COMMISSION OF THE EUROPEAN COMMUNITIES

Brussels, 10 December 2003

# BACKGROUND PAPER

## UNDERGROUNDING OF ELECTRICITY LINES IN EUROPE

# UNDERGROUNDING OF ELECTRICITY LINES IN EUROPE

*Table of contents*

# 1. Introduction

The issue of undergrounding of overhead lines is not new, as underground cables have been used since many decades for low and medium voltage lines in urban areas. As more environmental considerations started to be taken into account in the construction of electricity networks since the 1970's, underground cables started to be used in high voltage and extra high voltage lines, but in limited cases owing to their high cost.

Some countries such as The Netherlands have reached in the early 1970's the conclusion that a network based on underground cable systems was the answer to many problems of electricity networks of environmental nature, such as reliability, space occupancy, reusability of rights of way for other purposes. Since this period, various developments in the manufacturing of cables and their accessories coupled with more efficient installation methods, have led to significantly reduced construction costs for underground cables.

However, underground cables remain still more expensive than the equivalent overhead lines having the same transmission capacity. This fact is less pronounced in lower voltages while in higher voltages the cost of cables is still manifold higher than the equivalent overhead lines.

When lifetime costs are taken into account as well as other advantages of underground cables, these latter can be considered as a feasible solution for a number of cases, e.g. in urban areas, in areas with high aesthetic value, in cases requiring increased security of supply in critical sections of electricity networks (as underground cables are not affected by adverse weather conditions such as wind, snow, ice, etc).

For example, the storms of December 1999 in France destroyed significant parts of the French electricity system causing a lot of blackouts. As a result, the French authorities decided to follow a new policy of undergrounding significant parts of their electricity system in order to secure supply availability under adverse weather conditions.

A first search on this issue showed that only few other European countries have followed concrete policies in undergrounding overhead lines. On the other hand the running by the Commission of the Transeuropean networks (TEN) Programme in energy since 1995, showed that many critical missing electricity links between Member States on the extra high voltage (400 KV mainly and 225 KV) could not be realised owing to strong local objections for environmental reasons. This situation has led the Commission to issue a Communication on "European Energy Infrastructure"[1]( Ref.[1]) in December 2001, stressing in particular the need to complete these missing links and in particular the cross-border links, in order that the internal electricity market to operate without barriers. It is generally expected that the use of underground cables in environmentally critical sections of the missing cross-border links could alleviate or minimise local oppositions to the construction of overhead lines, as underground cables are not visible and their effect on the environment is usually les than overhead lines.

Therefore, taking into account all these facts the Commission decided to review the situation of undergrounding of overhead lines in Europe and investigate the possibilities for proposing a co-ordinated concerted new action in this field. Such an action could be undertaken in the

---

1 COM(2001) 775 final

framework of the Transeuropean Networks of Energy, with the aim to speed up the construction of missing electricity interconnectors and to increase security of supply of electricity in Europe.

It is of great interest to review the current situation of electricity networks (overhead lines and cables) in Europe according to the categories of networks in respect to their voltage: low voltages (200V to 400V), medium voltages (10kV to 50kV) characterised generally as distribution networks, high voltages (60KV to 150KV) that are attributed in some countries as distribution and in others as transmission networks, and finally extra high voltages (220KV to 400KV) which constitute the main transmission networks of Europe. This review will be based on the most comprehensive available source of information the Report [13] "L'enfouissement des lignes électriques à haute et très haute tension"[2], as well as on information contained in study Ref. [16][3] as updated after contacts with Europacable[4] and various European transmission system operators (TSO's)

**(a) Low voltage networks (200 - 400V) and medium voltage networks (10 - 50 kV)**

The following Tables 1 and 2 are based on information provided by Ref.[13] and updated with data provided by Ref.[16] and present the length of "low voltage networks" and "medium voltage networks" in a number of EU countries and Norway, as well as the percentage of underground cables in these networks. It can be seen that most of the countries have achieved to underground more than two thirds of their low and medium voltage networks, while the rest countries have achieved quite important percentages of undergrounding. Furthermore, the rates of annual increase of undergrounding cables show that a serious effort continues by the countries (for which data is available) to underground their low and medium voltage networks.

**Table 1: Situation of European networks of low voltage** (Source Sycabel[5 6])

| | Km of network | Length of network (m/habitant) | Percentage underground | Rate of undergrounding/year in the period 1999/2000 | |
|---|---|---|---|---|---|
| | | | | Km/year | % |
| Netherlands | 145.000 | 8,9 | 100 % | | |
| UK | 377.000 | 6,4 | 81 % | 9.000 | 1,4 |
| Germany | 926.000 | 11,3 | 75 % | 40.000 | 4,3 |
| Denmark | 92.000 | 17,6 | 65 % | | |
| Belgium | 108.000 | 10,6 | 44 % | | |
| Norway | 185.000 | 41,3 | 38 % | | |
| Italy | 709.000 | 12,1 | 30 % | 11.000 | 1,6 |
| France | 632.000 | 10,5 | 27 % | 20.000 | 3,1 |
| Portugal | 112.000 | 11,9 | 19 % | | |
| Spain | 241.000 | 6,0 | 17 % | | |
| Austria | 65.000 | 8,0 | 15 % | | |

2 "L'enfouissement des lignes électriques à haute et très haute tension", French Senate Report No. 154, 2001

3 "Overview of the potential for Undergrounding the Electricity Networks in Europe" Report by ICF Consultants to the European Commission, February 2003

4 Europacable: The Association of European cable manufacturers

5 Sycabel: The association of French cable manufacturers

6 data of 1998-1999 from Sycabel as updated according to data provided by Ref. [16]

**Table 2: Situation of European networks of medium voltage**

| | Km of network | Length of network (m/habitant) | Percentage underground | Rate of undergrounding/year in 1999/2000 | |
|---|---|---|---|---|---|
| | | | | Km/year | % |
| Netherlands | 101 900 | 8,9 | 100 % | 2 000 | 2,0 |
| Belgium | 65 000 | 6,4 | 85 % | 2 000 | 3,0 |
| UK | 372 000 | 6,3 | 81 % | 5 200 | 1,4 |
| Germany | 475 000 | 5,8 | 60 % | 12 000 | 2,5 |
| Denmark | 55 000 | 10,5 | 59 % | | |
| Sweden | 98 700 | 12,3 | 53 % | | |
| Italy | 331 000 | 5,7 | 35 % | 5 100 | 1,5 |
| France | 574 000 | 9,5 | 32 % | 8 000 | 1,4 |
| Norway | 92 000 | 20,5 | 31 % | | |
| Spain | 96.448 | 2,4 | 30 % | | |
| Portugal | 58 000 | 6,1 | 16 % | 950 | 1,6 |
| Austria | 57 000 | 7,0 | 15 % | | |

Source Sycabel (see footnotes 5 and 6)

### (b) High and Extra High voltage networks

The following Table 3 is taken form Ref. [13] and presents the situation of high and extra high electricity transmission networks in 8 EU countries, as well as in Norway and Switzerland, in a rather aggregate form in respect to voltages of networks.

**Table 3: Situation of High and Extra High voltage networks**

| | High Voltage | | | Extra High Voltage | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 60-90-110-150 kV | | | 220-275 kV | | | 380-400 kV | | |
| | Km of network | Km of underground | % | Km of network | Km of underground | % | Km of network | Km of underground | % |
| Netherlands | 6 457 | 905 | 14,0 | 648 | 6 | 0,9 | 1 979 | 0,4 | 0,02 |
| UK | 25 825 | 3 789 | 14,8 | 3 029 | 71 | 2,3 | 788 | 11 | 1,4 |
| Germany | 76 349 | 4 740 | 8,2 | 21 545 | 35 | 0,2 | 18 314 | 62 | 0,3 |
| Denmark | 8 005 | 1 673 | 20,9 | 5 578 | 375 | 6,5 | | | |
| Belgium | 5 172 | 396 | 7,6 | 267 | - | 0 | 883 | - | 0 |
| Norway | 19 825 | 624 | 3,2 | 6 049 | 64 | 1,1 | 2 316 | 36 | 1,8 |
| Italy | 36 677 | 449 | 1,2 | 13 641 | 387 | 2,8 | 9 751 | 9 | 0,1 |
| France | 50 513 | 1 984 | 3,9 | 27 890 | 813 | 2,9 | 20 794 | 2,5 | 0,01 |
| Portugal | 9 311 | 258 | 3,8 | 4 409 | - | 0 | 1 234 | - | - |
| Switzerland | 6 080 | 680 | 11,2 | 5 822 | 22 | 0,4 | 1 800 | - | 0 |

Source Sycabel (see footnote 5)

A similar but more complete Table 4 is synthesised from information collected from TSO's in the framework of the studies under Ref. [16] and [17][7]. Although there are some differences between the information provided by these tables 3 and 4, they present the same tendencies for the HV and EHV networks in Europe. The following conclusions can be drawn:

- In high voltage (HV) networks the percentages of underground cables are medium to low. Four countries (NL, UK, DK, CH) have achieved percentages between 10% and 20%,while the rest of the countries have lower percentages. These HV underground sections are usually those in urban and semi-urban areas, as well as in environmentally sensitive areas. The relatively high cost of underground cables in respect to overhead lines of HV (see Annex I, section I.3) should be considered as the main reason for such medium to low percentages of undergrounding achieved in the various European countries.

- In extra high voltage (EHV) networks the percentages of underground cables are very low, with average values around 0,5% for 380-400 kV lines and around 2,0% for 220-300 kV lines Usually, the underground sections refer to special projects in urban areas or environmentally sensitive areas, where the construction of overhead lines is rather impossible. The considerably high cost of underground cables in respect to overhead lines of EHV (see Annex I, section I.3) should be considered as the main reason for such low percentages of undergrounding achieved in the various European countries.

[7] "Unit costs of constructing new transmission assets at 380 kV within the EU, Norway and Switzerland", Report by ICF Consultants to the European Commission, September 2002

**Table 4: Length of high and extra-high voltage overhead lines and cables in Europe (source Ref. [16],[17]**

| Voltage kV | 380-400 kV | | | 220-300 kV | | | 110-150 kV | | land cable as percent of total network % | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Amounts in km | land cables | sea cables | lines | Land cables | Sea cables | Lines | land cables | lines | 380-400 kV | 220- 300 kV | 110-150 kV |
| Austria | **56** | **-** | **2,418** | **5** | **-** | **3,760** | **-** | **6,000** | **2.3** | **0.1** | **-** |
| Belgium | **-** | **-** | **883** | **-** | **-** | **267** | **225** | **3,717** | **-** | **-** | **5.7** |
| Denmark | **134** | **16** | **1,346** | **-** | **152** | **260** | **5** | **3,954** | **9.0** | **-** | **0.02** |
| Finland | **34** | **99** | **3,793** | **-** | | **2,400** | **-** | **15,200** | **0.9** | **-** | **-** |
| France | **11** | **-** | **20,869** | **828** | **-** | **25,496** | **n.a.-** | **n.a.** | **0.1** | **3.1** | **-** |
| Germany | **62** | **423** | **18,869** | **35** | **-** | **19,000** | **n.a.-** | **n.a.-** | **0.3** | **0.2** | **-** |
| Greece | **-** | **-** | **2,153** | **-** | **-** | **-** | **170** | **7,745** | **-** | **-** | **2.2** |
| Ireland | **-** | **-** | **438** | **75** | **-** | **1,676** | **83** | **3,611** | **-** | **4.5** | **2.6** |
| Italy | **53** | **316** | **9,761** | **165** | **-** | **12,557** | **222** | **31,158** | **1.7** | **1.3** | **0.7** |
| Luxembourg | **-** | **-** | **-** | **6** | **-** | **230** | **n.a.-** | **n.a.-** | **-** | **2.5** | **-** |
| Netherlands | **-** | **-** | **2,003** | **6** | **-** | **677** | **220** | **6,011** | **-** | **0.9** | **3.7** |
| Norway | **36** | **-** | **2,144** | **-** | **64** | **5,257** | **-** | **10,470** | **1.2** | **-** | **-** |
| Portugal | **-** | **-** | **1,235** | **11** | **-** | **2,588** | **-** | **2,400** | **-** | **0.5** | **-** |
| Spain | **-** | **15** | **15,892** | **92** | **-** | **16,351** | **-** | **20,706** | **-** | **0.6** | **-** |
| Sweden | **4** | **319** | **10,706** | **-** | **87** | **4,435** | **7** | **15,000** | **0.4** | **-** | **0.05** |
| Switzerland | **-** | **-** | **1,597** | **22** | **-** | **5,116** | **n.a.-** | **n.a.** | **-** | **0.4** | **-** |
| UK | **132** | **327** | **10,052** | **905** | **150** | **13,434** | **n.a.-** | **N,a,-** | **1.3** | **5.6** | **-** |
| **Total** | **522** | **1,515** | **104,772** | **2,150** | **453** | **113,504** | **849** | **125,972** | **0.5** | **1.9** | **0.67** |

## 2. Analysis by Country - Current situation of underground cables and relative policies

### Austria

Austria has only added 8 km of 380kV underground cable since 1990, principally in urban areas and linking power plants to sub-stations. However, plans by Austrian Power Grid to complete the 380kV ring in Austria, particularly in the area between the south of Burgenland and the east of Styria, have been stalled with around 30 local communities refusing to allow right-of-way for the line. The communities are arguing for an underground cable, which, APG contends is eight times costlier than an overhead line. Permit proceedings to complete the 380kV ring in the Salzburg area with the construction of a 150 km overhead line are progressing more smoothly.

Consideration is also being given to the construction of an additional interconnector with Italy running through the Brenner Pass by utilising the future 53 km tunnel of the high speed train between Austria and Italy. The proposed technology for the link is GIL although no decisions have yet been made on whether to proceed.

### Belgium

The Belgian transmission network operated by Elia has six different voltages between 30kV and 380kV..

| | | |
|---|---|---|
| Voltage 380 kV | 883 km lines | 0 km cables |
| Voltage 220 kV | 267 km lines | 0 km cables |
| Voltage 150 kV | 2005 km lines | 225 km cables |
| Voltage 70 kV | 2455 km lines | 208 km cables |
| Voltage 36 kV | 0 km lines | 1879 km cables |
| Voltage 30 kV | 3 km lines | 207 km cables |

Almost all the network at 36kV and below is underground. Some 8 percent of the 70kV network and 11 percent of the 150kV network is also underground. EHV networks are all overhead lines

There has been minimal new investment in new overhead lines in Belgium over recent years due to a government policy restricting the construction of new lines. In 1992 Electrabel made a declaration of principle about the development of new electricity networks. Since then, there has been a ban on the construction of overhead lines in conurbations and new overhead lines outside the conurbations may only be installed along existing or planned general infrastructure projects (i.e. railways, highways, waterways and airports). It was also agreed not to increase the total number of kilometres of overhead lines at voltages of 30 – 220kV. Following Elia's appointment as TSO for Belgium, they plan to discuss with the regulator whether this policy should be maintained, or amended, given the impact these measures have on the cost of transmission activities.

At the moment all new constructions are made necessarily with underground cables. Thus, major investments over the past few years have been the construction of a 14 km 150 kV underground cable between Braine-L'Alleud and Baisy-Thy and a 24 km 150kV underground cable between Avernas-Brustem-Landen. Furthermore, a 30 km 150 kV underground cable section with double circuit is under construction between Avernas and Bois l'Image, while a further 21 km 150 kV underground cable section with double circuit is planned to start its construction in early 2003. Taking into account that the total lengt of cable required for these "sections around Avernas will be more than 370 km, it looks to be one of the most important underground cable project currently under construction in Europe. The basic aim of this project is to supply the Brussels-Liege-Köln High-Speed-Train under construction.

Other 150kV cable projects are planned (e.g. to connect offshore wind farms) but the award of the appropriate permits has often been delayed.

**Denmark**

Denmark has two separate high voltage grid networks. The network in Western Denmark is operated and managed by Eltra, and in Eastern Denmark, Elkraft Transmission own the 400kV grid and Elkraft System operate as TSO.

The Eltra network is connected by DC sea cables to Norway and Sweden at voltages of 250kV. The Elkraft network is connected to Sweden via AC cables at voltages of 400kV (two cables established in 1973 and 1985), 132kV (established between 1951 – 1964) and 60kV. The total capacity is around 1,900 MW. The Eastern Denmark grid is also connected to Germany by a 166 km 400kV DC cable with a capacity of 600 MW. This was completed in 1995.

A decision has also been made to connect the two systems. The capacity will be 300 MW and a 70 km 400kV underground cable (Green Belt) will be laid. It is expected to be operational by 2004.

Within Europe, Denmark has been at the forefront of the replacement of transmission lines with cables following a decision in the early 1990s to restructure the power supply to the greater Copenhagen area. This included replacing six 132kV overhead lines linking the metropolitan area with the rest of Zealand with two new 400kV cable links and substations in the northern and southern parts of the city. More than 100 km of 400kV XLPE insulated cable were needed to form the two independent power links that went into operation in 1997 and 1999 respectively.

**Finland**

The transmission network in Finland consists of 3,793 km of 400kV overhead lines and 2,500 km of 220kV lines. There is also 34 km of underground land DC cables and 99 km of submarine cable representing the Fenno-Skan link with Sweden. Cables are used minimally, because they are considered by Fingrid to be unreasonably expensive at long transmission distances typical of Finland, and because they restrict land-use in the area where the cable has been buried. In the most densely populated areas, such as Helsinki, there are some 110kV cables.

Further increases in capacity between Finland and Sweden are under consideration. The options are increasing the capacity of the Fenno-Skan DC cable by 10 to 20 percent and the construction of a third 400kV AC line in the North. The feasibility study for this line is due to be completed at the end of 2003.

**France**

RTE (Gestionnaire du Réseau de Transport d'Electricité) operates two sub-systems: a 400kV main transmission and interconnection network which is used for energy exchanges between the French regions and other countries, and a regional sub-transmission network with three voltage levels: 225kV, 90kV and 63kV. Approximately 3 percent of the 63/90kV and 225kV network is buried, principally in urban centres.

In 1992 the Protocol between the State and EDF provided that EDF will co-ordinate with the developers of linear networks (SNCF and motorways) in order to examine the coexistence of electricity lines with transport projects. Under such a co-operation between EDF and SNCF a number of projects were examined as a new electricity line 400 kV between France and Italy utilising the new high-speed railway line Lyon-Turin.

In 1997, an Accord was agreed whereby EDF would bury 20 percent of all new high voltage lines. RTE state that this was achieved in 1998 when one quarter of all new HV lines (i.e. 63kV – 150kV) were laid underground. In the 1999 a new Accord had been agreed, which runs for three years, while the target for undergrounding was raised to 25 percent. It was also agreed that there would be no increase in the total length of the overhead line network. Priority is given to investments in urban areas, where the voltages are lower and although France is one of the most advanced countries when it comes to burying lines between 150kV and 230kV, while there has been almost no undergrounding of 380kV lines in recent years.

The storms of December 1999 in France destroyed significant parts of the french electricity system causing a lot of blackouts. As a result, the French authorities decided to follow a new policy of undergrounding significant parts of their electricity system in order to secure supply availability under adverse weather conditions.

This new policy was presented in the reference [2] "Accord Réseaux électriques et environnement 2001-2003" between 2 French Ministries, EDF and RTE, and it can be summarised briefly as follows:

(a) <u>Distribution networks</u>: should be made underground or protected

– 90% of all new medium voltage networks (or 6000 km per year)

– 2/3 of all new low voltage networks (or 8000 km per year)

(b) <u>Transmission networks</u>: 25% of all new lines of high voltage should be constructed underground (cases of 63, 90 and 225 kV lines), while in the case of 400 KV lines undergrounding should only happen in exceptional cases.

Major proposed projects require approval from the National Commission of Public Debate (an independent body) plus the acceptance from local authorities. The authorisation process usually takes at least five years.

France has been using XLPE technology at lower voltages since the 1970s and has a built a small (300 metres) GIL linking a nuclear power plant to a substation. Concerns over the use of GIL relate mainly to the use of SF6, which is a contributory factor to greenhouse gas.

**Germany**

The structure of the German electricity industry is complex with over 900 electricity companies, many of them small municipal utilities. The high voltage grid, though, is now owned by four large integrated companies – E.ON Netz, RWE Net, EnBW Transportnetze, which are subsidiaries of the three largest German electricity companies and Vattenfall Europe AG, which controls HEW, BEWAG and VEAG. There is approximately 35 km of buried 220kV and 62 km of 380/400kV underground cables principally in densely populated centres such as Berlin.

Authorisation for new transmission projects is set out in the Environmental Planning Act 1990. This stipulates the planning procedures to be adopted for construction of overhead cables of 110kV and above. The procedures set out in this legislation include the preparation of the planning document and the involvement of affected municipalities. An Environmental Impact Assessment (EIA) is also required. Planning permission is not as strict as in some other EU Member States and overhead pylons are generally exempt from the federal building planning permission procedures and regulations. A planning application to construct a tower simply has to be submitted approximately 14 days before construction commences. Many lines and cables are situated close to railway lines and motorways, since the land is owned by the federal or regional authorities and has a low ground cost/rent.

### Greece

Greece's transmission network consists of around 11,000 km of power lines and has until recently operated in isolation from the western European grid systems. The interconnected mainland transmission system consists of 400kV, 150kV and 66kV lines and is linked to neighbouring Albania, Bulgaria and the former Yugoslavia through lines of 400kV and 150kV. There is a new DC 400kV overhead line and submarine cable (Galatina-Arachthos) that links Greece with Italy. There are 170 km of underground cables of 150 kV and 110 km of submarine cables. In the 66 kV there exist 15 km of submarine cables.

### Ireland

The national grid in Ireland comprises over 5,800 km of high and medium voltage lines and cables. There is approximately 75 km of underground cables principally at 220kV in urban areas of Dublin.

### Italy

The Italian network consists of 9,761 km of 380kV lines, 12,557 km of 220kV lines and 20,332 km of 150/132kV lines. There is a 380kV AC cable linking Sicily with the Italian mainland (and there are plans to double the capacity) and 44km of DC land cable that forms part of the sea cable link with Greece.

The link between Otranto (It) and Aetos (Gr) required the laying of 163 km of submarine cable, which for a large section of its length lies at a depth of around 1,000 metres (a record for sea cables). At the Italian end, the 44 km of underground cable is an oil-filled single DC conductor that connects to a conventional substation at Galatina via a DC-AC conversion station. The project is designed to accommodate a doubling of transmission capacity in future years.

There also DC 200kV sub-sea cables linking Corsica with Sardinia and Italy with Corsica. There are plans to build a direct link between Italy and Sardinia and a feasibility study is being carried out. At 220kV there are underground cables in urban centres including Rome, Naples and Turin. The only land cable project under discussion at present is part of a new 27 km 380kV line linking Turbigo with Rho in the Milan area. A feasibility study has been carried out by TERNA, but the project has not yet been authorised.

Cabling may be considered in order to complete the 207 km 380kV line between Santa Sofia and Matera. The project commenced in 1992 and 200 km (97 percent) has been constructed but problems are remaining with the final 7 km. Authorisation has been suspended by the regional authority due to planned changes in the line and an EIA has yet to be approved. Once completed, the line will link up with the Italy – Greece interconnector.

Other planned investments include a 40 km 380kV line linking Redipuglia and Udine. This would link up with the planned Cordignano – Lienz interconnection with Austria. There are also plans to build a 215 km 380kV line between Rizziconi and Laino in southern Italy to reinforce the network between Sicily and Calabria. Work is due to start in April 2003 and the line should be operational by April 2006.

There are also plans to study a new interconnection between Italy and Slovenia.

**Luxembourg**

There are no 380kV lines at present in Luxembourg. The 220kV network measures around 236 km of which 6 km is underground cable.

**Netherlands**

The 380kV circuit length in the Netherlands is approximately 2,000 km and is all overhead line apart from a few cables close to power stations and industrial sites. There is over 220 km of underground cable at 150kV (mainly owned by TZH). There has been only minimal investment in extending the network over recent years, due in part to the difficulties in getting planning approval for new transmission lines. Some new lines are under plans and cabling will be considered, if there is significant environmental opposition, but Tennet prefers overhead lines, as they are cheaper and more reliable.

Tennet and National Grid of the UK have established a joint venture (BritNed) to assess the feasibility of the construction of a 1,320 MW sub-sea DC cable link between the Netherlands and the UK.

**Norway**

Over the past ten years, Statnett has not invested significantly in new power lines or cables with the exception of a subsea cable between Norway and Denmark (Skagerrak). Planned investments within Norway include the laying of a 130 km 300kV line between Klaebu and Sunndalsøra. Statnett is also planning to develop new subsea cable links with the Netherlands (NorNed) and the UK (North Sea Interconnector), although Statnett (with Statkraft and E.ON) terminated their discussions to construct the planned Viking Cable between Norway and Germany.

The long-term strategy aimed at expanding the transmission network in Norway includes construction of new lines at 420kV, reconstruction of existing 300kV lines to 420kV including reinforcement of towers. No underground land cable projects are included in the plan.

**Portugal**

The use of cables as an alternative has not been a major consideration in Portugal, although Rede Eléctrica Nacional (REN) is required to carry out an EIA for ministerial approval on all new power line investments. Only 11 km of the 220kV network is cable. The main transmission priorities in Portugal in recent years have been to improve the interconnections with Spain. The increase in capacity of the Balboa - Alqueva line is expected to be completed in 2004 and a new 86 km line with 1,350 MVA (Douro International) linking Recarei and Aldeadavila is expected to be completed by 2006.

**Spain**

The Spanish grid network has expanded rapidly in recent years and Red Electrica de Espana (REE) currently has some 1,800 km of 400kV lines under construction. As with Portugal, the use of cables as an alternative has not been a major consideration, although as elsewhere in the EU, all new HV power lines with a length in excess of 15 km are required to have an EIA.

Construction of new overhead lines has met strong opposition in Spain, but according to REE, the local community in Tarifa also opposed the underground cable link with Morocco.

Spain has been funding research into superconductivity and is looking closely into the developments in GIL, which was considered for the 400kV underground project at Madrid airport.

**Sweden**

The Swedish network consists of some 10,643 km of 400kV and 4,295 km of 220kV lines principally running north to south. There is only 4km of 400kV cable and 7 km of 130kV cable. There are HVDC cable links with Denmark, Germany and Poland.

As with the other Nordic countries, overhead lines are preferred to cables at 400kV. The country is sparsely populated and the average length of lines is much longer than in most of Continental Europe.

A study is underway concerning increases in transmission capacity between Norway and Sweden, in part due to planned increases in capacity between Sweden and Finland. These plans will focus on new lines rather than cables, with the exception of a possible sub-sea HVDC cable between Norway and southern Sweden.

**Switzerland**

The high voltage grid consists of some 1,600 km of 400kV lines and approximately 5,000 km of 220kV lines and is managed by seven integrated companies: Atel Netz, BKW-FMB and EOS form the ‘western group’ and CKW, EGL Grid, EWZ and NOK form the ‘eastern group’. In 1999 the companies established ETRANS, whose principal role is to coordinate the power transmission between the grids. There is a significant amount of uncertainty regarding the future electricity market in Switzerland, including the future organisation of the Swiss electricity grid.

**United Kingdom**

There are four transmission systems in the UK, each separately owned and operated. The largest system is owned and operated by National Grid in England & Wales. Scottish Power owns and operates the system in the south of Scotland and Scottish and Southern Energy own and operate the system in the north of Scotland. The fourth is the transmission system operated by Northern Ireland Electricity.

National Grid's transmission system operates at 400kV and 275kV and has an electrical circuit length of approximately 10,400 km of 400kV lines, 3,615 km of 275kV line, 132 km of 400kV underground cable and 425 km of 275kV cable in England & Wales. Most of the 275kV network was constructed in the 1950s and 1960s with the 400kV network being constructed in the 1970s. There is an interconnector with Scotland that has a capacity of 1,600 MW and also operates at 400kV. The link is currently being strengthened by the construction of a 75 km line (5.7 km underground) in North Yorkshire. Once completed the interconnector will be upgraded to 2,200 MW.

National Grid's network is connected to France via a 270kV DC cable with a capacity of 2,000 MW. A 500 MW sub-sea interconnector has recently been completed to link Northern Ireland with Scotland. The transmission systems in Scotland and Northern Ireland operate principally at voltages of 275kV and 132kV.

In England & Wales, approval for the construction of all but the most minor overhead line proposals rests with the Secretary of State for the Department of Trade and Industry. As undergrounding is considered to be a "permitted activity" for the utilities, consent is not needed for installation of underground cables. As part of any approval process, the construction of an overhead line of 220kV or more and over 15 km in length requires an Environmental Impact Assessment. The government can also request an EIA for construction of any overhead line in a sensitive area, or any line with a voltage above 132kV. In practice, these EIA's are rarely required.

Applications for overhead line projects are notified to the relevant local planning authorities. If they object to the planned line, the Secretary of State is required to call for a public enquiry. A recent case was the 75 km line between 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 wayleaves 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 and the cable £8.9 million/km, a cost factor multiple of 16 times) and environmental concerns over a 15-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 5.7 km cable section.

More recently, the UK government announced that it was examining a scheme to link wave and wind farms to the national grid by running a sub-sea cable down the west coast of Scotland and England.

## 3. Benefits from a policy of undergrounding of electricity networks in Europe

Firstly, is examined the case of undergrounding of critical sections of crossborder electricity interconnectors, for which there are strong local opposition leading to postponement or suspension of the project. By undergrounding these sensitive sections near to urban areas or near to rural areas of great aesthetic or historical value, the construction of the missing crossborder link could have better chances to be acceptable to local authorities and inhabitants; thus, it may be constructed, of course at an extra cost due to the underground sections. However, there will be extra benefits for the countries interconnected, as the trade of electricity may increase owing to the new link, and prices of electricity may reduce for customers,. Furthermore the need to keep reserve capacities in the interconnected countries may reduce leading to even lower prices of electricity.

In the next section 3.2 the results of a cost benefit analysis comparing extra costs of underground sections as well as the resulting benefits for a number of important missing crossborder links are presented ; the results are generally positive in the cases of use of underground cables over a reasonable length of the missing link. Of course more detailed studies for each link should be carried out, taking into account the specific and local characteristics of the link, before making decisions for construction of a missing link.

In the case of adoption of a general policy of undergrounding parts of electricity networks in Europe for reasons of increasing security of electricity supply, benefits may accrue to different sections of society. In the following Table 5 .an attempt is made to identify the various categories of benefits, as well the likely beneficiaries: utilities, their customers, local residents and the wider community.

**Table 5: Benefits from undergrounding of electricity lines**

| | Beneficiaries | | | |
|---|---|---|---|---|
| Benefit type | Utilities | Customers | Local residents | Wider community |
| Reduced electricity price (from construction of missing electricity links) | √ | √ | | √ |
| Reduced transmission losses | √ | | | √ |
| Lower maintenance costs | √ | | | |
| Improved electricity service | | √ | | |
| Reduced storm damage | √ | √ | | √ |
| Reduced accidents (inc. wildlife electrocutions) | | | √ | √ |
| Improved views/property values | | | √ | |
| Health & Environment (e.g. noise, EMFs, vegetation management) | | | √ | √ |

Source Study Ref. [16]

As pointed out in earlier sections underground cables generally experience lower losses than the equivalent overhead lines. Of course, most losses occur within the lower voltage distribution network, as in UK (England and Wales) it is quantified for example that approximately 2% of the electricity is lost in transmission networks while 7% is lost in distribution networks.

Anyhow, the reduced losses in underground cables, when considered over the whole lifetime of a project, render the ratio of overall costs between underground cables and overhead lines less unfavourable for underground cables (see section 2.3).

Operating and maintenance costs for cables should be less than for lines, however the repair of individual faults to underground cables can be much longer. According to data submitted as part of the proposed Basslink project in Australia, approximate costs of maintenance on National Grid's UK AC transmission system derived from 1999 cost data are:

- Overhead line maintenance (£600/circuit-km/year)

- Underground cable maintenance (£70/circuit-km/year)

Terna in Italy reported a similar annual amount (i.e. approx. €1,000/km) for overhead line maintenance. Their experience with cables to date is that maintenance costs are minimal.

Service experience of high voltage lines in the UK has shown that pylons/towers have a service life of 60 years and refurbishment of conductors and fittings is required at approximately 30-year intervals. In general, transmission cables have an estimated service life of 40 years, but service experience in the UK is that some oil-filled cables are ageing prematurely and need to be replaced at significant cost. RTE have also suffered maintenance problems with cable systems, but principally with the joints and the equipment linking the cable with overhead line.

An additional factor is the time required to repair faults. According to figures produced by Hydro Quebec (who operate over 150 Km of underground cable at voltage of 120 kV and above) in the Report *New Technologies for the Undergrounding of Electricity Lines at High and Very High Voltages, Assemblee Nationale* de France, a minor repair for an overhead line can be repaired within one day compared to up to 5 days for an underground cable. For a major repair, the difference is greater, 7 days for an overhead line and up to 20 days for a cable.

Another major benefit of underground cables is that they are not susceptible to storm damage and to adverse weather conditions. Minor storm damage to overhead lines across Europe is a frequent event, particularly at low/medium voltages, but occasionally (as happened in France in December 1999) significant damage can occur to the EHV/HV network.

Those storms in France in December 1999 resulted in around 8 % of the EHV/HV transmission network being put out of order and although 90 % of substations were re-connected within 4 days, it took six months to complete the repairs to the lines. The total cost of damages amounted to € 1.3 billion; but there was no estimate of the economic losses of all interrupted activities. The interruption lasted about 15 million customer-days.

Accidental contact with overhead lines is also a concern. Information from France shows that there were 19 deaths due to contact with overhead lines in France in 2000 compared to no deaths for contact with underground cables.

Another important advantage of underground cables is that they are “invisible” in contrast to overhead lines with pylons and wires causing visual intrusion. Therefore, underground cables present a strong advantage if constructed in the place of overhead lines in urban areas and in environmentally sensitive areas, as those of aesthetic, cultural and historical value (see also 2.4).

A direct consequence is that property values in proximity to underground cables would be higher than in the case when overhead lines were used instead. This is one additional benefit for local residents close to the location of electricity projects.

Finally, in terms of electromagnetic effects, the cables are rather preferable by local inhabitants. Cables cause no electric field around them, while their magnetic fields present higher values on the ground level just above the trench were the cables are buried; however, their magnetic field are weaker at a distance from the trench in comparison to the equivalent overhead lines (see also 2.4).

Impact of undergrounding on the price of electricity

After the substantial damages in the transmission system of France due to storms in December 1999, an assessment was made whether to replace the EHV lines with underground cables in France. The burial of all EHV lines was estimated to cost FF 700 billion (€107 billion) without quantification of the technical difficulties in laying 400kV lines underground over long distances. The view was that the cost could not be economically justified from the general interest and utility bill viewpoint. The more targeted plan to underground new 225kV lines or those to be replaced was assessed at an extra cost of FF 20 billion(€3 billion) over a period of 15 years which is the equivalent of € 200 million per year. It is not clear whether this is the additional capital or operating cost, if one assumes operating costs, the total costs of the transmission business in France in 2001 (according to EDF's 2001 financial statements) were € 2.1 billion, so the undergrounding of 225 kV lines would add approximately 10% to the cost base. As transmission costs represent approximately 10 percent of total electricity costs, this additional cost would represent an increase of 1 percent on the cost of electricity.

From information provided in Reference [16] it is estimated that the undergrounding of a percentage of 25% of the HV and EHV networks in Italy and UK will increase the price of electricity in these countries between 3% and 5%, while the undergrounding of all HV and EHV lines in Italy will increase the price of electricity by 16%.

## 4. Possible contribution of underground cables in the realisation of the priority projects of the EC Communication on "European Energy Infrastructure"

In its Communication on "European Energy Infrastructure", the European Commission identified 7 priority projects in electricity networks of Europe.

- EL1: France-Belgium-Netherlands-Germany: electricity reinforcements needed to remove frequent congestion across the Benelux region;
- EL2: Italian border to France, Austria and Switzerland; increasing electricity interconnectors capacities;
- EL3: France-Spain-Portugal; increasing electricity interconnectors capacity;
- EL4: Greece-Balkan countries: development of electricity infrastructure to connect Greece to the UCTE system;
- EL5: UK-Continental Europe and Northern Europe: increasing electricity interconnection capacity with France and establishing interconnection capacity with other countries (e.g. Netherlands and Norway);
- EL6: Ireland and both Northern Ireland and mainland UK; increasing electricity interconnectors capacity;
- EL7: Denmark-Germany: increasing interconnection capacity.

This section will look into the possible contribution of underground cables as a means achieving the Commission's objectives, in particular the interconnections between France/Spain, France/Italy, France/Belgium and Italy/Austria, etc. Future connections between the UK and Ireland and mainland Europe will be via sea cables, while the connections between Greece and the Balkan are under construction with overhead lines.

France/Spain

Several attempts have been made to increase interconnection capacity between France and Spain since the mid-1990s. This interconnection currently consists of two 400 kV lines (a Western route – 1,270 MVA between Hernani and Cantegrit and an Eastern route – 1,650 MVA between Vic and Baixas).

In the early 90's a new link between Cazaril (FR) and Aragon (Spain) with length 187m and capacity of 2300MW was decided and the construction advanced in Spain, up to beginning 1996, when the project was stopped by the French side, owing to environmental reasons. In 1996/1997, at the request of the French and Spanish governments, EdF and REE carried out a study into the various alternatives (some 27 alternatives were considered) available to increase interconnection capacity between the two countries. This study was financed by the TEN Programme in 1996 and examined the feasibility of an underground cable (either on land or under the sea) close to the Mediterranean coast, the use of rail or road tunnels between France and Spain and the construction of overhead lines at various places (East, West and Central) over the Pyrennées. The conclusions reached were:

- The cable by the Mediterranean coast was too expensive (FF10 billion, approximately € 1,5 billion). The estimated cost was 10 times that of an overhead line through the Central Pyrennes and the cable would have only half the capacity of the line. There were also concerns that the synthetic and GIL technologies had not developed sufficiently for such long distances;

- The road or rail tunnel alternative was dismissed as being too difficult to maintain and if a tunnel were considered to be the best alternative, it would be preferable to construct a separate tunnel for the sole use of the electricity cable;

- Aerial routes to the west and east Pyrennes involved technical problems because of differences between the Spanish and French networks. Any proposed development to the west or east would only operate at 1,200 MVA;

- The initial solution of aerial line through the centre of the Pyrennes (linking Cazaril and Aragon) was considered finally superior from a technical and economic view point while other aerial alternatives through mid Pyrennes would have higher cost and face equivalent environmental problems.

At the end of this study no decision has been taken by the 2 sides on the selection of one of the alternatives for construction.

– Since then further studies have been carried out and a 400kV line parallel to the existing line Bescano (F) and Baixas (E) is planned for completion in 2006. It will have a capacity of around 1,200 MVA and will run parallel to the future Perpignan-Figueres high-speed railway line. This project is one of the conditions laid down by the Commission for the approval of the acquisition of a majority stake in Hidrocantabrico by EnBW, in which EdF has a 34.5 percent stake. The study was financed by the TEN Programme in 2000.

– A new link is planned in order to increase the capacity between France and Spain to 4,000 MW. A new feasibility study is financed in 2002 by the TEN Programme to investigate the best alternative among 4 possible routes:

– Parallel to western route (Hernani – Cantegrit)

– Parallel to eastern route (Vic – Baixas)

– Through the mid-Pyrennes (alternative to Aragon-Cazaril)

– A new route through western Pyrennes

France/Italy

Several feasibility studies have been carried out into expanding the three current interconnections between France and Italy.

a). Grande Ile-Piossasco

A study was carried out in the mid 1990s into the construction of a new 380 kV line between Grande Ile in France and Piossasco in Italy with length of 180 km. The project would have yielded additional transmission capacity of 1,400 MW. The study in the Italian part was financed by the TEN Programme in 1995. Although authorised by the French authorities the project has been suspended because of authorisation problems in Italy and reactions by environmental groups in France. It may be considered as a case, where the use of underground cables in some environmentally critical sections could have made possible the construction of this project.

b). Combination with the new high-speed train line between Lyon and Turin

Since 1992, there has been a protocol in France whereby EDF should work with other infrastructure operators (e.g. SNCF and auto route companies) to examine the conditions for the cohabitation of major projects. EDF and SNCF have looked into the possibility of using railway tracks and tunnels between Lyon and Turin to lay a 400 kV cable.

According to a project study the 53 km future tunnel of the new high-speed train Lyon - Turin would be used to lay cables of a new 400 kV line. The tunnel route would involve the laying of a 400 kV cable on the other side of the track to the railway cables (and escape routes). This would also involve widening the tunnel from a diameter of 8 metres to 8.4 metres. The estimated extra cost for the electricity line was:

- FF 750 million for widening the tunnel;
- F 250 million for equipment to maintain the temperature between 25 and 30 °C;
- Between FF 200 and 700 million to reinforce 200 tunnel junctions.

The extra cost was therefore in the order of FF 1.2 to 1.7 billion (€ 183 to 260 million) compared to an estimated cost of FF 2.6 billion (€ 400 million) to build a new tunnel solely for the electricity cables. In addition, the cost of two 1,000 MVA cables was estimated between FF 1.5 and 2.0 billion making the total cost of the link between 3.0 and 3.5 million (FF) (approximately 450 to 530 million €). We understand that this project is still under review by RTE and GRTN.

France/Belgium

At the request of the Belgian and French electricity regulators, RTE and Elia carried out a study into the options for increasing the interconnections between France and Belgium. This study recommended the stringing of a second circuit on the existing overhead line between Avelgem (B) and Avelin (F) and the completion of the 380 kV line between Aubange (B) and Moulaine (F).

a). For the Avelgem – Avelin connection, underground cables were not foreseen as an economic option as the overhead line already exists and the only work required is to equip the second circuit. Additionally, had a cable been constructed between the two nodes, there would have been a problem of overloading of the underground cable and of underloading of the overhead line. Additional expense would have to be incurred on phaseshifters to address this problem.

b). Completion of the 380 kV link between Aubange – Moulaine has been considered for some time and the necessary 2 km double circuit line in Belgium has been built. Problems in obtaining the necessary permits have prevented the construction of the line in France, principally because the proposed 12 km route was passing through an urban area. The proposals have been revised to involve either a longer aerial route (18km) or a section of underground cable. The problem with the cable solution is that it would be limited to one circuit and would create additional expense when connected to the double circuit overhead line.

France/Germany

Plans to improve transmission links between France and Germany centre around the reconstruction of a 105 km 225 kV line into a 130 km 400 kV line between Vigy and Marlenheim and a new interconnection between Vigy (FR) and Uchtelfange (DE). The study had been financed by the TEN-Energy Programme. Overhead lines were chosen for cost reasons and the routes of the new lines were redirected away from residential areas in order to gain the support of local communities. Work commenced on the project in June 2002 while the interconnection Vigy-Uchtelfangen was inaugurated recently.

Netherlands/Germany/Belgium

There are currently no plans to construct new lines between the countries, although a two phase shifting transformer has recently been installed in Meeden (NL) to increase capacity from Germany by around 1,000 MW.

Denmark/Germany

The Western Denmark grid is connected to Germany with one 400 kV, one 220 kV and a 150 kV link. In connection with imports from Germany, the limit is currently approximately 800 MW. The constraints arise principally due to internal bottlenecks in southern Jutland and in Funen in Denmark.

Owing to the expansion of wind power in Schleswig-Holstein, the internal transmission capacity in the German network reduces the scope for exports from Denmark. Unless the German increase in wind power capacity is accompanied by network expansions, the export capacity will be further reduced to around 300 MW.

The possibilities of implementing network expansion in western Denmark and northern Germany is being analysed by Eltra and E.ON Netz, but it is unlikely that underground cables will be considered as an option to improve interconnections between the two countries. The only interconnection project being studied is the upgrading the 220 kV line between Flensburg and Kasso to 380 kV (length about 106 km). The study had been financed by the TEN-Energy programme.

Italy/Austria

At present the only link between Italy and Austria is a 220 kV line. There are plans to improve interconnections through the construction of an 120 km 380 kV double circuit line between Lienz and Cordignano with a capacity of 800 MVA. The feasibility study has been carried out with financing from TEN Energy Programme, but the project has yet to be authorised by the local authorities and it is hoped that the line could be completed by late 2004. The estimated cost is € 60 million. The use of underground cables could be envisaged in case that there are difficulties for authorisations by local authorities.

New consideration has been given for an additional new interconnection between Italy and Austria, by using the 52 km tunnel of the new planned high speed railway interconnection between Italy and Austria through the Brenner.

A consortium including GRTN (IT) and TIWAG (AU) has carried out a preliminary study, while a new feasibility study was financed in 2002 by the TEN Programme in order to investigate the feasibility of using GIL cables through the railway tunnel. The advantage of this solution would be that the cable is non-flammable and would not require compensation stations in the middle of the tunnel. However, it is the first time that GIL technology will be established over such a long distance (52 km).

Italy/Switzerland

There are 8 interconnections between Italy and Switzerland (2 at 380 kV and 6 at 220 kV).

There are plans to add an additional interconnection through the construction of a 35 km 380 kV double circuit with a capacity of 1,500 MVA between San Fiorano Brescia and Robbia. GRTN is developing the project on the Italian side and Ratia Energie is developing the Swiss side. The study of the Italian section had been financed by the TEN-Energy Programme. Authorisations in Switzerland are complete, while GRTN started the authorisation process and EIA in December 2001, but some local authorities have not yet given authorisation. The cost of the Italian part of the line is estimated at € 20million. There are no plans to use cables between Italy and Switzerland, but such a solution could be considered, in case of strong objections by local communities.

Finally, there are plans to construct a 11km 220kV merchant transmission interconnection between Italy and Switzerland. 9km of the link will be underground XLPE cable. The capacity of the link will be 400MW from Italy to Switzerland and 250MW in the other directions. The estimated total cost of the project is Euro 20m and the cable is estimated to cost five times the overhead line. In Switzerland the cable will go below the highway connecting Mendisio and Gaggiolo and in Italy the cable will be buried along a disused railway line. The project developers are AET (Swiss utility) and an Italian railway company. Authorisations are being sought and completion is expected by the end of 2005

## 5. Cost benefit analysis of interconnections

An initial assessment of cost and benefits for a limited number of new interconnections between France-Italy and France-Spain has been carried out by ICF Consultants in their Report [16] to the European Commission.

As an initial assessment of the economic viability of different potential interconnectors, the cost of constructing additional capacity across a number of borders has been compared to the projected benefits. The benefits have been estimated from forward electricity price curves produced by the ICF Consulting power market model (the Integrated Power Model or IPN). The analysis has been carried out on a marginal MW basis, i.e. what benefits would one additional MW of capacity produce. Given the possible impact of additional interconnection on market prices on one or both ends of a link, a more detailed feasibility analysis would have to be carried out for any specific proposal.

The following Table 6 shows the per MW benefits (discounted present value of future revenues from electricity trade minus the present value of construction costs) of four possible interconnections (between France-Italy and France-Spain) and per MW cost estimated that have been given by the companies involved in each project.

**Table 6: Cost –Benefit analysis of electricity interconnectors**

| Interconnection | Option | Cost € million | MW | Cost €/MW | NPV of Revenues €/MW | Net benefitsNPV €/MW[8] |
|---|---|---|---|---|---|---|
| France-Italy | Existing rail tunnel | 760 | 2,000 | 380,000 | 567,238 | 187,238 |
| France-Italy | New electricity tunnel | 900 | 2,000 | 450,000 | 567,238 | 117,238 |
| France-Spain | Mediterranean Cable | 1,500 | 1,200 | 1,250,000 | 586,398 | -663,602 |
| France-Spain | Overhead line Central Pyrennées | 168 | 1,200 | 140,000 | 606,829 | 466,579 |

Source: Study Ref. [16]

The assumptions used and are as follows:

- All values are expressed in terms of a marginal MW of capacity;
- A capacity of 2,000MW was assumed for the Italy-France projects and 1,200MW for the France-Spain interconnection;
- Capacity prices and energy prices are the results from a core run of the IPM (i.e. ICF Consulting's main tool for price forecasting);
- These forward prices are based on marginal production costs estimates and do not take into account of possible strategic behaviour by generators (e.g. market power);

[8] Revenue is based on 75 percent of the capacity price plus energy revenues net of an estimate for losses (2 percent), outages (3 percent) and maintenance (1 percent for cables and 10 percent for lines)

- The capacity revenue between France and Italy (as well as between France and Spain) is the sum of the capacity price in each country, less a 25 percent reduction due to the interconnections between the two markets;

- The energy revenue is the difference between the energy prices in the two neighbouring countries, less 1 percent for maintenance (10 percent in the case of the overhead line), 2 percent for losses and 3 percent for outages;

- The NPV is the net present value of investing in 1 MW of interconnection capacity, based on a 6 percent discount rate between 2005 and 2025;

- Cost estimates are taken from the feasibility studies carried out by the transmission companies;

- Under the above assumptions, the only project not to have a positive benefit is the Mediterranean cable between France and Spain.

The analysis shows that there is a net benefit (net NPV of revenues minus construction cost) associated with the interconnections between France and Italy and with the overhead line between France and Spain through the Central Pyrennées. The cable route France-Spain, however, is not beneficial unless the overall cost can be brought down by approximately 50 percent.

## 6. Conclusions

The following conclusions can be drawn out of the preceding sections:

(1) On the basis of the analysis in section 1 and especially of Tables 1 and 2 it can be said that the cases of electricity networks of low voltage (LV) and medium voltage (MV) are adequately advanced by Member States (MS) in terms of percentage of undergrounding, while MS continue their efforts to increase these percentage in order to achieve higher degree of security of supply. Consequently, it appears that no new coordinated action concerning undergrounding will be needed in the case of LV and MV electricity networks.

(2) On the basis of the analysis of the various sections and especially of Tables 3 and 4, it can be said that in the cases of high voltage (HV) and extra voltage (EHV) networks, the percentages of underground sections are very low when considering the weather and other risks, and therefore some type of coordinated action should be undertaken at European level. The aim will be to underground at least those sections which are prone to adverse weather conditions, so that better levels of security of electricity supply can be expected at European level. It will be up to Member States to carry out special studies and analyses in order to identify the optimum level for undergrounding their HV and EHV networks, taking into account a quantification of related costs and expected benefits for the specific geographical and climatic condition of each Member State.

(3) On the basis of the analysis of the various sections and especially of sections 3 and 5 in the case of Extra High Voltage (EHV) networks there are a number of important priority crossborder interconnections which are not constructed owing to strong local oppositions for environmental reasons. The use of underground cables in these environmentally critical sections of crossborder interconnections may solve the

problems and therefore facilitate and speed-up the construction of the missing links in the near future. The extra costs for undergrounding these critical sections is expected to be outweighed by the additional benefits from the operation of an integrated electricity market in Europe without crossborder barriers, fact that will allow increased exchanges and trade of electricity and may lead to lower prices of electricity.

# Appendix I

Available Technologies for underground cables

## I.1Technical aspects

Throughout the 20th century overhead electricity lines were regarded as the general mean of transmitting electricity. However, it must not be forgotten that for low and medium voltage distribution networks as well as for transmission networks up to 150 kV; underground cable solutions were and are used more and more in urban and suburban areas. For transmission of electricity in extra-high voltage networks of 220 and 380- 400 kV), underground cables were installed only in a few specific locations of dense urban areas or in areas with highly appreciated aesthetic value.

The use of underground cables has been possible owing to cost reductions allowed by technological improvements in cable manufacturing and installation techniques, and development of maintenance free solutions. The cost of underground cables can vary dependant upon the voltage of the cable, as well as upon local factors such as land value, need for permits, presence of tunnels, operational costs, etc

Examining the extra high (220 KV and 400 KV) voltage networks, which are of interest for transmission of electricity in the framework of the Transeuropean Networks of electricity, one can distinguish between the Alternative Current (AC) underground cables, which are the most usual case and the Direct Current (DC) underground cables that are of limited use in Europe.

AC underground cables

The usual type of cables used for many decades were those of fluid filled or mass impregnated type, either pressurised or not. Recent developments in extrusion techniques, in material handling systems and cleanliness of materials have led to the introduction of “solid” insulation cables usually based on polymeric plastic insulation.

Today Cross-linked- Polyethylene (XLPE) cables are possible at the very high voltage of 400 kV and almost a total of 2000 km of various projects exist in various parts of Europe. The manufacturing of optimised cables based on these solid insulation materials is more efficient, and when used together with standardised pre-moulded accessories, allows for easier and less costly installations than those for fluid filled cables.

One of the main advantages of underground cables is the low level of Joule losses compared with equivalent overhead lines. That is the reason why operation costs are very significantly reduced in the case of underground cables.

Yet, there is a limit in EHV undergrounding due to capacitive current requiring introduction of compensation stations for links above a certain length called the “critical length”. Usually, the maximum length between compensation stations is about 20 Km for EHV cables, which is small compared with overhead lines, where smaller capacitive current allows length 10 to 20 times longer. In general, technological progress has reduced costs and space requirements in the compensation field as well.

On the contrary, underground cables have better performance than overhead lines regarding electro-magnetic field generation. Metal screens eliminate radiated electric fields and the risk of electrical shocks, moreover the magnetic fields can be managed both in amplitude and space and are usually less than the equivalent overhead lines at a small distance from the trench of the cables.

There are 3 main ways to install underground cable systems:
- Directly buried underground
- Put in pre-built concrete conduits, or PE or PVC tubes
- Tunnels: cables can be installed either in dedicated tunnels or existing tunnels, originally built for other purposes. In some cases unused tunnels can provide an opportunity to significantly reduce costs and provide an acceptable solution for the high cost problem of underground solutions.

In addition to the cable developments described above, it must be added that installation techniques have also been improved. The wider adoption of direct laying, the use of "ploughing" and even "mole" techniques has reduced significantly the additional cost items associated with installation of the cable system. Whilst these techniques are often applicable to lower voltage cables, particularly over short distances, they are not generally suitable for HV and EHV transmission cables, which give off large amounts of heat and need careful control of the cable spacing and thermal environment.

Thus, the cable systems have developed significantly, whilst on a comparison basis, the overhead line, using air as insulation, has little chance of reducing distances between phases and ground. For overhead lines, increases in network operating voltage usually lead to bigger and more intrusive tower structures.

DC underground cables

DC cables are not used very much in Europe. The choice of DC transmission rather than AC, is unique for each scheme, but is usually selected when either distances of more than 100 Km are required to be covered, or for interconnecting grids that operate at different frequencies asynchronously.

Although not common so far, extruded cable systems for direct current (DC) applications are starting to be used up to 150 kV. Over this level and up to 500-600 kV, existing older technology (mass impregnated or fluid filled) can be adopted for high power transmission. Developments are being carried out to increase the voltage level of extruded technology.

Although the DC cables are cheaper than the equivalent AC cables with the same capacity, the cost of a full project with DC cables becomes quite high owing to the requirement to add on both ends of the DC link converter stations AC-DC and DC-AC, which are quite expensive.

Submarine cables

For reasons of completeness, submarine cables are referred hereto, although they are not part of this Communication. Submarine cables of either AC or DC type are constructed and operating in various parts of Europe separated by sea (between Scandinavia and mainland Europe, UK-France, UK-Ireland, Italy-Greece).

At high voltages up to 150 KV extruded cables with plastic insulation are in service, while at extra-high-voltage (up to 500 KV) fluid-filled cable systems are generally used, while

extruded systems are being under development.

## I.2 New technological developments

Under this title two new technological developments in cables will be examined: a). the Gas Insulated Line (GIL) and b). the High Temperature Superconductors (HTS).

### Gas Insulated Line (GIL)

For 400 kV links a new technology of GIL offers a complementary solution to XLPE cables. The technology derives from "armoured transformers" technology and is made from an aluminium tube of about 600 mm diameter filled up with insulating pressured gas $SF_6/N_2$ (mixture of nitrogen and $SF_6$). The conductor lies in the middle of the tube separated from the tube by regular spacers. There is finally an outer protection of anticorrosion coating.

The GIL alternative is competitive when very high transmission capacity e.g. 2000 to 4000 MW is to be transmitted over short distances. As an example for transmission of 2000 MW one GIL cable system would suffice, while for XLPE two cable systems of 1000 MW each would be required. Another advantage of GIL is that their electric field is zero, while their magnetic field is very low.

As disadvantages can be considered:

- Big diameter of each phase (600mm), making the system rigid and difficult to install in urban areas
- It uses big quantities of $SF_6$ (green house effect) with danger of leakage and need of continuous control
- As far as end of life aspects, this technology is halfway between overhead lines and underground XLPE cables, provided that the gas is recovered with special care.

A recent development of GIL use is referred to in Reference [7][9]. This project concerned the substitution of 420 m double overhead line of 220 kV traversing the airport of Geneva and constituting part of the UCTE international network.
The solution selected was that of GIL owing to the strict requirement of very low magnetic interference in the vicinity of the airport. Two circuits of 3 GIL (one per phase) were used (totalling 2x3=6 GIL cables) inside a tunnel below the level of the airport, in order to leave free the space for the PALEXPO fair buildings that were to be built above on this side adjacent to the Geneva airport. The project started in September 2000 and was completed within 3 months. This GIL link was considered as a second generation of GIL, as a new gas mixture was used as insulating medium, consisting mainly of nitrogen and $SF_6$.

### High Temperature Superconducting cables (HTS)

Superconducting materials are known since about 90 years and have the ability to transport high currents without electric losses, when they are cooled to very low temperatures (at 4K equal to -269°C, with liquid helium as cooling material). The current material density in a superconductor is 300-10 000 times higher than in copper.

The discovery of high temperature superconducting material (HTS) in 1986 made a breakthrough, as the HT materials become superconducting at liquid nitrogen temperature (77K equal to -196°C). Cooling at this temperature is a factor of 1000 times less expensive

---

[9] N2/SF6 Gas insulated line of a new GIL generation in Service- CIGRE 2002, Paper 21-204. Alter,Amman, Boech, Degen and others.

than liquid helium cooling (at -269°C). Thus, new cost effective applications can be envisaged in electricity transmission.

Power cables based on the HTS materials can offer several advantages compared to conventional power cable technology due to the unique properties of the HTS material, the needed internal cooling and a perfect magnetic shielding (for some designs). The advantages of an HTS power cable are:

- High current and power rating
- Compact cable dimensions
- Low losses (less than 1%, compared to 5% to8% for traditional cables)
- No thermal interaction with the surroundings
- No magnetic interaction with the surroundings

Owing to these advantages HTS cables can become the best solution for replacement of old cables in compacted urban areas, where demand for electricity increased sharply and there is no space to lay down new cables. The replacement of old existing cables with HTS materials of the same size would offer a much higher capacity (e.g. about 5 times higher) than with conventional cables.

The main disadvantage to date has been the high cost of HTS wire. The wires used for conventional conductors for electricity transmission and distribution are usually made from copper or aluminium and the present cost for copper wire is approximately $10 per kAm (kiloamperes meters) and $2 per kAm for aluminium wire. In contrast, commercial HTS wire (which is made of bismuth strontium calcium copper oxide) costs around $200 per kAm. Various R&D programs expect to reduce the HTS cost to $50 per kAm, while in the US the Department of Energy Superconductivity programme has established a goal of $10 per kAm. A recent study of 2001 (Reference [10]) suggested that significant market penetration could be achieved with a cost of $20 per kAm.

In recent years, the United States government has contributed around $30million in programs aimed at meeting the challenge of long-term development of HTS technology for the transmission of electric power. A handful of commercial companies including American Superconductor Corporation have also developed and manufactured products using superconducting wires and power electronic converters. The technology involves grinding up the ceramic material, packing it into silver tubes, rolling the tubes into tapes and then heating the tapes up to produce wires long enough to be used as superconducting cables.

A number of cable manufacturers have been working on the development of cable demonstration projects, namely Pirelli Energy Cables and Systems (Italy), NKT Cables (Denmark), Sumitumo Electric Industries and Furukawa (Japan), Southwire (USA), LG Cabels (Korea) and Condumex (Mexico). This has led to a number of HTS cable demonstration projects including 400 metres of cable in Detroit and 90 metres of cable in Copenhagen.

In December 2002, Southwire and NKT formed a joint venture (ULTERA) whose aim is to produce a 300 metre HTS cable to be installed in an electricity distribution system in Colombus, Ohio by 2005. The new design combines a three-phase system, which before required three separate HTS lines, into one cable. This reduces by about one half the amount of superconducting material required and reduces the amount of space needed to install the cable. An update of the Detroit project was provided by American Superconductor and Pirelli to the US Department of Energy in July 2002. Of the three HTS cables installed, leaks had been determined in two of the cables that were significant enough to make the cables unstable so they cannot be energised. The project is to continue with just one cable, which it is hoped will lead to full commercialisation in due course.

In Denmark, (see Reference [11][10]), NTK Cables, in collaboration with the Technical University of Denmark and with support from several Danish electricity companies and the Danish energy Authority's Energy Research Programme, has been working on cable-related superconducting technology for a number of years. In My 2001 this led to the installation of the world's first superconducting cable in a public electricity grid, which entered service at Copenhagen's Amager substation, a central hub in the Danish capital's electricity supply system. The cable, which supplies more than 150 GWh of power, is part of a grid serving some 50,000 households and businesses. The cable, which is cooled using extremely cold liquid nitrogen, consists of three separate superconducting cables each 30 metres long spliced into the grid where the voltage is 30kV.

In concluding, at present, HTS cables are still in a prototype state and further research and investment will be required to bring down the cost of the wire before the technology can be used economically on a large scale. In the opinion of HTS manufacturers it is likely to be 8 to 10 years before this happens.

## I.3 Cost Considerations

In general terms underground cables are more expensive than the equivalent overhead lines that serves the same flow of electricity. Although a comparison of coasts need a full analysis as system during a lifetime, an attempt will be made to present data given in various references. The ratio of the cost of underground cable to the equivalent overhead line is usually used in various reports and studies as an "easy" indicator for comparisons. This ratio is generally increasing with the kV voltage of the cable/overhead line.

(a) Examples of cost ratios Cables/Overhead Lines

Some examples of cost rations presented in various sources are the following:

1. The French "Accord Réseaux Electriques et Environnement 2001-2003" (Ref.[2]) gives ratios of:

- 2-3 times for 63, 90 and 225 kV cables
- 5-7 times for 400 kV cables

2. The UK's National Grid Company report « Overhead or Underground » (Ref.[1]9 gives ratios between 15 and 25 for 400 kV cables

[10] Design, installation and operation of world's first High Temperature Superconducting Power Cable in a Utility Power Network, CIGRE 2002, Paper 21-205. Stergaard, Tonnensen.

3. The Europacable in the paper "Cable systems" (Ref.[3]) and in other information provided gives the following ratios:

- 1-2 times for medium voltage cables (10 kV and 20 kV)
- 3-6 times for 150 kV cables
- 5-10 times for 225 and 400 kV cables

The ICF Consultants in their Report to the European Commission (Ref. [16]) have contacted a number of transmission companies, electricity regulators and suppliers in Europe, who have provided estimates of the costs of construction of cables in comparison to aerial lines (see Table 7). The cost estimates of a 400 kV cable in comparison to a line vary quite considerably but in general the cost differences are narrowing compared to a few years ago. In France, for example, RTE has reduced its estimates for 400 kV cables from 20 times the cost of aerial lines to 10-12 times over the last couple of years. This is attributable to increased R & D into the economic life of cables, the laying cables at reduced depths and technological advances in cable design.

**Table 7: Multipliers of cost of cables in respect to overhead lines**

| | 380/400 kV Cables to lines multiplier | 150/220 kV Cables to lines multiplier | Source |
|---|---|---|---|
| Austria | 8 | - | Verbund APG Styria link |
| Belgium | N/a | N/a | Elia declined to provide a cost ratio due |
| Denmark | 7.2 | 4.0 | Eltra/Elkraft |
| ETSO | € 5million/km more | | ETSO |
| Finland | 3.5 (sea cable) | | Fingrid |
| France-rural | 10 | 2.2-3 | RTE-Piketty Report |
| Ireland | - | 7.7 | ESB National Grid |
| Italy | 5.9 | 5.5 | Electricity Authority |
| Norway | 6.5 | 4.5 | Statnett |
| UK (E&W) | 15-25 | N/a | National Grid |

Source: Study Ref. [16]

1. In a report prepared by CIGRE[11] (Ref.[5]), a quite comprehensive approach had been followed in analysing the data from a questionnaire covering 19 countries (mostly OECD countries) for costs of real projects of overhead lines and underground cables.

As the absolute values of costs of cables may have reduced owing to the technological developments in 6 years since 1996, the ratios of costs are to be considered carefully, but they show the general trend of increase of costs according to the voltage:

- Voltage range 110-219 KV ratio 7 (with spread 3,4-16)

---

11 CIGRE Joint Working Group 21.22.01, December 1996

- Voltage range 220-362 KV ratio 13 (with spread 5,1-22,1)
- Voltage range 363-764 KV ratio 20 (with spread 14,6-33,3)

In the same study there was an attempt to take into account the costs of losses of electricity during the lifetime of an overhead line and an underground cable. The analysis showed that a ratio of the range of 15 without considering losses, will become smaller-- between 12 and 7 - with the consideration of low and high losses during the lifespan of the cable versus the overhead line.

It is noteworthy to mention that in the last decades there is a continuous reduction of costs of cables, owing the development of solid insulations, the optimisation of cable design, the use of pre-moulded cable accessories and use of more advanced laying methods, all contribute to the drastic reduction of costs of cables, a fact that is not observed in the construction of overhead lines.

When coupling installed system costs and the operational costs over the lifetime of the systems, the comparison of overall costs between cables and overhead lines become less unfavourable for cables, as in the above mentioned case of reference [5] when the cost of electricity losses were taken into account. Whilst the load carrying capacity of an equivalent sized conductor in a XLPE cable is less than that in an overhead line, this is countered by the significant lower losses within the cable, which can be 30% to 60% less than those of an overhead line.

However, it must be stressed here that in case of adoption of a new European initiative to underground electricity lines in Europe, there will be a large demand for cables and it can be expected that a massive production of cables will create a real new market resulting to substantial reductions of prices of cables.

<u>(b) Other factors to be considered for cost comparisons</u>

Another factor that must be considered when comparing costs of systems, is the fact that the load patterns of the electricity networks become more constant with less pronounced daily and seasonal peaks, due to the availability of cheaper electrical equipment and more use of air-conditioning and computers. Since the cable systems have the ability to carry constant loads virtually independently of the ambient air temperature or wind speed, cable system has an additional advantage in lifetime costs comparisons when compared to overhead line systems.

Furthermore, due to environmental considerations the obtaining of right of way permits are getting more difficult. It is then necessary to also take into account the land itself and the cost of getting planning approval. The cost of the land required is getting more expensive especially in urban suburbs. The land coverage required for an overhead line is large and in addition cannot be re-used in general for its original purpose. In semi urban areas also the land at the side of an overhead line cannot be used due to radiation considerations. Property values close to overhead lines are also affected. Although to establish general values is difficult, it has been shown in specific studies that in some circumstances a replacement cable system could be financed by the recovery of used land for development purposes.

Detailed consideration must be also given to the costs of maintenance and refurbishment for overhead line systems. As well as preventative maintenance to towers and lines, the significant cost of tree pruning must be added if woodlands are part of the route.

(c) Cost of new technological developments (GIL and HTS)

Coming now to the case of innovative technologies for underground cables, such as GIL and HTS, there are not a lot of information as most cases refer to experimental pilot projects and tests. Anyhow, taking into account the high cost of special materials used and cooling technologies used in HTS technologies, it looks very unlikely that the overall construction and maintenance costs of GIL and HTS will be lower than those of usual underground cables.

In the case of a recent development of a 420 m long Gas insulated line at the Geneva airport to replace an existing 220 KV line (see [7]) it was calculated that cost of this achievement of GIL cable system (including the tunnel) was 12 to 15 times more expensive than that of a new overhead line of the same length.

It was also cited that in case that the life-cycle costs of a GIL transmission line of several kilometres in length were compared with the cost of an overhead line, cost-ratios of below the factor 10 can be achieved.

In another study carried out in the framework of the TEN-Energy Programme (see [8])[12], three alternative technologies of underground cables were examined (Fluid oil insulation cables, XLPE cables and GIL) for the substitution of a section of around 7 Km length (situated in the Western region of Rome in urbanised and natural areas) of 380 KV double-circuit overhead transmission line (between the 2,500 MW Torre Valdaliga Nord Power Plant and Aurelia Nord substation, just to the west of Rome). The plan was to replace the existing double circuit overhead line with cables along a number of possible routes (including a direct tunnel, along the roadside and across a turnpike/fields).
The oil-filled and XLPE cable solutions (4 circuits/12 cables) had a rated power of 1,000 MVA whilst the GIL solution (2 circuits/6 cables) had a rated power of 2,000 MVA.
The total estimated costs for the three alternatives were:

- Oil-filled $44m; 8,4 million €/km
- XLPE $36m; 6,8 million €/km
- GIL $68m; 12,9 million €/km

Compared to about € 0,4 to 0,5 million /km for overhead line, they give ratios of 1:17, 1:14 and 1:26 respectively.
XLPE was cheaper than oil-filled due to lower cable costs and HV switchgear. GIL was more expensive due to higher cable costs and accessories. Although XLPE was the cheapest solution and had the lowest maintenance requirement, TERNA decided to proceed with the GIL solution, as it deemed important to develop this technology.

These 2 cases support the view that the use of new innovative technologies can not reduce significantly the cost-ratio of underground cables in respect to overhead lines.

Concluding this section, it can be stated that the main disadvantage of underground cables in respect to overhead lines remains still the high initial construction cost especially for the extra high voltages of 220 kV and 380-400 kV, that are of interest for the electricity transmission systems in Europe.

[12] TEN Study E94/98. Project to substitute a part of a double circuit 380 kV overhead transmission line with an underground line. Region west of Rome, Italy.

## I.4 Environmental considerations

Environmental considerations have played during the last decades an important role in decisions about electricity transmission projects and are now replacing engineering considerations as the main criterion for selection. Various aspects of environmental considerations will be examined.

(a) Visual impact:

The cable systems present as their biggest advantage the fact that they are "invisible". Therefore, in urban areas and in environmentally sensitive scenic areas the use of underground cables is indispensable, in spite of high construction costs. It is commonly accepted that overhead lines are substantial structures and their visual impact outweighs in some cases their other advantages. Whilst to place a value on the effects of visual impact is a difficult and very subjective exercise, it is very common nowadays that the public opinion of local communities and environmentalists have rendered the construction of new overhead lines rather impossible in most places in Europe. The installation of a cable system has no permanent influence on the landscape, whilst overhead lines and their pylons can be very intrusive on the landscape or on an urban area and local amenities

(b) Impact during construction and operation:

Excavations during the laying of cables may cause a temporary visual intrusion and disturbance to flora and fauna, land uses and archaeological sites. There is much greater impact on land when laying underground cables, as much more quantity of soil has to be excavated than in the case of overhead lines, when only limited disturbances are caused in the area of pylons.

Of course, such disturbances caused by underground cables last temporarily for a relatively short period, while the construction of an overhead line is much quicker (about 5 times as fast). Sometimes, however, such effects on land uses may be in eversible even in the case of underground cables.

Again, due to environmental considerations it is becoming increasingly difficult to obtain right of way permits or even to renew existing ones. The required right of way is very much smaller for a cable and once installed, the land above is generally used again for its original purpose, except for planting trees. This can result in a considerable saving, considering that in an overhead line little use can be made of the land that lies directly under the line or even for some distance either side.

After construction, some constraints remain on farming. When overhead lines have been erected, farmers need to use agricultural machinery with care and observe height restrictions. With underground cable, certain subsoiling operations below 45cm cannot be carried out along the route; and trees cannot be allowed to grow because of the potential danger from root damage.

Repairs to overhead lines are far less disruptive. Damage to tower fittings or to conductors may involve the lowering of the conductors to the ground for repair, or sometimes repairs can be carried out from trolleys sent along the wires from the towers. Repairs can even be carried out from helicopters with the circuits live.

(c) Magnetic and electrical fields

Usually, there have been concerns expressed about the electric and magnetic fields caused by overhead lines, below them and at a distance around them. There is still a lot of debate in scientific circles about the effects of such fields and about their acceptability or not, and therefore safe conclusions can not be drawn in a definite manner.

Underground cables on the other hand cause no electrical fields by default, while the magnetic fields caused by them are rather higher just above the trench but are quickly reduced around the trench. Anyhow the magnetic fields both of overhead lines and cables are usually within the requirement of EU for minimum values.

(d) Consumption of raw materials and energy recycling

The gradual introduction of XLPE cables to replace older types of cables signified that the use of oil, fluids, lead and PVC rapidly diminished, while new material appeared such as aluminium and polyethylene (PE). This trend made the construction of cables much more environmentally friendly in itself. With reductions in size the cables use fewer natural resources and at the end of their life they have less scrap and more recyclable materials.

Another environmental factor that must be considered is the fact that, as underground cables incur fewer losses during their operation to transmit electricity than overhead lines, the amount of electricity generation required is reduced, which means less greenhouse gas emissions overall.

## I.5 Operational Considerations

Reliability of networks has always been an important factor in network operations. Cables have at present a good record of reliability with records showing that an average cable faults show 0,072 failures per 100 circuit km/year, with overhead lines showing around 0,170 failures per 100 circuit Km/year. These average figures are also confirmed by a study carried out by DISCAB Group over the last 12 years as presented in the ICF Congress in Barcelona in 1995 (see [3] p.5).

Cable systems with recent developments of new technologies show a decreasing trend of annual rates of failure, while overhead lines maintain a relatively constant failure rate mainly due to climatic reasons (wind, ice, snow and fog).

However, it is fair to point out that the time required for locating and repairing a fault is greater in cables than in overhead lines. Reference [1] indicates that the time of outage of a cable owing to a fault might be 25 times more than the time required for an overhead line of the same length. On the other hand Reference [3] indicates that recent surveys give a ratio of time of outages of 2 between a cable and an overhead line of the same length.

Transient faults (surge strikes) are still affecting overhead lines at an average rate of 2,3 times per 100 Km/year and most of them may be cleared through reclosure devices without any perceivable loss of supply. Such a form of outage is not present in cable systems.

The load of an overhead line and its capability to carry overloads is purely determined by the ambient air temperature and wind speed. Due to the daily unpredictability of both these parameters, the calculated continuous loading is set at average parameters, which in some cases mean about 40% of the total actual capacity. During overloads the temperature of the conductor can reach the design limits within minutes.

On the other hand, soil temperature is relatively constant, with a variation range generally within +/- 5 degrees centigrade over the whole year. Thus, the calculated continuous current permitted for underground cables can more closely match its capacity. In regard to overloads, again the stable environment and the bigger thermal capacity means that overloads of 20% can be accepted for up to 48 hours without exceeding the design limits of cables. The ability to use this property in the design and management of a transmission network is a big advantage for cable systems. Moreover, temperature monitoring is today a technology readily available for underground systems, which allows to safely optimise the utilisation of the network at any point in time.

Finally, other parameters affecting the security of the network may come into account in some areas. Cable systems once installed are not prone to either sabotage or theft of materials or energy, neither to external influence due to adverse weather conditions. It is important to refer at this point to the large damages caused to the french electricity transmission system during the wind storms in December 1999, fact that pushed the responsible french authorities (Ministries, EdF, RTE) to conclude the agreement presented in Reference [2].

## I.6 Comparison of technologies – Conclusions

All previous sections analysed the advantages and disadvantages of the various types of underground cables(UGC) from various points of view: technical, cost, environmental, operational. (The Tables of this section present a summary view of the various ways of transmitting electricity).

A first conclusion can be that Overhead Lines (OL) remain the most used means for electricity transmission, owing to their lower cost in comparison to UGC. The difference of costs between UGC and OL is still high and will remain, unless a future mass production of cables reduces their construction cost.

A second conclusion can be drawn when comparing the various types of UGC, that XLPE cables are generally considered to be the cheapest and most developed cable technology. GIL cables are to be used in special cases of short distances and when high load levels are present. Finally, the HTS option is still in R&D prototype stage and will need a number of years before they become commercially available.

A third conclusion may be that UGC are necessarily applied in special cases, such as in urban areas and sensitive ecological, aesthetic or historical areas, or where the security of supply is in danger due to frequent adverse weather conditions.

## Appendix II

### The main extra high voltage underground projects world-wide

*The main projects listed below concern extra high voltage underground lines (400 kV to 500 kV), often over long distances and which are able to convey substantial power (2,000 MW). Submarine links projects are not listed considering that undersea cables use different technology and are not necessarily subject to the same issues . The information appearing in this Annex is provided by References [7], [12], [16] and [18]*

### The Shin Keiyo Toyosu Line (Tokyo Crossing - Japan)

This is a **500 kV** AC line with three 900 MW circuits two of which have already been laid and put into operation since 2000. It uses the synthetic-insulated cable technology. The line was built over approximately **40 km** and cost a great deal to install because all of the line was laid either beneath tunnels or bridges. Because of the substantial distance that the line covers, reactive power compensation substations1 were installed at the extremities of the link.

### The Berlin Crossing (Germany)

It concerns the **400 kV** AC diagonal lines connecting the electricity Ring around Berlin to the city centre. A first section of **10.6 km** was constructed in 1978 as a double circuit **400 kV** with low-pressure oil –filled cables. A second section of **7.5 km** was built in the early 1990's as a double circuit 400kV cables of low-pressure oil-filled type. A new section of **6.3 km** with two circuits commissioned at the end of the 1990's . It used the synthetic-insulated cable technology by putting 2X3= 6 **XLPE cables of 400 kV** in a tunnel at a depth of 25 to 35 m below the city..

### The Copenhagen Lines (Denmark)

These two separate **400 kV** lines each with one circuit installed in 1997 and 1999 to connect central Copenhagen to the Danish 400 kV grid, through 2n connections in the north and south of the city. Synthetic-insulated cables were used for the project. The two lines have a length of **22 km and 14 km,** respectively.

### The Aalborg-Aarhus Line (Denmark)

To reinforce the 400 kV network in the western part of Denmark, the electrical utility Eltra is building a **400 kV** link covering a distance of 140 km (Aalborg-Aarhus). The line, with a capacity of 1200 MW, is mainly overhead, but is laid underground when it crosses urban areas and areas of ecological interest. Three cable sections (**2.5 km, 4.5 km, 7 km**) will be built using synthetic-insulated cables (double circuit). Commissioning is scheduled for 2004 for a **total cost** estimated at **140 million €**, the underground part representing a quarter of the cost (35 million €) for 10% of the length of the link.

### The Madrid Airport Extension (Spain)

The **400 kV** overhead line with two circuits and a capacity of 1,200 MW which ran alongside the Madrid airport had to be replaced by an underground line as part of a project to create new runways. The underground line uses the synthetic-insulated cable technology and will be laid in a tunnel covering a length of **12.1 km**. The works are under way for the first circuit with a length of cable of about 37 km (3 phases X 12.1 km).

**The London Power Reinforcement (United Kingdom)**

This is a **400 kV** line with two circuits and a capacity of 1,200 MW. The line is made up of two synthetic-insulated cables and covers a distance of **20 km** from the centre of London (St. John's wood) to the suburban area. The link is laid in a tunnel. Construction is under way with commissioning of the first circuit scheduled for 2004, and that of the second circuit a decade later depending on how demand develops. The cost of the line amounts to **350 million €**, including the electrical substations at the extremities of the line.

**Extension of the Geneva Exhibition Centre (Switzerland)**

This project concerned the substitution of 420 m double overhead line of 220 kV traversing the airport of Geneva and constituting part of the UCTE international network.
The solution selected was that of GIL- **gas-insulated cable** technology, owing to the strict requirement of very low magnetic interference in the vicinity of the airport. Two circuits of 3 GIL (one per phase) were used (totalling 2x3=6 GIL cables of **400kV**) inside a tunnel below the level of the airport, in order to leave free the space for the PALEXPO fair buildings that were to be built above on this side adjacent to the Geneva airport. The project started in September 2000 and was completed within 3 months. This GIL link was considered as a second generation of GIL, as a new gas mixture was used as insulating medium, consisting mainly of nitrogen 80% and $SF_6$ 20%.

**The Middlesbrough-York Line (United Kingdom)**

The 70 km long overhead line with two **400 kV** 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 wayleaves 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 and the cable £8.9 million/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 5.7 km 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 30 m of width and cost about **100 million €**.

**The Hong Kong Interconnection (China)**

The construction of a **12,5 km** cable interconnection between two substations in the urban area of Hong Kong has begun in 2001. The interconnection of **400 kV** will be completed in early 2004 and it will boost power supplies in an area of ongoing urban development, where the population is estimated to grow from 250,000 to over 340,000 in 2004; The new link is expected to serve the customers with quality and reliability, as well as to ensure sufficient supply capacity to cater for future demand.

**References-Sources of information used in this ANNEX 2**

[1] European Energy Infrastructure. Fighting congestion and building links. European Commission 2002

[2] “Accord Réseaux Electriques et Environnement” 2001-2003

[3] National Grid Company: Overhead or Underground? 2000

[4] Europowercab – Cable systems paper, 2002

[5] Comparison of High Voltage overhead lines and underground cables – CIGRE Joint Working Group, 1996

[6] Comparison of 130 kV XLPE cable systems and OH Lines, loading capacity, reliability and planning criteria, CIGRE 2002, Paper 37-104. Karlsson, Lundquist, Sollerjkvist (STRI) and Karlstrand, Norberg (ABB)

[7] N2/SF6 Gas – insulated line of a new GIL generation in Service – CIGRE 2002, Paper 21-204. Alter, Amman, Boech, Degen and others.

[8] TEN Study E94/98 “Project to substitute a part of a double circuit 380 kV overhead transmission line with an underground line”. Region west of Rome, Italy.

[9] RAPRA – High temperature superconducting transmission cables

[10] Analysis of future prices and Markets for High Temperature Superconductors, 2001, Mulholland, Scheahen & Mc Connell.

[11] Design, installation and operation of world’s first High Temperature Superconducting Power Cable in a Utility Power Network, CIGRE 2002, Paper 21-205. J. Stergaard, O. Tonnesen.

[12] ETSO Position Paper on use of Underground cables to develop European 400 kV Network, ETSO, January 2003

[13] L’apport de nouvelles technologies dans l’enfouissement des lignes électriques à haute et très haute tension, Report of French Senate N. 154, C. Kert, 2001

[14] Basslink – A National Grid Project “A review of Overhead Transmission Lines and Underground Cables”, April 2000

[15] Putting Cables Underground Report of Working Group, Australian Commonwealth Department of Communication, 1998

[16] Overview of the Potential for Undergrounding the Electricity Networks in Europe, Report by ICF Consultants to the European Commission, February 2003

[17] Unit costs of constructing new transmission assets at 380kV within the European Union, Norway and Switzerland. Report by ICF Consultants to the European Commission, September 2002.

[18] New 400 kV XLPE long distance systems, their first application for the power supply of Berlin, CIGRE 1998, Paper 21-109, Henningsen, Polster, Müller, Schroth