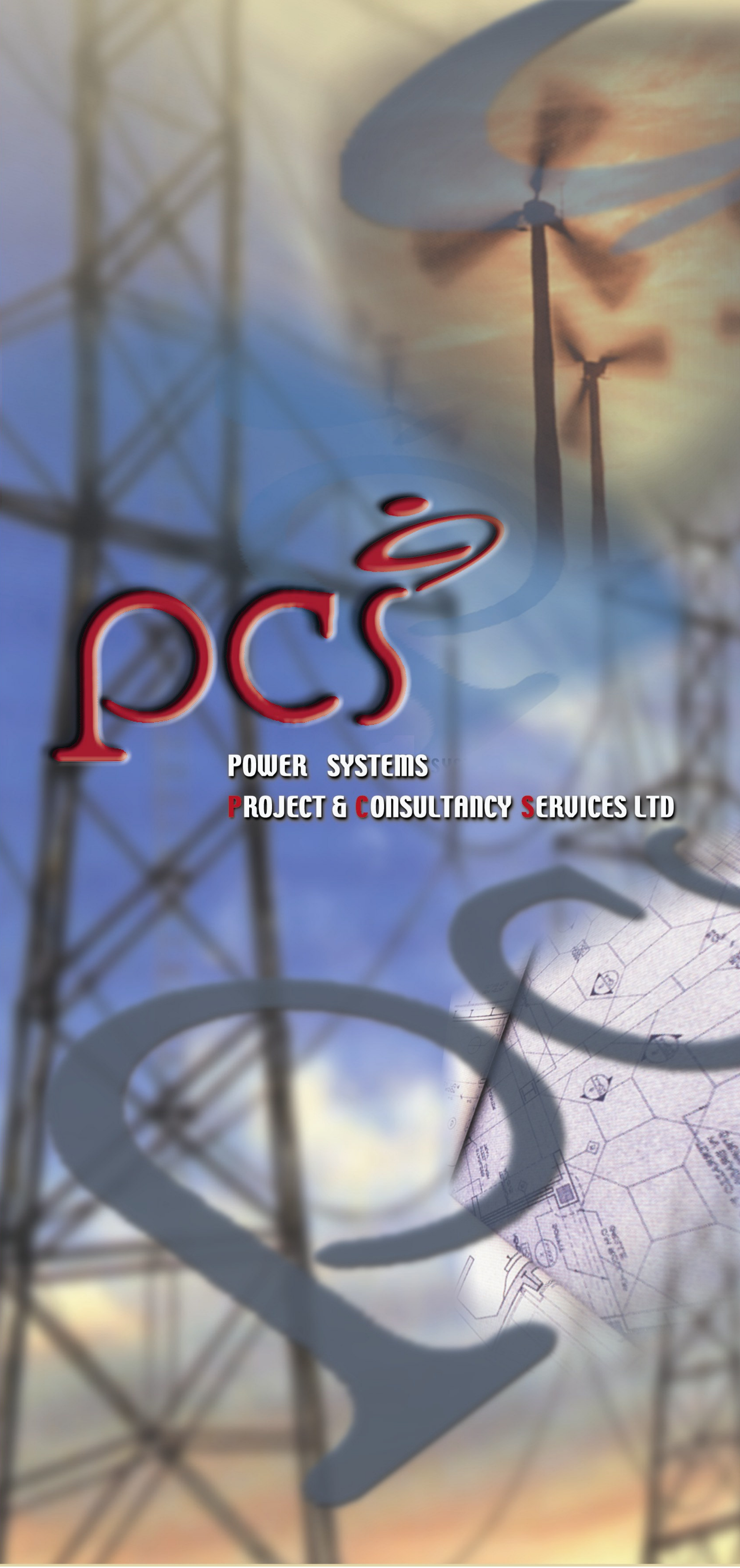

Report

Western Isles HVDC Connection Options

17 March 2006

PCS Document No: SSE/01/R/DM
Issue: B

Power Systems Project and Consultancy Services (PCS) Ltd
Brunel Building
Scottish Enterprise Technology Park
East Kilbride
G75 0QD
Telephone: 01355 813322 (Office)
Fax: 01355 813320
Email: david.moretti@pcs-scot.co.uk
URL: www.pcs-scot.co.uk

AMENDMENT RECORD			
Issue	**Date Issued**	**Date Effective**	**Purpose of Issue or Description of Amendment**
A	Feb 2006	Feb 2006	First Issue
B	17 Mar. 2006	17 Mar. 2006	Modified Based on SSE Comments: • Modified Text on Mainland Reinforcement Costs (8.2) • Additional text on AC System losses (8.4) • Modified text and costs for HVDC link outages and HVDC Classic capital costs based on two independent cables/module (8.5).

Table of Contents

Appendices

1 Introduction

The HVDC[1] connection options to the mainland UK transmission for 600MW[2] of renewable generation on the Western Isles are addressed in this paper with the following aspects considered in detail:

- Indicative capital cost estimates
- Estimated Cost of HVDC Link Losses
- Costs of HVDC Link Outages
- Indicative TNUoS[3] charges, including consideration of options for potential limitation of TNUoS charges.

2 Connection Locations

Viable UK mainland connection locations for the Western Isles link are Main Interconnected Transmission System (MITS) Substations (400kV or 275kV) located in Northern Scotland, or on/near the West Coast in Southern Scotland, England and Wales.

The locations considered as representing viable connection locations are detailed in Table 1:

Option	Location	Transmission System Owner
A	Beauly[4]	SHETL[5]
B	Hunterston	SPT[6]
C	Deeside	NGET
D	Pembroke	NGET

Table 1: Western Isles UK Connection Options

The connection distances for each of the connection options are given in Table 2:

[1] **H**igh **V**oltage **D**irect **C**urrent
[2] Based on Nov 2005 contracted generation a 600MW link capacity is considered sufficient, consideration of increasing the capacity of the link to 1000MW to cater for additional/future generation is considered in Appendix A
[3] **T**ransmission **N**etwork **U**se **o**f **S**ystem
[4] Initial feasibility studies undertaken by SHETL identified Beauly as the preferred MITS point of connection for Western Isles generation within SHETL's network, following detailed consideration of a number of possible connection options and routes,a wholly or partial cabled connection to Beauly via Ullapool was identified by SHETL as its preferred connection route/option for the Western Isles.
[5] **S**cottish **H**ydro **E**lectric **T**ransmission **L**imited
[6] **S**cottish **P**ower **T**ransmission

		Distance (km)	
Option	**Location**	**Subsea**	**Land**
A1[7]	Beauly (Remote)	93	43 (HVDC Cable) 30 (HVAC OHL)
A2[8]	Beauly (Local)	93	73 (HVDC Cable)
B1[9]	Hunterston (Subsea)	480	-
B2[10]	Hunterston (Subsea/Land)	370	40 (HVDC Cable)
C	Deeside	675	-
D	Pembroke	770	-

Table 2: Western Isles Connection Distances

In each of the connection options considered, the connection location on the Western Isles was taken as being in the vicinity of Arnish, near Stornoway, which has been identified by SHETL as a being a suitable location for a HVDC converter station.

3 Indicative Connection Routes

Indicative connection routes for each of the connection options considered are shown in Figure 1.

[7] The location of the mainland converter station is taken as approx 30km from Beauly, with the costs of the AC connection from the converter station to Beauly taken as being included within the North of Scotland zone charges.
[8] The location of the mainland converter station is taken as Beauly.
[9] Direct subsea connection to Hunterston
[10] Combined subsea and land route with a land crossing from suitable point on Firth of Lorn to east coast of Kintyre Peninsula. Alternative subsea/land routes with similar lengths, may, following route assessments, represent viable options for a Hunterston connection.

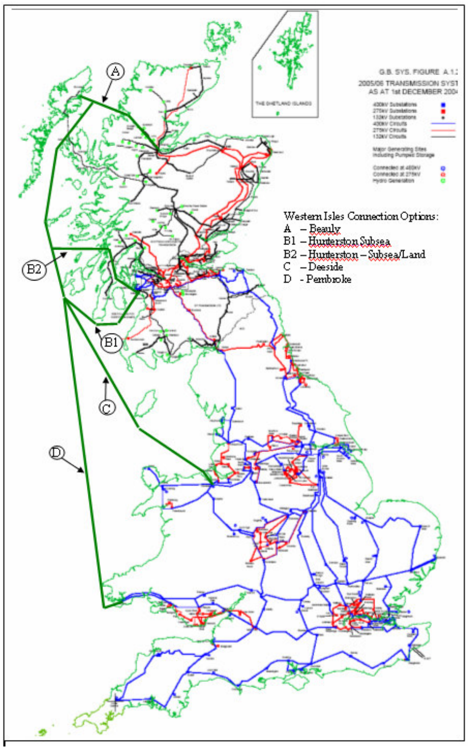

Figure 1: Indicative Western Isles HVDC Connection Routes

4 Mainland Zonal TNUoS Charges

The connection points considered are within the NGC Generation TNUoS zones indicated in Table 3 and illustrated in Figure 2, with the 2005 zonal tariff's also shown in Table 3.

Connection Point	Zone	Zone Name	Zone Tariff (£/kW)
Beauly	2	North Scotland	£20.93
Hunterston	9	South Scotland	£11.82
Deeside	14	South Yorks and North Wales	£3.12
Pembroke	19	South Wales & Gloucester	-£2.55

Table 3: Connection Points Generation Tariff Zone's

Additional TNUoS charges for the island connections were determined based on an annual return of 8.43%[11] of the connection capital cost, with the overall TNUoS charge determined based on the addition of the connection zone and island tariff's.

[11] Based on NGT paper 'Illustrative Transmission Charges for Scottish Island', June 2005

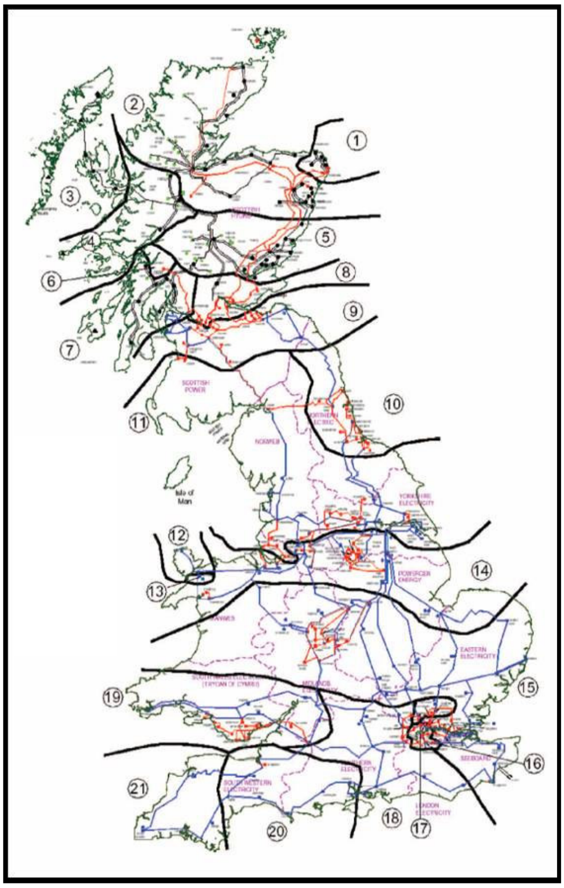

Figure 2: GB TNUoS Charging Zones

5 Firm and Non-Firm Connections

The conventional connection arrangement for generation connections is based on a technically firm, GB SQSS compliant connection, i.e. any single loss of transmission plant will not result in a reduction of generation export capability. However due to the high capital cost involved in the provision of redundant capacity for HVDC links and the intermittent nature of wind generation, a technically or commercially non-firm connection arrangement for HVDC offshore connections may, under some circumstances, represent a more cost effective connection arrangement for either/both the Transmission System Operator (TSO) and the generators, as discussed below:

- A technically firm, GB SQSS compliant, connection would result in higher TNUoS payments for the generator, but no energy unavailability costs due to outage of the link since constraint payments would be made by TSO[12]. The

[12] It is assumed that for a technically firm connection the TSO constraint payments would match the generator costs of energy unavailability.

TSO would be subject to the cost of the constraint payments for the period of the outage duration, it is also assumed that the TSO would be liable for the cost of additional generation to replace the unavailable generation for the initial 24hr period of the outage, with the generation capacity deficit met by other generators at no additional cost to the TSO following this initial 24hr period.

- A technically non-firm, GB SQSS non-compliant, connection arrangement would result in lower TNUoS payments for the generator due to lower capital installation cost, but the generator would be exposed to energy unavailability costs due to outage of the link since no constraint payments would be made by TSO. However it is assumed that, as for a firm connection arrangement, the TSO would be liable for the cost of additional generation to replace the unavailable generation for the initial 24hr period of the outage, with the generation capacity deficit met by other generators at no additional cost to the TSO following this initial 24hr period.

- If the generator's savings in TNUoS charges for a technically non-firm connection are higher than its energy unavailability costs due to outage of the link, then the technically non-firm connection arrangement represents a more economic connection option than a technically firm connection arrangement for the generator.

- If a generator selects a commercially firm connection arrangement i.e. pays TNUoS charges based on technically firm connection arrangement with firm access to the transmission system and constraint payments made in the event of transmission capacity being unavailable, then, assuming appropriate derogations could be obtained for GB SQSS, licence and other regulatory requirements, the TSO could choose to either:

  - Provide a technically and commercially firm connection arrangement and make constraint payments for the resultant lower volumes of unavailable energy, or

- Provide a technically non-firm, commercially firm arrangement and make increased constraint payments for the higher resultant volumes of unavailable energy.

If the capitalised cost of the technically non-firm, commercially firm arrangement and its associated constraint payments is lower than the capitalised cost of a technically and commercially arrangement and its associated constraint payments, then the technically non-firm, commercially firm arrangement is the lower cost, but higher risk[13] solution, for the TSO.

An assessment of both firm and non-firm connection arrangements in terms of costs to the TSO and the generator, for each of the connection options are included within this note.

6 HVDC Technology

Due to the connection distances and power levels, HVDC is considered as the only viable subsea transmission technology[14] for the Western Isles connection.

HVDC technology is presently available in two different forms:

- Voltage Sourced Converter (VSC) technology
- Line or Current Commutated technology, commonly known as HVDC Classic.

Assessment of the current developments and applications of the both HVDC VSC and HVDC Classic technology indicates that in terms of technical capabilities, HVDC VSC technology is more suited to the connection of i) renewable generation and ii) existing demand on the Western Isles due to its ability to operate at low power levels and accommodate power reversals.

[13] Constraint payments due to HVDC link outages would be influenced by equipment fault rates, fault repair times (which in the case of subsea cables could be prolonged due to weather and mobilisation delays), renewable generation energy costs and generation seasonal output levels (which may be upto 125% of annual load factor during winter periods)

[14] Viability of HVAC subsea connections are limited by the connection distance, power levels and system losses. Only the Beauly connection option could possibly be considered for a HVAC connection, however the consideration of such a connection option is outside the scope of this note.

Based on discussions with manufacturers, modifications to the operation and control of HVDC Classic, and the use of additional equipment such as synchronous compensators, would be expected to enable it to operate satisfactorily for the Western Isles. However the use of HVDC Classic technology would be regarded as presenting a higher level of technical risk than HVDC VSC technology.

The largest current commercially available HVDC VSC modules are rated at 335MW[15]. However in the case of HVDC Classic there is no practical limitation on the size of each module and for the basis of this assessment it is taken that each HVDC Classic module would be rated at 600MW.

The distances of the Hunterston, Deeside and Pembroke connection options are in excess of current submarine cable connected HVDC VSC schemes and the majority of installed HVDC Classic schemes, the full technical (and financial) implications and areas of risk for the HVDC converters and cables of extending current technology to cover the estimated distances would need to be considered in further detail if any of these options are considered to represent viable connection options.

The lower operating voltage for HVDC VSC technology (150kV) compared to that of HVDC Classic technology (500kV) and the associated increase in cable losses and % voltage drop for HVDC VSC technology may impose connection distance limitations for HVDC VSC technology compared to HVDC Classic technology. This has not been addressed as part of this paper and would need to be considered in further detail if any of the Hunterston, Deeside or Pembroke options are considered to represent viable connection options[16]. In terms of this paper the use of HVDC VSC technology for the long connection distances of the Hunterston, Deeside and Pembroke connections options are considered to represent an increased level of technical risk compared to the use of HVDC VSC technology for the Beauly connection options or

[15] Higher rated HVDC VSC Modules with ratings of upto 500MW at a HVDC operating voltage of 150kV and 1000MW at a HVDC operating voltage of 300kV are currently under development, however these have not been taken into account in these assessment, but may require to be considered for any future detailed optimisation assessments.

[16] The connection distances for the Hunterston connection options are at the limitations of the capability of HVDC VSC with an operating voltage of 150kV. The longer connection distances for the Deeside and Pembroke connection options would require a HVDC VSC operating voltage of 300kV, which would increase the level of technical risk associated with these options since both the HVDC VSC modules and cables are presently under development with no operational experience.

the use of HVDC Classic technology for the Hunterston, Deeside or Pembroke connection options.

The subsea cable connection distance for Beauly is sufficiently short that it could be installed in a single installation with a continuous cable (i.e. no joints) for each circuit, with an estimated subsea cable manufacture and installation period of 18-24 mths, which would be within the HVDC converter manufacture and installation period.

The increased subsea cable connection distances for the Hunterston, Deeside and Pembroke connection options would:

- Require the subsea cables to be jointed, of which it is understood none are presently in-service, and are still undergoing testing and development.

- Result in significantly increased cable manufacturing and installation periods with estimated cable manufacturing and installation periods (based on existing production capacity) of

    - 6 to 8 years for Hunterston
    - 10 to 11 years for Deeside
    - 11 to 12 years for Pembroke

The cable manufacturing times may be reduced by increasing current production capacity. The extent of any reduction in cable manufacturing timescales due to increased production capacity and the lead times for any such production capacity increase is uncertain at this stage.

The firm and non-firm HVDC connection arrangements considered are indicated in Tables 4 and 5.

Connection	**HVDC VSC** **(See Note 1)**	**HVDC Classic** **(See Note 2)**
Firm	3 x 335MW Modules	2 x 600MW Bipole (See Note 3)
Non-Firm	2 x 335MW Modules	1 x 600MW Bipole

Table 4: Firm and Non-Firm Connection Configurations

Notes:
1: HVDC VSC – Voltage Sourced Converter technology
2: HVDC Classic – Current Commutated technology
3: Only Bipole configuration considered appropriate for subsea installation

Connection Option		HVDC VSC		HVDC Classic	
		Firm	Non-Firm	Firm	Non-Firm
A	Beauly	√	√	√	√
B1	Hunterston (Subsea)	√	√	√	√
B2	Hunterston (Subsea/Land)	√	√	√	√
C	Deeside	√	√	√	√
D	Pembroke	√	√	√	√

Table 5: Firm and Non-Firm Connection Options

Notes:
1: Deeside and Pembroke connections distances considered to be beyond the viable connection distance for HVDC VSC. Hunterston connection distances considered to be at the limit of the viable connection distance for HVDC VSC.

Each of the HVDC technologies have the capability to be expanded to ratings above 600MW by the installation of additional HVDC modules (converters and cables), as discussed in Appendix A for a capacity of 1000MW.

7 Basis of Connection Assessments

The basis used for the connection assessments were:

- Generation load factor in the range 35% to 45%[17]
- Generation revenue of £55/MWhr
- Cost of Losses[18] = £25/MWHr
- HVDC link outage costs determined based on
    - HVDC module cable fault rate of 0.06038 faults/yr/100km[19], based on 2 cables per HVDC module.

[17] No details have been provided from the potential generation developers of the anticipated annual load factor for wind generation in the Western Isles. A load factor range of 35% to 45% is considered to represent a typical load factor range, with the higher load factors occurring for higher average wind speed sites or over installation of capacity.
[18] Based on losses being met by conventional generation as part of the market balancing mechanism
[19] HVDC cable fault rate based on combination of operational experience of existing HVDC links and exposure to environmental and third party damage for subsea installation based on 80% of route buried, 10% protected and 10% unburied/unprotected. HVDC VSC module outage rates based on two cables per module, HVDC Classic module outage rates based on single cable with integrated return per module.

- Cable repair time of 10 weeks (70 days)[20] for subsea cable faults and 4 weeks (28 days) for land cable faults.
- Generator HVDC Outage Costs/TSO Constraint Cost = £45/MWhr[21]
- TSO Generation Replacement Costs = £25/MWhr for 24hr period after each fault
- Cost of repair excluded

- Costs of Western Isles local connections excluded

8 Assessment of Connection Options

The assessments undertaken for the connection options considered are detailed below:

8.1 Estimated Annual Generation Revenue

The estimated annual generation revenue, which would be independent of the mainland connection point, for the range of load factors considered, is shown in Table 6

Load Factor	35%	40%	45%
Energy Cost (£/MWHr)	£55	£55	£55
Annual Revenue (£M)	£101	£116	£130

Table 6: Estimated Annual Generation Revenue

8.2 Indicative Connection Capital Costs

The indicative island connection capital costs[22] for each of the Western Isles connection options considered are shown in Tables 7 and 8 and illustrated in Figure 3.

[20] Based on estimated typical repair time, maybe subject to delays due to a number of factors such as fault location,weather conditions, vessel/personnel availability, extent of damaged cable.
[21] Based on SKM costs from Transmission Investment for Renewable Generation, Dec 2004, OFGEM Ref 288/04
[22] Excluding mainland transmission AC system equipment costs, finance costs and TO on-costs.

	Beauly (A1 - Remote) HVDC VSC		Beauly (A2 - Local) HVDC VSC		Hunterston (Subsea) HVDC VSC		Hunterston (Subsea/Land) HVDC VSC		Deeside HVDC VSC		Pembroke HVDC VSC	
Costs (£M)	Firm	Non-Firm	Firm	Non-Firm	Firm	Non-Firm	Firm	Non-Firm	Firm	Non-Firm	Firm	Non-Firm
Converters	£ 210	£ 140	£ 210	£ 140	£ 210	£ 140	£ 210	£ 140	£ 210	£ 140	£ 210	£ 140
HVDC Cable (Subsea)	£ 88	£ 59	£ 88	£ 59	£ 455	£ 303	£ 349	£ 233	£ 634	£ 422	£ 727	£ 484
HVDC Cable (Land)	£ 75	£ 50	£ 126	£ 84	£ 5	£ 3	£ 70	£ 47	£ 5	£ 3	£ 5	£ 3
OHL	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -
Total	£ 373	£ 249	£ 424	£ 283	£ 670	£ 447	£ 629	£ 419	£ 849	£ 566	£ 942	£ 628

Table 7: Indicative Connection Cost Estimates for HVDC VSC Technology

	Beauly (A1 - Remote) HVDC Classic		Beauly (A2 - Local) HVDC Classic		Hunterston (Subsea) HVDC Classic		Hunterston (Subsea/Land) HVDC Classic		Deeside HVDC Classic		Pembroke HVDC Classic	
Costs (£M)	Firm	Non-Firm	Firm	Non-Firm	Firm	Non-Firm	Firm	Non-Firm	Firm	Non-Firm	Firm	Non-Firm
Converters	£ 280	£ 150	£ 280	£ 150	£ 280	£ 150	£ 280	£ 150	£ 280	£ 150	£ 280	£ 150
HVDC Cable (Subsea)	£ 127	£ 64	£ 127	£ 64	£ 656	£ 328	£ 505	£ 252	£ 918	£ 459	£ 1,051	£ 525
HVDC Cable (Land)	£ 110	£ 55	£ 184	£ 92	£ 8	£ 4	£ 102	£ 51	£ 8	£ 4	£ 8	£ 4
OHL	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -
Total	£ 517	£ 269	£ 591	£ 306	£ 944	£ 482	£ 887	£ 454	£ 1,206	£ 613	£ 1,338	£ 679

Table 8: Indicative Connection Cost Estimates for HVDC Classic Technology

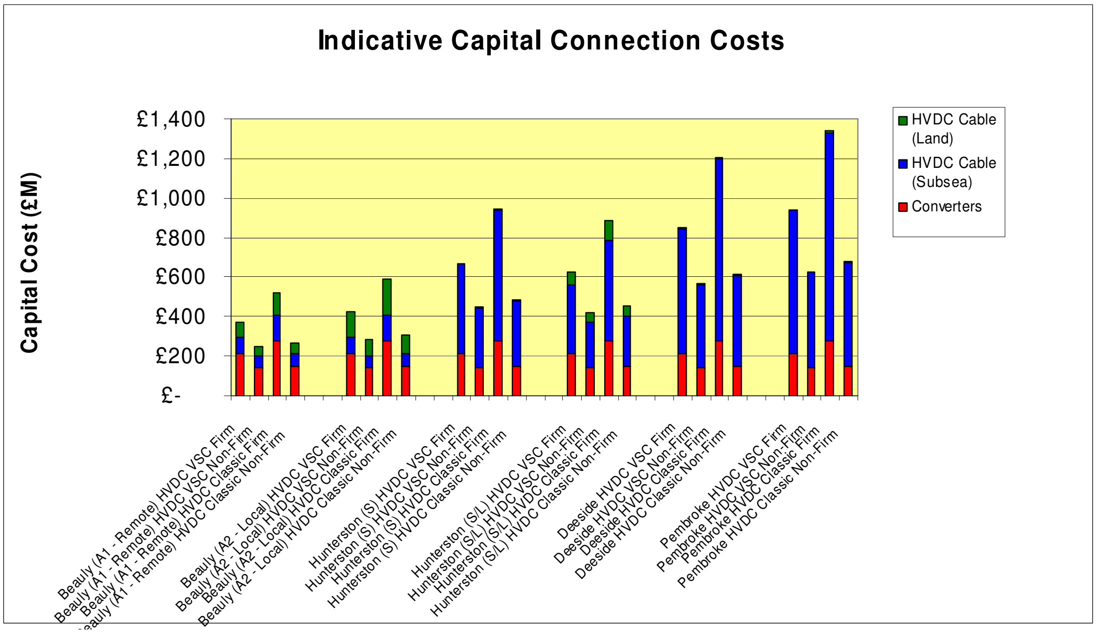

Figure 3: Indicative Capital Connection Cost Estimates

From the indicative capital connection cost estimates detailed in Tables 7 & 8 and Figure 3, it is evident that:

- A connection at Beauly would be the lowest capital connection cost option, with HVDC VSC technology being the lowest capital cost solution for Beauly for both firm and non-firm connection options.
- As the subsea connection distance increases for the Hunterston, Deeside and Pembroke connection options, HVDC Classic becomes the lowest capital cost

solution for a non-firm connection, while HVDC VSC technology *(if technically viable)* would be the lower cost option for a firm connection arrangement.

- The incremental costs between firm and non-firm connection arrangements are lower for HVDC VSC than HVDC Classic due to the modular configuration of HVDC VSC technology.

- The HVDC cable costs are the dominant components of the Hunterston, Deeside and Pembroke connection options costs.

In addition to the HVDC connection capital costs outlined above, it is recognised that 600MW of W.Isles generation would contribute to transmission reinforcements in each of the mainland zones.

The annual TNUoS charges for a 600MW generation input associated with each mainland zone will provide an additional fund for any transmission system reinforcements that are required for its connection. On the assumption that the mainland TNUoS charges remain cost reflective, the investment costs of such reinforcements should be matched by the additional charges, and have not been considered further here.

Based on the indicative costs detailed above, the indicative capital cost/MW/km for each connection option is shown in Table 9 for the connection arrangements considered.

		Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
HVDC VSC	Firm	£ 3,555	£ 4,038	£ 2,326	£ 2,556	£ 2,096	£ 2,039
	Non-Firm	£ 2,370	£ 2,692	£ 1,551	£ 1,704	£ 1,397	£ 1,359
HVDC Classic	Firm	£ 4,926	£ 5,633	£ 3,278	£ 3,606	£ 2,978	£ 2,897
	Non-Firm	£ 2,558	£ 2,912	£ 1,674	£ 1,843	£ 1,514	£ 1,470

Table 9: Indicative Connection Costs per MW/km

The indicative connection costs per MW/km shown in Table 9 show that:

- Costs per MW/km are significantly higher for Beauly due to i) the proportionally higher cost of the HVDC converters for the Beauly options, increased volume of HVDC land cable for the Beauly options, which has a higher unit cost than subsea cable.

- Increasing the connection distance reduces the cost per MW/km, as expected.

8.3 Indicative TNUoS Charges

Indicative TNUoS charges were determined for each of the Western Isles connection options assessed based on the following scenarios:

i) Generation connections in the Western Isles having full TNUoS liability with the TNUoS differential charge based on the annual return of 8.43% of the indicative capital connection costs for each option.

ii) Generation connections in the Western Isles having limited TNUoS liabilities with the Western Isles TNUoS charge reduced by either[23]:

a) 50% of value above £25/kW

b) 50% of value above the highest existing charge zone (£23.10 for Skye zone)

8.3.1 Full TNUoS Liability

Indicative Western Isles TNUoS charges based on full liability for both the mainland and Island connection aspects were determined on the indicative capital connection costs and mainland zonal charges for each connection option with the values calculated shown in Table 10 and illustrated in Figure 4.

			Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
HVDC VSC	Firm	Island	£ 52.44	£ 59.57	£ 94.13	£ 88.34	£ 119.26	£ 132.34
		Mainland	£ 20.93	£ 20.93	£ 11.82	£ 11.82	£ 3.12	-£ 2.55
		Total	**£ 73.37**	**£ 80.50**	**£ 105.95**	**£ 100.16**	**£ 122.38**	**£ 129.79**
	Non-Firm	Island	£ 34.96	£ 39.71	£ 62.76	£ 58.89	£ 79.51	£ 88.23
		Mainland	£ 20.93	£ 20.93	£ 11.82	£ 11.82	£ 3.12	-£ 2.55
		Total	**£ 55.89**	**£ 60.64**	**£ 74.58**	**£ 70.71**	**£ 82.63**	**£ 85.68**
HVDC Classic	Firm	Island	£ 72.67	£ 83.10	£ 132.64	£ 124.62	£ 169.45	£ 188.05
		Mainland	£ 20.93	£ 20.93	£ 11.82	£ 11.82	£ 3.12	-£ 2.55
		Total	**£ 93.60**	**£ 104.03**	**£ 144.46**	**£ 136.44**	**£ 172.57**	**£ 185.50**
	Non-Firm	Island	£ 37.74	£ 42.95	£ 67.73	£ 63.72	£ 86.13	£ 95.43
		Mainland	£ 20.93	£ 20.93	£ 11.82	£ 11.82	£ 3.12	-£ 2.55
		Total	**£ 58.67**	**£ 63.88**	**£ 79.55**	**£ 75.54**	**£ 89.25**	**£ 92.88**

Table 10: Indicative TNUoS Unit Charges (Full Liability)

[23] Based on options outlined in DTI consultation 'Adjusting Transmission Charges for Renewable Generators in the North of Scotland', July 2005

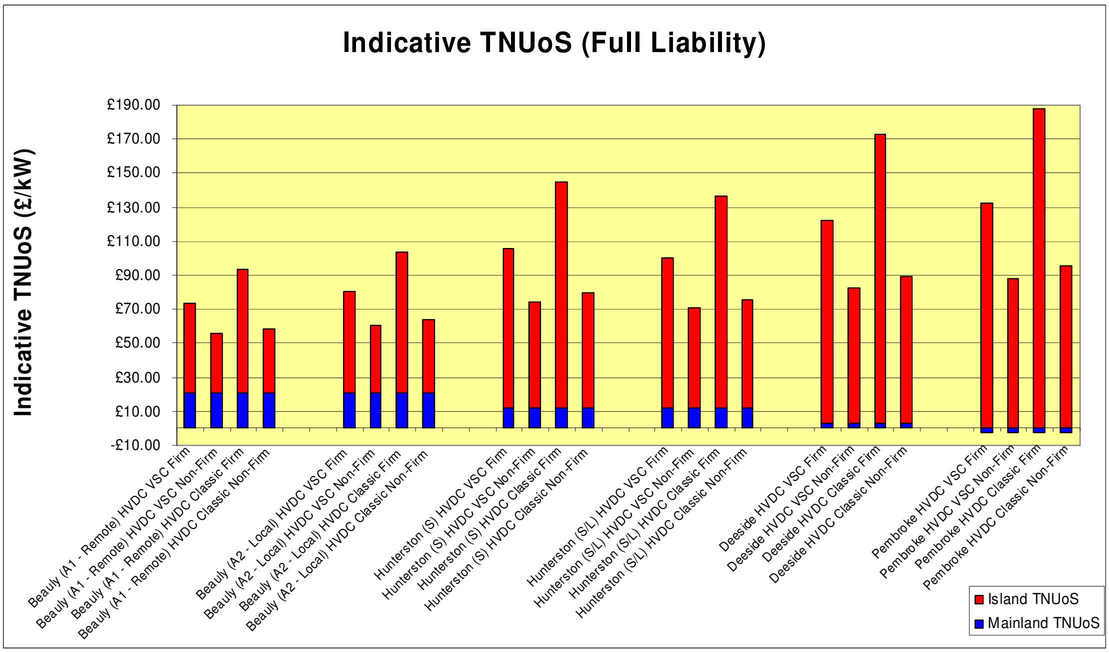

Figure 4: Indicative TNUoS Charges (Full Liability)

Based on the indicative full liability TNUoS charges shown in Table 10, the indicative annual TNUoS revenue for each connection option is shown in Table 11, with these indicative annual TNUoS revenues shown as percentages of the estimated annual generation revenue in Table 12 for the range of load factors considered.

		Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
HVDC VSC	Firm	£ 44	£ 48	£ 64	£ 60	£ 73	£ 78
	Non-Firm	£ 34	£ 36	£ 45	£ 42	£ 50	£ 51
HVDC Classic	Firm	£ 56	£ 62	£ 87	£ 82	£ 104	£ 111
	Non-Firm	£ 35	£ 38	£ 48	£ 45	£ 54	£ 56

Table 11: Indicative TNUoS Annual Revenue (£M) (Full Liability)

			Generation Load Factor		
			35%	40%	45%
Beauly (A1 - Remote)	HVDC VSC	Firm	44%	38%	34%
		Non-Firm	33%	29%	26%
	HVDC Classic	Firm	56%	49%	43%
		Non-Firm	35%	30%	27%
Beauly (A2 - Local)	HVDC VSC	Firm	48%	42%	37%
		Non-Firm	36%	31%	28%
	HVDC Classic	Firm	62%	54%	48%
		Non-Firm	38%	33%	29%
Hunterston (Subsea)	HVDC VSC	Firm	63%	55%	49%
		Non-Firm	44%	39%	34%
	HVDC Classic	Firm	86%	75%	67%
		Non-Firm	47%	41%	37%
Hunterston (Subsea/ Land)	HVDC VSC	Firm	59%	52%	46%
		Non-Firm	42%	37%	33%
	HVDC Classic	Firm	81%	71%	63%
		Non-Firm	45%	39%	35%
Deeside	HVDC VSC	Firm	73%	64%	56%
		Non-Firm	49%	43%	38%
	HVDC Classic	Firm	102%	90%	80%
		Non-Firm	53%	46%	41%
Pembroke	HVDC VSC	Firm	77%	67%	60%
		Non-Firm	51%	44%	40%
	HVDC Classic	Firm	110%	96%	86%
		Non-Firm	55%	48%	43%

Table 12: Annual TNUoS Revenue (Full Liability) as Percentage of Annual Generation Revenue

From the indicative full liability TNUoS charges and revenue detailed in Tables 10-12 & Figure 4, it is evident that:

- The Beauly connection options have the lowest overall TNUoS charges, even though they have the highest mainland TNUoS component due to the high North of Scotland zonal charge.

- The TNUoS charges would represent a significant proportion of the annual revenue of Western Isles generation.

- Reduced levels of mainland TNUoS zonal charges for Hunterson, Deeside and Pembroke connection options reduce the differentials in overall TNUoS charges compared to Beauly connection options, particularly for non-firm connections.

- The indicative TNUoS charges calculated for the Western Isles generation are significantly above the range of £30.2 - £ 60.6/kW detailed in the DTI consultation[24] for connection of generation in the Western Isles, with the exception of the non-firm HVDC VSC connections to Beauly, which have a TNUoS charge of £55.89/kW for the HVDC converter stations located remotely from Beauly and £60.64/kW for the HVDC converter stations located local to Beauly.

8.3.2 Reduced TNUoS Liability

Indicative TNUoS charges for the Western Isles were determined for each of the scenarios detailed above.

Indicative reduced liability TNUoS charges are shown in Table 13 and illustrated in Figure 5, with the indicative annual TNUoS revenue for each connection option shown in Table 14, with these indicative annual TNUoS revenues shown as percentages of the estimated annual generation revenue in Table 15 for the range of load factors considered.

		Reduced Liability Basis	Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
HVDC VSC	Firm	50% above £25/kW	£ 49.19	£ 52.75	£ 65.48	£ 62.58	£ 73.69	£ 77.39
		50% above Highest Zone Charge	£ 48.24	£ 51.80	£ 64.53	£ 61.63	£ 72.74	£ 76.44
	Non-Firm	50% above £25/kW	£ 40.45	£ 42.82	£ 49.79	£ 47.86	£ 53.81	£ 55.34
		50% above Highest Zone Charge	£ 39.50	£ 41.87	£ 48.84	£ 46.91	£ 52.86	£ 54.39
HVDC Classic	Firm	50% above £25/kW	£ 59.30	£ 64.51	£ 84.73	£ 80.72	£ 98.78	£ 105.25
		50% above Highest Zone Charge	£ 58.35	£ 63.56	£ 83.78	£ 79.77	£ 97.83	£ 104.30
	Non-Firm	50% above £25/kW	£ 41.83	£ 44.44	£ 52.27	£ 50.27	£ 57.12	£ 58.94
		50% above Highest Zone Charge	£ 40.88	£ 43.49	£ 51.32	£ 49.32	£ 56.17	£ 57.99

Table 13: Indicative TNUoS Unit Charges (Reduced Liability)

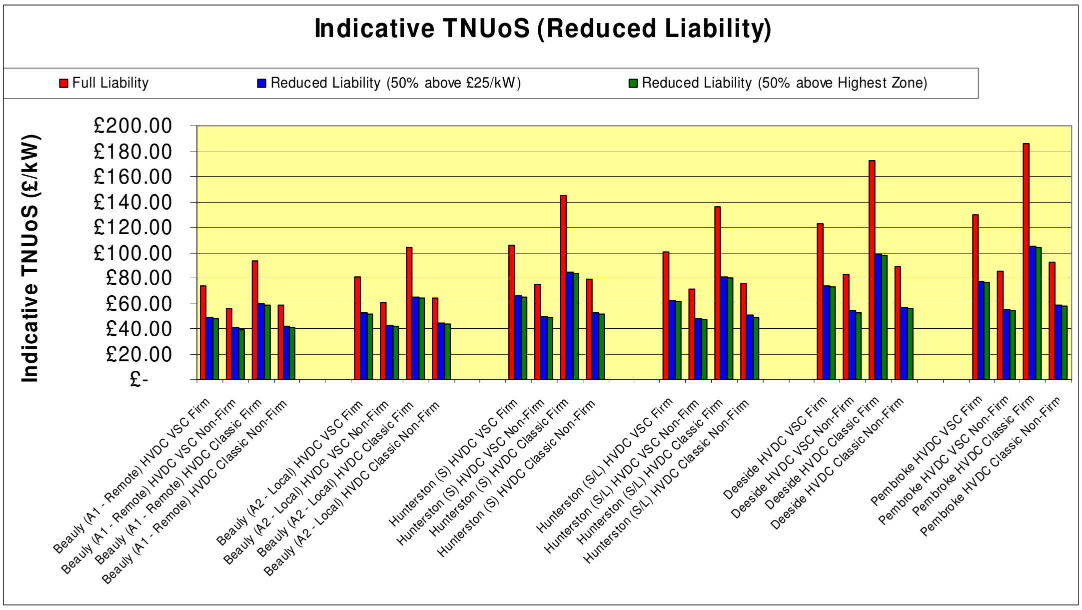

Figure 5: Indicative TNUoS Charges (Reduced Liability)

[24] Table 2 of DTI consultation 'Adjusting Transmission Charges for Renewable Generators in the North of Scotland', July 2005

		Reduced Liability Basis	Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
HVDC VSC	Firm	50% above £25/kW	£ 30	£ 32	£ 39	£ 38	£ 44	£ 46
		50% above Highest Zone Charge	£ 29	£ 31	£ 39	£ 37	£ 44	£ 46
	Non-Firm	50% above £25/kW	£ 24	£ 26	£ 30	£ 29	£ 32	£ 33
		50% above Highest Zone Charge	£ 24	£ 25	£ 29	£ 28	£ 32	£ 33
HVDC Classic	Firm	50% above £25/kW	£ 36	£ 39	£ 51	£ 48	£ 59	£ 63
		50% above Highest Zone Charge	£ 35	£ 38	£ 50	£ 48	£ 59	£ 63
	Non-Firm	50% above £25/kW	£ 25	£ 27	£ 31	£ 30	£ 34	£ 35
		50% above Highest Zone Charge	£ 25	£ 26	£ 31	£ 30	£ 34	£ 35

Table 14: Indicative TNUoS Annual Revenue (£M) (Reduced Liability)

			Reduced TNUoS Liability					
			50% above £25/kW			50% above Highest Zone Charge		
			Generation Load Factor			Generation Load Factor		
			35%	40%	45%	35%	40%	45%
Beauly (A1 - Remote)	HVDC VSC	Firm	29%	26%	23%	29%	25%	22%
		Non-Firm	24%	21%	19%	23%	20%	18%
	HVDC Classic	Firm	35%	31%	27%	35%	30%	27%
		Non-Firm	25%	22%	19%	24%	21%	19%
Beauly (A2 - Local)	HVDC VSC	Firm	31%	27%	24%	31%	27%	24%
		Non-Firm	25%	22%	20%	25%	22%	19%
	HVDC Classic	Firm	38%	33%	30%	38%	33%	29%
		Non-Firm	26%	23%	20%	26%	23%	20%
Hunterston (Subsea)	HVDC VSC	Firm	39%	34%	30%	38%	33%	30%
		Non-Firm	30%	26%	23%	29%	25%	23%
	HVDC Classic	Firm	50%	44%	39%	50%	43%	39%
		Non-Firm	31%	27%	24%	30%	27%	24%
Hunterston (Subsea/ Land)	HVDC VSC	Firm	37%	32%	29%	37%	32%	28%
		Non-Firm	28%	25%	22%	28%	24%	22%
	HVDC Classic	Firm	48%	42%	37%	47%	41%	37%
		Non-Firm	30%	26%	23%	29%	26%	23%
Deeside	HVDC VSC	Firm	44%	38%	34%	43%	38%	34%
		Non-Firm	32%	28%	25%	31%	27%	24%
	HVDC Classic	Firm	59%	51%	46%	58%	51%	45%
		Non-Firm	34%	30%	26%	33%	29%	26%
Pembroke	HVDC VSC	Firm	46%	40%	36%	45%	40%	35%
		Non-Firm	33%	29%	26%	32%	28%	25%
	HVDC Classic	Firm	62%	55%	49%	62%	54%	48%
		Non-Firm	35%	31%	27%	34%	30%	27%

Table 15: Annual TNUoS Revenue (Reduced Liability) as Percentage of Annual Generation Revenue

The difference in annual TNUoS revenue between the amount paid by the Western Isles generation for the full and reduced liability scenarios would be recovered from other electricity suppliers and customers within the UK[25], an indication of the levels of annual TNUoS revenue costs that would require to be recovered for the reduced liability options is provided in Table 16 and illustrated in Figure 6.

		Reduced Liability Basis	Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
HVDC VSC	Firm	50% above £25/kW	£ 15	£ 17	£ 24	£ 23	£ 29	£ 31
		50% above Highest Zone Charge	£ 15	£ 17	£ 25	£ 23	£ 30	£ 32
	Non-Firm	50% above £25/kW	£ 9	£ 11	£ 15	£ 14	£ 17	£ 18
		50% above Highest Zone Charge	£ 10	£ 11	£ 15	£ 14	£ 18	£ 19
HVDC Classic	Firm	50% above £25/kW	£ 21	£ 24	£ 36	£ 33	£ 44	£ 48
		50% above Highest Zone Charge	£ 21	£ 24	£ 36	£ 34	£ 45	£ 49
	Non-Firm	50% above £25/kW	£ 10	£ 12	£ 16	£ 15	£ 19	£ 20
		50% above Highest Zone Charge	£ 11	£ 12	£ 17	£ 16	£ 20	£ 21

Table 16: Indicative Levels of Annual TNUoS Revenue Recovery for Reduced Liability Scenarios

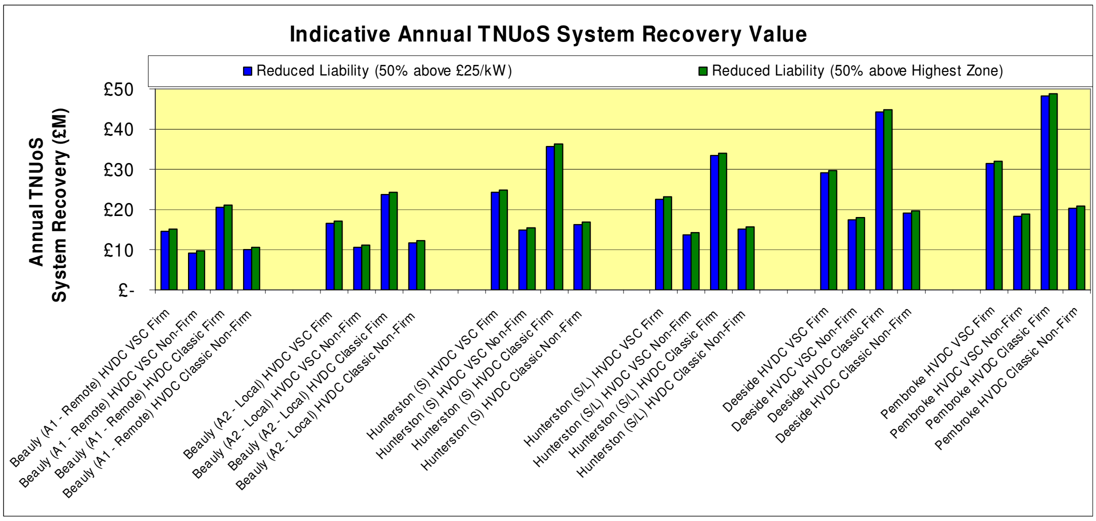

Figure 6: Indicative Annual TNUoS System Recovery for Generator Reduced TNUoS Liability

From the indicative reduced liability TNUoS charges and revenues detailed in Tables 13-16 & Figures 5 and 6, it is evident that:

- The Beauly connection options would remain the lowest TNUoS charging options, irrespective of the connection configuration or TNUoS reduction scenario.
- The Beauly connection options result in the lowest levels of TNUoS revenue recovery from other system users for the reduced liability TNUoS scenarios.
- The annual levels of TNUoS recovery from other system users for the reduced liability scenarios are significantly in excess of the levels indicated in the DTI consultation[26] due to the larger capital connection costs and associated TNUoS charges determined in these assessments.

[25] Section 7 of DTI consultation 'Adjusting Transmission Charges for Renewable Generators in the North of Scotland', July 2005
[26] Section 7 of DTI consultation 'Adjusting Transmission Charges for Renewable Generators in the North of Scotland', July 2005

8.4 Estimated Cost of HVDC Link Losses

The estimated annual and capitalised values of HVDC link losses for each connection option were determined based on a generation load factor of 40%, with the values shown in Table 17. The estimated levels of system losses as a percentage of the annual generation output are shown in Table 18, with the capitalised cost of the losses added to the connection capital costs for each option in Figure 7

			Beauly (A1 - Remote)		Beauly (A2 - Local)		Hunterston (Subsea)		Hunterston (Subsea/Land)		Deeside		Pembroke	
			Annual	Capitalised	Annual	Capitalised	Annual	Capitalised	Annual	Capitalised	Annual	Capitalised	Annual	Capitalised
HVDC VSC	Firm	Converter Losses (£M)	£ 2.3	£ 27.1	£ 2.3	£ 27.1	£ 2.3	£ 27.1	£ 2.3	£ 27.1	£ 2.3	£ 27.1	£ 2.3	£ 27.1
		Cable Losses (£M)	£ 0.7	£ 8.1	£ 0.8	£ 9.8	£ 2.4	£ 28.6	£ 2.1	£ 24.5	£ 3.4	£ 40.3	£ 3.9	£ 45.9
		Total (£M)	£ 3.0	£ 35.2	£ 3.1	£ 36.9	£ 4.7	£ 55.7	£ 4.3	£ 51.5	£ 5.7	£ 67.3	£ 6.2	£ 73.0
	Non-Firm	Converter Losses (£M)	£ 2.4	£ 29.0	£ 2.4	£ 29.0	£ 2.4	£ 29.0	£ 2.4	£ 29.0	£ 2.4	£ 29.0	£ 2.4	£ 29.0
		Cable Losses (£M)	£ 1.0	£ 12.2	£ 1.2	£ 14.8	£ 3.6	£ 42.9	£ 3.1	£ 36.7	£ 5.1	£ 60.4	£ 5.8	£ 68.9
		Total (£M)	£ 3.5	£ 41.2	£ 3.7	£ 43.8	£ 6.1	£ 71.9	£ 5.5	£ 65.7	£ 7.5	£ 89.4	£ 8.3	£ 97.9
HVDC Classic	Firm	Converter Losses (£M)	£ 1.2	£ 14.0	£ 1.2	£ 14.0	£ 1.2	£ 14.0	£ 1.2	£ 14.0	£ 1.2	£ 14.0	£ 1.2	£ 14.0
		Cable Losses (£M)	£ 0.2	£ 2.9	£ 0.3	£ 3.5	£ 0.9	£ 10.3	£ 0.7	£ 8.8	£ 1.2	£ 14.5	£ 1.4	£ 16.6
		Total (£M)	£ 1.4	£ 17.0	£ 1.5	£ 17.6	£ 2.1	£ 24.4	£ 1.9	£ 22.8	£ 2.4	£ 28.5	£ 2.6	£ 30.6
	Non-Firm	Converter Losses (£M)	£ 1.8	£ 21.0	£ 1.8	£ 21.0	£ 1.8	£ 21.0	£ 1.8	£ 21.0	£ 1.8	£ 21.0	£ 1.8	£ 21.0
		Cable Losses (£M)	£ 0.5	£ 5.8	£ 0.6	£ 7.1	£ 1.7	£ 20.6	£ 1.5	£ 17.6	£ 2.4	£ 29.0	£ 2.8	£ 33.1
		Total (£M)	£ 2.3	£ 26.9	£ 2.4	£ 28.1	£ 3.5	£ 41.7	£ 3.3	£ 38.7	£ 4.2	£ 50.1	£ 4.6	£ 54.2

Table 17: Estimated Annual and Capitalised HVDC Link Losses

		Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
HVDC VSC	Firm	5.64%	5.92%	8.93%	8.26%	10.80%	11.70%
	Non-Firm	6.60%	7.02%	11.54%	10.53%	14.33%	15.70%
HVDC Classic	Firm	2.72%	2.82%	3.91%	3.66%	4.58%	4.91%
	Non-Firm	4.31%	4.51%	6.69%	6.20%	8.03%	8.69%

Table 18: Estimated HVDC Link Losses as Percentage of Generation Output

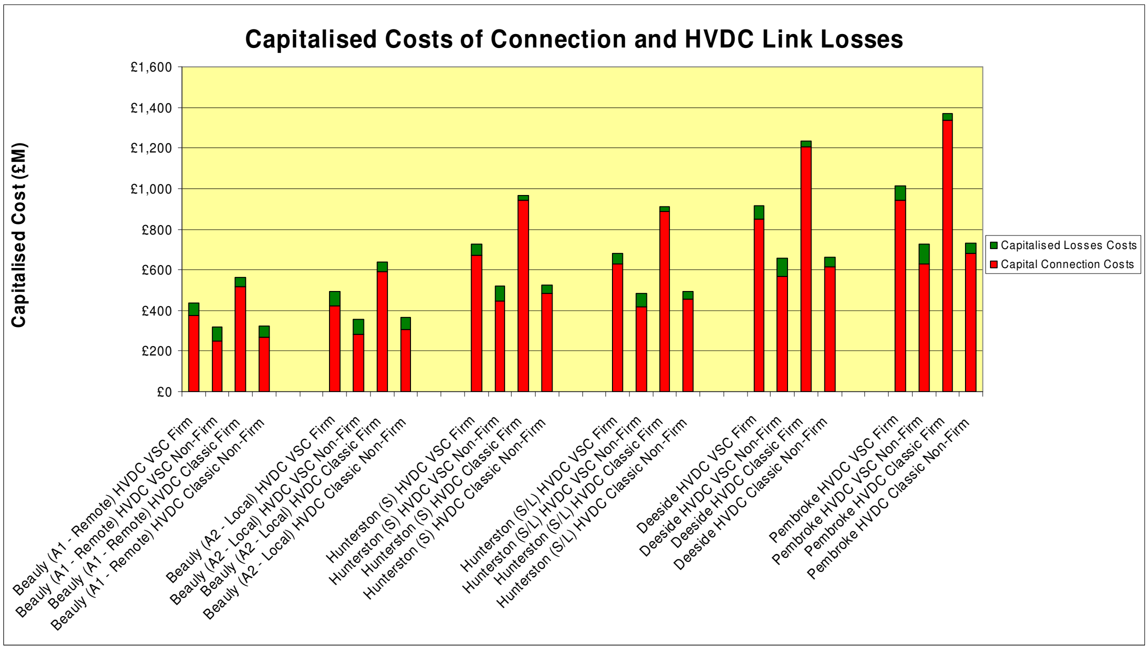

Figure 7: Capitalised Connection and HVDC Link Losses Costs

From Tables 17 & 18 and Figure 7, it can be seen that:

- The Beauly connection options have significantly lower level of HVDC link losses than any of the other connection options and represent the most efficient transmission connection configuration for generation in the Western Isles.
- The estimated losses with HVDC Classic technology are significantly lower than those estimated for HVDC VSC technology for all connection options.

Connection of the Western Isles generation at Beauly would increase the level of AC system losses compared to connection further South in the UK system, it is estimated that these additional AC system losses for connection at Beauly would be capitalised at approx £30M.

These additional capitalised costs of AC system losses for a connection at Beauly have been taken into account in the comparison of the various options.

8.5 Estimated Costs of HVDC Link Outages

The estimated costs for both the generators and the TSO, that could arise due to forced outages of the HVDC links for the various connection options were determined for both converter and cable outages.

The converter outage rates were taken as being consistent for all connection options of similar configuration, irrespective of connection distance. The cable outage rates were determined based on a common cable fault rate/yr/100km and the connection distance for each connection option.

The repair time of any subsea cable faults would be subject to a number of factors in relation to fault location[27], equipment and personnel mobilisation[28] and access[29] which may increase the repair time for any particular fault repair.

[27] location of faults on seabed may require use of divers or ROV vessels
[28] Specialised equipment such as joints, fitting out of repair vessels, availability of specialised repair vessels and personnel
[29] Adverse weather conditions, raising of cables to make repair etc

The estimated annual and capitalised costs of HVDC link outages are shown in Table 19 based on a generation load factor of 40%.

			Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
HVDC VSC	Firm	Annual Outage Costs (£M)	£ 0.1	£ 0.1	£ 0.7	£ 0.5	£ 1.2	£ 1.5
		Capitalised Outage Cost (£M)	£ 1	£ 1.6	£ 8	£ 6	£ 14	£ 17
	Non-Firm	Annual Outage Costs (£M)	£ 2	£ 2	£ 6	£ 5	£ 8	£ 9
		Capitalised Outage Cost (£M)	£ 25	£ 28	£ 68	£ 58	£ 93	£ 105
HVDC Classic	Firm	Annual Outage Costs (£M)	£ 0.1	£ 0.1	£ 0.5	£ 0.4	£ 0.8	£ 1.0
		Capitalised Outage Cost (£M)	£ 1	£ 1	£ 6	£ 4	£ 10	£ 12
	Non-Firm	Annual Outage Costs (£M)	£ 3	£ 2	£ 6	£ 5	£ 8	£ 9
		Capitalised Outage Cost (£M)	£ 31	£ 28	£ 74	£ 64	£ 99	£ 112

Table 19: Estimated Costs of HVDC Link Outages

8.6 Summary of Capitalised Costs

The estimated overall capitalised cost of each of the connection options including capital connection costs, capitalised cost of losses and the capitalised costs of HVDC link outages are detailed in Table 20 and shown in Figure 8 for TSO costs and Figure 9 for generator costs.

			Beauly (Remote)		Beauly (Local)		Hunterston (Subsea)		Hunterston (Subsea/Land)		Deeside		Pembroke	
			Generator	TSO	Generator	TSO	Generator	TSO	Generator	TSO	Generator	TSO	Generator	TSO
HVDC VSC	Firm	Capitalised Connection Cost (£M)	373	373	424	424	670	670	629	629	849	849	942	942
		Capitalised Outage Cost (£M)	-	1	-	2	-	8	-	6	-	14	-	17
		Capitalised Losses Cost (£M)	-	65	-	67	-	56	-	52	-	67	-	73
		Total Capitalised Cost (£M)	**373**	**440**	**424**	**492**	**670**	**733**	**629**	**685**	**849**	**930**	**942**	**1032**
	Non-Firm	Capitalised Connection Cost (£M)	249	249	283	283	447	447	419	419	566	566	628	628
		Capitalised Outage Cost (£M)	25	0	28	0	68	1	58	1	93	1	105	1
		Capitalised Losses Cost (£M)	-	71	-	74	-	72	-	66	-	89	-	98
		Total Capitalised Cost (£M)	**274**	**320**	**311**	**356**	**515**	**519**	**478**	**486**	**659**	**656**	**733**	**727**
HVDC Classic	Firm	Capitalised Connection Cost (£M)	517	517	591	591	944	944	887	887	1206	1206	1338	1338
		Capitalised Outage Cost (£M)	-	1	-	1	-	6	-	4	-	10	-	12
		Capitalised Losses Cost (£M)	-	47	-	48	-	24	-	23	-	29	-	31
		Total Capitalised Cost (£M)	**517**	**565**	**591**	**640**	**944**	**974**	**887**	**914**	**1206**	**1243**	**1338**	**1381**
	Non-Firm	Capitalised Connection Cost (£M)	269	269	306	306	482	482	454	454	613	613	679	679
		Capitalised Outage Cost (£M)	31	0	28	0	74	0	64	0	99	1	112	1
		Capitalised Losses Cost (£M)	-	57	-	58	-	42	-	39	-	50	-	54
		Total Capitalised Cost (£M)	**300**	**325**	**334**	**364**	**556**	**525**	**517**	**493**	**712**	**664**	**791**	**734**

Table 20: Capitalised Connection Costs

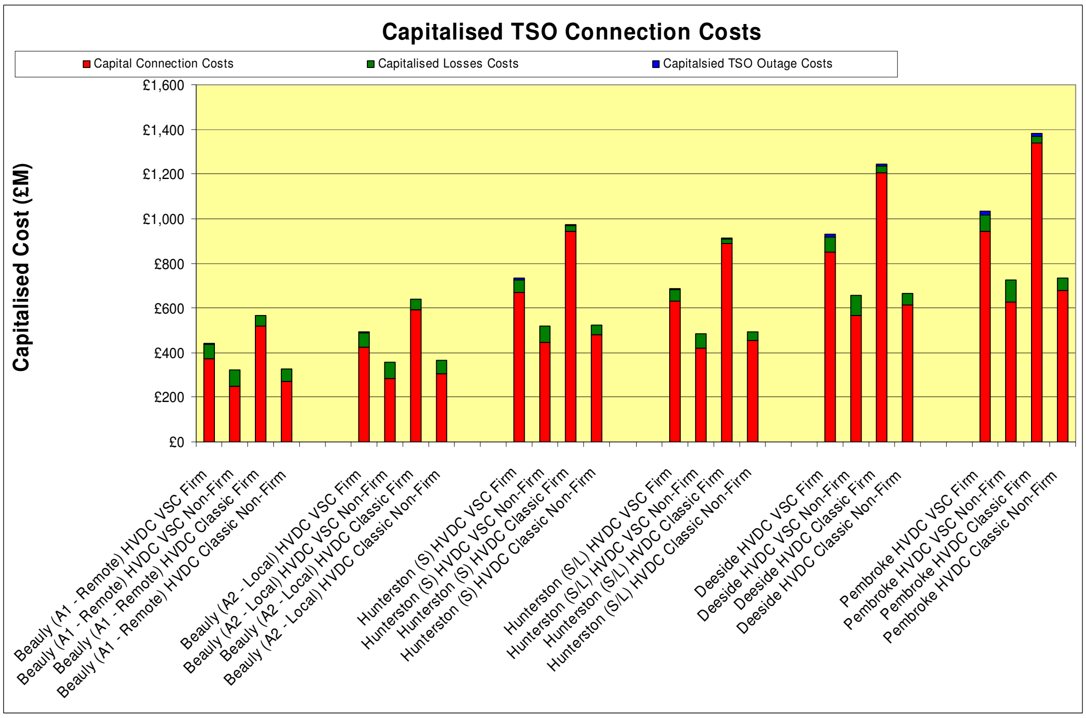

Figure 8: Capitalised TSO Costs

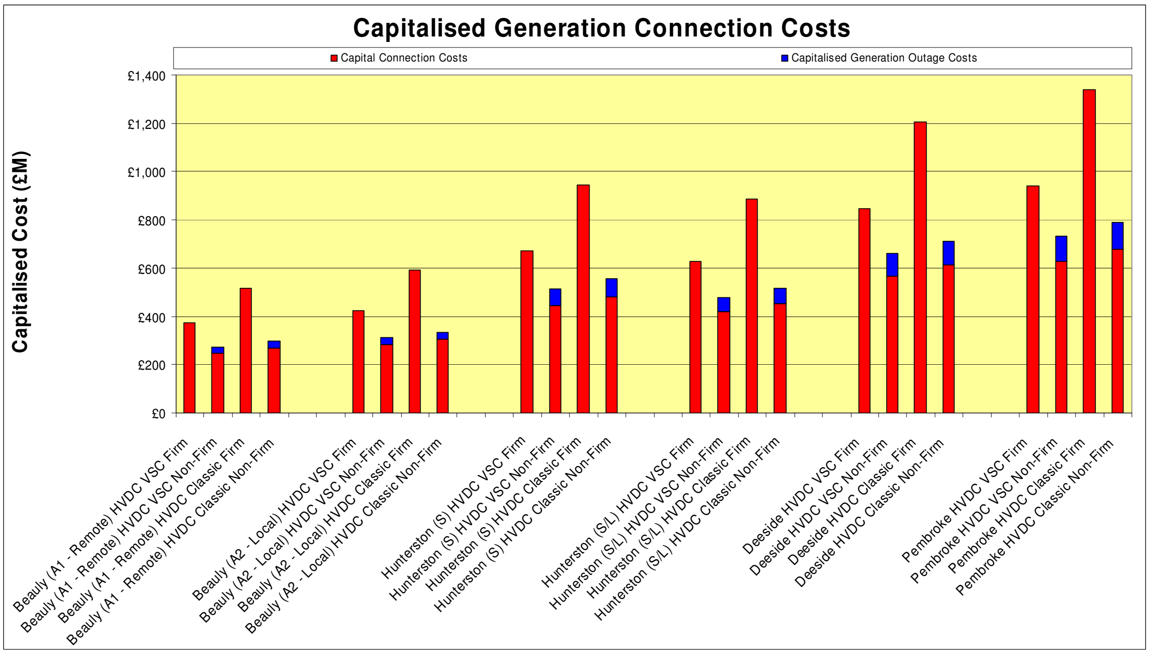

Figure 9: Capitalised Generation Costs

The TSO costs associated with the HVDC link outages for the firm connection configurations for the Hunterston, Deeside and Pembroke connection options are significantly above those for the non-firm connection configurations since

i) the long connection distances of these options result in very low levels of link availability due to a high probability of simultaneous subsea cable outages due to very high fault rates and protracted repair times.

ii) the TSO unit costs for simultaneous HVDC link outages for a firm configuration are substantial due to the cost of generation constraint payments.

As evident from Tables 19 and 20, the Beauly connection options would result in significantly lower TSO costs due to HVDC link outages than the Hunterston, Deeside or Pembroke connection options, with a non-firm connection resulting in the lowest TSO costs for all connection options considered.

The generation costs detailed in Table 20 indicate that a HVDC VSC non-firm connection configuration for the Beauly connection options would result in a lower cost connection option for generators than a firm connection since the generator's HVDC link outage costs of £25M - £31M for a non-firm connection are well below the capital connection cost savings of £121M - £141M that a non-firm connection configuration would achieve.

In the case of the Hunterston, Deeside and Pembroke connection options, a non-firm HVDC VSC connection configuration would also be the lowest overall cost generator connection configuration.

The estimated annual generator costs taking into account HVDC link outage costs and each of the TNUoS charging basis considered are shown in Table 21 and illustrated in Figure 10.

			Beauly (A1 - Remote)			Beauly (A2 - Local)			Hunterston (Subsea)			Hunterston (Subsea/Land)			Deeside			Pembroke		
			100% TNUoS	50% TNUoS Above £25kW	50% TNUoS Above Highest Zone	100% TNUoS	50% TNUoS Above £25kW	50% TNUoS Above Highest Zone	100% TNUoS	50% TNUoS Above £25kW	50% TNUoS Above Highest Zone	100% TNUoS	50% TNUoS Above £25kW	50% TNUoS Above Highest Zone	100% TNUoS	50% TNUoS Above £25kW	50% TNUoS Above Highest Zone	100% TNUoS	50% TNUoS Above £25kW	50% TNUoS Above Highest Zone
HVDC VSC	Firm	Annual TNUoS Cost (£M)	£ 44	£ 30	£ 29	£ 48	£ 32	£ 31	£ 64	£ 39	£ 39	£ 60	£ 38	£ 37	£ 73	£ 44	£ 44	£ 78	£ 46	£ 46
		Annual Outage Cost (£M)	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -
		Total Annual Cost (£M)	£ 44	£ 30	£ 29	£ 48	£ 32	£ 31	£ 64	£ 39	£ 39	£ 60	£ 38	£ 37	£ 73	£ 44	£ 44	£ 78	£ 46	£ 46
	Non-Firm	Annual TNUoS Cost (£M)	£ 34	£ 24	£ 24	£ 36	£ 26	£ 25	£ 45	£ 30	£ 29	£ 42	£ 29	£ 28	£ 50	£ 32	£ 32	£ 51	£ 33	£ 33
		Annual Outage Cost (£M)	£ 2	£ 2	£ 2	£ 2	£ 2	£ 2	£ 6	£ 6	£ 6	£ 5	£ 5	£ 5	£ 8	£ 8	£ 8	£ 9	£ 9	£ 9
		Total Annual Cost (£M)	£ 36	£ 26	£ 26	£ 39	£ 28	£ 27	£ 51	£ 36	£ 35	£ 47	£ 34	£ 33	£ 57	£ 40	£ 40	£ 60	£ 42	£ 42
HVDC Classic	Firm	Annual TNUoS Cost (£M)	£ 56	£ 36	£ 35	£ 62	£ 39	£ 38	£ 87	£ 51	£ 50	£ 82	£ 48	£ 48	£ 104	£ 59	£ 59	£ 111	£ 63	£ 63
		Annual Outage Cost (£M)	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -
		Total Annual Cost (£M)	£ 56	£ 36	£ 35	£ 62	£ 39	£ 38	£ 87	£ 51	£ 50	£ 82	£ 48	£ 48	£ 104	£ 59	£ 59	£ 111	£ 63	£ 63
	Non-Firm	Annual TNUoS Cost (£M)	£ 35	£ 25	£ 25	£ 38	£ 27	£ 26	£ 48	£ 31	£ 31	£ 45	£ 30	£ 30	£ 54	£ 34	£ 34	£ 56	£ 35	£ 35
		Annual Outage Cost (£M)	£ 3	£ 3	£ 3	£ 2	£ 2	£ 2	£ 6	£ 6	£ 6	£ 5	£ 5	£ 5	£ 8	£ 8	£ 8	£ 9	£ 9	£ 9
		Total Annual Cost (£M)	£ 38	£ 28	£ 27	£ 41	£ 29	£ 28	£ 54	£ 38	£ 37	£ 51	£ 36	£ 35	£ 62	£ 43	£ 42	£ 65	£ 45	£ 44

Table 21: Estimated Annual Generation Costs (Including Outage Costs) for Proposed TNUoS Charges Capping Scenarios

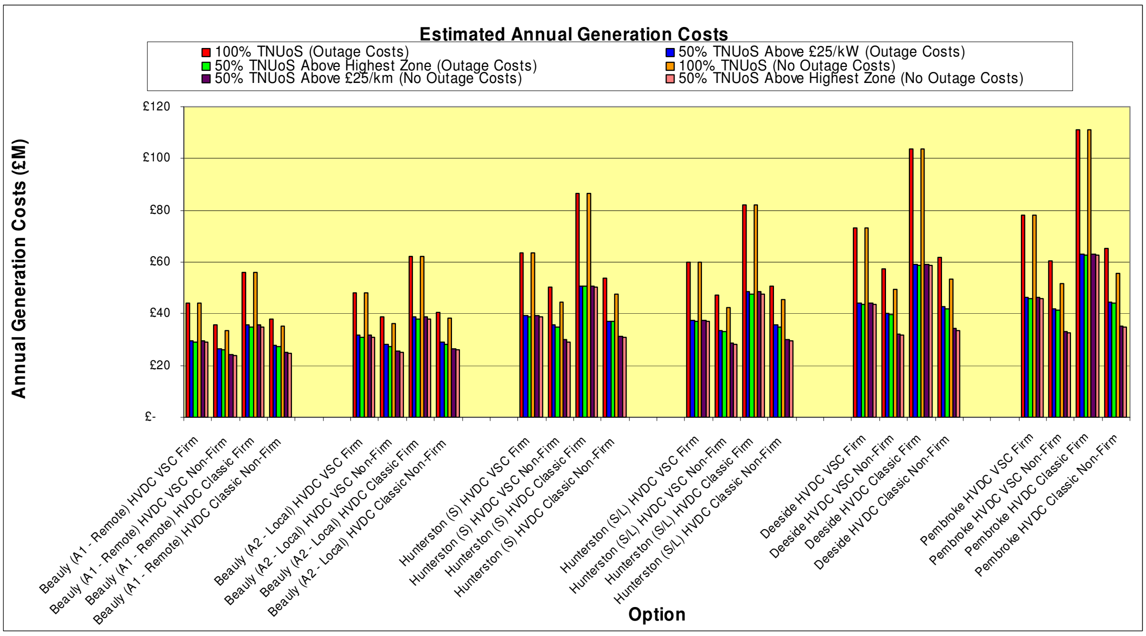

Figure 10: Estimated Annual Generation Costs (Including Outage Costs) for Proposed TNUoS Charges Capping Scenarios

The estimated annual generation charges detailed in Table 21 and Figure 10 indicate that:

- The Beauly connection options would represent the lowest cost generation connection options under the reduced TNUoS charging scenarios presently under consideration.

- When generation HVDC link outage costs are taken into consideration, capping of the TNUoS charges significantly reduces the differential cost margins between firm and non-firm connection options.

- A non-firm HVDC VSC connection arrangement would represent the lowest cost generator connection for all options, with the estimated levels of outage costs being below the increased TNUoS charges for a firm arrangement, even when capping of the TNUoS charges are taken into consideration.

9 Summary Comparison of Connection Options

Based on the various assessments detailed above, a comparison of each of the connection options considered is shown in Table 22.

It is evident that a connection to Beauly for the Western Isles generation would be highest availability, lowest cost connection option for the TSO and generators, with the lowest costs for generation financial support via TNUoS charges reduction.

In addition a connection to Beauly would enable the preferred technology of HVDC VSC to be utilised on an economically viable basis compared to HVDC Classic, taking into account the cost of losses and outages associated with both technologies.

		Subsea Cable		HVDC Converter		HVDC Link Losses	HVDC Link Availability		HVDC Link Outage Costs		Connection	TNUoS Charges		
Option		Timescale	Risk	VSC Technology	Classic Technology	Annual Cost	Firm	Non-Firm	Firm Connection	Non-Firm Connection	Capital Cost	Full Liability	Reduced Liability	System Recovery for Reduced Liability
A1	Beauly (Converter Remote)	Short (1.5 - 2 yrs)	Low (No Joints)	Yes	Yes	Low (£1.4-£3.5M/yr)	High (VSC = 99.7% Classic = 99.9%)	High (VSC = 96.7% Classic = 97.8%)	Low (£0.1M/yr)	Low (£2-£3M/yr)	Low (£249M - £517M)	Low (£56-£94/kW)	Low (£40-£59/kW)	Low (£9-£21M/yr)
A2	Beauly (Converter Local)	Short (1.5 - 2 yrs)	Low (No Joints)	Yes	Yes	Low (£1.5-£3.7M/yr)	High (VSC = 99.6% Classic = 99.9%)	High (VSC = 96.5% Classic = 97.7%)	Low (£0.1M/yr)	Low (£2-£3M/yr)	Low (£283M - £591M)	Low (£61-£104/kW)	Low (£42-£64/kW)	Low (£11-£24M/yr)
B1	Hunterston (Subsea)	Long (6 - 8 yrs)	High (Joints)	Possible Connection Distance Limitation	Yes	Medium (£2.1-£6.1M/yr)	High - Medium (VSC = 95.3% Classic = 99.2%)	Medium (VSC = 86.8% Classic = 93.6%)	Medium (£0.5-£0.7M/yr)	Medium - High (£6M/yr)	Medium (£447M - £944M)	Medium (£75-£144/kW)	Medium (£49-£85/kW)	Medium (£15-£36M/yr)
B2	Hunterston (Subsea/Land)	Long (6 - 8 yrs)	High (Joints)	Possible Connection Distance Limitation	Yes	Medium (£1.9-£5.5M/yr)	High - Medium (VSC = 97.0% Classic = 99.4%)	Medium (VSC = 89.7% Classic = 94.7%)	Medium (£0.4-£0.5M/yr)	Medium - High (£5M/yr)	Medium (£419M - £887M)	Medium (£70-£136/kW)	Medium (£47-£81/kW)	Medium (£14-£34M/yr)
C	Deeside	Long (10 - 11 yrs)	High (Joints)	Possible Connection Distance Limitation	Yes	High (£2.4-£7.5M/yr)	Medium - Low (VSC = 90.6% Classic = 98.5%)	Medium - Low (VSC = 80.5% Classic = 91.4%)	Medium (£0.8-£1.2M/yr)	High (£8M/yr)	High (£566M - £1206M)	High (£83-£172/kW)	High (£53-£98/kW)	High (£17-£45M/yr)
D	Pembroke	Long (11 - 12 yrs)	High (Joints)	Possible Connection Distance Limitation	Yes	High (£2.6-£8.3M/yr)	Medium - Low (VSC = 87.5% Classic = 98.1%)	Medium - Low (VSC = 77.2% Classic = 90.4%)	Medium (£1-£1.5M/yr)	High (£9M/yr)	High (£628M - £1338M)	High (£816-£185/kW)	High (£54-£105/kW)	High (£18-£49M/yr)

Table 22: Comparison of Western Isles HVDC Connection Options

APPENDIX A

INCREASING CAPACITY OF WESTERN ISLES LINK TO 1000MW

A: Increasing Capacity of Western Isles Link to 1000MW

Due to the modular nature of the HVDC links for the Western Isles it would be possible to expand both the firm and non-firm arrangements detailed for a 600MW capacity connection to a 1000MW capacity connection by the inclusion of additional modules, as shown in Table A.1 .

Connection	HVDC VSC	HVDC Classic
Firm	4 x 335MW Modules	2 x 600MW Bipole 1 x 400MW Bipole
Non-Firm	3 x 335MW Modules	1 x 600MW Bipole 1 x 400MW Bipole

Table A.1: Firm and Non-Firm 1000MW Connection Configurations

The use of an additional 400MW rated Bipole module for HVDC Classic would be a lower cost option than the use of a 600MW module.

If a firm 600MW capacity link was installed, it would be possible to operate the link as a non-firm 1000MW capacity link with no additional HVDC link infrastructure. However as is evident from the assessment of costs associated with HVDC link outages in the main report, the operation of non-firm connection arrangement would not be expected to be acceptable to generators for the connection options considered, with the exception of a connection to Beauly.

Conversely the operation of a firm connection arrangement would incur significant operational costs for the TSO, with the exception of a connection to Beauly, due to the high costs of generation constraint payments associated with HVDC link outages.

Indicative incremental capital costs for the expansion of a 600MW capacity link to 1000MW capacity by additional HVDC modules are detailed in Table A.2, with indicative timescales for the installation of the additional modules also detailed.

	Beauly (A1 - Remote)	Beauly (A2 - Local)	Hunterston (Subsea)	Hunterston (Subsea/Land)	Deeside	Pembroke
Additional HVDC VSC 335MW Module Indicative Cost (£M)	£ 124	£ 141	£ 223	£ 210	£ 283	£ 314
Additional HVDC Classic 400MW Module Indicative Cost (£M)	£ 193	£ 208	£ 385	£ 343	£ 490	£ 543
Additional Module Indicative Timescale	2 - 2.5 yrs	2 - 2.5 yrs	2.5 - 3 yrs	2.5 - 3 yrs	4 - 4.5yrs	4.5 - 5 yrs

Table A.2: Incremental Costs and Timescales for Expansion to 1000MW

A detailed assessment of the impact on HVDC link losses and availability for the expansion of a 600MW capacity link to 1000MW is omitted from this paper, but the findings of the main report, that a connection to Beauly would be the lowest cost, most efficient and most reliable option would still be applicable.