UNDERGROUND VS. OVERHEAD POWER LINES

Media Mohee Al-Deen
Electrical Engineer

Introduction

As economic growth in the world drives intensive electric energy demand, the need for advanced electric networks is fundamental for sustained and optimal usage of assets and resources available. For more than century electricity networks have primarily remained with the traditional model of being generated from generation plants, usually situated far from densely populated areas, transmitted through overhead transmission lines over long distances until they reach the locality where they are stepped down for commercial and residential use. Although the operational model of the system hasn’t completely changed, the advent of new technologies and smart grid concepts are bringing about some changes to the electricity generation, transmission and distribution systems around the world. One of these changes is increased installation of underground transmission networks as underground cables have become more advanced, reliable and cost effective.

This paper aims to provide an impartial analysis of the technical and business merits of building an Overhead Transmission Line (OHTL) versus an Underground Transmission Line (UGTL). Although many factors contribute to the tradeoff between overhead and underground power distribution, this paper focus on the most common ones in construction, cost, reliability and environmental impact.

Underground Power Lines

The innovation and development of Underground Cables and accessories technology has made underground transmission line more and more feasible in the last few years. Many countries are now building a large portion of their transmission network with underground infrastructure. New transmission projects continue to being proposed, planned and built all over the world. The need for a water crossing, the desire to preserve open space and other aesthetic issues push towards considering installing underground transmission in more and more cases.

Figure (1) Underground Power Lines

In some cases, going underground is necessary in order to bring a project to completion, based on public pressure or constrained space. In addition, in more and more instances, underground or submarine transmission is becoming the first choice for longer distances. The main benefits of Underground Cables include being more aesthetical in surroundings, less losses, less operating costs and being non-susceptible to storms and icing.

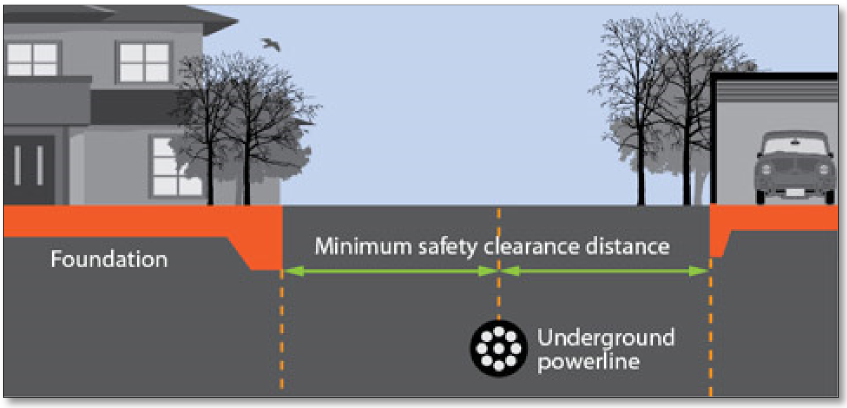

Figure (2) Undergroung lines placement consideration

Underground cables are a viable alternative to overhead transmission lines when proper consideration is given to the many details of using these types of systems. Cables, however, have differing characteristics than overhead lines that must be factored into design, ratings, switching, reactive compensation, operation, maintenance and repair

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)

Each cable type is constructed using different components, that makes each type has its own characteristics in handling the pressure, power transfer capability, operation & maintenance, cost ..etc.

Overhead Power Lines

Overhead transmission of electric power has been along the years and will still continue one of the most important elements of today's electric power systems. Power transmission from generating stations to industrial sites and to substations is the fundamental object of the transmission systems. This function accomplished by overhead transmission lines that connect the power plants into the transmission network, interconnect various areas of the transmission networks, interconnect one electric utility to another or deliver the electric power from various areas within the transmission network to the distribution substations, from which distribution system supply residential and commercial consumers.

Figure (3) Overhead Power Lines

High voltage overhead power lines must satisfy many simultaneous requirements: minimum electrical resistance (to reduce losses), safe clearance above the ground, sufficient strength for the applied loads ..etc. A wide variety of cable specifications are available to meet the demands for different current carrying capacity in many different climates and types of terrain.

Long-distance overhead conductors use aluminum in preference to copper - the lower electrical conductivity being more than compensated by the lower density and cost. In composite Steel-Al cables, the steel carries most or all of the mechanical load, and the electrical current. Aluminum is often now used throughout, serving both electrical and mechanical purposes.

Overhead cables range in size from 5-40 mm in diameter, using layered helical winding, with the twist direction alternating between layers. The individual strands are typically 2-4 mm in diameter, convenient for wire drawing and winding. In reinforced cables, the inner strands predominantly carry the load.

Underground Power Line vs. Overhead Power Line

There are many factors which determine the technical requirements for the planning and design of building or upgrading an existing transmission line for the power system to be either Overhead or Underground and some of those factors are:

- Environmental Constrains
- Weather Conditions
- Power System Consideration
- Cable Construction
- Power Stations Type
- Power Availability & Stability
- Maximum acceptable levels of electrical and magnetic field

In addition to the cost and efforts required to build and maintain each type, environmental and governance policy constrains available in the region where the power system will be build or upgraded.

The following sections will discuss in more details each of those factors to settle the tradeoff between Overhead Power Lines and Underground Power Lines.

1. Environmental Constrains

Environmental constrains cover statutory requirements, utility policy with regard to environmental matters and also public and private views and concerns.

The permanent and temporary effect of a new overhead line or underground line can be usually quantified but public reaction to the project may sometimes be emotional.

Therefore, the evaluation of the environmental impact of such projects is fairly complicated and involves many aspects, most of which can be considered and analyzed only from a qualitative point of view.

The major constrains likely to be encountered are magnetic fields and to a less extent electrical fields with relevant exposure limits, land occupation and depreciations and limitations to land use. Visual impact is important overhead power lines and some impact may also be produced by exterior installations of a cable circuit such as terminations and reactive power compensation equipment. In many cases, remedial actions can be taken to reduce the effects on the environment.

Also, one of the environmental constrains is the nature of region which need power system it might be a crossing water or forest where building the power system based on overhead powerlines might be more complicated and expensive comparing to underground power lines.

2. Weather Conditions

Weather conditions can have severe impact on the power systems and can cause power outages which can lasts for weeks and months. Therefor a careful study for the weather conditions should be considered before deciding the type power lines (overhead or underground).

Overhead power lines are typically more economical but they are susceptible to damage from wind-borne tree branches, wreckages and ice-loading conditions from extreme weather. The damages can cause extended power outages that in extreme cases cannot be restored for days or even weeks. The cost for repairing the physical damages can be in the billions of dollars. During long outages after a catastrophe, there are also associated intangible impacts to a utility's customers such as despair, discomfort, anxiety and helplessness.

3. Power System Consideration

Cables are essentially long distributed capacitors that generate capacitive vars. significant charging current generated in AC cable systems means that underground cables are always thermally limited as compared to overhead lines that may have thermal limits, surge impedance, loading limits or stability limits.

Underground lines have lower positive sequence (series) and surge impedances as compared to similar overhead lines. As such, they will tend to carry more load when operating in parallel with an overhead line. Also, due to the significant amount of capacitance in the cable, switching transients must be considered carefully. Ferranti effect (voltage rise) in lightly-loaded cables is uncommon, but dense urban cable-using utilities often consider shunt reactors. Unlike overhead lines where faults can be temporary, cable faults are permanent.

4. Cable Construction

One of the most important technical differences between overhead power line and underground power line are insulation, thermal heating and installation techniques. In overhead lines, air acts as the insulating medium around the bare conductors attached to overhead structures. Based on the clearance requirements at different voltage levels and structure design, each conductor is spread wide apart from each other and the ground. In the case of underground lines heavy insulating medium has to be in place. Earlier generations of cable had oil impregnated paper as the insulation. The oil was borne in the cable via a pressured oil-duct through the center. Another type of insulation had high pressure fluid, e.g. nitrogen or oil, and was covered in a steel shielding. More recently cross-linked poly ethylene (XLPE) insulated cable has emerged as the most preferred cable for low to extra high voltage applications.

5. Terminate Stations Types

There are essentially two ways to terminate underground cable circuits; substations and transition poles. Substations require more space and usually a fenced perimeter, but they allow greater flexibility for connecting other equipment and can more easily support multiple cables per phase or installed spare conductors.
Compact transition poles are convenient for areas where siting a new substation is not practical.

For overhead the size of substations varies quite a lot, depending on whether they serve mainly residential properties, or also commercial and industrial units, schools and institutions such as hospitals, often have their own substation.
Overhead power lines substations can be grey metal boxes in a fenced or walled enclosure. Sometimes they are inside a metal or brick box. They can also be found in plastic (glass fiber and strengthened polycarbonate/ ABS type material) structures. These are usually grey or cream/buff colored.

6. Power Availability & Stability

While both transmission lines (overhead and underground) are reliable by design. They are impacted differently; overhead transmission lines are exposed to weather conditions while underground transmission lines can be dug into. Failure pattern may vary by location, design, weather, environment, awareness, standards and other factors.

In the case of faults, locating faults in overhead lines is easier. Once located visually, the restoration process can start. Due to ease of accessibility, overhead failures on average can be fixed within few days. Historically underground failures take longer to locate and restoration of XLPE type can last 5-9 days based on factors such as condition of equipment, availability of replacements, ease of access, and expertise of workers. This results in an unavailability of cables being higher than that of overhead lines. However, failure data for XLPE cables is being conservatively estimated as they have not been utilized for many years and failure rate is very low.

7. Electo- Magnatic Fields (EMF)

An electromagnetic field is generated when charged particles, such as electrons, are accelerated. Electo-magnetic fields (EMF) are created around cable or conductors when they carry current. With higher voltage the higher the strength of the electric field becomes and with higher current the higher the magnetic field becomes.

For the underground cables the individual conductors, being insulated, can be closer together, leading to greater cancellation and lower fields. However, unless they are buried very deeply, they can also be approached more closely, leading to higher fields. Overall, ground-level magnetic fields from underground cables fall much more rapidly with distance than those from a corresponding overhead line, but can actually be higher at small distances from the cable.

For the overhead power lines, the magnetic field produced by a current in a conductor falls with distance from the conductor. Where there is more than one current forming part of one or more electrical circuits, there is also partial cancellation between the magnetic fields produced by the individual currents, and that cancellation generally becomes better at greater distances. Overall, the magnetic field is highest at the point of closest approach to the conductors and falls quite rapidly with distance. Similarly, there is partial cancellation between the electric fields produced by the voltages on individual conductors, and the electric field is usually highest at the point of closest approach to the conductors and falls quite rapidly with distance

The below figure shows the resultant EMF for both underground and overhead power lines.

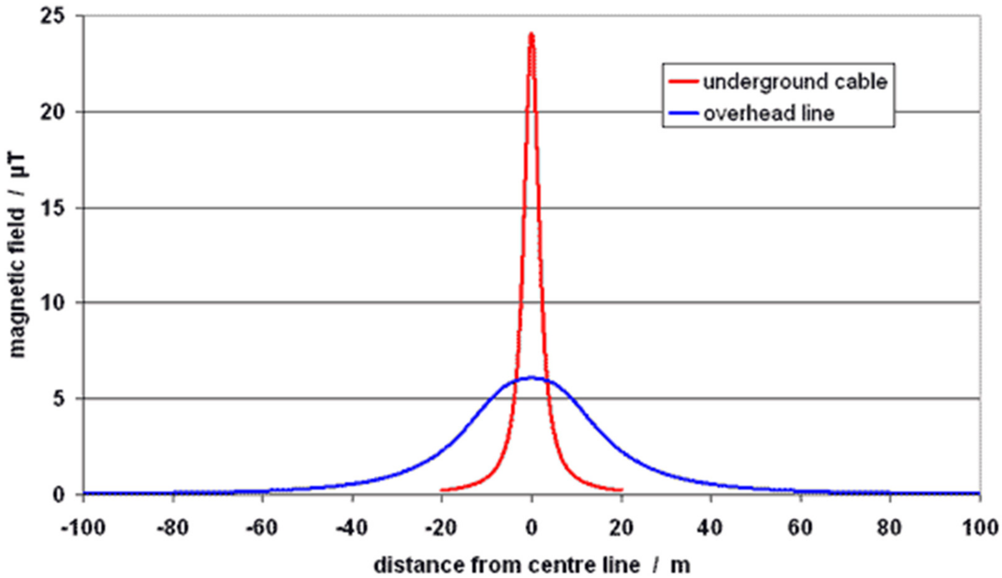

Figure (4) EMF for Overhead & Undergound Power Lines

8. Cost Comparison

The availability of equipment, ease of construction, continued access and expertise makes the construction costs for overhead lines lower than for underground lines where civil costs are high as it requires digging trenches, building vaults and installing splice joints form a big portion of the complexity and cost of the underground installation. However, overhead lines require significant civil construction as well in terms of access roads and foundations platforms for the overhead structures.

However, when the cost of building transmission line is calculated construction cost is not the only criteria that should be considered. Other costs aspects such as maintenance, repair, losses, environmental impact, failures should be also calculated carefully and added to the cost of cables construction to conclude the total cost.

As per different studies, although the initial investment in Underground Power Lines investment is higher, energy losses and life-cycle operating and maintenance costs will reduce the overall life-cycle ratios. Cost prudence with a longer term outlook can definitely ensure that investments on this magnitude can serve power requirements for the entire life cycle and future needs of the electricity grid.

9. Safety

Safety around electrical equipment is the major concern of any company in the electrical sector around the world. Working on or around existing electrical equipment is a part of modern life for the engineers/workers and also for the general public. The risks are escalated in the case of high voltage transmission lines. Best safety standards have to be followed in the design of the lines and during the construction stages of the projects. The biggest risk is the direct contact to energized lines and with ground at the same time. Fallen lines due to failure, lightning, wind, icing and/or storms can pose this threat if they continue to be energized. In the case of underground transmission, people or equipment can dig into the ground and contact risk can occur. Installing cable inside concrete encased ducts and adequate protection schemes are ways of mitigating or lowering these risks.

In general, many of the public safety concerns can almost be eliminated in the underground option. The weather and accessibility risks will continue to remain in any overhead design.

Conclusions

Underground cable systems can be a possible alternative to overhead lines with proper consideration of many factors related to the design, specification, manufacturing, installation and maintenance of the underground system.

Also, considering that usage of overhead lines is not feasible all the times due to sensitive areas along the planned route for installation, specialized obstacles (waterways, bridges, etc.) in addition to the weather conditions that might affect overhead power line reliability.

Although the civil construction cost of underground lines is higher comparable to same capacity in the overhead lines, there are others cost criteria such as maintenance, losses, environmental impact that can make underground lines as preferred alternative to the overhead lines.

References

1. Overhead Power Lines: Planning, Design, Construction, Peter Nefzger, Ulf Kaintzyk, Joao Felix Nolasco, Springer 2003
2. Underground Electric Transmission Lines, https://psc.wi.gov/thelibrary/publications/**electric**/**electric**11.pdf
3. Underground Power Cable Considerations: Alternatives to Overhead, Earle C. (Rusty) Bascom, Victor D. Antoniello, 47th Minnesota Power Systems Conference (MIPSYCON)