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Risk Assessment and Replacement Strategy for Cable 1 of HVDC Pole 1

Prepared by

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Risk Assessment and Replacement Strategy for Cable 1 of HVDC Pole 1 (Executive Summary)

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The recent field inspection identified that the cable 1 of HVDC Pole 1 has some armour damages near the top touch down point of the first catenary with three broken wire strands [1]. According to the cable specialist, Mr. Joseph Jue, the section of the cable 1 with armour damages can have a high possibility of fatal failure within a couple of years.

The questions we are facing for the replacement strategy of the damaged section of the cable 1 are:

- Should we replace it?
- If yes, should we replace it before or after it fails?

This report performed a quantified risk assessment for the end-of-life failure of the damaged section of the cable 1 through an EENS study. The basic idea is to compare risks and risk costs for the three options: replacing the damaged section of the cable 1 now (before it fails), replacing it right after it fails and not replacing it regardless of its failure.

The results indicate:

- The cumulative risk to the VI power supply system in the 5 year's period from 2006 to 2010 for the option of replacing the damaged section of the cable 1 now is higher than the option of replacing it after it fails.
- Although the cumulative system risk in the 5 year's period for the option of replacing it after it fails is lower than not replacing it, the benefit/cost ratio for the replacement is less than 1.0. The later it fails, the lower the benefit/cost ratio is.

After the cable 1 is permanently out-of-service, the HVDC will have a maximum capacity of 492 MW (336 MW for Pole 2 and 156 MW for Pole 1) without any field work. The operation mode with the half of Poles 1 and 2 can still provide the capacity of 246 MW. If one of the two 900 amp cables for Pole 2 is exchanged with the remaining 600 amp cable for Pole 1, the maximum capacity of the HVDC can reach 570 MW. This operation mode may require some field work and cost.

The recommendations are:

- The cable 1 of Pole 1 is used as it is.
- If the cable 1 does not fail in 2006, it is recommended to not replace it even if it fails later, that is, the HVDC will be operated without the cable 1 if it fails later than 2006.
- If the cable 1 fails in 2006, an update study may be needed with a more accurate estimate on the in-service date of the 230 kV line.
- It is necessary to prepare a detailed plan for the VI supply prior to the 230 kV line in service, including a contingency plan for end-of-life failure of the cable 1.

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1. Introduction

The recent field inspection identified that the cable 1 of HVDC Pole 1 has some armour damages near the top touch down point of the first catenary with three broken wire strands [1]. According to the cable specialist, Mr. Joseph Jue, the section of the cable 1 with amour damages can have a high possibility of fatal failure within a couple of years.

The questions we are facing for the replacement strategy of the damaged section of the cable 1 are:

- Should we replace it?
- If yes, should we replace it before or after it fails?

To answer these two questions, a risk assessment associated with the cable 1 has to be performed. The HVDC is a power source to VI power supply. The importance of the cable 1 and thus its replacement strategy should depend on its impacts on the VI power supply but not just the status of the cable 1.

The purpose of this study is to provide a quantified risk assessment for the end-of-life failure of the damaged section of the cable 1 and recommendations for its replacement strategy.

2. Method and Modeling

The method includes the following steps:

(1) Estimating average unavailability of individual HVDC components including both repairable and end-of-life failure modes
(2) Calculating capacity levels and capacity probability distributions of HVDC Poles 1 and 2 for the case with the existing cable 1
(3) Calculating capacity levels and capacity probability distributions of HVDC Poles 1 and 2 for the case with the replaced cable 1
(4) Calculating capacity levels and capacity probability distributions of HVDC Poles 1 and 2 for the case without the cable 1
(5) Evaluating the risks of VI power supply system for the three cases in (2), (3) and (4)
(6) Performing the analysis for the replacement strategy of the cable 1

In the recent reliability study for the Vancouver Island Transmission Reinforcement Project (VITR) [2], the steps 1 and 2 have been completed. This report focuses on the steps (3) – (6).

The model of evaluating the risk of VI power supply system is shown in Figure 1. The EENS index is used to express the risk of VI power supply. The MCGSR computing program is used to conduct the risk assessment. The basic concepts regarding EENS and MCGSR can be found in [3, 4].

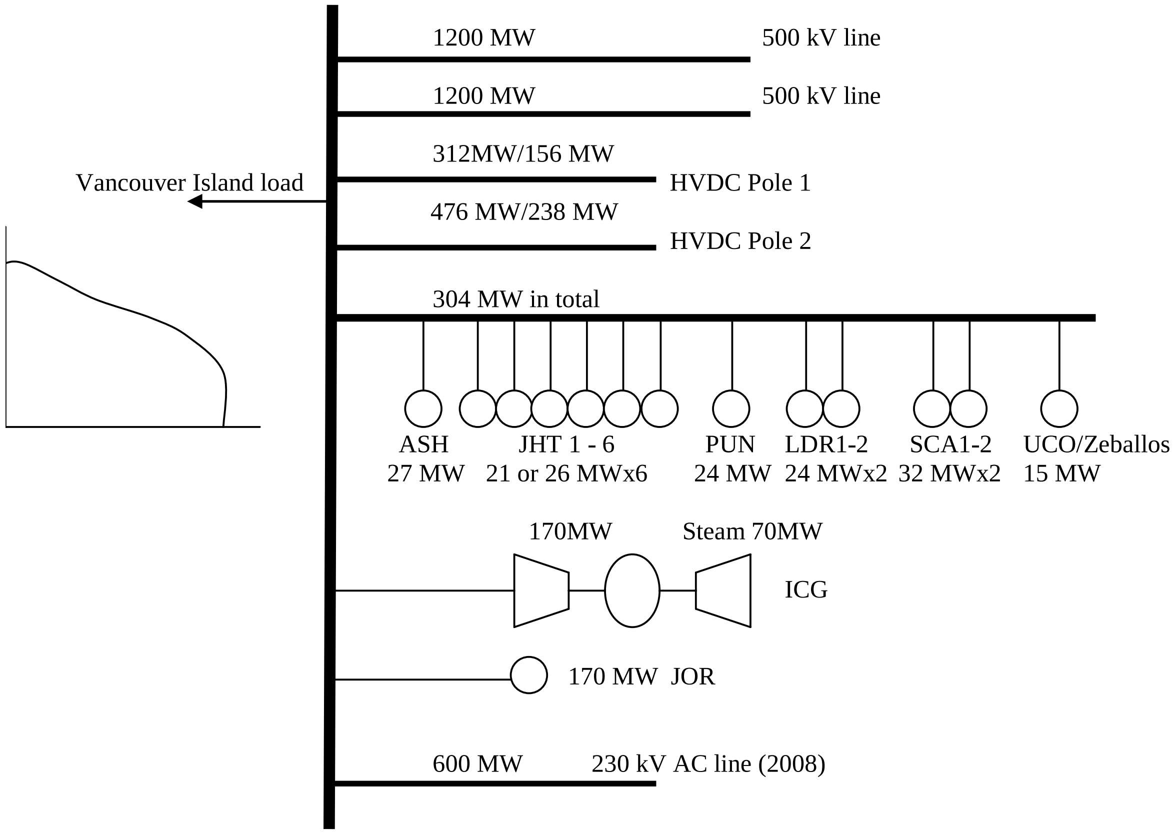

Figure 1 Risk Evaluation Model for Vancouver Island supply

3. Study Conditions

- The time frame in the study is the 5 year's period from 2006 to 2010. The VITR project (a new 230 kV line to VI supply) is assumed to be in service in 2008.

- In case of replacement, only the damaged section of the cable 1 near Galiano Island (5 km) is replaced. The total length of the cable 1 is 32.5 km. With the replaced section, the unavailability of the cable 1 is reduced proportionally in terms of its old portion with respect to the total length.

- The peak loads from 2006 to 2010 are based on the most recent load forecast (December 2005) while the annual load curves for all the 5 years under the study follow the same shape that is based on the hourly load records in 2004.

- Sea return (neutral return current flowing through water in the sea) is not an acceptable option for continuous long time operation since this may cause possible corrosions of facilities of customers and residents around the area.

- Both Poles 1 and 2 of HVDC were modeled using three capacity states (full up, derated to half and full down). If the cable 1 of Pole 1 has the end-of-life failure with permanent out-of-service, the capacities of both HVDC Poles 1 and 2 will be derated. The capacity of Pole 1 is limited by one 600 amp cable whereas the capacity of Pole 2 is limited due to the fact that the currents flowing through Poles 1 and 2 have to be balanced.

- The phase shifting transformer (PST) was modeled by assuming that it is in series with the 230 kV line and no bypass operation for the PST.

- The capacity of two 500 kV lines is assumed to be the continuing rating (1200 MW). A short time (2 hours) overloading capacity (1300 MW) is not considered since the repair time used in the simulation (138 hours) is much longer than 2 hours. In other words, considering a 100 MW higher capacity for only 2 hours will not have effective impacts on the results for one year's simulation.

4. Data

4.1 HVDC Capacity

There are two 600 amp cables for Pole 1, one 600 amp cable for neutral current return and two 900 amp cables for Pole 2. The full capacities of HVDC Poles 1 and 2 for the existing HVDC system (the cable 1 still in service) are:

Pole 1: 260 kV x 1200 amp = 312 MW
Pole 2: 280 x 1700 amp = 476 MW
(Note: 1700 amp but not 1800 amp has been used due to restriction of converter capacity)

With the cable 1 out-of-service, only one 600 amp cable is operated for Pole 1 and another 600 amp cable for neutral return. To make the currents of Poles 1 and 2 to be balanced, the maximum current for Pole 2 is 1200 amp. The capacities of Poles 1 and 2 without the cable 1 are calculated as follows:

Pole 1: 260 kV x 600 = 156 MW
Pole 2: 280 kV x 1200 = 336 MW

4.2 Failure data

The failure data for the 500 kV lines and on-Island generating units are based on historical failure records. The failure data for a new 230 kV AC line includes two portions for overhead line and submarine cable. The failure data for the overhead portion are based on the average of existing 230 kV lines in the BC Hydro system, which are obtained from BCTC's CROW (Control Room Operations Window) system. The failure data for the submarine cable are based on an engineering estimate. This is a relatively pessimistic estimate since the repair time is assumed to be 3 months (2190 hours) considering that repair activities under water will be extremely difficult. This pessimistic data estimate means that the VI supply will more rely on HVDC. The failure data of the phase shift transformer (PST) that is in series with the 230 kV line is based on historical failure records of the PST on 2L112 in the HC Hydro system. All these data are the same as those used in the report for the VITR project [2] and are given in Appendix A and B.

The capacity state probabilities of the existing HVDC system are obtained from the previous report [5] and are the same as those used in the report for the VITR project [2]. These probabilities are presented in Tables 1 and 2. The capacity state probabilities of the HVDC system with the replaced cable 1 are evaluated and presented in Tables 3 and 4. The capacity state probabilities of the HVDC system without the cable 1 are evaluated and presented in Tables 5 and 6. The following observations can be made:

- Replacing the cable 1 can slightly increase the probabilities of both poles at the maximum capacity levels. However, the increase is very small because only one cable section of 5 km is replaced and the rest portion (27.5 km) is still an aged cable and the impact of the cable 1 on the capacity probability distribution of the whole HVDC is minimal.
- The probabilities of HVDC Poles 1 and 2 at the maximum capacity without the cable 1 are slightly higher than those with the cable 1, which results in slightly lower probabilities at the zero and/or derated capacity levels for the case without the cable 1. This is because all the cables are required to reach the maximum capacity, or say, all the cables are logically in series in the reliability model. One basic concept in reliability evaluation is that removing one more component from a series logical model leads to a higher success (at the maximum capacity) probability or a lower failure probability. The impact of the cable 1 out-of-service is mainly the reduced capacities for both Poles 1 and 2 but not capacity state probabilities.

Table 1 Capacity state probabilities of Pole 1 with all existing cables

	Probability at 312 MW only	Probability at 156 MW	Probability at zero MW
2006	0.106243735	0.152434503	0.741321762
2007	0.075725132	0.124754433	0.799520435
2008	0.051009050	0.097306577	0.851684374
2009	0.032753449	0.072326656	0.894919895
2010	0.019887959	0.050931581	0.929180460

Table 2 Capacity state probabilities of Pole 2 with all existing cables

	Probability at 476 MW only	Probability at 238 MW	Probability at zero MW
2006	0.554333069	0.216997424	0.228669507
2007	0.512838492	0.217244321	0.269917187
2008	0.463541606	0.218515517	0.317942876
2009	0.413689862	0.216221708	0.370088431
2010	0.362198344	0.211159543	0.426642113

Table 3 Capacity state probabilities of Pole 1 with the replaced cable 1

	Probability at 312 MW only	Probability at 156 MW	Probability at zero MW
2006	0.106944494	0.152709123	0.740346383
2007	0.076228654	0.125058682	0.798712664
2008	0.051351387	0.097602359	0.851046254
2009	0.032975628	0.072585300	0.894439072
2010	0.020024502	0.051138621	0.928836877

Table 4 Capacity state probabilities of Pole 2 with the replaced cable 1

	Probability at 476 MW only	Probability at 238 MW	Probability at zero MW
2006	0.557989321	0.214615684	0.227394995
2007	0.516248523	0.215131435	0.268620042
2008	0.466652574	0.216735362	0.316612064
2009	0.416496079	0.214758473	0.368745447
2010	0.364685055	0.210011597	0.425303347

Table 5 Capacity state probabilities of Pole 1 without the cable 1

	Probability at 156 MW only	Probability at 78 MW	Probability at zero MW
2006	0.122508347	0.147066434	0.730425219
2007	0.087353876	0.123346221	0.789299902
2008	0.059378386	0.098648047	0.841973567
2009	0.038348715	0.074954605	0.886696679
2010	0.023438967	0.053882509	0.922678524

Table 6 Capacity state probabilities of Pole 2 without the cable 1

	Probability at 336 MW only	Probability at 168 MW	Probability at zero MW
2006	0.578098707	0.201516114	0.220385180
2007	0.535003695	0.20351056	0.261485745
2008	0.483762895	0.206944509	0.309292596
2009	0.431930277	0.206710684	0.361359039
2010	0.378361967	0.203697894	0.417940139

4.3 Load data

The load model used in the study was the most recent Vancouver Island peak load forecast for 2006/07 to 2010/2011. 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.

5. EENS Evaluation and replacement analysis

The impacts of different replacement strategies depend on the year of the 230 kV line in service. The planned in-service year of the 230 kV line is 2008 but it may be delayed. Two in-service years are considered below.

5.1 230 kV line in-service in 2008

The EENS indices for VI power supply system with the existing cable 1, with the replacement of damaged section of the cable 1 and without the cable 1 from 2006 to 2010 are evaluated and shown in Table 7. It can be seen that the EENS indices for using the existing cable 1 and replacing damaged section of the cable 1 are almost the same due to the fact that there are same state capacities but very minor differences in capacity probability distributions for the two cases.

Table 7 EENS for VI supply system (MWh/year)
(the 230 kV line in service in 2008)

	With existing Cable 1	With replaced Cable 1	Without Cable 1
2006	4850	4843	6097
2007	5655	5642	6881
2008	1140	1138	1406
2009	1271	1268	1504
2010	1542	1541	1755

Using the results in Table 7, a replacement strategy analysis for the cable 1 can be performed. The following three options are considered for comparison:

(1) Replacing the cable 1 now (in 2006) before it fails.
(2) Replacing the cable 1 after it fails.
(3) Not replacing the cable 1 (using it until it fails and operating the HVDC without it after its failure).

In the following analysis, the replacement duration is assumed to be one year. As mentioned in the assumptions, the period of the five years from 2006 to 2010 is considered in the analysis.

(1) If the cable 1 is replaced now (in 2006) before it fails, the HVDC will be operated without the cable 1 for replacement in 2006 and with it (after replacement) from 2007 to 2010. The total EENS for the period of the 5 years is: 6097+5642+1138+1268+1541 =15,686 MWh.

(2) If the cable 1 is replaced after it fails, there will be different possibilities since it can fail in any year from 2006 to 2010. If it fails now and is replaced right away, the total EENS for the 5 year's period is the same as that for Option (1) (replacing now). If it fails in some year later and starts replacement right after its failure, the HVDC will be operated without the cable 1 for that year, with the existing cable 1 for years before that year and with the replaced cable 1 for other years after that year. For example, if it fails in early 2007, the total EENS for the period of the 5 years is: 4850+6881+1138+1268+1541=16,396 MWh. The total EENS indices for replacement after the failure in the period of the 5 years for the different failure years are summarized in Table 8.

(3) If the cable 1 is never replaced, (i.e., it is used until it fails and the HVDC is operated without it after its failure), the VI supply risk also depends on the year in which it fails. The later it fails, the lower the risk is. For example, if it fails in early 2008, the total EENS for the period of the 5 years is: 4850+5655+1406+1504+1755=15,170 MWh. The total EENS indices for not replacing the cable 1 after its failure in the period of the 5 years for the different failure years are summarized in Table 9. Note that if the cable 1 fails in early 2010, the total EENS without replacement in the 5 year's period is the same as that with replacement because the replacement is assumed to take one year and therefore the HVDC will be still operated without

the cable 1 during replacement. Performing the replacement in 2010 will only have a benefit on VI reliability after 2010, which will be minimal.

Table 8 Total EENS with replacement after the failure in the 5 year's period for different failure years (the 230 kV line in service in 2008)

Failure year of Cable 1	EENS (MWh)
In early 2006 (now)	15,686
In early 2007	15,678
In early 2008	14,720
In early 2009	14,690
In early 2010	14,671

Table 9 Total EENS without replacement after the failure in the 5 year's period for different failure years (the 230 kV line in service in 2008)

Failure year of Cable 1	EENS (MWh)
In early 2006 (now)	17,643
In early 2007	16,396
In early 2008	15,170
In early 2009	14,904
In early 2010	14,671

By comparing the total EENS indices between the two options of replacing the damaged section of the cable 1 before and after its failure, it can be seen that replacing the cable 1 after its failure results in a lower risk. The later its failure occurs, the lower risk is.

To compare the two options of replacing the cable 1 after its failure and not replacing it, we should compare the reduced risk due to replacing it against the cost required to replace it. The total EENS indices for the two options, reduction of EENS and reduction of risk cost due to replacing it (benefit) in different failure years are summarized in Table 10. The reduced risk cost is the product of the reduced EENS and unit interruption cost. The unit interruption cost is estimated as follows:

The provincial GDP at market prices for 2004 is $157.241 Billion [6]
The total electricity energy domestic consumption for 2004/2005 is 51,205 GWh [7]
The unit interruption cost is: 157.241e9/51.205e9 = $3.07/kWh

Table 10 Total EENS for the two options, reduced EENS and reduced risk cost due to replacement (the 230 kV line in service in 2008)

Failure year of Cable 1	EENS (MWh) (No replacement)	EENS (MWh) (With replacement)	Reduction of EENS (MWh)	Reduction of risk cost (M$)
In early 2006 (now)	17,643	15,686	1957	6.008
In early 2007	16,396	15,678	718	2.204
In early 2008	15,170	14,720	450	1.382
In early 2009	14,904	14,690	214	0.657
In early 2010	14,671	14,671	0	0

The actual cost of replacing the cable 5 of HVDC Pole 2 in 2003 was $8 million [8] (See Appendix D). Joseph Jue confirmed that the work to replace the cable 1 will be similar. The reduction of risk cost due to replacement is benefit and the benefit/cost ratios for different failure years are listed in Table 11. It can be seen that the benefit/cost ratio for any year in which the cable 1 may fail is less than 1.0. This indicates that not replacing the cable 1 is more cost effective than replacing it. As a sensitivity analysis, the benefit/cost ratio obtained by tripling the unit interruption cost is still less than 1.0 for any failure year from 2007 (inclusive) to 2010 except the case where the cable 1 was assumed to fail now (in 2006), which is unlikely.

Table 11 Benefit/cost ratios for replacement (the 230 kV line in service in 2008)

Failure year of Cable 1	Benefit/cost ratio
In early 2006 (now)	0.751
In early 2007	0.276
In early 2008	0.173
In early 2009	0.082
In early 2010	0

5.2 230 kV line in-service in 2009

If the in-service date of the 230 kV line is delayed to 2009, the failure of the cable 1 will have more impacts on the risk of the VI supply system. In this case, the EENS indices for VI power supply system with the existing cable 1, with the replaced section of the cable 1 and without the cable 1 from 2006 to 2010 are shown in Table 12.

Table 12 EENS for VI supply system (MWh/year) (the 230 kV line in service in 2009)

	With existing Cable 1	With replaced Cable 1	Without Cable 1
2006	4850	4843	6097
2007	5655	5642	6881
2008	6677	6667	7866
2009	1271	1268	1504
2010	1542	1541	1755

By the similar calculations, the total EENS indices with and without replacement after the failure in the period of the 5 years for the different failure years are summarized in Tables 13 and 14 respectively.

Table 13 Total EENS with replacement after the failure in the 5 year's period for different failure years (the 230 kV line in service in 2009)

Failure year of Cable 1	EENS (MWh)
In early 2006 (now)	21,215
In early 2007	21,207
In early 2008	21,180
In early 2009	20,227
In early 2010	20,208

Table 14 Total EENS without replacement after the failure in the 5 year's period for different failure years (the 230 kV line in service in 2009)

Failure year of Cable 1	EENS (MWh)
In early 2006 (now)	24,103
In early 2007	22,856
In early 2008	21,630
In early 2009	20,441
In early 2010	20,208

Using the information in Tables 13 and 14 and the same unit interruption cost, the total EENS indices of the two options, reduction of EENS and reduction of risk cost due to replacing the cable 1 for the case of the 230 kV line in service in 2009 are summarized in Table 15. The benefit/cost ratios for different failure years are listed in Table 16. It can be seen that if the cable 1 fails in 2007 or afterwards, replacing the cable 1 is still not cost effective even if the 230 kV line is assumed to be delayed to 2009 whereas if the cable 1 fails in early 2006 and if the in-service date of the 230 kV line is delayed to 2009, the benefit/ratio of replacing it is slightly larger than 1.0. However, the likelihood of the later situation is small and the benefit is marginal.

Table 15 Total EENS for the two options, reduced EENS and reduced risk cost due to replacement (the 230 kV line in service in 2009)

Failure year of Cable 1	EENS (MWh) (No replacement)	EENS (MWh) (With replacement)	Reduction of EENS (MWh)	Reduction of risk cost (M$)
In early 2006 (now)	24,103	21,215	2888	8.866
In early 2007	22,856	21,207	1649	5.062
In early 2008	21,630	21,180	450	1.382
In early 2009	20,441	20,227	214	0.657
In early 2010	20,208	20,208	0	0

Table 16 Benefit/cost ratios for replacement (the 230 kV line in service in 2009)

Failure year of Cable 1	Benefit/cost ratio
In early 2006 (now)	1.108
In early 2007	0.633
In early 2008	0.173
In early 2009	0.082
In early 2010	0

6. Conclusions

This report performed a quantified risk assessment for the end-of-life failure of the cable 1 of HVDC Pole 1 through an EENS study. The basic idea is to compare risks and risk costs for the three options: replacing the damaged section of the cable 1 now (before it fails), replacing it right after it fails and not replacing it regardless of its failure.

The results indicate:

- The cumulative risk to the VI power supply system in the 5 year's period from 2006 to 2010 for the option of replacing the damaged section of the cable 1 now is higher than the option of replacing it after it fails.
- Although the cumulative system risk in the 5 year's period for the option of replacing it after it fails is lower than not replacing it, the benefit/cost ratio for the replacement is less than 1.0. The later it fails, the lower the benefit/cost ratio is.

After the cable 1 is permanently out-of-service, the HVDC will have a maximum capacity of 492 MW (336 MW for Pole 2 and 156 MW for Pole 1) without any filed work. The operation mode with the half of Poles 1 and 2 can still provide the capacity of 246 MW. If one of the two 900 amp cables for Pole 2 is exchanged with the remaining 600 amp cable for Pole 1, the maximum capacity of the HVDC can reach 570 MW. This operation mode may require some field work and cost. The concern may be associated with the operation mode of only half Pole 2 available. In this case, the firm capacity is reduced to 168 MW (after the cable 1 fails) from 238 MW (before the cable 1 fails). After the 230 kV line is in service, this concern will no longer exist.

7. Recommendations

- The cable 1 of Pole 1 is used as it is.
- If the cable 1 does not fail in 2006, it is recommended to not replace it even if it fails later, that is, the HVDC will be operated without the cable 1 if it fails later than 2006.
- If the cable 1 fails in 2006, an update study may be needed with a more accurate estimate on the in-service date of the 230 kV line.
- It is necessary to prepare a detailed plan for the VI supply prior to the 230 kV line in service, including a contingency plan for end-of-life failure of the cable 1.

References

[1] BC Hydro Report, Pole 1 and Pole 2 DC Cable - 2005 ROV Inspection (Summary of Results), January 2006

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[3] R. Billinton and Wenyuan Li, *Reliability Assessment of Electric Power Systems Using Monte Carlo Methods*, Plenum Press, New York, 1994

[4] Wenyuan Li, *Risk Assessment of Power Systems: Models, Methods, and Applications*, IEEE and Wiley, 2005

[5] BCTC Report, Probability Distribution of HVDC Capacity and Impacts of Two Key Components, May 5, 2004

[6] BC Stats Webpage - BC GDP at Market Prices and Final Domestic Demand: http://www.bcstats.gov.bc.ca/data/bus_stat/bcea/bcgdp.asp

[7] BCH Hydro Webpage - Quick Facts: http://w3ex/info/reports/reports921.html

[8] Info_PM project variance report for HVDC Pole 2 – Cable #5 section replacement, Feb 20, 2006

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 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

$f(overhead)=0.2778+0.2136=0.4914$
$r(overhead) = \Sigma fr/\Sigma f = (0.2778*16.85+0.2136*16.40)/(0.4914)=16.65$

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

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

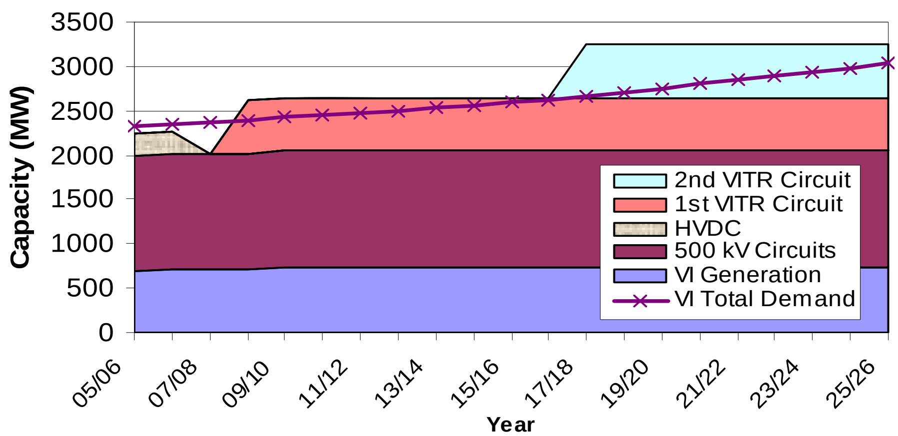
Appendix C: Load forecast and resources balance for 2005/06 to 2025/26

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).



Appendix D:
Info_PM project variance report for HVDC Pole 2 – Cable #5 section replacement

IPMR732 | Info_PM | 20-FEB-2006 8:48:16 AM
FFL | Project Variance Report ($000) | Page 1

Project Costing View : **Total Loaded Costs**
Project : P2C5REPL HVDC Pole 2 - Cable #5 Section Replacement | Status : I
Project Manager : RE(ROSS) NELSON

Task	Description	Approved	Forecast	Assigned	Committed	Actuals	Status
Capital: 1103295	**Parent #: 1103294**		**Client #: 1103070**				
0000	HVDC Pole 2 - Cable #5 Repair	0.0	0.0	0.0	0.0	0.0	C
A000	Project management	37.1	70.1	0.0	70.1	70.1	C
B3100	Equipment contract	60.9	69.8	0.0	69.8	69.8	C
B3200	Civil design	20.4	1.2	0.0	1.2	1.2	C
B3220	Survey & mapping	45.6	0.0	0.0	0.0	0.0	C
B3400	OH transmission design	0.0	0.0	0.0	0.0	0.0	C
B3420	U/G cable Design	93.1	105.2	0.0	102.7	105.2	C
C000	Enviromental services	69.6	118.4	0.0	118.4	118.4	C
F000	Community Relations	10.2	0.8	0.0	0.8	0.8	C
F100	Aboriginal/Archaeological Issues	10.2	1.3	0.0	1.3	1.3	C
G500	System planning	70.4	38.6	0.0	38.6	38.6	C
H3100	Contract Management	50.7	79.3	0.0	79.3	79.3	C
H3200	Civil construction	0.0	0.0	0.0	0.0	0.0	C
H3420	OH transmission Installation	0.0	19.0	0.0	19.0	19.0	C
H3440	Sub marine Cable Installation	2327.8	2340.7	0.0	2340.7	2340.7	C
H3441	LMT-Prepare spare cable	0.0	0.0	0.0	0.0	0.0	C
H3442	LMT-Assist Contractor	377.9	755.2	0.0	755.2	755.2	C
H3600	Testing	30.6	0.0	0.0	0.0	0.0	C
M3200	Civil Materials	10.2	1.1	0.0	1.1	1.1	C
M3440	Misc cable and Accessories	4213.7	3999.4	0.0	3999.4	3999.4	C
N000	Field Services	20.4	-0.5	0.0	-0.5	-0.5	C
PLAN	Plan Task	0.0	0.0	0.0	0.0	0.0	C
Q000	Quality Assurance	34.1	23.7	0.0	23.7	23.7	C
SEST	Summary Task	0.0	0.0	0.0	0.0	0.0	C
CONT	Contingency	60.2	0.0	0.0	0.0	0.0	A
	Capital Direct Total	7543.0	7623.1	0.0	7620.7	7623.1	
	Overhead	452.6	352.8		352.8	352.8	
	IDC	26.0	-22.0		-22.0	-22.0	
	Indirect Cost Subtotal	478.6	330.8		330.8	330.8	
	Capital Total	8021.6	7953.9	0.0	7951.5	7953.9	
Retirement/Dismantling: 1103295	**Parent #: 1103294**		**Client #: 1103070**				
H230R	RETIRE CABLE	0.0	68.2	0.0	68.2	68.2	C
	Retirement Total	0.0	68.2	0.0	68.2	68.2	
Z999	Unassigned Actuals	0.0	0.0	0.0	0.0	0.0	A
	Project Total	8021.6	8022.2	0.0	8019.8	8022.2	