PROPOSED BEAULY TO DENNY 400kV STEEL TOWER DOUBLE CIRCUIT OVERHEAD ELECTRICITY TRANSMISSION LINE

THE USE OF UNDERGROUND CABLE AS AN ALTERNATIVE TO OVERHEAD LINE IN SPECIFIC LOCATIONS – INQUIRY DOCUMENT APL 5/16

Errata

It has been pointed out that there are transcription errors in the January 2007 report "The use of Underground Cable as an alternative to Overhead Line in Specific Locations", designated as Inquiry Document APL 5/16. With apologies, this note details these errors, and accompanies replacement pages for the report.

It should be noted that these errors do not in any way reflect the substance or conclusions of the report. (The original report pages, which these replace, may be discarded.)

1. **Figure 2-7, page 19:**

   This diagram is no longer classed "Preliminary – For Comment Only"

   The present attachment of pages 18 and 19 updates this situation.

2. **Table 4-2, page 51:**

   Whilst the caption for this table "Beauly-Denny – Summary Costs – Direct buried 2500mm2 Cable" is correct, the figures in the body of the table were taken from another table in Appendix 6 – that on page 152 instead of page 153.

   The present attachment of pages 50 and 51 corrects this error.

3. **Paragraphs 263 and 264, page 54:**

   The cost per km of UGC in paragraph 263 should have read £9.6M/km (instead of £1.08/km).

   Paragraph 264, which relates to paragraph 263, has been slightly re-worded to improve clarity.

   The present attachment of pages 54 and 55 reflects these changes.

4. **Tables 5-12, 5-17, 5-22 and 5-27, on pages 85, 91, 104 and 112 respectively:**

   A transcription error has occurred in Section II "Cable Route Costs" in each of these tables. In every case the "Total cable route for section" cost (£k) was stated as 53925. The correct values are given below, and the present attachments correct these errors.

Table 5-12:	Case study 2 – Total cable route for section (£k) =	42281
Table 5-17:	Case study 3 – Total cable route for section (£k) =	29957
Table 5-22:	Case study 4 – Total cable route for section (£k) =	73356
Table 5-27:	Case study 5 – Total cable route for section (£k) =	52736

(Note: The figures for Case Study 1, given in Table 5.7, are correct.)

5. Chapter 9 Abbreviations, page 130:

The explanation of “HGDL” has been added, and the present attachment of pages 130 and 131 reflects this addition.

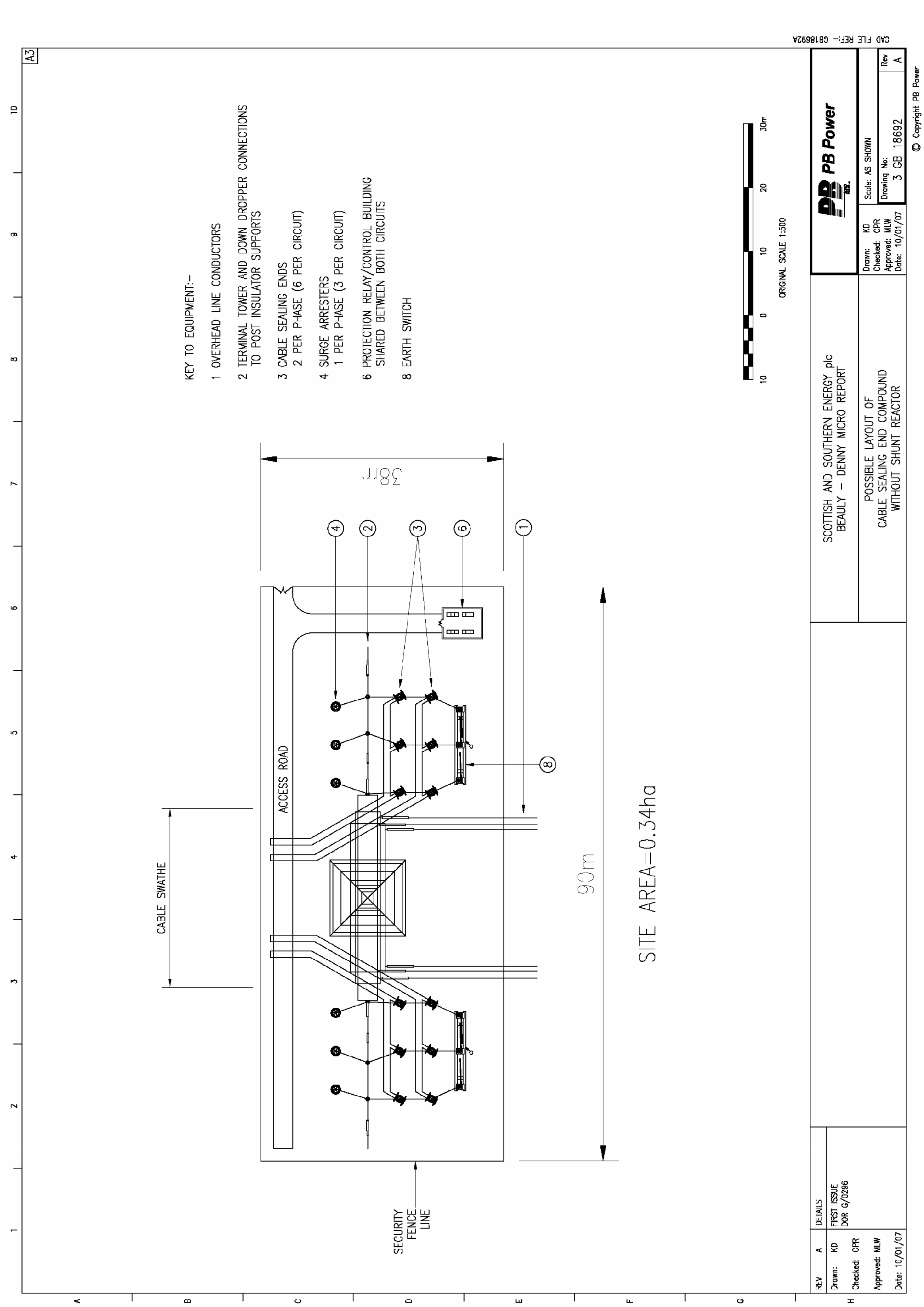
MLW
16 February 2007

107) However, system modelling for the five selected case studies shows that, technically at least, there is the possibility of relocating some of these reactors from the cable sealing end compounds to nearby substations, with a resultant cut in the number of reactors required from twelve to six. This will only be possible if there is adequate space at the substations to house the reactors, and if planning permission for their extension can be obtained. Figure 2-7 shows a sample sealing end compound layout without reactors. By comparing the compound layouts in Figure 2-6 and Figure 2-7 it can be seen that the ground area of each compound may be reduced by about 0.1 hectares if the reactors can be relocated to the substations.

108) In the costs that are presented later in this report, it has been assumed that reactive compensation has been placed at the nearest substations to the UGCs.

109) It should be noted that a terminal tower, cable sealing ends, surge diverters, earthing switches, post insulators for busbar support and relay building would be required at each cable sealing end compound regardless of whether compensating reactors are located in the compound or at nearby substations. Appendix 10 depicts the terminal tower and connections to sealing ends.

Figure 2-7 Cable sealing end compound layout - without shunt reactors



Current Rating:	Matching the post-fault continuous winter rating at 90˚C of the 2 x 700mm^2 (Arucaria) overhead line circuit (4050 amps)

4.5 Summary of Costs

4.5.1 Base Case

248) The cost estimates for the base case options for each of the five case studies are provided in Table 4-2. It will be seen from this base case that the average cost of 1 km OHL, including capitalised maintenance and replacement in 40 years time, is estimated at about £0.97M, and, with contingency included too, is estimated at £1.07M.

249) Similarly, the average cost of 1km cable, given the same maintenance, 40 year replacement conditions, and its own contingency, is estimated at £14.4M (or £13.3M if the cost of works at the ends of the cable are ignored). The overall cost ratio in this case between OHL and UGC is thus approximately 15.5 times.

250) Appendix 6 provides equivalent cost summary tables for all the combinations that may be obtained from the options on the three parameters listed in Table 4-1 above (eight combinations including the base case option).

Table 4-2 Beauly-Denny – Summary Costs – Direct buried 2500mm^2 Cable

Estimate parameters:-

Cable voltage = 275kV & 400kV
Cable diameter = 2500sqmm
Cables in ducts or direct-buried = direct-buried
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	**Garva Bridge to South Dalwhinnie**	**Lower Taylorton - Logie (Stirling SE)**	**Lower Taylorton - Cocksburn Wood (Stirling SE + NE)**	**Glen Burn to Touch Road (Stirling W)**	**Average with contin-gency**	**Average without contin-gency**
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.45	9.61	7.71	12.54	10.19		
B. Cable route construction & lifetime costs (£M)	53.93	42.28	29.96	73.36	52.74		
Total cable costs (£M)	64.37	51.89	37.67	85.90	62.92		
Cable costs inc. 15% contingency (£M)	74.03	59.67	43.32	98.78	72.36		
Cable cost per km (£M/km) - but see below	11.02	12.83	14.49	11.73	12.49	14.4	12.5
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	68.15	56.09	40.87	92.80	67.74		
Cable cost compared to OHL (times)	12.6	16.7	17.7	16.5	15.7	15.5	14.8
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	10.06	11.73	13.47	10.72	11.47	13.2	11.5

259) Further information on the costing approach and assumptions may be found in Appendix 5.

4.5.4 Conclusions

260) OHL costs, including contingency, are estimated at around £1.08M/km.

261) UGC costs, including contingency, are estimated at around £14.1M/km.

262) On this basis, the mid-point UGC / OHL cost ratio is estimated at about 15.6.

263) UGC costs, excluding contingency and using estimates 20% below supplier central expectations, are estimated at around £9.6M/km.

264) The mid-point UGC / OHL cost ratio is estimated at 10.6.

265) The actual costs of undergrounding even one of these case study sections, for example the Beauly – Eskadale section, would be at least an extra £66M above the cost of the equivalent OHL.

CHAPTER 5: CASE STUDIES

5.1 Introduction

266) This section considers undergrounding in three locations in proximity to the overhead line route. In the SHETL area there are two case studies, each with their own location: in the SPT area, a single location includes three case studies. These case studies were selected in order to encompass the majority of the types of circumstance that may be encountered in underground cable routing.

267) Co-ordinates given in the form “NH 494 443” are approximate ordnance survey reference points. The cases were studied in the order running from north to south, and they are thus presented in this order. The following generic considerations were addressed prior to finding a cable route for each case study.

5.2 Cable System Design Considerations

268) The main engineering aspects considered for these cable system designs are:

- Cable system performance requirements voltage and rating,
- Installation method, location and routing,
- Power cable and accessory design, and
- Cable section lengths and trench arrangement.

5.2.1 Cable System Performance Requirements, Voltage and Rating:

269) The cable system operating line voltage and current rating are determined by the overall power transmission design requirements.

270) Power cable systems generate heat when transmitting power between source and load. This heat is generated by cable losses, principally conductor resistive (I^2R) losses. A 90°C limit is set for XLPE insulated cables under continuous operation. The heat generated must be dissipated into the environment if the cable conductor is not to overheat.

271) Secondary heat loss generation also occurs in the cable’s metallic sheath and in the XLPE insulation; the latter being a dielectric loss. These heat losses, together with the conductor heat loss comprise the total heat loss that must be transferred from the cable into the environment during operation.

272) The materials surrounding the conductor thermally insulate the conductor from the environment and restrict the heat transfer. The heat flow is also further restricted by the materials used to bury the cables in the ground. A minimum depth of burial of 1150mm has been applied in accordance with SHETL’s agreement with the National Farmers Union that cable cover tiles shall be covered by at least 1000mm of soil to prevent inadvertent damage, particularly in areas subject to ploughing.

273) The continuous current carrying capacity of cables is therefore restricted by the amount of heat generated and the rate at which this heat energy is capable of being dissipated whilst limiting the maximum conductor temperature to 90°C. When calculating continuous ratings (using the international standard IEC 60287), all cable heat loss is considered to eventually dissipate into the atmosphere. This calculation

Table 5-11 Case Study 2 – OHL costs

		Garva Bridge to South Dalwhinnie
A. OHL Construction costs for Case Study (£k)		
Length (km):		3.65
Tower type:		SSE400
	D std (no. off)	9
	D55 (no. off)	1
	DT (no. off)	0
Tower Steelwork (£k):		
	D std	280
	D55	63
	DT	0
Tower Foundations (£k):		
	D std	56
	D55	22
	DT	0
Conductors, inc. OPGW (£k):		934
Insulators & fittings (£k):		175
Labour, Engineering & Project Mgmt (£k):		1020
Total works (£k):		2550
Accommodation + compensation per Case Study (£k):		184
Case study environmental measures & PR (£k):		17
Construction and Accommodation Totals (£k):		2751
NB: Balfour B Construction "Differences" estimates (£k)		1520
B. OHL Operational costs (£k over 40 year life) - DCF rate = 6%		
Maintenance (£k)		205
Wayleaves (£k)		52
40-year replacement (£k)		248
Total operational costs for Case Study OHL (£k)		504
Operational costs (£/km/annum)		3
Total costs for Case Study OHL (£k)		**3255**
Total costs for Case Study OHL inc. 10% contingency (£k)		**3581**
Total OHL cost per km (£k/km): average = £1049k / km)		982

UGC costs

346) The length of the cable, and the number of joints that would be used to underground this section of overhead line are to be found at the top of Table 5-12. Below these items, in the same table, will be found the UGC cost estimates for this case study. Please refer to the notes in Case Study 1, Paragraphs 317) to 322), which apply equally to this Case Study.

Table 5-12 Case Study 2 – UGC costs

	Garva Bridge to South Dalwhinnie
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	4.044
No. of UGC joints joints in section	5
A. Construction Costs	
i. CABLE-END COSTS	
Sealing-end terminal tower	
steelwork	246
foundations & construction	173
2 Sealing-end compounds:	
Cable termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	50
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	40
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	100
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	10
land purchase	20
access road > 150m	0
Total cable-end for section	5173
ii. CABLE ROUTE COSTS	
400kV UGC	8978
275kV UGC	8007
Cable joints	1398
Other equipment - supply and install	2655
Civils - supply and install	20894
Accommodation (not wayleaves)	100
Route environmental measures	250
Total cable route for section	42281
Total construction costs for Case Study UGC (£k)	47453
Total UGC cost per km (£k/km, average= £11492k / km)	11734
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	227
Wayleaves (£k)	131
40-year replacement (£k)	4077
Total operational costs for Case Study UGC (£k)	4434
Total costs for Case Study UGC (£k)	51888
Total costs for Case Study UGC inc. 15% contingency (£k)	59671
Total UGC cost per km (£k/km): average = £14389k/km)	14755

Table 5-16 Case Study 3 – OHL costs

		Lower Taylorton - Logie (Stirling SE)
A. OHL Construction costs for Case Study (£k)		
Length (km):		2.39
Tower type:		L12
	D std (no. off)	5
	D55 (no. off)	3
	DT (no. off)	0
Tower Steelwork (£k):		
	D std	109
	D55	127
	DT	0
Tower Foundations (£k):		
	D std	22
	D55	44
	DT	0
Conductors, inc. OPGW (£k):		612
Insulators & fittings (£k):		115
Labour, Engineering & Project Mgmt (£k):		686
Total works (£k):		1715
Accommodation + compensation per Case Study (£k):		155
Case study environmental measures & PR (£k):		11
Construction and Accommodation Totals (£k):		1881
NB: Balfour B Construction "Differences" estimates (£k)		n/a
B. OHL Operational costs (£k over 40 year life) - DCF rate = 6%		
Maintenance (£k)		147
Wayleaves (£k)		20
40-year replacement (£k)		178
Total operational costs for Case Study OHL (£k)		345
Operational costs (£/km/annum)		4
Total costs for Case Study OHL (£k)		**2226**
Total costs for Case Study OHL inc. 10% contingency (£k)		**2448**
Total OHL cost per km (£k/km): average = £1066k / km)		1025

UGC costs

358) The length of the cable, and the number of joints that would be used to underground this section of overhead line are to be found at the top of Table 5-17. Below these items, in the same table, will be found the UGC cost estimates for this case study. Please refer to the notes in Case Study 1, Paragraphs 0 to 322), which apply equally to this Case Study.

Table 5-17 Case Study 3 – UGC costs

	Lower Taylorton - Logie (Stirling SE)
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	2.6
No. of UGC joints joints in section	3
A. Construction Costs	
i. CABLE-END COSTS	
Sealing-end terminal tower	
steelwork	174
foundations & construction	137
2 Sealing-end compounds:	
Cable termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	50
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	40
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	100
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	7
land purchase	13
access road > 150m	20
Total cable-end for section	5074
ii. CABLE ROUTE COSTS	
400kV UGC	5772
275kV UGC	5148
Cable joints	839
Other equipment - supply and install	1996
Civils - supply and install	15838
Accommodation (not wayleaves)	64
Route environmental measures	300
Total cable route for section	29957
Total construction costs for Case Study UGC (£k)	35031
Total UGC cost per km (£k/km, average= £11492k / km)	13473
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	134
Wayleaves (£k)	63
40-year replacement (£k)	2443
Total operational costs for Case Study UGC (£k)	2639
Total costs for Case Study UGC (£k)	37670
Total costs for Case Study UGC inc. 15% contingency (£k)	43321
Total UGC cost per km (£k/km): average = £14389k/km)	16662

UGC costs

377) The length of the cable and the number of joints that would be used to underground this section of overhead line are to be found at the top of Table 5-22. Below these items, in the same table, will be found the UGC cost estimates for this case study. Please refer to the notes in Case Study 1, Paragraphs 0 to 322), which apply equally to this Case Study.

Table 5-22 Case Study 4 – UGC costs

	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	7.32
No. of UGC joints joints in section	11
A. Construction Costs	
i. CABLE-END COSTS	
Sealing-end terminal tower	
steelwork	174
foundations & construction	137
2 Sealing-end compounds:	
Cable termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	50
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	40
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	100
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	18
land purchase	36
access road > 150m	20
Total cable-end for section	5109
ii. CABLE ROUTE COSTS	
400kV UGC	15906
275kV UGC	14496
Cable joints	3076
Other equipment - supply and install	4684
Civils - supply and install	34413
Accommodation (not wayleaves)	181
Route environmental measures	600
Total cable route for section	73356
Total construction costs for Case Study UGC (£k)	78465
Total UGC cost per km (£k/km, average= £11492k / km)	10719
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	376
Wayleaves (£k)	178
40-year replacement (£k)	6877
Total operational costs for Case Study UGC (£k)	7431
Total costs for Case Study UGC (£k)	85896
Total costs for Case Study UGC inc. 15% contingency (£k)	98781
Total UGC cost per km (£k/km): average = £14389k/km)	13495

5.7 Case Study 5 - Glen Burn to Touch Road

5.7.1 Finding a Cable Route

378) The cable route between Glen Burn and Touch Road traverses through farm land of which the sort shown in Figure 5-29 Preliminary Route Option is typical.

Figure 5-28 View from road near Craigarhall Plantation looking south

379) The preliminary route plot is shown in Figure 5-29.

Figure 5-29 Preliminary Route Option

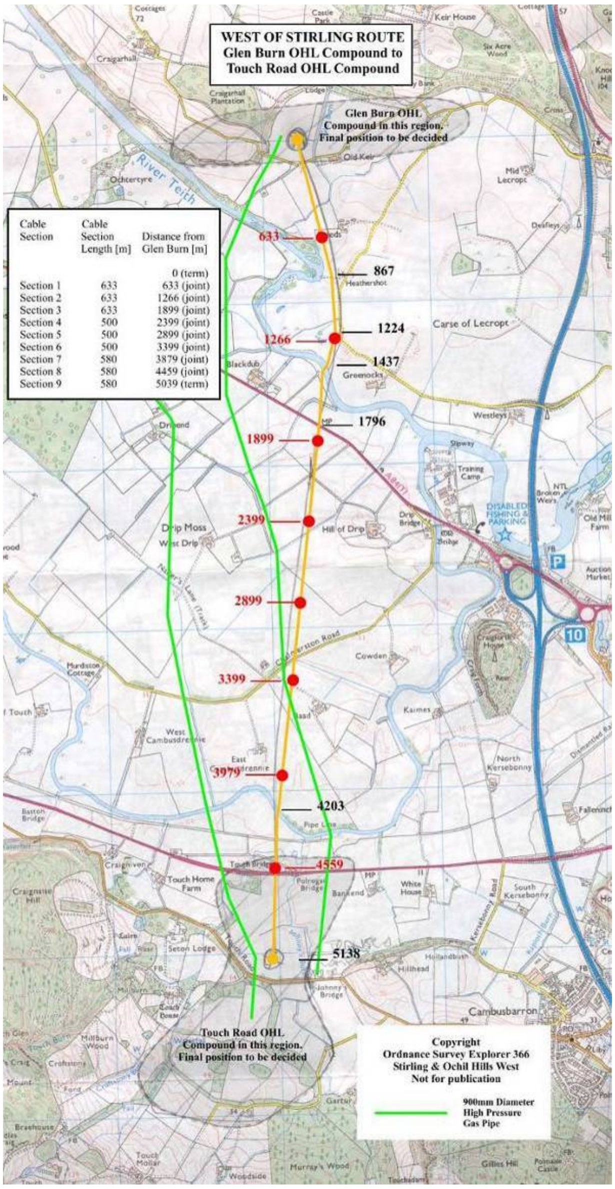


Table 5-26 Case Study 5 – OHL costs

		Glen Burn to Touch Road (Stirling W)
A. OHL Construction costs for Case Study (£k)		
Length (km):		4.90
Tower type:		L12
	D std (no. off)	11
	D55 (no. off)	2
	DT (no. off)	0
Tower Steelwork (£k):		
	D std	240
	D55	85
	DT	0
Tower Foundations (£k):		
	D std	48
	D55	30
	DT	0
Conductors, inc. OPGW (£k):		1254
Insulators & fittings (£k):		236
Labour, Engineering & Project Mgmt (£k):		1262
Total works (£k):		3155
Accommodation + compensation per Case Study (£k):		317
Case study environmental measures & PR (£k):		22
Construction and Accommodation Totals (£k):		3494
NB: Balfour B Construction "Differences" estimates (£k)		n/a
B. OHL Operational costs (£k over 40 year life) - DCF rate = 6%		
Maintenance (£k)		302
Wayleaves (£k)		41
40-year replacement (£k)		365
Total operational costs for Case Study OHL (£k)		708
Operational costs (£/km/annum)		4
Total costs for Case Study OHL (£k)		**4201**
Total costs for Case Study OHL inc. 10% contingency (£k)		**4622**
Total OHL cost per km (£k/km): average = £1066k / km)		943

UGC costs

387) The length of the cable, and the number of joints that would be used to underground this section of overhead line are to be found at the top of Table 5-27. Below these items, in the same table, will be found the UGC cost estimates for this case study. Please refer to the notes in Case Study 1, Paragraphs 0 to 322), which apply equally to this Case Study.

Table 5-27 Case Study 5 – UGC costs

	Glen Burn to Touch Road (Stirling W)
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	5.039
No. of UGC joints joints in section	8
A. Construction Costs	
i. CABLE-END COSTS	
Sealing-end terminal tower	
steelwork	174
foundations & construction	137
2 Sealing-end compounds:	
Cable termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	50
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	40
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	100
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	13
land purchase	25
access road > 150m	0
Total cable-end for section	5072
ii. CABLE ROUTE COSTS	
400kV UGC	11187
275kV UGC	9977
Cable joints	2237
Other equipment - supply and install	3571
Civils - supply and install	25340
Accommodation (not wayleaves)	125
Route environmental measures	300
Total cable route for section	52736
Total construction costs for Case Study UGC (£k)	57808
Total UGC cost per km (£k/km, average= £11492k / km)	11472
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	259
Wayleaves (£k)	122
40-year replacement (£k)	4734
Total operational costs for Case Study UGC (£k)	5115
Total costs for Case Study UGC (£k)	62923
Total costs for Case Study UGC inc. 15% contingency (£k)	72362
Total UGC cost per km (£k/km): average = £14389k/km)	14360

CHAPTER 9: ABBREVIATIONS

AC	Alternating current
CBS	Cement bound sand (14:1 sand to cement mix by volume)
Circuit	This report refers often to "circuits". A circuit is the simplest way of connecting two parts of a power transmission network together. A very high voltage AC power circuit almost always comprises three conductors (or bundles of conductors) - the three AC phases – since this is the most efficient way of transmitting the energy, and these three phases may be held above ground (in the case of an overhead line) or below ground (in the case of an underground cable. In the UK the transmission system is normally designed to have two circuits running on each route, which provides continuity of supply should one circuit become faulty. For this reason there are normally 6 sets of power conductors supported by any very high voltage pylon. (The seventh wire, at the top of the structure, does not carry power, but acts as a lightning conductor to reduce losses of supply due to lightning strikes.)
DTI	Department of Trade and Industry
DTS	Distributed temperature sensing system. This is used to measure temperatures along a length of fibre optic cable attached to a power cable
EIA	Environmental Impact Assessment
HGDL	Historic Gardens and Designed Landscapes
kV	Kilovolt – 1000 Volts
LOD	'limits of deviation' – the limits of deviation of tower positions from a proposed centre-line
MVA	Mega Volt Ampere
MVAR	Mega Volt Ampere Reactive
NGET	National Grid Electricity Transmission Company
OHL	Overhead line
PI	Public Inquiry

pu	per unit (alternative to expressing percentage)
SHETL	Scottish Hydro Electric Transmission Ltd (SSE)
SPT	SP Transmission Ltd
SSE	Scottish and Southern Energy (sometimes referred to as SHETL)
TOV	Temporary overvoltage
UGC	Underground cable
XLPE	Cross-linked polyethylene

Scottish Hydro Electric

ScottishPower

Proposed Beauly to Denny 400kV Overhead Transmission Line

The Use of Underground Cable as an alternative to Overhead Line in Specific Locations

FINAL REPORT
JANUARY 2007

PB POWER

In association with

mtla .co.uk

CCI *Cable Consulting International Ltd.*

EXECUTIVE SUMMARY

1) This document has been commissioned by Scottish Hydro Electric Transmission Ltd in association with SP Transmission Ltd. The overall objective is to examine the specific environmental, technical, cost and programme implications of underground cable installations. Five case studies have been selected because, collectively, they encompass the majority of the types of circumstances that may be encountered in underground cable routeing.

2) The method of investigation is that of "case study". The locations of the case studies resulted from the overall objective and from the need to include within the studies, amongst other things:

- Crossings of roads,
- Crossings of railways,
- Crossings of rivers,
- Variety of ground cover / habitat,
- Geometric pattern of landscape,
- Steep slopes, and
- Running cable out of substations for a length of the route.

3) From north to south, the three locations are:

- Within SHETL's area-

Location 1 Study 1	Beauly Substation to Eskadale Wood
Location 2 Study 2	Garva Bridge to South Dalwhinnie

- Within SPT (Stirling) area - based on 3 scenarios as follows-

Location 3 Study 3	Under grounding from foot of Ochils escarpment to south of the River Forth
Location 3 Study 4	Under grounding from the SHETL / SPT boundary on Sherrifmuir to south of the River Forth
Location 3 Study 5	Under grounding on the west of Stirling from a suitable agreed location to the west of Dunblane to an area in the vicinity of Cambusbarron

4) The study looks at a number of technical options (voltage, underground cable size, and method of cable burial), and concluded that:

(i) technically viable cable routes could be found for each of the case studies,

(ii) a list of cable routeing considerations have been identified, but this does not preclude any proposed cable route needing to be considered carefully on a case-by-case basis to achieve an acceptable balance between technical, environmental and cost considerations,

(iii) the case studies support the long-held proposition that there is no reason to assume that an underground cable route would be the same route that an overhead line route would follow,

(iv) the environmental impact of underground cable (both short and long term) may be considerable, though once installed its visual impact is likely to be lower than that of overhead lines except at the cable sealing ends,

(v) in Britain, Europe, and around the world, at transmission voltages very little underground cable is used when compared to overhead lines, especially in rural areas,

(vi) at 275kV and 400kV, oil-filled cable is becoming obsolete for AC transmission purposes. XLPE designs are now the main solution for new installations. However, there is still relatively little running experience (and thus relatively little reliability experience) with 400kV XLPE cable systems, especially buried systems with large conductor designs over long distances (above 1km),

(vii) based on the five case studies, the costs for the underground cable solutions for the Beauly-Denny connection are likely to be between 12 and 18 times more than their overhead line equivalents, and

(viii) though the cost ratios between UGC and OHL are discussed in this document, it is noted that in practical terms the actual sums of money involved are the more relevant quantities to report for a given application. For example, the difference in cost of undergrounding just the Beauly – Eskadale section of the proposed route is likely to cost at least £66M more than the overhead line solution.

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CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 SHETL and SPT Legal Obligations

5) Scottish Hydro Electric Transmission Limited (SHETL) and SP Transmission Ltd (SPT) are required by the Electricity Act 1989 to develop and maintain an efficient, coordinated and economical system of electricity transmission, to facilitate competition in the supply and generation of electricity, and to have regard to the preservation of amenity and fisheries. To fulfil these requirements, SHETL and SPT take into account economic, operational and environmental factors to assess the advantages and disadvantages of overhead lines (OHL) and underground cables (UGC).

6) The separate licences under which SHETL and SPT operate requires them to build secure networks capable of withstanding single circuit faults without loss of supply. Therefore each strategic link in the network normally comprises two circuits, allowing uninterrupted power flow through one circuit during maintenance or repair of the other.

1.1.2 Beauly to Denny AC Transmission Project and Undergrounding

7) The Beauly/Denny AC Transmission Project is proposed as 220km of new double circuit 400kV overhead transmission line from Beauly substation to a new substation near Denny via Fasnakyle, Fort Augustus, Tummel and Braco[1].

8) The alternatives of either undergrounding the whole transmission project or sections of it have been raised through:

- Stakeholders Meetings
- Environmental Impact Assessment Scoping Opinion
- Consultation responses to the ES

9) Previous reports have established the need for the Beauly-Denny connection - see, for example, Chapter 3 of the ES - and considered the feasibility of using alternating current (AC) underground cable (UGC) to put the whole connection underground[2]. The latter work, however, concluded that to underground the entire route requires detailed analysis to confirm its technical feasibility, and would be many times the cost of an overhead line solution.

1.1.3 Purpose of This Report

10) This present report has therefore been commissioned by SHETL and SPT to consider issues associated with UGC installations. It is to examine the technical, environmental, cost and programming implications of using UGC at three locations

[1] Para 10.1.1.1 of the ES
[2] "Beauly-Denny Transmission Interconnection – A Generic Comparison of the use of alternating current (AC) underground cable as an alternative to overhead line with reference to the proposed Beauly-Denny Interconnection", PB Power for Scottish and Southern Energy, December 2006

of relevance to the Beauly-Denny OHL and is to inform the case for the proposed OHL at the Public Inquiry (PI).

11) The full terms of reference are provided in Appendix 1. These, however, may be summarised as follows:

- To review the technical, environmental and cost considerations of the use of 400kV and 275kV AC underground cables for 5 case-studies in 3 locations – 2 locations in SHETL's operational area, and one location (with 3 studies) in SPT's operational area.
- To develop an approach to circuit routeing for underground cables in SHETL and SPT areas in order to be able to assess proposals for underground cables either in terms of the whole OHL or sections of it.
- To review and refer to relevant literature.

1.1.4 SHETL Policy for New and Replacement AC Transmission Circuits

12) Each transmission project is different and requires its own careful analysis and solution.

13) SHETL has a documented policy[3] for new or replacement 275 and 400kV AC Transmission Circuits for application to major projects.

14) Key elements within the policy are clarified in the Environmental Statement (ES)[4] as follows:

- Both economic and operational factors normally support an overhead line approach to transmission circuits.
- Visual amenity can support an underground approach. However, other environmental factors, such as natural and cultural heritage considerations, the effect on the hydrology and the difficulty and length of time to re-establish ground cover, weigh against the use of cables. These factors primarily relate to the construction phase and restrictions on land use on the cable route once installed. On balance, an overhead approach is to be preferred.
- It is therefore SHETL and SPT's approach that in situations where an exceptionally high value is placed on visual amenity, and where no suitable alternative route for an overhead line can be identified, they will consider laying underground transmission cables.

15) This approach is similar to that adopted by the other licensed transmission operators in the UK.

1.1.5 SHETL and SPT Existing Transmission Circuits

16) Although SHETL and SPT have underground cables as part of their existing high voltage (132kV and above) AC transmission networks, underground cable usage is limited to 55km in SHETL's area and 217km in SPT's area. By far the greater part of the existing transmission network, 4790km in SHETL's area and 3740km in SPT's area[5], is of steel lattice tower overhead line design scaled to the operating voltage

[3] "Policy for Scottish Hydro Electric Transmission Ltd New or Replacement 275kV and 400kV Transmission Circuits", PO-PS-021 Rev:1-03

[4] Paragraph 6.3.7, Proposed Beauly to Denny 400kV overhead transmission line environmental statement volume 1 : Main text , Sept 2005. (ES)

[5] Para 6.3.1 of the ES

and local physical conditions. All the underground cables are in urban areas or where the use of OHL is impracticable.

17) The ratio of circuit lengths underground to overhead is 1.3% for SHETL's area and 5.8% for SPT's area. This compares with a recent commission of the European Communities paper which concluded that land based underground cables account for 2.4% of the total 220kV to 400kV transmission networks in Europe[6].

1.2 Approach

18) The approach has included:

- A review of technical, environmental and financial considerations regarding the use of UGC in SHETL and SPT operational areas,
- Discussions and correspondence with local and international class contractors and cable system suppliers,
- Detailed consideration of the use of UGC for the three case study locations along the 220km 400kV OHL Beauly-Denny double circuit connection,
- The development of an approach to circuit routeing through literature review, regular discussion, and the use of these case studies, including site visits, and
- A field study of the underground cables at Torness Power Station.

1.3 The Study

19) A Working Group comprising SHETL, SPT, PB Power (electricity utility consultants) MTLA (landscape architects) and CCI (Cable Consulting International) undertook the study and prepared this Report.

20) In addition, the companies ENVIROS and SAC Environmental have been commissioned to undertake a literature review on the effects of construction compaction and heat dissipation on reinstated vegetation. In addition they have been asked to carry out a field study of soil temperatures to be found around an underground power cable at different locations near Torness Power Station.

21) Pending completion of the Enviros and SAC study the conclusions of this present report thus remain provisional. It is anticipated that the Enviros and SAC study will be complete by mid January 2007, following which an addendum to this report will be prepared.

1.4 Structure of this Report

22) Chapter 2: Considerations for Underground Cable Systems, provides information on the type of cable system to be employed and its method of installation.

23) Chapter 3: Environmental Considerations, discusses the environmental aspects of a cable installation.

24) Chapter 4: Financial Considerations, discusses the financial implication of the various design alternatives considered and compares the UGC and OHL costs for the case studies.

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[6] Para. 6.3.1.2 of the ES

25) Chapter 5: Case Studies, discusses five individual underground cable routes in three areas along the Beauly to Denny overhead line route.

26) Chapter 6: Approach to Circuit Routeing, this chapter discusses the methods used to route an underground cable.

27) Chapter 7: Review of XLPE Insulated Cable Circuits in Operation. There are a number of circuits installed around the world at 275kV and 400kV. This chapter reviews the XLPE installations currently in service.

28) Chapter 8: Overhead Line or Underground Cable: Summary Comparison and Conclusions. This chapter summarises the findings regarding the use of UGC as opposed to OHL.

29) Chapter 9: Abbreviations. This chapter lists the abbreviations used within the study.

30) Chapter 10: Reviewers and Contributors. List of the reviewers and contributors to this report.

CHAPTER 2: CONSIDERATIONS FOR UNDERGROUND CABLE SYSTEMS

2.1 EHV Cable Systems

31) In the past the dominant extra high voltage (EHV) cable designs in the United Kingdom have been low pressure oil filled cables (also known as fluid filled cables) which have a paper or paper and polypropylene laminate insulation. However, these cables are becoming obsolete and new installations are using cross-linked polyethylene (XLPE) insulated cable designs. It is thus recommended that if any underground cable sections are to be used on the Beauly-Denny connection, then XLPE insulated cables shall be employed.

32) Figure 2-1 illustrates 400kV XLPE cable and its constituent components and features. Visually, 275kV XLPE is very similar to its 400kV equivalent.

33) The design of a cable system will have been the subject of long term reliability testing before being adopted by a utility for its strategic circuits.

2.1.1 Conductors

34) Directly buried cable circuits do not receive the benefit of air cooling and in order to meet the current rating requirement for the Beauly – Denny connection a cable circuit needs twice the number of conductors as an overhead line.

35) Being mostly underground, there is little chance of the conductors being struck by lightning.

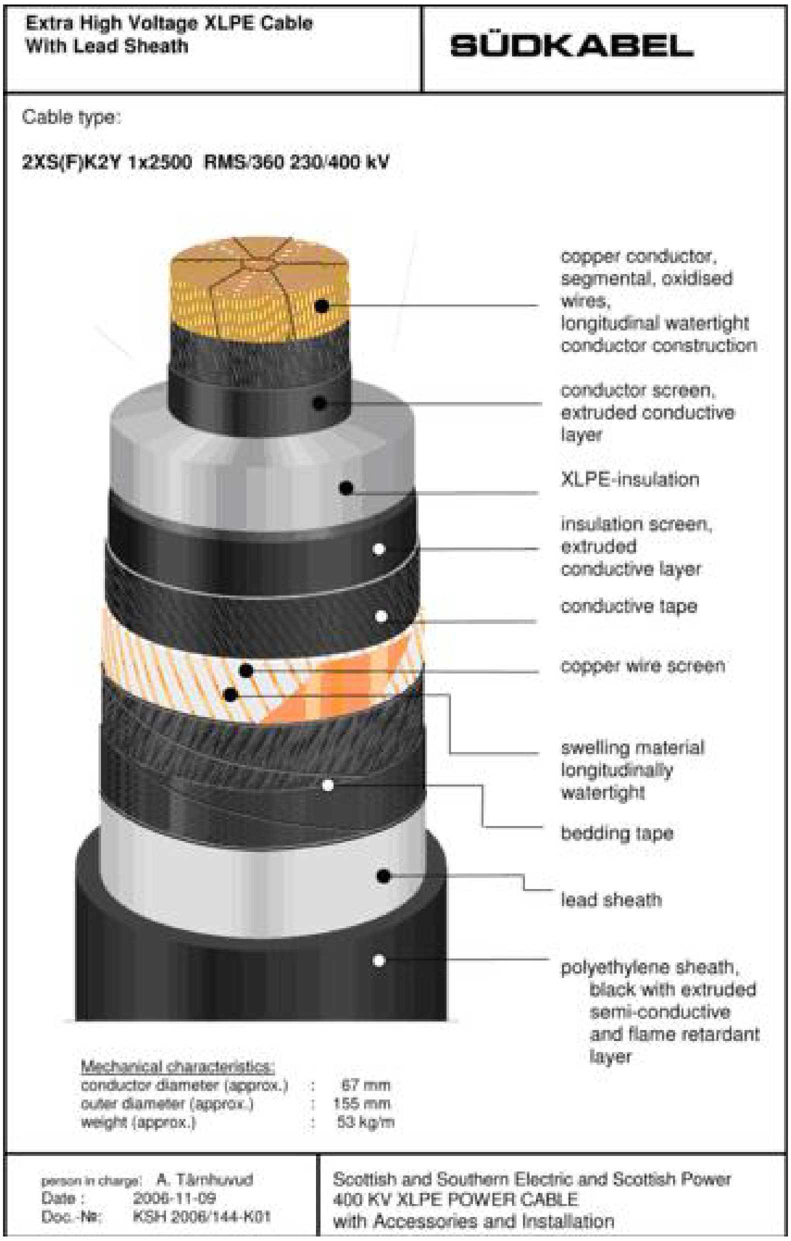
36) There is a requirement for one or more earth conductors to ensure an adequate return path for fault currents. These conductors may be integrated into the cable design or where necessary, such as on end point bonded systems, supplied as a separate earth conductor.

37) EHV transmission conductors are made from either copper or aluminium. Solid or stranded aluminium conductors are available but for the high power transmission requirements such as the connection between Beauly and Denny, stranded copper conductors are required due to copper's lower electrical resistance. The strands of a copper conductor may also be surface treated (e.g. with oxidisation or enamelling) to reduce the conductor's A.C. resistance.

38) For high power connections the conductors consist of a number of individual wires stranded together into conductor segments (six segments is typical) which are twisted together to form a circular conductor. This geometric arrangement of conductor wires is designed to further reduce the conductor's AC resistance.

39) As AC conductors become larger there is a diminishing return on their current carrying capacity. Large conductors are also difficult to manufacture and handle due to the large number of wires to be stranded together, the conductor's weight and its minimum bending radius. For EHV transmission cable the conductor size range is generally between 500mm² to 2500mm². 3000mm² conductors are available on the market however these have a limited economic application.

Figure 2-1 400kV XLPE Insulated Cable (courtesy Südkabel Gmbh



40) For buried cables it is advisable to use a water blocked conductor design. Conductor water blocking limits the extent of any water ingress into the cable should severe damage occur (for example due to a fault). During manufacture the conductor wires are compacted together with a water blocking tape or powder. The water blocking agent is designed to swell-up when in contact with moisture and prevent water penetrating for hundreds of metres along the cable. This water penetration can be rapid, particularly in an area where the cable is installed below the water table.

41) When cable conductors are connected together it is necessary to remove both the conductor wire coatings and the water blocking agents at the jointing position prior to assembling the joint or termination. This is necessary to ensure a good electrical connection between one conductor and the next at the joint position. If this is not achieved the connection will overheat and damage the joint.

42) A full radial and longitudinal water blocked cable design is thus preferred for a buried installation to limit the extent of any water penetration into the cable in case of cable damage.

2.1.2 Conductor Screen

43) The conductor screen consists of a semi-conducting compound which is designed to electrically smooth the surface of the conductor to present an unblemished surface to the insulation. The conductor screen is extruded onto the cable conductor along with the insulation and the insulation screen in a single process. This is achieved using a triple headed extrusion die where the screen and insulation compounds are injected into a die simultaneously.

2.1.3 Insulation

44) XLPE insulation consists of thermoplastic polythene molecules which have been cross-linked to produce a thermosetting material. The non cross-linked polythene and the cross-linking agents which are to form the insulation are extruded at high temperatures and pressures. This process must be completed under clean and controlled conditions to prevent gas cavities, material contamination, screen blemishes and conductor eccentricity which may adversely affect cable performance.

45) Following extrusion the cable must undergo a period of degassing. During this process the cable is heated in an oven for several weeks to remove a substantial percentage of the by-products of the insulation cross linking process. These by-products must be removed from the insulation if the desired service life of the cable is to be achieved.

46) At room temperature, XLPE is a white translucent polymer. XLPE capable of operating at temperatures up to 90ºC. Research organisations are active in studying the performance of XLPE materials above 90°C however at around 105 ºC XLPE changes its crystalline state and becomes a transparent soft and flexible material. It is current practice to limit the temperature of XLPE insulated EHV cables to 90°C under normal operating conditions.

47) It is essential that XLPE insulation is kept free of water when used on extra high voltage (EHV) cables. If water is allowed to come into contact with the insulation the high electric stress in the cable causes the formation of water trees which gradually destroy the properties of the XLPE insulation resulting in electrical failure.

2.1.4 Insulation Screen

48) The insulation screen consists of a semi-conducting compound which is designed to electrically smooth the surface of the outer earthed sheath to present an unblemished surface to the insulation.

2.1.5 Metallic Barrier

49) EHV transmission voltage cables require a moisture impermeable metallic barrier around the insulation screen. A number of alternative designs for the metallic barrier have been offered by manufacturers. These may be broken down into two categories a) seamless and b) seamed.

50) Prior to the application of a metallic barrier semi-conducting protective cushioning and water blocking tapes are applied. In addition, outer screening wires may also be

applied to meet the charging current and fault current carrying requirements for the system along with further cushioning and water blocking semi-conducting tapes.

51) Seamless metallic barriers (sheaths) are extruded form either lead alloy or aluminium. The manufacturing equipment required to apply these sheaths is large and expensive for manufacturers to install, maintain and operate. These sheaths are used on oil filled cables. Lead sheaths are the most common type of seamless metallic barrier being used for both underground and sub-sea applications. Extruded sheaths also have excellent water tightness and are considered to be more mechanically robust than seamed constructions.

52) Seamed metallic barriers consist of a flat metal strip or foil applied longitudinally with the longitudinal seam being brazed, welded or glued. The manufacturing equipment required to apply this type of metallic barrier is less expensive to install maintain and operate than a seamless design. Manufacturers offer a number of alternative materials for the seamed sheath including aluminium, copper and stainless steel. Cables with seamed barriers are lighter and less expensive to manufacture than seamless metallic sheathed cables. Some manufacturers offer seamed barriers that use a thin metal foil with the seam being secured by means of an adhesive.

53) For the Beauly – Denny transmission circuits the design of any cable would require it to be capable of installation in a wet and harsh environment. Whilst some manufacturers may claim that metallic barriers with a seamed sheath would be capable of performing satisfactorily for the service life of the cables there is an additional risk that a latent defect in the seam would permit an ingress of water or water vapour into the cable insulation. This would result in cable failures, at multiple locations.

54) The Arhus – Aalborg project in Denmark uses a buried cable with a foil design of radial water blocking. These cables were placed into service in 2004 and it will be interesting to see if the longer term performance of these cables is satisfactory. The use of an aluminium conductor and foil design probably contributed significantly to the low cost ratio UGC to OHL. It should be noted that the cables installed on the Arhus – Aalborg project would not be capable of carrying the 1700A per cable required for the Beauly – Denny connection.

55) For long term reliability it is recommended that a seamless sheath be employed for any directly buried 400kV XLPE installations in Scotland. This is in accordance with the current practice of the National Grid and specified within their technical specifications[7].

2.1.6 Oversheath

56) A polymeric oversheath is applied over the metallic barrier. The oversheath material is a thermoplastic and is slightly permeable to moisture. Medium or high density polythene is the preferred material of choice as it offers good mechanical penetration resistance at high installation temperatures and thus reduces the incidence of damage during cable laying.

57) The fire performance of polyethylene is poor however and for ‘in air’ installations a fire retardant coating, an alternative material (PVC), or a co-extruded fire retardant compound may be used.

[7] National Grid Technical Specification TS 1, TS 2.5 and TS 3.5.2 amongst others.

58) It is usual to apply a conductive layer on the outside of the cable either as a co-extrusion or as a graphite paint layer to allow DC testing of the oversheath to confirm integrity both after manufacture and laying.

2.1.7 Bending Performance

59) The installation bending radius of a cable may be as low as twelve times its diameter (12D). Such a small bending radius should only be used at positions where formers are used to constrain the cables from further bending.

60) For installation in a cable trench a minimum bending radius of 20D may be employed. Usually cable installers prefer to install the cable with a bending radius of 30D or above, as this eases the pulling forces required to install the cable.

2.2 Cable System Accessories

61) There are three main types of accessories:

- joints
- terminations
- earthing and bonding equipment

62) Joints and terminations are the weakest points of a cable system. This is due to the high electrical stress control requirements of accessory designs (particularly on large conductor cables) and the need for accessory component assembly on site.

63) In operation, thermomechanical forces act upon an accessory as the cable conductor expands and contracts with temperature. The high reliability required of a joint or termination will depend upon a fully tested manufacturing design, a specialised manufacturing process, a fully considered installation design and a high standard of accessory assembly.

64) The design of an accessory will have been the subject of long term reliability testing. Components will also have passed factory manufacturing tests.

65) Accessories are assembled onto the cable on site without the controlled environment of a factory. Reliable performance on EHV accessories therefore requires skilled jointers, specialist tooling and a suitably prepared jointing environment.

66) Testing requirements are set out in internationally recognised standards (section 5.2.2 on page 57).

67) In order that the cable system as a whole carries a manufacturer's warranty, of between six to ten years, it is invariably the case that a manufacturer will insist that his own jointers assemble each accessory.

2.2.1 Joints

68) In order to increase the reliability of the system, it can be advantageous to increase the cable section lengths and reduce the number of joints as part of the overall design solution.

69) Cable joints connect together separate drum lengths of cable to make a continuous electrical connection. Each cable manufacturer will offer its own design of joint. The main components of a joint are:

- the conductor connector
- the insulation and stress control
- the radial water barrier
- the outer protective covering
- partial discharge detection devices

70) The conductor connector is required to allow the flow of current between one cable conductor and the next. This connection is overlaid with factory prepared insulation in the form or either one or three piece joint insulation mouldings which are applied by the jointer on-site.

71) A metal shell is used to maintain continuity of the cable's outer sheath (or metallic barrier) and screening wires to allow the connection of any bonding leads. The metallic shell also provides a water barrier to prevent water entering the joint.

Figure 2-2 275kV Joint bay Containing Six Joints

Photo: courtesy of Prysmian Cables and Systems Ltd

72) Figure 2-2 is a photograph of six joints in a 275kV joint bay. This particular joint bay does not have any earthing or bonding leads installed.

73) The joint is enclosed in an outer protective covering which has sufficient electrical insulation to allow routine cable oversheath and joint protection testing to be performed (10kV dc at commissioning, 5kV dc thereafter). The joint protective

covering is also designed to withstand ground surface loadings (typically 5 tonnes/m^2).

74) The method of detecting partial discharge within a joint varies from one manufacturer to the next. The favoured method is currently to place sensors within the joint. These are used to detect incipient failure within the joint in order that a fault in service may be avoided. Partial discharge is a phenomenon which has been found to be a precursor to electrical failure. Detection of partial discharge at an early stage (particularly during commissioning testing) can prevent catastrophic failure and allow preventative maintenance.

2.2.2 Terminations

75) Air, SF6 Gas and oil immersed terminations are all available for XLPE cables. However, for the Beauly-Denny connection only air insulated cable terminations would be required within overhead line cable sealing end compounds and for connection on to the air insulated equipment within substations. This report therefore only considers this type of termination. Figure 2-3 provides an example of the cable sealing end (of which there will be 12 per compound) flanked by examples of surge arrester and earth switch.

Figure 2-3 400kV Cable Outdoor Sealing End (ODSE) Termination

76) Cable terminations will be required to interconnect the cable with the overhead line or substation busbar. The overhead line and busbar are insulated by the air which has a lower electrical performance than the cable insulation.

77) The cable insulation separates the cable conductor from the earth using a few centimetres of insulation. Air insulation requires several metres of insulation to provide the same performance. It is therefore inevitable that the cable terminations must be large enough in order to raise the live cable conductor above any objects at earth potential to avoid a flashover. In order to ensure the safety of personnel and plant this electrical clearance distance must also make allowance for such effects as those produced by rain, ice and snow which will all come to rest on the outer surface of the cable termination during its lifetime. Clearances to other equipment must also be maintained to allow cable insulation withstand testing.

78) In general EHV cable terminations consist of :

- a conductor connector,
- an electrical stress control cone,
- a hollow air insulator containing insulating oil or SF_6 gas and covered externally with sheds,
- an oil level or gas pressure indication, and
- a partial discharge monitoring device.

79) The conductor connector (or stalk) connects between the cable conductor and the overhead line or busbar off-going connector. This stalk carries the electrical current from the conductor to the overhead line or busbar.

80) Unlike a power cable or a joint, the electrostatic field of a cable termination extends beyond the outer surface of the termination. Thus the insulation screen of the power cable is stripped from the underside of the conductor connector down to a point that reduces the electrical stress in the air. The electrical stress is further reduced by the stress control cone which is used to smooth the electric field both in the termination and in the surrounding air.

81) The insulator surrounding the XLPE cable is hollow and filled with either silicone or polybutene oil. Dry type terminations are also available which contain Sulphur hexaflouride (SF_6) gas. However, SF_6 is a known green house gas.

82) For terminations filled with oil, provision must be made to accommodate the thermal expansion and contraction between the minimum and maximum operating temperatures. This may require oil compensators to be installed either within the termination or external to it. Monitoring of the oil pressure is recommended as a severe loss of oil could result in termination failure. Each termination will hold around 300 litres of oil.

83) The method of detecting partial discharge within a termination varies from one manufacturer to the next. The favoured method is currently to place sensors within the termination or around the earth bonding leads.

84) The earthing or bonding connection is attached to the termination close to the connection with the cable screening wires or metal sheath. This connection is electrically separated from the termination support structure such that a cable DC oversheath test may be performed.

2.2.3 Earthing and Bonding Equipment

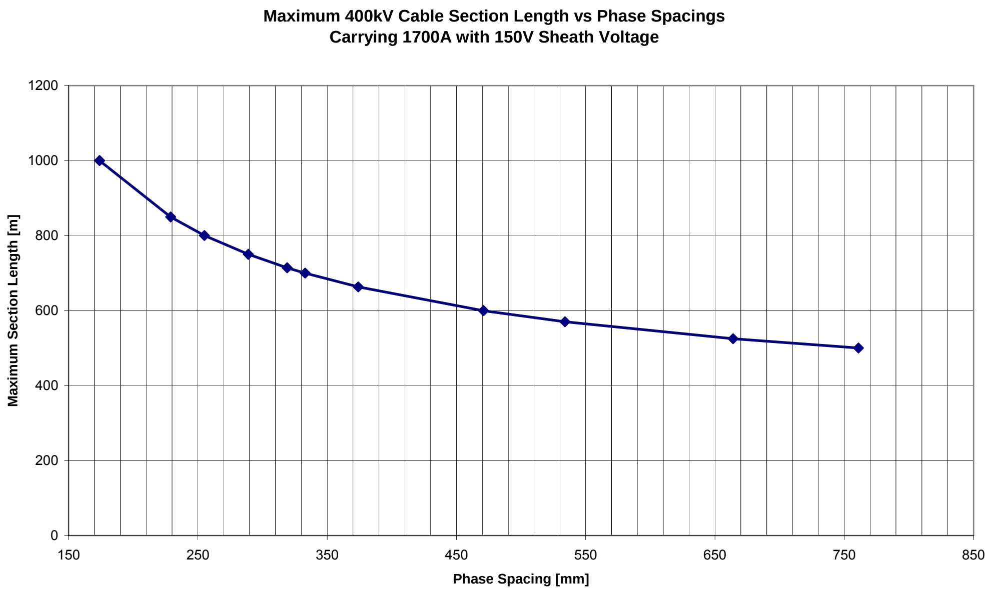
85) In order to achieve the required cable circuit ratings the preferred method for earthing and bonding of the cable system are the special bonding arrangements described in Engineering Recommendation C55/4[8].

86) The application of special bonding can reduce cable sheath heat generation considerably. However, a voltage will be induced into the cable sheath and screening wires. The magnitude of this voltage increases with, a) the magnitude of the current flowing in each of the circuit phase conductors, b) the spacing between the cable sheath/screen and each conductor, c) the geometric arrangement of the cables within the cable trench (or trenches), d) the length of cable between specially bonded joints or terminations.

87) It is a requirement of Engineering Recommendation C55/4 to limit the voltage on cable sheaths under normal continuous operating conditions to 150V for both 275kV and 400kV systems. This voltage limit is principally set for reasons of safety to third parties.

88) The maximum sheath standing voltage will limit the maximum length of a cable section between joint bays/terminations and the number of cable joints installed. This standing voltage may be reduced, and therefore the cable section length increased, by installing the cables in close proximity to each other and obtaining the benefits of increased magnetic field cancellation.

Figure 2-4 Impact of Phase Spacing on Maximum Section Length



89) Figure 2-4 is a typical plot of the effect of cable phase spacing on the maximum cable section lengths during the winter pre-fault loading for a 2500sq.mm conductor 400kV cable.

90) Special bonding arrangements require the use of earth link pillars (above ground) or link boxes (underground) to be positioned at joint bays and terminations. It is a

8 "Insulated Sheath Power Cable Systems", Electricity Networks Association, Engineering Recommendation C55, Issue 4 1989 and Amendment 1 1995

preference of both SPT and SHETL that link pillars are used as these are easier to maintain.

91) Link pillars (Figure 2-5) or link boxes will be required at every specially bonded joint bay or termination position. One pillar or box is required for each group of three power cables. At a position where twelve joints are located a total of four pillars will be required. These pillars are connected to the joint metallic shell by means of concentric bonding cables. In order to achieve the highest current rating on the cables the connections within the link pillars cross connect one cable sheath to the next or earth down all cable sheaths, as is appropriate, as required by the special bonding design.

92) Where the links in a pillar or box cross connect cable sheaths, a sheath voltage limiter is installed. This device prevents over voltages appearing on the cable sheath (or metallic barrier) during abnormal system events.

Figure 2-5 Link Pillar in Arable Field

93) The bonding cables and equipment within these pillars are capable of delivering both electric shocks and burns. The pillars must be capable of withstanding an internal flash-over in case of an abnormal system event. The pillars must also be protected from farm equipment and large animals by appropriate bollards and/or stock proof fencing. Each pillar will have a separate earth mat for the bonding system and the link pillar carcass. This mat consists of bare copper tape and earth rods installed below ground.

2.3 Installation Design

94) In addition to the section length criteria mentioned above, other factors that need to be taken into account when selecting section lengths include the following:

- Balanced minor sections within a 3 cable major section,
- Sheath voltage limiter requirements,
- Manufacturing weight and height restrictions,
- HV AC testing capability and test set access positions,
- Transportation limits e.g. vehicle width, axle weight and bridge heights,
- Access through country villages and lanes,
- Cable pulling-in force limitations,
- Access to cable drum pulling-in and winch positions ,
- Steep gradients, and
- Permissible joint bay locations and maintenance access to link furniture.

95) The cable trench arrangement is an optimisation process taking into account the cost of cable and the cost of civil works for various trench widths and depths.

96) Where special constructions are required for the cables to pass under or over obstructions, these singular points require consideration within the overall design in order to establish that a route is both practical and economic.

97) Consideration of the cable installation arrangement must include the practicalities of the civil works and ensure that sufficient space and swathe is allowed to permit economic and safe working practices to prevail along the cable trench and at jointing locations.

2.3.1 Thermomechanical Design

98) A cable with a 2500mm² copper conductor can generate a force of several tonnes when it is heated to its maximum operating temperature.

99) Various sections of the cable routes have steep profiles. There is some anecdotal evidence that 400kV cables installed in England on a steep gradient, which are surrounded by cement bound sand backfill, are subject to sliding down the steep slopes.

100) Where gradients are significant cable installers must perform a detailed thermomechanical design analysis. Cable snaking and the use of conductor anchor joints may be necessary in order to ensure that movement at the highly stressed cable/accessory interfaces does not occur.

101) The use of a seamless corrugated aluminium sheath (not as widely manufactured as a lead sheath) can improve thermomechanical performance. Some manufacturers however have experienced difficulties water blocking and ensuring insulation screen/sheath electrical continuity in large conductor cables with aluminium sheaths. The use of an aluminium sheath would have to be explored carefully with manufacturers if they are to be considered.

2.3.2 Charging Current and Reactive Compensation

102) Both overhead lines and underground cables have the property of adding electrical capacitance in parallel with the normal transmission system circuit. However, due to the proximity of the main conductor in a cable to the earth that surrounds it, this effect is much greater in underground cable than for overhead lines.

103) The cable capacitance allows cable insulation charging currents to flow, which can cause significant, unwanted changes to the transmission system voltage and loss of useful power transfer capacity. These voltage changes need to be corrected to avoid equipment damage and poor quality of supply at consumer premises.

104) The normal way of controlling such voltages is to install "reactive compensation" in the form of shunt reactors. Electrically, these reactors perform in exactly the opposite way to cables (they are electrically inductive rather than capacitive) and consequently, by siting reactors at the ends of a section of cable, the capacitive effect of the cable on the transmission system may be neutralised. These reactors are however large and expensive.

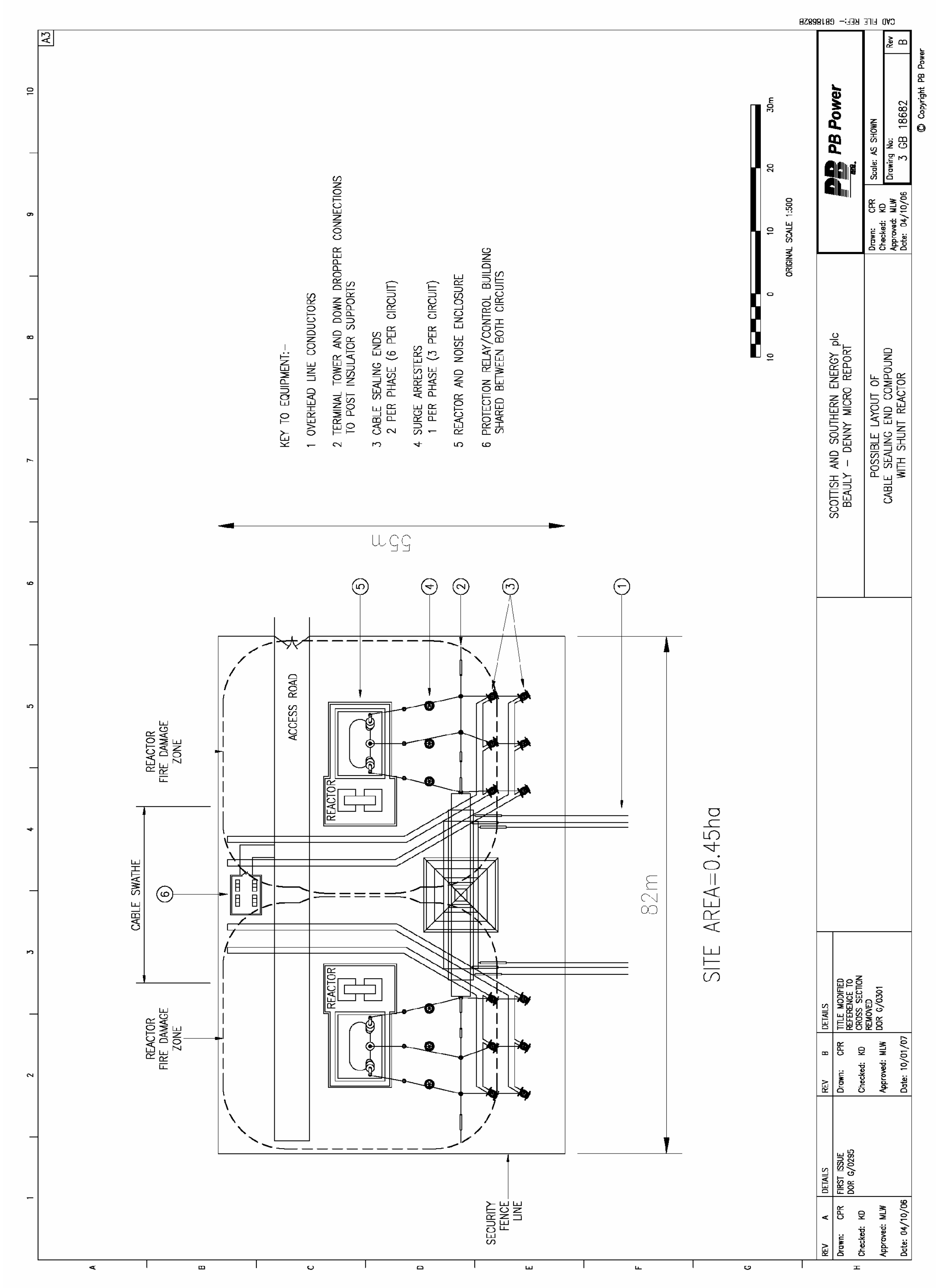
105) Cable charging current is determined by the system voltage and by the dielectric capacitance of the cable insulation. Typical values of capacitance for large conductor size 400kV cables are as follows:

Table 2-1 Typical 400kV XLPE Cable Dielectric Capacitance

Cable Conductor Size	Dielectric Capacitance
2500mm²	219pF/m
2000mm²	204pF/m

106) Normal practice with significant sections of underground cable is to place any required reactive compensation at the ends of the cable. For these case studies, this practice would result in a total requirement of twelve reactive compensators – a pair at each of the five cable sealing end compounds, and two in the Beauly substation. The arrangement for a pair of these reactors, if installed in the cable sealing end compounds, could be as shown in Figure 2-6.

Figure 2-6 Cable sealing end compound layout - with shunt reactors

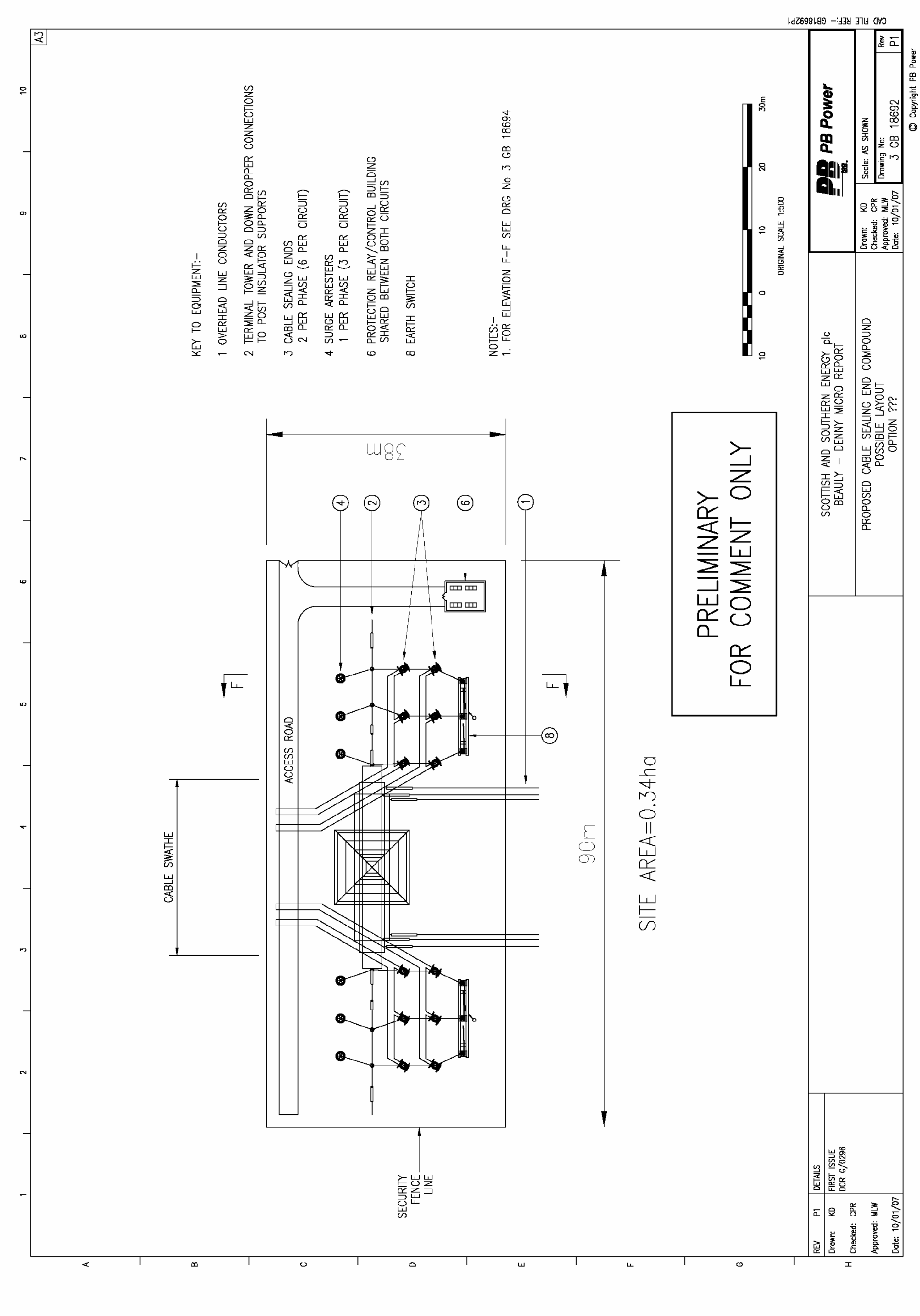


107) However, system modelling for the five selected case studies shows that, technically at least, there is the possibility of relocating some of these reactors from the cable sealing end compounds to nearby substations, with a resultant cut in the number of reactors required from twelve to six. This will only be possible if there is adequate space at the substations to house the reactors, and if planning permission for their extension can be obtained. Figure 2-7 shows a sample sealing end compound layout without reactors. By comparing the compound layouts in Figure 2-6 and Figure 2-7 it can be seen that the ground area of each compound may be reduced by about 0.1 hectares if the reactors can be relocated to the substations.

108) In the costs that are presented later in this report, it has been assumed that reactive compensation has been placed at the nearest substations to the UGCs.

109) It should be noted that a terminal tower, cable sealing ends, surge diverters, earthing switches, post insulators for busbar support and relay building would be required at each cable sealing end compound regardless of whether compensating reactors are located in the compound or at nearby substations. Appendix 10 depicts the terminal tower and connections to sealing ends.

Figure 2-7 Cable sealing end compound layout - without shunt reactors



2.3.3 Protection From, and Safety of, Third Parties

110) The design of the cable system is inherently safe for the normal activities of the general public. The depth of the cable installation, which is normally about 1 metre, is sufficient not to require any additional precautions beyond the provision of cable warning (cover) tiles. At joint bay positions it will be necessary to bring earthing and bonding cables to surface-mounted link pillars or link boxes. At these locations the link equipment is normally protected from livestock, machinery and vehicles with stock-proof fencing. Where the power cables themselves rise to the surface they will be within cable sealing-end compounds or substations that are protected by high security fencing.

2.4 Construction

111) The method, location and routing of a cable circuit are each determined during a site survey which considers the practicalities of employing a cable system.

112) Examples include installation, a) in air on cable supports, b) in surface trough, c) in the ground directly buried with or without thermally stabilised or replacement backfill, d) ducts either filled or unfilled, e) in tunnel with or without forced cooling.

113) The location of the cable route will be limited by such issues as, a) the total length of cable required, b) the availability and cost of land, c) access limitations, d) ground conditions and ground stability for excavation and cable installation, e) obstructions e.g. unstable ground, difficult terrain, tree roots and immovable structures, f) disturbance to the environment and stakeholders, g) maintenance access.

114) Access to the entire route must be agreed before works can commence. Ideally this will be performed prior to the commencement of construction works or a risk assessment will have been taken on each area of doubt. The following paragraphs in this construction section detail the main tasks to be undertaken.

Site Accommodation and Storage

115) It would be necessary to locate a local site storage facility along the cable route where site offices may be located and materials stored. This storage location would vary from site to site and depend on the availability of local land for hire, availability of utilities, security considerations, environmental suitability and the proximity of the site to main roads.

116) If the site accommodation is to be located on farm land then the site set-up area should have the top soil removed and stored separately for final reinstatement. A suitable surface is installed for the placing of site and security offices, welfare facilities, cable drums, aggregates, tiles, timber and vehicles etc. The area should then be made secure with suitable fencing and gates.

117) Dependent upon the location, generators, fresh and waste water storage tanks, waste material and flammable gas storage will be required to support the operational and welfare facilities. Floodlighting may also be required.

118) Access to the site may require traffic management to be installed to allow safe entry and egress from the site accommodation.

Enabling Works

119) Enabling works are those construction works that should be performed before the main works begin. The works may, for example, enable access to the site, confirm the route is free of impassable obstructions and/or perform advance construction work at specific locations (such as drilling locations) to enable the free flow of the main work programme.

120) Prior to commencing the main excavations it would be necessary for the contractor to identify any route obstructions and make sure that an economic solution exists to cross or divert each obstruction or to reposition the cable route accordingly.

121) Details of recorded services would be obtained from utilities and discussions held with land owners regarding any services on their property. This will include unrecorded services installed by the land owner such as land drains.

122) Underground services are located by trial hole excavation with the assistance of location equipment (such as ground penetrating radar).

123) Where roads are to be crossed a decision must be made on the method to be used. The installation of polythene or uPVC ducts is common place and this may include a concrete encasement. This will require traffic management with the timing of road works being agreed with the community council and other interested stakeholders. For busy carriageways the use of trenchless methods such as directional drilling may be necessary to prevent unacceptable traffic disruption.

124) At railway crossings, where it is not possible for the cables to cross the railway on an existing structure, such as a road bridge, crossings are usually performed using trenchless methods to avoid disruption to railway services.

125) There are a number of methods available for river crossings. These include bridging, drilling or tunnelling beneath the river bed, dredging a trench in the river bed and laying the cables direct on the river bed or in ducts. These methods may also be applicable to standing water such as ponds or lochs. The preferred method for crossing the rivers is the use of nearby existing structures such as road bridges or failing this by directional drilling or boring.

126) In order to gain access to some areas of the route it may be necessary to install temporary access roads leading from public roads to the working swathe. It may also be necessary to improve the surface of any existing farm tracks. Temporary access roads will be removable and consist of either aggregate installed on a porous membrane or timber/metal matting.

2.5 Cable and Circuit Spacings

127) The need to keep the cable conductors from becoming too hot requires that they be separated from each other underground. For the Beauly-Denny connection 12 conductors are required and these would normally be arranged in four groups of three. The space requirements for these four groups of conductors, plus the haul road and width for the temporary storage of spoil from the trenches, amounts to a working swathe some 30m wide.

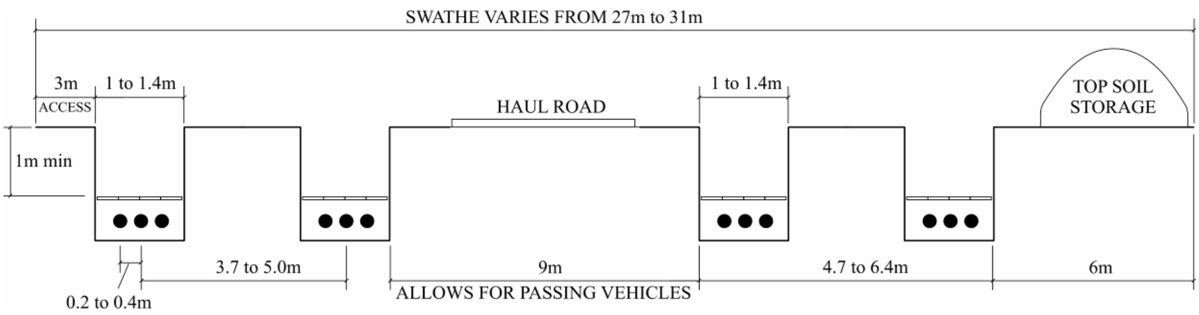
128) Figure 2-8 illustrates a swathe arrangement. The cable trench containing three cables will be between 1.0m and 1.4m wide. A 3m access way is allowed between the outer trench and the fence to permit access from both sides of the trench during

such activities as cable pulling and the installation of any drainage. Thermal separation between groups of cables for the same circuit will be between 3.7m and 5.0m. The trench width and circuit separations are approximate as these will be dependant upon the cable build available from the manufacturer and whether air filled ducts are employed.

129) A central reserve of 9.0m is allowed to install a haul road with passing places. This road will allow construction traffic to move up and down the swathe collecting and delivering materials with minimal disruption to local roads. This separation also provides thermal independence between the circuits.

130) A storage area of 6m has been allowed to retain top soil for the duration of the works.

Figure 2-8 Double circuit cable construction – swathe cross-section



131) This type of cable layout has been developed over a number of years' experience and is consistent with recent practice in the UK – for example the "Second Yorkshire Line" where a proportion of the route was placed underground.

Swathe Preparation

132) Prior to any excavation the area within the swathe must be worked during the right time of year. This will depend on the ground condition. Generally the best time for working on the land is between April and October when rain and snow fall are less prominent. There would be an issue regarding disturbance of breeding birds that would require to be addressed.

133) If required, following a land drainage study, a drainage system would be installed to collect water running across or off the swathe. Where necessary this drainage system would include settlement ponds to avoid silt entering water courses.

134) Within the swathe the top soil would be stripped and stored to one side. A temporary haul road would then be installed along the route between access points onto local roads. These access points would require to be agreed with the community council and interested parties. In principle the haul road would carry as much as possible of the construction traffic. However, some vehicle journeys on local roads would be inevitable to reach the site access points and make use of such facilities as road bridges where rivers or railways cut across the route. Wheel washing facilities would require to be maintained at all haul road egress points. Road signage would have to be provided to direct construction traffic towards and away from site access points over predetermined routes.

135) The working swathe would be protected by fencing with limited and controlled access and egress to the site.

Excavation of and backfilling of direct buried trenches

136) Along the cable route four trenches would have to be excavated to accommodate the power cables. Additional excavations would be required at the joint bay positions to accommodate the power cable joints. If the ground is waterlogged dewatering may also be necessary.

137) In order to reduce the amount of material removed from the site the two outer trenches, farthest from the haul road, would be excavated first. Mechanical excavation would be performed and the material to be removed from site would be placed into tipper trucks. A significant portion of this initially excavated material would be removed from site. The actual quantity of material removed would depend on the dimensions of the trench for each particular cable section, depth of the topsoil and the quantity of imported thermally stable cement bound sand (CBS) required. A portion of the excavated material may be retained and stored within the swathe separate from the top soil.

138) In order to keep the cable trench clean and safe it is usual practice to shore the trench. Shoring may be provided in a number of ways. For example, traditional double sided close timbering shoring, hydraulic shoring or box shoring. Another option is to “batter back” the sides of the excavation to a safe angle however if the ground consists of wet sand or silt, the safe angle of batter could be less than 10° above horizontal with insufficient room within the swathe for such a wide excavation. “Battering back” would also require the use of permeable membrane sheeting to prevent foreign material such as stones from falling into the trench and being mixed in with the cable surround where it could damage the cables.

Figure 2-9 A close timbered cable trench

139) Excavation of the trenches would include joint bay excavation. A joint bay for three joints will be in the order of 10m long and 3m wide and approximately 2m deep. The base of the joint bay must be level and a concrete pad installed (some 150mm thick with light reinforcement) as a working surface. The sides of the excavation are shored to prevent collapse.

140) On completion of the excavation the cable trench bottom is cleared of sharp or large objects and any free water is pumped from the excavation.

141) Following the installation of the cables, ducting, CBS and cover tiles in the outer trenches, the excavated material which was not removed from site would be used to infill the trenches and would be compacted. The inner two trenches nearest the haul road would then be excavated and the excavated material used to top-up the backfill of the outer trenches. The remainder of the excavated material would be stored on site, separate from the top soil and used to complete the backfill of the inner trenches and joint bays following cable system installation. Once backfill is completed, the surplus material would need to be removed from site as waste / landfill.

Excavation of and backfilling of ducted trenches

142) Where cables are installed in ducts, these would be installed in a continuous operation with excavation at the front, followed by ducts, CBS, tile and warning tape installation with backfilling following on.

143) For a fully ducted cable system the ducts would be installed from joint bay to joint bay.

Cable Installation for Direct Buried Installation

144) Once the bottom of the cable trench has been cleared of sharp and large objects, a cable bedding of CBS 100mm thick is laid. The CBS is tamped into place to form a firm surface upon which cable installation may take place. This thickness may be increased to accommodate a fibre optic communication duct, alternatively the fibre optic duct may be installed above the cover tile where plough damage is not anticipated.

145) As the trench is being prepared the drums containing the power cables would arrive at one of the joint bay positions. The area around the joint bay would have been prepared to accept the drums onto a hard standing. The drums are delivered to site by low loader or cable trailer. A typical low load trailer is 18m long, 2.5m wide and has a ground clearance of 560mm. It has an unladen weight of 28 tonnes and this gives a loaded weight of around 59 tonnes for a 500m cable length.

Figure 2-10 Cable Drum Carrying Trailer

Cable drum and trailer

146) Transporting the drum over motorways and major roads should not present any problems and the low loader width is such that a Police escort should not be necessary.

147) If cable lengths longer than about 500m are used, drum widths would have to increase, and under such circumstances the drums may be loaded transversely onto the vehicle with the drum spindle aligned along the length of the vehicle trailer. This transverse mounting of cable drums on to low load trailers allows much wider drums to be transported. However they would still be limited by height restrictions; for example 16’ 3” (4.95m) bridge clearance on motorways.

148) Specialist hauliers would also be required to transport large drums. Such hauliers can provide low load trailers with rear wheel steering and tandem tractor units for steep inclines. Figure 2-11 shows a low bed trailer height of around 450mm. The trailer is also fitted with rear wheel steering.

149) Different manufacturers use different drum sizes to suit their cable manufacturing facility and it is important that drum weights and dimensions are fully investigated at the contract tender stage.

150) Transporting the drum through country villages and along country lanes may present problems and the temporary removal of street furniture, overhanging tree pruning, bridge strengthening, possible road closures and other road safety and access measures may be necessary.

Figure 2-11 Cable Drum Load Transversely onto a Trailer

151) In order to limit the overland portion of the route it is suggested that cable drums arrive at suitable ports in Scotland capable of handling large drums, such as Grangemouth or Inverness.

152) Closer to each construction site the roads, particularly in the Ochil Hills, become steep and narrow with sharp bends. It would be recommended that a detailed transportation and access survey be undertaken for all sites if cable undergrounding is to take place.

153) Upon arrival in Scotland (there are no UK factories manufacturing these cables), the cable drum would either be unloaded at a temporary storage site or taken directly to the cable pulling-in position.

Figure 2-12 Offloading cable drums

154) A cable pulling system is then installed into the trench. Traditionally this is a steel bond and winching system with free spinning cable rollers placed along the bottom of the trench. Other methods include the use of motorised rollers or tracked caterpillar drives. Winching equipment is normally diesel powered however generators will be required to power electrically operated cable pulling systems. Communication during the cable pulling operation is by radio hand-set to supervisors strategically positioned along the cable route. The winch or power roller system operators are also included in this communication system.

Figure 2-13 Cable installation in an open cut trench

155) The cable drum is threaded with a spindle and raised from the ground using hydraulic jacks mounted on lifting frames (jack stands). The cable is then pulled from the drum into the cable trench onto rollers. Enough cable is pulled from the drum until sufficient is available in the far joint bay for jointing onto the next cable length. The cable is then lifted off the rollers onto the trench floor. This process is repeated for all cables following which the rollers and pulling equipment are removed from the trench. The cable is then positioned in the trench at the correct spacing.

156) Following the power cable installation any earth continuity conductor cables, installed with each group of three power cables, are installed with a mid-point transposition of the section length from one side of the centre cable to the other.

157) Distributed temperature sensing (DTS) fibres or DTS ducts for fibres would be placed on the cables and/or in the backfill at this stage. These fibres are used as part of a temperature monitoring system to calculate the cable conductor temperature along the cable route to estimate the load capacity of the cables and detect any locations where soil or cable surface temperatures are abnormally high.

158) Cement bound sand (CBS), delivered by mixer (Figure 2-14) would then tamped into position around and over the cables to a depth of approximately 100mm to 150mm above each cable. Cover tiles containing a warning are then installed above the cables, these are fabricated from either reinforced concrete or reclaimed polymeric materials (retailed as Stokboard).

Figure 2-14 Delivery of CBS to the cable trench

159) At this point the timber shuttering is removed and the trench is then further backfilled with previously excavated material. The backfill is compacted and includes warning tapes installed 150mm above the cover tiles.

160) The duration of the excavation, cable installation and backfilling works for the twelve cables in a cable section will depend on the nature of the ground e.g. rock content, dewatering content etc. In general it would be expected that the twelve cables would be installed and backfilled over a 600m section in around sixteen weeks.

Cable Installation Ducted Sections

161) Unless the ground conditions are poor, it is not usual for the trench to require shoring with timber when the ducts are installed. The duct system must be installed with care to avoid sharp discontinuities at duct joints, duct or joint breakage, duct wall crushing or the ingress of foreign objects into the duct.

162) Cable installation into a ducted system relies on a low coefficient of friction between the cable duct and the cable. This is achieved by installing the ducts with very gradual bends using as few discontinuities as possible, good duct cleaning and the use of biodegradable water based lubricants during cable pulling.

163) Cable pulling calculations are required to determine the expected maximum cable pulling force required and the side wall forces expected between the cable and the duct wall. The handling of the power cable drum ready for pulling is the same as that described previously for a direct buried installation. The cable is winched into place by pulling on the leading end of the cable (known as nose pulling).

164) The DTS fibres are attached to the outside of the duct or installed within a separate duct attached to the outside of the power cable duct.

Jointing

165) Once the cables have been installed into a joint bay a temporary weatherproof structure would be erected over the bay. The joint bay would be cleaned internally and the cables prepared on a concrete joint bay floor. The jointing operation would require dry, clean conditions and good lighting.

166) Jointing should only be performed by trained personnel. It is also necessary to ensure that these personnel are trained in safe methods of work, particularly when working close to other transmission lines that may induce dangerous voltages onto the cables being jointed. In most circumstances the jointing team would be employees of the company supplying the cable system or alternatively (and less preferable) jointers from a contractor that have received training from the cable system supplier to a standard suitable to assemble the joints and maintain the suppliers warranty.

167) Either three or six power cable joints may be made off in a joint bay. There are six main stages in the jointing process which are as follows:

- Preparation of the joint bay and checking of materials, drawings, assembly and safety instructions (this action is required to ensure that all components, equipment, drawings and instructions are available before jointing commences),
- Preparation of the cables including positioning and straightening,
- Assembly of the accessory primary insulation,
- Assembly of the accessory secondary insulation,
- Assembly of the link equipment and auxiliary cable equipment onto foundations or pits previously installed, and
- Following joint bay backfilling, initial secondary insulation checks by application of DC voltage.

168) The duration required to complete a three joint bay will depend on a number of factors including the number of joint bays available for jointing (backlog), the number of jointers assigned to the work programme for the project, the joint complexity, the location of the joint bay, access or working restrictions, any induced voltage working requirements and the speed at which each jointer feels competent and safe to assemble each type of accessory. Once a jointing team is available to assemble a joint bay the process should take in the order of three to four weeks. This period includes the assembly of the jointing shelter.

169) A power supply would be required in the joint bay to operate equipment and lighting and in the winter to provide heating. Silenced generators would be positioned at joint bays where noise pollution may cause a disturbance. The general objective would be to reduce noise levels to 40-45 dB(A) at night, and 50-55 dB(A) during the day, at the nearest residence or at the boundary of the premises.

170) The jointers' transport is normally a covered van. Self loading vehicles would deliver and collect the jointing structures and fencing. Security patrols will be active with regular night time visits to any excavated joint bays.

171) Stock proof fencing and/or bollards would be erected to prevent damage to any equipment which is not buried.

Jointing Terminations

172) The cables would be brought out of the ground into a sealing-end compound that is fenced for safety reasons. The fence also surrounds the first Overhead Line (OHL) tower, the cable compensation reactors, and a blockhouse to accommodate the electrical protection and control systems relating to the cable. A sealing-end compound would be required at each end of a cable section (unless the cable terminates within a substation).

Figure 2-15 Weatherproof Sheeted Enclosure for Cable Termination Assembly

173) The method of installation of the cable terminations depends on the supplier as each use differing methods. The first is to make the termination off in the horizontal position and then to raise it to the vertical position in its completed form. The second method is to assemble the termination in its final vertical position.

174) The advantage of the first method is that the termination can be assembled at ground level in much smaller weatherproof enclosures. Some manufacturers do not consider such a technique as suitable for their design of cable termination and have concerns that the internal parts of the termination may move during the lifting process and result in the termination failing in service.

175) Assembling the termination in the vertical position requires that a large weatherproof scaffolding structure is assembled (Figure 2-15). This structure is covered with

sheeting. These structures must be carefully designed to withstand a high wind load and are secured with guy ropes and anchored with ground weights. The size of the structure will depend on the spacing of the cable terminations for electrical clearance and whether or not the installer uses a crane or an internal beam and hoist arrangement to install the termination insulator over the prepared cable end.

176) The large scaffolds may take two or three weeks to construct after which the cables are pulled into position up the structure. The jointers then prepare and terminate the cables. Following assembly of the termination the scaffolding structure is dismantled.

177) Link equipment is then installed inside the substation (normally secured to the termination support structure) which provides a removable earth connection to the cable termination.

178) Partial discharge sensing cables, used to carry signals of unwanted electrical discharge from within the accessory, are terminated into a local marshalling box. The DTS fibres are also terminated into a local marshalling box. These marshalling boxes are located within either the substation or a building within the cable sealing end compound.

179) Following installation of the cable, the termination of three cables will take around 7 to 8 weeks to complete. This time period includes for the erection and dismantling of the scaffold.

<u>Swathe Reinstatement</u>

180) Following installation of all cable and joints in a section the swathe would be cleared. This will include the removal of any remaining security fencing, uplifting and removal of the haul road and temporary hard standing areas reinstatement of surfaces and top soils.

181) Where necessary this reinstatement may include replanting of hedges, replacement of fences, removal of temporary land drains and settlement ponds, reinstatement of permanent land drains and the like.

182) If trees are removed, these would only be replaced if their roots did not interfere with the power cable installation. The allowable distance of any tree from a cable would depend on the type of tree and its expected future growth.

183) Where beneficial, and prior to top soil replacement, the ground would be subject to sub-soil ripping to break up the compaction due to construction activities.

2.6 Operation

184) In common with the OHL, trees would need to be obviated from the route during the operational life of the underground cable (UGC), and like the OHL, once the installation had been completed, the ground, apart from small sections of the route accommodating joint bays, could be returned to low growing vegetation or agricultural land. The building of permanent structures is not normally permitted over directly buried cables for reasons of maintenance access and safety.

185) Unlike an OHL, however, a low level of "transformer-type" hum would emanate continuously from the sealing-end compounds (if reactors are installed there), whilst along the route the cable would be silent.

2.6.1 Magnetic Fields

186) Both OHL and UGC product magnetic fields, whose intensity is directly proportional to the current flowing through the conductors. Thus, as the circuit load varies throughout the day and the year, the magnetic field would fluctuate.

187) Appendix 7 provides diagrams of the shape of the magnetic fields surrounding OHL and UGC, and also indicates the variations in intensity with distance from the circuits.

188) Appendix 7 also reports on calculations of the magnetic field intensity that would be produced by the pre-fault continuous phase current of 3400 amps. The intensity of the magnetic fields produced by both OHL and UGC are low enough to fall within the 100µT guideline published by the Electricity Networks Association.(ENA).[9]

2.6.2 Faults and Reliability

189) There is conflicting opinion expressed between operators and manufacturers of cables regarding the comparative reliability between OHL and UGC. In a Europacable document supplied to the Vice President of the European Commission on 19 June 2002 the view was expressed that cables have always had a good reliability record with cable faults of 0.072 failures per 100 circuit km per year, and OHL showing around 0.17 "permanent failures" per 100 circuit km per year. This statistic does not, however, take any account of repair times or circuit availability.

190) The European Transmission System Operators organisation (ETSO) published, on 31 January 2003, their "ETSO Position on use of Underground Cables to develop European 400kV networks". They state:

191) "Even though the fault rate is expected to be lower than for overhead lines, this is not necessarily true for EHV networks because of the UGC techniques for fault finding and repairs (terminations, joints).

192) While taking into account all of the constituent elements of the connections as well as incidents due to external causes, the experience of some ETSO members shows that the rate can be higher for an UGC (mainly due to external causes and accessories)t than for an OHL.

193) As far as repair time is concerned, it seems that the repair duration differences are still in favour of OHL and become increasingly so as the voltage rises. For an UGC, it takes more time to locate and repair a fault, on average 25 times longer than it does for an OHL. The experience shows that the repair duration of cable damage requires between two weeks and 2 months depending on the technology and location of the fault."

194) Data recorded by National Grid Company (and reported in the Babtie report[10]) of 0.126 hrs /km /year for OHL, 6.4hrs per year /circuit km/yr for UGC (for the NGC network) seems to support this ETSO position, and it is concluded that this is likely

[9] "EMF The Facts", Energy Networks Association, Issued June 2004

[10] Babtie's report was entitled "The Highland Council, Cairngorms National Park Authority and Scottish Natural Heritage: Undergrounding of EHV Transmission Lines"

to be more representative of the present reality for EHV cables than the Europacable opinion.

2.6.3 Repair Time and Weather

195) Weather may restrict access to the cable in very wet spells or prolonged periods of snow. Repairs to cable require excavations of the cable and the provision of clean and dry conditions for jointing. Either of these may affect cable repair times.

196) The whole subject of reliability and availability is discussed further in the paper "Beauly-Denny Transmission Interconnection – A Generic Comparison of the use of alternating current (AC) underground cable as an alternative to overhead line with reference to the proposed Beauly-Denny Interconnection", PB Power for Scottish and Southern Energy, December 2006.

2.6.4 Maintenance and Life Expectancy of Cable

197) A cable system design life of 40 years is provided by manufacturers with warranty periods of up to 10 years being provided.

198) Maintenance of power cable systems falls into three categories:

- route patrols and inspections,
- planned service maintenance, and
- emergency fault repairs.

199) Most cable damage is the result of third party activity. Regular patrolling of the cable route looking for third parties working close to the cable route is a preventative measure. The frequency of such patrols would depend upon a risk analysis of third party activity likely to take place along the cable route. Routes where cables are buried under roads which are likely to be opened by other service providers are generally at greater risk of damage than cables running through pasture. During a patrol, inspections would be made of all above ground furniture to check externally that they have not been damaged or vandalised and that security locks are in place.

200) Planned service maintenance would require the opening of link kiosks or pits. Internal inspections of the pillars would check the condition of the pillar and the equipment contained within. Cable oversheath integrity tests would be performed at link pillar positions as would the tests on the sheath voltage limiters, where these are installed. These tests consist of applying a potentially dangerous DC voltage and thus are only performed by a trained test engineer (normally a contractor) under controlled test conditions and safe working practices.

201) Some cable manufacturers are offering "maintenance free" systems. However this statement refers only to planned service maintenance. It is advisable to check the condition of any equipment which is susceptible to third party interference. If damage to the cable system does not immediately cause a primary insulation failure (e.g. as the result of a glancing blow to the cable by an excavator) any puncturing of the oversheath or metallic sheath or barrier would allow water ingress, corrosion and progressive XLPE insulation deterioration leading to primary insulation failure. Unlike oil filled cables, XLPE cables do not contain any pressurised liquid which, when monitored, would indicate a puncture to the cable's metallic sheath. It would be recommended therefore that unless a system of continuous monitoring is installed for the SVLs and the cable oversheath that regular oversheath integrity tests (preferably annually) be performed.

2.7 Cable End-Of-Life

202) When EHV XLPE cables become due for decommissioning the following options are available:

- reduce the operating voltage level to extend the cable systems service life,
- remove the cable system entirely and reinstate,
- partially remove the cable system, and
- remove the cable system entirely and install a new system in its place.

203) Depending on the reason for the decommissioning of a cable circuit the cable system may be capable of operating at a lower voltage level, e.g. 132kV or 11kV. Not every circuit would necessarily be in the correct position to be useful when operating at a lower voltage and there would be a number of practical difficulties associated with connecting the cable system to a lower voltage network, in particular any transition connections.

204) Whilst there is a considerable quantity of copper in a cable it is not foreseen that the price of scrap copper will increase sufficiently for it to cover the full cost of excavation and reinstatement of the cable system. The materials in a large conductor EHV cable system are not biodegradable. In order to completely remove direct buried cables from the ground a similar process must be undertaken as that for the installation. This would include a swathe and haul road. It is not foreseen that the CBS would be removed from the ground but that all else would. This would include the cable, tiles, warning tape, auxiliary cables, joints and link equipment and above ground furniture.

205) If partial removal of the cable system is required then this could be limited to the items above ground that adversely effect visual amenity, such as pillars and associated fencing or bollards. For oil filled cables it is desirable to remove the cable joints as these contain oils and some contain significant quantities of bitumous compound. XLPE joints do not contain oil and modern joint secondary insulation protection exists which uses inactive resins in place of bitumen. There is therefore no reason to remove the joints beyond any necessity for removing the cable. If however the cables are installed in air filled ducts, the cable may be withdrawn from the ducts at duct opening positions without the need to excavate the entire length of trench. Under these circumstances removal of the joints would be sensible as the joint bays are likely to be convenient places to expose the duct ends. Withdrawing the cable from the ducts without excavating the cable trench would leave the polymeric ducts in place along with the surrounding CBS, warning tiles and tapes.

2.8 Upgrading

206) If it is envisaged that 275kV cable might need to be replaced with 400kV cable in the future, then the use of ducts from the outset could make the upgrade less disruptive and costly, always providing that a duct size that is suitable for both 275kV and 400kV cable may be found. The cost of installing cable systems is covered in Chapter 4:Financial Considerations.

CHAPTER 3: ENVIRONMENTAL CONSIDERATIONS

3.1 Introduction

207) This chapter takes as its basis the Considerations for Underground Cable Systems set out in Chapter 2 and examines the potential environmental impacts resulting from construction and operation and compares these to the potential impacts identified in relevant literature (Appendix 2).

3.2 Method

208) The method involved:

- Literature review, regular discussion review, visits to and information on recent relevant projects and the use of case studies including site visits.

- Field study of soil and temperature conditions in the vicinity of a 400kV underground cable at Torness Power Station (See Section 1.3 for availability of this report).

3.3 Impacts

3.3.1 Potential Construction Impacts of Cable Route

Figure 3-1 Potential Impacts of Cable Route

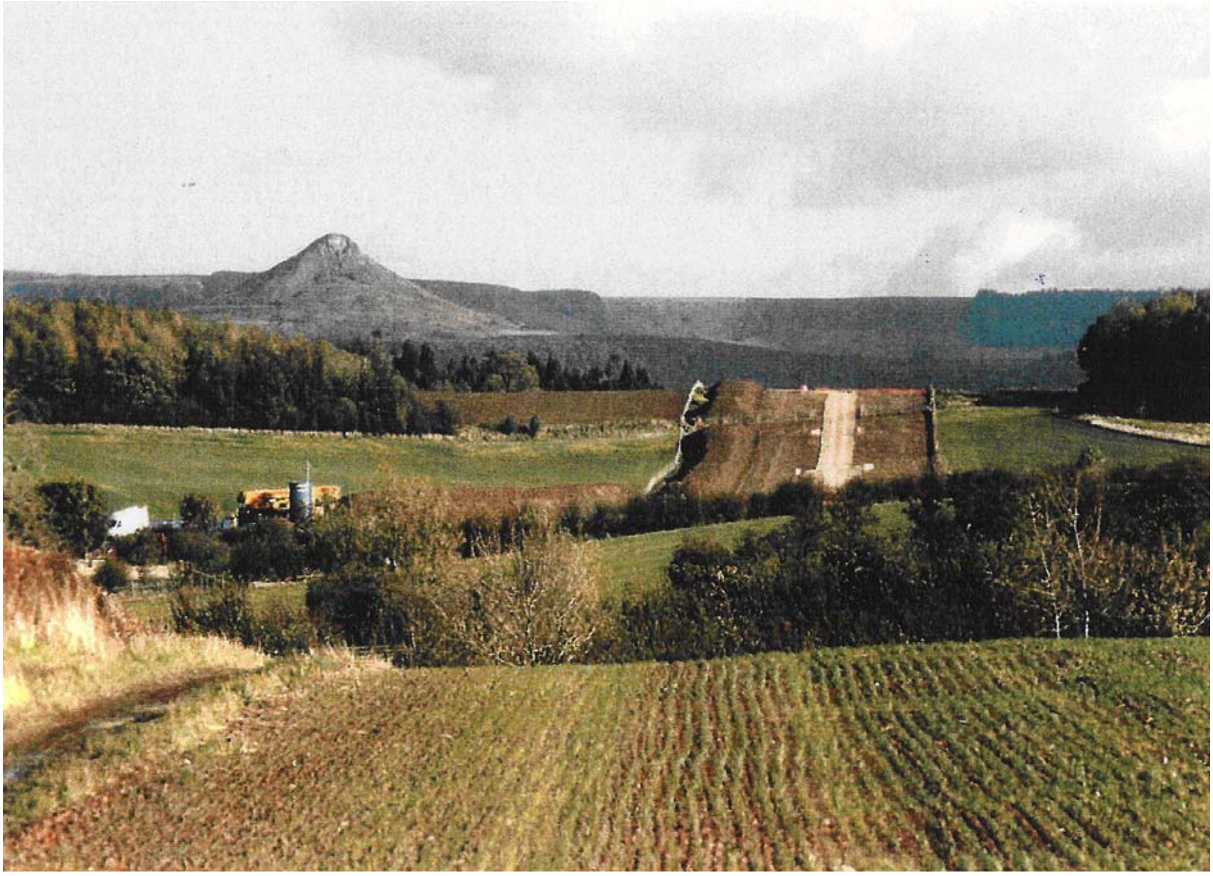
209) The construction of cable trenches and joint bays requires new drainage works, and normally also requires substantial access tracks for construction equipment used in trenching and cable, laying, and for the export and import of material throughout the length of the cable route. A swathe cross-section for double circuit cable construction is shown at Figure 2-8 above, which has been used as the basis for considering potential impacts of a cable route. An example swathe is shown in Figure 3-3. As depicted in Figure 3-1, provision of cable trenches and temporary and/or permanent access tracks has the potential to impact upon natural and cultural heritage resources, visual amenity and landscape character, with the following being particular considerations:

- ground cover/habitat particularly blanket bog, wet and dry heaths,
- sensitive species,

- landscape character, visual amenity and natural heritage interests particularly through the loss of individual trees, felled corridors through semi-natural and other woodlands and commercial forestry and loss of hedges,
- archaeology and cultural heritage features, both known and unknown,
- land use,
- people and property as a result of increased noise levels, changes to air quality as a result of additional traffic and disturbance to water supplies,
- geology and soils through excavation and disposal of excess material,
- hydrology, fresh water bodies and water courses, particularly existing man made drainage systems such as field drains and water quality,
- road network through additional traffic, and
- time taken for reinstatement to become effective visually and ecologically.

Figure 3-2 Excavation of a Joint Bay Position

Figure 3-3 Working Swathe



3.3.2 Potential Mitigation of Construction Impacts of Cable Route

210) The impact of construction activities can be mitigated by:

- route selection,
- the ability to deviate the cables around local topographic and other features,
- appropriate construction methods, particularly to reduce impact on drainage and to reduce compaction,
- the timing of construction particularly in relation to breeding, nesting and rearing sites of birds, mammals and aquatic species, and
- adopting a ducted design of cable installation that allows for the shortest lengths of open trench at a time.

3.3.3 Potential Operational Impacts of Cable Route

211) Drainage will be affected by the cable trenches, joint bays, access tracks, compaction due to plant movements, and the use of thermally stabilised backfill around the cables which relies for its effectiveness on a sand cement dry mix using a sand that compacts well with a low void ratio. This effect may be to either increase the moisture content in the soil within the reinstated construction area or to reduce it. While the general compaction can be broken up after construction, this may be achieved only to a limited depth and extent. Even on the assumption that the original ground cover has been stripped, stored and replaced appropriately it is still considered that this can result in a change in vegetation over time, as may be seen on many pipelines in upland areas (Figure 3-5).

Figure 3-4 Potential Operational Impacts of Cable Route - link pillars included.

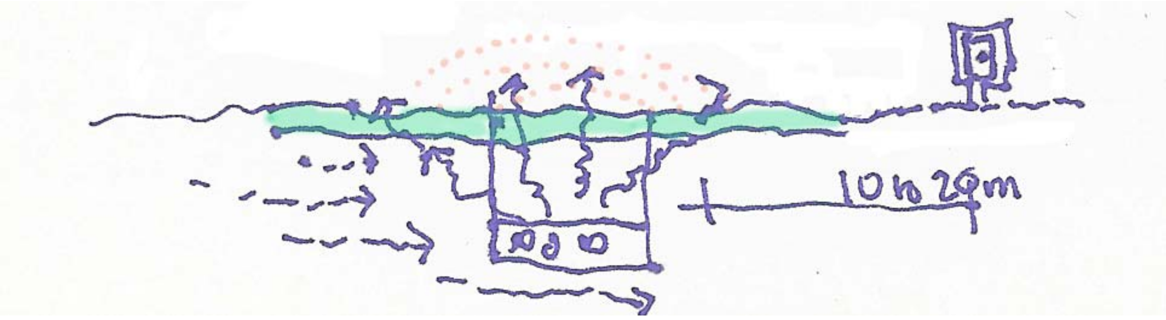


Figure 3-5 Gas pipelines visible from the air at Elvanfoot

212) The operation of the cables will result in the dissipation of heat into the surrounding soil. At high loads this will cause movement of moisture within the soil and an increase in soil temperature above ambient.

213) The alteration to drainage, soil moisture and temperature has the potential to directly affect, over time, the species composition of the reinstated ground cover. This may result in the reinstated ground cover being ecologically and visually different from the surrounding undisturbed ground cover (Figure 3-4). This would have an effect on the landscape character and visual amenity when viewed from above. It may also adversely impact on natural heritage interests. This effect can, for example, be seen in the aerial photographs taken of long established 400kV oil filled cables in arable fields (Figure 3-6).

214) Similar views are expressed in the Jacobs Babtie report for the Highlands Council et al, entitled Undergrounding of Extra High Voltage Transmission Lines, paragraphs in sections 3.4, 3.5 and 3.6, and the Summary and Conclusions on page 84. Reference is also made to the third paragraph on page 4 of the ETSO Position on Use of Underground Cables to Develop European 400kV Networks, 31 January 2003.

215) The report Underground Transmission Cable Limitations Technical Review TE 112740 prepared for EPRI (Electric Power Research Institute) by Power Delivery Consultants 1999 refers at paragraph 4.5 to Soil Heat Dissipation Limitations and in 4.6 to Uncertainties in as-built thermal conditions. Paragraph 8.1: Environmental Disturbance During Construction refers to disruption due to traffic, disturbance to historical artefacts, disturbance of wetlands and other environmentally sensitive areas and disturbance of contaminated land.

216) The report also states in Paragraph 8.3: Increase Soil Temperature that localized increases in soil temperature produced by underground transmission lines have been an issue in some cases when obtaining public acceptance for proposed line routes. This is due to the concern that underground transmission cables will affect soil temperature and moisture to the point that trees or other vegetation will be adversely affected. Double circuit high pressure fluid filled and XLPE underground transmission cable may produce maximum heat losses in the order of 40 to 60 watts per foot due to the loss mechanisms discussed in Section 3.2 (Cost of Losses). These losses produce maximum soil temperatures of approximately 60°C at the cable (or pipe) and earth interface. The soil temperatures then decrease with distance to ambient soil temperature. This local increase in soil temperature becomes negligible (even at maximum load conditions) at distances of 15 to 20 feet from the trench centre line. It also notes that most cable system designers prefer to keep planned cables some distance from large trees due to possible reduction in soil moisture content by tree roots. This report references EPRI Report RP7826: (Study of Environmental Impact of Underground Electric Transmission Systems May 1975), this report is now unavailable.

217) Eurelectric, in their Statement on Using Underground Cable Technologies for High or Very High Voltage Transmission Links (150kV and above) in Europe March 2004 in section 4.2 paragraph 3, stress that burying high voltage cables cannot be compared to the relatively simpler process of laying gas, water or oil pipes because of the extent of the construction involved.

218) The study referred to in Section 1.3 examines physical properties of the soil that effect heat dissipation, the likely effects of an increase in soil temperature on plant productivity, the existence of any soil temperature measurements above underground cables (particularly in topsoil) and the likely effects of soil disturbance on plant productivity/species diversity. It will also establish whether heat dissipation effects can be separately identified from construction disturbance effects. The study is likely to conclude that patterns of differential growth across the width of an underground cable corridor will be apparent within the landscape over a relatively short time span. These patterns will be less obvious in higher productivity agricultural fields, and more obvious in uncultivated and semi-natural and natural environments.

219) To support the literature review a field study is being undertaken of the Torness 400kV underground cables (fluid filled), where construction and cable current are known, to measure temperatures and soil properties in different soil and vegetation conditions. A dead power cable, where the construction is known but where no net

heat flow is anticipated, has also been studied. A report of the field study and conclusions will form an Addendum to this report in January 2007.

Figure 3-6 Cable Route Visibility During Different Seasons

220) In summary, the potential operational impacts are the:

- change over time of species composition of reinstated ground cover as a result of changes to drainage, compaction and heat dissipation
- effect on visual amenity of areas looking from above the route as a result of patterns of differential growth across the width of an underground cable corridor, which will be apparent within the landscape over a relatively short time span.
- disruption to land use as a result of a restriction on drainage and deep cultivation, restriction on building in the vicinity of the cable route and tree planting in the vicinity of the cables, and, prohibition or restriction of forestry operations in vicinity of cable route.

3.3.4 Potential Mitigation of Operational Impacts

221) The potential mitigation of operational impacts can be by:

- design in terms of cable spacing and depth, and
- routeing to avoid ground cover / habitats that are sensitive to change in drainage and temperature regimes.

3.3.5 Potential Impacts of Terminal Tower and Sealing End Compound

Figure 3-7 Overhead Line Cable Sealing End Compound Construction

222) The potential impacts are upon

- natural heritage interests as a result of loss of ground cover/habitat,
- sensitive species,
- visual amenity as a consequence of the terminal tower,
- landscape character, visual amenity and natural heritage interests through loss of trees, felled corridors through either individual or as part of a semi-natural or other woodlands and commercial forestry and loss of hedges,
- archaeology,
- noise, and
- hydrology and water courses, existing man made drainage systems such as field drains and water quality.

3.3.6 Potential Mitigation of Terminal Tower and Sealing End Compound

223) The potential mitigation is:

- Location, and
- Use of bunding and/or screen planting (which takes time to be come effective) to screen fencing and equipment and use of colour to reduce visual impact.

3.4 Environmental Effects and Mitigation Measures

224) A review of relevant literature was undertaken to confirm the potential impacts and mitigation measures and their effects and is given in Table 3-1 with additional details in respect of sources, in Appendix 2.

Table 3-1 Environmental Impacts and Mitigation Measures for Cables

IMPACT		DETAILED CONSIDERATION	MITIGATION MEASURES
NATURAL HERITAGE (FLORA & FAUNA)	Habitats	Active blanket bog (not possible to restore if lost and area greater than that disturbed due to hydrology changes).	Preferable to Avoid
		Wet and dry heaths (not all may be restorable, and restored communities may in the long term be replaced with communities with much higher proportions of grasses, sedges and rushes likely to attract grazing animals).	Preferable to Avoid
		Semi-natural woodland (loss of trees).	Preferable to Avoid
		Simple and recently established habitats (reversibility and habitat fragmentation).	Preferable to Avoid
		Difficulty of reinstatement after construction in terms of ground & drainage disturbance	Routeing, if not able to avoid Method Reinstatement Plan
		Difficulty of maintaining reinstated habitat over time due to a combination of the impact of construction on drainage and heat dissipation during operation	Design Routing Method Reinstatement Plan Monitoring
	Fresh Water	Water course crossings - disturbance and pollution - obstruction to fish movement - water quality - impact on species present	Method
	Sensitive Species	Species subject to statutory protection - European protected species - Breeding Birds listed in Annex 1 of the Birds Directive and/or Schedule 1 of Wildlife and Countryside Act. - Animals in Schedule 5 of WCA	Avoid, if not able to avoid Routeing Timing Method
LANDSCAPE	Landscape Character & visual amenity	Cable Trench reinstatement and Visual Impact	Design Method Reinstatement Plan
		Access Tracks during construction and reinstatement and use in operation	Routeing Design Method Reinstatement Plan
		Terminal Tower and Sealing End Compounds	Location Design Method Reinstatement Plan
		Settlement Ponds	Routeing Design Method Reinstatement Plan
		Joint Bays	
		Link Pillars	
		River crossing including reinstatement	
		Road upgrades and bridge strengthening	
		Loss of trees, hedges and fragmentation of landscape features such as stone walls	
CULTURAL HERITAGE	Archaeology	Known sites (recorded)	Preferable to Avoid
		Unknown sites (high in fertile lowland and particular flood plain areas)	Possible damage or loss

IMPACT		**DETAILED CONSIDERATION**	**MITIGATION MEASURES**
			Method
		Effect on setting	
LANDUSE	Disruption to Land use	Farming	Restriction on drainage and deep cultivation
		Buildings	Restriction on building within 5m of cable route
		Planting over cable	Trees restricted
		Woodland and Commercial Forestry - Felled corridor has landscape and visual effects. - Would prohibit or restrict forestry operations particularly those requiring the use of wheeled or treaded vehicles.	Preferable to Avoid
PEOPLE	Noise	Traffic noise and vibration	
GEOLOGY AND SOIL		Rock cutting and disposal of excess material	
HYDROLOGY	Impact on drainage		Method
	Impact on water quality		Method
PROPERTIES	Impact on water supplies		
TRANSPORT	Impact of additional vehicle movements on existing road network		
AIR QUALITY	Impact of additional traffic movements and excavation		Method
RECREATION AND TOURISM		No evidence of impact.	
EMF		There are only magnetic fields associated with UGC but NRPB guidelines met.	

3.5 Conclusion

225) A review of literature listed in Appendices 2 and 3 confirmed a broad consensus on potential environmental impacts, detailed considerations and mitigation measures for underground cable routes.

226) While there is evidence of the actual construction impacts of underground cable routes, terminal towers and sealing end compounds, there is almost no evidence of the operational impacts of underground cable routes; although there is for pipelines. While it is clear that this lack of evidence was recognised in 1975, it is only recently that focus on the possible use of underground cables in rural areas of Europe has lead to the recognition of the need to understand and investigate operational

impacts, particularly the effect of heat dissipation on the success of vegetation reinstatement.

227) The main potential impact of construction is the disturbance to ground cover/habitats and the subsurface conditions caused by the width and length of the route resulting from the number, dimensions and spacing of the trenches required to contain the required number and spacing of cables and circuits.

228) The main potential impact of cable operation is the effect of heat dissipation on ground cover / habitat. This is likely to result in patterns of differential growth across the width of the underground cable corridor that will be apparent within the landscape over a relatively short time span.

229) The main mitigation measures are through route selection, design, construction and reinstatement methods and timing, taking into account the effects of soil disturbance and heat dissipation in relation to the success of vegetation reinstatement.

CHAPTER 4: FINANCIAL CONSIDERATIONS

4.1 Sources of information, and assumptions

230) The costs provided in this report are intended to allow a comparison of the OHL and the UGC options for each of the case studies. Setup costs have been included in the cable costs, since it is believed that these assumptions represent the most likely costs that would be incurred where undergrounding occurs.

231) The most accurate costs estimates for construction work in the power industry are obtained from tenders by suppliers. The business of tendering, however, is very costly and time consuming for the suppliers, and has thus been considered an inappropriate method of estimating when no purchase is intended. In this situation, the most realistic estimates would normally be derived from recent SHETL and SPT contracts for similar work. However, for the cable installation in particular, no similar contracts with SPT or SHETL exist, so other less direct methods have been used to build up price estimates for this report.

232) For the highest price components of the work, the 400kV and 275kV power cables, cost data has been requested from suppliers in a less formal manner than through tendering. Two suppliers responded to our request and provided costing information on much of the cables' auxiliary equipment and on construction too. Figures from the supplier providing the lower cost estimates have been referenced by this report.

233) For the other activities and components, particularly the civil works, the directional drilling, and the OHL costs, information has been derived from a number of sources including:-
- Cable Consulting International Ltd., cable consulting specialists,
- Balfour Beatty OHL contractors,
- SHETL,
- SPT, and
- PB Power equipment specialists and project engineers.

1) Cable terminations will be required to interconnect the cable with the overhead line or substation busbar. The overhead line and busbar are insulated by the air which has a lower electrical performance than the cable insulation.

234) A full list of costing information sources are presented and numbered in Appendix 4, and source numbers in other parts of this report refer to this Appendix. Appendix 5 provides a list of costing assumptions. The approach that has been used is that, where there is room for doubt about OHL costs, the higher option has been taken, whilst for UGC, the lower cost has been HL cost ratios.

4.2 Estimates, Uncertainty, and Contingency

235) Cost estimates for the construction of a new circuit are subject to many types of uncertainty and, insofar as they affect the project cost they are often classified into "physical" and "price" variations. This section briefly identifies some of the factors involved, since it is important to bear these in mind when considering the cost estimates in the "Case Studies" section of this report.

236) The physical factors that can affect the costs of a project relate to changes in quantities, methods of working, or period of implementation, and might include:

- Civil engineering / geological uncertainties,
- Inaccuracies in quantity estimation,
- Manufacture and transport problems,
- Weather (for site installation work),
- Other delays to the project that may or may not be controllable by the supplier, and
- Metal exchange prices (copper and lead).

237) The price factors that can bear upon the cost of the project include:

- Changes to estimates in unit prices,
- Current market conditions (how busy are the suppliers, availability of materials),
- Contract conditions, and the flexibility to vary the price after the contract has been signed, and
- International exchange rates.

238) As the time for a project's execution comes closer it is often possible to reduce many of these risks by site surveys, geological surveys, agreeing price contracts, or even by consulting the weather forecast where the weather is a material factor in the success of the operation. Before this time, however, a contingency cost is normally added to the estimate to take these other risks into account. The contingency level is sometimes the subject of Company policy, but in practice should reflect the risk (likelihood and impact) of unidentified costs coming to light later. Contingency costs have thus been added to the project "best estimates", although these contingencies have been identified separately here for the benefit of the reader.

239) Whilst weather, exchange rates, and many other factors could affect the pricing of this project, the biggest single risk at this point is seen to be the uncertainties related to the workability of the terrain (steep in some places) and the geology (rock in some places, soft ground cover in others). This risk impacts much more heavily on the UGC solution than on the OHL for two reasons:

(i) whilst the UGC has to pass right through the rock or soft ground in its path (or suffer a possibly lengthy and thus costly diversion), the OHL tower locations may be chosen with a considerable degree of flexibility, allowing the circuit to sail over difficult stretches of terrain without difficulty.

(ii) the cable trenching contractor needs to operate on every part of the route, and where access becomes difficult due to the steepness (or other characteristic) of the land, costs can escalate in unexpected ways.

240) The prices obtained for the cable materials are based on the metal prices of copper at US$ 8000/tonne[11] and lead at US$1700/tonne. Tower prices have been based

[11] Metal prices are quoted on the London metals Exchange in US$ per tonne, and the cable suppliers used these rates to provide their cost estimates for these case studies in UK£. It might appear, therefore, that suppliers take the foreign exchange risk when providing quotations, but in fact their final

upon a steel price of £1200/tonne. World prices for metals have seen unusual rates of increase in recent years, and are subject to significant fluctuation. .

241) For these reasons this report has assumed a 10% contingency factor for the OHL solution, and a 15% contingency for sections of UGC.

4.3 OHL Cost Estimates

242) Construction costs for the case study sections of OHL have been estimated in two different ways. Firstly a detailed estimate was made by adding together the estimated costs of the various equipment and works necessary for the construction, including making appropriate allowances for accommodating other services crossing the route and for any environmental impact reparation. Secondly, and for comparison purposes, the OHL contractor was requested to estimate the costs that would be saved if the case study sections of OHL were omitted from a contract to build 220km of OHL – that is, the entire Beauly – Denny route.

243) Regarding operation of the OHL, maintenance and wayleave costs have been estimated over the nominal 40 year life of an OHL, and on top of these has been included the equipment replacement cost in 40 years time. Certain assumptions have been made about the estimate of replacement costs of OHL. These assumptions have been made for all the case studies, and are summarised as follows:-

(i) The costs for future years have been discounted to arrive at a present value. The discount rate chosen for this purpose is the same as that currently used for "return on investment" by the National Grid on their Connection Charging Statement, namely 6%.

(ii) The choice of period before which the equipment is replaced, namely 40 years, has also been guided by this NGET document.

(iii) OHL towers are often considered to have indefinite lives – that is, with appropriate care and maintenance they can survive ad infinitum, with corroding or damaged parts being replaced as and when necessary. Conductor systems, however (the conductors, insulators, and fittings) are seen to require replacement, and experience to date suggests that prudent replacement for these items occurs at around 40 years. However, in the event that this strategic circuit cannot be taken out of service for re-conductoring for operational reasons, it may be necessary to build a second route and then refurbish or decommission this present double circuit. For this reason the full construction costs are included in these cost estimates in 40 years time. (Note: If the existing towers were reused for circuit refurbishment in 40 years time rather than building a second route in its entirety, this would save some 2% of the overall lifetime costs of the OHL option.)

(iv) Wayleaves are considered to be negotiated and paid as a 20 year capital lump sum rather than annually.

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prices for supply will be based upon the prices of metals at the time of the supply contract rather than at the time of any quotation, so the foreign exchange risk still comes back to the purchaser.

(v) OHL maintenance is considered to include regular safety patrols, brush clearance, and sundry repairs as well as tower painting at 20 – 25 year intervals.

4.4 Cable Costing Options

244) The design of the UGC installation involves careful judgement, since many options are presented to the designer. Examples include:

(i) the cable route

(ii) the cross section of the cable conductor and conductor surface treatment,

(iii) the metallic barrier (sheath) material, and use and thickness of screening wires,

(iv) the spacing of the conductors in the trench,

(v) the number of conductors per phase,

(vi) the depth of the cable below ground, and

(vii) the distance between joints.

245) These factors, and many others - especially those dealing with the cooling and the manner in which the cable is housed underground - all affect the rating of the cable, the cost and disruption of the construction, and the degree of heating that is evident at the surface when the cables are in operation.

246) To cost all these options would be an unnecessary and costly exercise, so at SHETL and SPT's request a base case design was adopted, and three major parameters were then varied to assess the sensitivity of the cost to each. Table 4-1 lists these three parameters, and indicates the "base case" option in the right-hand column:

Table 4-1 Cable Parameters – Costed Options

		Base Case
Voltage Rating:	Options of: (i) 400kV for one circuit, 275kV for the other, and (ii) 400kV for both circuits	(i)
Cable type:	Options of: (i) 2500mm^2 copper conductor XLPE insulated UGC, and (ii) 2000mm^2 copper conductor XLPE insulated UGC.	(i)
Installation Type:	Options of: (i) Cables direct-buried in cement-bound sand (CBS) (ii) Cables in ducts	(i)

247) Alongside these parameters, it is assumed throughout these case studies that the current rating parameter will be as follows:

Current Rating:	Matching the post-fault continuous winter rating at 90˚C of the 2 x 700mm^2 (Arucaria) overhead line circuit (4050 amps)

4.5 Summary of Costs

4.5.1 Base Case

248) The cost estimates for the base case options for each of the five case studies are provided in Table 4-2. It will be seen from this base case that the average cost of 1 km OHL, including capitalised maintenance and replacement in 40 years time, is estimated at about £0.97M, and, with contingency included too, is estimated at £1.07M.

249) Similarly, the average cost of 1km cable, given the same maintenance, 40 year replacement conditions, and its own contingency, is estimated at £14.4M (or £13.3M if the cost of works at the ends of the cable are ignored). The overall cost ratio in this case between OHL and UGC is thus approximately 15.5 times.

250) Appendix 6 provides equivalent cost summary tables for all the combinations that may be obtained from the options on the three parameters listed in Table 4-1 above (eight combinations including the base case option).

Table 4-2 Beauly-Denny – Summary Costs – Direct buried 2500mm^2 Cable

Estimate parameters:-
Cable voltage = 275kV & 400kV
Cable diameter = 2500sqmm
Cables in ducts or direct-buried = in ducts
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

	These 3 options are mutually exclusive						
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	**Garva Bridge to South Dalwhinnie**	**Lower Taylorton - Logie (Stirling SE)**	**Lower Taylorton - Cocksburn Wood (Stirling SE + NE)**	**Glen Burn to Touch Road (Stirling W)**	**Average with contin-gency**	**Average without contin-gency**
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.13	9.13	7.50	11.95	9.78		
B. Cable route construction & lifetime costs (£M)	54.45	42.64	30.19	73.54	53.19		
Total cable costs (£M)	64.57	51.77	37.69	85.49	62.97		
Cable costs inc. 15% contingency (£M)	74.26	59.54	43.35	98.31	72.41		
Cable cost per km (£M/km) - but see below	11.06	12.80	14.50	11.68	12.50	14.4	12.5
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	68.39	55.95	40.90	92.33	67.79		
Cable cost compared to OHL (times)	12.6	16.6	17.7	16.4	15.7	15.5	14.8
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	10.15	11.82	13.56	10.74	11.56	13.3	11.6

4.5.2 Cost Comparison Summary Table

251) Having identified the costs associated with the base case cable design and with the three design parameter values discussed above, the remainder of this discussion now focuses upon the costs averaged across the five case studies, and across these three design parameter values.

252) Comparisons between the OHL and UGC costs in the tables of Appendix 6 may be summarised as shown in Table 4-3. Appended to the table are firstly some brief notes thereon. These are followed by more detailed notes on the interpretation of the information contained within lines, 1-3, 4-6, 7-8, and 9-11.

Table 4-3 Summary of Costings (see also note below on uncertainties)

Line	Item	Average		
1	OHL costs inc. 10% contingency (£M/km OHL route)	1.08	Note 1	
2	Cable costs inc. 15% contingency (£M/km UGC route)	14.1		
3	**Extra cost of undergrounding (£M/km OHL route)**	**15.7**	Note 2	
4	Cable / OHL cost ratio km for km (times)	13.1		
5	Cable / OHL cost ratio due to extra km (times)	2.5	**Maximum**	**Minimum**
6	Overall Cable / OHL cost ratio (times)	15.6	18.4	12.3
7	Cost of cable ends only (no route costs) - SSE (£M)	4.54	Note 3	
8	Cost of cable ends only (no route costs) - SPT (£M)	4.43	Note 4	
9	Premium for 2500sqmm over 2000sqmm cable (£M/km cable route)	0.38		
10	Premium for 400kV only over 400kV / 275kV (£M/km cable route)	0.56		
11	Premium for ducted cable over direct buried cable (£M/km cable route)	-0.01	Note 5	

Notes to Table 4-3

Note 1: (Line 1) Only one OHL configuration was used for comparison – the double circuit 400kV steel lattice tower with twin Arucaria (2 x $700mm^2$) AAAC conductor.

Note 2: (Line 3) Extra cost of undergrounding partly due to equipment costs, and partly due to extra route length of UGC compared to OHL.

Note 3: (Line 7) This includes two SSE400 terminal towers.

Note 4: (Line 8) This includes two L12 terminal towers.

Note 5: (Line 11) Ducting & direct-buried cable whole-of-life costs break even.

Note 6: Cable supplier estimates were prepared on basis of +/- 20%. Lowest estimates used here.

4.5.3 Description of Items in the Summary Table

253) Lines 1 – 3: These provide the average costs per km for the 400kV OHL design proposed for the Beauly – Denny Overhead Transmission Line, and the average costs of the UGC that might be used to replace specific sections of that OHL. Also included is the headline figure of the average *extra* cost per km of the OHL being undergrounded in the five specific case study sections of the line, namely

£15.7M/km. The reason why this average cost per km of the OHL route is greater than the cost per km of the cable route is that, in four cases out of five, it was found that the cable route itself needed to be longer than the OHL route it replaced.

254) Lines 3 – 6: These show the calculated UGC / OHL cost per km ratios: (a) the increase due to the extra cost per km of cable equipment over the same length of OHL equivalent, (b) the increase due to the extra route length required by the UGC solution, and (c) the overall ratio.

255) Lines 7 – 8: The costs of the sealing end compounds and their equipment are, broadly speaking, fixed, whilst the cost of the UGC itself is proportional to the route length. Because the fixed costs of the compounds are so substantial their costs can significantly affect the average cost per km of an UGC. The fixed costs used in these estimates are thus shown here to aid understanding of the make-up of the estimates. Larger towers are used in the highlands to accommodate the more severe weather to be found there.

256) Lines 9 – 11: Three design parameters of the UGC solution were varied to assess sensitivity to these aspects: Line 9 indicates that using 2500mm^2 instead of 2000mm^2 cable would cost around £380k per km extra. Line 10 shows that making both circuits 400kV instead of designing one circuit for 275kV would cost about another £560k per km. Line 11 suggests that, taking the lifetime cost of the installation, and assuming that the cables will be replaced at the end of their lives, the financial view is indifferent to the choice of method for installing the cables – the use of ducts, or direct burial.

257) Note that if the 15% cable contingency factor is disregarded, and if the full -20% factor (see Appendix paragraph 470) of the uncertainties of the cable cost estimates from cable suppliers is also taken into account, the headline figure of the average extra cost per km of the OHL being undergrounded drops to around £10.3M, as shown in Table 4-4 below. This table also shows a commensurate drop in the UGC / OHL cost ratios.

258) Although this results in a cable cost estimate that is unreasonably optimistic, it still shows an overall UGC / OHL cost ratio of greater than 10 times.

Table 4-4 Summary of Costings (Lowest estimate & no cable contingency)

Line	Item Note 6	Average
1	OHL costs inc. 10% contingency (£M/km OHL)	1.08
2	Cable costs inc. 15% contingency (£M/km UGC)	9.6
3	**Extra cost of undergrounding (£M/km OHL route)**	**10.3**
4	Cable / OHL cost ratio km for km (times)	8.9
5	Cable / OHL cost ratio due to extra km (times)	1.68
6	Overall Cable / OHL cost ratio (times)	10.6
7	Cost of cable ends (no route costs)- SSE (£M)	3.09
8	Cost of cable ends (no route costs)- SPT (£M)	3.02
9	Premium for 2500sqmm over 2000sqmm cable (£M/km cable route)	0.26
10	Premium for 400kV only over 400kV / 275kV (£M/km cable route)	0.38
11	Premium for ducted cable over direct buried cable (£M/km cable route)	-0.01

259) Further information on the costing approach and assumptions may be found in Appendix 5.

4.5.4 Conclusions

260) OHL costs, including contingency, are estimated at around £1.08M/km.

261) UGC costs, including contingency, are estimated at around £14.1M/km.

262) On this basis, the mid-point UGC / OHL cost ratio is estimated at about 15.6.

263) UGC costs, excluding contingency and using estimates 20% below supplier central expectations, are estimated at around £1.08/km.

264) The mid-point UGC / OHL cost ratio is estimated at 10.6.

265) The actual costs of undergrounding even one of these case study sections, for example the Beauly – Eskadale section, would be at least an extra £66M above the cost of the equivalent OHL.

CHAPTER 5: CASE STUDIES

5.1 Introduction

266) This section considers undergrounding in three locations in proximity to the overhead line route. In the SHETL area there are two case studies, each with their own location: in the SPT area, a single location includes three case studies. These case studies were selected in order to encompass the majority of the types of circumstance that may be encountered in underground cable routing.

267) Co-ordinates given in the form “NH 494 443” are approximate ordnance survey reference points. The cases were studied in the order running from north to south, and they are thus presented in this order. The following generic considerations were addressed prior to finding a cable route for each case study.

5.2 Cable System Design Considerations

268) The main engineering aspects considered for these cable system designs are:

- Cable system performance requirements voltage and rating,
- Installation method, location and routing,
- Power cable and accessory design, and
- Cable section lengths and trench arrangement.

5.2.1 Cable System Performance Requirements, Voltage and Rating:

269) The cable system operating line voltage and current rating are determined by the overall power transmission design requirements.

270) Power cable systems generate heat when transmitting power between source and load. This heat is generated by cable losses, principally conductor resistive (I^2R) losses. A 90°C limit is set for XLPE insulated cables under continuous operation. The heat generated must be dissipated into the environment if the cable conductor is not to overheat.

271) Secondary heat loss generation also occurs in the cable’s metallic sheath and in the XLPE insulation; the latter being a dielectric loss. These heat losses, together with the conductor heat loss comprise the total heat loss that must be transferred from the cable into the environment during operation.

272) The materials surrounding the conductor thermally insulate the conductor from the environment and restrict the heat transfer. The heat flow is also further restricted by the materials used to bury the cables in the ground. A minimum depth of burial of 1150mm has been applied in accordance with SHETL’s agreement with the National Farmers Union that cable cover tiles shall be covered by at least 1000mm of soil to prevent inadvertent damage, particularly in areas subject to ploughing.

273) The continuous current carrying capacity of cables is therefore restricted by the amount of heat generated and the rate at which this heat energy is capable of being dissipated whilst limiting the maximum conductor temperature to 90°C. When calculating continuous ratings (using the international standard IEC 60287), all cable heat loss is considered to eventually dissipate into the atmosphere. This calculation

includes, inter alia, the cable material properties and dimensions, the effects of any mutual heating between cables, the depth of burial and the thermal properties of the soil surrounding the cables and the temperature of the atmosphere into which the heat will eventually be lost.

274) Heat transfer from a cable circuit is improved by, a) minimising cable losses, b) increasing the cable spacing, c) minimising cable burial depth, d) maintaining the cable surround's soil thermal resistivity at a low value.

275) Table 5-1 gives the pre and post fault ratings for the cable. This requirement is to meet the performance of the overhead line and thus both the 275kV and the 400kV cables must be designed to carry the same current. SHETL have advised that the post fault rating is only for a 24 hour period after which the rating will fall back to the pre-fault rating.

Table 5-1 Seasonal Circuit Ratings and Maximum Ambient Temperatures

400kV and 275kV	Winter (Dec to Feb)	Normal Cold (Mar, Apr, Nov)	Normal Hot (Sep, Oct)	Summer (May to Aug)
Pre-Fault Rating of the OHL	3400A	3270A	3270A	3040A
Post-Fault Rating of OHL (24 hour duration)	4050A	3890A	3890A	3620A
Pre-fault Rating per Cable (2 cables per phase)	1700A	1635A	1635A	1520A
Post-fault Rating per Cable (24 hour duration) (2 cables per phase)	2025A	1945A	1945A	1610A
Direct buried	10°C	10°C	15°C	15°C
Filled surface trough	10°C	15°C	25°C	35°C

276) The power cable conductor size and design will be affected by the cable current rating requirement. For the power transmission requirement between Beauly and Denny it will be necessary to install two underground cables per phase to meet the overhead line rating.

277) The heat delivered into the ground by the cables will tend to dry out the soil by driving moisture away. Under these circumstances the soil thermal resistance is likely to increase allowing less heat to escape from the cable. This may result in overheating of the cable system. In order to prevent overheating of the cable as a result of soils drying out, a backfill with known thermal properties when dry is used around the cables within the 50ºC isotherm. In the UK the most common material used for this purpose is cement bound sand (CBS). This material is selected quarry sand mixed with cement in the ratio of 14:1 by volume. The requirement for the sand and CBS mixture is specified in ENA TS97-1 (Special backfill material for cable installations, published in 1997).

278) For the purposes of current ratings the soil outside of this isotherm is assumed to have a thermal resistivity of 1.05Km/W in the winter and Normal Cold months and 1.2Km/W in the Summer and Normal Hot months in line with standard UK practice.

279) A field survey of the indigenous soil thermal resistivity should be measured to confirm the cable rating figures assumed. If areas of soil are found that do not meet with these requirements then the cables must be more widely spaced or the indigenous materials exchanged for more thermally acceptable material. This procedure is not a common occurrence in the UK and usually occurs on industrial sites where high thermal resistivity materials such as coke, flyash or steel slag may be found. Such testing requires the excavation of test pits to the depth of the cable burial and the insertion of a test probe into the ground. This probe contains a heating element and thermocouple assembly. Temperature readings are taken at regular intervals and the thermal resistivity of the soil calculated.

Figure 5-1 EHV Cable Sample

5.2.2 Selected EHV XLPE Cable System Standards

280) IEC 62067 – Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) - Test methods and requirements , 14/03/2006

281) IEC 60287 – Electric cables - Calculation of the current rating - Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General, 23/11/2001

282) EA Engineering Recommendation C55/4 1989 – Amendment 1, 1995 – Insulated Sheath Power Cable Systems,

283) Although not publicly available, there is an agreement between National Grid and SHETL / SPT for the National Grid Standards to be used as reference guides for installations in Scotland.

5.2.3 Location of Terminal Towers and Sealing End Compounds

284) Based on the first identification by SHETL and SPT of the start and end points of the underground cable section for each case study, the Landscape Architect from the EIA team, through desk study and then site visits, identified a suitable location for the terminal tower and sealing end compounds such that they would be within the limits of deviation (LOD) of a tower location on the proposed overhead transmission

line. For the West of Stirling Case Study, Glen Burn to Touch Road, since the proposed overhead transmission line runs to the East of Stirling, search areas were given to the Landscape Architect within which locations for the terminal tower and sealing end compounds were identified on the assumption that an overhead line could be routed to these locations.

285) The Initial Routes east of Stirling from Lower Taylorton to Logie (Case Study 3) and Lower Taylorton to Cocksburn Wood (Case Study 4) and West of Stirling (Case Study 5) were identified by SPT. These routes were based on examining specific issues. The Lower Taylorton to Logie was to examine the implications of crossing the River Forth and a major road, The Lower Taylorton to Cocksburn Wood was based on examining both the crossing of the River Forth, a major road and the assent of the Ochil's escarpment while the West of Stirling Route was to examine river and road crossings and a route through agricultural land.

5.2.4 Landscape Architect's Comments on Sealing End Compound Locations

5.2.4.1 East of Stirling (locations considered from south to north)

286) The following paragraphs provide the landscape architect's comments on the locations of the sealing end compounds to the East of Stirling.

287) Figure 5-2 is a copy of the preliminary sketch showing the basic concept for the three route studies in the Stirling Area. Route 1 is case study 3, route 2 is case study 4 and route 3 is case study 5.

Southern sealing end compound

288) No obvious locations exist to the south of the River Forth in the area as indicated by SPT, within the Lower Taylorton area. This is a very level area with little or no tree cover. In addition a location to the north of the river would be preferable.

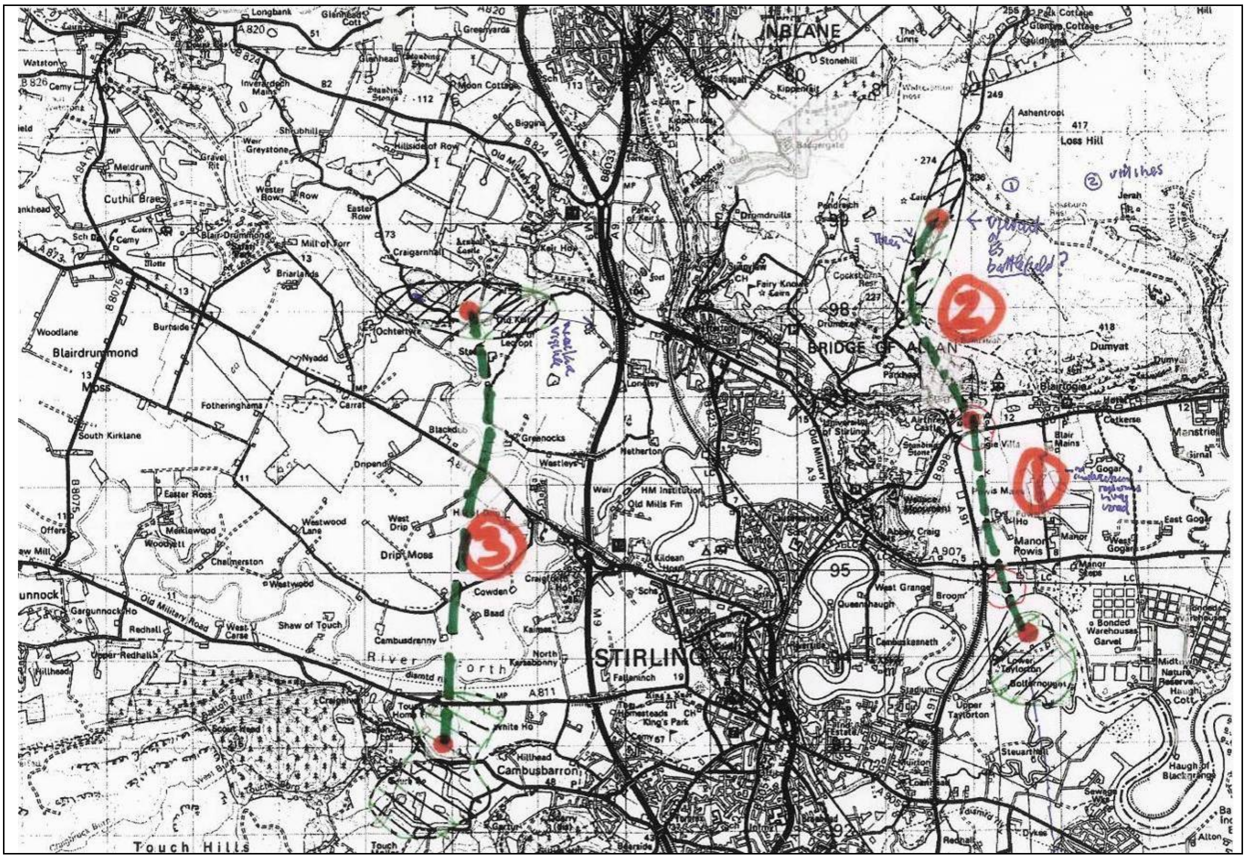
289) Consideration would need to be given to the potential problems of development within the flood plain, in this area.

290) Various options exist for a southern sealing end compound, all of which would be visible from the adjacent areas, to a greater or lesser extent. These are:

- A location to the south-east of Manorneuk and south of the mineral railway line. However this appears to be a former tip area and the ground conditions may therefore be problematic. There is, however, some tree cover present in this area that would assist in screening. There is also access into this area from the road to the north.
- A location to the south-west of Manorneuk, south of the railway line and east of the stream that joins the River Forth in this area (TD208B area / south of this tower position). There appears to be some limited tree cover in this area. This location would be visible from the A9 where it is on embankment as it crosses the railway line. Additional screen planting would be advisable.
- A location as far south as possible within the area between the A91 and the River Forth, as close as possible to the area where the road crosses the river. This has the advantage of being closer to the more industrial edge of eastern Stirling. This would require a realignment of the overhead line route from this point east or south-east and raises issues regarding potential 'wirescape' in

the Stuarthall area –undergrounding of other lower voltage lines could become a consideration.

Figure 5-2 Case Studies 3, 4, 5 - Routes & Sealing End Compound Search Areas



Central / northern sealing end compound

291) Within the Logie / Airthrey Castle area, the location identified by SPT is appropriate; this should be located close to the foot of the Ochils (though outside the boundary of the AGLV) and to the south of the woodland cover. A position on, or just to the east of the line of the existing 132kV line would be acceptable. The site would require further screening to protect the cemetery and caravan park areas. Consideration could be given to grading any sloping areas of ground so that a false bund is created on the southern / lower edge of the site, as additional screening.

Northern sealing end compound

292) Within the Sheriffmuir area, the only possible area appears to be as indicated by SPT, on the line of the existing 132kV line and within the former woodland area (now reduced to two lines of trees separated by the clearance corridor for the existing line). TD197A is the approximate location of this area. There may be some archaeological constraints (as reported for the proposed alternative alignment of the 400kV line at Sheriffmuir). However, this location is unlikely to be a realistic option, given the damage that would result from taking an underground cable down the southern slopes of the Ochils.

5.2.4.2 West of Stirling (locations considered from north to south)

Northern sealing end compound area

293) HGDLs at Drummond and Keir are constraints within this area. In addition there are extensive areas of Ancient Woodland present within this area. In looking for a location for a sealing end compound, some consideration has to be given to the potential route of any 400kV overhead line south from the proposed Braco substation. In my opinion, it could be difficult to find a suitable route for this line in this direction, in particular between the A820 and the A84. The topography of the area and the numbers of properties evident from the OS map (in addition to woodland areas) suggest that this could be difficult to achieve without incurring significant adverse effects on one or more environmental aspects. Although Gillespies had identified a route through this area at the strategic routeing stage, it is possible that this was done without any comprehensive analysis of this route. As stated above, the OHL should extend to the south of the River Teith.

294) If an overhead line route could be found through this area then the location for the sealing end compound, as identified by SPT, would seem to be acceptable. If not, a possible alternative could be within the area to the east of the Blair Drummond Safari Park, perhaps at GR 746 978. However, this area is likely to be sensitive in terms of recreation / tourism (the safari park), the HGDL at Drummond Park, and the extensive areas of Ancient Woodland (and an SSSI) in the area to the south of the A84. It may be difficult to route underground cables through this area. A crossing of the River Forth would also be required.

Southern sealing end compound area

295) Within the Cambusbarron / Touch area is a further HGDL, at Touch House. It is suggested that a location for a sealing end compound should be further to the south than as shown by SPT, perhaps at GR 763 926 (approx.). It would be preferable to avoid incursion into the Touch Hills AGLV, to the south of this area.

296) A route for an overhead line from this area, southwards to the proposed Denny North substation, would be difficult to achieve without significant adverse effects on people and Ancient Woodland, at least. The archaeology in this area could also be an issue. The OHL could follow the route of the M80 north from Dunipace but reaches a pinch point at Cambusbarron; the only route west to the south of this (without cutting through woodland) is via the Bannock Burn and this would probably be unacceptable locally.

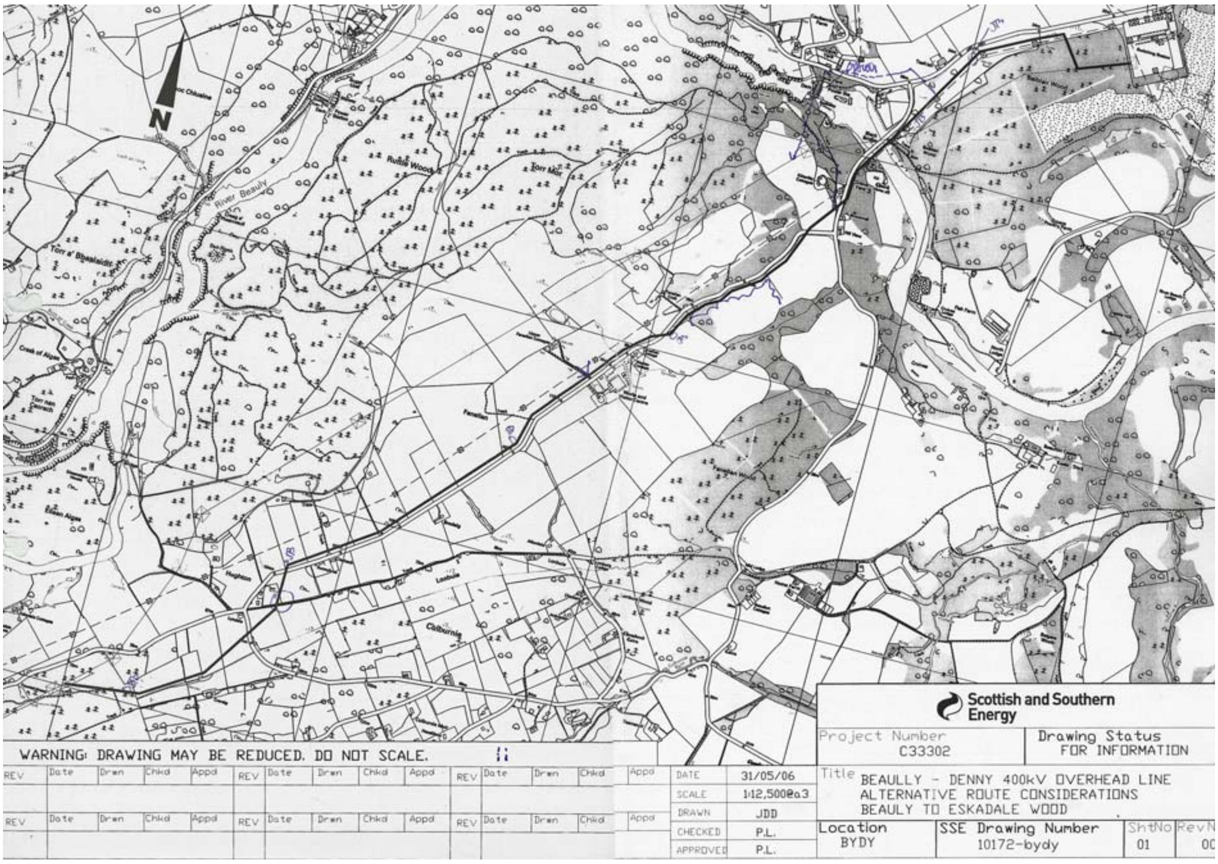
297)

5.3 Case Study 1 - Beauly Substation to Eskadale Wood

5.3.1 Finding a Cable Route

298) The cable route runs from the new proposed Beauly 400kV Substation at co-ordinate NH 504 446. A cable sealing end compound in Eskadale Wood has been assumed to be sited at NH 470 409.

Figure 5-3 Initial Route from Beauly to Eskadale



299) The landscape architect considered that the northern sealing end compound would be located within the quarry and the southern sealing end compound would be in the preferred location to the south of the minor road. Both would be in the best positions in respect of the impact on the potential landscape and visual aspects.

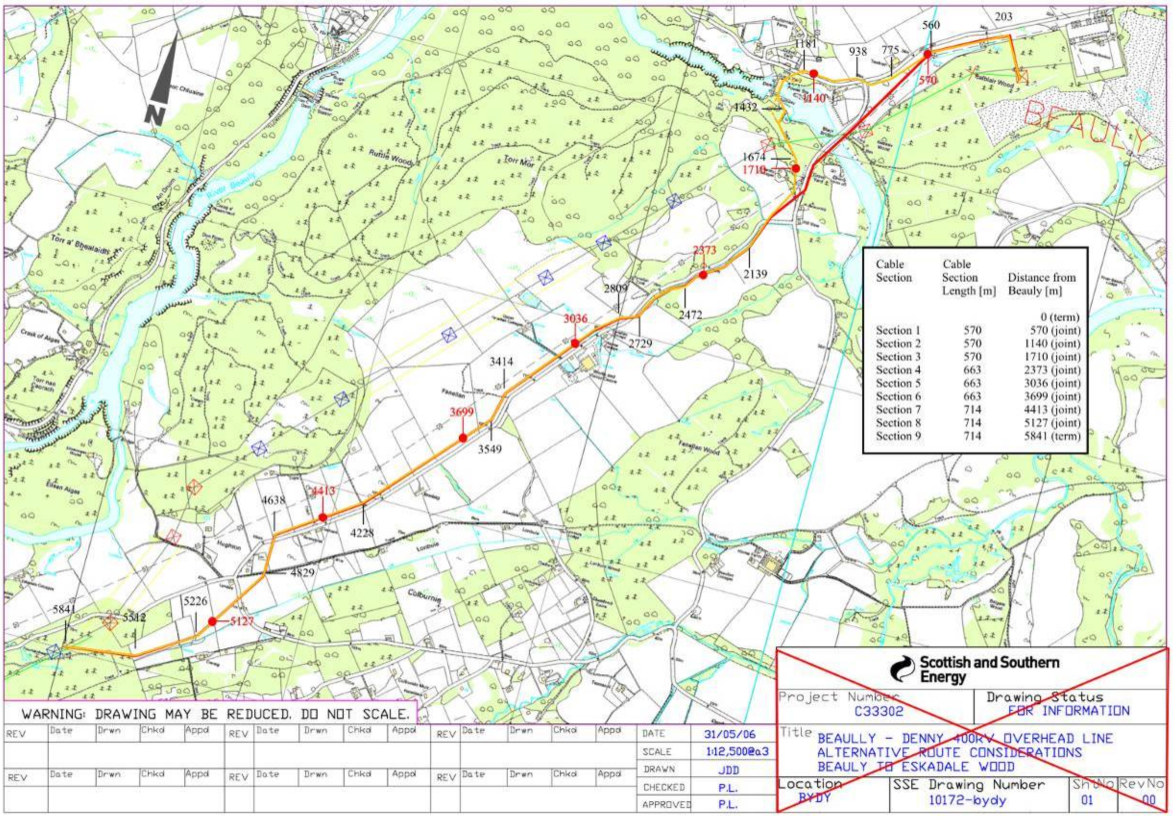
300) The majority of the route runs through farmland and a photograph of the farmland near Beauly Substation is shown in Figure 5-4.

Figure 5-4 Farmland near Beauly Substation

301) The Initial Route from Beauly to Eskadale Wood was identified by SHETL Figure 5-3 and represented the strategy of using the shortest route which in addition allowed access from existing roads. This route assumed going under the River Beauly. The

case study was also chosen to examine a river crossing with steep banks and an adjacent road bridge, routing through an area with a variety of woodland, grassland and drainage conditions in an area used for grazing and with country roads providing access.

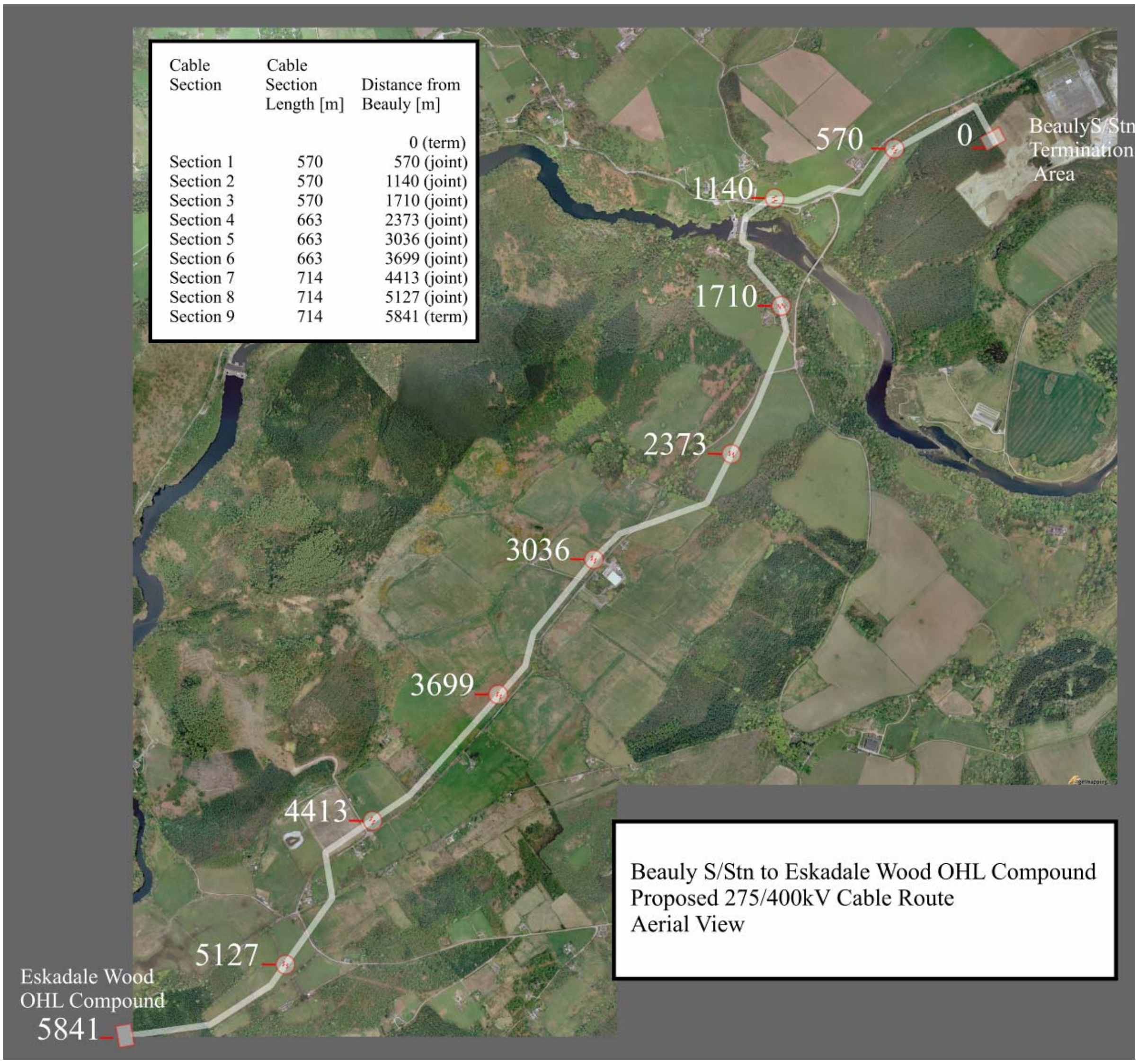
Figure 5-5 Route Development



302) Following site visits and discussions with SHETL engineers it was considered that the most promising crossing of the Beauly River would be achieved by using the existing structure of Kilmorack Power Station. This route is shown in Figure 5-5.

303) The selected cable route is shown the annotated aerial photograph of Figure 5-6. The route length of 5841m has been scaled from the aerial photograph and associated ordnance survey maps.

Figure 5-6 Cable Route from Beauly to Eskadale Wood



304) Table 5-2 shows the fully cross bonded section length options for this route. Due to route obstructions, properties, access requirements and environmental concerns it will be necessary to vary the cable section lengths for ease of installation and environmental mitigation.

Table 5-2 Fully Cross Bonded Section Length Options

Number of major cross bonded cable sections	Number of minor cross bonded cable sections	Number of joint bays	Average Cable Section Length [m]	Comment
1	3	2	1947	Too long for 150V sheath induced voltage limit
2	6	5	974	Too long for 150V sheath induced voltage limit
3	9	8	649	Acceptable
4	12	11	487	Acceptable

305) The annotated aerial photograph in Figure 5-6 includes the proposed cable route and locations of joint bays.

306) The cable section lengths selected and the major cross bonded sections are given in Table 5-3.

Table 5-3 Cable Section Lengths, Beauly – Eskadale

Cable Section	Length [m]	Running Length [m]	Bonding
1	570	570	Cross Bonded Major Section
2	570	1140	
3	570	1710	
4	663	2373	Cross Bonded Major Section
5	663	3036	
6	663	3699	
7	714	4413	Cross Bonded Major Section
8	714	5127	
9	714	5841	

307) The following table describes the cable route and comment upon the main features along the route including the site access points.

Location	Comments
NH 504 446	Beauly Substation
NH 497 440	Black Bridge - The length of the first three cable sections which comprise the first major cross bonded section is dictated by the crossing of the River Beauly. An original proposal was to cross on or near Black Bridge (NH 497 440). However, the bridge is in a poor condition and the cable approach to the river at this point is unsuitable due to the steep bank and the requirement for the cables to be installed at great depth (estimated at over 10m) in order to pass beneath the river.
NH 494 442	Kilmorack Hydroelectric Power Station - An alternative route to Black Bridge is to use the structure of the Kilmorack hydroelectric power station further upstream. This river crossing dictates the position of the joint bays which must be reasonably accessible, preferably on flat ground and not subject to flooding. Using section lengths of 570m places the first three joint bays in

Location	Comments
	positions which meet these requirements. If one of the circuits is installed at 275kV it will be necessary to increase the cable length on the first section to a new termination position inside Beauly Substation. This may require the 275kV joint bays at 570m (NH 500 445) and 1140m (NH 495 443) to be repositioned. However if possible the joint bay at 1710m (NH 495 439) should not move.
NH 500 445	Joint bays at chainage 570m. The joint bays at this location lie on the South side of the A831. The cable will be installed between Beauly substation and this first joint bay location. Access to these joint bays would be via the haul road which has access to the A831 at NH 498 443.
NH 498 443	A831 Site Access Point. At this location there is an existing farm vehicle access gate to the field to the South of the A831. The cables will cross under the A831 in ducts. Access to the fields north of the A831 may be made at this point.
NH 495 443	Joint Bay at chainage 1140m. This joint bay lies north of the A831 There are no major installation problems envisaged with the cable route from Beauly substation up to the joint bays at chainage 1140m. The cables are installed in existing pasture. Access to the haul road located on the fields north of the River Beauly will be via the A831 where the cable route crosses the road (NH 498 443).
NH 494 443	Kilmorack Cemetery - The cables must cross the A831 to the East of the cemetery at NH 494 443.
NH 494 442	Kilmorack Power Station. On leaving the joint bay at 1140m there is a bottleneck where the cables are required to re-cross the A831 and traverse down a steep tree covered embankment within the grounds of Kilmorack Power Station. This region also contains the 132kV oil filled cables employed to export power from the hydro-power station. It may be necessary here to split the circuit groups further apart to find suitable routes down this tree covered embankment and avoid the largest trees, some felling of which will be inevitable due to their density. At the bottom of the embankment there is a car park and access road for the lower level of the power station. The proposal here is to place the cables in surface concrete troughs with heavy duty lids suitable for supporting heavy traffic. The cables will then cross, on steelwork, over the outflow and spillway from the power station. On the southern side of the power station the cables will descend the vertical retaining wall of the spillway, again on steelwork, and enter the river bank. The cables will then be required to climb the bank and again several routes, one for each group of cables may be necessary. The cable route in this area will need further study as there is only a narrow track from the south bank of the power station up to the road with woodland in rocky terrain either side. The woodland also contains a mammal population.
NH 495 439	Joint bay at 1710m. The southern bank of the river Beauly alongside the river is liable to flooding when the river is in full flood. The joint bay position

Location	Comments
	at 1710m has thus been located above this flood plain level. This is required as the associated link pillars which must be readily accessible (SHETL do not wish to employ the more problematic link boxes) and these are only weather proof and not watertight.
NH 495 438	Kiltarlity Cottages. The cable route proposed runs to the West of the Kiltarlity Cottages and would require the clearance of a number of trees. Access to the cable route would include the use of the access road to the cottages. Consideration would need to be made towards the provision of joint or temporary alternative access for residents of the cottages.
NH 493 438	Field to the West of Kiltarlity Cottages. Upon leaving the joint bay at chainage 1710m the cable route moves into the field adjacent to the Kiltarlity Cottages. This route was chosen to avoid disruption to the road leading to Black Bridge. The route shown does not follow the edge of the field but cuts across the field towards the road leading to Eskadale. Subject to a satisfactory survey of the cable route from the south bank of the river Beauly up to the field adjacent to the Kiltarlity Cottages, it may be possible for the cable route to pass to the East of the cottages with the cable route and the joint bay at chainage 1710m being in the adjacent field. This has the advantage of requiring less tree clearance inside the broad leafed semi-natural woodland. However this alternative route may pass through an area of unknown archaeological remains. Vehicle access to the south bank of the Beauly River would still require use of the access roads around the Kiltarlity Cottages due to the steep gradients involved.
NH 495 436	Kiltarlity Site Access Point. A construction site access point would be located at the position where the haul road cuts the road to Eskadale. Access would be to the fields both north and South of this. The cable route passes under the road to Eskadale in ducts installed by open cut installation. A ditch or burn is to be crossed near this location. The method of crossing this burn will depend on the volume of water movement at the time of year that the crossing is installed. Methods of crossing include water diversion, water coarse ducting, damming and pumping or directional drilling. The preferable method is to install a water duct of adequate size and weight bearing capacity such that the haul road can pass over the burn.
NH 493 432	Joint bays at chainage 2373m. From the access point on the road to Eskadale (NH 495 436), the cable route runs in the field to the south of the road where the joint bay at chainage 2373m is located.
NH 492 431	Fenellan Wood. The cable route runs to a point (NH 492 431) at the end of the field where there is a thinning of Fenellan Wood. The route passes through this point to limit the extent of any tree felling required.
NH 491 430	Field bordering Fenellan Wood. From NH 492 431 the cable route runs back across this field (NH 491 430) towards the road to Eskadale and crosses the road at a point (NH 490 430) to the West of Fenellan Cottages.
NH 490 430	Fenellan Wood Site Access Point. The cable route crosses the road in ducts

Location	Comments
	which shall be installed by open cut methods. This will require traffic management. Site access is possible at this location onto the haul road on both sides of the road. The route runs to the north of the road to Eskadale. It follows the road but remains clear of the pond and the edge of the field to avoid damage to trees or hedgerows. It will be necessary to determine if any special precautions are required to protect species dependant upon the pond. It may be necessary to position the cable route further to the north West if the ground surrounding the pond is particularly wet. Any ditches feeding into the pond would be ducted to allow the haul road to pass above. These will either be permanent or temporary installations. The cables would be ducted beneath water courses.
NH 488 429	Joint bays at chainage 3036m. Access to this joint bay would be via the Fenellan Wood Site Access Point.
NH 487 428	Access road to Upper Fenellan Cottages. Ducts will be installed beneath this road and the ditches either side to maintain access to the farm buildings.
NH 484 423	Joint bays at chainage 3699m. Access to this joint bay would be via the Fenellan Wood Site Access Point. **Figure 5-7 Route near joint at chainage 3699** 
NH 479 418	Joint bays at chainage 4413m. Access to this joint bay would be via the Fenellan Wood Site Access Point.
NH 480 419	Access road to farm buildings. Ducts will be installed beneath this road to maintain access to the farm buildings.
NH 479 418	Access road to farm buildings. Ducts will be installed beneath this road to maintain access to the farm buildings.
NH 478 417	Sunnybrae Site Access Point. This access point gives access to the north side of the road. If possible, access should be given to the South side of the road to avoid traffic passing through Hughton village. However, there is a change in level on the South side of the road which may prevent the installation of a suitable access for construction traffic. The cable route traverses to around Hughton to the South and East.
NH 478 415	Lonbuie Access Road. Ducts will be installed beneath this road to maintain access to the buildings along this road.

Location	Comments
NH 477 414	Hughton Site Access point. Where the cable route crosses the road from Hughton to Culbernie access may be gained to the haul road either side of the road. There are some unoccupied farm buildings close to this location.
	Figure 5-8 Route at road crossing between chainages 4638 & 5127 
NH 476 412	Joint bays at chainage 5127m. Access to these joint bays shall be obtained via the Hughton Site Access Point.
NH 473 410	Entrance to Eskadale Wood. From the joint bay at chainage 5127m the route runs to the boundary of Eskadale Wood in fields. Access to this point shall be obtained via the Hughton Site Access Point.
NH 470 409	Eskadale Wood Overhead Line Cable Sealing End Compound. A position for the location of the sealing end compound has been assumed. In order for the cables to reach this location it will be necessary for the trees to be felled and no further planting to take place above the cables. Access to the Eskadale Wood compound for the cable construction activities would be via the Hughton Site Access point. It may be possible to use longer cable section lengths and an end point bonded section on this route.

308) Reference ecological, archaeological and designated sites for landscape or conservation information has been extracted from the Environmental Statement Volume 2 figures.

309) Ecological information indicates that the route runs through neutral grassland semi-improved, improved grass land and through or close to woodland broadleaved semi-natural.

310) The general routing of the cables is reasonably close to the existing roads and away from known cultural heritage or archaeological sites. The route does not pass through any known statutory designated nature conservation sites.

311) The route as selected does not pass through any areas sensitive to unknown remains.

5.3.2 Financial Details

312) The case study is based upon the underground of the following section of OHL:

Table 5-4 Case Study 1 – OHL parameters

	Beauly to Eskadale Wood	
Source	Overhead Line Section #1	
3	Length (km):	5.17
3	No. of spans:	13
	Tower type	SSE400
8	D std - no.off	7
8	D55 - no off	6
8	DT - no off	1

OHL Costs

313) The OHL cost estimates for this case study are provided in Table 5-5. The table is divided into two sections – Section A. OHL Construction costs for case study, and Section B. OHL operational costs. Section A firstly provides the detailed estimate of building the OHL by adding the component costs together. This is followed by Balfour Beatty's estimate of the savings on the contract for a long OHL if this case study section of the OHL was NOT built (their "differences" estimates) – that is, if its place was taken by an UGC.

314) It will be noticed that these two estimates are quite different, which is to be expected since (a) the latter takes no account of services accommodation or any environmental aspects, and (b) the site set-up costs would still be incurred more or less unaltered regardless of whether there was a short gap in the OHL construction route.

315) The operational costs in Section B and the contingency have already been discussed in section 4.2.

316) Overall cost per km and effective cost per km per annum are included in the table.

Table 5-5 Case Study 1 – OHL costs

		Case Study #1 Beauly to Eskadale Wood
A. OHL Construction costs for Case Study (£k)		
Length (km):		5.17
Tower type:		SSE400
	D std (no. off)	7
	D55 (no. off)	6
	DT (no. off)	1
Tower Steelwork (£k):		
	D std	218
	D55	378
	DT	123
Tower Foundations (£k):		
	D std	44
	D55	132
	DT	61
Conductors, inc. OPGW (£k):		1322
Insulators & fittings (£k):		248
Labour, Engineering & Project Mgmt (£k):		1684
Total works (£k):		4211
Accommodation + compensation per Case Study (£k):		284
Case study environmental measures & PR (£k):		23
Construction and Accommodation Totals (£k):		4519
NB: Balfour B Construction "Differences" estimates (£k)		2545
B. OHL Operational costs (£k over 40 year life) - DCF rate = 6%		
Maintenance (£k)		338
Wayleaves (£k)		73
40-year replacement (£k)		409
Total operational costs for Case Study OHL (£k)		820
Operational costs (£/km/annum)		4
Total costs for Case Study OHL (£k)		**5339**
Total costs for Case Study OHL inc. 10% contingency (£k)		**5873**
Total OHL cost per km (£k/km): average = £1066k / km)		1137

UGC costs

317) Estimates for the cost of the UGC that could replace the five case study sections of OHL have been developed using the same approach as for the OHL. The cable length and number of joints used to underground this section of overhead line would be as follows:

318)

Table 5-6 Case Study 1 – UGC parameters

Source	Underground Cable Section #1 - Beauly to Eskadale Wood	
3	Length (km):	5.841
3	No. of UGC joints in section	8

319) As with the OHL there are certain assumptions that have been made with respect to the cable costs:

- All costs assume 2 cables per phase
- XLPE cable is considered throughout
- 2500 mm^2 copper conductor (base case)
- 400kV on one circuit, 275kV on the other. (base case)
- Cable direct-buried. (base case)

320) The UGC cost estimates for this case study are provided in Table 5-7. The table is divided into two sections – Section A. UGC Construction coasts for case study, and Section B. UGC operational costs. Section A is itself divided into 2 sections, the first dealing with all the costs associated with the ends of the cable, the second dealing with the cable route itself. The reason for this split is that, as has already been described, there are major works required at the ends of the cable, both in terms of the equipment requirements (terminal tower, cable sealing ends, surge arresters, earth switches and protection, that together form a small substation) and also the system requirements (reactive compensation, that may be placed at the cable ends, or may be located at a nearby substation).

321) As for the OHL solution, the operational costs in Section B have been discussed earlier in Paragraph 244), as has the contingency, in the paragraphs up to and including Paragraph 242).

322) Overall cost per km is included in the table, both in terms of the route costs alone, and including end costs and contingency.

Table 5-7 Case Study 1 – UGC costs

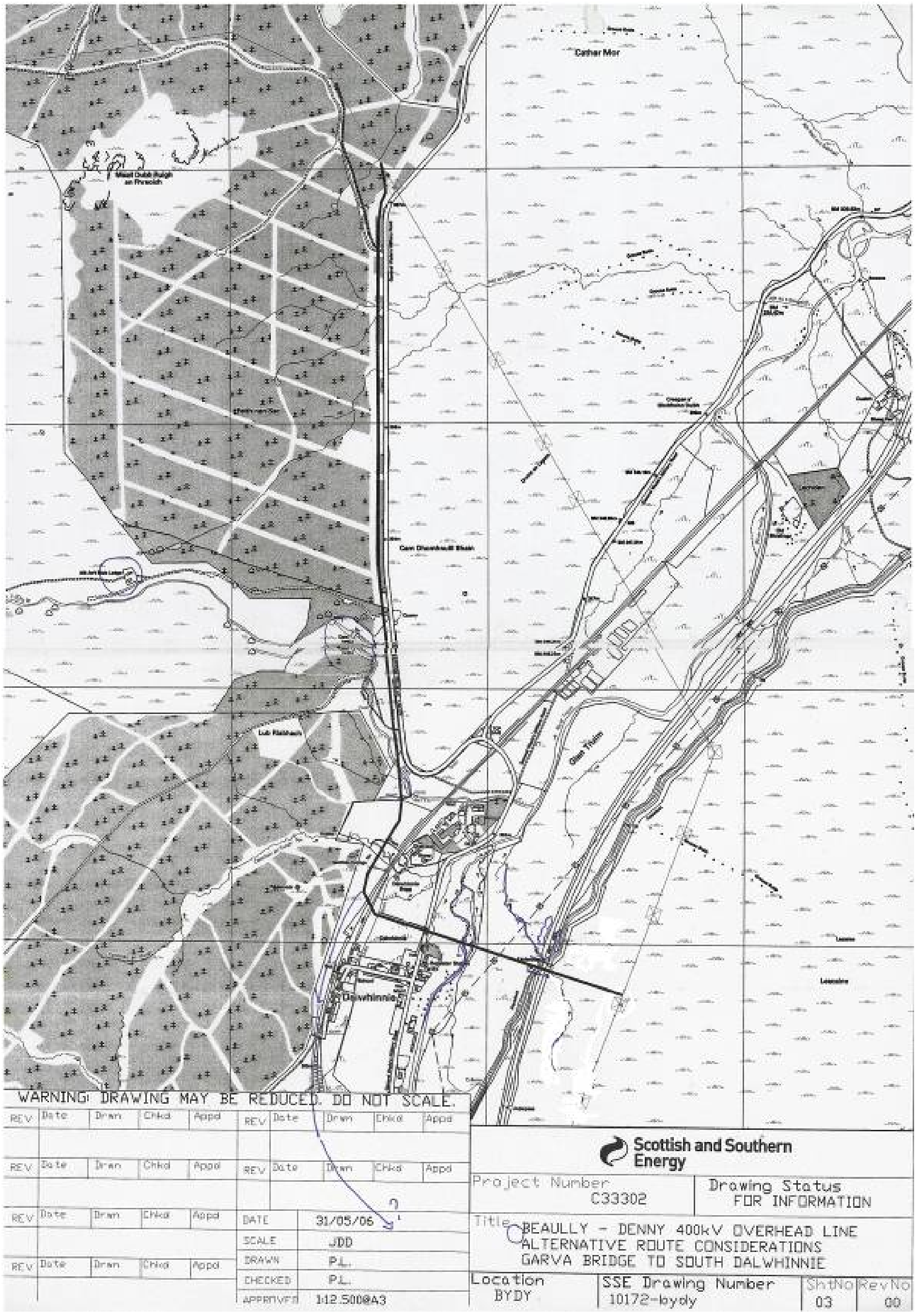
	Beauly to Eskadale Wood
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	5.841
No. of UGC joints joints in section	8
A. Construction Costs	
i. CABLE-END COSTS	
Sealing-end terminal tower	
steelwork	123
foundations & construction	86
2 Sealing-end compounds:	
Cable termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	25
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	20
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	50
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	0
land purchase	7
access road > 150m	0
Total cable-end for section	4845
ii. CABLE ROUTE COSTS	
400kV UGC	12974
275kV UGC	11571
Cable joints	2237
Other equipment - supply and install	3578
Civils - supply and install	23230
Accommodation (not wayleaves)	160
Route environmental measures	175
Total cable route for section	53925
Total construction costs for Case Study UGC (£k)	58770
Total UGC cost per km (£k/km, average= £11492k / km)	10062
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	281
Wayleaves (£k)	109
40-year replacement (£k)	5210
Total operational costs for Case Study UGC (£k)	5600
Total costs for Case Study UGC (£k)	64370
Total costs for Case Study UGC inc. 15% contingency (£k)	74026
Total UGC cost per km (£k/km): average = £14389k / km)	12674

5.4 Case Study 2 - Garva Bridge to South Dalwhinnie

5.4.1 Finding a Cable Route

323) The Initial Route from Garva Bridge to South Dalwhinnie was identified by SHETL (Figure 5-9) and represented a route using the existing 11kV wood pole line wayleave with access to the existing A889. Based on knowledge of environmental considerations in the area this route represented the strategy of using existing areas of disturbance.

Figure 5-9 Case Study 2 - Initial Route



5.4.1.1 Landscape Architects Comments on the Location of Sealing End Compound to the East of the A9 at Dalwhinnie

324) The A9 is elevated above the level of the village as it passes to the east of Dalwhinnie and this would limit views of the area proposed for the sealing end compound, for the majority of properties in the village. It is possible that more elevated properties located further to the west of the village itself, may have more distant views of this area.

325) To the south of the proposed location of the sealing end compound, there is scattered roadside birch, 4-8m high, on the eastern side of the A9, though this is sporadic and not dense planting.

326) Some tree planting (mixed conifer and broadleaf) is establishing on the west facing embankment, facing the village, though at present is only 2-4m higher than the road level. In time this should increase and will add to the obstruction of views eastwards.

327) A further area of screen planting, to both sides of the A9 and planted at the same level as the road, occurs to the north – mainly conifer but with some rowan and birch, approx. 150-160m in extent, north of the river crossing. This may relate to the distillery and could have been planted to screen the nearest traffic on the A9, from view.

328) To the east of the A9 the ground rises slightly before falling away and then rising again to Leacainn. The hillside comprises open moor land and rough grazing with post and wire fencing.

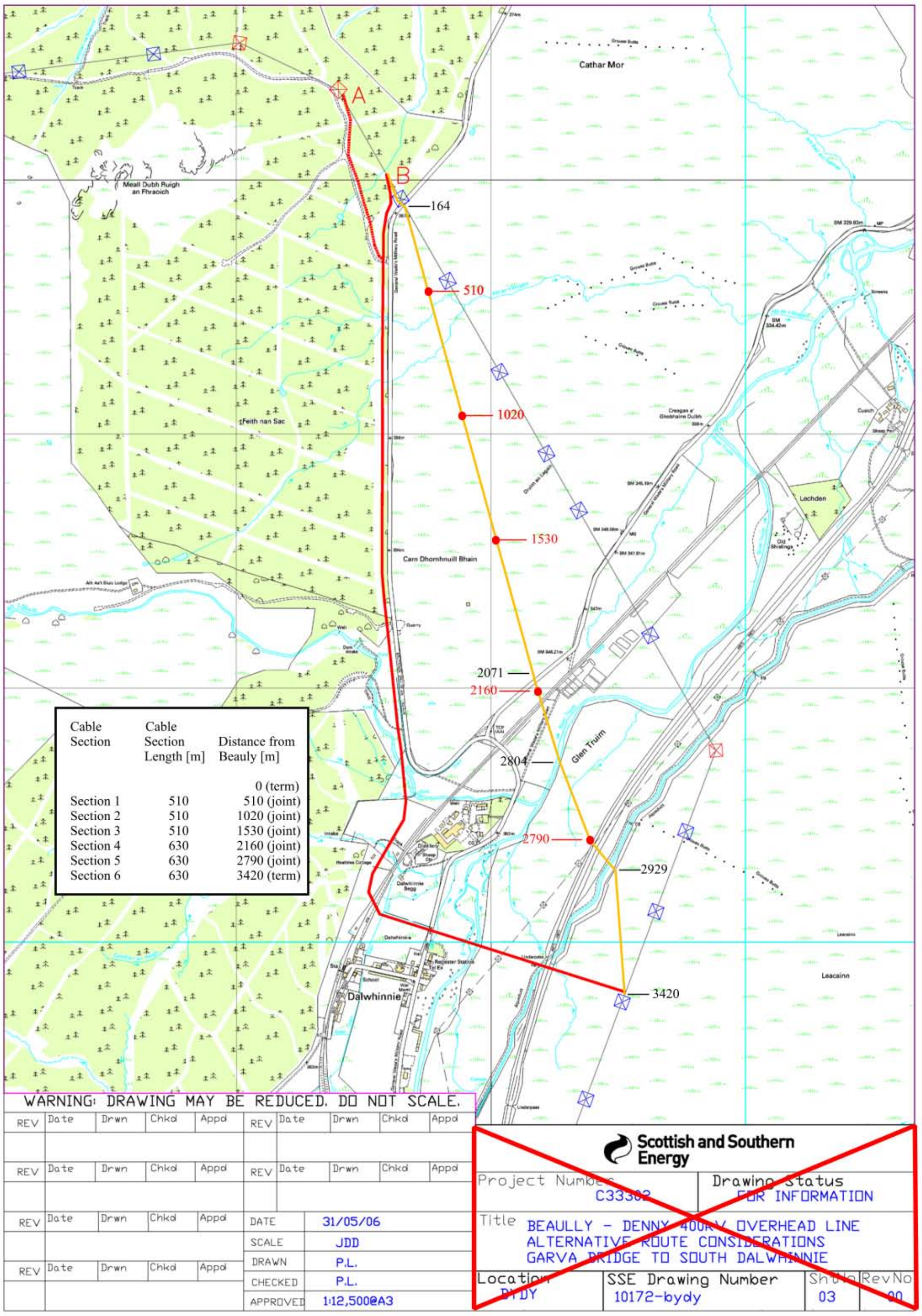
329) In the area where the proposed cable would cross the A9, the road is some 3-4m higher than the land to the east with a further fall in levels, eastwards (as above). The A9 in this area is at a relatively high point in comparison with the road further to the south and north.

330) The sealing end compound would mainly be viewed by motorists on the A9, as oblique and transient views. For southbound motorists views would be restricted to the section of road between the cutting to the north and the tree screen at the river crossing; after this, there would be a further brief view before the compound was behind the direction of view. For northbound motorists, views would extend from the existing snow break planting (FT128 area) northwards, though the compound may be screened in part by the mounding at the southbound lay-by. Views would cease once the motorist had passed to the north of the northern roadside tree screen.

331) Further screening may be possible through the use of low mounding / earthworks as a partial screen around the western and southern sides of the compound. In addition, extending the roadside screen of conifers, northwards to the cutting side slope, would assist in screening views, particularly for southbound motorists. Planting at the compound location would be out of character in this landscape and is not recommended.

332) Figure 5-10 shows the shortest route between the OHL CSE compound at Garva Bridge and the OHL CSE compound at South Dalwhinnie.

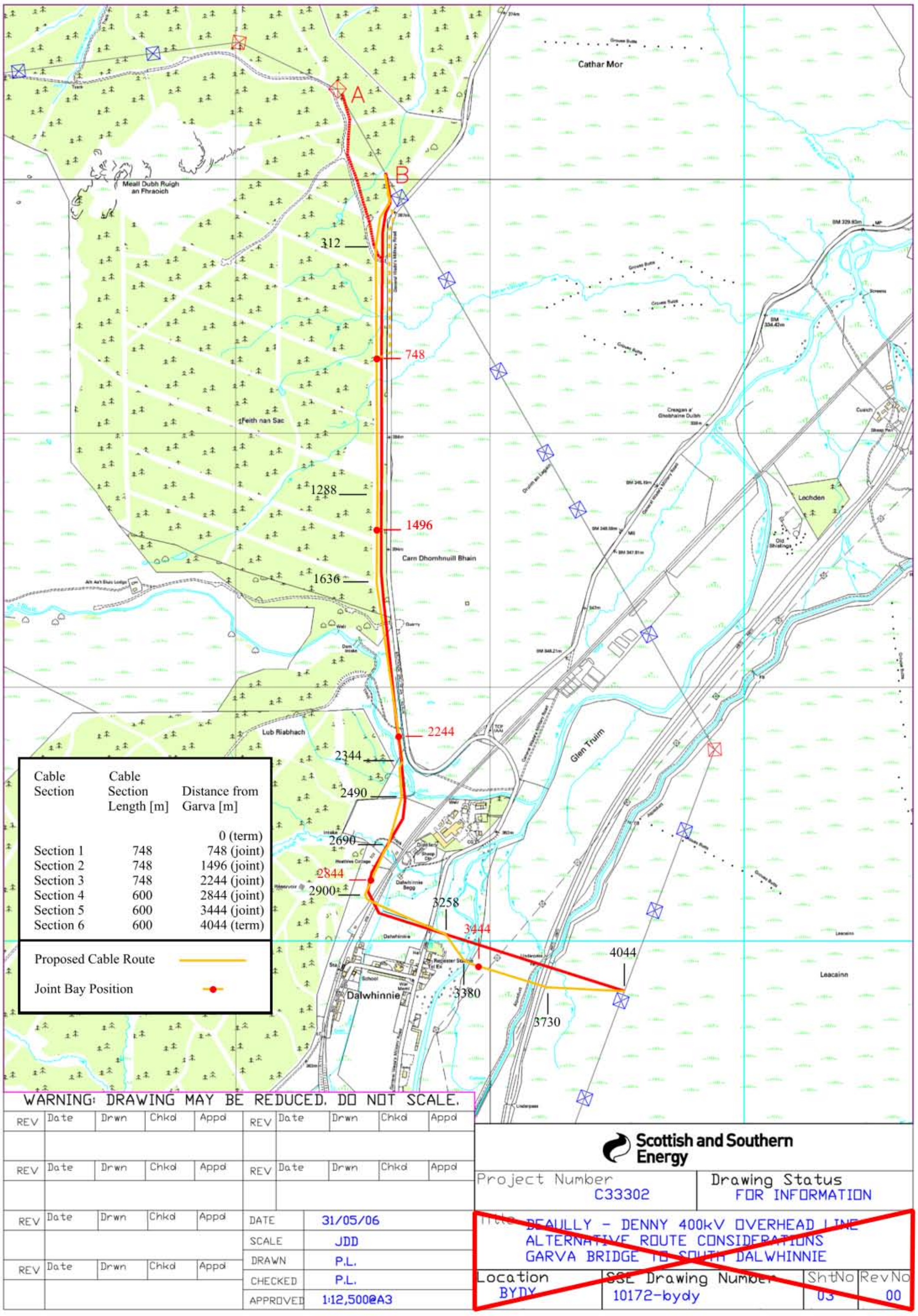
Figure 5-10 Case Study 2: Shortest Route Option compared to SHETL Initial Route



333) Note that the shortest route for Case Study 2 is across open heather and grass moorland.

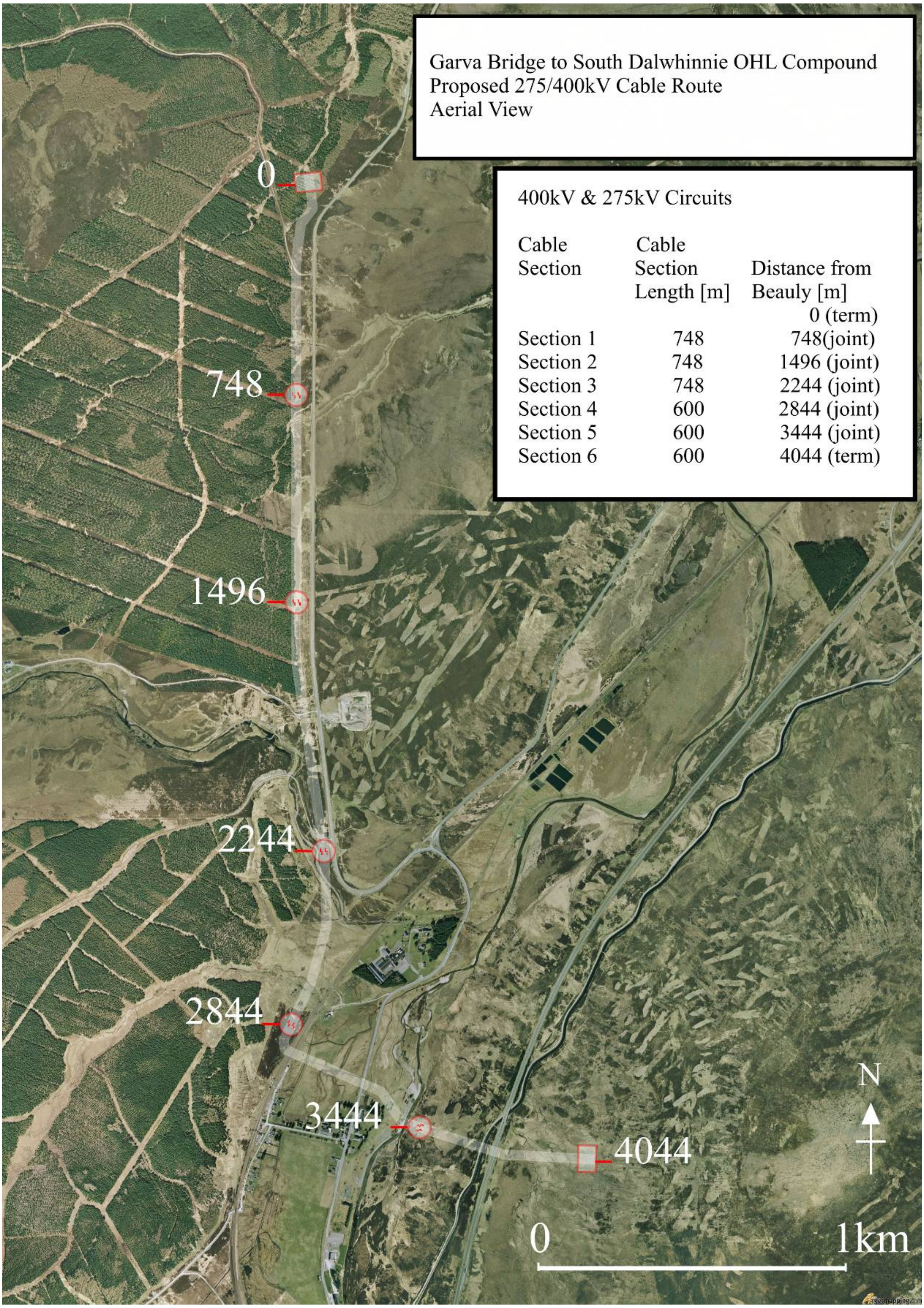
334) Use of existing 11kV wayleave option

Figure 5-11 Adjustments to SHETL Initial Route Option



335) Figure 5-11 is a drawing of the cable route following SHETL's original proposal using the 11kV wayleave to the west of the A889(T). A site visit suggested preference for Sealing End Compound at B.

Figure 5-12 Cable Route from Garva Bridge to South Dalwhinnie



336) The selected cable route is shown in Figure 5-12 and has a route length of 4044m. This route crosses a number of waterways and a drainage plan will be necessary to avoid silting of the waterway or the water extraction points for the Dalwhinnie Distillery which extracts its water from the Lochan an Doire-Uaine spring.

Table 5-8 Fully Cross Bonded Section Length Options

Number of major cross bonded cable sections	Number of minor cross bonded cable sections	Number of joint bays	Average Cable Section Length [m]	Comment
1	3	2	1348	Too long for 150V sheath induced voltage limit
2	6	5	674	Acceptable
3	9	8	449	Acceptable but section lengths are short

337) Table 5-8 shows the fully cross bonded section length options. An average section length of 674m has been chosen for this circuit.

338) There is a considerably shorter route for the cables from the Garva Bridge compound to South Dalwhinnie, in more or less a straight line, Figure 5-10. This was discounted as it would mean excavating a swathe across Cathar Mor, which should be preferably avoided. The cable route therefore follows a line where previous activity, such as forestry, does not preclude cabling. In order to utilise the route given in Figure 13 it will be necessary to dismantle the wood pole 11kV line that runs parallel to the A889. A replacement 11kV cable could be installed alongside the EHV cables, possibly in ducts under the haul road (the cost of this operation has not been included in the case study).

Table 5-9 Cable Section Lengths, Garva Bridge – Dalwhinnie

Cable Section	Length [m]	Running Length [m]	Bonding
1	748	748	Cross Bonded Major Section
2	748	1496	
3	748	2244	
4	600	2844	Cross Bonded Major Section
5	600	3444	
6	600	4044	

339) Table 5-9 lists the selected cable section lengths. The bonding lead length at each joint connecting the link pillars to the power cable joints should be in the order of 10m in length or less. If longer lengths are required, calculations should be

performed to ensure that the cable sheath and joint barrier surge protection is not compromised.

340) The following table lists the main features and their location along the cable route:

Location	**Comments**
NN 635 880	Garva Bridge overhead line cable sealing end compound.
NN 635 876	Forestry Road North Site Access Point. This access point utilises the existing forestry access point and will connect the haul road to General Wades Military Road ,the A889(T), shown in Figure 5-13. **Figure 5-13 View from A889 towards Dalwhinnie**  Access to both the overhead line compound to the north and the cable route to the South will be obtained from this point. The forestry track will be ducted to maintain access for forestry traffic if required. The cable route runs in the existing 11kV overhead line reserve, see Figure 5-14.

<table>
<tr><th>Location</th><th>Comments</th></tr>
<tr><td></td><td>Figure 5-14 Existing 33kV Wood pole Line Wayleave
</td></tr>
<tr><td>NN 635 872</td><td>Joint bays at chainage 748m</td></tr>
<tr><td>NN 635 866</td><td>Joint bays at chainage 1496m</td></tr>
<tr><td>NN 636 858</td><td>Forestry Road South Site Access Point. This access point will connect the haul rod to the A889(T). This access point makes use of an existing track and will be ducted if necessary to maintain access for forestry traffic if required.</td></tr>
<tr><td>NN 636 857</td><td>Joint bays at chainage 2244m</td></tr>
<tr><td>NN 636 856</td><td>Directional drill under the River Allt an t-Sluic.</td></tr>
<tr><td>NN 636 853</td><td>Rail Crossing Site Access Point. There is an unmanned railway crossing point at this location where construction traffic may be permitted to cross. It will be necessary for discussions with the rail operator to confirm that this crossing may be used and the necessary safety precautions put in place. Access to the rail crossing would be via the A889(T) road and an improvement of the existing access. The access road would also need to be ducted to allow access to the buildings on the West side of the railway. Figure 5-15 shows the railway from the footbridge looking north. The 11kV wood pole lines can be seen.</td></tr>
</table>

Location	Comments
	Figure 5-15 View from Dalwhinnie Station over bridge looking north. 
NN 635 853	Crossing of the Coachan an Ruigh Spring will require ducting (temporary or permanent) of the spring with cables passing beneath.
NN 635 852	Joint bays at chainage 2844m. This joint bay shall be accessed via the Rail Crossing Site Assess Point. The view from Dalwhinnie over to the A9 can be seen in Figure 5-16. **Figure 5-16 From Dalwhinnie to A9 Bridge** 
NN 639 849	Directional drill under the River Truim. The possibility of the River Truim or its tributaries bursting its banks should also be considered. Under such circumstances the link pillars must remain above any flood waters. If necessary, this may be achieved by mounting any pillar under threat on a raised pad. The flood history in the Dalwhinnie area should be investigated.

Location	Comments
NN 639 847	Joint bays at chainage 3444m. This joint bay shall be accessed from the A9.
NN 641 848	Directional drill under the aqueduct and the A9. The position of the joint bays dictates the section lengths and these locations have also been considered to allow separation of the cable phases during the directional drill under the A9 and the outflow from hydro power station. This requires a detailed rating study with site survey measurements to establish the depth of cover over the cables under the A9 embankment. Crossing of the railway, River Truim, the A9 and the water channel from the hydroelectric power station may be achieved by the use of directional drilling. Specialist contractors will need to be consulted regarding drilling in this area as the ground is likely to contain significant amounts of rock and boulders.
NN 642 848	Burn crossing.
NN 644 848	South Dalwhinnie overhead line cable sealing end compound. This is an assumed position.

341) The ecology is assumed data as the ecology survey in the ES does not cover the cable route. Within the existing 11kV wayleave which will be utilised for the cable route the vegetation consists of dried dwarf heath (acid). The route also crosses acid grass land and wet dwarf heath of low to moderate local value.

342) The route is within the boundary of the Cairngorms National Park and a view of the general Highland Environment is shown in Figure 5-17.

343) There are no areas of sensitivity to unknown archaeological remains along the route.

Figure 5-17 The Highland Environment at Dalwhinnie

5.4.2 Financial Details

344) The case study is based upon the undergrounding of the following section of OHL:

Table 5-10 Case Study 2 – OHL parameters

Source	Garva Bridge to South Dalwhinnie	
3	Length (km):	3.65
3	No. of spans:	9
	Tower type	SSE400
8	D std - no.off	9
8	D55 - no off	1
8	DT - no off	0

OHL Costs

345) The OHL cost estimates for this case study are provided in Table 5-11. Please refer to the notes in Case study 1, Paragraphs 314) to 316), which apply equally to this case study.

Table 5-11 Case Study 2 – OHL costs

		Garva Bridge to South Dalwhinnie
A. OHL Construction costs for Case Study (£k)		
Length (km):		3.65
Tower type:		SSE400
	D std (no. off)	9
	D55 (no. off)	1
	DT (no. off)	0
Tower Steelwork (£k):		
	D std	280
	D55	63
	DT	0
Tower Foundations (£k):		
	D std	56
	D55	22
	DT	0
Conductors, inc. OPGW (£k):		934
Insulators & fittings (£k):		175
Labour, Engineering & Project Mgmt (£k):		1020
Total works (£k):		2550
Accommodation + compensation per Case Study (£k):		184
Case study environmental measures & PR (£k):		17
Construction and Accommodation Totals (£k):		2751
NB: Balfour B Construction "Differences" estimates (£k)		1520
B. OHL Operational costs (£k over 40 year life) - DCF rate = 6%		
Maintenance (£k)		205
Wayleaves (£k)		52
40-year replacement (£k)		248
Total operational costs for Case Study OHL (£k)		504
Operational costs (£/km/annum)		3
Total costs for Case Study OHL (£k)		**3255**
Total costs for Case Study OHL inc. 10% contingency (£k)		**3581**
Total OHL cost per km (£k/km): average = £1049k / km)		982

UGC costs

346) The length of the cable, and the number of joints that would be used to underground this section of overhead line are to be found at the top of Table 5-12. Below these items, in the same table, will be found the UGC cost estimates for this case study. Please refer to the notes in Case Study 1, Paragraphs 317) to 322), which apply equally to this Case Study.

Table 5-12 Case Study 2 – UGC costs

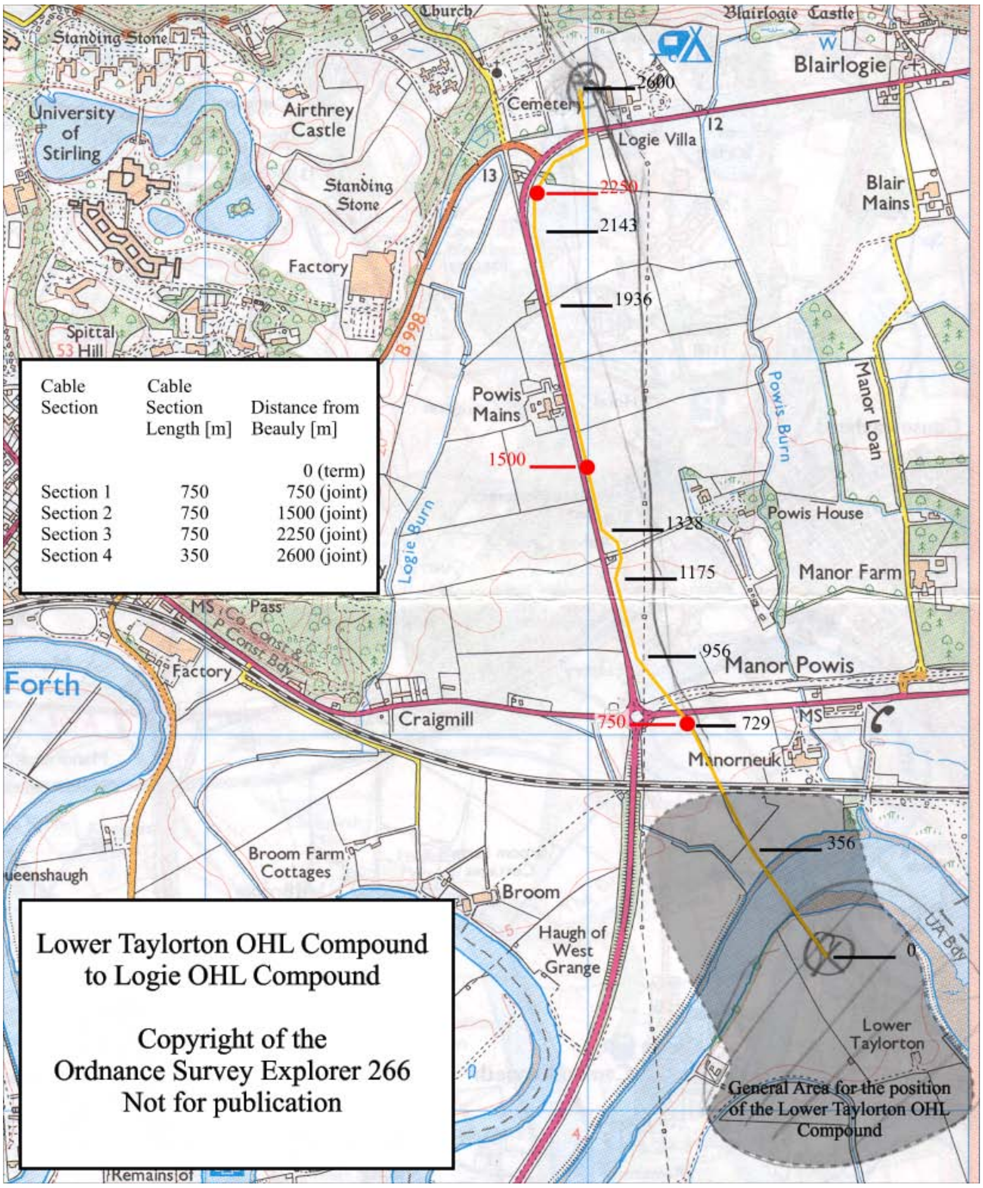
	Garva Bridge to South Dalwhinnie
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	4.044
No. of UGC joints joints in section	5
A. Construction Costs	
i. CABLE-END COSTS	
2 Sealing-end terminal towers (1 for Beauly-Eskadale):	
steelwork	246
foundations & construction	173
2 Sealing-end compounds:	
Termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	50
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	40
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	100
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	10
land purchase	20
access road > 150m	0
Total cable-end for section	5173
ii. CABLE ROUTE COSTS	
400kV UGC	8978
275kV UGC	8007
Cable joints	1398
Other equipment - supply and install	2655
Civils - supply and install	20894
Accommodation (not wayleaves)	100
Route environmental measures	250
Total cable route for section	53925
Total construction costs for Case Study UGC (£k)	47453
Total UGC cost per km (£k/km, average= £11496k / km)	11734
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	227
Wayleaves (£k)	131
40-year replacement (£k)	4077
Total operational costs for Case Study UGC (£k)	4434
Total costs for Case Study UGC (£k)	51888
Total costs for Case Study UGC inc. 15% contingency (£k)	59671
Total UGC cost per km (£k/km): average = £14394k / km)	14755

5.5 Case Study 3 – Lower Taylorton to Logie

5.5.1 Finding a Cable Route

347) Figure 5-18 shows the cable route plotted on an OS map. This route is very similar to the route shown in Figure 5-19.

Figure 5-18 Preliminary Route Option and Cable Section Lengths



348) The selected cable route is shown in Figure 5-19 and runs from an OHL compound to be positioned near the River Forth at Lower Taylorton (either north or south of the River Forth) in the area marked. A terminal tower position has been arbitrarily selected on the South side of the river for the purposes of this report.

349) The route runs alongside the A91 to a new OHL terminal compound at Logie. The OHL compound will be on, or close to, the line of the existing 132kV OHL.

350) The cable section lengths suitable for the route shown in Figure 5-18 were considered from the options calculated and shown in Table 5-13.

Table 5-13 Section Length Options (2600m Route)

Number of major cross bonded cable sections	Number of minor cross bonded cable sections	Average Cable Section Length [m]	End point bonded section [m]	Number of joint bays	Comment
1	3	867	-	2	Cable lengths are too long for most manufacturers.
2	6	433	-	5	Length is <500m which is short and introduces 3 extra joint bays.
1	3	750	350	3	Acceptable.

351) It would be possible to use a fully cross bonded installation with an average section length of 433m as show in Table 5-13. However, this length is rather short and the option exists to use an end point bonded arrangement on the closing cable section in to Logie OHL compound. The end point bonded arrangement is also shown in Table 5-14

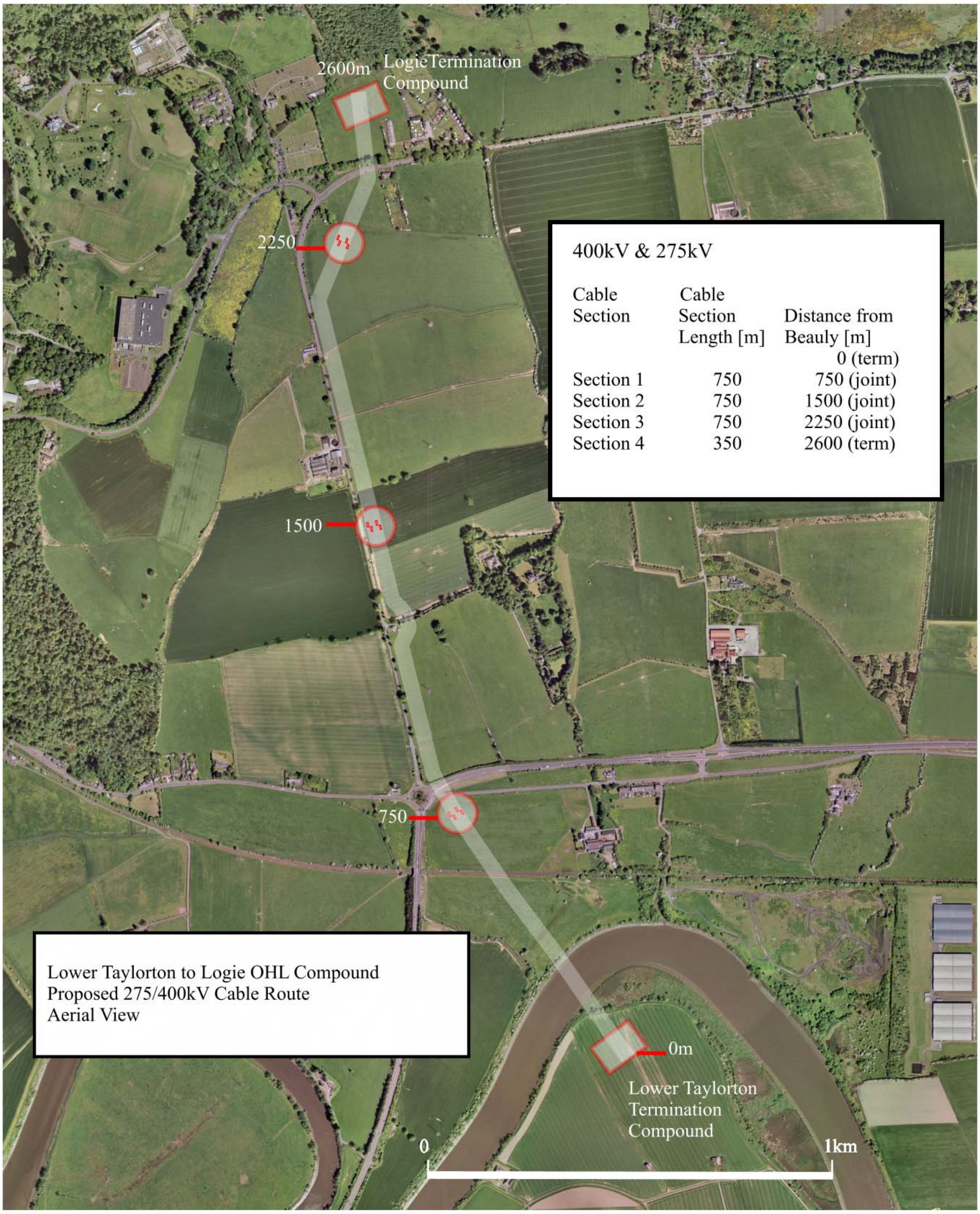
352) The end point bonded section will require the installation of an earth continuity conductor sized to carry through fault current. The recommended earth continuity cable size for a 400kV system is 500mm².

Table 5-14 Cable Section Lengths, East of Stirling Option 1

Cable Section	Length [m]	Running Length [m]	Bonding
1	750	750	Cross Bonded Major Section
2	750	1500	
3	750	2250	
4	350	2600	End Point Bonded Section

353) The section lengths in Table 5-14 are suitable for use along the cable route shown in Figure 5-19.

Figure 5-19 Cable Route Lower Taylorton Compound to Logie Compound



354) The following table lists the main features of the final route selection and their location along the cable route:

Location	Comment
NS 826 944	Lower Taylorton Overhead Line Cable Sealing End Compound. The position of the compound is in arable land.
NS 825 945	Directional Drilling under the River Forth
NS 822 948	Directional drilling under the railway.

NS 821 950	Joint bays at chainage 750m. Figure 5-20 is a view of the access road to joint bay 750m. **Figure 5-20 View looking west to existing line and A91 roundabout from old A907** 
NS 821 950	Crossing of the A907. Subject to the agreement with the local authorities it would be possible to open cut the A907 with 50% of the road width closed at a time.
NS 820 954	Access Road to Powis House. Road to be ducted to allow access to residence.
NS 820 957	Joint bays at chainage 1500m
NS 819 964	Joint bays at chainage 2250m
NS 820 966	Crossing of the A91 at Logie. Subject to the agreement with the local authorities it would be possible to open cut the A91 with 50% of the road width closed at a time.
NS 819 967	Assumed position for the Logie overhead line cable sealing end compound.

355) There are no statutory designated nature conservation sites along the route. The ecological value of the land route is of negligible to low ecological value. The River Forth is of moderate local ecological value. There is however a mammal population along the route. The entire route is in an area sensitive to unknown archaeological remains.

5.5.2 Financial Details

356) The case study is based upon the undergrounding of the following section of OHL:

Table 5-15 Case Study 3 – OHL parameters

Source	Lower Taylorton - Logie (Stirling SE)	
3	Length (km):	2.39
3	No. of spans:	7
	Tower type	L12
8	D std - no.off	5
8	D55 - no off	3
8	DT - no off	0

OHL Costs

357) The OHL cost estimates for this case study are provided in Table 5-19. Please refer to the notes in Case study 1, Paragraphs 313) to 316), which apply equally to this case study.

Table 5-16 Case Study 3 – OHL costs

		Lower Taylorton - Logie (Stirling SE)
A. OHL Construction costs for Case Study (£k)		
Length (km):		2.39
Tower type:		L12
	D std (no. off)	5
	D55 (no. off)	3
	DT (no. off)	0
Tower Steelwork (£k):		
	D std	109
	D55	127
	DT	0
Tower Foundations (£k):		
	D std	22
	D55	44
	DT	0
Conductors, inc. OPGW (£k):		612
Insulators & fittings (£k):		115
Labour, Engineering & Project Mgmt (£k):		686
Total works (£k):		1715
Accommodation + compensation per Case Study (£k):		155
Case study environmental measures & PR (£k):		11
Construction and Accommodation Totals (£k):		1881
NB: Balfour B Construction "Differences" estimates (£k)		n/a
B. OHL Operational costs (£k over 40 year life) - DCF rate = 6%		
Maintenance (£k)		147
Wayleaves (£k)		20
40-year replacement (£k)		178
Total operational costs for Case Study OHL (£k)		345
Operational costs (£/km/annum)		4
Total costs for Case Study OHL (£k)		**2226**
Total costs for Case Study OHL inc. 10% contingency (£k)		**2448**
Total OHL cost per km (£k/km): average = £1066k / km)		1025

UGC costs

358) The length of the cable, and the number of joints that would be used to underground this section of overhead line are to be found at the top of Table 5-17. Below these items, in the same table, will be found the UGC cost estimates for this case study. Please refer to the notes in Case Study 1, Paragraphs 0 to 322), which apply equally to this Case Study.

Table 5-17 Case Study 3 – UGC costs

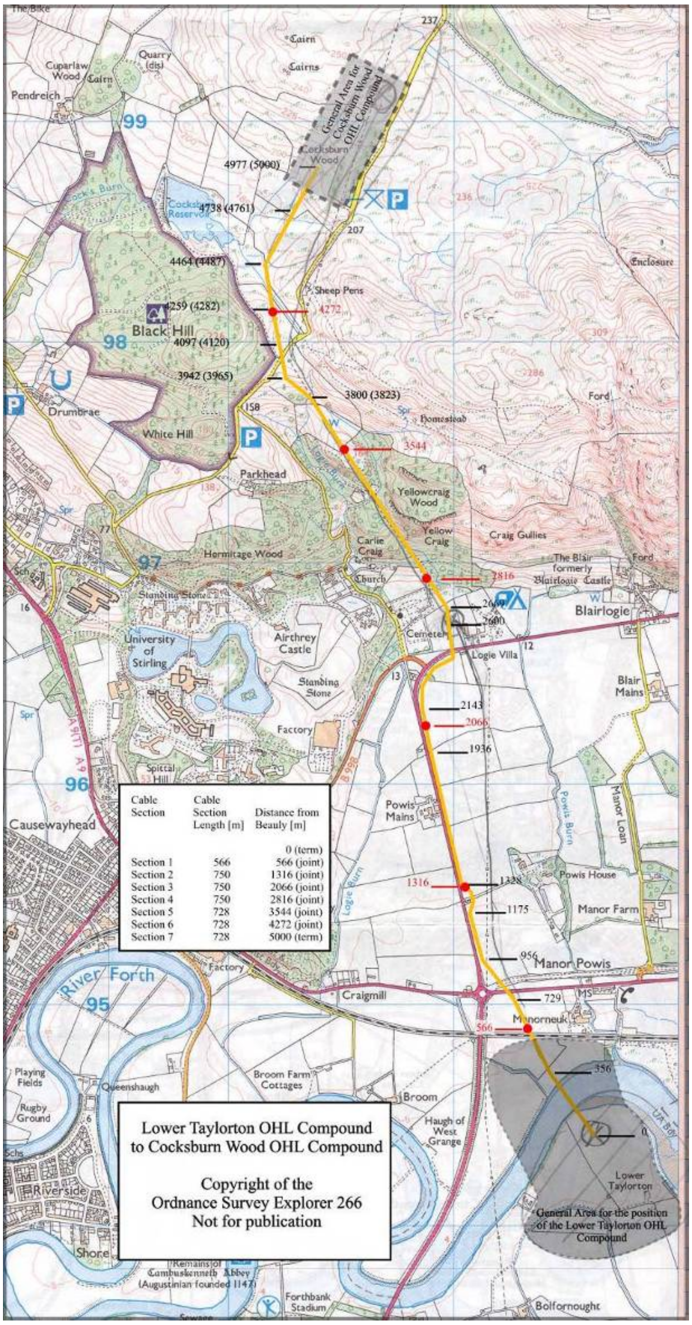
	Lower Taylorton - Logie (Stirling SE)
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	2.6
No. of UGC joints joints in section	3
A. Construction Costs	
i. CABLE-END COSTS	
2 Sealing-end terminal towers (1 for Beauly-Eskadale):	
steelwork	174
foundations & construction	137
2 Sealing-end compounds:	
Termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	50
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	40
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	100
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	7
land purchase	13
access road > 150m	20
Total cable-end for section	5074
ii. CABLE ROUTE COSTS	
400kV UGC	5772
275kV UGC	5148
Cable joints	839
Other equipment - supply and install	1996
Civils - supply and install	15838
Accommodation (not wayleaves)	64
Route environmental measures	300
Total cable route for section	53925
Total construction costs for Case Study UGC (£k)	35031
Total UGC cost per km (£k/km, average= £11496k / km)	13473
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	134
Wayleaves (£k)	63
40-year replacement (£k)	2443
Total operational costs for Case Study UGC (£k)	2640
Total costs for Case Study UGC (£k)	37670
Total costs for Case Study UGC inc. 15% contingency (£k)	43321
Total UGC cost per km (£k/km): average = £14394k / km)	16662

5.6 Case Study 4 - Lower Taylorton to Cocksburn Wood

5.6.1 Finding a Cable Route

359) Figure 5-21 shows the preliminary route. This route follows reasonably close to the existing 132kV overhead line. However, a major obstacle was recognised as being the route up the Ochil Hills.

Figure 5-21 Preliminary Route Option and Section Lengths

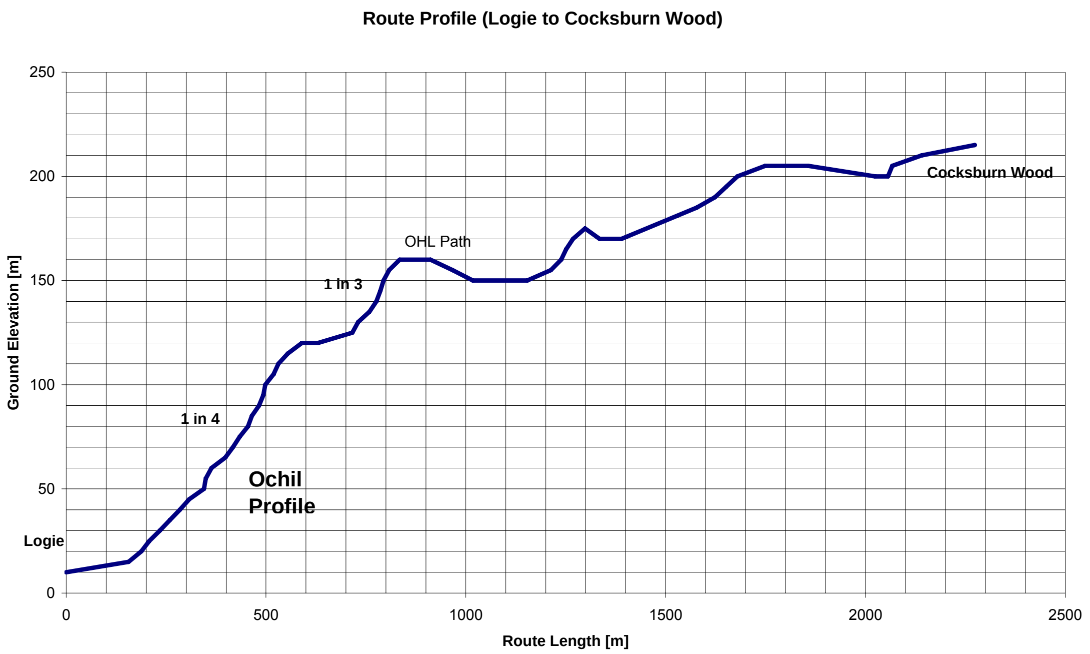


360) The shortest route is up an escarpment in the Ochil Hills between Yellow Craig and Carlie Craig. This escarpment is steep and a profile extracted from an Ordnance Survey map can be seen in Figure 5-23. The shortest cable route is problematic and is not suitable for economic EHV power cabling as it is both difficult to access for maintenance and will require an extensive civil construction in order to install and secure the power cables. This route should only be considered as a very last resort.

Figure 5-22 Existing line and Ochil Hill escarpment from Cemetery north of Logie Villa

361) Figure 5-22 shows a view of the Ochil Hills and some appreciation of the difficulty of installing a cable up the steepest sections which are more easily traversed with an oversailing overhead line.

Figure 5-23 Steep Ground Profile of the Ochil Hills

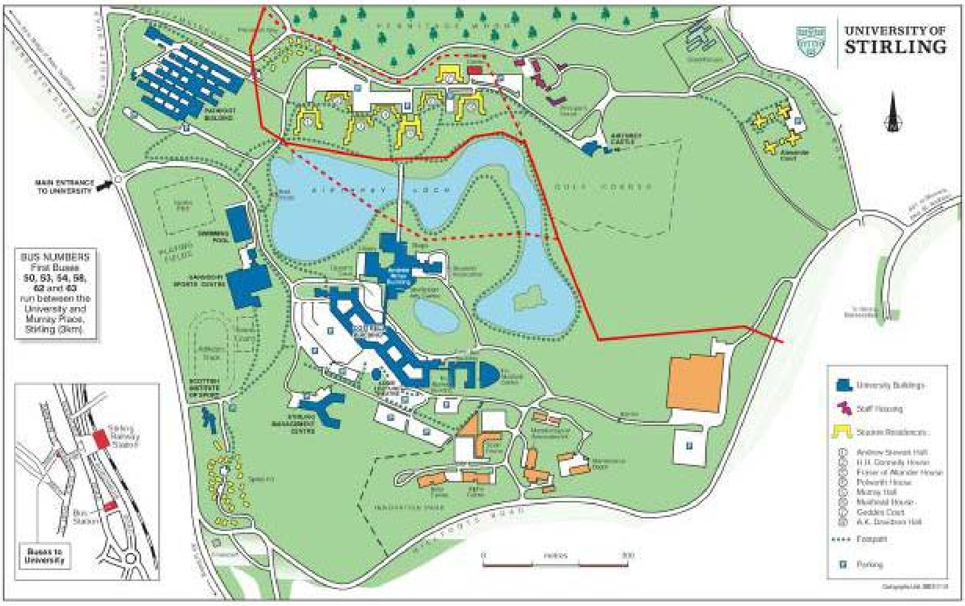


362) The possible cable route is shown in Figure 5-26 and runs from an OHL compound to be positioned near the River Forth at Lower Taylorton in the area marked. A terminal tower position has been arbitrarily selected on the South side of the river for the purposes of this case study. The route runs alongside the A91 towards Logie.

363) An alternative route was considered to avoid the Ochil Hills escarpment. This is a route through Stirling University and Bridge of Allen shown in Figure 5-25.

364) Figure 5-24 indicates a number of route possibilities through Stirling University to reach the alternative routes up the Ochil Hills. It should be noted that site visit to the University was not performed as this was not possible in the time available, however the aerial photography indicates that a route may be possible.

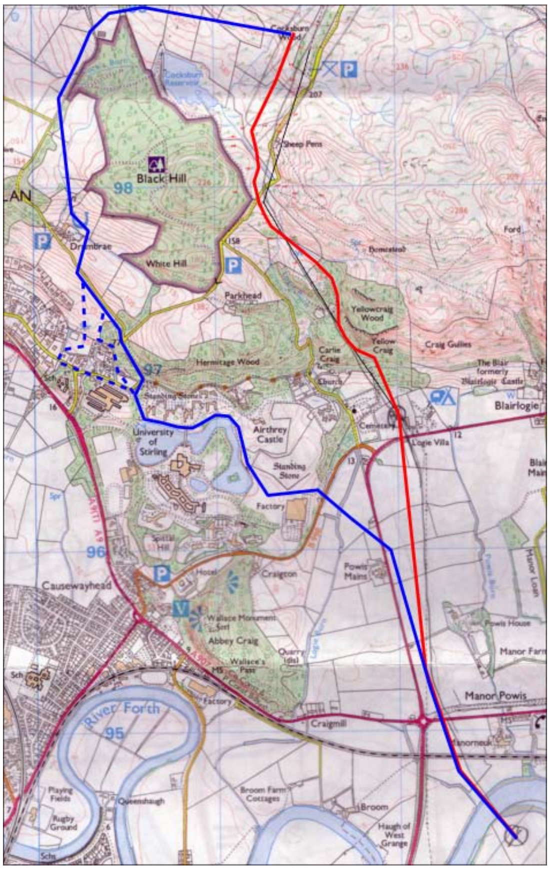
Figure 5-24 Alternative routes through Stirling University Campus



365) Consideration was also given to the available routes up the Ochil Hills to the west of Stirling University. These can be seen indicated in blue in Figure 5-25.

366)

Figure 5-25 University of Stirling Route Option



367) Site visits to possible route options to traverse the Ochil Hills were made where public access was available. It was considered, but not costed, that it would probably be too costly to attempt to take all twelve cables along the same route

when traversing the Ochil Hills. This was due to the amount of rock that would require clearing on one option and the likely increased disturbance and lack of property access to the residents of the Bridge of Allen on the other. It was decided therefore to split the circuits for a portion of the route. The selected route is shown in Figure 5-26.

368)

Figure 5-26 Cable Route Lower Taylorton to Cocksburn Wood

Circuit 1 (400kV)

Cable Section	Cable Section Length [m]	Distance from Beauly [m]
		0 (term)
Section 1	613	613(joint)
Section 2	613	1226 (joint)
Section 3	613	1839 (joint)
Section 4	601	2440 (joint)
Section 5	600	3040 (joint)
Section 6	600	3640 (joint)
Section 7	600	4240 (joint)
Section 8	600	4840 (joint)
Section 9	600	5440 (joint)
Section 10	575	6015 (joint)
Section 11	575	6590 (joint)
Section 12	575	7165 (term)

Circuit 2 (275kV)

Cable Section	Cable Section Length [m]	Distance from Beauly [m]
		0 (term)
Section 1	*613*	*613 (joint)*
Section 2	*613*	*1226 (joint)*
Section 3	*613*	*1839 (joint)*
Section 4	*601*	*2440 (joint)*
Section 5	*600*	*3040 (joint)*
Section 6	*600*	*3640 (joint)*
Section 7	*652*	*4292 (joint)*
Section 8	*652*	*4944 (joint)*
Section 9	*652*	*5596 (joint)*
Section 10	*575*	*6171 (joint)*
Section 11	*575*	*6646 (joint)*
Section 12	*575*	*7321 (term)*

369) Cable section lengths were calculated for the route described in Figure 5-21 however as this route is not the preferred option, these calculations are not described.

370) Table 5-18 gives the cable section length options for the route shown in Figure 5-26.

Table 5-18 Average Cable Section Lengths, Lower Taylorton to Cocksburn Wood

Number of major cross bonded cable sections	Number of minor cross bonded cable sections	Average Cable Section Length [m]	Number of joint bays	Comment
1	3	2440	2	Cable sections too long.
2	6	1220	5	Cable sections too long
3	9	813	8	Cable section lengths too long
4	12	610	11	Acceptable length

371) The actual cable lengths per section are shown in Table 5-19. These lengths vary for the circuits as the route splits due to a lack of room for a single route to the top of the Ochil Hills. Numbers in italics are for the longer route. The longer route would be a 275kV circuit as this would be less expensive to install than a 400kV circuit due to the cable price.

Table 5-19 Cable Section Length from Lower Taylorton to Cocksburn Wood

Cable Section	Length [m]	Running Length [m]	Bonding.
1	*613*	*613*	Major Cross Bonded Section
2	*613*	*1226*	
3	*613*	*1839*	
4	*601*	*2440*	Major Cross Bonded Section
5	*600*	*3040*	
6	*600*	*3640*	
7	600 *652*	4240 *4292*	Major Cross Bonded Section
8	600 *652*	4840 *4944*	
9	600 *652*	5440 *5596*	
10	575 *575*	6015 *6171*	Major Cross Bonded Section
11	575 *575*	6590 *6646*	
12	575 *575*	7165 *7321*	

372) The following table lists the main features and their location along the cable route:

Location	**Comment**
NS 826 944	Lower Taylorton Overhead Line Cable Sealing End Compound. Access to this compound and the cable route up to the River Forth will be obtained using local roads. This may cause some disruption to local traffic. Positioning the compound north of the River Forth will avoid this disruption and avoid the project risks and costs associated with a cable crossing beneath the River Forth..

Location	Comment
NS 825 945	Directional Drilling under the River Forth. If directional drilling is not possible it would be preferable to install the cables in the bed of the river, for example by dredging a channel. Dredging could cause damage to the river environment. Bridging over or tunnelling under the river would be more expensive alternatives. An overhead line crossing of this river would be considerably cheaper.
NS 822 948	Directional drilling under the railway. It will be necessary to gain permission from the Network Rail to directionally drill under the railway. Traditionally the railway does not allow ducted open cut excavations of the railway. If directional drilling is not possible the use of tunnelling or bridging would need to be considered. Alternatively diversion of the route to make use of the deck of the A91 road bridge over the railway may be considered. Use of the A91 would however cause considerable traffic disruption for the duration of the works. Access to the route between the railway and the River Forth may be obtained via the Manorneuk Farm access crossing of the railway and associated farm track. This access would only be required for the installation of the system between the River Forth and the railway. If the terminal compound were moved north of the River Forth, then a suitable permanent access road would need to be installed between the compound and the A907 via the unmanned railway crossing near Manorneuk farm. Discussions with Network Rail on the suitability of use of this rail crossing would be required.
NS 822 949	Joint bays at chainage 613m. Access to this joint bay may be obtained from the A907 site access point.
NS 821 950	Crossing of the A907. A907 site access point. Subject to the agreement of the local authorities it would be possible to open cut the A907 with 50% of the road width closed at a time. This position would be a site access point for the area between the railway and the A907 to the south and the A907 and the A91 site access point. The cable route crosses the old A907 which services farms to the south of the new road. Reinstatement of this road at the crossing point suggested (near the roundabout with the A91) is unlikely to be necessary.
NS 820 954	Joint bays at chainage 1226m. Access to this joint bay will be obtained from either the A907 or A91 site access points.
NS 820 954	Access Road to Powis House. Road to be ducted to allow access for residents.
NS 818 960	A91 Site access point. Where the cable route crosses the A91 site access will be obtained in a southerly direction to the A907 and to the north as far as Logie Burn.
NS 818 960	Joint bays at chainage 1839m. Access to this joint bay shall be via the A91 site access point.
NS 817 962	Logie Burn crossing. This crossing may be obtained either by directional

Location	Comment
	drilling, water course ducting or over pumping.
NS 816 963	B998 road crossing and site access point. This site access point will give access to the route from the B998 down to the Logie Burn. The B998 shall be crossed by directional drilling or by installing ducts in an open cut trench (two operations ducting 50% of the road width at a time). Access to the factory site to the West of the B998 shall be made via the factory site access road. This road will also need to be ducted using a 50% open cut method.
NS 815 963	Factory site access point. This access point will be utilised for all works inside the factory grounds and University of Stirling. A security post will be required at the boundary between the factory and university to ensure that both the factory and the university security are not compromised. Co-operation with all parties will be a key issue in the success of the construction of this project.
NS 814 963	Joint bays at chainage 2440m. Access to this joint bay will be via the factory site access point.
NS 814 964	Standing stone. An archaeological point of interest. The cable route skirts this point to the South.
NS 812 963	University of Stirling access road crossing No. 1. The cable route enters the grounds of the University of Stirling from the Factory access point. If this road cannot be closed for the duration of the works it will be ducted by open cut trenching methods. The cable route then runs north of Airthrey Loch in the university grounds. A number of trees on the campus will be affected by this work.
NS 810 967	Joint bays at chainage 3040m. These joint bays will be accessed via the Factory site access point located to the East of the joint bays.
NS 808 966	Bridge access inside University of Stirling. The cable route runs along the north bank of the loch and passes beneath the access to the pedestrian footbridge over the loch. If it is necessary to maintain access to the footbridge a suitable structure may be erected over the works. It will be necessary to divert or close other footpaths within the working swathe.
NS 805 967	University of Stirling access road crossing No. 2. This is likely to be one of the busier roads in the campus and thus it will be necessary to duct under this road by open cut trenching methods to maintain access. This road will not carry construction traffic which shall solely utilise the haul road.
NS 805 968	Joint bays at chainage 3640m. These joint bays will be accessed via the factory site access point to the East of the joint bay positions. It will be necessary to install a vehicle turn around point near this location.
NS 805 968	University of Stirling access road and car park crossing No. 3. This is the access road to University buildings and an associated car park. It will be necessary to install ducts under this road and the adjacent car park. The Pendreich Way footpath inside the university grounds, which connects the University building to ten dwellings, will require diversion or closure.

Location	Comment
NS 805 969	Cable circuits northern and Southern Routes. At this point the cable circuits diverge for the ascent of the Ochil Hills. This separation is required due the lack of a cable route that can accommodate all four cable groups (two groups of three cables for each of the two circuits) for this ascent. These separate routes are problematic and the "best" available routes that could be found for this case study.
NS 805 968	Northern Route, Hermitage Wood. The northern route cables pass under the University boundary wall into Sheriffmuir Road and cross into the paddock to the north of the road. The cables then hold to the eastern side of the paddock and travel north to the end of the paddock. At this point the cables enter Sheriffmuir Road. The cable route then utilises the road and it will be necessary to close both Sheriffmuir Road and Pendreich Road where each passes through Hermitage Wood. This closure will be required for the duration of the cable installation works between the joint bays at chainages 3640m and 4240m. This road closure would affect about 500m of road. All road routes affected have alternatives and no dwellings are stranded. Installation of the cable route under the road through Hermitage Wood would require excavation or blasting through rock. It is proposed that the cables are installed either side of the road. The road passes through an existing cutting in the rock face. Due to the lack of space it will be necessary to excavate and lay each group of three cables separately. Maps indicate that Mill Lade stream passes through Hermitage Wood and it will be necessary for the cables to traverse this water course. Where the cables emerge from Hermitage Wood they will leave the road and enter the fields to the South of Pendreich Road.
NS 804 973	Northern Route joint bays at chainage 4240m. The joint bays are located in the fields to the South of Pendreich Road. The cables for the northern Route join with the Southern Route cables as they run parallel in fields to the Southern side of Pendreich Road.
NS 805 968	Southern Route joint bay at chainage 3640m. After leaving the university campus cables run under the car park servicing the university buildings. It will be necessary to close the car park during these works. The route then runs alongside, and inside of, the boundary wall of the University. This will require some tree clearance. Prior to the cables exiting the University campus onto the Kenilworth Road the cables must cross the Mill Lade stream. This route will cause disruption to a number of residents of the Bridge of Allen along which the route proceeds. On entering Kenilworth Road it is proposed that the cables are positioned on opposite sides of the road. It will be necessary to work on each group of three cables separately in order to allow the roads to remain open using suitable traffic management. The Southern cable route turns into Welgate Drive.
NS 801 971	Southern Route Joint Bays at chainage 4292m. These joint bays are located in Welgate Drive on opposite sides of the road. Welgate Drive is accessible via the A9(T) road.

Location	Comment
	The cables proceed to the end of Welgate Drive where they enter private property. The cable route must traverse through the private property and enter the fields at the rear of the property.
NS 802 973	The fields at the rear of Welgate Drive are to the south of Pendreich Road. There is a reasonably steep incline up to Pendreich Road which appears to be suitable for negotiation by tractor or tracked vehicles only. The southern cable route joins with the northern cable route at the top of the field. The field will be accessed via the Pendreich Road site access point.
NS 800 977	Southern Route joint bays at chainage 4944m. These joint bay are located south of Pendreich Road next to Mine Wood to the West of Drumbrae farm.
NS 800 977	Road crossing near Drumbrae Farm. The cables will be installed in ducts under this Pendreich Road (crossing number 1) using open trench methods. This road crossing will be ducted and will remain open for local access to Drumbrae Farm
NS 801 978	Northern route joint bays at chainage 4840m. These joint bays are located north of Pendreich Road next to Mine Wood to the West of Drumbrae Farm. The cable route then runs alongside and to the east of Mine Wood. At a suitable opening in the trees alongside the Pendreich Road the cable route re-crosses Pendreich Road (crossing No. 2). This road crossing will be ducted by open cut methods. The road will remain open for local access at this location for Drumbrae Farm. The shortest route to Cocksburn Wood terminal compound has been rejected as this leads over Black Hill. The route would require the felling and sterilising of a substantial swathe of community woodland.
NS 800 983	Joint bays at chainage 5440m *(5596m)*. Accessed from Pendreich Road site access point.
NS 800 983	Pendreich Road Crossing No.3 and Pendreich Road site access point. This position will be the site access to the fields adjoining the Pendreich Road and the fields leading to Cocksburn Wood OHL compound. This road crossing will be ducted by open cut methods. The road will remain open for local access at this location for Drumbrae Farm and Pendreich Farm.
NS 801 986	Cock's Burn crossing. There are two options at this location, either to divert the burn into a duct such that the haul road may traverse over the burn or to utilise the existing farm road crossing. The preference would be to duct the burn in order that the haul road may pass over the burn. The cable will be installed in ducts beneath the burn either by open cut methods or utilising a drilling technique. The cables then run northwards alongside the Pendreich Farm access road.
NS 803 988	Road crossing to Pendreich Farm. This road crossing will be ducted by

Location	Comment
	open cut methods. The road will remain open for farm access.
NS 803 988	Joint bays at chainage 6015 *(6171).* These joints are located alongside the access road to Pendreich farm.
NS 808 989	Joint Bays at chainage 6590 *(6646).* This joint bay will be accessed via the Pendreich Road site access point.
NS 814 988	Cocksburn Wood Terminal Compound. **Figure 5-27 Cocksburn Reservoir and Black Hill Viewed from Cockburn Wood**  Figure 5-27 is a view of the landscape on top of the Ochil Hills at Cocksburn Wood looking back towards Logie. It should be noted that the access to the top of the Ochil Hills is liable to present some problems for cable delivery, particularly for heavy loads containing 40 tonnes of cable. Haulage contractors would be able to provide assessments of routes from ports of delivery to site and this should be undertaken at an early stage. This location could be served either by the haul road or via Sherrifmuir Road, which has a weight restriction further north that must be overcome.

373) There are no statutory designated nature conservation sites along the route. From Lower Taylorton to chainage 1500m The ecological value of the land route is of negligible to low ecological value. The River Forth is of moderate local ecological value. There is however a mammal population along the route. The entire route is in an area sensitive to unknown archaeological remains.

374) Beyond chainage 1500m no ecological or archaeological data was available at the time of compiling the report. However, from aerial photography the route appears to pass through improved and semi-improved grass land, woodland broad leaved and semi-natural. The route does not traverse any know archaeology or its extent. It is not known if the route passes through any areas sensitive to unknown remains.

5.6.2 Financial Details

375) The case study is based upon the undergrounding of the following section of OHL:

Table 5-20 Case Study 4 – OHL parameters

Source	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)	
3	Length (km):	4.80
3	No. of spans:	13
	Tower type	L12
8	D std - no.off	10
8	D55 - no off	4
8	DT - no off	0

OHL Costs

376) The OHL cost estimates for this case study are provided in Table 5-21. Please refer to the notes in Case study 1, Paragraphs 313) to 316), which apply equally to this case study.

Table 5-21 Case Study 4 – OHL costs

		Lower Taylorton - Cocksburn Wood (Stirling SE + NE)
A. OHL Construction costs for Case Study (£k)		
Length (km):		4.80
Tower type:		L12
	D std (no. off)	10
	D55 (no. off)	4
	DT (no. off)	0
Tower Steelwork (£k):		
	D std	218
	D55	169
	DT	0
Tower Foundations (£k):		
	D std	44
	D55	59
	DT	0
Conductors, inc. OPGW (£k):		1230
Insulators & fittings (£k):		231
Labour, Engineering & Project Mgmt (£k):		1301
Total works (£k):		3252
Accommodation + compensation per Case Study (£k):		311
Case study environmental measures & PR (£k):		22
Construction and Accommodation Totals (£k):		4745
NB: Balfour B Construction "Differences" estimates (£k)		n/a
B. OHL Operational costs (£k over 40 year life) - DCF rate = 6%		
Maintenance (£k)		296
Wayleaves (£k)		40
40-year replacement (£k)		358
Total operational costs for Case Study OHL (£k)		694
Operational costs (£/km/annum)		4
Total costs for Case Study OHL (£k)		**5438**
Total costs for Case Study OHL inc. 10% contingency (£k)		**5982**
Total OHL cost per km (£k/km): average = £1066k / km)		1246

UGC costs

377) The length of the cable and the number of joints that would be used to underground this section of overhead line are to be found at the top of Table 5-22. Below these items, in the same table, will be found the UGC cost estimates for this case study. Please refer to the notes in Case Study 1, Paragraphs 0 to 322), which apply equally to this Case Study.

Table 5-22 Case Study 4 – UGC costs

	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	7.32
No. of UGC joints joints in section	11
A. Construction Costs	
i. CABLE-END COSTS	
2 Sealing-end terminal towers (1 for Beauly-Eskadale):	
steelwork	174
foundations & construction	137
2 Sealing-end compounds:	
Termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	50
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	40
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	100
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	18
land purchase	36
access road > 150m	20
Total cable-end for section	5109
ii. CABLE ROUTE COSTS	
400kV UGC	15906
275kV UGC	14496
Cable joints	3076
Other equipment - supply and install	4684
Civils - supply and install	34413
Accommodation (not wayleaves)	181
Route environmental measures	600
Total cable route for section	53925
Total construction costs for Case Study UGC (£k)	78465
Total UGC cost per km (£k/km, average= £11496k / km)	10719
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	377
Wayleaves (£k)	178
40-year replacement (£k)	6877
Total operational costs for Case Study UGC (£k)	7431
Total costs for Case Study UGC (£k)	85897
Total costs for Case Study UGC inc. 15% contingency (£k)	98781
Total UGC cost per km (£k/km): average = £14394k / km)	13495

5.7 Case Study 5 - Glen Burn to Touch Road

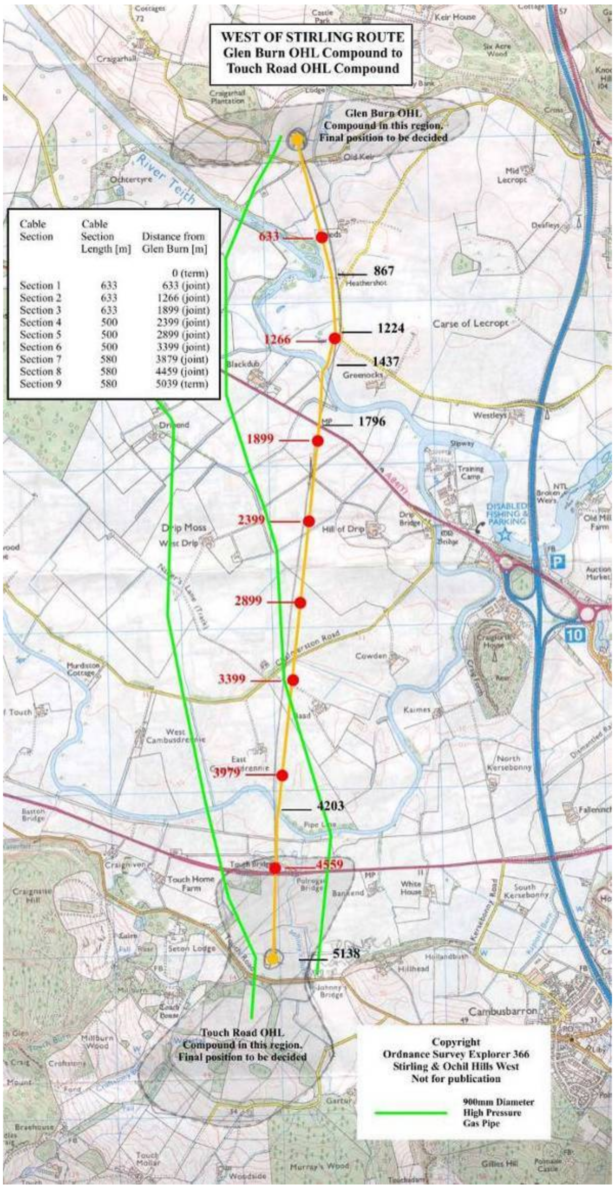
5.7.1 Finding a Cable Route

378) The cable route between Glen Burn and Touch Road traverses through farm land of which the sort shown in Figure 5-29 Preliminary Route Option is typical.

Figure 5-28 View from road near Craigarhall Plantation looking south

379) The preliminary route plot is shown in Figure 5-29.

Figure 5-29 Preliminary Route Option



380) The final cable route for this option is shown in Figure 5-30. This cable route runs north – south from Glen Burn in the north to Touch Road in the South. For the purposes of this report two locations have been selected for the positions of the OHL compounds. . Any alternative terminal positions are likely to alter the cable length and bonding arrangements.

Table 5-23 Fully Cross Bonded Section Length Options

Number of major cross bonded cable sections	Number of minor cross bonded cable sections	Number of joint bays	Average Cable Section Length [m]	Comment
1	3	2	1680	Too long for 150V sheath induced voltage limit
2	6	5	840	Too long for manufacture and delivery
3	9	8	560	Acceptable length

381) The average section length of 560m has been selected as this gives a number of options for the installation, either ducted or direct buried. It should be noted however that the use of the longer direct buried 840m section lengths would reduce the number of joint bays by up to 3. It is felt however that the induced voltage levels on the cable sheaths would rise above 150V on sections which include directional drilling under the rivers.

Table 5-24 Cable Section Lengths, Glen Burn to Touch Road

Cable Section	Length [m]	Running Length [m]	Installation Options.
1	633	633	Major Cross Bonded Section
2	633	1266	
3	633	1899	
4	500	2399	Major Cross Bonded Section
5	500	2899	
6	500	3399	
7	580	3879	Major Cross Bonded Section
8	580	4459	
9	580	5039	

Figure 5-30 Cable Route Glen Burn to Touch Road Compound

382) The following table details the position and the location of the main features along the proposed cable route:

Location	Comments
NS 762 980	Glen Burn overhead line compound. This overhead line compound will be accessed via the "northern site access point".
NS 762 978	Crossing of local access road for farms. Northern Site Access Point. This access point will be used as the entry point for all traffic onto the haul road between the Glen Burn OHL compound and the River Teith.
NS 763 974	Joint bays at chainage 633m accessed via the northern site access point.
NS 764 971	Heathershot path crossing. Fishermen's access to the River Teith. A pedestrian access way will be provided across the site if this footpath may not be closed.
NS 764 968	Spring crossing to be ducted to allow the construction traffic to pass over and the cables to pass beneath.
NS 764 968	Joint bays at chainage 1266m shall be accessed via the northern site access point.
NS 763 965	River Teith Crossing. This river is to be crossed using directional drilling techniques. The River Teith is a statutory special area of conservation and thus drilling under the river from a position remote from the river banks is required.
NS 762 962	A84(T) road crossing. A84(T) Site access point. The A84(T) is a busy trunk road and traffic control into the site and across the road will be required. It is proposed that this road is crossed by directional drilling methods to avoid the need to open the road surface. This access point to the site will be used for all site traffic between the Rivers Teith and Forth.
NS 762 962	Joint bays at chainage 1899m
NS 762 959	Crossing of access road to West Drip Farm. This road will be ducted by open cut means. It is not proposed to use this road as a site access point. Less local disruption will be caused if the A84(T) access point is used instead.
NS 762 957	Joint bays at chainage 2399m
NS 762 956	Drain crossing. It will be necessary to duct this drain in order that the haul road may cross over.
NS 762 952	Joint bays at chainage 2899m
NS 762 948	Crossing of Charlmerston Road. This road will be ducted by open cut means. It is not proposed to use this road as a site access point. Less local disruption will be caused if the A84(T) access point is used instead.
NS 761 947	Joint bays at chainage 3399m

Location	Comments
NS 762 948	Crossing of access road to Baad Farm. This road will be ducted by open cut means. It is not proposed to use this road as a site access point. Less local disruption will be caused if the A84(T) access point is used instead.
NS 761 944	Crossing of the Bathgate to Kinbuck Feeder 11 gas main. Two 900mm high pressure steel gas pipes run in a north – south direction in the general area of the cable route. These gas mains are owned by National Grid (Transco) and are the connections Braco – Bathgate Feeder 10, and Bathgate- Kinbuck Feeder 11. The cables will cross the Bathgate to Kinbuck Feeder 11 main and it will be necessary to establish the depth of cover over the pipe to decide whether the power cables cross over or under the gas pipe. The gas mains also pass through the areas designated for the overhead line cable compounds. It will in all cases be necessary for the cables to have at least 1 metre of cover over the cable warning cover tile to ensure the cable system is below plough depth. Extreme caution and a safe system of work must be employed particularly when working in the vicinity of these gas mains. Guidance should be sought from Transco with regard to any safe working practices that they require should be employed when close to the gas mains.
NS 761 941	Joint bays at chainage 3979m
NS 761 937	Crossing of the River Forth. Crossing of the River Forth will be achieved by directional drilling. Consideration may also be given to the installation of a cable bridge if directional drilling is not preferred.
NS 761 934	A811 road crossing. Site access point. This access point will be used to access the route between the River Forth and Johnny's Burn.
NS 761 936	Joint bays at chainage 4559m
NS 761 931	Crossing of Johnny's Burn. This crossing will be achieved by directional drilling.
NS 760 930	Touch Road Overhead line cable sealing end compound
NS 761 928	Touch Road. Site access point to OHL compound and the cable route up to the crossing of Johnny's Burn.

383) As with all routes, where joint bays are located in fields, the link pillars will require protection from farm equipment and livestock. This protection may be afforded by stock proof fencing forming a pen around the link equipment.

384) There is no baseline information for the environmental or archaeological impact assessments available for this area. Aerial photography indicates that the entire route will be within arable farmland. A limited number of field trees and hedge rows will need to be cleared.

5.7.2 Financial Details

385) The case study is based upon the undergrounding of the following section of OHL:

Table 5-25 Case Study 5 – OHL parameters

Source	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)	
3	Length (km):	4.80
3	No. of spans:	13
	Tower type	L12
8	D std - no.off	10
8	D55 - no off	4
8	DT - no off	0

OHL Costs

386) The OHL cost estimates for this case study are provided in Table 5-26. Please refer to the notes in Case study 1, Paragraphs 313) to 316), which apply equally to this case study.

Table 5-26 Case Study 5 – OHL costs

		Glen Burn to Touch Road (Stirling W)
A. OHL Construction costs for Case Study (£k)		
Length (km):		4.90
Tower type:		L12
	D std (no. off)	11
	D55 (no. off)	2
	DT (no. off)	0
Tower Steelwork (£k):		
	D std	240
	D55	85
	DT	0
Tower Foundations (£k):		
	D std	48
	D55	30
	DT	0
Conductors, inc. OPGW (£k):		1254
Insulators & fittings (£k):		236
Labour, Engineering & Project Mgmt (£k):		1262
Total works (£k):		3155
Accommodation + compensation per Case Study (£k):		317
Case study environmental measures & PR (£k):		22
Construction and Accommodation Totals (£k):		3494
NB: Balfour B Construction "Differences" estimates (£k)		n/a
B. OHL Operational costs (£k over 40 year life) - DCF rate = 6%		
Maintenance (£k)		302
Wayleaves (£k)		41
40-year replacement (£k)		365
Total operational costs for Case Study OHL (£k)		708
Operational costs (£/km/annum)		4
Total costs for Case Study OHL (£k)		**4201**
Total costs for Case Study OHL inc. 10% contingency (£k)		**4622**
Total OHL cost per km (£k/km): average = £1066k / km)		943

UGC costs

387) The length of the cable, and the number of joints that would be used to underground this section of overhead line are to be found at the top of Table 5-27. Below these items, in the same table, will be found the UGC cost estimates for this case study. Please refer to the notes in Case Study 1, Paragraphs 0 to 322), which apply equally to this Case Study.

Table 5-27 Case Study 5 – UGC costs

	Glen Burn to Touch Road (Stirling W)
2500sqmm UNDERGROUND CABLE COSTS (£k)	
Length (km):	5.039
No. of UGC joints joints in section	8
A. Construction Costs	
i. CABLE-END COSTS	
2 Sealing-end terminal towers (1 for Beauly-Eskadale):	
steelwork	174
foundations & construction	137
2 Sealing-end compounds:	
Termination equipment - supply and install	472
2 off 400kV 3-ph earth switch	22
6 off 400kV surge arresters	66
6 off 400kV down-droppers, insulators	50
2 off 275kV 3-ph earth switch	16
6 off 275kV surge arresters	48
6 off 275kV down-droppers, insulators	40
2 ends cable protection	660
2 civils (site prep,150m access road,relay house)	100
Other (at nearest substation):	
1 off 400kV 160MVAr shunt reactor + civils and bund	1650
1 off 275kV 90MVAr shunt reactor + civils and bund	1000
2 off reactor protection	600
accommodation	13
land purchase	25
access road > 150m	0
Total cable-end for section	5072
ii. CABLE ROUTE COSTS	
400kV UGC	11187
275kV UGC	9977
Cable joints	2237
Other equipment - supply and install	3571
Civils - supply and install	25340
Accommodation (not wayleaves)	125
Route environmental measures	300
Total cable route for section	53925
Total construction costs for Case Study UGC (£k)	57808
Total UGC cost per km (£k/km, average= £11496k / km)	11472
B. Operational costs (£k over 40 year life)	
Maintenance (£k)	259
Wayleaves (£k)	122
40-year replacement (£k)	4734
Total operational costs for Case Study UGC (£k)	5116
Total costs for Case Study UGC (£k)	62924
Total costs for Case Study UGC inc. 15% contingency (£k)	72362
Total UGC cost per km (£k/km): average = £14394k / km)	14360

5.8 Conclusions

5.8.1 Routeing Procedure

388) A common six step routeing procedure emerged from the Case Studies:

1 The start and end points were identified in broad terms by SHETL and SPT,

2 The Landscape Architect identified locations for the terminal tower and sealing end compounds that connected to a tower within an LOD of the proposed overhead line route, based on desk study and site visits,

3 A straight line was drawn between the terminal tower/sealing end locations. This line represented the likely least cost baseline against which cable route options were developed. These options were assessed having regard to the technical requirements of the underground cable system alongside the environmental and other routeing considerations.

4 A varying number of cable route options were developed and assessed based on desk top study and site visits. A preferred option was selected which met the general routeing objective in terms of balancing the underground cable system technical requirements, environmental and routeing considerations, which in turn require to be balanced with the length of route, in respect of which, cost and disturbance are dominant considerations,

5 The preferred cable route option was checked for impacts against the baseline environmental data contained within the ES and if necessary, any changes made, and

6 The proposed route was costed with allowances included for directional drilling, thrust boring, ducting, tree and hedge replacement, landscaping of sealing end compounds, special work to habitats, and communications with the public.

389) It is likely that a similar procedure would be part of any underground routeing process.

5.8.2 Routeing Considerations

390) It is possible to identify a list of Routeing Considerations based on those emerging from the Case Studies. However, this can only be of a general nature as each route will require to be considered on a case by case basis.

5.8.3 Striking the Balance

391) As with OHL design, striking the balance between technical, environmental and cost considerations is the key element of route selection. This is an iterative process, as the route investigation proceeds towards a finalised design. The UGC routes given in the case studies are one stage of the iterative process based on information available at this time.

392) These Routeing Considerations are different from the Holford Rules used for routeing OHLs. The Case Studies from which these considerations have been

developed clearly support the long held proposition that there is no reason to assume that the UGC route with the least on-balance environmental disturbance would be the same route that an OHL with the least on-balance environmental disturbance would follow.

5.8.4 Financial Conclusions

393) The text above has presented cost comparisons for the "base case", that is, for 2500mm^2 cable, direct buried, and operating with one circuit at 400kV and the other at 275kV. For this case, and taking into account reasonable likely costs for the OHL and UGC solutions for the Beauly-Denny connection, the five case studies indicate that the UGC installations are likely to cost between 12 and 18 times more than their OHL equivalents. If UGC costs are compared with the Balfour Beatty "differences" estimates for the OHL (only made available for Case Studies 1 and 2) then these ratios rise to more than 25 times.

CHAPTER 6: APPROACH TO CIRCUIT ROUTEING

6.1 Method

394) Development of an approach to circuit routeing through literature and regular discussion review, and the use of case studies including site visits.

6.2 Established Practice

395) Unlike the Holford Rules for OHL, there is very little established practice published for UGC. Note the following:

- According to Europacable[12] underground cables are rarely appropriate for an entire new AC power transmission project,
- According to Europacable, for “long projects”, a combination of overhead lines and partial undergrounding may be appropriate to balance the needs of Regulators, Economic Stakeholders, Local Communities and the Natural Environment, and
- The only known UK example of a cable undergrounding in a rural area as a result of Inspector’s Recommendation is a 5.7km section of the 400kV North Yorkshire Line.

6.3 Objective and Approach to Routeing

6.3.1 Routeing Objective

396) The SHETL and SPT objective of the routeing process for an UGC is to facilitate the design, construction and operation of UGC circuits in a manner that is technically feasible and financially viable whilst causing, on balance, the least disturbance during construction and operation to the environment and the people who live, work and use it for recreation.

6.3.2 Environmental Considerations for Cable Routeing

397) The approach is based on the premise that the major impacts of underground cable circuits are likely to arise from the construction of cable trenches and associated works in combination with heat dissipation from the cables during operation and that the effects of these impacts may lead to vegetation changes which will become visible when viewed from above. This is likely to be least visible in flat arable land, more visible in improved or semi-improved grassland used for grazing and most visible in upland semi-natural or natural groundcover

398) Due to the potential geographic scale of these impacts the best way to mitigate and manage them is through route selection and successful habitat reinstatement through control of construction and heat emissions from cables in relation to soil type, groundcover and land use.

[12] “Overview of Underground Power Cables at High/Extra High Voltage Levels – Europacable Presentation to SHETL 2006

399) In addition, well routed cables will take into account other environmental and technical considerations and should seek to avoid altogether, where possible, habitats which are difficult to reinstate.

6.3.3 Routeing Strategy

400) The routeing strategy is a three stage process, as follows:

- Select underground cable corridor after identification of options, reporting and consultation,
- Select preferred cable route after identification of route options, reporting and consultation.
- Undertake environmental appraisal of proposed cable route.

6.3.4 Routeing and Deviation Considerations

401) Underground cables are not subject to published routeing guidelines such as the Holford Rules which relate to new overhead transmission lines. However the Case Studies have provided a list of Routeing and Deviation Considerations. This list is not inclusive but may be useful as a guide when applied on a project-by-project basis in a rural landscape.

402) Strategic Routeing Considerations:

- What is the power transfer requirement and what width of swathe is required? Is sufficient space available to accommodate the cables, accessories and earthing?
- Will access be granted for the cable route considered and if so, what time, trouble, cost and effort must be expended to obtain the route?
- What are the ground conditions along the route into which the cable system must be installed? Is the ground stable and can it, in all reasonability, be expected to remain stable and suitable for the service life of the cable system? Will it be necessary to move any obstructions from the cable route and if so at what cost, time, effort and trouble?
- Is the cable route one within which it is safe to construct a cable system? If constructed will the cable system provide the required service life? Will the system be economic and maintainable? Will the installation be safe and have an acceptable level of reliability when in operation for owners, operators and third parties?
- What disruption would the use of a proposed cable route cause to third parties and is it possible to mitigate the time, cost, effort and trouble likely to be caused by a route selection?
- Will the cable route have an adverse impact on the local and surrounding environment? How can this impact be mitigated and to what cost in terms of time, trouble and effort would be required?
- Will the cable route be viewed from above? If so, what length will be seen, at what distance, over what type of ground cover with what probability of successful long term reinstatement?
- As a result consider avoiding wet areas and habitats that are sensitive and habitats that are difficult to reinstate successfully;
- Following existing linear features particularly those that have already created disturbance such as roads or existing overhead line wayleaves;

- Considering access for construction and operation – consider use of existing crossings / structures at roads and railways. For river crossings consider banks, substrate and width of river and use of existing structures. Where this is not possible for major rivers which may be crossed by OHL, avoid cable crossings.

403) Detailed Routing Considerations:

- Preferable to avoid areas of flooding for joint bays and link pillar locations;
- Preferable to avoid steep cross slopes and gradients;
- Follow existing linear features particularly those that have already created disturbance such as roads or existing overhead line wayleaves;
- Preferable to avoid settlements, particularly those with a concentrated pattern of development;
- Preferable to avoid loss of landscape features such as individual trees, hedges, semi-natural and other woodlands and commercial forestry or use existing gaps;
- Preferable to cross water courses and other infra-structure at the narrowest, most accessible points;
- Preferable to avoid known archaeology;
- Preferable to avoid properties and water supplies;
- Preferable to avoid areas where excavation or ground levels may change in the future.
- Preferable to avoid areas with unstable, contaminated or high thermal resistivity ground.
- Preferable to avoid protected environments
- Minimum access to the transmission system to reduce outage requirements.

404) Deviation Considerations

- Unknown archaeology
- Cable route obstructions
- Ground with high thermal resistivity
- Unsafe, unstable or contaminated ground
- Protected environments
- Proximity to existing overhead lines, cables and other system equipment to reduce access to the system including outage requirements.

Siting of Terminal Tower and Sealing End Compound

405) Terminal Towers and Sealing End Compounds are not subject to specific siting guidelines, however the Holford Rules: Guidelines for the Routeing of New High Voltage Overhead Transmission Line with NGC 1992 and *SHETL 2003 Notes* contain a Supplementary Notes on the Siting of Substations. The Case Studies have been used as a basis for adjusting these notes for the siting of a Terminal Tower and Sealing End Compound.

Siting Considerations for Terminal Tower and Sealing End Compound

406) Siting considerations should include:

- Pay due regard to areas of high amenity value (Consider Holford Rules 1 and 2) and take advantage of the visual containment offered by natural features such as woodland, while fitting in with the landscape character of the area.
- Take advantage of ground form with the appropriate use of site layout and levels to avoid intrusion into surrounding areas.
- Consider the effects on the natural and cultural heritage and existing land use.
- Consider access requirements
- Consider alternative designs for terminal tower and sealing end compound equipment in the context of the relationship of terminal tower and sealing end compound with background and foreground features, in order to reduce the prominence of structures from main viewpoints.
- Consider use of bunding where this would not appear out of place and/or screen planting (which takes time to be come effective) to screen fencing and equipment and use of colour to reduce visual impact.

6.4 Conclusion

407) A Routeing Objective, Environmental Approach, Routeing Strategy and Routeing Considerations and Deviation Considerations can be developed for underground cables.

408) The Routeing Considerations are not a set of hierarchical rules or guidelines such as the Holford Rules for the routeing of overhead transmission lines but are a set of practical considerations which enables a route to be identified that causes on balance the least disturbance, including successful reinstatement after construction and during operation and decommissioning, to the environment and the people who live, work and use it for recreation.

CHAPTER 7: REVIEW OF XLPE INSULATED CABLE CIRCUITS IN OPERATION

7.1 Major EHV Cable Systems in Service around the World

409) At voltages between 220kV and 300kV the worldwide in-service XLPE insulated cable experience is extensive and a list has not been produced for this study. Experience of 275kV XLPE installations in the UK however, particularly with large conductor designs is modest.

410) At 400kV and above the list of worldwide projects in-service, although growing, is smaller than that which would be produced for systems from 220kV up to 300kV. Of particular interest to any application the Beauly-Denny route is the experience of 400kV cable systems that a) include joints and therefore only those over 1km in length are considered and b) are buried or ducted applications.

411) Table 7-1 list the major projects at 400kV and above that are known to be in service with joints. The circuit lengths have been adjusted to an equivalent single circuit length of three power cables per circuit as some installations are double circuit or two cables per phase. This list does not cover every installation in service around the world but does provide a sufficient number for some analysis.

Table 7-1 Major XLPE Projects in service at 400kV and above

Cable Supplier	Service Date	Voltage	Country	Circuit Name or Location	Cable Length – Equiv. Single cct km	Installation Type
J Power	1996	500kV	Japan	Shinkeiyo-Toyosu	19.84	Tunnel
Viscas	1996	500kV	Japan	Shinkeiyo-Toyosu	14.49	Partial direct buried
J Power	1997	500kV	Japan	Shinkeiyo-Toyosu	18.44	Tunnel
NKT	1997	400kV	Denmark	Metropolitan Power Project South link	22	Direct buried
Viscas	1997	500kV	Japan	Shinkeiyo-Toyosu	5.21	Direct buried
Prysmian (Siemens)	1998	400kV	Germany	Berlin	6.83	Tunnel
Südkabel (ABB)	1998	400kV	Germany	Berlin	6.83	Tunnel
Nexans	1999	400kV	Germany	Berlin	5.52	Tunnel
NKT	1999	400kV	Denmark	Metropolitan Power Project North Link	12.67	Direct buried
J Power	2000	500kV	Japan	Shinkeiyo-Toyosu	36.79	Tunnel
Prysmian	2000	400kV	UAE	Taweelah	5.23	Direct buried

Cable Supplier	Service Date	Voltage	Country	Circuit Name or Location	Cable Length – Equiv. Single cct km	Installation Type
Südkabel (ABB)	2000	400kV	Germany	Berlin	5.68	Tunnel
Viscas	2000	500kV	Japan	Shin-Toyosu Eitaibashi	40	Tunnel and direct buried
Südkabel (ABB)	2001	400kV	Abu Dhabi	Unknown	8.62	Unknown
Viscas	2001	400kV	Saudi Arabia	Al Jamia	11.2	Partial direct buried
Nexans	2002	400kV	Spain	Madrid Airport	6	Tunnel
Prysmian	2003	400kV	Spain	Madrid Airport	13.45	Tunnel
Silec (Sagem)	2004	400kV	Denmark	Nordjitlands Vaerket-Trige Arhus – Aalborg	27	Direct buried
Südkabel (ABB)	2004	400kV	Spain	Madrid Airport	13.39	Tunnel
Südkabel (ABB)	2004	500kV	Russia	Moscow, Bureya HPP	2.65	
Südkabel (ABB)	2005	400kV	Greece	Thesalonika Power	6	Unknown
Südkabel (ABB)	2005	400kV	UK	Dartford Tunnel	5.4	Tunnel
Südkabel (ABB)	2005	400kV	UK	Elstree-St Johns Wood	20.57	Tunnel
Prysmian	2005	400kV	Italy	Flumesanto	1	Ducts
Prysmian	2005	400kV	Netherlands	Nieuwe Waterweg and Calandkanaal crossings	4.23	Buried
Prysmian	2006	380kV	Austria	Vienna	10.4	Buried
Südkabel	2006	500kV	Sudan	Merowe	2.3	
Südkabel	2006	400kV	Buthan	Tala Hydroelectric	2.97	Unknown
Prysmian	2006	400kV	UAE	Interconnection of Abu Dhabi Island	12.5	Direct buried
Südkabel	2008	500kV	China	GouPiTan HPP	3.35	Unknown

412) From Table 7-1 it can be seen that a significant number of early projects have been installed in tunnels. This is because EHV cable circuit tend to be installed in areas of high population density and congestion and obtaining permission to direct bury circuits becomes increasingly difficult. Some utilities have also taken the view that, as 400kV XLPE systems are still in their infancy, a tunnel installation will allow easier partial discharge monitoring of individual cable joints and will allow for faster circuit repair in the event of a failure. The lower fire risk of XLPE cables, compared to oil filled cables, makes them better suited to a tunnel environment.

413) The number of 400kV direct buried applications is growing as confidence in 400kV XLPE systems increases. The direct buried environment is more onerous for a cable system than a tunnel environment. The last major 400kV buried cable system

was installed on the National Grid system as part of the second Yorkshire Line. This is an oil filled cable system.

414) There are no significant circuit lengths (over 1km) of 400kV XLPE cable in air filled ducts in service in the UK. However, an EHV ducted system has been installed at 275kV (Scottish Power Busby – Giffnock, 5.7km commissioned in 2006). Ducted systems are in use on EHV cable systems in the USA.

415) The majority of EHV power cable installations, regardless of the cable construction, take place in urban areas. Where power cables are used in rural areas it is almost invariably for connecting between sections of overhead line or connections from overhead line into substations where oversailing conductor congestion limits OHL access. One country that does not permit the installation of overhead line is the Republic of Singapore. Singapore is a small island and the transmission system does not transmit power over the large distances found in most countries. At 400kV the Singaporean power transmission company specifies oil filled cables as they believe these to be more reliable at this voltage level having experienced a number of high profile faults with their 230kV XLPE cable installations.

Table 7-2 Equivalent single circuit 400kV km for Case Studies

Route	Route Length km	1 x 400 + 1 x 275 Equivalent Single Circuit 400kV application	2 x 400 Equivalent Single Circuit 400kV application
Beauly – Eskadale	5.8	11.6	23.4
Garva Bridge – Dalwhinnie	4.0	8.1	16.2
Lower Taylorton to Logie	2.6	5.2	10.4
Lower Taylorton to Cocksburn Wood	7.3	14.3	29
Glen Burn to Touch Road	5.1	10.3	20.6

416) If a single circuit 400kV cable installation were installed for the routes between:

- Beauly – Eskadale
- Garva Bridge – South Dalwhinnie
- Glen Burn to Touch Road

417) This would total an equivalent single circuit 400kV application of 30km which would, probably represent the largest buried 400kV installation project undertaken in the world. This figure would be doubled if both circuits were installed at 400kV.

7.2 Summary of Underground Cable Use

418) The review concludes that:

- Most undergrounding takes place in urban areas, very little undergrounding takes place in rural areas.
- Most undergrounding in rural areas is part of an overhead line route

- Within the UK, the most recent rural installation of 400kV cable is 5.7km in length installed the Vale of York, this however is an oil filled installation. The National Grid do not currently have any 400kV XLPE installations with joints directly buried in the UK, although installations are planned.
- In Europe, ELTRA[13] have installed the longest rural installation at a similar voltage in Jutland where a single circuit, two cables per phase, 14km 400kV underground cable runs through an area of waterways and outstanding natural beauty. The system installed however has a much lower power rating that required for the Beauly – Denny line.
- In urban areas, however, cable circuit lengths of up to 20km may be found in London – for example the St Johns Wood - Elstree 400kV single circuit XLPE cable through a purpose-built tunnel.

7.3 Conclusion

419) Compared to the total length of 400kV overhead line circuits on electricity transmission systems, there is generally very little underground cable.

420) The quantity of 400kV XLPE cable in service is growing as oil filled cable becomes obsolete. However in the UK, there is currently only limited short-length experience of the use of directly buried XLPE cables at 400kV. Worldwide there is a higher level of service experience using buried 400kV XLPE systems with land mark European projects in Denmark being among the most notable.

[13] "400kV Interconnection Arhus – Aalborg", Soren Damsgaard Mikkelsen, Workshop 380kV – Kabel, 23rd Sept 2002, Wien

CHAPTER 8: OVERHEAD LINE OR UNDERGROUND CABLE: SUMMARY COMPARISON AND CONCLUSIONS

8.1 General

421) Overhead lines and underground cables essentially perform the same role, namely they provide electrical links between points on a transmission network. The differences in the technologies they employ provide the following comparative advantages.

	Overhead Lines	Underground Cables
Physical	Easier to cross difficult terrain	Easier to use in urban environments
	Quicker to build	
	Shorter routes normally possible	
Technical	Higher availability	
	Lower impact on electrical network	
	Quicker and easier to maintain / repair	
Environmental	Lower overall environmental impact	Lower landscape and visual impact
		Silent operation, apart from sealing ends
Cost	Very much lower whole life cost	

8.2 Physical Differences between OHL and UGC

<u>Conductors and Insulation</u>

422) OHL: A double circuit[14] 400kV or 275kV OHL of the type proposed by SHETL comprises seven sets of conductors that together make up two independent 3-phase circuits (6 or 12 power-carrying conductors) and a ground, or “earth”, wire

[14] Provision of two circuits allows for energy to continue to flow to consumers through one circuit in the event that the other is out of service for maintenance or repair.

(one conductor). Each conductor is normally of aluminium alloy designed for mechanical strength, lightness, and electrical conductivity. The single ground wire takes the dual role of protecting the circuits from lightning strikes and (usually) providing a secure route for optical fibre telecommunications.

423) Phase insulation is provided by substantial porcelain or glass insulator strings at the supporting towers, and by the air surrounding the conductors. The reason why the towers support the 400kV conductors so high above the ground is to ensure that safety clearances are not infringed by anything on the ground below the conductors.

424) UGC: A double circuit 400kV or 275kV UGC normally comprises either six, or in this case, twelve single power conductor cores, to accommodate the power rating that is anticipated to be required of each circuit. Each cable conductor core is normally of multi-stranded copper construction. In addition to these power cables, the trenches will also contain DTS cables, earth continuity cables on end-point bonded sections, and often fibre optic cables to carry through any OHL earth wire fibre.

425) In the past, insulation for cable power conductor was provided by many layers of tightly wrapped paper tape impregnated with oil. However, underground transmission class cables which use such oil and paper tape insulation are becoming obsolete, largely due to the environmental hazards that such cable designs present. Increasingly, therefore, this is being replaced with cross-linked polyethylene (XLPE), a plastic that is extruded around the conductor. This solid insulation does not contain oil and is therefore seen to be less of an environmental hazard. Power cable systems are considerably more expensive to purchase than overhead line systems as they require a larger conductor cross section (more metal), use more materials for the insulation and protective barriers, require more elaborate machinery to manufacture, take longer to fabricate, are more difficult to install, require more expensive accessories and are heavier to transport.

Surrounding Conditions

426) OHL: The seven conductor sets are supported by steel angle iron towers (pylons) whose height and span lengths are governed by the need to maintain safety clearance around the high voltage conductors. The standard height of the L12 towers that would be used in SPT's area is 46.5m above ground level, whilst that for the SSE400 towers designed for use in the Scottish uplands is 50.5m. In either case, however, actual tower heights will vary depending upon the terrain and local conditions.

427) Undergrowth beneath the overhead line, and to a distance of 7.5m either side of the outermost conductors, would be restricted to an absolute maximum height of 5m, as indicated in Figure 8-1. However, normal agricultural activity could continue around and beneath the OHL, since the normal use of the land will have been taken into account at the design stage. Trees to be grown above 5m would, however, need to be much further from the OHL centre line (up to 40m), as shown in Appendix 9.

428) UGC: As has already been described in Section 2.5, the twelve cables would be accommodated by up to four trenches, each around one metre deep, which together with the preparation area and access track would require a swathe some 30m wide.

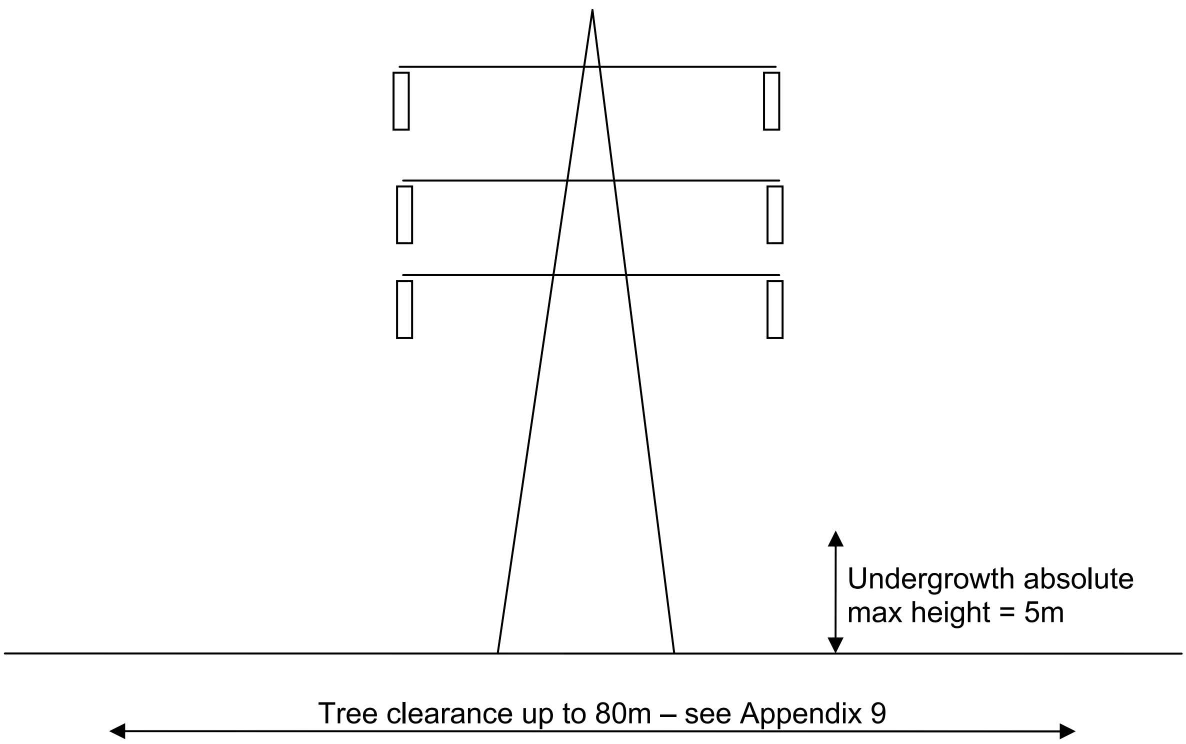
429) Normal agricultural activities may be continued above and around the UGC once installed, however, as described further in Section 2.6, trees whose roots would disturb the cable trenches would not be permitted, neither would building construction.

Construction

430) OHL: A route survey would be followed by brush clearance and preparation of foundations for each tower. On average, towers are placed about 350m apart, though this depends significantly upon terrain and other routing factors. Heavy load access would be required to each tower site for excavators, for the removal of spoil, for the delivery of foundation materials and tower steelwork and, later, for the delivery of insulators and fittings. Later, also, at the angle towers (the towers where the route changes direction), drums of conductor wire will be delivered.

431) Once the foundation concrete has been poured and cured, a crane would normally visit each site to assist with tower construction.

Figure 8-1 OHL – tree and brush clearances



432) On average it would take about one week to actually build a tower and a little longer to install the insulator strings. Another week would be required sometime after that to string all the conductors along the set of towers that comprise a particular straight-line section of the route. In practice, however, a number of towers in the area are likely to be worked upon at the same time, and there will be periods of inactivity at any given location whilst other sections of the route are being constructed.

433) UGC: A route survey would be followed by brush clearance and preparation of trenches. Any drainage requirements would normally be satisfied at this time too. A full description of the construction activities for UGC is provided in Sections 2.4 and 2.5 of this report, however, in general it is expected that the work on a particular section of the cable route would take around 16 weeks.

Operation and Maintenance

434) OHL: Once or twice a year the line would be inspected for damage or safety issues. Much less frequently, access would be required for brush control and tower maintenance purposes.

435) UGC: Annually, access would be required to the joint bays and link positions for test purposes.

In Summary

436) From the foregoing discussion it can be seen that the biggest physical differences between OHL and UGC installations are:

- UGC installations are more disruptive to the local environment than OHL during the construction phase;
- OHL installations are more visible than UGC during the operational phase, although the UGC has greater visual impact at the ends of the cable where sealing-end compounds are required to join UGC to OHL; and
- During operations occasional access to the circuits will be required for maintenance and safety purposes.

437) The document "Overhead or Underground", produced by UK's National Grid Company [15], the licensed transmission operator for England and Wales, and in particular a section titled "A question of insulation" discusses all these issues further, outlining the practical implications which arise from the laying of underground cables and the construction of an overhead line.

8.3 Technical Differences between OHL and UGC

Technically, so far as the electricity transmission network is concerned, the difference between OHL and UGC is the type of insulation used and the practicalities of designing, constructing and operating a safe system with them.

438) For OHL, the insulation is air, whilst for the UGC, in these case studies at least, the insulation would be XLPE. As a result of their insulation types and geometric arrangements, UGC has a much higher capacitance than OHL and thus compensating reactors must be provided for the UGC installations. This is described in more detail in Section 2.3.2.

8.4 Environmental Differences between OHL and UGC

Landscape and Visual Impact

439) The main advantage of UGC when compared to OHL is the reduction in the effects on visual amenity and landscape character, though this advantage may be reduced by the effects of UGC on ground cover / habitats when viewed from above. UGC also reduces the potential for bird collision.

[15] "Overhead or Underground" produced by the UK's National Grid Company

440) The main disadvantages of UGC when compared to OHL relate to the greater impact on habitats, unknown archaeology, drainage and land use of construction both in terms of the extent of the area disturbed, the equipment required and the volume of materials involved particularly.

441) Because of the visual impact of terminal towers and sealing end compounds, and the fact that they determine the start and end points of OHL, care must always be taken with their location.

442) For UGC at 275kV and 400kV, once constructed and in operation, though the cables themselves will not be seen, the route of the cable trench is likely to be visible when viewed from above throughout the life of the installation except in high productivity agricultural areas.

443) For OHL the visual impact varies depending upon the viewing point but, from close up, it is normally significant and remains so throughout the life of the installation.

Acoustic Noise

444) During poor weather such as fog rain and ice, OHL will emit an audible sizzle or hiss. UGC, on the other hand, is silent except at the sealing-end compounds where the high voltage connections will also emit a sizzle or hiss in poor weather. If shunt reactors are required in the cable sealing end compounds these will emit an audible hum. This operational noise associated with the proposed overhead line or sealing end compounds is not considered to be a environmentally significant.

Electric and Magnetic Fields

445) Electric fields exist near and under OHL, but none are produced by UGC. On the other hand, magnetic fields are produced by both OHL and UGC, though the patterns of these fields are different for the two types of installation.

446) The magnitudes of both the electric and the magnetic fields experienced in the proximity of the OHL and UGC considered by these case studies are less than those above which the International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommends further consideration should be given to exposure levels. Further detail is provided in Appendix paragraph 476) and onwards.

8.5 Cost Differences between OHL and UGC

447) The results of the comparisons between the costs of OHL and UGC, and between the costs of the three cable design options, may be summarised as shown in Table 8-1.

Table 8-1 Summary of Costings

Line	Item	Average		
1	OHL costs inc. 10% contingency (£M/km OHL route)	1.08	Note 1	
2	Cable costs inc. 15% contingency (£M/km UGC route)	14.1		
3	**Extra cost of undergrounding (£M/km OHL route)**	**15.7**		
			Note 2	
4	Cable / OHL cost ratio km for km (times)	13.1		
5	Cable / OHL cost ratio due to extra km (times)	2.5	**Maximum**	**Minimum**
6	Overall Cable / OHL cost ratio (times)	15.6	18.4	12.3
7	Cost of cable ends only (no route costs) - SSE (£M)	4.54	Note 3	
8	Cost of cable ends only (no route costs) - SPT (£M)	4.43	Note 4	
9	Premium for 2500sqmm over 2000sqmm cable (£M/km cable route)	0.38		
10	Premium for 400kV only over 400kV / 275kV (£M/km cable route)	0.56		
11	Premium for ducted cable over direct buried cable (£M/km cable route)	-0.01	Note 5	

Notes to Table 8-1 – see Section 0 for notes and description of the content of this table.

8.6 Conclusions

448) There is limited use of underground cables in rural areas.

449) All new EHV cable systems in the UK for the foreseeable future are likely to be XLPE insulated.

450) For 400kV XLPE cable there is still a limited worldwide experience of direct buried installations however the quantity being installed in this manner is increasing. There are no known 400kV XLPE installations above 1km in length installed in air filled ducts in Europe. If air filled ducts are to be used an engineering study of the thermo-mechanical effects of cables in ducts will be required as a part of the installation design.

451) The long term environmental issues for OHL are largely limited to landscape and visual impact.

452) The long term environmental issues for UGC are the landscape and visual impact of cable sealing end compounds and terminal towers, above ground furniture servicing the cable system, and the likely differential effects on ground cover / habitat when viewed from above.

453) The balance involved in selecting a proposed route for an OHL involved technical and environmental considerations, though the dominant considerations were landscape and visual impact, and nature conservation interests. In the case of the proposed Beauly – Denny OHL cost was understood not to be part of the balance.

454) The balance involved in selecting an underground cable route is much more complex than that for an OHL. This is because of the need to strike a balance not only between underground cable system technical requirements, environmental and financial considerations, but also with the length of cable route which is directly related to both cost and disturbance. With underground cables, therefore, the cost is the dominant consideration.

455) One reason for the dominance of the cable costs is that, at least in the 5 case studies, the UGC route was found to be longer than the OHL route it was replacing

(about 20% of the extra costs is explained by this). The extra route length in any given case may depend upon a number of different factors.

456) In these case studies underground cable solutions cost between about 12 to 18 times the cost of the OHL equivalent. The higher ratios are to be found firstly on the shortest sections of UGC and secondly on the UGC routes where the greatest deviation from the proposed OHL route was necessary.

457) Though the cost ratios between UGC and OHL are discussed in this document, it is noted that in practical terms the actual sums of money involved are the more relevant quantities to report for a given application. For example, the difference in cost of undergrounding just the Beauly – Eskadale section of the proposed route is likely to cost at least £66M.

458) The preferred route for an underground cable is unlikely to be identical to that for an overhead line.

459) An approach to the routing of an underground cable system has been proposed, but it must be applied on a case by case basis. It is unlikely that a set of rules, such as the Holford Rules used for OHL routeing, could be established to take into account the engineering, environmental and financial balance for UGC.

CHAPTER 9: ABBREVIATIONS

AC	Alternating current
CBS	Cement bound sand (14:1 sand to cement mix by volume)
Circuit	This report refers often to "circuits". A circuit is the simplest way of connecting two parts of a power transmission network together. A very high voltage AC power circuit almost always comprises three conductors (or bundles of conductors) - the three AC phases – since this is the most efficient way of transmitting the energy, and these three phases may be held above ground (in the case of an overhead line) or below ground (in the case of an underground cable. In the UK the transmission system is normally designed to have two circuits running on each route, which provides continuity of supply should one circuit become faulty. For this reason there are normally 6 sets of power conductors supported by any very high voltage pylon. (The seventh wire, at the top of the structure, does not carry power, but acts as a lightning conductor to reduce losses of supply due to lightning strikes.)
DTI	Department of Trade and Industry
DTS	Distributed temperature sensing system. This is used to measure temperatures along a length of fibre optic cable attached to a power cable
EIA	Environmental Impact Assessment
kV	Kilovolt – 1000 Volts
LOD	'limits of deviation' – the limits of deviation of tower positions from a proposed centre-line
MVA	Mega Volt Ampere
MVAR	Mega Volt Ampere Reactive
NGET	National Grid Electricity Transmission Company
OHL	Overhead line
PI	Public Inquiry
pu	per unit (alternative to expressing percentage)

SHETL	Scottish Hydro Electric Transmission Ltd (SSE)
SPT	SP Transmission Ltd
SSE	Scottish and Southern Energy (sometimes referred to as SHETL)
TOV	Temporary overvoltage
UGC	Underground cable
XLPE	Cross-linked polyethylene

CHAPTER 10: REVIEWERS AND CONTRIBUTORS

10.1 Reviewers:

Scottish Hydro Electric Transmission Ltd (SHETL)

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10.2 Main Contributors:

Beauly to Denny EIA Team

Gillian Beauchamp (Wardall Armstrong) Landscape Architect

Enviros

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William Crooks (Scottish Agricultural College)

Appendix 1 Terms of Reference (ToR)

Beauly – Denny: The Use of Underground Cable as an alternative to O/H Line in Specific Locations.

Terms of Reference

Introduction

460) It is proposed that a co-authored report (or separate reports) is (are) produced by PB Power and MTLA covering each of the locations where underground cable sections may be required. The author(s) of the report(s) or parts may be required to provide evidence at a Public Inquiry (PI).

Overall Objective

461) The overall objective is to examine the specific environmental, technical, cost and programme implications of underground cable installations. Five case studies have been selected because, collectively, they encompass the majority of the types of circumstances that may be encountered in underground cable routeing. The locations of the case studies resulted from this overall objective and from the need to include within the studies, amongst other things:

- Crossings of roads,
- Crossings of railways,
- Crossings of rivers,
- Variety of ground cover / habitat,
- Geometric pattern of landscape,
- Steep slopes, and
- Running cable out of substation for a length of the route.

462) The report will inform the case for the proposed overhead line in preparation for a PI.

Scope

463) The report (or reports) will comprise detailed self standing documents, drawing on the existing high level papers currently under preparation by PB Power and MTLA, but will also include specific information from each case study. This would include a detailed assessment of environmental factors, technical issues, construction issues, cable routing details and detailed costings.

464) From north to south the three locations are;

- Within SHETL's area:

Location 1 Study 1	Beauly Substation to Eskadale Wood
Location 2 Study 2	Garva Bridge to South Dalwhinnie

- Within SPT (Stirling) area based on 3 scenarios as follows:-

Location 3 Study 3	Under grounding from foot of Ochils escarpment to south of the River Forth

Location 3 Study 4	Under grounding from the SHETL / SPT boundary on Sherrifmuir to south of the River Forth
Location 3 Study 5	Under grounding on the west of Stirling from a suitable agreed location to the west of Dunblane to an area in the vicinity of Cambusbarron

Structure

465) Part 1 - PB Power to produce an engineering based report. The contents of Part 1 should address the following:

1. It could be used by SHETL and SPT as evidence for PI. It should cover all the specific issues associated with the underground alternatives for the scenarios outlined above. It should be compared with the HVAC transmission line proposal, including technical, broad environmental, project programme, installation, construction and operation / maintenance issues. Consideration should be given to any technical constraints due to the overall length of the underground cable sections under consideration in both the SHETL and SPT areas.

2. It should consider and compare the most suitable cable technologies (included ducted systems) for these specific scenarios.

3. It should include a specific cost comparison between the overhead HVAC transmission proposal and the underground alternatives for all the scenarios.

4. In addition to the cost of cables, reactive compensation equipment, installation, etc. the report should include lifetime costs for maintenance, location of faults, access costs, repair costs and potential decommissioning costs etc. for the specific scenarios and this should be compared to the overhead proposal.

5. The specific report should reflect and refer to the previous reports where appropriate e.g. PB Power, Jacobs Babtie, MTLA etc.

466) Part 2 - MTLA - Based on Part 1, this part will address the specific environmental issues associated with the specific locations and individual scenarios including;

1. Development of cable section solutions against MTLA cable routeing criteria including identification of cable sealing end compounds

2. Appraisal of environmental baseline against technical, installation, construction and operation / maintenance issues.

3. Involvement of EIA subconsultants to address specific environmental issues, e.g. landscape and visual, and ecology.

Appendix 2 Review of Environmental Impact of Underground Cables

REVIEW OF ENVIRONMENTAL IMPACTS OF HIGH VOLTAGE 275KV/400KV) AC UNDERGROUND CABLES

IMPACT		DETAILED CONSIDERATION	SNH 2005	TJP 1996	THC/CN PA/SNH 2005	ES Chapter 6 2005	SHETL Policy 2005	Discussions with SHETL /SPT & case studies
NATURAL HERITAGE (FLORA & FAUNA)	Habitats	Active blanket bog (not possible to restore if lost & area greater than that disturbed due to hydrology changes).	√	√[16]	√	√[17]	√[18]	
		Wet and dry heaths (not all may be restorable, and restored communities may in the long term be replaced with communities with much higher proportions of grasses, sedges and rushes likely to attract grazing animals).			√			
		Semi-natural woodland (loss of trees).			√			
		Simple and recently established habitats (reversibility and habitat fragmentation).			√			
		Difficulty of reinstatement after construction in terms of ground & drainage disturbance				√	√	
		Difficulty of maintaining reinstated habitat over time due to a combination of the impact of construction on drainage and heat dissipation during operation						√
	Fresh Water	Water course crossings - disturbance and pollution - obstruction to fish movement - water quality - impact on species present	√		√			
	Sensitive Species	Species subject to statutory protection: - European protected species - Breeding Birds listed in Annex 1 of the Birds Directive and/or Schedule 1 of Wildlife and Countryside Act. - Animals in Schedule 5 of WCA	√					
LANDSCAPE	Landscape Character & visual amenity	Cable Trench reinstatement and Visual Impact		√	√	√		
		Access Tracks during construction and reinstatement and use in operation						
		Terminal Tower and Sealing End Compounds						
		Settlement Ponds						
		Joint Bays						
		Link Pillars						
		River crossing including reinstatement						
		Road upgrades and bridge strengthening						
		Loss of trees, hedges and			√	√		

[16] Refers generally to habitats
[17] Refers generally to flora and fauna
[18] Refers generally to flora and fauna

IMPACT		DETAILED CONSIDERATION	SNH 2005	TJP 1996	THC/CNPA/SNH 2005	ES Chapter 6 2005	SHETL Policy 2005	Discussions with SHETL /SPT & case studies
		fragmentation of landscape features such as stone walls						
		Potential visibility of cable trenches over times when viewed from above						√
CULTURAL HERITAGE	Archaeology	Known sites (recorded)		√	√	√	√	
		Unknown sites (high in fertile lowland and particular flood plain areas)		√	√			
		Effect on setting			√			
LANDUSE	Disruption to Land use	Farming		√		√	√	
		Buildings		√	√	√	√	
		Planting over cable			√	√	√	
		Woodland and Commercial Forestry - Felled corridor has landscape & visual effects. - Would prohibit or restrict forestry operations particularly those requiring the use of wheeled or treaded vehicles.		√	√			
PEOPLE	Noise	From cable cooling stations (if long directional drill but not normal) Traffic noise and vibration			√			NA to XLPE
GEOLOGY AND SOIL		Rock cutting and disposal of excess material Geology			√			√
HYDROLOGY	Impact on drainage					√	√	√
	Impact on water quality							√
AIR QUALITY	Impact of additional traffic movements & excavation				√			
EMF		No difference between OHL and UGC other than that there are no electric fields associated with UGC. NRPB guidelines met in all cases.						√

SNH 2005 — Letter From David Law of SNH to Andrew Robertson of SSE dated 16 December 2005, regarding the Western Isles to Beauly Transmission line.

TJP 1996 — Turnbull Jeffrey Partnership Discussion Paper: "Where Might Undergrounding an Overhead Transmission Line in Rural Areas be Considered" Version 1.1 March 1996.

THC/CNPA/SNH — Jacobs-Babtie for The Highland Council, Cairngorms National Park Authority, and Scottish Natural Heritage: "Undergrounding of Extra High Voltage Transmission Lines" 2005.

ES Chapter 6 — Scottish Power and Scottish and Southern Energy: "Proposed Beauly to Denny 400kV Overhead Transmission Line Environmental Statement Volume 1": Main Text Chapter 6 Section 6.3 - Undergrounding High Voltage Transmission Lines September 2005.

SSE Policy — Scottish and Southern Electricity Power Distribution Policy for Scottish

Hydro Electric Transmission Limited New of Replacement 275 and 400kV Transmission Circuits (PO PS 012) Rev 1-03 October 2006.

Other Sources Consulted

Europacable — Overview of Underground Power Cables at High/Extra High Voltage Levels - Presentation to SHETL 2006.

IFC Consulting — Overview of the Proposed 400kV Overhead Transmission Line near Beauly, Scotland 3 August 2004.

Eurelectric — Union of the Electricity industry (Eurelectric) Statement of Using Underground Cable Technologies for High or Very High Voltage Transmission Links (150kV and above) Europe March 2004.

ETSO — ETSO Position of Use of underground Cables to Develop European 400kV Networks 31 January 2003.

EPRI — Underground Transmission Cable Limitations Technical Review TE 122740 prepared for EPRI (Electric Power research Institute) by Power Delivery Consultants 1999

Appendix 3 Bibliography

MARK TURNBULL UNDERGROUND LITERATURE SOURCES

DATE	AUTHOR	TITLE
24/3/05	Jacobs/Babtie	The Highland Council, Cairngorms National Park Authority & Scottish Natural Heritage Undergrounding of Extra High Voltage Transmission Lines (Pages 1-5 and 85-106 missing)
6/04	David Penny	Policy for Scottish Hydro Electric Transmission Ltd New or Replacement 275 and 400kV Transmission circuits (PO-PS-021 Rev 1.02)
11/05	Mark Turnbull	Undergrounding High Voltage Transmission Lines based on Policy for Scottish Hydro Electric Transmission Ltd New or Replacement 275 and 400kV Transmission circuits (PO-PS-021 Rev 1.02)
25/11/05	Mark Turnbull/ SHETL	Email in response to Undergrounding High Voltage Transmission Lines and Policy for Scottish Hydro Electric Transmission Ltd New or Replacement 275 and 400kV Transmission circuits (PO-PS-021 Rev 1.02)
11/6/06	Stuart Courtier	Policy for Scottish Hydro Electric Transmission Ltd New or Replacement 275 and 400kV Transmission circuits (PO-PS-021 Rev 1.03)
26/10/98	Scottish Power plc	DRAFT Scottish Power plc Power Systems Division Approach to and Policy on Undergrounding of Circuits
2005	Scottish Power	Issues Paper Beauly to Denny 400kV Overhead Line Summary of the issues raised during consultation: West of Stirling Route Option and Use of Underground Cable
October 2002	Richard Cowell UK CEED	The Scope of Undergrounding Overhead Electricity Lines A Report by the UK Centre for Economic and Environmental Development for Friends of the Lake District.
February 2003	Friends of the Lake District	A Clear View: Reducing the Impact of Overhead Wires A summary report by Friends of the Lake District based on a full report by the UK CEED
September 2004	Richard Cowell	Market Regulation and Planning Action: Burying the Impact of Electricity Networks Appeared in Planning Theory & Practice Vol. 5
2000	National Grid	Overhead or Underground?
	National Grid	The National Grid Company plc and new high voltage Transmission Lines : Guidelines for Line Routeing (The Holford Rules) and Undergrounding
Sept 2005 August 04	Mark Turnbull ICF Consultancy	Email to Peter London on ICF Report (Beauly) and Undergrounding ICF Report overview of the Proposed 400kV Overhead Transmission line near Beauly.

6 March 1996	Mark Turnbull Turnbull Jeffrey Partnership	"Where Might Undergrounding an Overhead Transmission Line in Rural Areas be Considered?"
2006	Europacable	Overview of Underground Power Cables at High/Extra High Voltage Levels (PowerPoint Presentation)
March 2004	Eurelectric	Union of the Electricity Industry (Eurelectric) Statement on Using Underground Cable Technologies for High or Very High Voltage Transmission Links (150kV and above) Europe.
January 2003	ETSO	ETSO Position on Use of Underground Cables to Develop European 400kV Networks.
1999	EPRI	Underground Transmission Cable Limitations Technical Review TE 112740 prepared for EPRI (Electric Power Research Institute) by Power Delivery Consultants.

Appendix 4 Sources of Costing Information

No.	Details of source
1	Email Reid, SPT - Lodge, SSE 20Sept06 - Winfield, PBP 21Sept06
2	Email Lodge, SSE - Winfield, PBP 20Sept06
3	Distances scaled, counted, or read from OS map details of UGC sections emailed by Lloyd, CCI September 2006: Cable#1 21/9/06, Cable #2 and #3c 25/9/06, Cable #3 26/9/06
4	Twr weights.xls, spreadsheet from Dave Marshall (PBP) - email 29Sep06
5	Costs Beauly Denny cable alt.doc file from Dave Marshall (PBP) - 29Sep06
6	Phone conversation Richard Crosse (SPT) - Mark Winfield (PBP) 13Oct06
7	Draft Report Oct06, by Simon Lloyd (CCI)
8	PBP (Mark Winfield) estimate
9	SSE / SPT / CCI / PBP Meeting 19Oct06
10	Jacob Babtie Report “Undergrounding of Extra High Voltage Transmission Lines”
11	CCI Cost spreadsheet Nov06 (see "Cable Cost Details" sheet of this workbook)
12	PBP (Mark Winfield) estimate from cable protection costs
13	PBP (Mark Winfield) estimate from recent advice to other utility (+ Steve Archer on civil works costs)
14	PBP (Mark Winfield/ Steve Archer/Chris Thorn) estimate after discussion
15	PBP / CCI (Mark Winfield / Simon Lloyd) estimate after discussion
16	PBP (Mark Winfield/Dave Marshall) estimate after discussion
17	Spreadsheets from Balfour Beatty - Estimates of differences in OHL contract cost if sections are undergrounded 30Nov06
18	SHETL / PBP (Lodge / Winfield) discussion and detail wayleaves notes, in SHETL offices, 29Nov06
19	MTLA (Mark Turnbull) 2-page note on Environment and PR costs for cable and OHL, 30Nov06

467)

Appendix 5 Costing Information and Assumptions

No.	Source	Description		
1		The OHL route can be brought to the ends of Stirling West UGC option for the same cost as to the Stirling East UGC option.		
2	3	OHL route lengths are as given in table below - scaled from maps providing cable chainages:		
		Beauly to Eskadale Wood (km)	5.17	
		Garva Bridge to South Dalwhinnie (km)	3.65	
		Lower Taylorton - Logie (Stirling SE) (km)	2.39	
		Lower Taylorton - Cocksburn Wood (Stirling SE + NE) (km)	4.80	
		Glen Burn to Touch Road (Stirling W)	4.90	
3	4	Cost of tower steelwork (£k/tonne)	1.2	
4	6	Weight of L12 DT terminal tower (tonne)	14 below	
5	4	Weight of SSE400 DT terminal tower (tonne)	14 below	
7	4	Labour cost - foundation + steelwork(£k per tower)	50	
12	5	Unit cost of 400kV single core UGC (£k/km)	370	
13	5	Unit cost of 275kV single core UGC (£k/km)	330	
14a		Unit cost of tower steelwork, (£k per tower):		
		L12:		Weights(T)
	6	D std - no.off	22	18.2
	6	D55 - no off	42	35.3
	6	Terminal tower, DT - no off	87	72.5
		SSE400:		
	4	D std - no.off	31	25.9
	4	D55 - no off	63	52.5
	4	Terminal tower, DT - no off	123	102.4
14b		Foundations (% of tower cost):		
	4	D std	20%	
	4	D55	35%	
	4	DT	50%	
14c	6	Unit cost of conductors - 2 x Arucaria+OPGW (£k/km)	256	
14d	6	Unit cost of insulators & fittings(£k/km)	48	
14e	4/8	Labour, Engineering & Project Mgmt(% of OHL cost)	40%	
14f	8	OHL Scaffold costs (% of tower capital cost)	25%	
14g	15	Maintenance cost pa (% of OHL capital cost)	0.5%	
14h	9	Wayleaves cost per tower (£k pa)	0.1	
16		No river-crossing towers will be required for any of the routes		
17a	13	Unit cost of 400kV 1-ph surge arrester	11	
17b	13	Unit cost of 275kV 1-ph surge arrester	8	
17c	13	Unit cost of 400kV 3-ph earth switch	11	
17d	13	Unit cost of 275kV 3-ph earth switch	8	
19	8	Wayleaves cost per cable km pa	1	
	16	Cable + Reactor maint. cost pa (% of capital cost)	0.030%	
20a	18	Contingency - OHL	10%	
20b	18	Contingency - Cable	15%	

Further Notes on the costing approach and assumptions

468) Estimates have been prepared using current supplier guidance where that is reasonably available. The second source of information has been SSE and SPT, informed if possible by recent actual contracts. A third source has been knowledge of contracts obtained through the experience of the three consultancy companies – PB Power, CCI, and MTLA – who contributed to the main report. Occasionally, for small items, where no direct information was available, interpolation or extrapolation has been used to complete the picture.

469) It has been assumed, in these costs that, whether or not the rest of the route is direct buried, when a cable is to pass beneath physical barriers, for example, roads or rivers, then either trenches or directional drilling will first be used to install ducts. This allows the cables to be drawn in and/or recovered later without further disruption to the users of the thoroughfare.

470) Information was supplied by two cable suppliers on a non-firm basis and, as explained elsewhere, are subject in some cases, to +/- 20% variation to that which may be given if a full binding quotation were provided. Nevertheless, central, or "best estimates" of known costs have been used throughout, and a contingency percentage has then been applied.

471) For the reasons described more fully in Section 4.2 above, these estimates have assumed a 10% contingency factor for the OHL solution, and a 15% contingency for the UGC solution which is much more exposed to the uncertainties of ground condition, geology and weather.

472) The "whole of life" costs have been estimated on the basis of a 40 year equipment life, and replacement at end of life, as explained in Section 4.3 above. For the reasons described in the same Section, a 6% discount rate was used for present value (PV) calculations.

473) The costs represent the estimates of lifetime costs, including supply and construction, wayleaves, operation and average repairs, and including total replacement at 40 years. This might be pessimistic both for the OHL and the UGC, but the stance is justified as follows: For the OHL previous UK transmission experience indicates that conductor systems and fittings may need replacing at around 40 years. Also, whilst it is highly unlikely that the towers would need more than a small proportion of steel members to be replaced at that time, there is a desire not to favour the OHL costings with optimistic estimates. For the UGC, it has been UK transmission experience that the majority of 400kV and 275kV cables are still healthy around their 40th birthdays, however a small proportion have not survived that long. Since there is relatively short operational experience of the large diameter XLPE cables (and particularly their joints) at 400kV it seems prudent to allow for the possibility of replacement at 40 years

Appendix 6 Eight Costing Cases

Eight Costing Cases

474) The main text of this report considered the costing comparison of one set of design options for the UGC, a “base case”, with one circuit at 400kV, one circuit at 275kV, with cable conductor diameter = 2500mm^2, and with cable direct-buried.

475) In fact eight different sets of options were costed, and the tables on the following eight pages show the summary results for each of these. They are based upon the full set of combinations provided by selecting options for the following three variables:-

Table-A1 Costing Options

Variable	Option 1 (Select all Option 1 for base case)	Option 2
1	One circuit at 400kV, one circuit at 275kV	Both circuits at 400kV
2	Cable conductor diameter = 2500mm^2	Cable conductor diameter = 2000mm^2
3	Cable direct-buried	Cable laid in ducts

Estimate parameters:-

Cable voltage = 275kV & 400kV
Cable diameter = 2000sqmm
Cables in ducts or direct-buried = in ducts
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	**Garva Bridge to South Dalwhinnie**	**Lower Taylorton - Logie (Stirling SE)**	**Lower Taylorton - Cocksburn Wood (Stirling SE + NE)**	**Glen Burn to Touch Road (Stirling W)**	**Average with contin-gency**	**Average without contin-gency**
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	9.98	9.03	7.44	11.77	9.66		
B. Cable route construction & lifetime costs (£M)	53.05	41.67	29.57	71.81	51.98		
Total cable costs (£M)	63.03	50.70	37.00	83.58	61.63		
Cable costs inc. 15% contingency (£M)	72.48	58.31	42.56	96.11	70.88		
Cable cost per km (£M/km) - but see below	10.79	12.54	14.23	11.42	12.23	14.1	12.2
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	66.61	54.72	40.11	90.13	66.26		
Cable cost compared to OHL (times)	12.3	16.3	17.4	16.1	15.3	15.1	14.5
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	9.91	11.58	13.32	10.51	11.32	13.0	11.3

Estimate parameters:-

Cable voltage = 275kV & 400kV
Cable diameter = 2000sqmm
Cables in ducts or direct-buried = direct-buried
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	Garva Bridge to South Dalwhinnie	Lower Taylorton - Logie (Stirling SE)	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)	Glen Burn to Touch Road (Stirling W)	Average with contin-gency	Average without contin-gency
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.30	9.51	7.65	12.36	10.06		
B. Cable route construction & lifetime costs (£M)	52.52	41.31	29.33	71.63	51.53		
Total cable costs (£M)	62.82	50.82	36.98	83.99	61.59		
Cable costs inc. 15% contingency (£M)	72.25	58.44	42.53	96.59	70.83		
Cable cost per km (£M/km) - but see below	10.76	12.57	14.22	11.47	12.22	14.1	12.2
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	66.38	54.86	40.08	90.60	66.21		
Cable cost compared to OHL (times)	12.3	16.3	17.4	16.1	15.3	15.1	14.5
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	9.82	11.49	13.23	10.48	11.23	12.9	11.3

Estimate parameters:-

Cable voltage = 275kV & 400kV
Cable diameter = 2500sqmm
Cables in ducts or direct-buried = in ducts
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	Garva Bridge to South Dalwhinnie	Lower Taylorton - Logie (Stirling SE)	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)	Glen Burn to Touch Road (Stirling W)	Average with contin-gency	Average without contin-gency
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.13	9.13	7.50	11.95	9.78		
B. Cable route construction & lifetime costs (£M)	54.45	42.64	30.19	73.54	53.19		
Total cable costs (£M)	64.57	51.77	37.69	85.49	62.97		
Cable costs inc. 15% contingency (£M)	74.26	59.54	43.35	98.31	72.41		
Cable cost per km (£M/km) - but see below	11.06	12.80	14.50	11.68	12.50	14.4	12.5
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	68.39	55.95	40.90	92.33	67.79		
Cable cost compared to OHL (times)	12.6	16.6	17.7	16.4	15.7	15.5	14.8
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	10.15	11.82	13.56	10.74	11.56	13.3	11.6

Estimate parameters:-

Cable voltage = 275kV & 400kV
Cable diameter = 2500sqmm
Cables in ducts or direct-buried = direct-buried
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	Garva Bridge to South Dalwhinnie	Lower Taylorton - Logie (Stirling SE)	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)	Glen Burn to Touch Road (Stirling W)	Average with contin-gency	Average without contin-gency
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.45	9.61	7.71	12.54	10.19		
B. Cable route construction & lifetime costs (£M)	53.93	42.28	29.96	73.36	52.74		
Total cable costs (£M)	64.37	51.89	37.67	85.90	62.92		
Cable costs inc. 15% contingency (£M)	74.03	59.67	43.32	98.78	72.36		
Cable cost per km (£M/km) - but see below	11.02	12.83	14.49	11.73	12.49	14.4	12.5
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	68.15	56.09	40.87	92.80	67.74		
Cable cost compared to OHL (times)	12.6	16.7	17.7	16.5	15.7	15.5	14.8
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	10.06	11.73	13.47	10.72	11.47	13.2	11.5

Estimate parameters:-

Cable voltage = 400kV only
Cable diameter = 2000sqmm
Cables in ducts or direct-buried = in ducts
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	Garva Bridge to South Dalwhinnie	Lower Taylorton - Logie (Stirling SE)	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)	Glen Burn to Touch Road (Stirling W)	Average with contin-gency	Average without contin-gency
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.37	9.35	7.70	12.20	10.01		
B. Cable route construction & lifetime costs (£M)	55.03	43.01	30.45	74.39	53.86		
Total cable costs (£M)	65.39	52.36	38.16	86.60	63.87		
Cable costs inc. 15% contingency (£M)	75.20	60.21	43.88	99.59	73.45		
Cable cost per km (£M/km) - but see below	11.20	12.95	14.68	11.83	12.68	14.6	12.7
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	69.33	56.63	41.43	93.60	68.83		
Cable cost compared to OHL (times)	12.8	16.8	17.9	16.6	15.9	15.7	15.0
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	10.28	11.96	13.73	10.88	11.73	13.5	11.7

Estimate parameters:-

Cable voltage = 400kV only
Cable diameter = 2000sqmm
Cables in ducts or direct-buried = direct-buried
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	Garva Bridge to South Dalwhinnie	Lower Taylorton - Logie (Stirling SE)	Lower Taylorton - Cocksburn Wood (Stirling SE + NE)	Glen Burn to Touch Road (Stirling W)	Average with contin-gency	Average without contin-gency
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.68	9.82	7.91	12.78	10.41		
B. Cable route construction & lifetime costs (£M)	54.50	42.65	30.22	74.21	53.41		
Total cable costs (£M)	65.18	52.47	38.13	86.99	63.82		
Cable costs inc. 15% contingency (£M)	74.96	60.34	43.85	100.04	73.39		
Cable cost per km (£M/km) - but see below	11.16	12.97	14.67	11.88	12.67	14.6	12.7
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	69.08	56.76	41.40	94.06	68.77		
Cable cost compared to OHL (times)	12.8	16.9	17.9	16.7	15.9	15.7	15.0
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	10.19	11.87	13.64	10.86	11.64	13.4	11.6

Estimate parameters:-

Cable voltage = 400kV only
Cable diameter = 2500sqmm
Cables in ducts or direct-buried = in ducts
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	CASE STUDY #2	CASE STUDY #3a	CASE STUDY #3b	CASE STUDY #3c		
	Beauly to Eskadale Wood	**Garva Bridge to South Dalwhinnie**	**Lower Taylorton - Logie (Stirling SE)**	**Lower Taylorton - Cocksburn Wood (Stirling SE + NE)**	**Glen Burn to Touch Road (Stirling W)**	**Average with contin-gency**	**Average without contin-gency**
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.58	9.49	7.80	12.47	10.20		
B. Cable route construction & lifetime costs (£M)	57.13	44.47	31.39	77.00	55.68		
Total cable costs (£M)	67.71	53.96	39.19	89.47	65.87		
Cable costs inc. 15% contingency (£M)	77.87	62.06	45.07	102.89	75.75		
Cable cost per km (£M/km) - but see below	11.59	13.34	15.07	12.22	13.07	15.0	13.1
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	71.99	58.47	42.62	96.91	71.13		
Cable cost compared to OHL (times)	13.3	17.3	18.4	17.2	16.4	16.2	15.5
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	10.64	12.32	14.09	11.24	12.09	13.9	12.1

Estimate parameters:-

Cable voltage = 400kV only
Cable diameter = 2500sqmm
Cables in ducts or direct-buried = direct-buried
Source of OHL comparison costs = PB Power Estimates
Present value discount rate = 6.00%

			These 3 options are mutually exclusive				
	CASE STUDY #1	**CASE STUDY #2**	**CASE STUDY #3a**	**CASE STUDY #3b**	**CASE STUDY #3c**		
	Beauly to Eskadale Wood	**Garva Bridge to South Dalwhinnie**	**Lower Taylorton - Logie (Stirling SE)**	**Lower Taylorton - Cocksburn Wood (Stirling SE + NE)**	**Glen Burn to Touch Road (Stirling W)**	**Average with contin-gency**	**Average without contin-gency**
I. TOTAL OVERHEAD LINE COSTS - £M (inc. present value lifetime costs)							
OHL Construction & Lifetime Costs (£M)	5.34	3.26	2.23	5.44	4.20		
OHL costs inc. 10% contingency (£M)	5.87	3.58	2.45	5.98	4.62		
OHL cost per km (£M/km)	1.14	0.98	1.02	1.25	0.94	1.07	0.97
II. TOTAL UNDERGROUND CABLE COSTS - £M (inc. present value lifetime costs)							
A. Cable-end construction & lifetime costs (£M)	10.89	9.97	8.01	13.05	10.59		
B. Cable route construction & lifetime costs (£M)	56.61	44.11	31.16	76.82	55.22		
Total cable costs (£M)	67.50	54.07	39.16	89.87	65.82		
Cable costs inc. 15% contingency (£M)	77.62	62.18	45.04	103.35	75.69		
Cable cost per km (£M/km) - but see below	11.56	13.37	15.06	12.28	13.06	15.0	13.1
III. COMPARING UNDERGROUND CABLE AND OVERHEAD LINE COSTS FOR EACH ROUTE CASE STUDY							
Extra cost of undergrounding (£M)	71.75	58.60	42.59	97.37	71.07		
Cable cost compared to OHL (times)	13.2	17.4	18.4	17.3	16.4	16.2	15.5
IV. CABLE COST PER km FOR LONG SECTIONS, BASED UPON COSTS FOR EACH CASE STUDY (END COSTS IGNORED)							
Cable cost per km (£M/km) - Long routes	10.55	12.23	14.00	11.22	12.00	13.8	12.0

Appendix 7 Magnetic Fields

MAGNETIC FIELDS

476) The Energy Networks Association (ENA) publish the following Position Statement on EMFs:

ELECTRIC AND MAGNETIC FIELDS AT MAINS FREQUENCY

1. Electric and magnetic fields (EMFs) are produced by all electrical installations and equipment such as domestic appliances, overhead lines, underground cables and many transport systems. There is some public concern about a possible connection between these fields and health. The Energy Networks Association and its member companies take any suggestion of a risk to health seriously and are fully committed to the health, safety and welfare of the public and employees.

2. Over the last twenty years, major research programmes throughout the world have explored whether EMFs have an adverse impact on health. Although the balance of the evidence is against a link between ill health and EMFs, some studies have suggested that exposure to EMFs may be harmful to health. International bodies such as the World Health Organization and the International Agency for Research on Cancer and, in the United Kingdom, the Radiation Protection Division of the Health Protection Agency (RDP) have investigated this issue and have concluded that there is no established cause-and-effect link between EMFs and ill health. They have, however, recognised that the possibility cannot be ruled out.

3. The RDP is the UK body with statutory responsibility for advising on EMFs. ENA member companies carry out their activities in accordance with RDP guidance.

4. The ENA and its member companies are committed to responsible behaviour and recognise that precautionary approaches are part of European and UK environmental policy. However, we believe that present scientific evidence does not justify any change either in the electricity industry's operating practices, which are in line with current guidance, or in the everyday utilisation of electricity by our customers. Nevertheless, we keep this issue under review and look to the RDP and Government for advice.

5. While there remains any uncertainty over the EMF and health issue, ENA member companies will continue to support and contribute to the funding of credible research into EMFs. This includes an independent trust which supports biological research.

6. We will continue to monitor closely scientific research, overseas developments and major reviews of scientific, medical and engineering research concerned with electric and magnetic fields.

7. We are committed to providing members of the public, the industry's employees and customers with full and up to date information about EMFs and health.

20 December 2006

477) The following two diagrams indicate the shape of the magnetic fields to be found around overhead lines and underground cables.

478) The diagrams with blue backgrounds show how in both cases the magnetic field is concentrated around the conductors. The graphs with grey backgrounds indicate how the intensity of the fields in which a person could stand vary as that person walks away from the centre line of the overhead line or cable installation.

479) The calculations depicted in the diagrams were performed with a phase current of 3400 amps (1700 amps per cable core). At that current, the magnetic field intensity in which a person could stand is within the guidelines of 100μT that are issued by

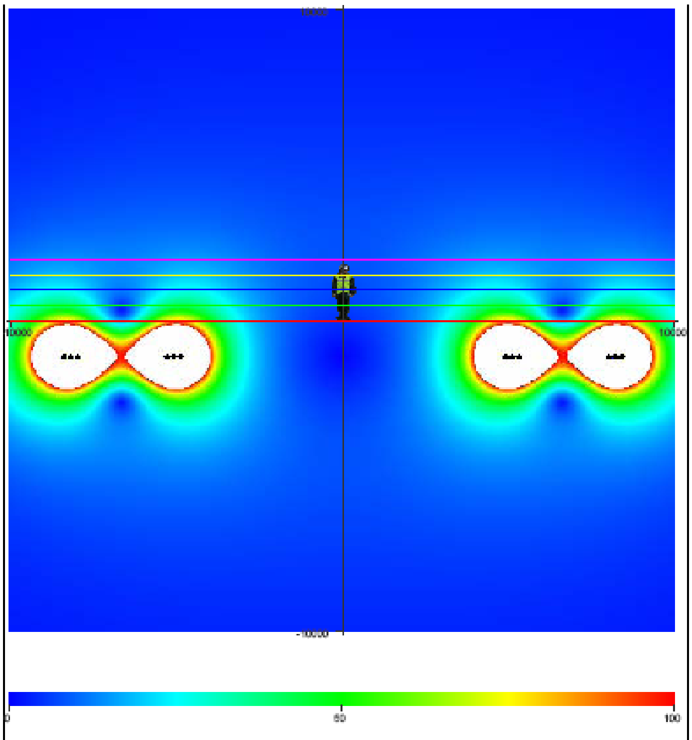
the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and adopted by the ENA[19].

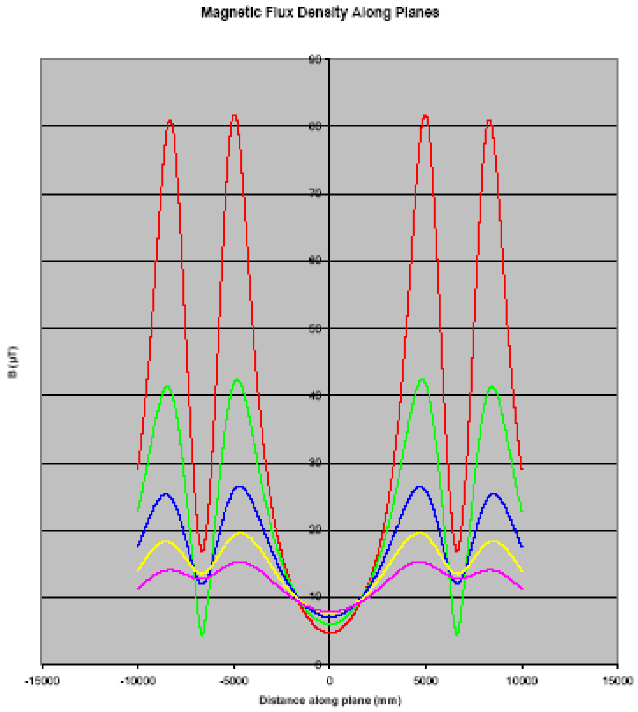
480) Further information on research, contacts, and current understanding of the facts, may be found at the ENA website:

http://www.energynetworks.org/spring/she/EMFs.asp

19 "Electromagnetic Fields – The Facts", an information booklet issued by ENA in June 2004 and available from their website http://www.energynetworks.org/spring/she/EMFs.asp.

Figure A7-1 Magnetic fields close to underground cables





Example

15:53, 27 Oct 2006

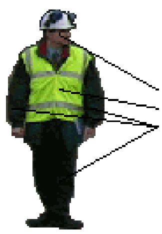
Cable Details

Cable group	Cable	Current	Phase	Cable position x (mm)	y (mm)
1	1	1700	Red	-8400	-1150
	2	1700	Yellow	-8200	-1150
	3	1700	Blue	-8000	-1150
2	1	1700	Red	-5300	-1150
	2	1700	Yellow	-5100	-1150
	3	1700	Blue	-4900	-1150
3	1	1700	Blue	4900	-1150
	2	1700	Yellow	5100	-1150
	3	1700	Red	5300	-1150
4	1	1700	Blue	8000	-1150
	2	1700	Yellow	8200	-1150
	3	1700	Red	8400	-1150

Maximum Flux Density Along Planes

Plane	Orientation	Position of plane (mm)	Maximum flux density Bmod (μT)	Brms (μT)	Position of maxima along plane (mm)	
1	Horizontal	0	81.85	57.88	-4960	4960
2	Horizontal	500	42.38	29.97	-4800	4800
3	Horizontal	1000	26.54	18.77	-4680	4680
4	Horizontal	1500	19.59	13.85	-4640	4640
5	Horizontal	2000	15.26	10.79	-4680	4680
6						
7						
8						
9						
10						

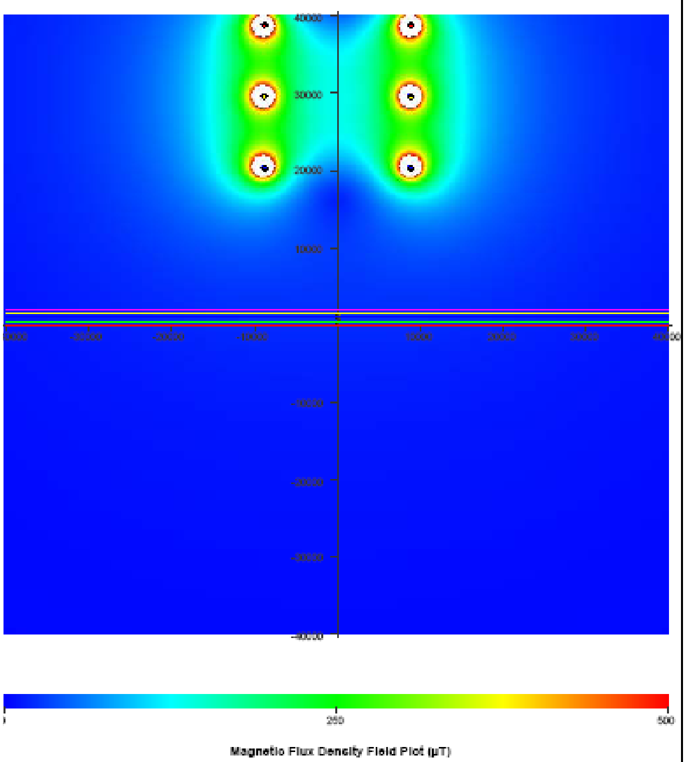
Flux Density In Body

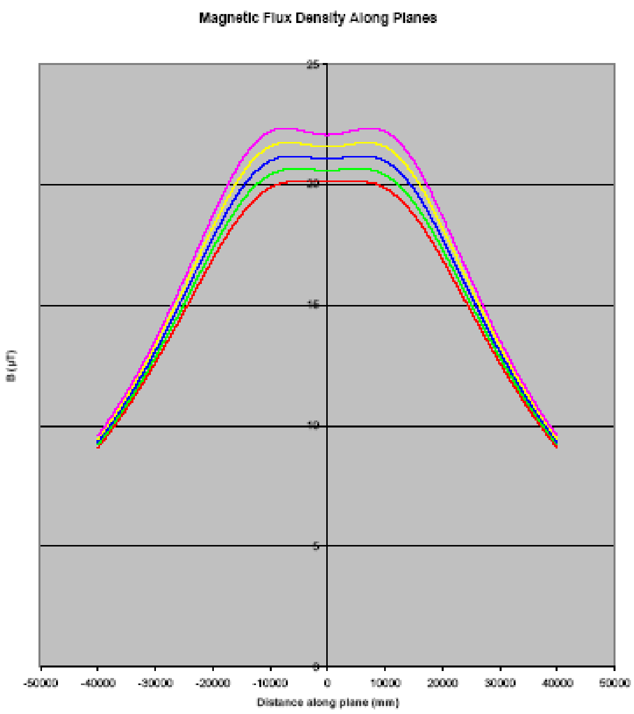


Part of body	Maximum flux density Bmod (μT)	Brms (μT)	Spacially averaged Bmod (μT)	Brms (μT)
Head	7.82	5.53	7.77	5.49
Torso	7.73	5.47	7.31	5.17
Limbs	7.81	5.52	6.63	4.69
Whole body	7.82	5.53	6.93	4.90

2/2 Fluxden Excel version 3b

Figure A7-2 Magnetic fields close to overhead lines





1/2 Fluxden Excel version 3b

Example

15:51, 30 Oct 2006

Cable Details

Cable group	Cable	Current	Phase	Cable position x (mm)	y (mm)
1	1	3400	Red	-8850	38900
	2	3400	Yellow	-8850	29600
	3	3400	Blue	-8850	20300
2	1	3400	Red	8850	38900
	2	3400	Yellow	8850	29600
	3	3400	Blue	8850	20300

Maximum Flux Density Along Planes

Plane	Orientation	Position of plane (mm)	Maximum flux density Bmod (µT)	Brms (µT)	Position of maxima along plane (mm)	
1	Horizontal	0	20.16	14.25	-4480	4480
2	Horizontal	500	20.67	14.61	-5440	5440
3	Horizontal	1000	21.20	14.99	-6240	6240
4	Horizontal	1500	21.76	15.39	-6880	6880
5	Horizontal	2000	22.36	15.81	-7360	7360
6						
7						
8						
9						
10						

Flux Density In Body

Part of body	Maximum flux density Bmod (µT)	Brms (µT)	Spacially averaged Bmod (µT)	Brms (µT)
Head	21.58	15.26	21.58	15.26
Torso	21.58	15.26	21.25	15.03
Limbs	21.58	15.26	20.98	14.84
Whole body	21.58	15.26	21.11	14.92

2/2 Fluxden Excel version 3b

Appendix 8 (This appendix is no longer used)

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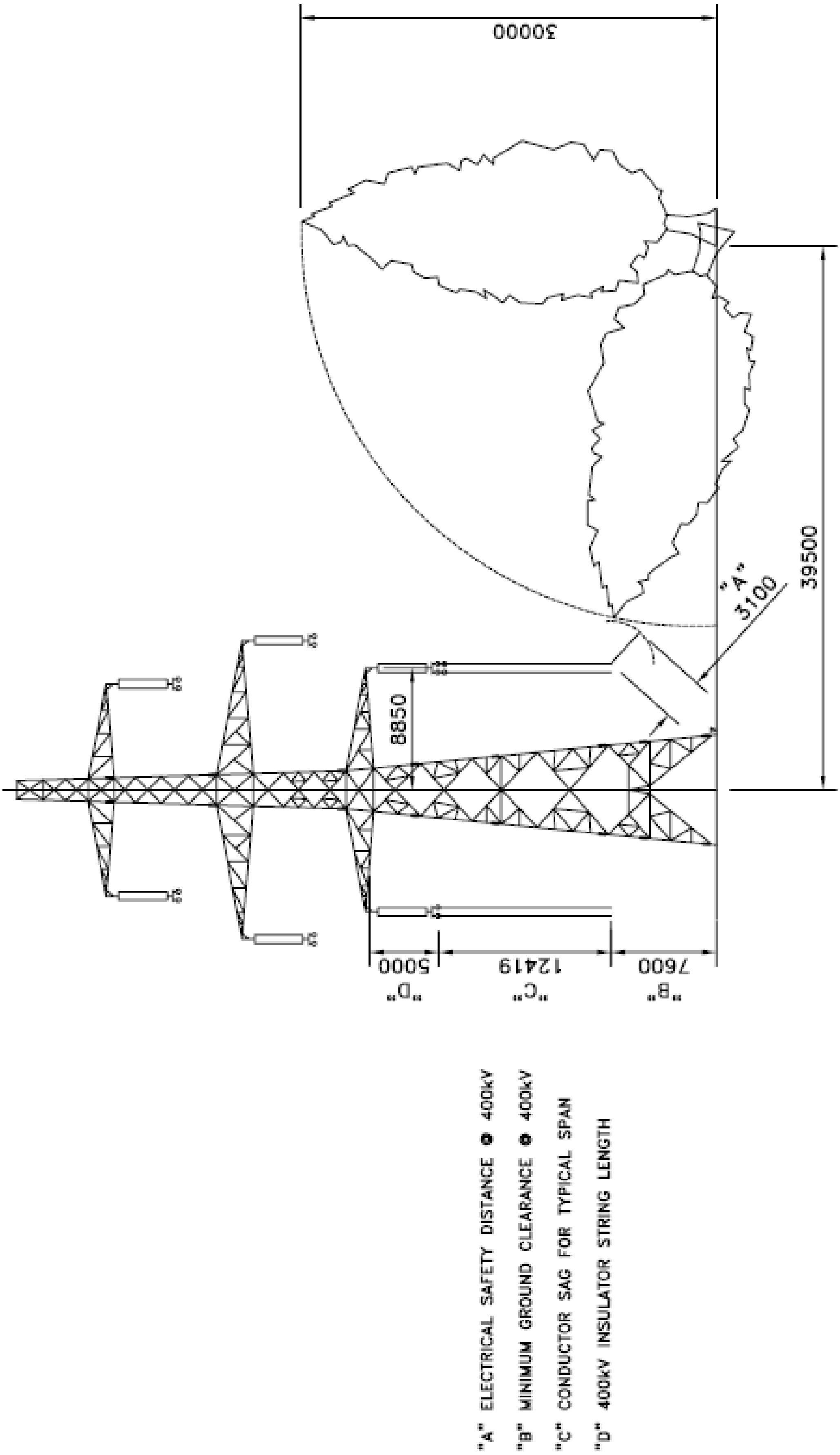
Appendix 9 SSE400 Tower Clearance to Trees

(Detail from Scottish Power / Scottish and Southern Energy Environmental Statement for the Proposed Beauly – Denny 400kV Overhead transmission Line, Figure 13.3)

Figure A9-1 SSE400 400kV tower clearance to trees



Appendix 10 Typical Cable Sealing End Terminal Tower Arrangement

Figure A10-1 Typical arrangement of terminal tower & connections to sealing ends