Wraxall & Failand Parish Council

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Hinkley C Connection Project
Consultation Response
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10 July 2013

Dear Sirs

Re Hinkley Point C Connection Project

We commissioned the attached report as part of our challenge to National Grids proposals and to independently verify the proposals using an acknowledged world expert and user of the conventional and alternative transmission technologies.

One significant conclusion is that the life cost of a complete undergrounded solution is only 3.3 times greater than the scheme proposed by National Grid. (The reader should be aware that life costs exclude property blight, loss of tourism, direct or anxiety induced health costs etc.)

Serious technical assumptions made by National Grid were questioned in the proposals. The discovery of these matters will be of value to National Grid and save them time and money.

We look forward to continuing our relationship for the benefit of all parties.

Yours sincerely,

Freda Shattock

Clerk

Wraxall and Failand Parish Council

Cc: SoS for Energy Edward Davey MP, Dr. Liam Fox MP, IPC, OFGEM, CPRE, Cllr Bob Cook, Cllr Charles Cave, North Somerset Council, Nailsea Town Council, Sedgemoor District Council, Nailsea Action Group, Stour Valley Underground, No Moor Pylons.

Report

Commissioned by Wraxall and Failand Parish Council

On

Hinkley point C connection project

The National Grid's proposals for the erection of 400KV Transmission lines and associated pylons

THE NEUMANN REPORT

Report produced by:
Prof Claus Neumann
with introduction by
Dr. Hugh Pratt
and Chris Ambrose
June 2013

Abstract

To assist officers of statutory authorities in coming to a local decision, and to other authorities in coming to a regional decision, the Wraxall and Failand parish council commissioned the attached report.

To date, the statutory authorities have had to rely upon information provided by National Grid, a monopoly utility supplier funded and controlled by the government. Regrettably this information was, in our opinion, from the outset so insufficiently correct as to be misleading, e.g.:

1. The unstated assumption that some of the line must be undergrounded in areas of outstanding natural beauty (AONB).

2. The substantial errors in the estimations of physical disruption caused by undergrounding and their associated costs.

3. The technical errors in the power carrying capacity of their proposed design.

4. The substantial errors in the estimation of the whole life costs of all technologies.

5. The failure to consider undersea or gas insulated line (GIL) solutions or even acknowledge that National Grid already use these technologies.

6. The bland comparison, at the outset, that any underground solution would be 17-20 times the cost of an overhead line.

7. The cost comparisons, by Parsons Brinkerhoff on behalf of IET, which failed to consider the attraction of pricing by different forms of contract.

Approach

Wraxall and Failand parish council's approach was to request carefully quantified comparative costs of the proposed hybrid line, including physical impact, against that of a 100% undergrounded solution. In order to achieve independence of mind and thought this work has been undertaken by a world expert familiar with, and a major user of, all types of high-voltage transmission technologies.

Result

We have been able to demonstrate in a carefully constructed technical report that the full life costs of a 100% underground GIL solution would only be approximately three times the cost of the proposed overhead hybrid line, (50 km over head and 7km undergrounded).

Conclusion

We suggest that decision makers should use National Grid's information appropriately and realise its limitations. They should recognise that a preferred route corridor adjacent to the M5 is a realistic possibility. Our proposal, as evidenced from the attached report, is that a GIL solution should be considered.

Executive Summary

Walking through the history

The reader may be wondering how we arrived at this position following four years of intense work? A brief summary of the process involved may be useful.

Wraxall and Failand parish council (W&FPC) have consistently maintained that the proposed connection should not involve overhead cables and pylons at all but rather be run subsea or underground. The most acceptable underground route is considered to be the industrialised M5 corridor. The various reports, produced by W&FPC, all suggest that such a solution is viable and would remove the impact on the people they represent.

National Grid are constrained by legislative requirements to seek the lowest cost solution, although in areas of outstanding natural beauty they are allowed to underground.

Undeclared, at the outset, was that National Grid had a business plan recognising that at least 10% of the transmission line would be undergrounded in order to pass through areas of outstanding natural national beauty. This was not immediately recognised, with the result that the public have been confused by cost comparisons between a 100% overhead line and a 100% underground line.

The engineering complications of producing a hybrid line were not articulated, by National Grid, at the outset nor the increased costs associated with such a solution. Any form of undergrounding is a driver for additional costs. Furthermore the cost comparisons excluded whole-life costs, which gave the overhead line solution a more attractive position by excluding transmission losses. This necessitated that we obtained a "like for like" comparison of costs and issues which would enable us to extrapolate the data.

Although W&FPC had competent Councillors in this area of engineering it was felt that an acknowledged expert, with experience in all forms of high voltage transmission technology, should be approached to give an independent review of this matter.

W&FPC therefore sought a feasibility study from Prof. Dr.-ing. Claus Neumann with direction from Cllrs Dr Hugh Pratt and Chris Ambrose C Eng. The attached study considered how far the proposed Hinkley hybrid connection could be technically and economically feasible by the application of GIL technology under the existing legislative, least cost, requirements. This is to overcome environmental concerns when constructing the connection as an OHL along National Grid's proposed route.

A substantial issue is that these legislative requirements excluded losses due to property blight, loss of well-being of the countryside, loss of business and tourism, reduction in grid security due to storms and flood, vandalism or terrorism etc. These additional costs tip the financial balance in favour of undergrounding the transmission lines.

The expectation was that the results of the study would by extension produce sufficient information to enable a comparator for the M5 corridor to be produced.

Synopsis of Prof. Claus Neumann's report

The conclusions from this report are that a GIL solution in place of the underground cables would bring cost benefits in terms of reduced capital outlay and running costs, increased reliability, and consequently less outage time and a reduction in energy losses.

It is obvious that a 100%, or even hybrid, overhead line represents the most economical solution, as the report concludes. This is despite the fact that GIL operating costs are considerably lower and the system more reliable than an overhead line, this does not compensate for the higher cost.

It should be pointed out again that this report does not include any of the costs which are not required to be considered under legislation but impact the environment and livelihood of those living anywhere near the route corridor.

Some particular points of interest, from the report, are:

1. The maintenance costs for overhead lines include yearly inspections by patrol and a more intensive inspection after about 10 years. GIL is surveyed remotely by an online monitoring system, making the maintenance cost distinctly lower than an overhead line.

2. All transmission systems have energy losses that are paid for in our electricity bills. The losses with a GIL solution are up to 60% lower than the overhead line solution depending on the number and size of conductors selected.

3. GIL can be laid on the ground, directly buried, run in a prefabricated tunnel or a poured-on-site tunnel.

4. The costs for installing are dependent on the method chosen and the environmental and ground conditions. However, whichever solution is selected, the excavation work for GIL, even for directly buried, is less than that for cable.

5. National Grid have miscalculated the current carrying capacity of the proposed cables on the overhead lines. As a result, they suggest only two cables instead of three cables per phase. This report has allowed for and corrected National Grid's omission.

6. This report starts from a perspective of quantifying the costs of a 100% underground and 100% overhead line and then focuses on the required hybrid solution required for the Hinkley connection.

7. The conclusion is that the whole life costs of a fully undergrounded GIL solution is only 3.3 times that of a hybrid solution using 50 km of overhead line and 7 km of underground line in the areas of outstanding natural beauty.

8. The reader may well be aware, from manufacturers' data, that GIL transmission losses are lower than for cable or OHL. This report shows GIL transmission losses are actually slightly higher due to the design/capacity requirements in this scenario not falling into the optimum GIL selection. The wall thickness for GIL requires detailed design which is not appropriate for any feasibility study.

9. This report confirms that the width with required for a direct buried cable, at 14m, which is 25% of that proposed by National Grid responding, to Wraxall & Failand's Report, which required 61m.

10. This report's conclusions represent the current National Grid design which has varied considerably over the last four years. Initially the design required feed line of 6 GW, with 6 cables bundled per circuit, now it has been upgraded to a strategic double circuit carrying 3.4 GW with 2 cables bundled per circuit.

Cllrs. Dr. Hugh Pratt and Chris Ambrose

Abbreviations and symbols

A	Ampere
AAAC	All Aluminum Alloy Conductor
Amprion	German equivalent to National Grid
AONB	Area Of Outstanding Natural Beauty
Bundle	When several cables are bundled together to carry sufficient current
Bushing	The insulating item which is under investigation
Circuit	The cables which comprise part of the transmission which experience the same voltage and current at the same moment.
cct	Circuit
EEX	European Energy Exchange
LCC	investment costs, discounted operational costs, over 40 years, and discounted renewal costs not including health or blight.
HV	High Voltage
HVDC	High-Voltage DC
Installation	the installing of equipment
Investment	the cost of Supply and installing equipment
kV	Kilo, (1000), volts
GIL	Gas Insulated Line
mm^2	millimetres squared area
MW	Megga, (million), Watt
MWh	Megga Watt hour
MVA	Megga, (million), volt amp which can differ from MW
OHL	overhead line
Outage	disconnection of power transmission
PD	partial discharge
Strategic	The requirement of N+1 security which means that there is a spare or redundant circuit
Termination joint	a joint at the end of the circuit
UHF	Ultra high frequency
XPLE	Cross linked polyethylene

Executive Summary

In the Southwest of England and South of Wales new power plants are proposed. Among others a nuclear power plant at Hinkley Point C is planned consisting of two reactors generating 3,260 MW in total. The existing system is not capable of transmitting this additional load, the grid has to be upgraded with new lines. Different options were investigated and finally National Grid favoured a 400 kV connection between Seabank and Hinkley via Bridgwater.

The transmission technologies studied included overhead lines (OHL), underground lines like cables or gas-insulated lines (GIL) and HVDC connections. Based on the findings two corridors were considered in which an OHL connection between Seabank and Bridgewater was to be installed.

This report considers how far this connection is technically and economically feasible by the application of GIL technology, and compares this solution with other transmission technologies.

There is a short description of the different alternative solutions, OHL, GIL and cables, and their respective availability. The comparison clearly demonstrates that the availability of the circuit is considerably reduced when cable technology is used. This is due to the failure rates and the distinctly longer outage time.

The non-availability of the underground cable solution is about 70 times larger compared to OHL and at minimum five times larger than the GIL technology.

To install GIL, 57 km in length, needs a technical and logistical expenditure to obtain a reasonable installation time. For that, an infrastructure consisting of about ten logistical hubs have to be set up which are used for preassembly as well as for assembly and testing of the different sections.

The investment and financial expenditure for the different alternatives is split into costs for equipment and for civil engineering. The latter one can only roughly be estimated, as no detailed information on the environmental and ground conditions is presently available. The cost expenditure for OHL amounts to about £1.2m per route km for a double circuit with a triple bundle of conductors.

The costs for the GIL solution is in the range of £11m per route km for a buried type, £12m for a type laid in tunnel made by prefabricated concrete elements and £14.5m for a type laid in a tunnel made by concrete poured onsite, a double circuit each assumed.

The costs for the cable solution is in the range of £13.5m per route km for a buried cable system with two circuits, about £15m for a system laid in tunnel made by prefabricated concrete elements and about £18m for a system laid in a tunnel made by concrete poured onsite. The costs are for three cables per phase in parallel and include the costs for shunt reactors which are required for compensation.

For life cycle costs (LCC) assessments the operational costs and the costs for renewal have to be determined beside the investment costs. The operational costs consist of maintenance costs and the more significant transmission losses.

The operational costs, dominated by the loss costs, discounted over a period of 50 years are as follows per route km: About £1.1m for OHL, £0.8m per route km for a GIL, £0.5m for cable system.

The costs for renewal, which takes place after 40 or 50 years, are also discounted. For OHL the renewal of the conductors only, not pylons, is considered and costs £0.04m per route km. The renewal of the GIL costs £0.7m per route km for the buried type and £0.5m per route km for the type laid in a tunnel. The costs for renewal of the cable system are quantified to £1.6m per route km for the buried cable and £1.2m per route km for the cable laid in a tunnel.

Based on the investment, the operational and the renewal cost quoted above, the 100% OHL solution represents the most economic solution. The 100% underground solutions are five to nine times more expensive. The buried GIL is the most favorable underground solution. Due to the extra over cost for the tunnel the underground solutions laid in a tunnel are the most expensive. With the application of prefabricated tunnel elements the GIL option installed in a tunnel could be of interest, since there are some benefits at the replacement procedure. But the additional investment costs compared with the direct buried solution cannot be disregarded.

However, the report recognises that from the economical and ecological point of view with special regard to areas of outstanding natural beauty, AONB, it is necessary to establish this link as a hybrid line. Sections in areas of AONB should be installed as underground lines and the other sections may be OHL. With regards to this, the buried GIL option for the underground section is the most economic solution.

The LCC costs of a hybrid line with 13% buried GIL underground, is only about 60% more expensive when compared to a 100% OHL solution. The cable solutions are not of the best solution due to higher costs compared to the GIL solutions and the higher non-availability. The LCC costs of a 100% underground GIL, buried or in a tunnel made of prefabricated elements are 3.3 or 3.4 times respectively more than the required hybrid line with a 13% underground section.

Author

The author of this report is honorary professor at Darmstadt University of Technology, Germany, where he gives a lecture in high voltage switchgear and substations. Until 2010 he was with the German transmission system operator (TSO) Amprion in Dortmund, Germany. His main fields of activities were HV and EHV technology and system layout; fundamental design and layout of HV and EHV apparatuses and systems; investment, maintenance and renovation strategy and methodology, monitoring and diagnostics; planning and initiation of operative measures for system extension and renovation.

He was involved in the first long-term investigation on a prototype of a buried GIL and a GIL laid in a prefabricated tunnel. Furthermore he was engaged in the pilot installation of the first buried GIL near the Frankfurt airport. Meanwhile he has been or is still active in GIL projects in the Middle East and in Germany.

He has written more than 100 publications and scientific contributions.

Table of contents

1. Introduction

In the Southwest of England and South of Wales new power plants are to be erected, with a low-carbon emission policy, to ensure the long-term power supply. It is planned to build a nuclear power plant at Hinkley Point C consisting of two reactors generating 3,260 MW in total. The existing system is not capable of transmitting this additional power and periods of congestion have been observed in the past, the grid therefore has to be extended with new lines. National Grid has optioneered, weighed and costed various transmission technologies as overhead lines (OHL), underground lines by cables, gas-insulated lines (GIL) and also HVDC connections.

This report shall consider how far this connection is technically and economically feasible by the application of GIL technology to overcome the environmental concerns when establishing the connection with OHL.

2. Consideration of the basic system layout of the new Hinkley-Seabank connection

The existing transmission system in the South West and South Wales will not be sufficient for the higher levels of generation and demand that are forecast for the future. In connection with Hinkley Point C Connection Project, additional transmission capacity of about 3,000 MW is needed. After various pre-studies National Grid finally considered 5 different connection options which are given in **Fig. 1**.

Fig. 1: National Grid's connection options

According to National Grid's studies, option 4 was preferred. This consists of an onshore connection between Seabank and Bridgwater (57km in length) and the existing connection between Bridgwater and Hinkley in order to provide the required capacity across both the South West and South Wales & Gloucestershire boundaries as well as the necessary circuits to facilitate the connection of new generation at Seabank [1]. Based on this finding two corridors with OHL connection between Seabank and Bridgwater should be realised. The route corridors and the OHL configuration and the ratings are presented in **Fig. 2**.

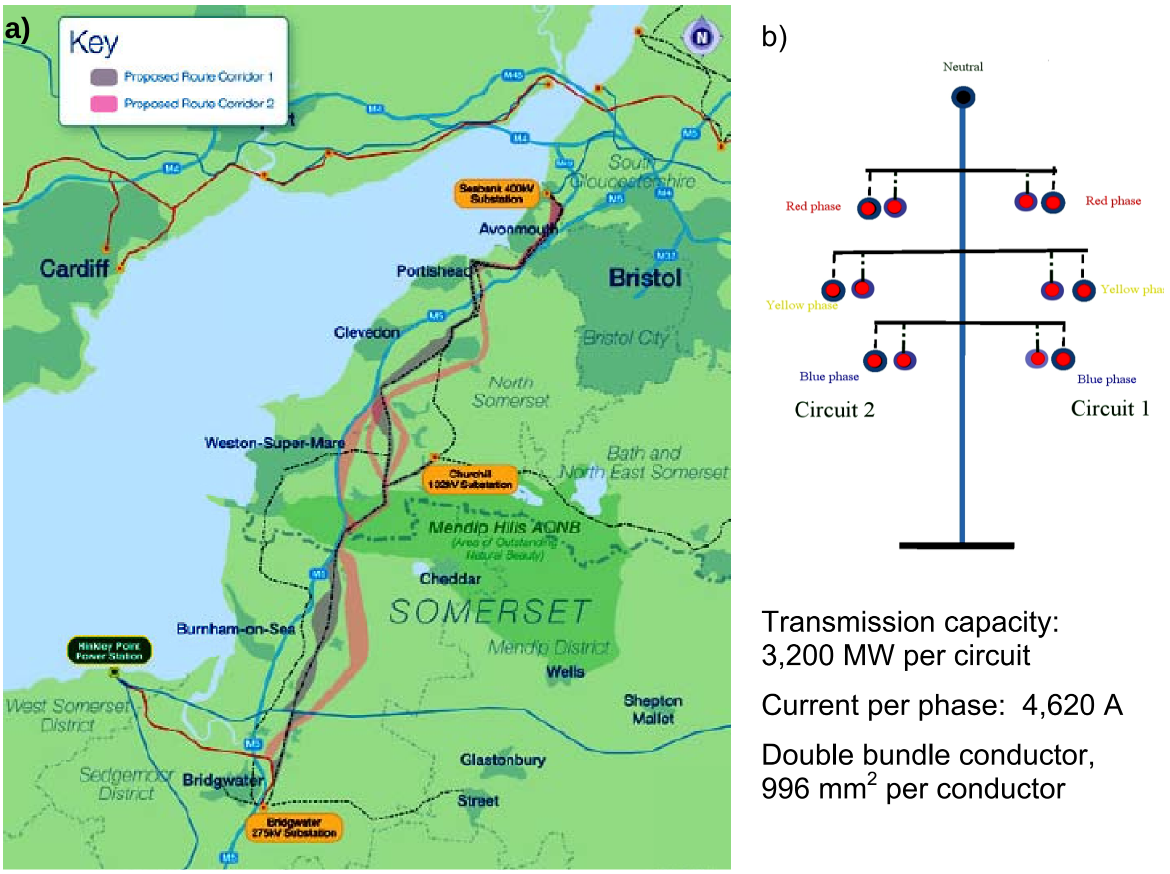


Fig. 2: National Grid's route corridors for Seabank – Bridgwater connection and OHL configuration

a) Route corridor   b) 400 kV OHL configuration and ratings

The line should consist of two circuits with a transmission capacity of 3,200 MW carrying a rated current of 4,260 A per phase. National Grid's design shows double bundled conductors with AAAC type conductors with a physical cross-section of 996 mm^2. According to the data sheet of a manufacturer the maximum current at 90°C is 1,659 A [2]. National Grid's design has therefore to be modified as a double bundle has only a current carrying capability of 3,318 A. In this report a triple bundle shall be considered.

The double circuit design was chosen for redundancy reasons, to manage the outage of one circuit in the event of a fault or for maintenance work. However, it should be checked, that the current carrying capability of the two bundle conductor is not sufficient for this rating and if system stability is to be guaranteed in case of an outage of the remaining circuit.

As the route corridors under consideration between Seabank and Bridgwater are near by the motorway M5, an underground connection beside the motorway applying the GIL technology was proposed by Wraxall & Failand Parish Council. GIL can be directly buried or laid in a tunnel or mounted on a substructure, as it is shown in **Fig. 3** [3, 4]. The latter solution needs to be mounted on gantries. As the installation would be accessible for the public, it has to be protected by fences. Moreover, this design does not fit with the demand for an environmentally friendly solution. Therefore this approach is no longer considered. The costs specified in chapter 5.2 are presented for information only. However the tunnel solution, adjacent to the motorway, continues to be a possibility.

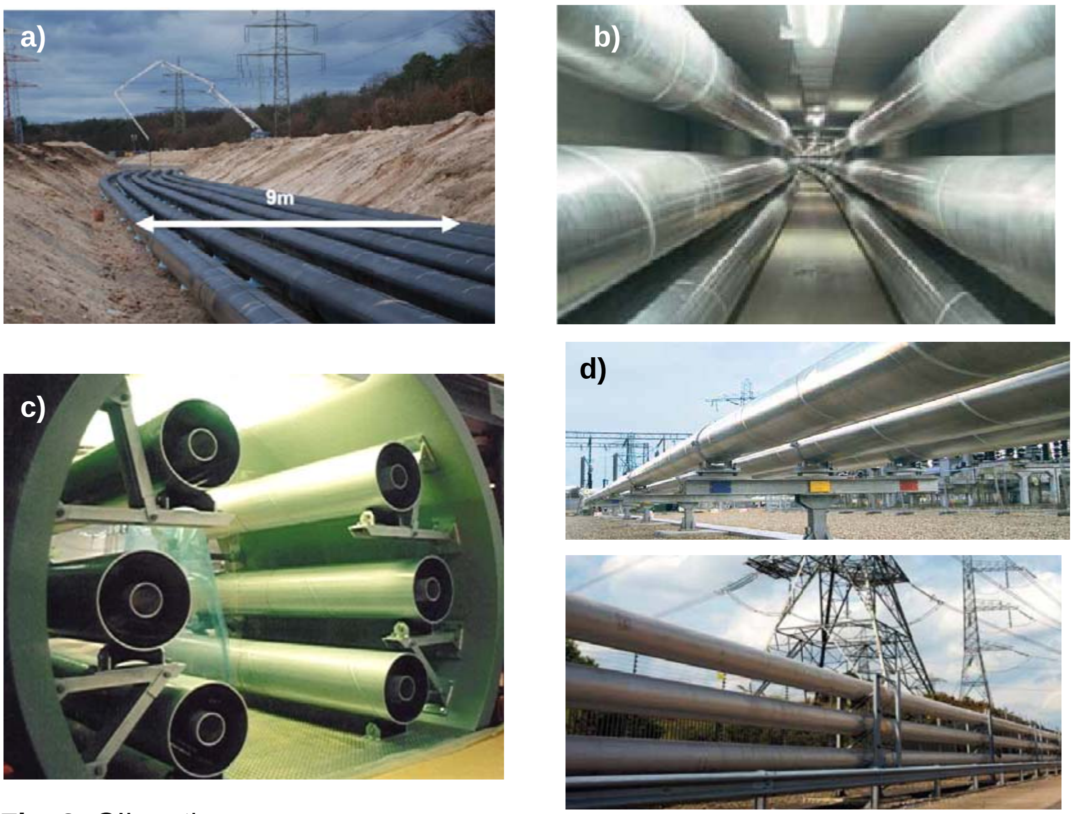


Fig. 3: GIL options

a) Direct buried
b) Installed in a tunnel established onsite, cross section 3 x 2.5 m
c) Installed in a prefabricated tunnel, 3.5 m diameter
d) Mounted on substructures

The ratings of the GIL must correspond with the OHL ratings, i. e. the GIL circuit should be rated for a transmission capacity of 3,200 MW or for a current carrying capability of 4,620 A. The options presented in Fig. 3, have a current rating of 3,150 A, thus will presumably require thicker wall thickness of the conductor and the enclosure.

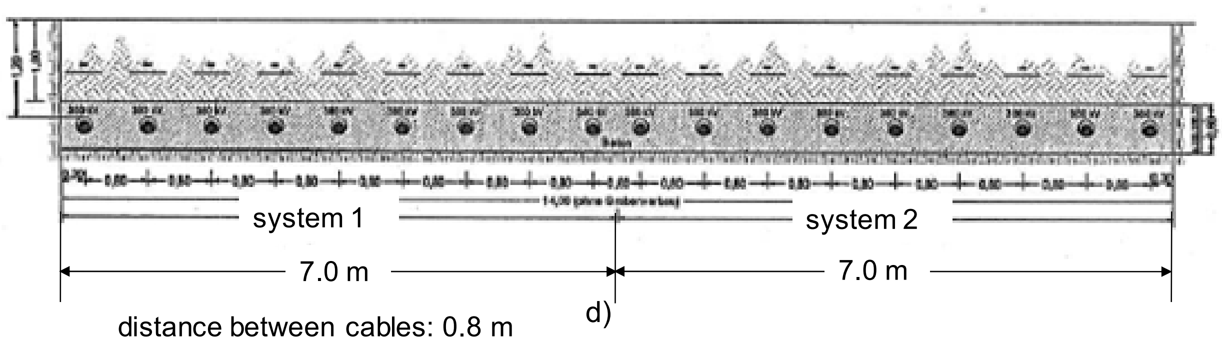


Fig. 4: Trench of a 400 kV double circuit transmission system with three XLPE cables ($2500\ mm^2$) per phase in parallel.

To give a full view of the different underground solutions, a cable solution rated for a transmission capacity of 3,200 MW is also considered. **Fig. 4** shows the trench of a 400 kV double circuit transmission system with three XLPE cables ($2{,}500\ mm^2$) per phase in parallel. Similar to the GIL option this option can also be directly buried or laid in a tunnel. According to [5] the transmission capacity of a 400 kV XLPE cable with a cross section of $2{,}500\ mm^2$ is in the range between 850 and 1,200 MVA depending on the laying conditions in question. Assuming a current carrying capability of about 1,500 A three cables in parallel per phase will have to be installed. Additionally, shunt reactors are required for longer cable sections to compensate the reactive power of the cables.

3. Network security of the different alternatives

For assessment of the different alternative solutions the availability, i. e. failure rates and the outage time in case of a failure, has to be taken into account. For GIL no international data are available, this availability assessment is based on data provided by a GIL manufacturer (**Table 1**). The OHL data are taken from the failure statistics of the German Forum for Network technology and Network operation – FNN [6] (**Table 2**).

- **Failure statistics according to manufacturer SIEMENS**
  - **90/3 km GIL & 110/3 km gas-insulated busbars (GIB) installed**
  - **Mean service time:15 a**
  - **Up to now no arcing failure**

	Failure rates		*Outage time*	
GIL & GIB	failures / year ∗ 100 km circuit length	<0.10	hours per failure	600

Table 1: GIL and GIB failure rates and outage time

	Failure rates		Outage time	
Multipole failures *)	failures / year ∗ 100 km circuit length	0.33	hours per failure	12
Single pole failures	not relevant for availability, as cleared by auto reclosing			

***)** including unsuccessful reclosure

Table 2: OHL failure rates and outage time

For the total circuit, 57 km in length, the non-availability is presented in **Table 3**.

- **57 km 400 kV GIL – 57 km 400 kV OHL**

GIL	Failures per year	Non-availability [hours per year]
In total	<0.057	**<34.2**

OHL	Failures per year	Non-availability [hours per year]
In total	0.19	**2.3**

Table 3: Failure rates and non-availability for the total circuit, 57 km in length, depending on the technology applied

The non-availability of GIL circuit of 57 km in length is at maximum 15 times larger than that of an OHL only connection (**Table 3**).

For comparison the findings are compared with a cable only connection. The failure and outage time data are taken from CIGRE Brochure 379, April 2009 [7]. It is assumed that each circuit consists of three cables per phase in parallel to achieve the current carrying capability requested of 4,620 A. The statistical data are given in **Table 4**.

- **400 kV XLPE cables, accord. to CIGRE Brochure 379, April 2009**

Failure rates		220…500 kV	
Cable	failures / year ∗ 100 km circuit length	int.	0.067
		ext.	0.067
Joints	failures / year ∗ 100 components	int.	0.026
		ext.	0.022
Termi-nations	failures / year ∗ 100 components	int.	0.032
		ext.	0.018

Outage time	220…500 kV	
Cable installations	hours per failure	600

Table 4: Cable failure rates and outage time

For this assessment only internal failures of cables (0.067 failures / year•100 cct. km), joints (0.026 failures/year•100 components) and terminations (0.032 failures/year•100 components) are considered. Presuming 12 joints per circuit km (a cable joint each 750 m and 9 cables in parallel), the total failure rate of the circuit and the non-availability are illustrated in **Table 5**.

- **57 km 400 kV cable circuit, three cables in parallel**

Cable installation	Failures per year	Non-availability [hours per year]
Cable	0.076	
Joints	0.178	
Terminations	0.006	
In total	0.260	**156**

Internal failures are considered only

Table 5: Failure rates and non-availability for the circuit in XLPE cable technology

The comparison clearly demonstrates that the availability of the circuit is considerably reduced when cable only technology is used due to the failure rates and the distinctly longer outage time. The non-availability of the cable solution is about 70 times greater than OHL and at least five times greater than GIL technology. This fact has to be taken into account in the redundancy consideration.

4. Realisation of a GIL 57 km in length

According to the manufacturers' experience the GIL installation requires about 6 month, per km double circuit, which can be accelerated to 3 month per km with additional plant and technicians. Additionally, the time for erection of the tunnel or for preparing the trench has to be taken into account.

In general, the pre-assembly and assembly are carried out in a temporary workshop located in the middle of the corridor and considered to be the logistical main hub at site. To obtain a reasonable installation time, for longer sections, several of those logistical hubs have to be established. If an installation time of 2.5 years can be accepted, an infrastructure consisting of about ten logistical hubs has to be set up for the specified length of 57 km.

As well as the assembly process the testing procedure also has to be adopted. Usually sections of 500 to 1,000 m form a separate gas compartment. The separate compartments are connected by special adapter housings, as is shown in **Fig. 5**. For a buried GIL the adapter housing is accommodated in a small shaft building.

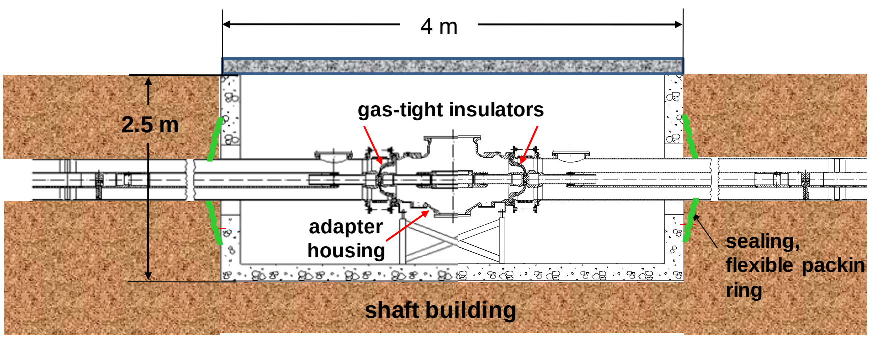


Fig. 5: Adapter housing for connection of two gas compartments

Each compartment should be tested separately for gas tightness, gas humidity, voltage drop and the HV test. For HV testing the adapter housing can be used for adoption of a test bushing. The HV test provides information about the dielectric integrity of the test object and can considerably be improved with a PD measurement using the UHF method. For this purpose the GIL has to be fitted with PD sensors. A typical sensor arrangement can be seen in **Fig. 6** [8]. These sensors applied for onsite HV testing, can also be employed for PD monitoring during service.

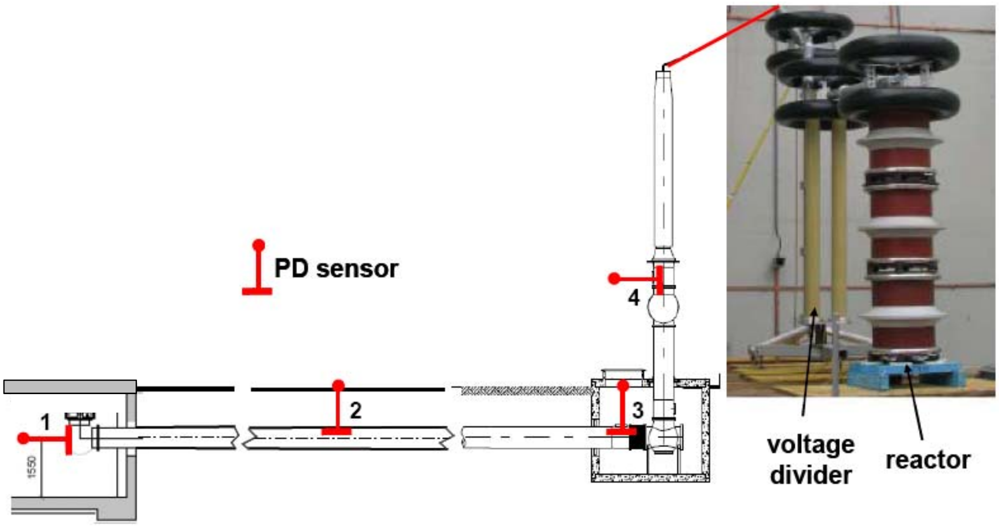


Fig. 6: Test arrangement for HV testing of a GIL test section fitted with PD sensors

After successful testing the relevant section has to be kept sealed to prevent ingress of humidity which would affect the dielectric long-term performance.

In the way presented section by section can be assembled and tested. Finally, the various sections have to be inter-connected in the adapter housings.

5. Investment and financial expenditure for the different alternatives

The investment and financial expenditure for the different alternatives is strongly dependent on environmental and ground conditions. This is mainly true for the underground solutions, but has also to be taken into account for the OHL solution. As no detailed information is available the expenditure for civil engineering work can only be estimated. The cost estimation is derived from projects in Germany which have recently been realised or will be realised in the near future.

5.1. OHL solution

The current carrying capability requested requires heavy conductors. These in turn necessitate strong towers which increase the cost expenditure for the OHL connection. Therefore, costs of £1.2m per km are assumed for the double circuit line. Surcharges resulting from the special geographical or environmental conditions, such as bogs, are not estimated.

5.2. GIL technology

For GIL technology three options, direct buried and two tunnel solutions are considered. For information the costs of the option laid above the ground and mounted on gantries are also given, at which the costs for protection of the installation by fences are disregarded. The costs in details are compiled in **Table 6**.

GIL option	Costs for equipment [£m per circuit km]	Costs for laying system [£m per route km] *)	Costs in total [£m per route km] *)
Direct buried	4.6	2.0	11.2
Tunnel, prefabricated elements	4.2	3.5	11.9
Tunnel, concrete poured onsite	4.2	6.2	14.6
Above ground, mounted on gantries	4.2	0.5	8.9
*) double circuit			

Table 6: Costs for GIL connection

For the installed transmission equipment alone a basic price of £4.2m per km per circuit is assumed. The direct buried option is more expensive, as it has to be fitted with anti-corrosion protection, so a surcharge of 10 % will be added.

The costs for laying are largely dependant on the environmental and ground conditions so estimations only can be given. The direct buried option (see Fig. 3a) which requires digging a trench and refilling which is estimated to be £2.1m per km for the double circuit. Due to the high current rating refilling with thermal stabilized refilling material is presumed for the direct buried, not for the tunnel design.

GIL can also be installed in a tunnel consisting of prefabricated concrete tube elements or in a concrete tunnel poured onsite (see Fig. 3 b, c). Based on recent quotations, the costs for prefabricated concrete elements, 3 m in diameter and 3 m in length, amount to £3.5m per km including excavation work and refilling. The cost for a tunnel with a cross section of 2.5 m x 3.0 m, concrete poured onsite (see Fig. 3 b), is about £6.2m per km including excavation work and refilling.

5.3. Cable technology

As with the GIL technology, three options are considered. Due to the rated current of 4,620 A three cables in parallel per phase have to be installed. In this design a 400 kV XLPE cable with a cross section of 2,500 mm^2 and a current carrying capability of about 1,500 A per cable is assumed.

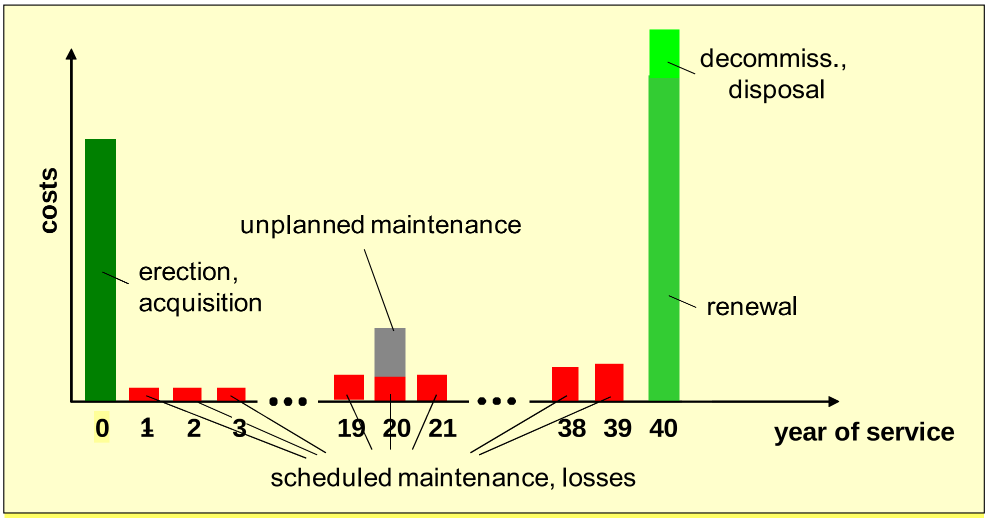
The cable costs including joints and terminations are estimated to be £5.6m per circuit km. Furthermore, 20% additional costs are adopted compared with the GIL technology for laying in a wider trench or tunnel to accommodate 9 cables per route. The costs for equipment comprise costs for cables and costs for shunt reactors, which are required for longer cable sections to compensate the capacitive charging power of the cables (**Table 7**).

Cable option	Costs for equipment [£m per circuit km]		Costs for laying [£m per route km] *)	Costs in total [£m per route km] *)
	cables	shunt reactor		
direct buried	5.6	1.1	2.3	13.5
Tunnel, prefabri-cated elements	5.6	1.1	4,0	15.2
Tunnel, concrete poured onsite	5.6	1.1	7.1	18.3
*) double circuit				

Table 7: Costs for cable connection

6. Life cycle cost assessment

It is common practice to select technology for projects based on a life cycle cost (LCC) assessment. Beside the investment costs, which are given in section 5, the LCC process also considers the cost of ownership, i. e. the operational cost as well as the costs for renewal after the end of service life of the equipment under consideration. The operational costs comprise the maintenance and the loss costs. The cost shares and the general procedure of LCC assessment is illustrated by means of **Fig. 7**.



All payments in future to be represented as present values to year 0
Discounting → interest rate: 8 % / a; inflation rate: 2 % / a

Fig. 7: General procedure of LCC assessment

At the beginning, year zero, the investment costs, i. e. the costs for erection and acquisition, are quoted. In the following years of service the maintenance and loss costs per year are considered as well as unplanned maintenance or special measures like renewal of corrosion protection. At the end of service life the costs include decommissioning and renewal. All the payments in the future are represented as present values and have to be discounted to the year zero. For discounting an interest rate of 8% and inflation rate of 2% will be taken into account over a period of 50 years.

6.1. Assessment of operational costs

The operational costs, maintenance and loss costs per route km, are estimated according to **Table 8**.

Transmission technology	Maintenance costs [1000£ per km*year]	Loss costs [1000£ per km*year]	Operational costs over 50 years , discounted [£m per km]
OHL	5.1	64.1	1.08
GIL, direct buried	1.8	46.9	0.77
GIL, tunnel	3.5		0.79
Cable, direct buried	2.4	25.8	0.44
Cable, tunnel	4.1		0.47

Table 8: Operational costs per route km (two circuits) depending on the transmission technology

The maintenance costs differ between planned and unplanned, i. e. repair costs. The planned maintenance costs for OHL include yearly inspection, by patrol, and a more intensive inspection after about 10 years. The GIL is completely surveilled by monitoring devices therefore the planned maintenance costs are distinctly lower compared with OHL. However, additional costs have to be considered for the tunnel option. For the cable options the same planned maintenance costs as for the GIL options are presumed. The unplanned maintenance costs are derived from the failure rate and the average repair costs per failure. Details are given in Annex, **Fig. A1**.

As the loss costs depend on the loading of the circuit, an average loading for both circuits of 34% of the rated current is assumed as presented in [9]. (The 100% loading of one circuit is disregarded, since it is an extraordinary case which can be ignored in the LCC assessment). Due to the 34% load current the conductor is heated to 40 or 50°C for which the conductor resistance is determined.

Additionally the following losses are considered:
OHL: Corona losses
GIL: Enclosure losses
Cable: Losses due to skin and proximity effect, sheath losses and dielectric losses

To guarantee the current carrying capability of 4,620 A in case of an outage of one circuit, (n-1) conditions, a triple bundle of an AAAC conductor with a cross section of 996 mm^2 each is used for the OHL calculations. (The reader will remember that the design in Fig. 2b would overload a double bundle conductor).

The GIL losses are determined for a conductor thickness of 16 mm and an enclosure thickness of 8.5 mm.

For the cable solution three XLPE cables in parallel with a cross section of 2500 mm^2 each are assumed.

Further details of the specific resistance assumed for different transmission technologies can be taken from Annex, **Fig. A2**.

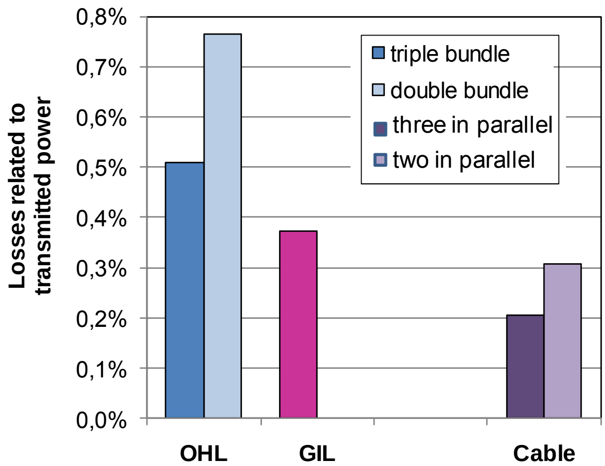


Fig. 8: Joule losses related to the transmitted power; current: 34% of rated current

Fig. 8 shows the Joule losses related to the transmitted power at 34% of the assumed rated current. The losses of the GIL solution are about 30% less than the OHL solution, if a triple bundle conductor is applied, as it is required according to the current carrying capability given in the data sheet [2]. If a double bundle conductor could be employed, the GIL losses would be more than 50% less than the OHL solution. As the cable solution requires three cables in parallel, the losses of this solution are the smallest and are 40% compared to OHL. If two cables in parallel could be employed, the cable losses would amount to about 60% of the OHL.

For the financial assessment of the loss costs a price of £37.5 per MWh was specified referring to the prices at the European Energy Exchange (EEX) for base load [10].

6.2. Assessment of renewal costs

The costs for renewal are given in **Table 9**. These costs include a share for dismounting and disposal. This share is assumed to be 15% of the investment costs for renewal. The renewal costs themselves strongly depend on the transmission technology under consideration.

Transmission technology	Renewal costs [£m per route km]	Renewal costs, discounted [£m per route km]	Renewal costs, discounted related to invest costs, [% per route km]
OHL	0.38	0.04	3.5
GIL, direct buried	12.8	0.74	6.6
GIL, tunnel	9.4	0.54	3.7 [1)]
Cable, direct buried	15.6	1.59	11.7
Cable, tunnel	11.3	1.15	6.2 [1)]
[1)] tunnel, concrete poured onsite			

Table 9: Renewal costs depending on the transmission technology

For OHL a renewal of the conductors after 40 years is presumed. The renewal of the pylons would take place after 80 years and is beyond the period under consideration. For GIL a renewal after 50 years and for cables after 40 years of service is considered. With systems laid in a tunnel only the cost for renewal of the equipment is considered. In case of buried systems the preparation of the trench and the refilling is allowed for.

6.3. Life cycle costs in total

The life cycle costs are composed of investment costs, discounted operational costs and discounted renewal costs.

Fig. 9 shows the LCC costs for the alternative solutions related to the investment costs for an OHL solution.

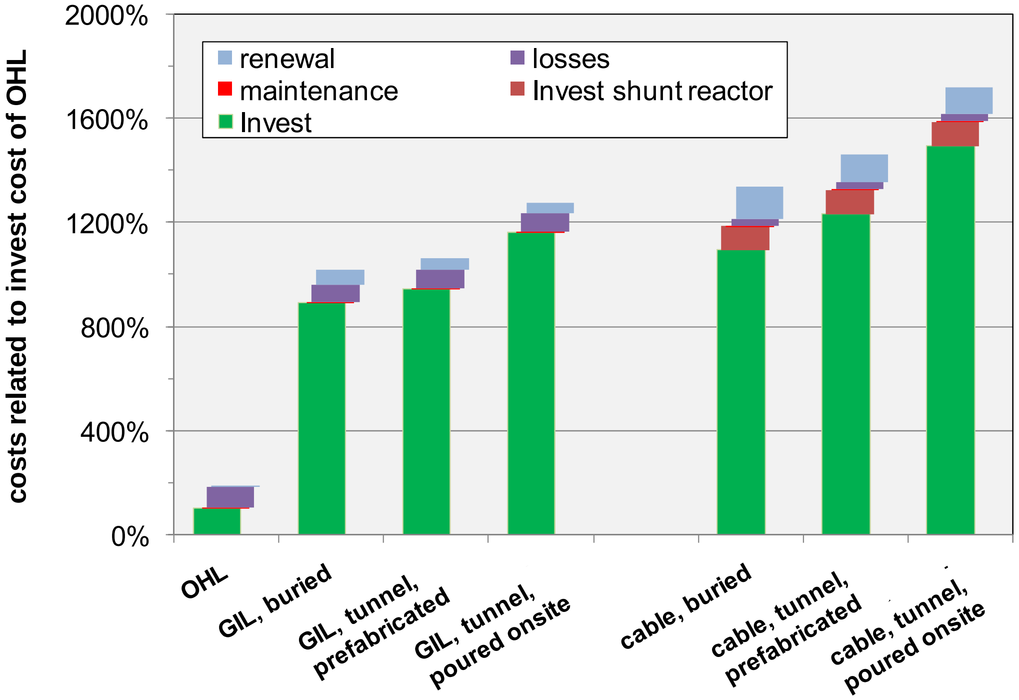


Fig. 9: Life cycle costs for different technologies related to investment costs of OHL solution (losses related to 34% of the rated current)

Based on the investment costs, the operational costs and the renewal costs quoted above, the OHL solution represents the most economic solution. The underground solutions with GIL are five to seven times more expensive. Due to the extra over cost for the tunnel, the underground solutions laid in a tunnel are more costly than the direct buried solution. The buried GIL is the most favorable underground solution. The GIL option installed in a tunnel could be of interest, since there are some benefits to the replacement procedure. But the additional investment costs compared with the direct buried solution cannot be disregarded. The underground solutions with cables are seven up to nine times more expensive compared with the OHL solution caused by the cable cost and the shunt reactor costs.

Due to these cost relations it is necessary from the ecological and economical point of view to establish this link as a hybrid line, i.e. sections in areas of outstanding natural beauty, AONB, are installed as underground lines and the other sections may be OHL. Based on the findings in section 5, 6.1 and 6.2 a LCC assessment is performed for a hybrid line consisting of 50 km OHL and 7 km underground line. The result is presented in **Fig. 10**.

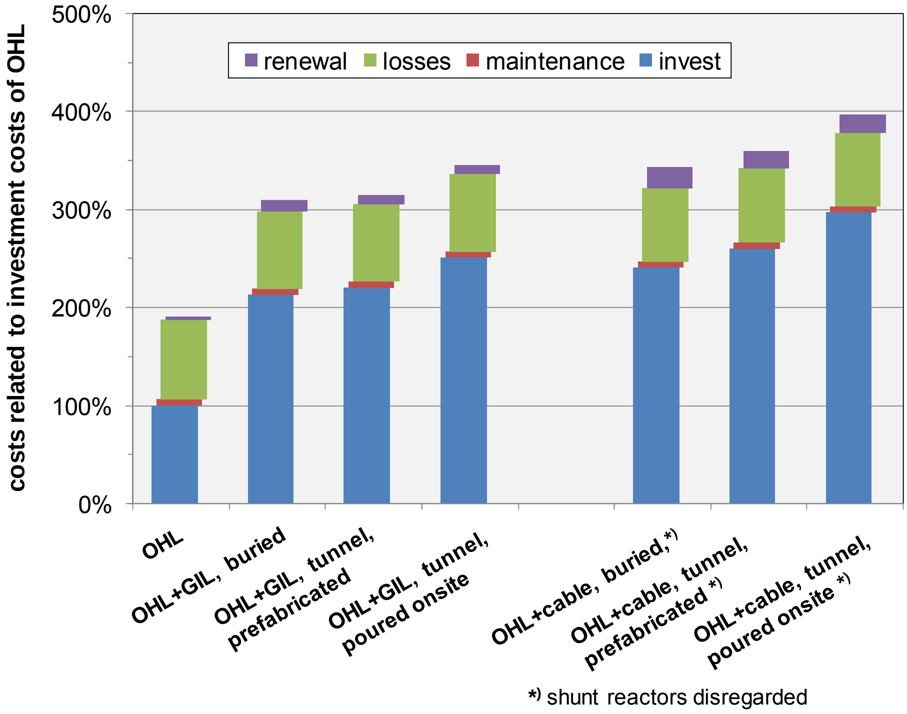


Fig. 10: LCC assessment for a hybrid line consisting of 50 km OHL and 7 km underground line

The LCC costs of a hybrid line with a 13% underground section in buried GIL technology are only about 60% more expensive when compared to a 100% OHL solution. The cable solutions are not of the best solutions due to higher costs compared to the GIL solutions and the higher non-availability.

A comparison of Fig. 9 and Fig. 10 shows that the LCC costs of a 100% underground GIL, buried or laid in a tunnel made of prefabricated elements, are 3.3 or 3.4 times respectively more than the LCC costs of the hybrid line consisting of 7 km GIL and 50 km OHL.

7. Conclusions and recommendations

The analysis of the GIL transmission technology demonstrates that a 57 km long underground connection requires considerable technical and financial expenditure compared to a conventional OHL solution. The solution is technically feasible, but needs some specific logistic provisions. Regarding the LCC costs the direct buried GIL solution is about five times more expensive than the conventional OHL solution which needs a 2,500 mm^2 AAAC type triple bundle conductor. The other underground transmission technologies – GIL in a tunnel, cable buried or laid in a tunnel – are still more expensive.

Because of the significant technical and financial expenditure it is recommended to proceed with the GIL solution in those regions where environmental concerns dominate. Therefore it is suggested to identify regions where an underground solution is of interest with regard to environmental issues. In the next step a more precise feasibility study can be carried out regarding the special condition of the region under consideration. That would allow a more defined assessment of the technical and financial expenditure which is needed for project management.

Due to the high current carrying capability requested a cable solution is less favorable with regard to availability as well as to investment and LCC costs and needs additional expenditure for shunt reactors.

Finally, it has to be noted that further aspects, loss due to property blight, loss of business and tourism, reduction in national or grid security to storms, vandalism or terrorism etc., have to be regarded in the final decision making process. These aspects were not considered in this report.

8. References

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[10] European Energy Exchange (EEX). www.eex.com

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Annex

9. Annex

OHL	5000	[£/km a]	per line (double circuit)
GIL, buried	1666	[£/km a]	per double circuit
GIL, tunnel	3332	[£/km a]	per double circuit
cable, buried	1666	[£/km a]	per double circuit
cable, tunnel	3332	[£/km a]	per double circuit

	OHL	GIL	Cable	
failure rate	0,333	0,10	0,456	failures100 km*/a
repair costs	8000	80000	80000	[£/failure]
repair costs	27	80	365	[£/km*a] per circuit
repair costs	53	160	730	[£/km*a] per double circuit

OHL	5053	[£/km a]	per line (double circuit)
GIL, buried	1826	[£/km a]	per double circuit
GIL, tunnel	3492	[£/km a]	per double circuit
cable, buried	2396	[£/km a]	per double circuit
cable, tunnel	4062	[£/km a]	per double circuit

Table A1: Planned and unplanned maintenance costs

		Specific loss resistance per phase [mΩ / km]	Losses per circuit [kW / km]
OHL	AAAC conductor type, 996 mm^2 per conductor, 50°C conductor temperature, triple bundle	12.0	97.6 [1)]
GIL	Aluminium conductor & enclosure, 16 mm conductor thickness, 8.5 mm enclosure thickness, 40°C conductor temperature, 30°C enclosure temperature	9.64	71.4
Cable	XLPE, Cu conductor, 2500 mm^2 cross section, 50°C conductor temperature, 3 cables in parallel	3.61	39.2 [2)]

[1)] including corona losses

[2)] including dielectric losses

Table A2: Specified loss resistance and Joule losses for the different transmission technologies under consideration