



# **Partial undergrounding of extra high voltage power transmission lines – Stirling Visual Impact Mitigation Scheme**

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# Partial undergrounding of extra high voltage power transmission lines – Stirling Visual Impact Mitigation Scheme

## 1. Introduction

Following an invitation by Stirling Council and the Beaully Denny Steering Group, Europacable have produced this paper, outlining the feasibility and technical aspects of partial undergrounding of Extra High Voltage (EHV) power transmission lines and commenting on the paper produced by Cable Consulting International (CCI) “*Undergrounding in the Stirling Area of the Beaully Denny 400kV line*” for Scottish Power in relation to the Stirling Visual Impact Mitigation Scheme.

The objective of this paper is to give an overview of the parameters which need to be taken into account when reviewing a possible partial undergrounding of an EHV transmission project using XLPE cable technology.

## 2. Executive Summary

The objective of this document is to provide information on the feasibility and technical aspects of partial undergrounding of 400kV XLPE transmission lines based on the expertise of European cable systems manufacturers and to provide comments on the report prepared by Cable Consulting International (CCI) and PB Power for Scottish Power in relation to the Stirling Mitigation Scheme.

The conclusion in the CCI report is that the technical position with regards to underground cables (UGC) and overhead lines (OHL) has not changed significantly since the Beaully to Denny Public Inquiry ended in 2007. From a technical perspective, the technical assessor to the Beaully Denny Public Inquiry (Giles Scott) concluded in his report that partial undergrounding using XLPE cables is a viable option.

CCI also conclude that UGC would still be significantly more expensive to install than OHL. CCI maintain that references to other cable projects around the world where less expensive connections are installed reveals that the power transfer requirements are significantly lower than those required for the Beaully Denny line. We agree with this statement but believe it ignores two main points.

All underground costs shown in the CCI report are based upon two cables per phase. It should be pointed out that the case for two cables per phase was described by Giles Scott, Technical Assessor as “marginal” and that he was not convinced about the 60% scaling factor used by the Applicants for wind generation<sup>1</sup>. He stated that for undergrounding, 3.3GW of capacity was a sensible horizon to plan (as opposed to the higher 6.7GW scenario) and that at 3.3GW, he was not convinced that a second cable circuit was justified; Several projects that include partial undergrounding of 400kV links are being planned by Transmission System Operators (TSO) across Europe, in particular Germany and the Netherlands that match the capacity of Beaully- Denny. These are being installed in response to national government legislation that places restrictions on the construction of new OHL in close proximity to residential dwellings. In such cases, the regulator has allowed the TSO to pass on any incremental costs to end customers;

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<sup>1</sup> Beaully Denny Public Inquiry Report of the Technical Assessor 11 February 2009



CCI start their report with a deeply negative approach and make reference to some failures in cable projects, notably an incident in a tunnel in China in 2006 containing 220kV cables. The causes of this serious event are not completely clarified and it seems quite unlikely that the fire produced by the XLPE cables could have assumed the described proportions. CCI say they are also aware of cable failures of 400kV XLPE systems in the UK, United Arab Emirates and Germany, but provide no further detail. They do, however, confirm that there have been no faults or incidents with 400kV XLPE cables laid in tunnels in the UK.

The common reference for the service experience of EHV cables is CIGRE (International Council on Large Electric Systems) Technical Brochure 379 “*Update of Service Experience of HV Underground Cable Systems*”<sup>2</sup>. CCI make no reference to this paper which reports the fault on cables over the period 2000 – 2005 for land cable systems according to voltage classes (60 to 219kV and 220 to 500kV).

Taking into account the failure rates for EHV cables and accessories of the Cigre study, failure rates for a defined cable system can be calculated. Assuming partial undergrounding of a 10 km section of line (with single cable lengths of 1,000 metres), the failure rate of a single system amounted to 0.0307 failures per year. This equates to 33 years between failures.

In summary, the technology is robust, the service experience is increasing but it will cost a lot more than an equivalent section of OHL. On the basis of international competitive tendering for a modern 400kV underground cable system, including its installation, it is believed that some cost savings will be reached in respect of the cost estimates expressed in the CCI report. Higher costs would need regulatory approval but transmission costs represent only a small portion (i.e. around 3 percent) of the electricity bill and can be spread over 28 million electricity consumers throughout Great Britain over the life of the asset.

### 3. Partial undergrounding of Extra High Voltage power transmission lines

#### 3.1. Technical aspects of high voltage cross linked polyethylene (XLPE) cables

##### 3.1.1. History of XLPE cables

- At high voltage levels (110-150kV) TSO and Europacable member companies have more than 25 years of commercial experience with XLPE cables.
- EHV cables of 220kV and 275kV XLPE have been applied for over 20 years.
- EHV cables of 400kV have been in use over the last 14 years, with the oldest 400kV XLPE cable being in operation in Copenhagen since 1996; the majority of the projects have become operational during the past few years as reported in Annex 6.
- With a length of 40km the longest double circuit EHV XLPE cable (500kV laid in a tunnel) has been in use in Japan since 2000.
- With over 1,100 km of 220kV and over 200 km of 400 kV cable circuit length<sup>3</sup> installed in Europe, it is a mature technology that performs well based on established international

<sup>2</sup> CIGRE 379 Update of Service Experience of HV Underground and Cable Systems, April 2009

<sup>3</sup> We herewith define as follows:

1. Cable system = 3x single phase cable
2. Cable circuit = group of n cable systems making one transmission circuit
3. Double cable circuit = two cable circuits making two separate transmission circuits to double the capacity

<sup>4</sup> CIGRE B1-302 Turbigio- Rho An example of the use of Underground XLPE cables in a meshed transmission grid, 2006

International Electrotechnical Commission (IEC) standard 62067. It is generally recognized as 'state-of-the-art' although each transmission project is, due to its specific features, unique.

3.1.2. XLPE cable design

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- 1) Copper conductor (alternative Al)
- 2) Semiconductor
- 3) XLPE insulation
- 4) Semiconductor
- 5) Waterblocking
- 6) Metallic screen and water barrier (aluminium laminated foil)
- 7) Polyethylene outer sheath

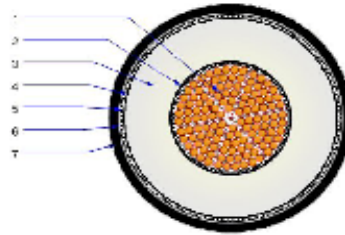


Figure 1 : Example of XLPE cable design; note that there are also other solutions, e.g. lead sheaths or welded smooth aluminium sheaths (Diameter: 140mm; Weight: 40kg per meter).

3.1.3. Cable length / Transport

- XLPE cables can be delivered in lengths of up to 1150 meters. Typically, for most applications at 400kV they are delivered in lengths of 700 – 1000 meters.
- Main considerations on length are possible limitations resulting from logistics: Weight and size of the cable drum have to be considered for transport.
- Cable drums are usually transported on road or rail to the actual site.
- Typical drum dimension:
  - 4.2 m overall diameter
  - 2.5 - 3 m overall width
  - 35 - 40 tonne weight.



Figure 2: 400kV XLPE drums transported by truck

3.1.4. Installation of XLPE cables

- XLPE cables can be directly buried into the ground or installed in tunnels, ducts or pipes to respond to requirements from surroundings, to enhance protection against external damage or to facilitate link to other installations.
- When directly buried, the typical depth is around 1.5 meters. In these cases, most of the excavated soil (70% - 80%) can be refilled into the trench if the soil is of such type as sand, clay, pea gravel or any mixture thereof. This soil does not have to be transported from the construction site. The XLPE cable is surrounded by a sand blending, in some cases a



Figure 3 : 220 kV cable system pulled in pipes and buried

mixture of sand and weak cement (CBS cement bound sand) for better heat dissipation. This has to be delivered to the site and the excavated soil (max 30%) has to be transported away.

- This installation type is mostly applied in rural areas. When installed in ducts or pipes to ensure additional mechanical protection against external damages, access to the cable can be facilitated. In cases where surface routes are not possible the cable can be installed in tunnels.

### 3.1.5. Joint bays

- Cable sections are linked every 700-1000m by so called joint bays. These are typically around 10m by 2.5m by 2.1m depth. The location of the joint bays is part of the design to allow access.
- Joint bays can be directly buried into the ground, surrounded only by a sand blending. If required, joint bays may be placed into an underground structure.
- There is no or only little visibility of these installations above ground.
- Developments in prefabricated joints and terminations technology make the erection of joints on site easier, shortening the time needed to complete the joint bay's installation.



Figure 4: Example of a 400 kV joint bay directly buried into the ground

### 3.1.6. Transition stations or Cable Sealing End Compounds

- Transition stations link the overhead line to the partially undergrounded section.
- The size of the transition station largely depends on the transmission capacity and protective installations that are required for the specific line.
- The size of a transition station will be between 2,000-4,000m<sup>2</sup>, depending on voltage, number of circuits and type of additional apparatus or accessories installed. These compounds can often be screened to provide some visual mitigation.



Figure 5: Overhead line cables transition station (400kV)

Transition compounds contain terminations, surge arresters, grounding connectors and a dead-end tension tower for the overhead line. Depending on design criteria of the TSO,



voltage transformers, current transformers and container building for auxiliary equipment may be included.

### 3.1.7. Cable termination

- Transmission cable terminations are generally installed inside the transition stations at the extremities of the cable line. In some cases the terminations are installed at the OHL/UGC transition station and, for voltages of 275kV and below, may also be installed directly on the last overhead line tower.
- The cable termination may be of the porcelain or composite type.



Figure 6: 400 kV Termination

### 3.1.8. Life expectancy

- Based on a 12 month prequalification test with load cycles within IEC Standard 62067, XLPE cables and accessories have been designed to ensure a technical life of several decades.
- Monitoring systems, both on-line and off-line, allow a continuous 'health check' on the cable temperature and possible partial discharges to take timely measures to ensure its longevity.

### 3.1.9. Norms and standards

- The existing IEC standard 62067 requires specific prequalification protocol for transmission cable systems. This prequalification process consists of a 12 month test having the scope to demonstrate long term satisfactory performance of the complete cable system (cable and their accessories).
- Several bodies, in particular the IEC and the International Council on Large Electric Systems (CIGRE), facilitate the development of best practices and issue harmonized rules for fundamental principles in EHV cable technology. This ensures that the industry meets a minimum level of standardization and quality.

### 3.1.10. Time to install

- The installation time depends on the characteristics of the cable route, the type of installation and the civil works required.
- In the case of the Turbigo-Rho line in Milan (Italy), the construction of a six cable 8.4 km 400kV underground section along road-sides took 14 months to complete<sup>4</sup>. In this case cables run along both sides of urban roads, crossing many other infrastructures using directional drilling. The soil was mainly clay mixed with gravel stones. The minimum depth of laying was 1.2 meters in accordance with Italian standards.
- The average installation time per km (direct buried in urban area) is 1.5 months/km for opening the trench per circuit, cable laying and closing the trench. For the cable laying alone, 1 – 2 days per km and per phase is required.



### 3.1.11. Time to test / commission

Additional tests can be carried out after the installation including the partial discharges on the accessories that may require approximately another week depending on the length of the circuit and the number of accessories to be tested. It should be noted that the scope of the test after installation is to ascertain that the operations such as the cable pulling, the joints and terminations mounting etc. are carried out in the proper manner and not to check the quality of the cable and the accessories that have previously been tested in the factory.

## 3.2. Integration of partial undergrounding in transmission networks

### 3.2.1. *Transmission capacity*

The cable will be designed in order to be able to carry the load flows under normal and under emergency conditions corresponding to the grid build up conditions and the imperatives of the network concerning reliability and security of supply.

Other aspects must also be considered when integrating an UGC section into an OHL grid (capacitive and reactive power situation, protections, switching order etc).

A typical overhead transmission line consists of two systems, each allowing the transmission of a nominal current of 3600 Amp. In order to meet the (n-1) conditions, each of the two cable circuits will be loaded up to 70% (which makes 2520 Amp) in normal conditions. In case of the loss of one system the remaining one must be able to transmit 3600 Amp for the emergency period.

### 3.2.2. *Transmission losses*

The cable cross section consists mostly of single core copper conductors (sometimes aluminium) and usually has a higher cross section compared to an OHL which normally uses aluminum conductors, although the use of bundle conductors for OHL may equalize the cross sections. However, copper has a lower resistance than aluminium; so for the same flow conditions, the level of losses in cables is lower than in OHL. Metallic sheath losses have also to be taken into account for UGC: these depend on cable laying configuration, type of connection of the metallic sheath (cross-bonding or not).

A comparison of losses for OHL and UGC depends on the dimension and number of conductors and systems per transmission circuit, on needs for cooling, and reactive power compensation. Losses also vary much by the actual load on the line. Therefore the calculation of losses must be made on a case by case basis.

However the partial undergrounding of a cable section of a few kilometers length in a transmission circuit will only originate a small part of the losses of the whole link and will not reduce the energy losses significantly.

## 3.3. Reliability of links with partial undergrounding

XLPE cable systems undergo thorough test procedures according to IEC Standards with thermal and electrical stress levels exceeding operational levels before being placed in



operation. Qualified cable systems are carefully checked before delivery and commissioning:

- Following production the XLPE cable and all system components undergo a thorough verification procedure, routine tests, to confirm compliance with homogenous quality according to international standards.
- Following installation, the cable system is subject to a commissioning test to confirm proper installation.

Once in the ground, the XLPE cable system is safely in place and well protected against any external weather influences. As any important infrastructure, partial undergrounding solutions shall be carefully designed to be protected against extreme weather conditions (e.g. floods, landslides, avalanches).

Monitoring systems allow close tracking of cable performance to ensure no overheating of the cable system.

### 3.4. Environmental aspects of partial undergrounding

#### 3.4.1. Environmental impacts during operation

##### 3.4.1.1. Trench width for directly buried cables

Trench widths will depend mainly on:

- the desired transmission capacity
- the general geology of the soil
- existing surrounding structures (roads, highways, rails roads, rivers or waterways)
- the thermal resistivity of the refilled soil material in the trench
- other cable systems adjacent to the new ones
- space available

Each circuit is installed in a trench approx 1 to 1.5 meters deep and 1 to 2 meters wide. If two systems are to be installed in two separate trenches spaced 5 meters apart, the total space or right of way would be less than 10 meters. If three trenches are required, the total space would be less than 15 meters. If four trenches are required, the total space would be around 20-25 meters. In any case the cable systems must be accessible permanently along the route.

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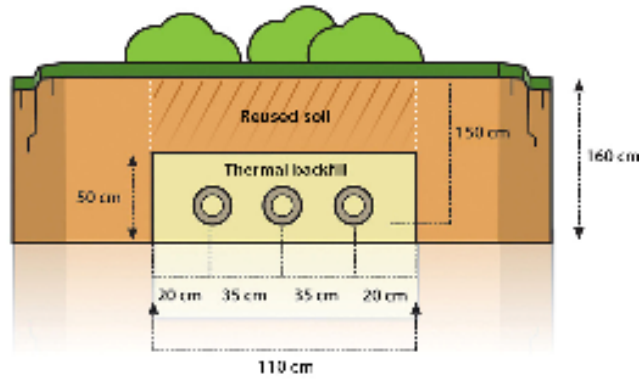


Figure 7: Example of a single AC 400kV system carrying 1250 MVA

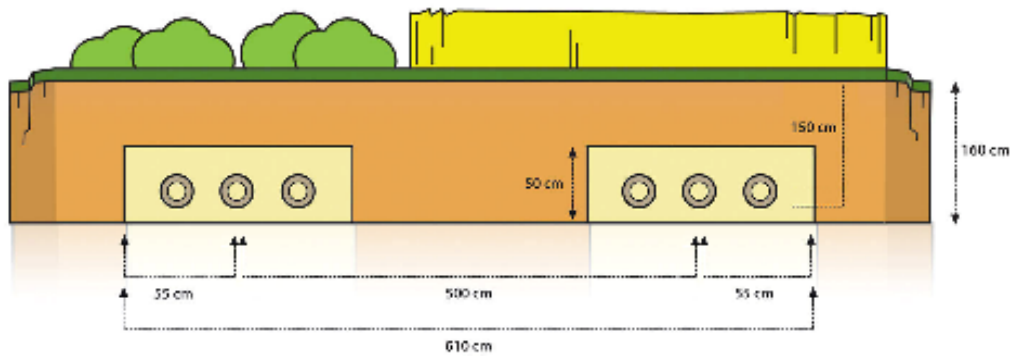


Figure 8: Example of a double AC 400kV circuit carrying 2500 MVA

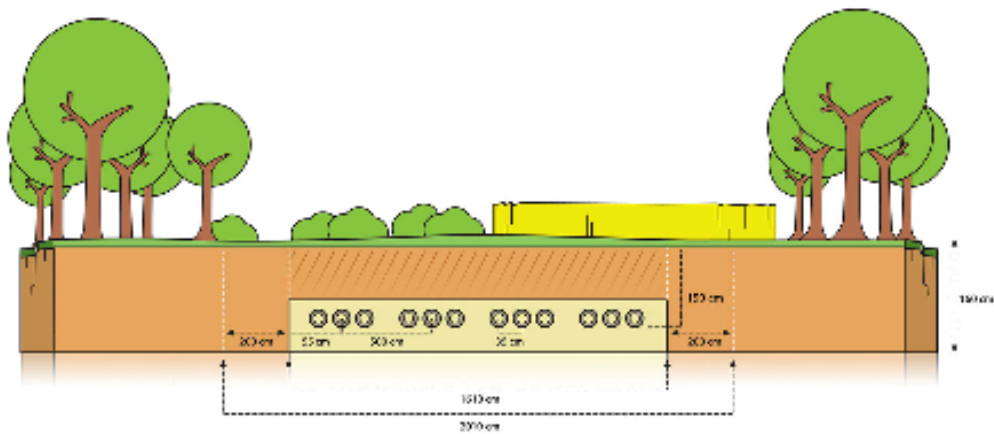


Figure 9: Example of two double AC 400kV circuits carrying 5000 MVA in total



**3.4.1.2. Use of land**

The only restriction on the use of land over a partially underground section is that no deeply rooted trees may be planted within the corridor width plus a margin of up to 5 meters to prevent roots encroachment into the cable trench. Apart from that there are no limitations to cultivation, including agricultural farming. The laying depth of the cable systems has to be sufficient to avoid any damage to the cable trench and cables themselves by agricultural activities above the cables. The corridor must be kept free from any buildings.

**3.4.1.3. Possible heating of ground**

During operation, the temperature of the cable will rise dependent on the current carried and load factor. Heat distribution to surrounding soil depends on the backfill material. The impact of heat release on soil temperature is strictly local and very limited. It is only under long term full load conditions that soil directly over the trench may heat up by approximately 2° Celsius – in partial load operations this value is lower. If necessary, the thermal impact may be additionally mitigated by the use of a cable with a larger conductor size.

**3.4.2. Environmental impacts during installation**

- Civil works required to partially underground a high voltage transmission line may have a considerable impact on the environment. Heavy machinery will be required for trenching as well as for delivery of cable drums. During the construction period, access tracks and haul roads are required to the site. These are removed following the completion of the works but there will be a need to consider ongoing requirements for operational access.
- Waterways or particularly sensitive areas can be crossed by applying drilling techniques to install the cable. Distances of up to 1km can be crossed.
- In most cases, the cable system is directly buried hence 70% - 80% of the soil can be re-filled in the trench. For the period of the construction the soil can be stored alongside the trench. Up to 30% of backfill material has to be transported to the trench and the equivalent soil will be transported away from the site.

Depending on the type of vegetation, the landscape is usually reinstated within 18 – 24 months. The surface vegetation above the installation is managed to ensure no route encroachment for the life time of the cable system.



Figure 10 : cable route at site



Figure 11: Installation of 400 kV XLPE cables



### 3.5. Cost aspects of partial undergrounding

#### 3.5.1. Installation cost

Generally speaking, due to the complexity of the technology and scale of civil works, installation costs of an EHV cable solution per km will always be higher than an equivalent distance of an OHL.

Each project is unique and a full macroeconomic assessment of the cable system should be made that takes into consideration installation costs, life costs, maintenance costs, impact on land, environmental protection etc.

When lifetime costs and other costs are taken into consideration, the cost factor compared to OHL can vary between 3 and 10 times for direct burying. Some projects involving the construction of cable tunnels have been higher than this range due to the cost for civil works, which can be up to 60% of the installation cost. Where partial undergrounding is considered, the multiple applies only to the undergrounded part of the link. This factor needs to be verified against the specific requirements of the project taking also into account the costs of the transition stations and compensation equipments, if required.

The following figure shows the respective investment costs of UGC and OHL based on the experience gained by the TSO in France (RTE). For a UGC with a capacity of 3000-4000 MVA, (similar to Beaulieu Denny) the range is €5-9m/km (i.e. £4-7.5m/km) which is well below the estimates provided by CCI/PB Power in APL 5/16 and APL/STG-41 and in the updated report ER 439 rev1.

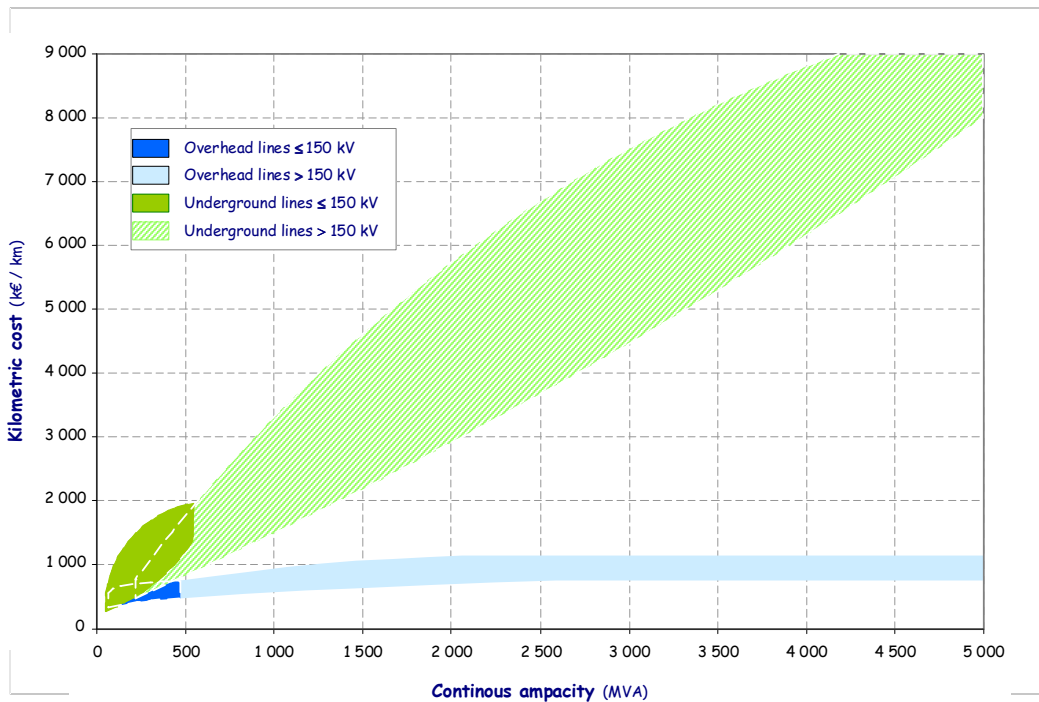


Figure 12: Investment costs (without reactive compensation)

### 3.5.2. Cost of operation

Once in operation, a cable system itself is nearly maintenance free. Monitoring systems allow partial discharge surveillance. As with any transmission corridor, the cable route requires regular inspection to prevent any encroachment.

As previously mentioned in a partial undergrounding solution, as the UGC section represents only a limited part of the total length of the link, it will not significantly affect the amount of operational expenditures generated by the whole link.

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### 3.5.3 Other costs

A variety of additional cost aspects are considered in public debates of partial undergrounding projects. Some of these are difficult to quantify and lack clear and transparent criteria. However, there should a consideration of some social costs, such as the impact of transmission lines on visual amenity and property values in close proximity of a proposed transmission line or indemnifications for the right of way for the overhead line or UGC.

### 3.5.4 Impact

If only one tenth of the length of a project is subject to partial undergrounding and the investment cost of this section is 3 to 10 times the cost of the current overhead section, partial undergrounding would lead an increase of the investment cost by a factor of 1.2 to 2, excluding costs for transition stations, reactive power compensation etc.

The economical balance of transmission projects is highly sensitive to the recourse to partial undergrounding and such a decision must be carefully analysed with all stakeholders including the regulator whose authorisation is in many cases needed by the TSO to ensure an appropriate cost recovery through the transmission tariff.

## 4. Review of Undergrounding Report by Cable Consulting International

### 4.1. Overview

Cable Consulting International (CCI) and PB Power were retained by SP Transmission to provide a review of 275/400kV AC undergrounding in the Stirling area. Their report ER 439 rev1 is included as Part 2 of the Stirling Visual Impact Mitigation Scheme. As pointed out by CCI, representatives from the two companies also gave evidence at the Public Inquiry on behalf of SHETL and SP Transmission.

Europacable do not dispute the overall conclusion that undergrounding any sections of the line around Stirling would be significantly more expensive, however, there are significant omissions on information concerning some current projects in Europe where undergrounding is either being installed or being planned.



In most cases this is as a result of decisions made at a government or planning authority level that is requiring the TSO to consider and implement partial underground solutions for new EHV transmission lines.

There are also a number of instances in the report where we believe information has been misrepresented.

**4.2. Other relevant current projects in Europe**

In section 8.1.2 CCI refer to some underground projects that have been completed around the world in recent years. A significant omission is any reference to AC EHV underground projects that are currently being planned or installed by TSOs in Europe. Most of these are in response to legislation or policies recently introduced by governments that restrict the use of OHL and/or to speed up the authorisation of new transmission lines.

In the Netherlands, the government has introduced legislation that restricts the future construction of OHL and also accelerates the authorisation procedures for approving new transmission lines. New OHL are not allowed within 300m of buildings unless a new design “Wintrack” pylon (which emits a lower EMF) is used and for every kilometre of new OHL, a kilometre of UGC must be built. The Dutch TSO (Tennet) have decided to underground two 10km sections of cable along the Randstad 380kV project, which forms part of the backbone of the Dutch EHV transmission system. The new cable sections will have a capacity of around 2,640 MVA and are 2 cables/phase (i.e. 12 cables). The section from Wateringen to Blieswijk is expected to be in operation in 2012 and the section from Blieswijk to Beverwijk in 2014.

In Germany, plans are being advanced for 4 “pilot projects” that will be built in the next few years and will have similar power ratings to the Beaulieu Denny line. Federal Legislation (“Enlag”) introduced in 2009 requires a TSO to consider undergrounding if a proposed new transmission line passes within 200m of individual houses or 400m of housing developments in urban areas and the regulator has authorised the recovery of any additional costs on the pilot projects through the transmission tariff. The Lander (State) of Lower Saxony originally passed their own underground cable law in December 2007 enforcing the same restrictions on new transmission lines but this has now been over-ruled by the Federal Enlag law. The current progress on the 4 pilot projects is listed below.

Approval proceedings for partial undergrounding of the 59km Ganderkesee - St Hulfe line 380kV (3,600A per system) started in March 2009. The TSO, Transpower, is now owned by the Dutch TSO Tennet and has just changed its name to Tennet TSO GmbH. The takeover has allowed the companies to share experiences and research with their Randstad project. On this line, the TSO is currently proposing to lay twelve cables in a 15m trench within a 30-45m wide work area for an 8.3km section at the northern end of the line, although the new government of Lower Saxony, headed by Prime Minister David McAllister, maintains its position that no lines closer than 400 meters may be introduced to residential developments. On the basis of the law, this would result in seven underground sections covering 56% of the line. According to the TSO, undergrounding the 8.3km section could costs around €100m (€12m/km); On the 167km Diele - Niederrhein 380kV (3,600A) project in Lower Saxony and North Rhine Westphalia, TSO Amprion is proposing 14.5km of undergrounding in 3 separate sections of 4.5, 5 and 5km, out of a total of 87km transmission line. The regional planning process commenced in 2010 and the line is expected to be operational by 2015;

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For the Wahle - Mecklar project (3,600A) in Lower Saxony and Hesse, Tennet TSO is currently assessing several overhead routes and is in consultations with the local

communities. At a recent workshop of TSOs<sup>5</sup>, they stated that they anticipate undergrounding around 16km of the 200km line. The fourth project is the 60km Lauchstadt to Redwitz 380kV project in Thuringa and Bayern. It will be 3,600A per system and the stakeholders have demanded a non visible solution through the important tourist Rennsteig area of the Thuringa Forest. The TSO, 50Hertz, is planning a 1.7km cable in the Rennsteig area with a 15% slope/gradient. This represents an enormous challenge and has not been executed before in Germany. During the test phase, a double circuit cable will be tested to assess its reliability. To ensure service security, the current proposal is to erect a low height OHL alongside the cable which will be dismantled once security is established. In Austria, the government of Salzburg has introduced legislation that is similar to the Enlag in Germany. The "LEG" however requires TSOs to underground new transmission lines if they come within 200m of individual buildings and 400m of housing developments. The TSO, Verbund, is opposed to undergrounding any of the 100km section of 380kV line (3,600A) between Elixhausen and Tauern, but the current plan for an OHL solution is not accepted by three communes (Eugendorf, Koppel and Flachgau) or the Salzburg government.

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A report by EU Coordinator Georg Adamowitsch in July 2009 supported a re-routed OHL but this has not been accepted by the Government of Salzburg. In July 2010, Salzburg Energy Minister Sepp Eisl met with EU Energy Commissioner Günter Oettinger who commented: *"Concerning upgrading the grid, one has to weigh every individual case and in general should accept overhead lines but one may not concentrate on them fundamentally. For reasons such as maintaining good neighbourhood interests and also for reasons of the landscape, undergrounding can be the sensible addition. It is for this reason we would need both, overhead lines as a general case and also the willingness to invest into underground cables."*<sup>6</sup>The ongoing debate between the TSO and government is clearly delaying the project.

The cases above demonstrate that TSOs in Europe are moving ahead with cable solutions when required to do so by planning authorities or national legislation. A similar situation would exist in Scotland if undergrounding was required in the Stirling area.

CCI also make reference in their report to the proposed 60km 400kV OHL from Seabank to Bridgwater ("Hinkley Point Connector") in the Somerset/Avon area of England. The proposals from National Grid are still under public consultation until March 2011, so any comments about potential undergrounding of the line are not yet formal policy. However, National Grid Project Manager David Mercer, has said on more than one occasion in public, that should an AC overhead solution be preferred, they would need to give serious consideration to partial undergrounding of the line through the Mendip Hills Area of Outstanding Natural Beauty and in the urban area around Avonmouth. This included a public meeting in Nailsea chaired by Liam Fox, MP on 27<sup>th</sup> November 2009 and an interview on BBC Radio 4 on 28<sup>th</sup> June 2010.

#### 4.3. Costings

Updated costs for undergrounding and an overhead line have been prepared by CCI. According to the report, costs for cable system materials, jointing, system testing have been obtained from cable manufacturers and costs for civil works have been provided by Balfour Beatty, who it should be pointed out in the report do have the contract for the design of the OHL. Updated costs for an overhead line, sealing end costs and tunneling technology were provided by PB Power, which since October 2009 has been a subsidiary company of Balfour Beatty.

<sup>5</sup> Renewables Grid Initiative Workshop, Arnhem, 7 September 2010

<sup>6</sup> Salzburg Nachrichten 16 July 2010



Respecting EU competition requirements, Europacable can only provide general statements and observations regarding cost factors used for partial undergrounding of the Beaulieu Denny line. However, it is noted that:

- CCI state that information provided by cable manufacturers “has been used in the production of this report”. No information is provided on how it has been used – e.g. lowest quote, average cost or the range of cost quotes;
- As with APL 5/16 and APL/STG-41, CCI have not provided any breakdown of civil works costs. In Case Study 5 in APL5/16 “civils” were estimated at £25.3m (48% of all cable route costs);
- All underground costs shown in the CCI report are based upon two cables per phase. It should be pointed out that the case for two cables per phase was described by Giles Scott, Technical Assessor as “marginal” and that he was not convinced about the 60% scaling factor used by the Applicants for wind generation<sup>7</sup>. He stated that for undergrounding, the 3.3GW was a sensible horizon to plan (as opposed to the higher 6.7GW scenario) and that at 3.3GW, he was not convinced that a second cable circuit was justified;
- International competitive tendering for all costs can be expected to produce lower prices than those quoted by CCI, PB Power or Balfour Beatty as evidenced by the data from RTE France;
- There is no overall explanation why estimated costs for the OHL have fallen in the latest report whereas costs for a UGC have risen. This is despite the comment on page 9 of the CCI report that new technology for OHL would likely increase the cost of the OHL construction;
- There is no doubt that the cost of an UGC in the Stirling area will be much higher than an equivalent length of OHL. The focus should be on whether any undergrounding around Stirling as a visual impact mitigation measure would make the whole Beaulieu Denny line uneconomic. In his report to the PLI, the technical assessor Giles Scott concluded that “partial undergrounding of the line in short lengths is practical” and his assessment was that the proposal could accommodate at least two typical sections of UGC (i.e. 5km each) and “still be the best scheme from an economic perspective”. This conclusion has not been assessed by CCI in their report.

#### 4.4. Service Experience, reliability and failure

CCI make reference to some failures in cable projects, notably an incident in a tunnel in China in 2006 containing 220kV cables. The causes of this serious event are not completely explained and it seems quite unlikely that the fire produced by the XLPE cables could have caused the amount of damage described. On Page 39 of the report, they say they are also aware of cable failures of 400kV XLPE systems in the UK, United Arab Emirates and Germany, but provide no further detail. On Page 10, they confirm that there have been no faults or incidents in 400kV XLPE cables laid in tunnels in the UK.

The common reference for the service experience of EHV cables is the Cigre Technical brochure 379 “*Update of Service Experience of HV Underground Cable Systems*”<sup>8</sup>. This paper, which is not mentioned in the CCI report, reviews the faults on land cables over the

<sup>7</sup> Beaulieu Denny Public Inquiry Report of the Technical Assessor 11 February 2009

<sup>8</sup> CIGRE 379 Update of Service Experience of HV Underground and Cable Systems, April 2009



period 2000 – 2005 for systems according to voltage classes (60 to 219kV and 220 to 500kV).

In this report, a failure is defined as “*Any occurrence on a cable system which requires the circuit to be de-energized*”, i.e. a failure is counted irrespective of the reason or length of outage time. This has to be taken into account when comparing this study with other failure statistics.

Once in operation, the cable is protected by the surrounding soil. However as confirmed by the Cigre Technical brochure, external damages (e.g. other construction works) contribute to 50% of cable system failures. As direct buried cable systems are more exposed to damage by external interventions than cable systems installed in ducts or tunnels appropriate mitigation means may be considered.

Taking into account the failure rates for EHV cables and accessories in the Cigre Technical brochure, failure rates for a defined cable system can be calculated. Assuming a partial undergrounding of 10 km, with single cable lengths of 1,000 metres, the failure rate of a single system amounts to 0.0307 failures per year or 33 years between failures. In a cable circuit consisting of two cable systems the probability of a failure of both cables is less than 0.0001 assuming a repair time of the first failure of approximately 1 month. A loss of the total circuit is therefore to be expected every 12,500 years, in other words the unavailability rate is practically negligible.

According to CIGRÈ Technical brochure 379, more than one third of the cable faults in EHV cable systems were repaired and the cable system was re-energized again within one week and more than 75% within one month (failures during commissioning and outage times less than 1 day and longer than 6 months were not considered in the survey). This includes fault location, repair and testing.

“*The 13% of AC-extruded cables which took more than 3 months for repair is probably due to a very low priority given to this repair*” (CIGRÈ Technical brochure 379) Operational constraints may have contributed to such a delay between repair and re-commissioning.

Down times are affected by various factors, including:

- Safe access to site;
- Clarification time for TSOs and, if required, independent experts to undertake a thorough investigation to assess the reasons behind a failure;
- Decisions on counter measures to prevent future failures;
- Availability/ordering / delivering of spare parts.

## 5. Conclusion

This document provides information on the feasibility and technical aspects of partial undergrounding of EHV transmission lines (AC 220kV - 400KV) based on the experience of European cable systems manufacturers and European Transmission System Operators and reviews comments made in the CCI report.



The document focuses on the use of 400kV XLPE cables, a technology that performs well based on established international standard IEC 62067. It is generally recognized as 'state-of-the-art' although each transmission project is unique due to its specific features.

Underground cables are more expensive than an OHL but in several countries in Europe, projects of a similar voltage and capacity to Beaulieu Denny are being planned by TSO as a response to requirements that do not allow 50 metre plus high pylons to be placed within minimum distances from properties, due principally to concerns over electro-magnetic fields and the impact on visual amenity.

Concerns are often raised over the impact of a potential outage on a transmission link containing a cable section. All transmission lines face the risk of outage but a cable failure is likely to take longer to repair than a failure on an OHL. Based on a recent industry study by the respected CIGRE, the failure rate for a single cable system amounts to 0.0307 failures per year. This equates to 33 years between failures, which is a highly acceptable level of availability.

In summary, the technology is robust, the service experience is increasing but it will cost a lot more than an equivalent section of OHL. The Beaulieu Denny Public Inquiry heard that undergrounding up to 10km of the line would not affect the overall economics of the 220km line. Higher costs would need regulatory approval but transmission costs represent only a small portion (i.e. around 3 percent according to Ofgem<sup>9</sup>) of the average electricity bill and can be spread over the 28 million electricity consumers throughout Great Britain over the life of the asset.

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<sup>9</sup> Transmission Price Control Review: Final Proposal December 2006

## 6. Annex

220kV XLPE cables have been installed in Europe since the mid 1990s. Locations include Cote d'Azur, Paris, Lisbon, Barcelona, Dublin, Madrid and Valencia. An overview of the main EHV XLPE Installations in Europe at 400kV is shown below:

Location	Project	Type of project	Cable circuits x length km	Cables per phase	Power MVA	Time period	Method of laying and cooling
Copenhagen	Elimination of OHL in urban area	City feeder	1x22,1x12	1	995	1996 1999	Direct buried
Berlin	Connect West/East system	City feeder	2x6;2x6	1	2x1100	1998 2000	Ventilated Tunnel
Madrid	Barajas Airport Expansion	Airport runway crossing	2x13	1	2x1720 winter 2x1390 summer	2002/3	Ventilated Tunnel
Jutland	AONB, waterway & semi urban areas	Partial undergrounding	2x14 in 3 sections	1	2x500 nominal 2x800 temporary overload	2002/3	Direct buried & ducts
London	St. Johns Wood/Elstree	City feeder	1x20	1	1600	2002/5	Ventilated Tunnel
Rotterdam	Rhine waterway crossings	Waterway crossings	2x2.1	1	1470	2004/5	Direct buried & pipes
Vienna	Provide power to centre of city	City feeder	2x5.5	1	2x620 2x1040	2004/5	Buried in concrete block & tunnel section
Milan	Section of Turbigio-Rho line	City feeder	2x8.5	2	2 x1100	2005/6	Direct buried & ducts
London	West Ham – Hackney	City feeder	2x6.3	1	1660 summer 1950 winter	2007/8	Ventilated tunnel
Switzerland/Italy	Mendrisio – Cagno	Interconnection	1x8	1	560	2007/8	Direct buried
Liverpool	Kirkby-Lister Drive	City feeder	1x10	1	1500	2007/10	Direct buried & ducts

