Report-BCTC-R009B

Expected Energy Not Served (EENS) Study for Vancouver Island Transmission Reinforcement Project

(Part II: Comparison between VITR and Sea Breeze HVDC Light Options)

December 23, 2005

Prepared by

Wenyuan Li
System Planning and Performance Assessment
British Columbia Transmission Corporation

DISCLAIMER

COPYRIGHT NOTICE

December 23, 2005

Expected Energy Not Served (EENS) Study for Vancouver Island Transmission Reinforcement Project
(Part II: Comparison between VITR and Sea Breeze HVDC Light Options)
(Executive Summary)

by Wenyuan Li
System Planning and Performance Assessment
British Columbia Transmission Corporation

The purpose of this study is to conduct a comparison in the reliability to VI power supply between the 230 kV line option (VITR proposed by BCTC) and the HVDC Light option (proposed by Sea Breeze Corporation). The technology used in the HVDC Light option is Voltage Source Converter (VSC).

Reliability of the VI power supply system depends on two factors: capacity of and failure probability of transmission supply sources. In the two options, 500 kV lines and local generation are identical. The 230 kV line option has a capacity of 600 MW at the receiving point whereas the Sea Breeze HVDC option has a capacity of 540 MW at the receiving point (574 MW at the delivery point minus 34 MW of losses). The Sea Breeze HVDC option is composed of underground cables, submarine cables and converter station equipment (valves, transformers, reactors, capacitors, controls, etc.), while the 230 kV line only consists of overhead lines, submarine cables and a phase shifting transformer. All these components are in series and the total length of underground and submarine in the Sea Breeze HVDC option (120.4 km) is much longer than that of the overhead line and submarine cable in the 230 kV line option (66.7 km). A basic concept in reliability evaluation is that more components in series and a longer distance of circuit will lead to a higher failure probability. Therefore, it can be qualitatively judged from both the capacity and failure probability of circuits that the 230 kV line will have higher supply reliability than the Sea Breeze HVDC link. The study given in this part of the report provides a proof through a quantified EENS reliability evaluation.

The failure data for HVDC components (converter station equipment, underground and submarine cables) used in the study are based on outage statistics in the similar HVDC projects across the world. Due to inherent uncertainty in the statistics, optimistic and pessimistic failure data estimates are obtained. The failure data for the 230 kV line are based on outage statistics of 230 kV overhead lines in the BC Hydro system and a pessimistic engineering estimate for the submarine cable (3 months of repair time due to extreme difficulties for repairing activities under water). The failure data of the phase shift transformer is based on historical failure records of the PST on 2L112 in the BC Hydro system.

The EENS study results indicate:

- The 230 kV AC line option can provide much better VI power supply reliability than the Sea Breeze HVDC link. The pessimistic failure data estimate is used for the 230 kV AC line. With the same pessimistic assumption of the failure data estimate for the submarine cable in the Sea Breeze HVDC link, the 230 kV AC line will result in about 26% to 32%

higher VI supply reliability. Even if the optimistic failure data estimate for the Sea Breeze HVDC link is used, the 230 kV AC line will still have about 15% to 18% higher VI supply reliability.

- The reason why the Sea Breeze HVDC provides lower reliability to VI supply (higher EENS) than the 230 kV AC line is not only because of its relatively higher unavailability but also due to that fact that the capacity of the Sea Breeze HVDC is 60 MW lower than the 230 kV AC line at the receiving point. The effect due to the lower capacity of 60 MW (600 MW - 540 MW) is comparable to the difference in the EENS caused by changing the availability from 97% to 93%.
- Although the Sea Breeze HVDC link unavailability based on the pessimistic failure data estimate is more than double of that based on the optimistic failure data estimate, the difference in the EENS indices for VI power supply system is only about 11% to 18 % depending on the load level on the Vancouver Island. In other words, VI power supply reliability will not have a significant variance when the availability of the Sea Breeze HVDC system ranges between 93% to 97%.

December 23, 2005

Expected Energy Not Served (EENS) Study for Vancouver Island Reinforcement Project (Part II: Comparison between VITR and Sea Breeze HVDC Light Options)

by Wenyuan Li
System Planning and Performance Assessment
British Columbia Transmission Corporation

1. Introduction

A report titled "Reliability Evaluation of Three Scenarios for Vancouver Island Power Supply – An Expected Energy Not Served (EENS) Study" was released for the VIGP project in June 11, 2003 [1]. In that report, three scenarios of VIGP (Portfolio 2), 230 kV line and HVDC life extension were evaluated and compared. Based on various technical studies and the VIGP hearing, it was decided to go ahead with the 230 kV line project.

The purpose of this study is to conduct a comparison in the reliability to VI power supply between the 230 kV line option (VITR proposed by BCTC) and the HVDC light option (proposed by Sea Breeze Corporation). The technology used in the HVDC light option is Voltage Source Converter (VSC).

Reliability of the VI power supply system depends on two factors: capacity of and failure probability of transmission supply sources. In the two options, 500 kV lines and local generation are the same. The 230 kV line option has a capacity of 600 MW at the receiving point whereas the Sea Breeze HVDC option has a capacity of 540 MW at the receiving point (574 MW at the delivery point minus 34 MW of losses). The Sea Breeze HVDC option is composed of underground cable, submarine cable and converter station equipment (valves, transformers, reactors, capacitors, controls, etc.), while the 230 kV line only consists of overhead line, submarine cable and a phase shifting transformer. All these components are in series and the total length of underground and submarine in the Sea Breeze HVDC option (120.4 km) is much longer than that of the overhead line and submarine cable in the 230 kV line option (66.7 km). A basic concept in reliability evaluation is that more components in series and a longer distance of circuit will lead to a higher failure probability. Therefore, it can be qualitatively judged from both the capacity and failure probability that the 230 kV line will have higher supply reliability than the Sea Breeze HVDC link. The study given below will provide a proof through a quantified EENS reliability evaluation.

The method and the computing tool used in this study are the same as those in Part I of the report (See Section 2 of Part I) [2]. The failure data for the 500 kV lines, 230 kV line (including overhead, submarine cable and phase shifting transformer) and local generating units are also the same as those in Part I. The failure data of Sea Breeze HVDC system are based on a published report, in which failure data of various HVDC components across the world are analyzed, and a published paper by CIGRE, in which the similar VSC-based HVDC project is presented.

2. Data

2.1 Sea Breeze HVDC system data

The Sea Breeze HVDC system data is summarized as follows.

Component	Parameter
Capacity	574 MW at delivering point, 540 MW at receiving point
Voltage	±150 kV
Converter station	150 m x 100 m
Underground cable (HVDC)	53.02 km (21.02 km on Lower Mainland, 32.0 km on VI)
Submarine cable (HVDC)	67.38 km (across the Straight of Georgia)
AC overhead lines	200 – 1000 m (from each converter station to nearby substation)

The detail data is given in Appendix D.

2.2 VITR 230 kV AC line data

The 230 kV line data is as follows:

Component	Parameter
Capacity	600 MW at receiving point
Phase shifting transformer	600 MW ±20 deg., 33 tap positions (can be bypassed)
Voltage	230 kV
Overhead lines (AC)	35.6 km
Submarine cable (AC)	31.1 km

2.3 Failure data

2.3.1 Failure data of the 230 kV line

The 230 kV AC line includes three portions: overhead line, submarine cable and phase shifting transformer. The failure data for the overhead portion were based on the average of existing 230 kV lines in the BC Hydro system, which were obtained from BCTC’s CROW (Control Room Operations Window) system. The failure data for the submarine cable were based on an engineering estimate. The failure data of the phase shift transformer is based on historical failure records of the PST on 2L112 in the BC Hydro system. The basic failure data used in the study is as follows:

Component	Failure frequency (failures/year)	Repair time (hours)
Overhead line (line-related)	0.2778	16.85
Overhead line (terminal-related)	0.2136	16.40
Submarine cable	0.1	2190
Phase shifting transformer	0.3333	3.06

It can be seen that a long repair time has been assumed for the submarine cable. This is based on the assumption that there is no specific shipping facility available for repairing activities under water. This is a pessimistic estimate. With the failure frequencies and repair times of components, the total FORs (Forced Outage Rate, i.e., unavailability) and equivalent repair times are:

For circuit (overhead and submarine cable combined):
FOR = 0.0259
Repair time = 383.74 hours

For the phase shifting transformer:
FOR = 0.000116
Repair time = 3.06 hours

Total unavailability of the 230 kV line (including overhead, submarine cables and PST):
FOR = 0.02602

The calculations for the FORs and repair times are given in Appendix B.

2.3.2 Failure data from other HVDC systems across the world

It is a reasonable approach to make use of failure data of other HVDC systems that have similarities to the Sea Breeze HVDC system.

1. Failure data from the Murraylink transmission interconnection project [3]

The Murraylink transmission interconnection project in Australia is a VSC-based HVDC link with only underground cable (177 km). The total availability of this VSC-based HVDC system in the one year is 97%, corresponding to an unavailability of 0.03 [3]. The most serious forced outage was a cable failure resulting in one week (168 hours) of outage in a year. Based on the data provided in Reference [3], the total unavailability can be broken down as follows:

- Unavailability due to the cable failure is: 1/52 = 0.019231. This unavailability corresponds to the whole underground cable of 177 km. Therefore, the unavailability in 100 km is 0.019231 x 100 /177 = 0.010864.
- Unavailability due to the converter station facilities is: 0.03 – 0.01923 = 0.010769.

2. Failure data from the report of “RAM Study Phase II: NORNED KABEL HVDC project” [4]

In this report, a comprehensive failure data analysis for HVDC components across the world (including converter station facilities, underground and submarine cables) was performed. Although the analysis is based on conventional HVDC systems, the reliability data especially on cables can be used as a reference in the reliability studies of the HVDC light. The failure data analysis given in the report shows that causes of cable failures mainly depend on its external environment (corrosion, ship accident, cable ducts, joints, etc.) and slightly on internal factors (such as insulation related to the voltage level). The failure data are always associated with uncertainty and the report provided pessimistic and optimistic estimates for failure data of both underground and submarine cables. According to the report, the following failure data are obtained:

- The average repair time of converter station facilities: 49.01 hours. This is a weighted average of repair times of various converter station components with their failures frequencies as weighting factors.

- Underground cable:

	Failure frequency (failures/year/100 km)	Repair time (hours)
Pessimistic estimate	0.057	312
Optimistic estimate	0.0144	288

- Submarine cable:

	Failure frequency (failures/year/100 km)	Repair time (hours)
Pessimistic estimate	0.2684	1272
Optimistic estimate	0.2684	936

Note: The failure frequency is associated with two portions: external and internal failures. The external failure frequency = 0.264 failures/year/100km and the internal failure frequency = 0.0044 failures/year/100km. It can be seen that the failure frequency is dominated by external factors. A larger estimate of internal failure frequency (0.0143 failures/year/100km) given in the report was not used in this study since it includes statistics in earlier years before 1965, which may be related to out-of-date technologies. Therefore the same failure frequency for both pessimistic and optimistic estimates is assumed.

2.3.3 Failure data used for the Sea Breeze HVDC system

The Sea Breeze HVDC system consists of three major portions: converter station, underground cable and submarine cable. The failure data for these three portions have to be estimated separately. The converter station facilities have similarities to those in other HVDC projects whereas the lengths of both underground and submarine cables are different from other HVDC projects.

The failure data for the Sea Breeze HVDC system is estimated with the following assumptions:

- The unavailability due to converter station facilities is the same as that obtained from the Murraylink transmission interconnection project since both HVDC systems use the VSC technology of ABB.

- The average repair time of the converter station facilities is the weighted average of repair times of various converter station components given in the report of “RAM Study Phase II: NORNED KABEL HVDC project”.
- For the unavailability of the underground cable, the failure data in the report of “RAM Study Phase II: NORNED KABEL HVDC project” provides the optimistic estimates and the failure data in the Murraylink transmission interconnection project provides the pessimistic estimates.
- For the repair time of the underground, the failure data in the report of “RAM Study Phase II: NORNED KABEL HVDC project” provides both optimistic and optimistic estimates.
- For the unavailability and repair time of the submarine cable, the failure data in the report of “RAM Study Phase II: NORNED KABEL HVDC project” provides the optimistic estimates and the failure data of the 230 kV AC line (submarine cable portion) provides the pessimistic estimates. The submarine portion in the 230 kV AC line option has the highest unavailability mainly due to the assumption of a long repair time (2190 hours). Using the assumption of the submarine cable of the 230 kV AC line option as the pessimistic estimate is reasonable since the purpose of the study is to conduct the comparison between the 230 kV AC line and Sea Breeze HVDC link.

It should be noted that in calculating the unavailability or failure frequency of underground and submarine cables for the Sea Breeze HVDC system, the values have been adjusted proportionally according to their actual lengths. The failure data used for the Sea Breeze HVDC system is as follows:

Optimistic estimates

Component	Length (km)	Repair time (hours)	Unavailability
Converter station facility		49.01	0.010769
Underground cable	53.02	288	0.000251
Submarine cable	67.38	936	0.019323
Whole HVDC (equivalent)		125.79	0.030344

Pessimistic estimates

Component	Length (km)	Repair time (hours)	Unavailability
Converter station facility		49.01	0.010769
Underground cable	53.02	312	0.005761
Submarine cable	67.38	2190	0.054164
Whole HVDC (equivalent)		268.85	0.070694

It can be seen that the optimistic estimate of the unavailability of the whole Sea Breeze HVDC system is slightly higher than that of the 230 kV line while the pessimistic estimate is twice higher than the optimistic estimate.

2.3.4 Failure data of 500 kV lines and local generating units

The failure data for the 500 kV lines and on-Island generating units were based on historical failure records and are the same as those used in Part I of the report. These data are given in Appendices A and B.

2.4 Load data

The load model used in the study was the most recent Vancouver Island peak load forecast for 2008/09 to 2022/23. The 8760 hourly load records in 2004 were used to model the annual load curve shape. The peak load forecast and the total VI generation MW are given in Appendix C.

3. EENS Evaluation

3.1 EENS for the Sea Breeze HVDC option using optimistic and pessimistic failure data

Both optimistic and pessimistic failure data for the Sea Breeze HVDC link were used to evaluate the EENS indices to Vancouver Island power supply. The results are shown in Table 1 and Figure 1. It can be seen that although the unavailability based on the optimistic failure data estimate is more than double of the unavailability based on the pessimistic failure data estimate, the difference in the EENS indices between the two cases is only about 11% to 18 %. In other words, VI power supply reliability will not have a significant variance when the availability of the Sea Breeze HVDC system ranges between 93 to 97%.

Table 1 EENS index (MWh/year) for Sea Breeze HVDC option

Year	HVDC	HVDC	Difference
Unavailability (Forced outage rate)	0.03034	0.07069	
Availability	0.96966	0.92931	
2008	3454	3888	11.16%
2009	3349	3767	11.10%
2010	3566	4047	11.89%
2011	3693	4211	12.30%
2012	3904	4522	13.67%
2013	4193	4824	13.08%
2014	4435	5167	14.17%
2015	4719	5468	13.70%
2016	5146	6020	14.52%
2017	5650	6716	15.87%
2018	6127	7329	16.40%
2019	6746	8059	16.29%
2020	7535	9150	17.65%
2021	8493	10299	17.54%
2022	9375	11385	17.65%

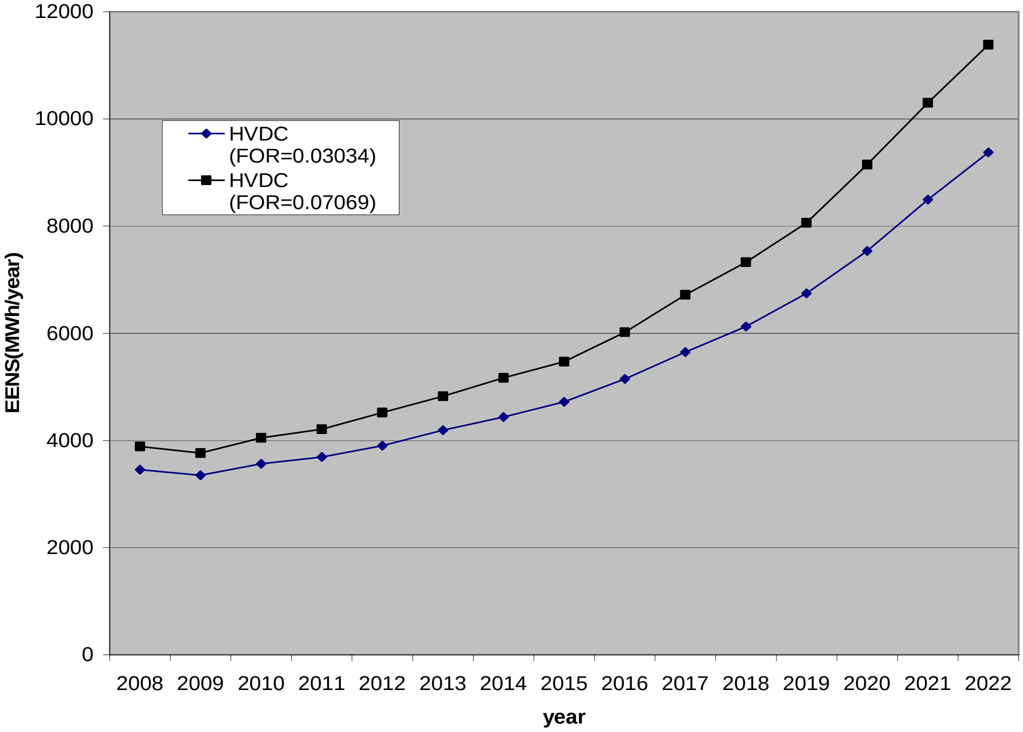


Figure 1 EENS index for Sea Breeze HVDC option

3.2 Comparison between the Sea Breeze HVDC link and 230 kV AC line options

The EENS indices for the Sea Breeze HVDC link and 230 kV AC line options are shown in Tables 2 and 3. The EENS indices for the Sea Breeze HVDC link in Table 2 correspond to the optimistic (lowest) failure data whereas those in Table 3 to the pessimistic failure data. The EENS indices for the 230 kV AC line are based on the assumption of the pessimistic failure data (0.1 failure/year and 2190 repair time for the submarine cable). It is noted that the optimistic failure data for the Sea Breeze HVDC link corresponds to the unavailability (FOR) of 0.03 or availability of 0.97. This estimate is, by chance, the same as the availability of HVDC system in the Murraylink transmission interconnection project in Australia, which used the same technology as the Sea Breeze HVDC system (VSC-based HVDC technology), although the two projects have different cable lengths. Also, it is noted that due to the pessimistic failure data assumption, the availability (97.4%) of the 230 kV AC line is only 0.4% higher than the availability (optimistic estimate) of the Sea Breeze HVDC link. However, even under this assumption, the 230 kV AC line option still provides a better VI supply reliability than the Sea Breeze HVDC link option (about 15% to 18% more reliable). If the pessimistic failure data are used for both options, the 230 kV AC line provides about 26% to 32% higher reliability than the Sea Breeze HVDC link.

Table 2 EENS indices (MWh/year) for Sea Breeze HVDC link (optimistic failure data) and 230 kV AC line (pessimistic failure data)

Year	HVDC	230kV line	Difference
Unavailability (Force outage rate)	0.03034	0.02602	
Availability	0.96966	0.97398	
Capacity	540 MW	600 MW	
2008	3454	2870	16.91%
2009	3349	2779	17.02%
2010	3566	2969	16.74%
2011	3693	3085	16.46%
2012	3904	3281	15.96%
2013	4193	3523	15.98%
2014	4435	3769	15.02%
2015	4719	3991	15.43%
2016	5146	4348	15.51%
2017	5650	4692	16.96%
2018	6127	5152	15.91%
2019	6746	5710	15.36%
2020	7535	6238	17.21%
2021	8493	6989	17.71%
2022	9375	7807	16.73%

Table 3 EENS indices (MWh/year) for Sea Breeze HVDC link (pessimistic failure data) and 230 kV AC line (pessimistic failure data)

Year	HVDC	230kV line	Difference
Unavailability (Forced outage rate)	0.07069	0.02602	
Availability	0.92931	0.97398	
Capacity	540 MW	600 MW	
2008	3888	2870	26.18%
2009	3767	2779	26.23%
2010	4047	2969	26.64%
2011	4211	3085	26.74%
2012	4522	3281	27.44%
2013	4824	3523	26.97%
2014	5167	3769	27.06%
2015	5468	3991	27.01%
2016	6020	4348	27.77%
2017	6716	4692	30.14%
2018	7329	5152	29.70%
2019	8059	5710	29.15%
2020	9150	6238	31.83%
2021	10299	6989	32.14%
2022	11385	7807	31.43%

3.3 Contribution of different capacities to the EENS

To discover the contribution of different capacities to the EENS, a study was conducted with the assumption that the capacity of the Sea Breeze HVDC link is increased to be the same as the 230 kV AC line (i.e., 600 MW) but with the unchanged unavailability (0.03) that is based on the optimistic failure data. The comparison in the EENS indices between this case and the case with 540 MW of capacity is given in Table 4. By comparing the “difference” columns in Tables 2 and 4, it can be asserted that only about 2% to 3% in the total difference of 15% to 18% in the EENS between the Sea Breeze HVDC link and 230 kV AC line is due to different unavailability values of the two options while the contribution of the different capacities (540 MW and 600 MW) to the EENS is about 13% to 15 %. Also, by comparing the numbers in the “difference” columns of Tables 1 and 4, it can be seen that the contribution due to the lower capacity of 60 MW (600 MW - 540 MW) is comparable to the difference in the EENS caused by changing the availability from 97% to 93%.

Table 4 Contribution to EENS (MWh/year) due to a capacity difference of 60 MW

Year	HVDC	HVDC	Difference
Unavailability (Forced outage rate)	0.030344	0.030344	
Availability	0.969656	0.969656	
Capacity	540 MW	600 MW	
2008	3454	2942	14.82%
2009	3349	2865	14.45%
2010	3566	3053	14.39%
2011	3693	3174	14.05%
2012	3904	3387	13.24%
2013	4193	3617	13.74%
2014	4435	3871	12.72%
2015	4719	4127	12.55%
2016	5146	4483	12.88%
2017	5650	4890	13.45%
2018	6127	5304	13.43%
2019	6746	5885	12.76%
2020	7535	6516	13.52%
2021	8493	7295	14.11%
2022	9375	8076	13.86%

4. Conclusions

This part of the report compared the Sea Breeze HVDC Light link with the VITR 230 kV AC line against Vancouver Island power supply reliability. The failure data for HVDC components (converter station equipment, underground and submarine cables) used in the study are based on outage statistics in the similar HVDC projects across the world. Due to inherent uncertainty in the statistics, optimistic and pessimistic failure data estimates are obtained. The failure data for the 230 kV AC line are based on outage statistics of 230 kV overhead lines and phase shifting transformer in the BC Hydro system and a pessimistic estimate for the submarine cable.

The EENS study results indicate:

- The 230 kV AC line option can provide much better VI power supply reliability than the Sea Breeze HVDC link. The pessimistic failure data estimate is used for the 230 kV AC line. With the same pessimistic assumption of the failure data estimate for the submarine cable in the Sea Breeze HVDC link, the 230 kV AC line will result in about 26% to 32% higher VI supply reliability. Even if the optimistic failure data estimate for the Sea Breeze HVDC link is used, the 230 kV AC line will still have about 15% to 18% higher VI supply reliability.
- The reason why the Sea Breeze HVDC provides lower reliability to VI supply (higher EENS) than the 230 kV AC line is not only because of its relatively higher unavailability but also due to that fact that the capacity of the Sea Breeze HVDC is 60 MW lower than the 230 kV AC line at the receiving point. The effect due to the lower capacity of 60 MW (600 MW - 540 MW) is comparable to the difference in the EENS caused by changing the availability from 97% to 93%.
- Although the Sea Breeze HVDC link unavailability based on the pessimistic failure data estimate is more than double of that based on the optimistic failure data estimate, the difference in the EENS indices for VI power supply system is only about 11% to 18 % depending on the load level on the Vancouver Island. In other words, VI power supply reliability will not have a significant variance when the availability of the Sea Breeze HVDC system ranges between 93% to 97%.

References

[1] BCTC Report, *Reliability Evaluation of Three Scenarios for Vancouver Island Power Supply – An Expected Energy Not Served (EENS) Study*, filed to BCUC in June 2003

[2] BCTC Report, *Expected Energy Not Served (EENS) Study for Vancouver Island Transmission Project (Part I: Reliability Improvements due to VITR)*, December 8, 2005

[3] A. Ericsson (ABB), al et, “Murraylink, The Longest Underground HVDC Cable in the World”, the CIGRE paper No. B4-103, 2004

[4] Berdal Stromme Report: *RAM Study Phase 2: NORNED KABEL HVDC Project*, Aril 15, 1998 (This report can be found at the following webpage; www.tennet.org/images/B2%20Berdal%20Stromme%20RAM%20study_tcm14-7508.pdf.)

Appendix A: Local Generating Unit Reliability Data

Generating unit	Capacity (MW)	FOR	Repair time (hrs)
ASH	27	0.004	15.35
JHT-1	21 *	0.0795	926.51
JHT-2	21 *	0.0008	2.31
JHT-3	21 *	0.003	36.32
JHT-4	21 *	0.0026	7.84
JHT-5	21 *	0.0096	28.70
JHT-6	21 *	0.0003	3.77
PUN	24	0.0010	13.74
LDR-1	24	0.0063	19.15
LDR-2	24	0.0026	6.60
SCA-1	32	0.0027	5.33
SCA-2	32	0.0218	28.26
UCO/Zeballos	15	0.004	15.35
JOR	170	0.0124	5.99
ICG	240	0.1065 **	50.30 **
Total	714		

Note:

1. The reliability data for the local hydro generating units are based on historical outage records. These data are the same as those used in the following previous reports:

[1] BC Hydro technical report, "Reliability Assessment of Vancouver Island Supply 2000/01", Section 3 of "Vancouver Island Operation Plan 2000/01" produced by NOS (Network Operation Services), Grid Operation Division, BC Hydro, January 15, 2001
[2] BC Hydro technical, "Reliability Assessment for Vancouver Island Supply Options", produced by NPP (Network Performance Planning), BC Hydro, December, 2001
[3] BC Hydro technical report, "Probabilistic & Economic Assessment of HVDC Short-term Investment Strategies", produced by NOS (Network Operation Services), Grid Operation Division, BC Hydro, June 2002

2. * The 6 units at JHT are assumed to increase their capacity by 5 MW each by 2009/2010.
3. ** The failure data for the ICG are based on historical statistics from the NERC database for combined cycle turbine units from 1977 to 2001. The raw data can be found at http://www.nerc.com/~filez/gar.html. The breakdown of forced and planned failure data is as follows:

Unit	Capacity (MW)	Unavailability		Failure Frequency (f/year)		Repair time (hrs)	
		Forced	Planned	Forced	Planned	Forced	Planned
ICG	240	0.03238	0.07407	13.22	5.32	21.46	122.0

Appendix B: 500 kV Line and 230 kV Line Reliability Data

Line	Capacity (MW)	FOR	Repair time (hrs)
500 kV line	1200	0.0293	137.81
500 kV line	1200	0.0293	137.81
230 kV line	600	0.0259	383.74
Second 230 kV line	600	0.0259	383.74
Phase shift transformer	600	0.000116	3.06
Common cause failure of two 500 kV lines		0.0004	2.98

Note:

1. The reliability data for the 500 kV lines (including the common cause failure data) are the same as those used in the following previous reports:

[1] BC Hydro technical report, “Reliability Assessment of Vancouver Island Supply 2000/01”, Section 3 of “Vancouver Island Operation Plan 2000/01” produced by NOS (Network Operation Services), Grid Operation Division, BC Hydro, January 15, 2001

[2] BC Hydro technical, “Reliability Assessment for Vancouver Island Supply Options”, produced by NPP (Network Performance Planning), BC Hydro, December, 2001

[3] BC Hydro technical report, “Probabilistic & Economic Assessment of HVDC Short-term Investment Strategies”, produced by NOS (Network Operation Services), Grid Operation Division, BC Hydro, June 2002

2. The common cause failure of two 500 kV lines refers to their simultaneous outage due to a common cause (lightning and terminal breaker failures).

3. The failure data of the phase shift transformer is based on historical failure records of the PST on 2L112 in the HC Hydro system. There were only 5 forced failures with a total of outage duration of 15.28 hours in the past 15 years since it was in service in 1990. This translates into the unavailability (FOR) of 0.000116, a forced failure frequency of 0.3333 failures /year and the repair time of 3.06 hours/repair.

4. The reliability data for the overhead portion of the new 230 kV line is based on the average of historical records of 230 kV lines in the BC Hydro system. The reliability data for the submarine portion is estimated as failure frequency=1/10 years and average repair time = 3 months. The total equivalent reliability data are calculated as follows (planned outage not considered):

Submarine portion:

f(cable)=1/10 years=0.1 f/year r(cable)=3 months =2190 hrs
FOR(cable)=f(cable)$*$r(cable)/8760 =0.025

Overhead portion- Line-related failure

f1=0.6945 /year/ 100 km*40 km=0.2778/year r1=16.85 hours

Overhead portion- terminal-related failure

f2=0.2136 r2=16.40 hours

Overhead portion – total

f(overhead)=0.2778+0.2136=0.4914
r(overhead) = Σfr/Σf = (0.2778*16.85+0.2136*16.40)/(0.4914)=16.65

FOR(overhead)=f(overhead)*r(overhead)/8760 = 0.00093

The total reliability data for the new 230 kV line is estimated as:

FOR(total) = FOR(cable) +FOR(overhead) – FOR(cable)*FOR(overhead)

= 0.025+0.00093-0.025*0.00093 =0.02591

f(total) = 0.1+0.4914=0.5914

r(total) = FOR(total)*8760/f(total) = 0.02591*8760/0.5914 = 383.74 hours

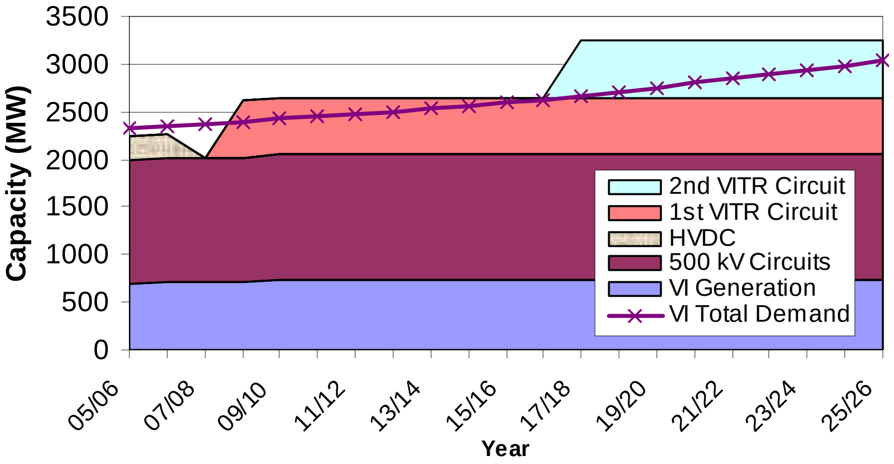
Appendix C: Load forecast and resources balance for 2005/06 to 2025/26

Vancouver Island Demand and Resource Balance

(Based on the BC Hydro Dec 2005 load forecast)

	VI Demand	VI Dep_Gen*	500 kV	HVDC	1st cct	2nd cct	Balance
	MW	MW	MW	MW	MW	MW	MW
05/06	2318	698	1300	240			-80
06/07	2349	714	1300	240			-95
07/08	2370	714	1300				-355
08/09	2397	714	1300		600		217
09/10	2425	744	1300		600		219
10/11	2454	744	1300		600		190
11/12	2470	744	1300		600		174
12/13	2498	744	1300		600		146
13/14	2531	744	1300		600		113
14/15	2561	744	1300		600		83
15/16	2589	744	1300		600		55
16/17	2628	744	1300		600		16
17/18	2668	744	1300		600	600	576
18/19	2710	744	1300		600	600	534
19/20	2753	744	1300		600	600	491
20/21	2800	744	1300		600	600	444
21/22	2847	744	1300		600	600	397
22/23	2892	744	1300		600	600	352
23/24	2937	744	1300		600	600	307
24/25	2983	744	1300		600	600	260
25/26	3030	744	1300		600	600	214

* The VI dependable generations are assumed to be same as the previous (NITS2004 dependable resource).


Capacity (MW)
3500
3000
2500
2000
1500
1000
500
0
05/06
07/08
09/10
11/12
13/14
15/16
17/18
19/20
21/22
23/24
25/26
Year
2nd VITR Circuit
1st VITR Circuit
HVDC
500 kV Circuits
VI Generation
VI Total Demand

Appendix C: Summary specification of Sea Breeze HDVC project

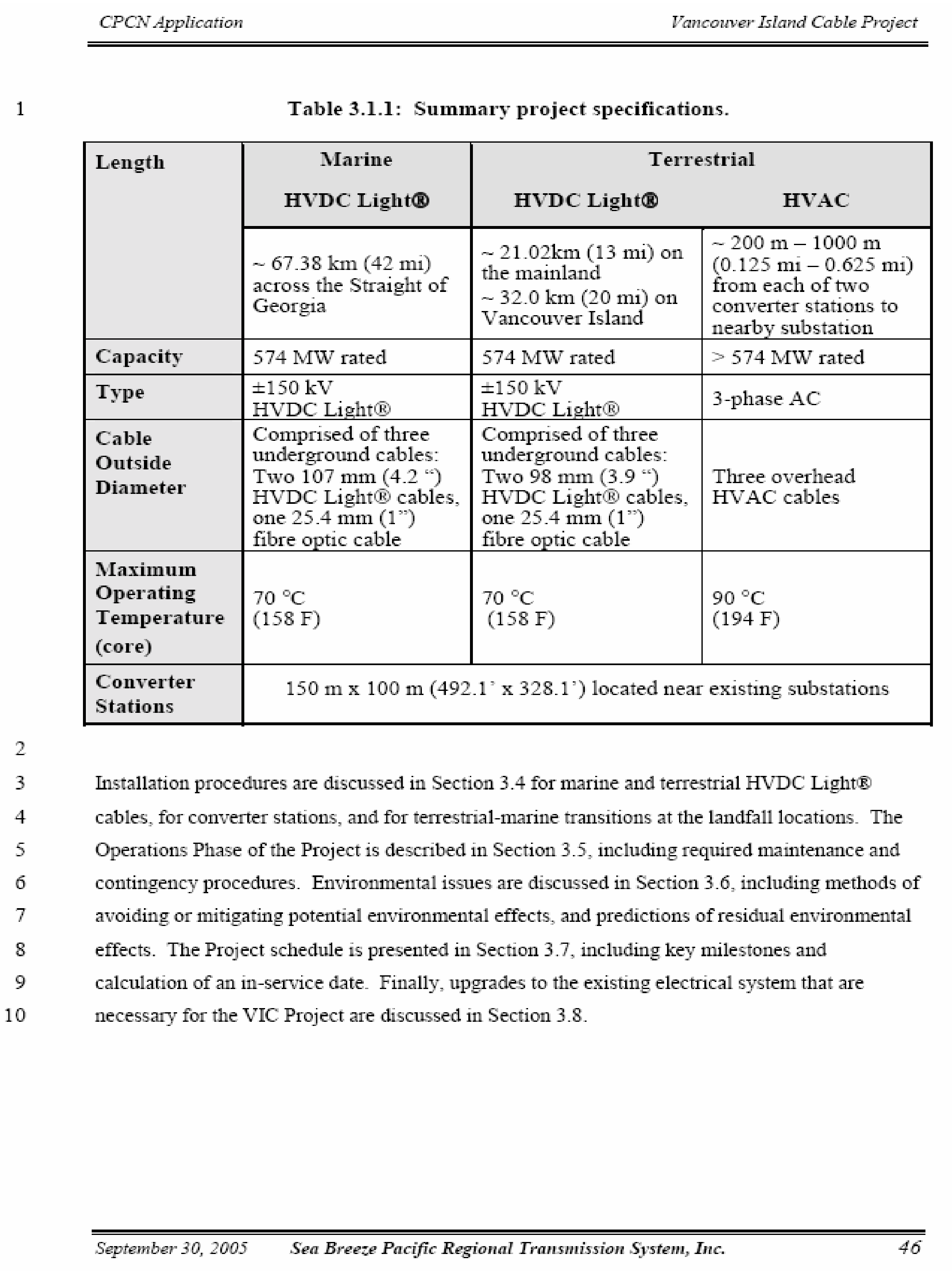


Table 3.1.1: Summary project specifications.

Length	**Marine**	**Terrestrial**	
	HVDC Light®	**HVDC Light®**	**HVAC**
	~ 67.38 km (42 mi) across the Straight of Georgia	~ 21.02km (13 mi) on the mainland ~ 32.0 km (20 mi) on Vancouver Island	~ 200 m – 1000 m (0.125 mi – 0.625 mi) from each of two converter stations to nearby substation
Capacity	574 MW rated	574 MW rated	> 574 MW rated
Type	±150 kV HVDC Light®	±150 kV HVDC Light®	3-phase AC
Cable Outside Diameter	Comprised of three underground cables: Two 107 mm (4.2 ") HVDC Light® cables, one 25.4 mm (1") fibre optic cable	Comprised of three underground cables: Two 98 mm (3.9 ") HVDC Light® cables, one 25.4 mm (1") fibre optic cable	Three overhead HVAC cables
Maximum Operating Temperature (core)	70 °C (158 F)	70 °C (158 F)	90 °C (194 F)
Converter Stations	150 m x 100 m (492.1' x 328.1') located near existing substations		

Installation procedures are discussed in Section 3.4 for marine and terrestrial HVDC Light® cables, for converter stations, and for terrestrial-marine transitions at the landfall locations. The Operations Phase of the Project is described in Section 3.5, including required maintenance and contingency procedures. Environmental issues are discussed in Section 3.6, including methods of avoiding or mitigating potential environmental effects, and predictions of residual environmental effects. The Project schedule is presented in Section 3.7, including key milestones and calculation of an in-service date. Finally, upgrades to the existing electrical system that are necessary for the VIC Project are discussed in Section 3.8.