running 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 and 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. Trees or large shrubs would not be allowed within the ROW due to potential problems with roots. Some herbaceous vegetation and agricultural crops may be allowed to return to the ROW.

Engineering limitations on constructing underground transmission lines

Many engineering factors limit the length of underground electric 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 less than 100 miles of underground transmission currently. Of the current underground transmission, all of it is 138 and 69 kV. There are no 345 kV underground segments in Wisconsin.

Operating Impacts

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 4). 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 4 shows some sample magnetic field measurements projected at different distances from underground lines and overhead lines. Maximum magnetic field strengths of underground transmission lines typically do not exceed a few mG at a distance of 25 feet. More information about EMF is presented in the PSC Overview pamphlet entitled, “EMF - Electric and Magnetic Fields”.

Table 4 Sample Magnetic Field Strength of Various Transmission Lines

Voltage	Construction	Amperes	Distance	mG
69 kV	Underground - XLPE	252	Centerline at surface	34.2
			50 feet from Centerline	0.9
69 kV	Underground - Pipe-type	204	Centerline at surface	0.8
			50 feet from Centerline	0.1
69 kV	Overhead	167	Centerline	23
			40 feet from Centerline	7.0
138 kV	Underground - Pipe-type	467	Centerline at surface	0.21
			50 feet from Centerline	0.05
138	Overhead	710	Centerline at surface	190
			50 feet from Centerline	46

Heat

Heat produced by the operation of an underground line raises the temperature a few degrees at the surface of the earth above the line. 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.

Potential fluid leaks

Although 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. Any soil contaminated with leaking dielectric oil would be classified as a hazardous waste. This means that any contaminated soil or 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 to show up in plants or wildlife (benzene is a known carcinogen).

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.

Safety measures

During construction, barricades and warning signs during the day and illuminated flashing signs and lamps at night would be required to guide traffic and pedestrians. After each day's work, steel plates

should cover any open trench. All open concrete vaults would have a highly visible fence around them. When the cable is pulled into the pipe the contractor should cordon off the work area.

To protect individual ducts (for SCFF and XLPE lines, Figure 9) 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”). The ducts themselves are electrically inert, but not as mechanically strong as concrete, tile, or soapstone ducts of years past. They are now generally polyethylene, polyvinylchloride (PVC), or fiberglass.

Reliability of Service

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

Repair rates – pipe-type lines

For pipe-type lines, the trouble rates in 1987, for about 2,536 miles of line² 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. Power Delivery Consultants, Inc., using some French data and the results of an informal survey, generated estimates that correspond to about:

- 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 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.

² calculated by Power Delivery Consultants, Inc.

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 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 is pipe-type cable that has been in service for more than 60 years. Overhead lines in northern Wisconsin have an assumed life, for accounting purposes, of about 32 years, but the lines actually last about twice as long.

Choosing Between Underground and Overhead

The choice to build an underground transmission line instead of an overhead line depends on a number of factors.

Except for special termination structures to connect it to the existing overhead system, an underground line would be mostly out of sight. An HPFF and HPGF line may also require pressurizing stations at intervals along the line. An underground line would also create much lower magnetic fields. These values might make it an attractive option in a residential or suburban area, especially where there is little concern about whether bushes or trees can be grown in the ROW.

While there is concern about the potential for an oil leak from a HPFF pipe-type line, the HPGF and XLPE types do not involve the use of oils. There are greater limitations in the level of current carried by HPGF and XLPE lines.

Trench construction associated with underground lines increases the possibility of environmental disruptions. The soil must be treated with care to preserve its ability to drain and to support the natural vegetation or crops. In a wetland, it is difficult to avoid disrupting the vegetation, soil

microbiology, and water flow. While low-growing woody vegetation would be allowed under an overhead line, the ROW for an underground line must be kept clear of woody vegetation, due to potential damage from roots.

The trench and concrete vaults make an underground line more expensive. The line's relative costs would increase if the trench was installed in winter or through a contaminated area requiring special disposal techniques for the soil that is removed.

There are different advantages and disadvantages for underground transmission lines. When compared with overhead transmission lines, underground lines produce less post-construction impacts. However in general, underground lines do have more construction impacts, costs more, and have operational limitations. For some projects the Commission could determine that a portion of a line should be underground to avoid specific impacts. Every project must be assessed individually to determine the best type of transmission line for each location.

The Public Service Commission has prepared other publications for important electric issues that can be viewed on the PSC website: <http://psc.wi.gov>.

- Common Power Plant Siting Criteria
- Electric Energy Efficiency
- Electric Power Plants
- Electric Transmission Lines
- EMF - Electric & Magnetic Fields
- Environmental Impacts of Electric Transmission Lines
- Nuclear Power Plant Decommissioning and Radioactive Waste Disposal
- Power Plants Approval Process
- Public Hearing Guide, Electric Construction Projects
- Renewable Energy Resources
- Right-of-Way and Easements in Electric Facility Construction
- Transmission Line Approval Process

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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