NEXTGEN HIGHWAYS

FACT SHEET

November 2022

Introduction to Buried High-Voltage Direct Current Transmission for Departments of Transportation

System Design

A high-voltage direct current (HVDC) transmission line consists of three elements, the cable and two converter stations (one at each end of the line to connect to the alternating current [AC] transmission system). Buried HVDC lines, or conductors, connect to DC to AC converter stations that would be sited outside the highway right-of-way (ROW). The exact distance from which converter stations will be located outside the interstate ROW will vary based on each buried HVDC transmission project's specific design requirements and constraints.

The buried HVDC cables would typically require only a small fraction of the width of the interstate ROW. Buried HVDC transmission cables require a corridor that is 5 feet wide and 5 feet deep, while interstate highway ROW in rural areas is typically 300 feet wide (see figure 1 below). Conductor sections must be connected, and those connections require protection in the form of cable joint boxes or vaults approximately every half mile along the transmission line route. Joint boxes—where two cable sections are joined—would need closer to 10 feet of width. Please note that during the design and construction process, space required for construction equipment and offset requirements for other utilities in the interstate ROW will need to be considered on a project-by-project basis.

Figure 1. Simple Buried HVDC Line and Highway Right-of-Way Diagram

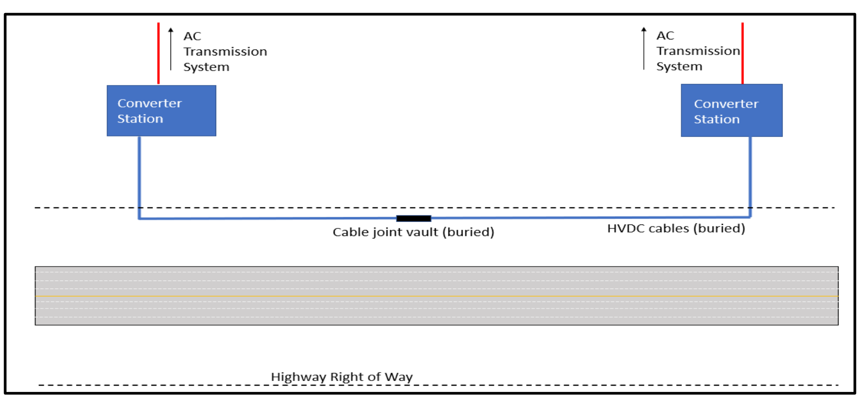
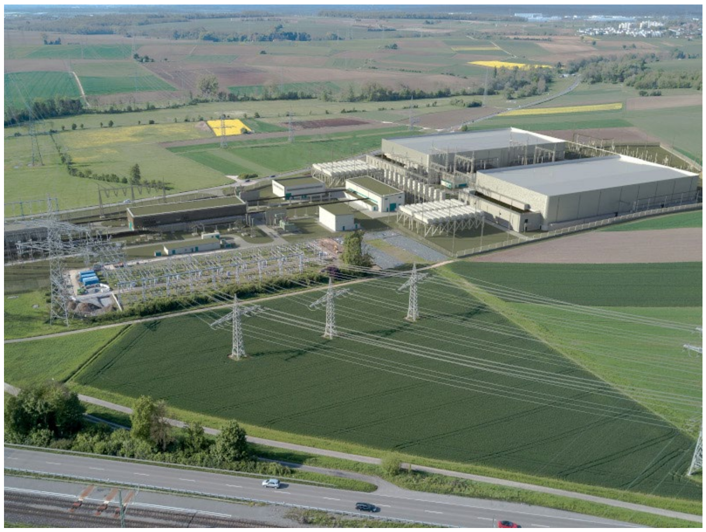


Figure 2 shows an AC-DC converter station of the SuedLink HVDC transmission line project located near Heilbronn, Germany. The station includes additional switching and transformer equipment to reliably connect the HVDC line to the AC transmission system. For buried HVDC transmission projects, this equipment is located adjacent to, not inside, the highway ROW.

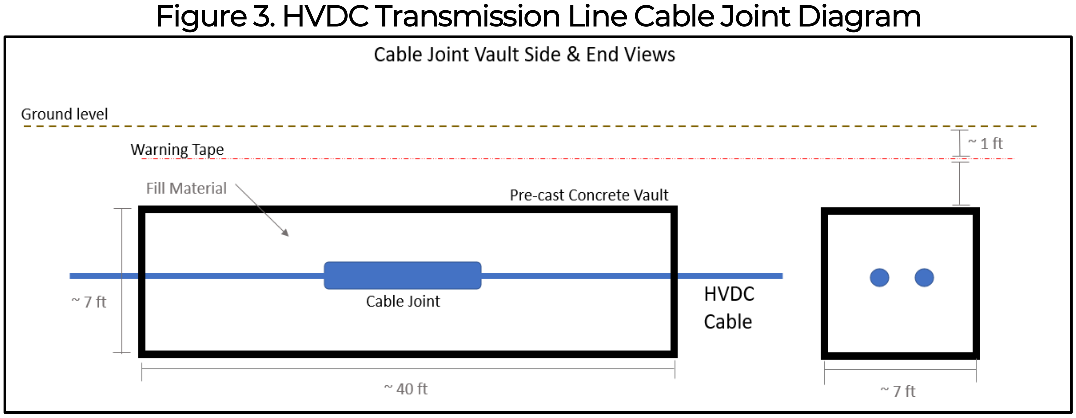
Figure 2. SuedLink HVDC Transmission Line AC-DC Converter Station



Photograph from NS Energy, "SuedLink HVDC Power Transmission Project."

As mentioned above, cable joint boxes or vaults are located approximately every half mile along the transmission line, where sections of cable must be joined together to form a continuous conductor. Figure 3 shows a diagram of a generic cable vault, which has a detailed design that can vary based on accessibility needs, cost, and security tradeoffs. These joint boxes or vaults are roughly 40 feet long, 10 feet wide, and 5–8 feet tall and are typically fully below grade. Note that each HVDC circuit requires its own joint boxes or vaults (two conductors per circuit), and the sizes noted here will vary based on the voltage level and design of any given HVDC project.

Figure 3. HVDC Transmission Line Cable Joint Diagram



Construction

Construction requirements vary depending on the construction technique employed, which will vary based on location and development density around the highway ROW. For open or rural areas without obstacles to navigate, two primary construction methods are used: open trench and integrated trench.

As shown in figure 4, open trenching allows the conductor cable to be laid in an open trench surrounded by protective sand. The trench is then backfilled with thermal backfill material or native soil. This relatively simple technique allows for the co-location of multiple cables (such as fiber optic lines for broadband internet). This technique does present some risk of theft during construction and dig-ins post-construction.

Figure 4. Example of Open Trench Construction

Credit: NKT

Another approach suitable for open areas is an integrated trench, lay, and fill technique. This is similar to the open trench technique except that the cable is fed into the trench immediately after excavation, followed by sand, mechanical protection, and backfill, shown in figure 5. This technique is often slower than the open trench technique and requires specialized equipment but does reduce theft risk during construction.

Figure 5. Example of Integrated Trench Construction

Credit: NKT

For areas that cross obstacles or waterways or are in dense urban areas, more sophisticated construction techniques are needed. The horizontal directional drilling technique uses horizontal drilling, boring, piping, and grouting along the transmission line's path to create a cavity or duct through which the conductor is pulled. This technique allows the line to be constructed without disturbing surrounding utilities and other infrastructure. However, it is more time-intensive and costly than the trenching techniques described above.

Regardless of the surrounding environment and obstacles, conductor sections must be joined along the entire route of the transmission line, typically every half mile. These joints are typically buried, but a clean environment is required to install and join cable sections. To create the clean environment, a shipping container is set up around the joint area. A two-person crew performs the work inside the joint area, taking approximately one week per joint per crew, as shown in figure 6. Once complete, the cable join vaults are typically 40 feet long, 10 feet wide, and 5–8 feet tall and are typically buried fully below grade.

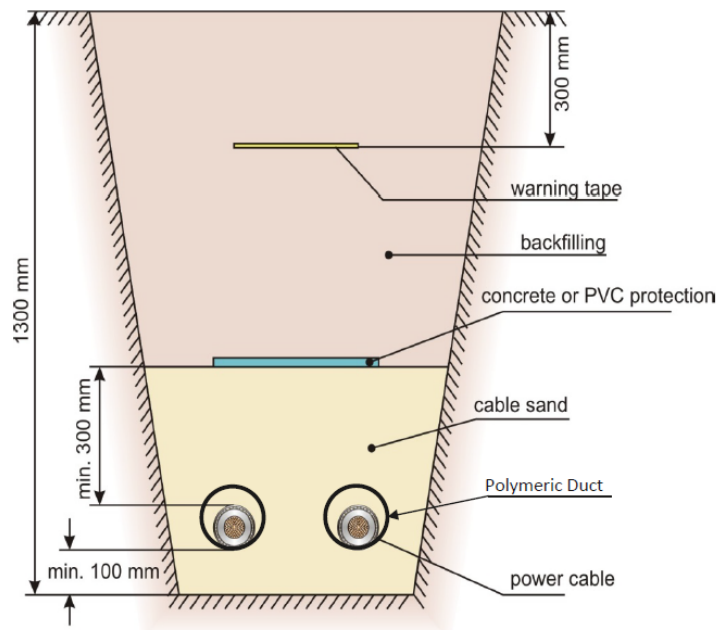
Figure 6. Example of HVDC Conductor Joint Construction

Credit: NKT

Lastly, cable protection is critical for buried HVDC transmission line construction. Cable protection mitigates dig-in and other risks and ensures reliable ongoing transmission line operation post-construction. Several protection schemes are put in place along the entire length of the buried cable. A warning tape is laid down approximately one foot below grade along the entire length of the cable path. Below this warning tape, approximately 3 feet deep and 1 foot above the cables, a concrete or PVC proactive layer is placed to mitigate dig-in risk. Then, depending on the design choices of the specific project, additional protection can be implemented around the cables themselves.

In a buried duct installation (see figure 7), a polymeric duct is placed in the trench along the length of the line, and then the cable is pulled through that duct. This installation technique provides additional protection for the cable. It has the added benefit of providing additional security against theft during construction and protection against dig-ins after construction is complete.

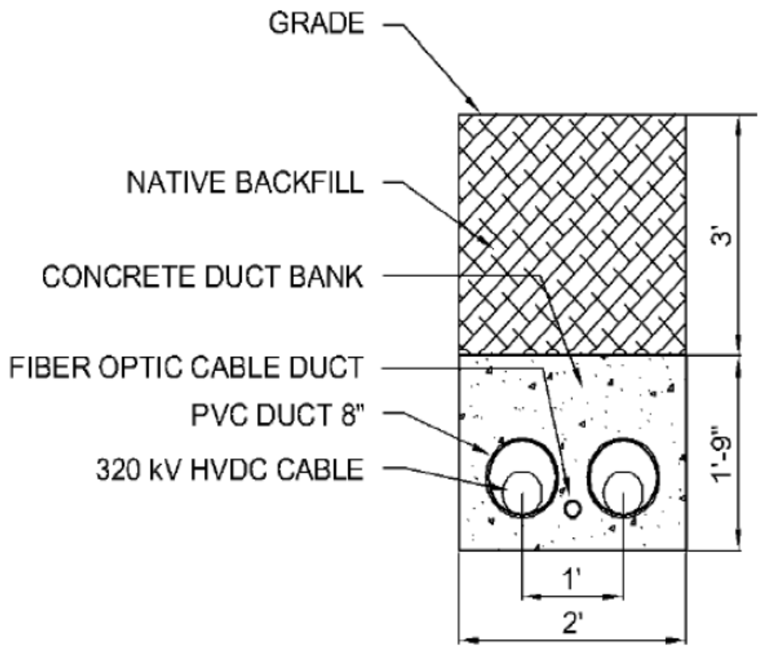
Figure 7. Diagram of a Buried Duct Installation



Credit: Southwire

Lastly, a duct bank system can be employed, which encapsulates the cable ducts into a concrete bank. A duct bank system provides additional protection against dig-ins compared to the direct buried cable or buried duct approaches. See figure 8 for a visual description of this technique.

Figure 8. Diagram of a Duct Bank System



Credit: Southwire

Maintenance

It is important to understand the potential need for transmission maintenance to assess the impact of transmission in the highway ROW upon traffic flow. Buried HVDC cables have a tested design life of 40 years. However, the actual useful life depends on the environment and operating conditions. Maintenance needs and associated accessibility needs are important considerations during the design phase of any buried HVDC transmission project. In principle, modern buried HVDC cables using cross-linked polyethylene (XLPE) insulation are maintenance-free. Unlike older designs, XLPE cables do not require cooling oil or oil pumping stations to operate the cables. However, cable joint vaults should be checked visually on a periodic basis, which includes visual inspection for signs of water ingress and measuring the connector resistance of the bonding leads. Though rare, a lightning strike can locally damage a cable such that a few meters of the cable would require replacement.

Beyond the buried conductors and joint vaults, no additional equipment would need to be located within or require access to a highway ROW that would require ongoing maintenance. Converter stations and other equipment would be located well outside the highway ROW.

Safety Considerations

Safety is always described as the first and highest priority for both the electric utility and transportation industries. As such, state departments of transportation and other industry stakeholders should be aware of the safety considerations related to the installation, operation, and maintenance of buried HVDC transmission lines within a highway ROW.

During construction, vehicles departing a travel lane on the highway pose a risk for construction personnel working near the travel lanes. Stationary or slow-moving construction equipment poses a potential vehicle collision hazard. In addition, when open trench construction techniques are used, the open trench can pose an additional vehicle collision risk. However, these hazards largely exist with any construction project in the highway ROW, and existing department of transportation processes and procedures already address construction-related safety considerations. For example, in Minnesota, projects must comply with the Minnesota Department of Transportation UAM Section VII, Construction and Maintenance Requirements and Traffic Control requirements as outlined in MN MUTCD Part 6, including the use of appropriate traffic control devices and traffic control plans.

After completing construction, safety concerns focus on unintentional contact with the transmission line. As shown in figures 7 and 8, there are several different methods employed to protect the buried transmission cable from accidental contact:

- **Surface markings/warnings:** As with all buried infrastructure, it is important to denote the presence of buried infrastructure and provide a phone number that can be called for further information.
- **Subsurface markings:** When construction personnel bury the transmission cable, they place a warning tape beneath the surface but well above the transmission cable. This warning tape provides an early alert for those digging in the vicinity of the cable.
- **Subsurface protection:** Different forms of physical protection can be added around the cable. The simplest of these is a hardened plastic board. The most advanced is full concrete ductwork.
- **Conduit:** Conduit can be used as a layer of protection for the transmission cable.
- **Cable insulation:** The strength and thickness of the cable insulation (and the cable itself) offer a final layer of protection. The cable insulation is sufficiently strong that it would be challenging to penetrate its full thickness with handheld tools.
- **Restricted access:** Highway ROW itself provides an additional layer of protection since state departments of transportation regulate access to the highway ROW.

Lastly, the transmission cable has a strong and thick layer of insulation. As such, simply touching the line while operational would not be problematic. For construction equipment to produce a dangerous line fault, it would have to either (1) pinch the cable against something hard and immovable (e.g., a large rock), or (2) exert enough force on the cable that it snapped into two pieces. Scraping against the cable would initially just displace the cable within the soil. If an operational line were to be severed, then a line fault could occur that would be dangerous to personnel working in the immediate vicinity.

Impact on Existing Utilities and Infrastructure in the Highway ROW

In certain cases, infrastructure already exists in or near the highway ROW. Common examples include radio communications devices, fiber optic cables, pipelines, and electric transmission and distribution lines. When considering the addition of new infrastructure to the highway ROW, it is important to ensure that it does not significantly impact the use of the highway ROW or the existing infrastructure.

Fortunately, buried HVDC transmission lines have minimal impact on surrounding infrastructure. Unlike AC transmission lines, DC transmission lines do not produce a time-varying electromagnetic field. As such, HVDC transmission cannot induce currents or create voltage potentials through capacitive effects on adjacent metal structures. Additionally, corrosion concerns are mitigated by newer buried HVDC cable designs (buried bi-poles with a metallic return). Such designs ensure that there are no appreciable leakage currents (i.e., voltage bleed) that could cause corrosion of adjacent metal pipes.

Importantly, buried HVDC transmission has no detrimental impact on communications equipment. The cables consist of conductive wires surrounded by an insulative polymer coating that prevents the ionization of air adjacent to the transmission line. The ionization of air—known as corona noise or corona discharge—is what produces the potential for radio communications interference (and the audible noise) associated with overhead transmission lines.[1]

In addition to the cables, converter stations could also potentially interfere with communications infrastructure. However, they are designed not to. Additionally, newer voltage-source converter station designs have the potential to produce significantly less interference than previous load-commutated converter designs.

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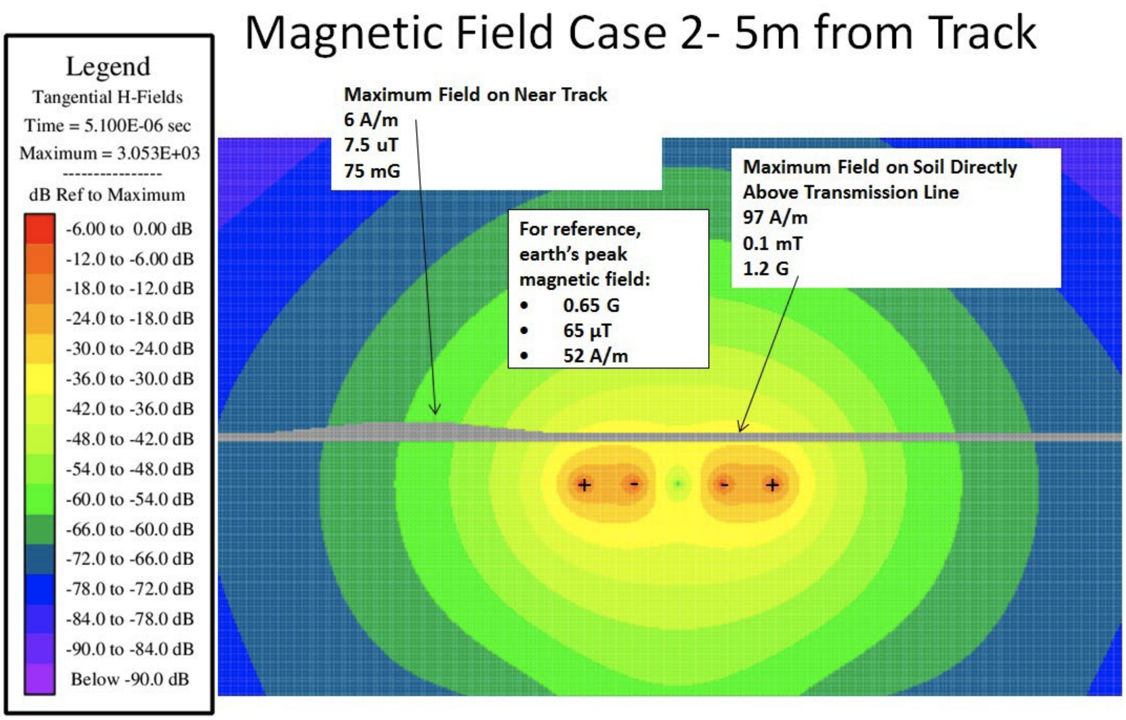
[1] Overhead transmission lines do not have an insulative coating. This 1997 US Department of Energy study thoroughly discusses the potential for radio, TV, and other communications interference associated with overhead AC and DC transmission lines - see section 10.2, which starts on page 72 of the PDF (page 58 of the study). Additionally, it provides a long list of related references starting on page 117 of the PDF (page 103 of the study).

Human Health Impacts

Simply put, there are no detrimental impacts to human health from buried HVDC transmission lines. Buried HVDC transmission lines produce a magnetic field. As shown in figure 9 below, the strongest portion of the magnetic field is present below ground, between the two cables that are operated as dipoles. At the Earth's surface, immediately above the cables, the magnetic field is roughly twice the strength of the Earth's magnetic field. A field of this strength has no known effects on human health, pacemakers, or defibrillators[2] and is approximately 1/100th to 1/400th of the allowed exposure limits.[3] As one moves away from the line, the magnetic field quickly falls in intensity. Ten feet from the line, the magnetic field is approximately 1/10th the strength of the Earth's magnetic field.



In the event of a line fault, the line will ground itself to the Earth via the cable shield ground points. The cable shield ground points are buried in the Earth every 1-3 miles. For the grounding process to produce a health risk, a person would have to have exposed and be touching one of cable shield ground points at the moment of a line fault. Additionally, they

[2] https://www.osti.gov/servlets/purl/580576

[3] https://www.efis.psc.mo.gov/mpsc/commoncomponents/viewdocument.asp?DocId=935827678

would have to be adjacent to the line fault. While theoretically possible, this is a highly unlikely event because it requires both a line fault (itself a highly unlikely event) to occur at the exact same time that digging activity in the highway ROW comes across one of the sparsely-spaced cable shield ground points.

Environmental Impacts

One of the advantages of buried HVDC transmission lines is that they have significantly fewer environmental impacts than overhead transmission lines, especially when the lines are buried in an existing ROW. Compared to overhead transmission lines, buried transmission lines have the following advantages:

- require far less ROW (approximately 20 feet in comparison with 100 feet or more)
- do not impact the viewshed
- do not pose an electrocution risk to birds or a collision risk to small aircraft

Buried HVDC transmission produces ~50 watts per meter of heat (per gigawatt of transmission capacity) under normal operating conditions.[4,5] Soil temperatures adjacent to the transmission line will increase by roughly one degree centigrade. However, heating of the local soil is carefully studied during the design process to ensure the safe operation of the transmission cable.

About NextGen Highways

The NextGen Highways is a collaborative initiative promoting the use of highways and other existing rights-of-way as infrastructure corridors where electric and communications infrastructure are strategically and safely co-located in existing highway right-of-way. Learn more at http://www.NextGenHighways.org

[4] This number is derived from line losses of less than 5 percent per 1000 km. [Per Southwire]

[5] 50 W/meter is <10 percent of the heat that would be generated by sunlight striking a square meter of the Earth's surface on a sunny day. (This accounts for the reflectivity of the earth's surface.)