Report-BCTC-R009A

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

(Part I: Reliability Improvements due to VITR)

December 8, 2005

Prepared by

Wenyuan Li
System Planning and Performance Assessment
British Columbia Transmission Corporation

DISCLAIMER

This report was prepared by BCTC solely for the purposes described in this report, and is based on information available to BCTC as of the date of this report. Accordingly, this report is suitable only for such purposes, and is subject to any changes arising after the date of this report. Unless otherwise expressly agreed by BCTC, BCTC does not represent or warrant the accuracy, completeness or usefulness of this report, or any information contained in this report, for use or consideration by any third party, nor does BCTC accept any liability out of reliance by a third party on this report, or any information contained in this report, or for any errors or omissions in this report. Any use or reliance by third parties is at their own risk.

COPYRIGHT NOTICE

December 8, 2005

Expected Energy Not Served (EENS) Study for Vancouver Island Transmission Reinforcement Project
(Part I: Reliability Improvements due to VITR)
(Executive Summary)

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

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 update the EENS evaluation for the 230 kV line scenario which is called the Vancouver Island Transmission Reinforcement project (VITR). The update is necessary due to the following:

- The new load forecast (December 2005) for Vancouver Island shows demand increases compared to the load forecast in 2002 which was used in the previous study in 2003. For example, the peak load forecast for 2008 has an increase of 153 MW compared to the peak load level used in the previous study.
- The annual load curve shape that is based on 2004 hourly records is available.
- The total generation capacity in Vancouver Island also has a small amount of increase. It will be 714 MW in 2008 while 688 MW was used in the previous study. By 2009, the generation capacity will be increased to 744 MW due to the generation smart project of BCH.
- In the 2003 study, HVDC was included in evaluation with an increasing unavailability caused by possible aging failures. Based on the information in the VIGP project hearing and BCTC/BCH's VI power resource plan, HVDC will be retired (zero dependable capacity) by 2007 for planning purposes. The time frame of this study is from 2008/09 to 20022/23 and the existing HVDC is not considered available and is excluded from the evaluation model. The impact studies of HVDC on VI reliability for only a short period (a couple of years before and after VITR in service) will be performed as a separate part of the VITR reliability study and summarized in Part IV of the report.

The report summarizes the EENS study for the VITR project based on the updated data available in December 2005. The results indicate that the 230 kV AC line will provide an essential improvement to Vancouver Island power supply reliability over the study period from 2008 to 2022. The EENS reduction and risk cost reduction due to the 230 kV line addition in the 15 year's period will be 379,594 MWh and $1,897 million respectively. If the second 230 kV line was added in 2017, it would lead to the EENS reduction of 30,485 MWh or the risk cost reduction of $152 million in the 5 year's period from 2017 to 2022. This reduction would be increased if a longer period was considered. The second 230 kV line was included in the study only for information. There is no decision yet on the second 230 kV line.

It should be noted that the risk cost estimates in the study are based on the unit interruption cost of $5/kWh, which was used in risk evaluation of system planning at BC Hydro in the past [4, 5], and are only for reference. More information regarding the range of the unit interruption cost can be found in Section 6 of Part IV of the report.

This report is the first part of the whole reliability study for the VITR project, which focuses on the comparison between the do-nothing and 230 kV line cases from 2008 to 2022. The other reliability studies for the VITR project are presented in the other parts of the report.

December 8, 2005

Expected Energy Not Served (EENS) Study for Vancouver Island Reinforcement Project (Part I: Reliability Improvements due to VITR)

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 update the EENS evaluation for the 230 kV line scenario which is called the Vancouver Island Transmission Reinforcement project (VITR). The update is necessary due to the following:

- The new load forecast (December 2005) for Vancouver Island shows demand increases compared to the load forecast in 2002 which was used in the previous study in 2003. For example, the peak load forecast for 2008 has an increase of 153 MW compared to the peak load level used in the previous study.
- The annual load curve shape that is based on 2004 hourly records is available.
- The total generation capacity in Vancouver Island also has a small amount of increase. It will be 714 MW in 2008 while 688 MW was used in the previous study. By 2009, the generation capacity will be increased to 744 MW due to the generation smart project of BCH.
- In the 2003 study, HVDC was included in evaluation with an increasing unavailability caused by possible aging failures. Based on the information in the VIGP project hearing and BCTC/BCH's VI power resource plan, HVDC will be retired (zero dependable capacity) by 2007 for planning purposes. The time frame of this study is from 2008/09 to 20022/23 and the existing HVDC is not considered available and is excluded from the evaluation model. The impact studies of HVDC on VI reliability for only a short period (a couple of years before and after VITR in service) will be performed as a separate part of the VITR reliability study and summarized in Part IV of the report.

This report provides the first part of the study for the VITR project reliability assessment, which focuses on the difference in the EENS index to Vancouver Island supply between the do-nothing case and the VITR project. The results show the reliability benefit due to the VITR project.

The method and the computing tool used in this study are mature and have been recognized by the academic field and the power industry for years [2, 3]. The failure data for the 500 kV lines and local generating units were based on historical statistics from the BC Hydro outage database. The failure data are the same as those used in the 2003 report.

2. Method, Computing Tool and Model

The method used to conduct EENS studies is the probabilistic reliability evaluation technique using Monte Carlo simulations. The EENS is a probabilistic index that is a combination of consequences and probabilities of all failure events sampled in the simulation. The method has been proved and recognized for many years [2]. The number of samples used in the study was 100,000 for each load level in the 15-step load model.

The computing tool used in the study is the MCGSR program (Monte Carlo Generation System Reliability), which is an evaluation tool for generation source system reliability. The basic concept and the simulation approach used in the program have been published for years and can be found in [2].

The EENS evaluation model for Vancouver Island power supply is shown in Figure 1. The 500 kV lines, 230 kV line and on-Island generating units were modeled. The second 230 kV line was included in the model only for the study purpose and there is no decision yet on the second 230 kV line. There are some very small local generating units with a capacity ranging from 0.8 to 3.8 MW. No failure data for these units is available. In the evaluation, these units were not individually modeled but rather, they were considered by distributing their capacities to other relatively large units. For the same reason, the UCO and Zeballos generating units were combined as one with the same failure data as the ASH unit. The second 230 kV line was assumed only for the study purpose.

This is a generation-demand reliability model, since all power supply sources, including generating units and transmission components, play a role of generation source. At the load side, an annual load curve is used. Individual failures of each power supply source and combinations of their failures are sampled using the Monte Carlo simulation technique. Each state in which the load cannot be met contributes to the EENS index. All components were modeled using two-state (up and down states) random variables. The common cause failure of the two 500 kV lines due to lightning was simulated using an independent random variable.

3. Data

3.1 Failure data

The failure data for the 500 kV lines and on-Island generating units were 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 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. 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. 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. These data are the same as those used in the 2003 report [1] and are given in Appendix A and B.

3.2 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.

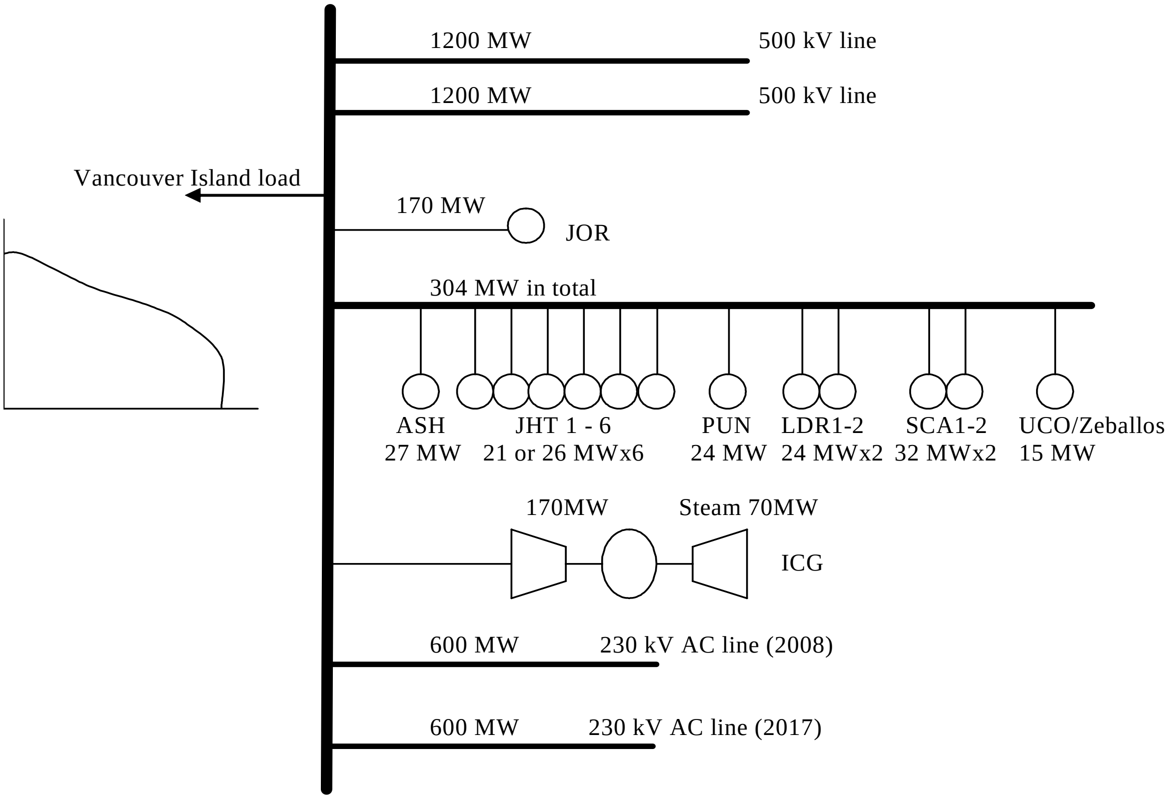

Figure 1 EENS Evaluation Model for Vancouver Island supply

4. Study Conditions

- The time frame in the study is 15 years from 2008/09 to 2022/23. The 2008/09 is the first year by which the 230 kV line will be in service. Any planning study associated with a capital investment should be conducted over a long time frame.

- The local transmission network on Vancouver Island (including network constraints and failures of network components) was not included in the model. Also, the grid system at the Lower Mainland side has been assumed to be perfect and was not incorporated into the study. These assumptions do not cause any negative impact on the results since the focus is the EENS indices to Vancouver Island supply.

- The peak loads from 2008 to 2022 were based on the most recent load forecast (December 2005) while the annual load curves for all the 15 years under the study follow the same shape that is based on the hourly load records in 2004.

- HVDC was not included in the model since HVDC is considered to be zero capacity from 2007 (retired) from a planning viewpoint. The reason of excluding HVDC has been given earlier in the section of Introduction.

- 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. This is a pessimistic assumption because in real life, when the PST fails, it can be bypassed and the 230 kV line will continue to supply in most cases according to the design.

- 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. Also, the same 500 kV line capacity is used in all the cases for comparison.

- The EENS evaluation was based on the "adequacy" concept, i.e., the loss of load in any system state was assumed to be exactly equal to the difference between the load level and the total available source capacity. In real life, there is a tendency of over-shedding of load if a system state is associated with transient or voltage instability and load shedding protective relaying systems.

5. EENS Evaluation

5.1 Cases

The following three cases are studied:

(1) Do Nothing

This is the existing system without any new power source and by assuming that HVDC will be retired in 2007. The system includes two 500 kV lines with each having 1200 MW capacity, 15 local generating units with a total capacity of 714 MW in 2008/2009 and 744 MW from 2009/2010 to 2022/2023.

(2) New 230 kV AC line to Vancouver Island (2008 in service)

The new 230 kV AC line with 600 MW capacity is added in 2008. It comprises 35.6 km of overhead line, 31.15 km of submarine cable and a phase shifting transformer.

(3) The second 230 kV AC line to Vancouver Island (2017 in service)

The second 230 kV AC line with 600 MW was assumed to be in service in 2017.

5.2 Results – EENS indices and risk costs

The EENS indices for the do-nothing and 230 kV line cases from 2008 to 2022 are summarized in Table 1 and depicted in Figure 2. The EENS indices for the first 230 kV line and possible second 230 kV line cases from 2017 to 2022 are summarized in Table 2 and depicted in Figure 3.

The EENS for the "do-nothing" case increases constantly and non-linearly over time. For the 230 kV AC line case, the EENS index is much lower compared to the do-nothing case and has a normal slow increase due to the load growth with the years. If the second 230kV line was added, it would provide the further decrease of the EENS index since 2017 compared to the first 230 kV line case.

The reduction in the EENS index due to the 230 kV line from 2008 to 2022 sums to 379,594 MWh. The average EENS reduction in one year for the 15 year's period is 25,306 MWh/year. If a value of $5/kWh is applied, which is the unit interruption cost used in risk evaluation of system planning at BC Hydro in the past [4, 5], the risk cost reduction due to 230 kV line addition from 2008 to 2022 will be up to $1,897.97 million. The risk cost reductions for each year are also given in Table 2.

If the second 230 kV line was added, the reduction in the EENS index due to its addition from 2017 to 2022 would sum to 30,485 MWh. The average EENS reduction in one year for the 5 year's period would be 6,097 MWh/year. If the $5/kWh was applied, the risk cost reduction due to adding the second 230 kV line from 2017 to 2022 would be $152.43 million. The risk cost reductions for each year are also given in Table 2. If a longer the period was considered, the second 230 kV line would result in a higher risk cost reduction since the load growth beyond 2022 would lead to much higher EENS indices.

It should be noted that the risk cost estimates based on the unit interruption cost of $5/kWh are only for reference. More information regarding the range of the unit interruption cost can be found in Section 6 of the Part IV of the report.

Table 1 EENS index (MWh/year) and risk cost reduction (M$/year) for do-nothing and 230 kV line cases

Year	Do-nothing	230 kV line	Difference in EENS (MWh)	Difference in risk cost (M$)
2008	14998	2870	12128	60.64
2009	14542	2779	11763	58.82
2010	16268	2969	13299	66.50
2011	17298	3085	14213	71.07
2012	19101	3281	15820	79.10
2013	21130	3523	17607	88.04
2014	23163	3769	19394	96.97
2015	25080	3991	21089	105.45
2016	28709	4348	24361	121.81
2017	32626	4692	27934	139.67
2018	36720	5152	31568	157.84
2019	40915	5710	35205	176.03
2020	46194	6238	39956	199.78
2021	52084	6989	45095	225.48
2022	57969	7807	50162	250.81
total			379594	1897.97

Table 2 EENS index (MWh/year) and risk cost reduction (M$/year) for the first and possible second 230 kV line cases

Year	230 kV line	Second 230 kV line	Difference in EENS (MWh)	Difference in risk cost (M$)
2017	4692	726	3966	19.83
2018	5152	831	4321	21.61
2019	5710	929	4781	23.91
2020	6238	1053	5185	25.93
2021	6989	1203	5786	28.93
2022	7807	1361	6446	32.23
total			30485	152.43

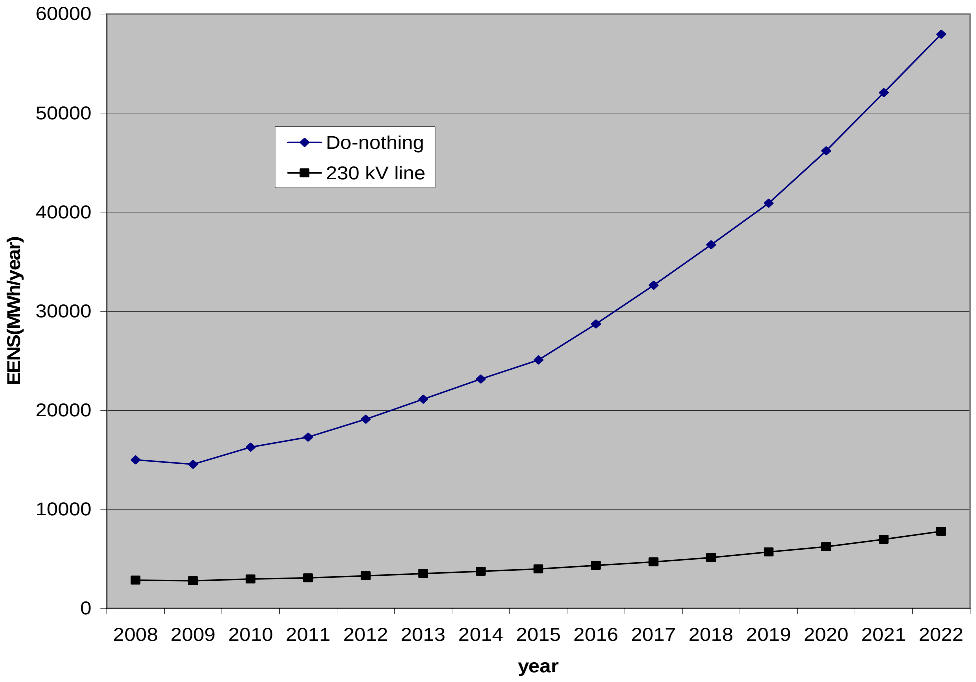

Figure 2 EENS index for do-nothing and 230 kV line cases (MWh/year)

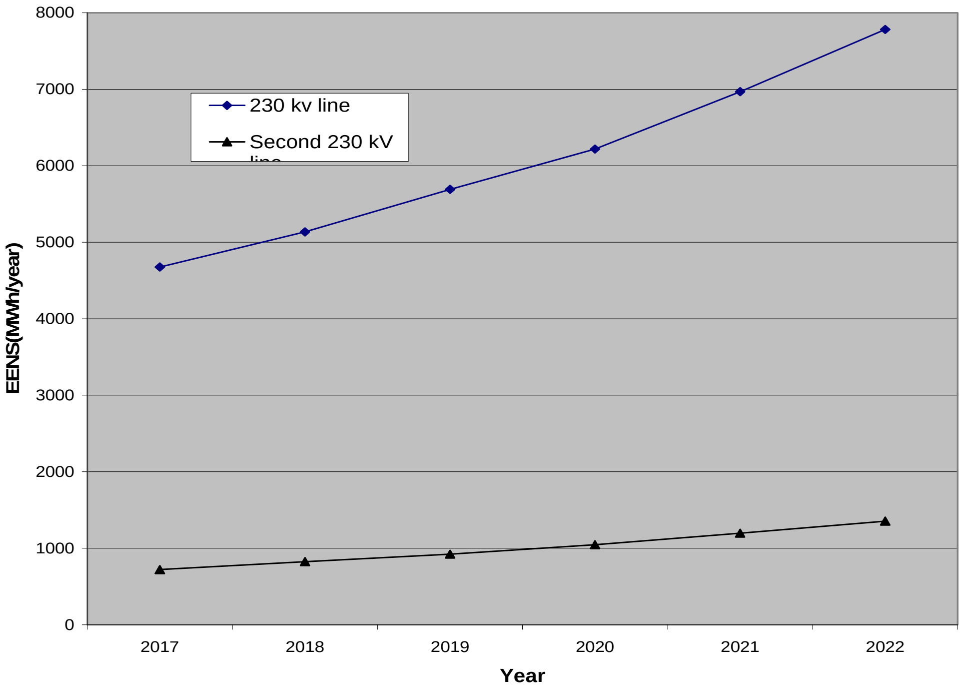

Figure 3 EENS index for the first and second 230 kV line cases (MWh/year)

6. Conclusions

The report summarizes the EENS study for the VITR project based on the updated data available in December 2005. Compared to the study for the VIGP project in 2003, the peak load forecast, on-island generation and load curve shape have been different. Also, the HVDC is excluded in this study since the HVDC will be retired (zero capacity) by 2007 for the planning purposes.

The results indicate that the 230 kV AC line will provide an essential improvement to Vancouver Island power supply reliability over the study period from 2008 to 2022. The EENS reduction and risk cost reduction due to the 230 kV line addition in the 15 year's period will be 379,594 MWh and $1,897 million respectively. If the second 230 kV line was added in 2017, it would lead to the EENS reduction of 30,485 MWh or the risk cost reduction of $152 million in the 5 year's period from 2017 to 2022. This reduction would be increased if a longer period was considered. The second 230 kV line was included in the study only for information. There is no decision yet on the second 230 kV line.

It should be noted that the risk cost estimates in the study are based on the unit interruption cost of $5/kWh, which was used in risk evaluation of system planning at BC Hydro in the past [4, 5], and are only for reference. More information regarding the range of the unit interruption cost can be found in Section 6 of the Part IV of the report.

This report is the first part of the whole reliability study for the VITR project, which focuses on the comparison between the do-nothing and 230 kV line cases from 2008 to 2022. The other reliability studies for the VITR project will be presented in other parts of the report.

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

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

[4] F. Turner, et al, “Reliability Worth: Development of a Relationship with Outage Magnitude, Duration and Frequency”, CEA paper, March 1994

[5] Wenyuan Li, Y. Mansour, et al, “Application of Transmission Reliability Assessment in Probabilistic Planning of BC hydro Vancouver South Metro System”, IEEE Transaction on Power Systems, 1995

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

$f1=0.6945\ /\text{year}/\ 100\ \text{km}*40\ \text{km}=0.2778/\text{year}$ $r1=16.85$ hours

Overhead portion- terminal-related failure

$f2=0.2136$ $r2=16.40$ hours

Overhead portion – total

$f(\text{overhead})=0.2778+0.2136=0.4914$

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

$FOR(\text{overhead})=f(\text{overhead})*r(\text{overhead})/8760 = 0.00093$

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

$FOR(\text{total}) = FOR(\text{cable}) +FOR(\text{overhead}) – FOR(\text{cable})*FOR(\text{overhead})$

$= 0.025+0.00093-0.025*0.00093 =0.02591$

$f(\text{total}) = 0.1+0.4914=0.5914$

$r(\text{total}) = FOR(\text{total})*8760/f(\text{total}) = 0.02591*8760/0.5914 = 383.74$ 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).