TRENDS IN THE 'UNDERGROUNDING' OF HIGH VOLTAGE POWER LINES

1 INTRODUCTION

The question about the use of underground cabling of power lines is frequently raised. This document presents an update of undergrounding worldwide, with a particular focus on 400kV and 765kV power lines.

2 TECHNICAL ISSUES

Overhead cables are only insulated at the pylons or posts that support them. Provided there is sufficient distance between the exposed cable and any earthed object, the air provides sufficient insulation. The air also cools the cable that gives off heat as current passes through it.

Underground cables need to be insulated against the surrounding soil. On low voltage reticulation networks (11kV & 22kV) the heat generated by the cable is low enough for standard insulation to be used. But on larger lines the methods of electrical and heat insulation becomes more onerous. Traditionally, cables were insulated with oil impregnated paper. The oil was carried into the cable by a central oil duct kept under pressure. Various forms of this occurred but a pressurised system was used in all cases to improve the dielectric properties. More recently solid cables have been developed using polyethylene-based insulation. The most common one is the cross-linked polyethylene cable (XLPE cable). This is even now used on 400kV cables. All cables have an external metallic sheath for protection and earthing should a fault develop.

Control of electrical losses and heat control are critical for underground cables. As a result, cables are as much as 4 times the diameter and 10 times the weight of equivalent overhead lines. Heat control is also a factor in the laying of the cables. The three phases of low and medium voltage cables (up to 132kV) can be placed in the same trench, while the phases for high voltage cables must be spaced apart, typically in a flat formation. The rating of the cable, soil conditions and climate all affect the spacing of the phases. Width of excavation may be anything between 15 and 30m depending on the technology used. In a recent case in the UK (see below) pressurised oil insulated cabling was used requiring a 30m width buried area. Most of the extra high voltage cables are located in the cooler climates and there is little experience of undergrounding 400kV cables in warm climates.

Large cables are less flexible than smaller cables and are made in shorter lengths. This means more joints per kilometre for large cables. Joints are more complex than the cable itself as all the different layers need to be connected and properly sealed. This is usually done on site rather than in the factory, and joints are therefore generally less reliable than the cable. High voltage testing is needed for each joint and special provisions need to be made to get the test equipment to site.

For smaller voltages, transitions between overhead and underground can normally be achieved by installing a 'termination' in the last tower structure. For large voltage lines the termination point is a high security transition compound (almost a mini-substation) dominated by a large strain tower. The area for the termination station can be over 2500m^2.

Faulting on underground cable is rarer. Bush fires, lightning strikes and bird related faults make up 80% of faults on overhead transmission lines in South Africa. These are not risks for underground cables. When such faults occur on overhead lines they are usually re-energised by automatically reclosing the circuit-breaker within a few seconds of the fault. More serious faults, such as a damaged line may be easily found and repaired within a few days at most.

On underground cables the faults are almost exclusively a permanent fault, requiring inspection and correction on site. This usually requires excavating a section of the line. However, location of faults is not easy unless there is clear evidence of excavation damage. Therefore, the search and repair underground cables can take several weeks to repair. This may severely compromise an N-1 or N-2 network design standard.

3 COST

Reports on cost vary between countries and are very dependent on terrain, land-use and size of line. However, all agree that underground cabling in orders of magnitude greater than overhead cables. Guideline figures are:

- Underground 22kV is 2 to 5 times more expensive
- Underground 132kV is 3 to10 times
- Underground 400kV is quoted as being between 10 to 20 times
- Underground 765kV is estimated at over 30 times (though there are no examples of this being done)

In South Africa, the costs of overhead 400kV lines are estimated at between R1-2 million/km. The markup for 'undergrounding' is therefore significant. International reports indicate that the recovery on this investment is only achieved on increased tariffs or through community commitment (taxes), though the latter refers to distribution networks (typically below 22kV). In South Africa, Eskom is a public utility and is answerable to the Public Finance Act in which all costs need to be declared and justified. Additional costs for undergrounding are subject to the same scrutiny and the costs would need to be recovered in some way. It is understood this is likely to be either by a general increase in tariffs or by direct contributions by those requiring underground cables.

4 MAINTENANCE

A mixed result arises here. Underground cables are reported to be more reliable, but outages are more difficult to fix as it is harder to find the fault, and therefore the outages last much longer on underground cables. Also, routine maintenance of underground cables is much lower in the initial years of operation (first 10 years appears to be the time span most regularly referred to), but maintenance costs can rise steeply thereafter. The lifespan of underground cabling is also shorter, in some cases it is reported to be half that of overhead cables. Nevertheless, there seems to be general agreement that the maintenance and operation of underground cabling is cheaper than overhead cabling. It has been reported that in the UK overhead line maintenance is estimated at £600/circuit-km/year (approx. R8100) while underground cable maintenance is at around £70/circuit-km/year (approx. R950). However, routine testing and monitoring of underground cables is being promoted to minimise outages arising from repair of faulty cables. This is increasing the maintenance cost of cables.

5 VISUAL BENEFITS OF 'UNDERGROUNDING'

It is commonly stated that there are distinct visual impact benefits in using underground cables. In the main this is seen to be true, especially in the urban environment where the observer is closer to the line and the land cover is largely disturbed from its natural state. However, in the natural environment, especially wooded and thornveld areas, root management may require that trees are kept out of the servitude and a 15-30m wide strip is cleared. Such strips in woodland areas are normally more noticeable at a distance than a power line (servitude management guidelines for overhead lines now allow small trees to remain under 400kV lines). Hence, it is not automatic that visual impacts are avoided by using underground cables. This would need to be assessed in each case.

6 TRENDS IN 'UNDERGROUNDING'

Underground electricity cables are typically only used in developed countries such as in the US, Europe and Australia, though reports on a number of 'developing' countries in eastern Europe (Poland and Romania) and Asia (China and Korea) have been found. Some of these have adopted policies on undergrounding (eg Netherlands and France, and some states in Australia), but these focus on low and medium voltage networks (200V to 50kV). The Netherlands, for example, adopted an underground cabling policy in the 1970's and has 100% of its low to medium voltage network underground. Next best is Belgium and the UK at 85% and 81% respectively. The average for Europe is estimated at around 50% to 60%[1].

The picture for high (50kV to 219kV) to extra high voltages (220kV and above) is quite different. Some countries have achieved high percentages of undergrounding in the high voltage range (e.g. Singapore 100%, Netherlands 89.9% and Denmark 24.3% for 50-109kV). However, as one approaches the extra high voltage range only Singapore stands out as with 100% undergrounded cabling while all other countries are less than 4%. A breakdown of worldwide average percentages of underground cable in each category is as[2]:

50-109kV	110-219kV	220-314kV	315-500kV	> 500kV
6.7%	2.9%	1.7%	0.5%	0%

There are no underground cables above 500kV. In the high and extra high voltage categories the underground sections are special projects in urban or highly sensitive environmental areas.

Since 1996 there has been a doubling of total installed underground cabling worldwide in the extra high voltage range (220kV to 500kV), though this has occurred mainly in five countries; Japan, France, Spain, UK and USA. In the US some 50% of capital expenditure on power lines is for underground lines, though still 80% of the infrastructure is overhead[3].

Hence, in developed countries there is a growth in underground cabling of low voltage distribution systems, the undergrounding of high voltage lines is rare and limited to highly sensitive areas. However, while there appears to be no policy

1 Commission of European Community, December 2003. Background Paper: Undergrounding of Electricity Lines in Europe.

2 CIGRE, 2006. Statistics on underground cable in transmission networks. Final report of CIGRE Working Group B1.07.

3 Brad Johnson, January 2004. Out of Sight, Out of Mind? A study of the costs and benefits of undergrounding overhead power lines. Edison Electric Institute.

development towards undergrounding high voltage lines, it is fair to report that the EU has given more attention to this in recent years as the interconnection between countries to reinforce national networks is being met with growing opposition.

There is little information on underground electricity cables in developing countries. Those in eastern Europe have had reasonably well developed electricity networks for some time. Though it is known that it does occur in some city areas, it is expected the practice of undergrounding is well behind that of developed nations. In South Africa, new 11kV and 22kV lines in residential areas are more regularly buried. However, though undergrounding of higher voltage lines has been considered at sensitive sites, it is understood that none have been constructed.

7 THE SOUTH AFRICAN SITUATION

Engineers in South Africa have refined the design of overhead power lines to such an extent that their relative cost is low compared to other countries. The towers and conductor bundles have been adapted to suit the environmental conditions in the country. The maintenance and monitoring of the lines is well understood and the network can be designed and operated to a high level of reliability.

Undergrounding of lines is occurring for the low voltage lines in urban areas. However, experience with undergrounding the larger lines (132kV and above) is very limited. The cables available on the market are not well tested in the South African climate and application in the warmer climates will need to be conservatively designed. At this stage any underground project is likely to be a pilot project to test designs under South African conditions. Extra high voltage underground cables are unlikely to be used on critical parts of the national network at this stage.

The expertise necessary for designing and preparing specifications for underground cables will need to be sourced on the international market. Such is the worldwide demand for power and transmission installations worldwide that it will be difficult to secure the necessary expertise in the usual planning and design timeframes. Additionally, extra high voltage cabling is made to order. Long lead times will need to be factored into the design and construction programme.

Finally, the availability of land in South Africa means that development pressures and land values do not support the cost-benefit needed to help justify underground cable costs. Eskom is more likely to purchase farms than commit to underground transmission lines.

8 CASE EXAMPLE: MIDDLESBROUGH-YORK 400KV LINE (UK)[4]

The Middlesbrough-York Line (United Kingdom) The 70km long overhead line with two 400kV circuits (each with a capacity of 2,000 MW) connects the cities of Middlesbrough and York. Significant public concern was raised over the decision to put overhead lines, rather than cables, through the Vale of York. An application to construct the line was made in 1991. Following several years of public enquiries and hearings it took 10 years for all consents and way-leaves to be put in place. National Grid was not in favour of an underground cable on the grounds of cost (the overhead line was expected to cost £540,000/km (approx R7.3m/km) and the cable £8.9 million/km (approx. R120m/km), a cost factor multiple of 16 times) and environmental concerns over a 15-30 metre swathe of sterilised land through the countryside. The UK government took the view that the additional cost could not be justified and the aerial route was eventually given the go-ahead with the exception of a 5.7km cable section in the middle of the English countryside. The technology used is a pressurized oil-insulated cable. The buried part covers a total ground area of 30m of width and cost about 100 million (Euro) (Approx R175million/km).

Please note, these are UK costs and are affected by local technical costs (e.g. terrain difficulties) and differences in the economies between two countries. However, this provides a good example of the scale of costs and decisions that have been made elsewhere in the world.

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[4] REVOLT News, November 2004. Issue 174.