Reliability Evaluation of Three Scenarios for Vancouver Island Power Supply - An Expected Energy Not Served (EENS) Study

June 11, 2003

Prepared by

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(Executive Summary)

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Introduction

This study provides a quantified response to an Information Request of the British Columbia Utilities Commission. The context for the Information Request is Vancouver Island Energy Corporation's (VIEC's) application for a certificate of public convenience and necessity for the Vancouver Island Generation Project (VIGP). VIEC is a wholly-owned subsidiary of BC Hydro. The Information Request is as follows:

> *60.4 Please provide a diagram that shows the "expected energy not served" ("EENS") in MW on Vancouver Island as actual energy not served for each of the past five years, and the forecasted EENS by year through 2012 for each of the following three scenarios:*
>
> - *VIGP (Portfolio 2)*
> - *New high voltage AC cable to Vancouver Island (Portfolio 3)*
> - *Life Extension of HVDC Pole 2 restoring 476 MW of capacity, as set out in BCUC IR 20.3 at Tab C*
>
> *Please discuss significant assumptions used in the analysis, and explain any discontinuities in the forecast curves.*

An EENS study is a quantified probability evaluation. The EENS is a reliability index that has been widely used to compare different planning alternatives in the power industry [2, 12, 13, 14].[1] However, it is important to appreciate that the EENS is a mathematical expectation computed according to modeling and data assumptions. An actual EENS value in every year in the past does not necessarily match the evaluated EENS. This does not decrease the significance of EENS in comparing planning scenarios. Also, it should be kept in mind that data used in the EENS evaluation are based on historical outage/failure records. The data are always associated with some uncertainty and so is the evaluated EENS.

There are two aspects of probabilistic power system reliability assessment: *adequacy* and *security*. Adequacy relates to the existence of sufficient facilities in the system to satisfy the consumer load demand and system operational constraints. Adequacy is therefore associated with static conditions that do not include system dynamic and transient disturbances. Security relates to the system's ability to respond to dynamic or transient disturbances arising within the system. Security is therefore associated with the response of the system to transient

[1] Citations for references in square brackets are set out in full at the end of this report.

electro-mechanical instability and voltage instability. The EENS study performed in the report is limited to the adequacy aspect.

The methods and the computing tools used in this study are mature and have been recognized by the academic field and the power industry for many years [1–3]. The reliability models used in the study were based on actual operation modes and available data. Particularly, the HVDC system has been modeled in detail by breaking it down into major components. The data for the 500 kV circuits and on-Island hydro generating units were based on historical statistics from the BC Hydro outage database. The data for the ICP and VIGP generating units were the typical data from the NERC outage report [5]. The HVDC component data, including the mean life and standard deviation, were obtained from expert engineering estimates.

Major Assumptions

The major assumptions used in the study are as follows:

- The time frame in the study is from 2003/04 to 2012/13.[2]

- The local transmission network on Vancouver Island (including network constraints and failures of network components) was not modeled. Also, the grid system at the Mainland side was assumed to be perfect and was not incorporated in the study. These assumptions do not cause any negative impact on the results, since the three comparative scenarios are all the power source options to Vancouver Island.

- Peak loads in the study period were based on the most recent load forecast while the annual load curves for all the 10 years under the study follow the same shape that is based on the hourly load records for 2002.

- The assumptions about HVDC Pole 2 are summarized in Appendix G.

- HVDC Pole 1 is retired for planning purposes but was included as a standby power source in the study. This inclusion was based on the fact that Pole 1 can still be used when needed from an operational point of view.

- The 230 kV AC circuit has a phase shifting transformer of compatible capacity connected in series at the VIT (Vancouver Island Terminal) station. Since the reliability of this equipment is very high, it was not included in the reliability model for this option.

- Water constraints in reservoirs and randomness of inflows were not simulated. These are only associated with the local hydro generating units that were identical in all the three scenarios in the comparison.

[2] In this report, when a year is represented on a stand-alone basis—e.g., "2003"—it indicates a BC Hydro fiscal year; i.e., 2003/04.

- Operation of the ICP and the VIGP was modeled using two states of full output and full down. The derated state (gas turbine operation with steam turbine out-of-service) was not considered. This was due to the fact that the available NERC outage statistics cannot distinguish the derated state.

- 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 to overshed load if a system state is associated with transient or voltage instability and load shedding protective relaying systems.

- Sensitivity studies to model pipeline failures were included.

- Sensitivity studies associated with data uncertainty of HVDC Pole 2 and ICP/VIGP generating units were performed.

Results

The EENS indices for the four scenarios from 2003 to 2012 are summarized in the following table and depicted in the accompanying graph. The EENS for the "Do Nothing" scenario increases constantly and non-linearly over time. The EENS for the HVDC Life Extension scenario has the same trend with a reduced rising slope at years 2004, 2005 and 2007, which have refurbishment activities.

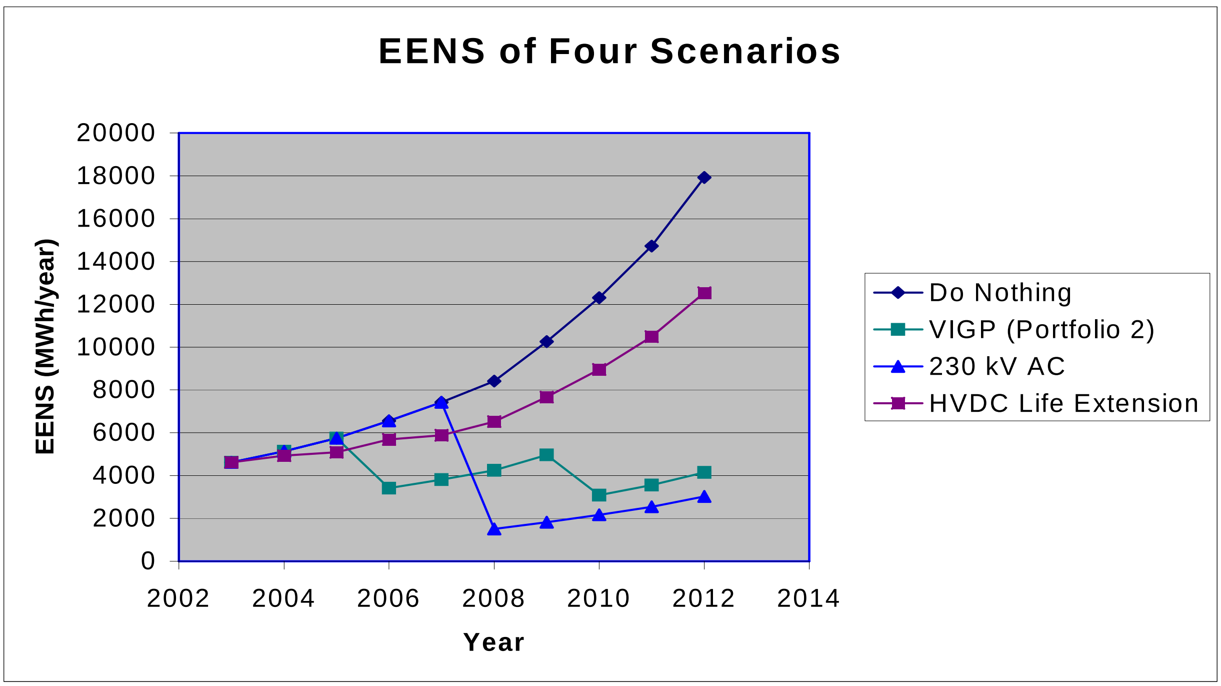
The results indicate that refurbishing the HVDC system slows down deterioration of Vancouver Island power supply reliability but does not effectively improve supply reliability in the long term. The whole HVDC system is aging and it is difficult to stop the aging process by replacing only a few old components and adding a couple of spares for some major components.

For the 230 kV AC circuit scenario, the EENS index has a big drop in 2008 when it is placed in service and then starts a normal slow increase due to load growth. This scenario provides the best overall reliability improvement from 2008 until 2012, the end of the study period.

The EENS for the VIGP scenario experiences two drop points, one in 2006 when the first generating unit comes into effect, and the other in 2010 when the second unit is placed in service. The reliability improvement from the VIGP occurs earlier and is close to that of the new 230 kV AC circuit from 2010 to 2012.

EENS Index for the Four Scenarios (MWh/year)

Year	Do Nothing	VIGP (Portfolio 2)	230 kV AC Cables	HVDC Life Extension
2003	4,621	4,621	4,621	4,621
2004	5,131	5,131	5,131	4,935
2005	5,748	5,748	5,748	5,082
2006	6,560	3,414	6,560	5,693
2007	7,425	3,811	7,425	5,887
2008	8,414	4,237	1,503	6,525
2009	10,261	4,964	1,815	7,673
2010	12,306	3,084	2,170	8,953
2011	14,715	3,555	2,544	10,485
2012	17,932	4,141	3,021	12,534



Comparison of EENS for the Four Scenarios

The EENS reductions due to the three reinforcement scenarios (VIGP, 230 kV AC and HVDC Pole 2 Life Extension) against the Do Nothing scenario are given in the following table and depicted in the accompanying graph. It can be seen that the 230 kV AC circuit provides the largest total EENS reduction in the 10-year study period, approximately 2.5 times that offered by the HVDC Life Extension scenario. The EENS reduction contributed by the VIGP scenario is approximately 2.4 times as much as that due to the HVDC Life Extension. The cumulative EENS reductions due to the VIGP and the 230 kV AC scenarios are quite close—in the order of 4.3% for the base case, and as small as 1.9% in the sensitivity studies discussed in the main body of this report.

EENS Reduction of Three Scenarios (MWh/year)

Year	VIGP (Portfolio 2)	230 kV AC Cables	HVDC Life Extension
2003	0	0	0
2004	0	0	196
2005	0	0	666
2006	3,146	0	867
2007	3,614	0	1,538
2008	4,177	6,911	1,890
2009	5,297	8,446	2,588
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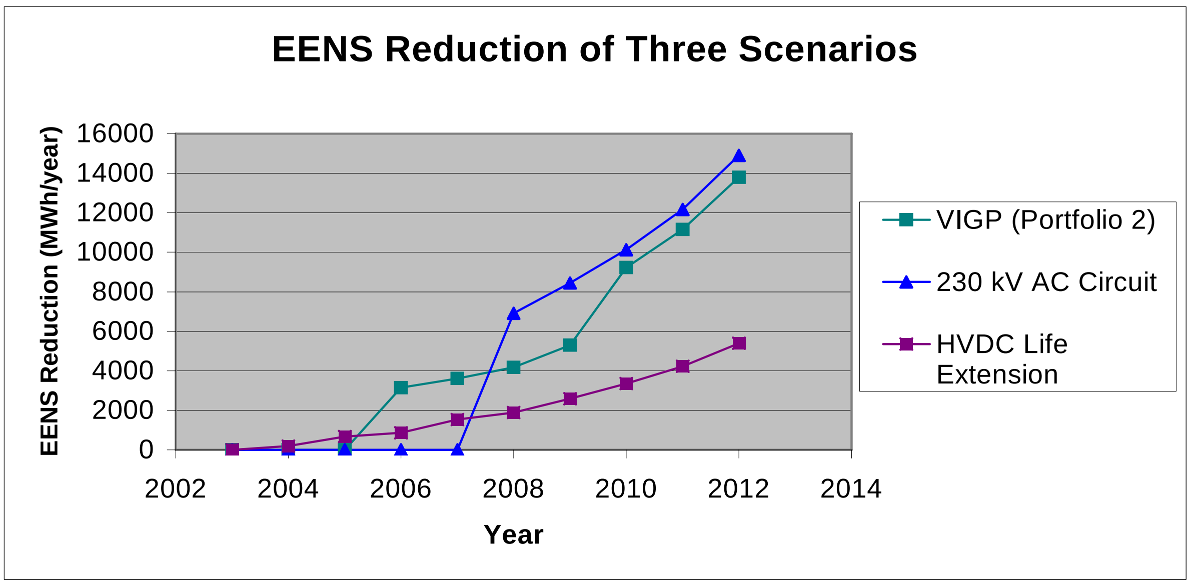
2011	11,161	12,171	4,230
2012	13,791	14,911	5,398
Total	**50,408**	**52,574**	**20,725**



EENS Reduction Due to the Three Scenarios

Conclusions

The EENS study results indicate that the 230 kV AC scenario provides the highest improvement to Vancouver Island power supply reliability over the study period. VIGP (Portfolio 2) provides the second highest reliability improvement. However, the difference in the cumulative EENS reduction between these two options is extremely close; i.e., in the order of only 1.9% to 4.3% over the study period.

The HVDC Life Extension scenario contributes some reliability improvement to the Island's power supply. However, the contribution is much less than that made by the 230 kV AC scenario or the VIGP scenario. A key reason is that the whole HVDC Pole 2 is aging. Refurbishing only a portion of major components cannot essentially resolve the problems due to the aging process.

A failure of the pipeline in the VIGP scenario would not significantly increase overall risk to Vancouver Island power supply. This is mainly due to the fact that the failure probability of the pipeline is much smaller than the failure probabilities of electric components in the Vancouver Island power supply system.

The sensitivity studies indicate that the uncertainty in the unavailability data of HVDC Pole 2 system, the ICP, and the VIGP would not change the reliability ranking of the three scenarios, although the decreased unavailability of HVDC Pole 2 or the ICP/VIGP generating units would reduce the EENS indices of all the scenarios. The impact on the results due to the uncertainty in the unavailability data of ICP and VIGP units is marginal.

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1. Introduction

The purpose of this study is to provide a quantified response to an Information Request posed by the British Columbia Utilities Commission in the context of Vancouver Island Energy Corporation's (VIEC's) application for a certificate of public convenience and necessity for the Vancouver Island Generation Project (VIGP). VIEC is a wholly-owned subsidiary of BC Hydro. The information request is as follows:

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There are two aspects of probabilistic power system reliability assessment: *adequacy* and *security*. Adequacy relates to the existence of sufficient facilities in the system to satisfy the consumer load demand and system operational constraints. Adequacy is therefore associated with static conditions that do not include system dynamic and transient disturbances. Security relates to the ability of the system to respond to dynamic or transient disturbances arising within the system. Security is therefore associated with the response of the system to transient

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It is important in a probabilistic reliability evaluation that reliability indices for indicating results and terms for processing outage data are correctly defined and consistently used. The definitions of major reliability terms related to the study are given in Appendix A.

2. Methodologies and Computing Tools

The method used to conduct EENS studies is the probabilistic reliability evaluation technique using Monte Carlo simulation. The EENS is a probabilistic index that combines 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.

In order to model the HVDC system more accurately, the HVDC system was broken down into major components. The total average unavailability due to both repairable and aging failures of the components was assessed using an analytical series/parallel technique [1].

The aging failures were modeled using a posteriori Weibull distribution, which has been recognized and used in the power industry for a long time [1,3,7].

The following three computing tools were used in the study:

(1) SPARE (Spare Analysis) calculates unavailability due to aging failures of components, which is part of the input data required by NEREL (see below). The input data for SPARE includes the mean life, deviation and age of each component. The modeling approach used in SPARE has been published in a peer-reviewed article in the *Power Engineering Review* of the Institute of Electrical and Electronic Engineers (IEEE) [3].

(2) NETREL (Network Reliability Evaluation) was developed to calculate unavailability of a network consisting of components in series/parallel and *m*-out-of-*n* systems. The methods used in NETREL are popular in reliability engineering [1].

(3) MCGSR (Monte Carlo Generation System Reliability) 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].

3. Models

The HVDC models are shown in Figures 1, 2 and 3. Pole 1 has been retired but can still be used as a standby power source. Pole 1 was assumed to operate with the 6-pulse mode at 156 MW capacity. The reliability model for Pole 1 is shown in Figure 1. For Pole 2, the two operation modes at 238 MW and 476 MW levels were considered. Figure 2 shows the 238 MW reliability model that creates the unavailability for the 238 MW capacity and above. Figure 3 represents the 476 MW reliability model that creates the unavailability for the 476 MW capacity only. Note that all the models are reliability models rather than physical operating connections. Also, the reliability models are in a representation composed of parallel and series structures except for the 600 amp cable system, which is a 2/3 system, meaning that two out of the three cables are needed for a success condition.

The EENS evaluation model for Vancouver Island power supply is shown in Figure 4. The 500 kV circuits, HVDC Poles 1 and 2, the 13 on-Island hydro generating units, and the ICP were included in all three scenarios. The VIGP generating units were modeled for the VIGP scenario, the new 230 kV AC circuit was included in the model for the 230 kV circuit scenario, and the HVDC refurbishment was considered in the model for the HVDC Pole 2 Life Extension scenario.

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 modeled. 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 except HVDC Pole 2 were modeled using two-state (up and down states) random variables. The HVDC Pole 2 was modeled using a three-state random variable (up state – 476 MW, derated state –238 MW and down state). The common cause failure of the two 500 kV circuits due to lightning was simulated using an independent random variable.

Repairable failures were considered for all the components. In addition, for HVDC components, aging failures were modeled due to the fact that the HVDC equipment is reaching its end-of-life stage. For the ICP and VIGP generating units, maintenance outages were also considered.

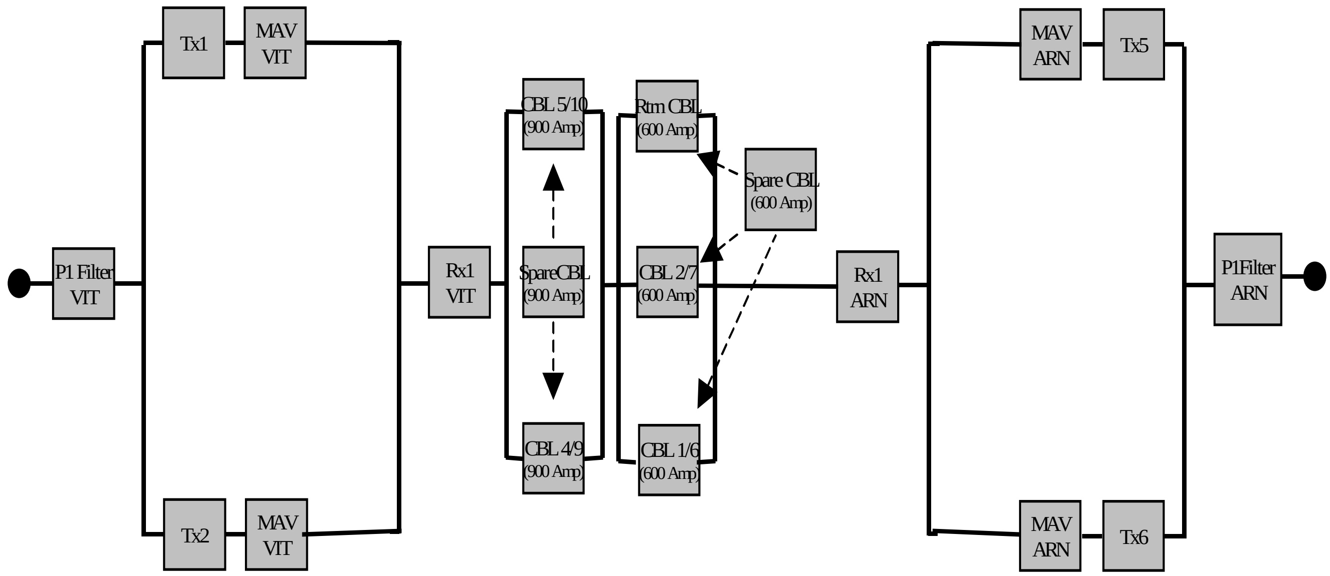

Figure 1: Reliability Model for HVDC Pole 1 (156 MW mode)

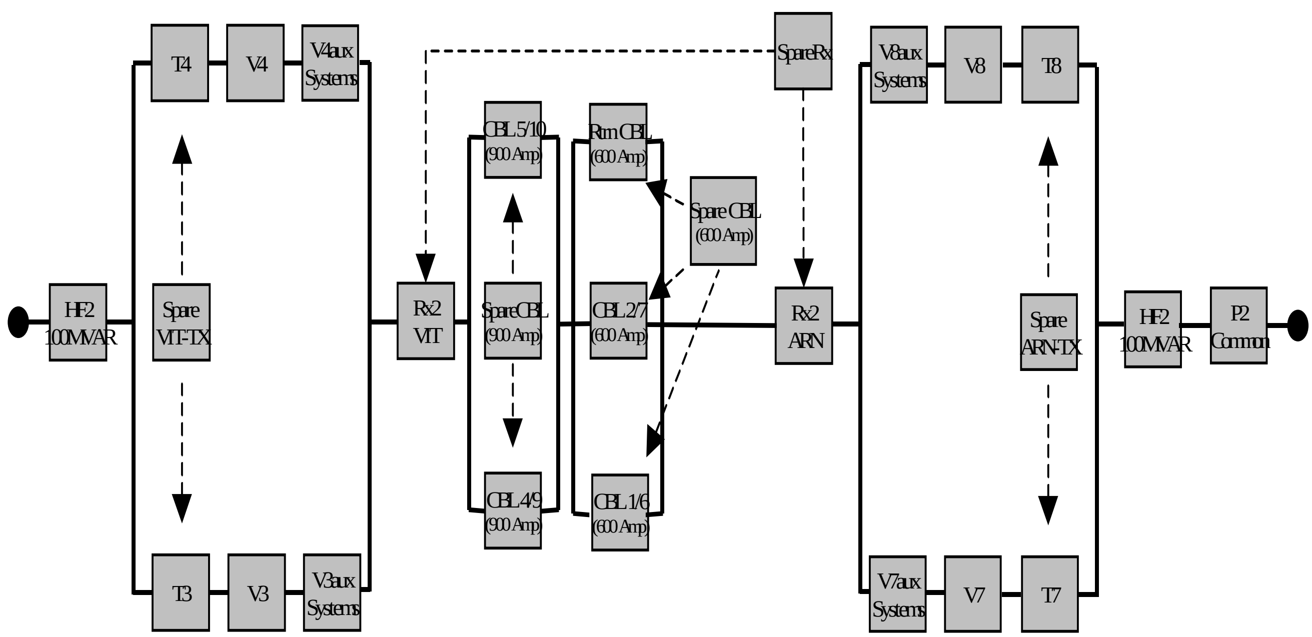

Figure 2: Reliability Model for HVDC Pole 2 (238 MW mode)

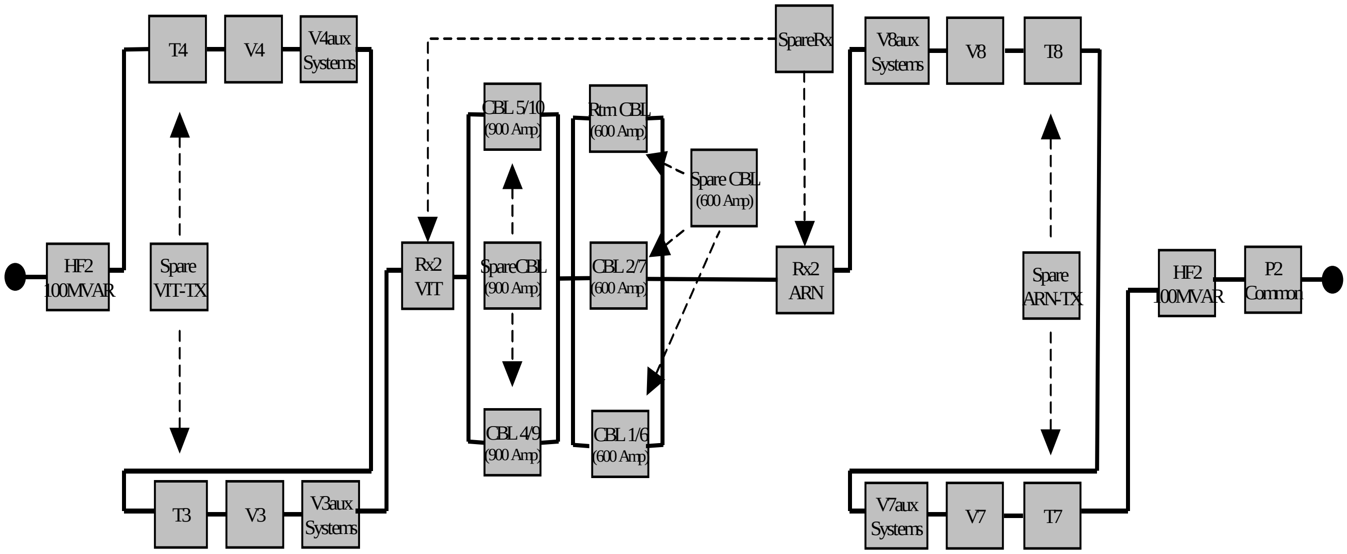

Figure 3: Reliability Model for HVDC Pole 2 (476 MW mode)

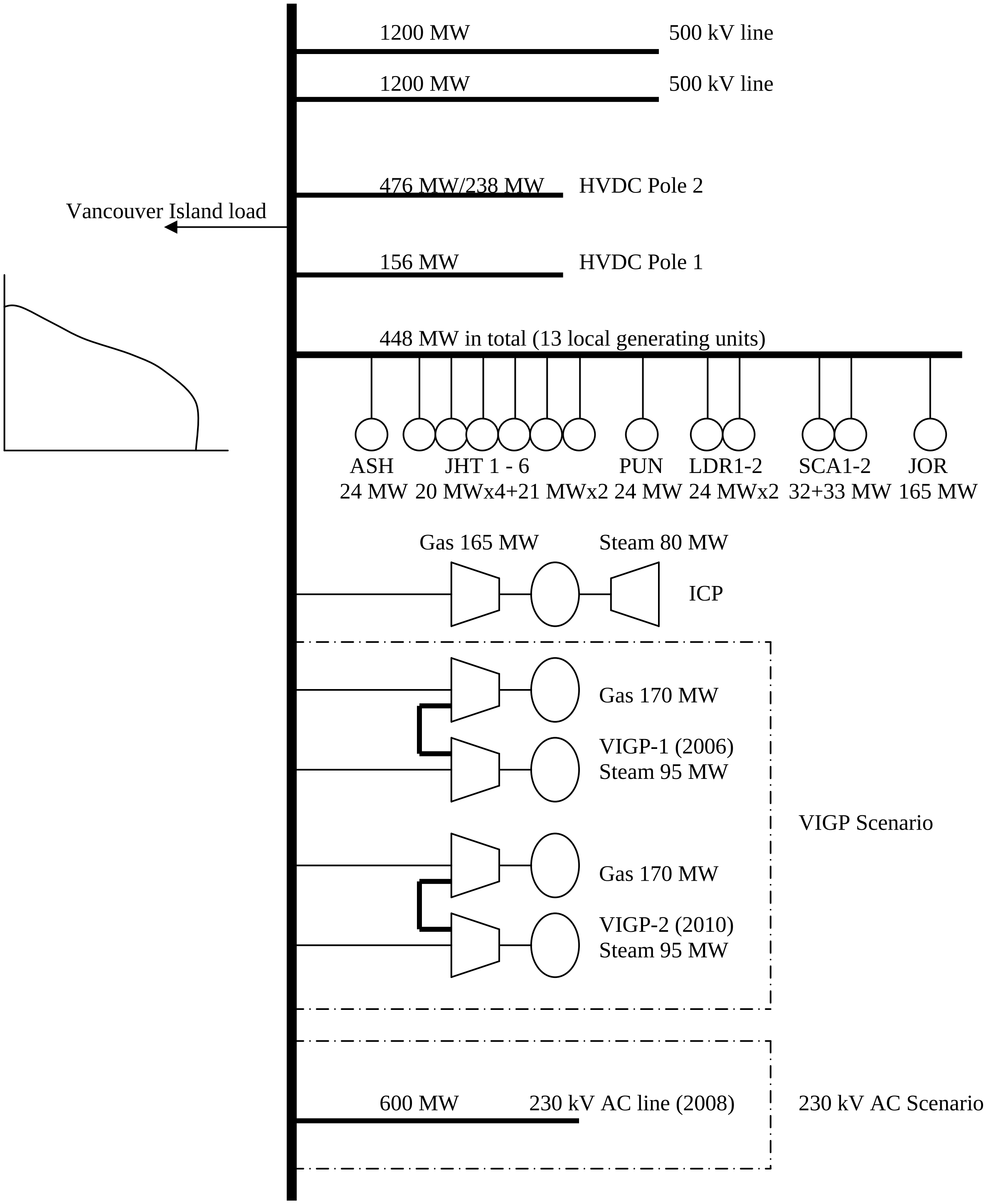

Figure 4 EENS Evaluation Model for Vancouver Island supply

4. Data

4.1 Failure Data

The failure data for the 500 kV circuits and on-Island hydro generating units were based on historical failure records. These data are the same as those used in the three previous reports [8, 9, 10].

The failure data for HVDC components, including both repairable and aging failures, were obtained from expert engineering estimates that were based on historical records, equipment condition assessment and CIGRE data [11].

The failure data of both forced outage and maintenance outage for the ICP and VIGP generating units were based on historical records of the typical combined cycle gas turbine units, which were retrieved from the NERC report [5].

The failure data for a new 230 kV AC circuit 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 circuits in the BC Hydro system, obtained from BC Hydro's CROW (Control Room Operations Window) system. The failure data for the submarine cable were based on an engineering estimate.

All the failure data assumed in the study are given in Appendices B, C, D and E.

4.2 Load Data

The load model used in the study was the most recent Vancouver Island peak load forecast for 2003/04 to 2012/13. The 8760 hourly load records in 2002 were used to model the annual load curve shape. The peak load forecast and the load duration curve are given in Appendix F.

5. Major Assumptions and Study Conditions

- The study time frame is 2003/04 to 2012/13.

- 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 Mainland side was assumed to be perfect and was not incorporated in the study. These assumptions do not cause any negative impact on the results since the three scenarios in the comparison are all the power source options to Vancouver Island.

- Peak loads from 2003 to 2012 were based on the most recent load forecast while the annual load curves for all the 10 years under the study follow the same shape that is based on the hourly load records for 2002.

- The assumptions on the HVDC Pole 2 are summarized in Appendix G.

- HVDC Pole 1 is retired for planning purposes but included as a standby power source in the study. This inclusion was based on the consideration that Pole 1 can still be used when needed from an operational point of view.

- The 230 kV AC circuit has a phase shifting transformer of compatible capacity connected in series at the VIT (Vancouver Island Terminal) station. Since the reliability of this equipment is very high, it was not included in the reliability model for this option.

- Water constraints in reservoirs and randomness of inflows were not simulated. These are only associated with the local hydro generating units that were identical in all the three scenarios in the comparison.

- Operation of the ICP and VIGP was modeled using two states of full output and full down. The derated state (gas turbine operation with steam turbine out-of-service) was not considered. This was due to the fact that the NERC outage statistics cannot distinguish the derated state.

- 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 to overshed load if a system state is associated with transient or voltage instability and load shedding protective relaying systems.

- Sensitivity studies to model pipeline failures were included.

- Sensitivity studies associated with data uncertainty of HVDC Pole 2 and the ICP/VIGP generating units were performed.

6. EENS Evaluation

6.1 Scenarios

The four scenarios for the comparison are as follows:

(1) Do Nothing

This is the existing system without any new power source and without any refurbishment of the HVDC system. This includes two 500 kV circuits each having 1200 MW capacity, HVDC Poles 1 and 2 with Pole 1 as a standby power source (it is in service when needed), 13 local hydro generating units with a total capacity of 448 MW, and the ICP with 240 MW capacity.

(2) VIGP (Portfolio 2)

The first 265 MW CCGT (combined cycle gas turbine) generating unit is added on the Island in 2006 and the second one in 2010, for a total of 530 MW capacity.[4]

(3) New 230 kV AC Circuit to Vancouver Island (Portfolio 3)

A new 230 kV AC circuit with 600 MW capacity is added in 2008. It comprises 40 km of overhead line and 32.5 km of submarine cable.

(4) HVDC Pole 2 Life Extension[5]

This scenario includes the following major refurbishment and replacements:

- 2 spare submarine 900 amp cables purchased 2004
- ARN Transformer spare repaired 2004
- VIT-RX2 reactor spare purchased and placed in service 2005
- VIT HF2 harmonic filter capacitor replaced 2007
- VIT V4 and ARN V8 valve replaced (half of Pole 2) 2007
- VIT T3 Transformer replacement (one phase each year) 2005, 2009, 2011

6.2 Evaluation Procedure

The EENS indices were evaluated using the methods and the computing tools described in Section 2. The procedure included the following steps:

- Create SPARE data files for all HVDC components from 2003/04 to 2012/13.
- Run SPARE to obtain unavailability due to the aging failure mode for each component from 2003 to 2012.
- Create NETREL data files for HVDC Poles 1 and 2 from 2003/04 to 2012/13 using the models shown in Figures 1, 2 and 3 (including both repairable and aging failure data of all components).

[4] Note that the size of the latter was also assumed to be 265 MW, whereas in the original Portfolio 2, the CCGTs subsequent to the VIGP were assumed to be 240 MW.

[5] This is the “Worst Case Scenario” on page 4 of the report at Tab C of the response to BCUC Staff IR 20.3.

- Run NETREL to obtain unavailability and repair time for HVDC Pole 1 and Pole 2 from 2003/04 to 2012/13.

- Prepare failure data (unavailability and repair time) of all other components for the Island's power supply (500 kV circuits, new 230 kV circuit, on-Island hydro generating units, ICP and VIGP generating units) based on historical outage records (BC Hydro outage database, NERC outage data, previous reports and other references).

- Create MCGSR data files for Vancouver Island power supply reliability evaluation for the four scenarios from 2003/04 to 2012/13.

- Run MCGSR to obtain the EENS indices for the four scenarios from 2003/04 to 2012/13.

- Modify the MCGSR data files for the VIGP scenario to include the estimated failure data of the pipeline.

- Run MCGSR to obtain the EENS indices for the VIGP scenario with a pipeline failure included.

- Modify the MCGSR data files for all the scenarios to reflect data uncertainty of HVDC Pole 2 and ICP/VIGP generating units.

- Run MCGSR to obtain the EENS indices for all the scenarios with the changed input data of HVDC Pole 2 and ICP/VIGP generating units.

6.3 Basic Results

The EENS indices for the four scenarios from 2003 to 2012 are summarized in Table 1 and depicted in Figure 5. The EENS for the "Do Nothing" scenario increases constantly and non-linearly over time.

The EENS for the HVDC Life Extension scenario has the same trend with a reduced rising slope at years 2004, 2005 and 2007, which have refurbishment activities. The results indicate that the HVDC refurbishment slows down deterioration of Vancouver Island power supply reliability but does not effectively improve the supply reliability in the long term. The whole HVDC system is aging and it is difficult to stop the aging process by replacing only a few old components and adding a couple of spares for some major components.

For the new 230 kV AC scenario, the EENS index has a big drop in 2008 when the circuit is placed in service and then starts a normal slow increase due to load growth. This scenario provides the best overall reliability improvement from 2008 until 2012, the end of the study period. The EENS for the VIGP scenario experiences two drop points, one in 2006 when the first generating unit comes into effect and the other in 2010 when the second unit is placed in service. The reliability improvement due to the VIGP occurs earlier and is close to that of the new 230 kV AC circuit from 2010 to 2012.

Table 1: EENS Index for the Four Scenarios (MWh/year)

Year	Do Nothing	VIGP (Portfolio 2)	230 kV AC Cables	HVDC Life Extension
2003	4,621	4,621	4,621	4,621
2004	5,131	5,131	5,131	4,935
2005	5,748	5,748	5,748	5,082
2006	6,560	3,414	6,560	5,693
2007	7,425	3,811	7,425	5,887
2008	8,414	4,237	1,503	6,525
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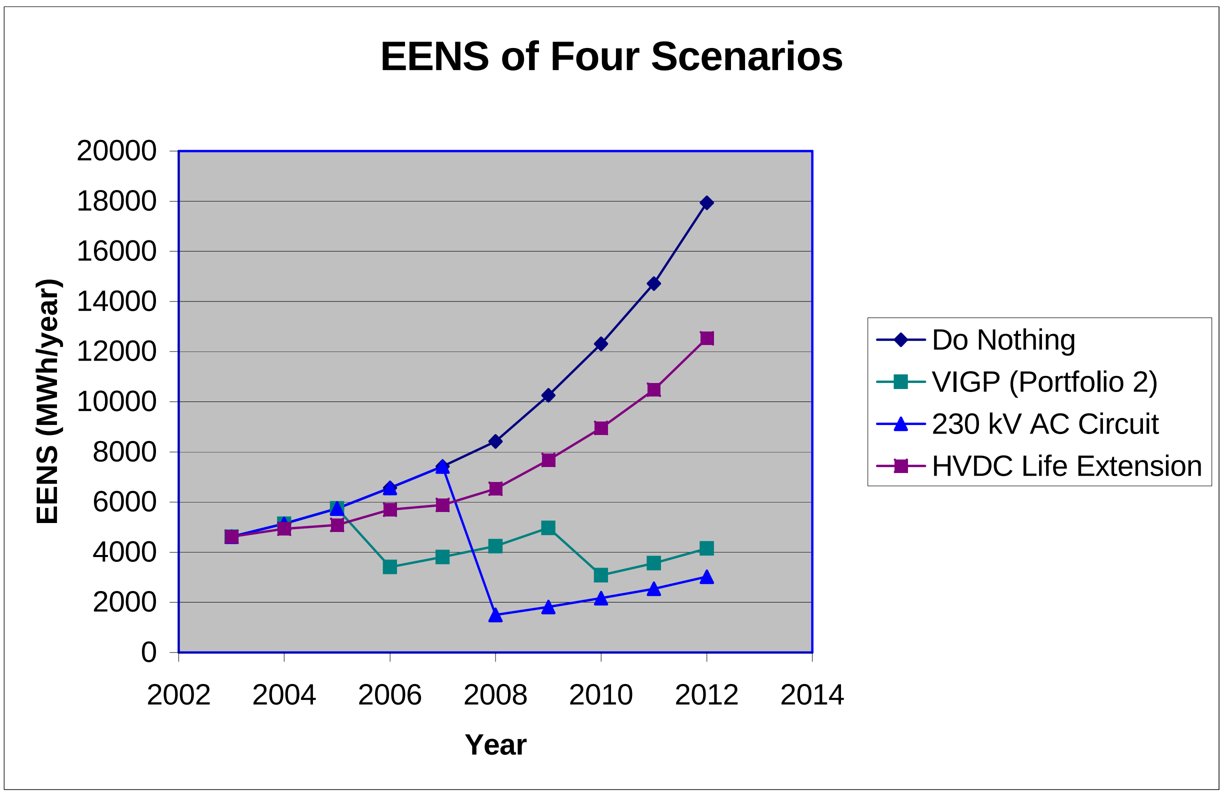

Figure 5: Comparison in EENS for the Four Scenarios

The EENS reductions due to the three reinforcement scenarios (VIGP, 230 kV AC and HVDC Pole 2 Life Extension) against the "Do Nothing" scenario are given in Table 2 and depicted in Figure 6. It can be seen from Table 2 that the new 230 kV AC circuit provides the largest total EENS reduction in the 10-year period of 2003 to 2012, which is 2.5 times as much as that offered by the HVDC Life Extension scenario. The EENS reduction contributed by the VIGP scenario is 2.4 times as much as that due to the HVDC Pole 2 Life Extension. The cumulative EENS reductions due to the VIGP and the 230 kV AC scenarios are quite close.

Table 2: EENS Reduction of Three Scenarios (MWh/year)

Year	VIGP (Portfolio 2)	230 kV AC Cables	HVDC Life Extension
2003	0	0	0
2004	0	0	196
2005	0	0	666
2006	3,146	0	867
2007	3,614	0	1,538
2008	4,177	6,911	1,890
2009	5,297	8,446	2,588
2010	9,222	10,135	3,352
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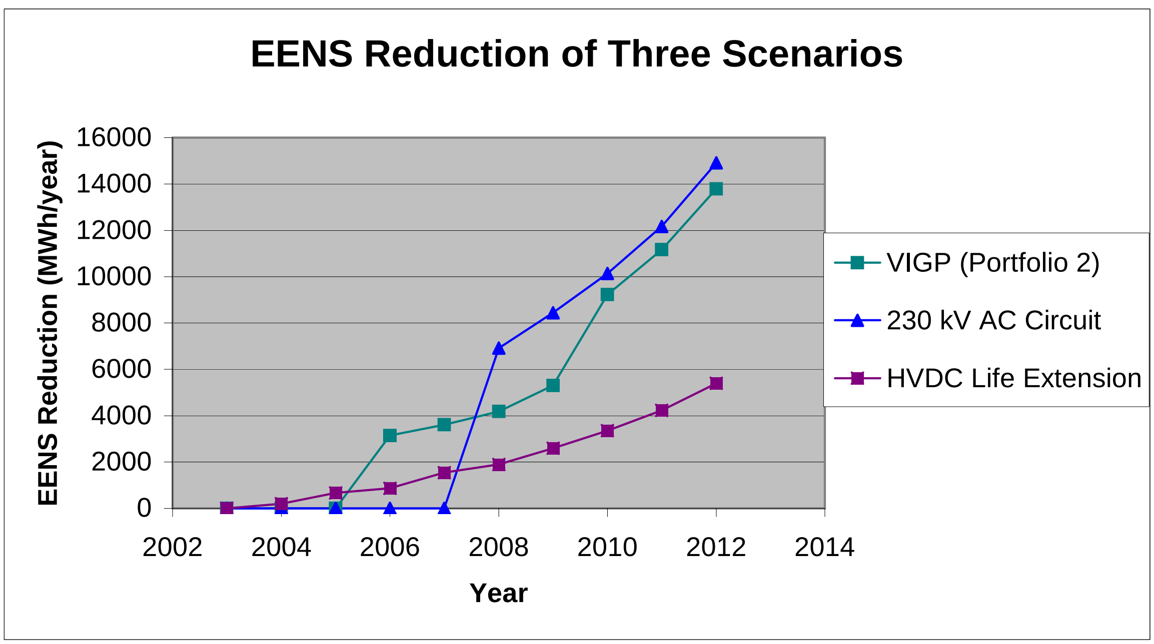

Figure 6: EENS Reduction Due to the Three Scenarios

6.4 Impact of Pipeline Failure on EENS

A pipeline failure would have an impact on the outputs of the ICP and VIGP generating units. The degree of the impact would depend on the nature of failures ranging from a derated MW output to full shutdown. In this impact study, the most severe consequence was assumed; i.e., the failure of pipeline occurs in the deep-water area and causes a full outage of both the ICP and the VIGP. The following failure data were estimated for the sensitivity study purpose (see Appendix E for the source of the data):

Failure frequency: 0.00507/year
Recovery time: 3 months (2190 hours)

The pipeline failure is modeled as follows: Before the VIGP generating units are in service, a pipeline failure causes the ICP outage. After the VIGP units are placed in service, a pipeline failure causes a common outage of both the ICP and VIGP units.

The EENS indices for the VIGP scenario with and without considering the pipeline failure are summarized in Table 3. It can be seen that the impact of pipeline failure on the EENS indices is extremely small and can be ignored under the above assumptions of the model and data.

Table 3 Comparison in EENS for VIGP Scenario With and Without Considering a Pipeline Failure (MWh/year)

Year	VIGP (No Pipeline Failure)	VIGP (With Pipeline Failure)
2003	4,621	4,622
2004	5,131	5,133
2005	5,748	5,752
2006	3,414	3,421
2007	3,811	3,822
2008	4,237	4,251
2009	4,964	4,983
2010	3,084	3,107
2011	3,555	3,591
2012	4,141	4,176

7. Sensitivity Studies

The sensitivity studies are necessary due to uncertainty of the outage data that are based on historical statistics.

The following two sensitivity calculations were performed:

- The unavailability values of the whole HVDC Pole 2 system for all the years were assumed to be reduced to 70% of the values used in the basic study. The reduction included the probabilities of not meeting the full capacity (476 MW) and not meeting the derated capacity (238 MW) and covered all the cases before and after the refurbishment from 2003/04 to 2012/13. This assumption implies that HVDC Pole 2 has much better performance than the expected estimate. In other words, the effects due to aging of components have been equivalently reduced. Note that the assumption would impact all the scenarios, and not just the HVDC Pole 2 Life Extension scenario, since Pole 2 without refurbishment was considered in all other scenarios.

- The forced outage rate based on actual forced outage records of the ICP generating unit in 2002 is smaller than that based on the NERC average outage data. Also, a better maintenance scheme in the future may reduce the unavailability due to maintenance activities. The unavailability values of the ICP and VIGP generating units were assumed to be reduced to 70% of the values used in the basic study. This assumption means that, in real life, both the ICP and VIPG have a better performance than the average.

7.1 Results With Reduced HVDC Pole 2 Unavailability

The EENS indices of the Vancouver Island power supply system for the four scenarios under the assumption of the better HVDC Pole 2 system performance are shown in Table 4 and depicted in Figure 7. The EENS reductions for the three reinforcement scenarios are given in Table 5 and shown in Figure 8. The following observations can be drawn:

- The conclusions on the relative comparisons among the three scenarios that are obtained in the basic results still hold. In other words, even a large uncertainty on the unavailability of HVDC Pole 2 will not change the reliability ranking of the three reinforcement scenarios.

- The EENS reductions (benefits) due to the three reinforcement scenarios against the "Do Nothing" scenario will be decreased under the assumption of better HVDC Pole 2 performance. The cumulative EENS reductions over the study period are decreased as follows:[6] (i) from 52,574 MWh to 42,869 MWh for a new 230 kV AC circuit; (ii) from 50,408 MWh to 40,909 MWh for Portfolio 2; and (iii) from 20,725 MWh to 15,069 MWh for the HVDC Life Extension.

- For a relative comparison, the EENS reduction for the 230 kV AC circuit over the HVDC Pole 2 Life Extension increases from 2.5 to 2.8 and the EENS reduction for the VIGP over the HVDC Pole 2 life extension increases from 2.4 to 2.7.

[6] The comparison is being made between the bottom lines of Table 2 and Table 5.

Table 4 EENS Indices for the Four Scenarios (MWh/year)
With Reduced Unavailability of HVDC Pole 2

Year	Do Nothing	VIGP (Portfolio 2)	230 kV AC Cables	HVDC Life Extension
2003	4,086	4,086	4,086	4,086
2004	4,439	4,439	4,439	4,337
2005	5,036	5,036	5,036	4,490
2006	5,718	2,972	5,718	4,990
2007	6,352	3,297	6,352	5,158
2008	7,171	3,640	1,223	5,673
2009	8,483	4,159	1,447	6,581
2010	9,979	2,496	1,708	7,668
2011	11,816	2,897	2,014	8,825
2012	14,235	3,382	2,423	10,439

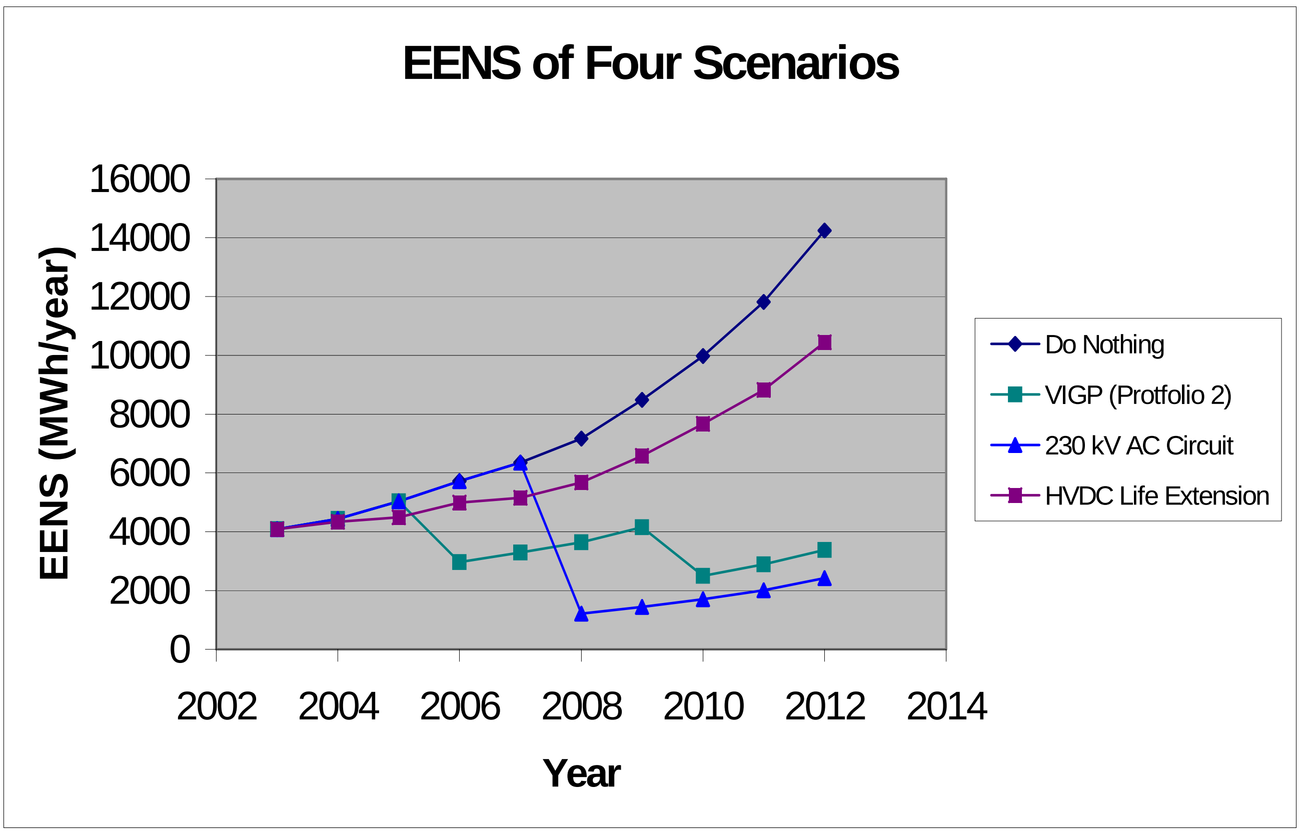

Figure 7 Comparison in EENS for the Four Scenarios With Reduced Unavailability of HVDC Pole 2

Table 5 EENS Reduction of Three Scenarios (MWh/year)
With Reduced Unavailability of HVDC Pole 2

Year	VIGP (Portfolio	230 kV AC cables	HVDC Life Extension
2003	0	0	0
2004	0	0	101
2005	0	0	546
2006	2,746	0	729
2007	3,055	0	1,194
2008	3,531	5,948	1,498
2009	4,324	7,037	1,902
2010	7,482	8,270	2,311
2011	8,919	9,802	2,992
2012	10,852	11,812	3,796
Total	**40,909**	**42,869**	**15,069**

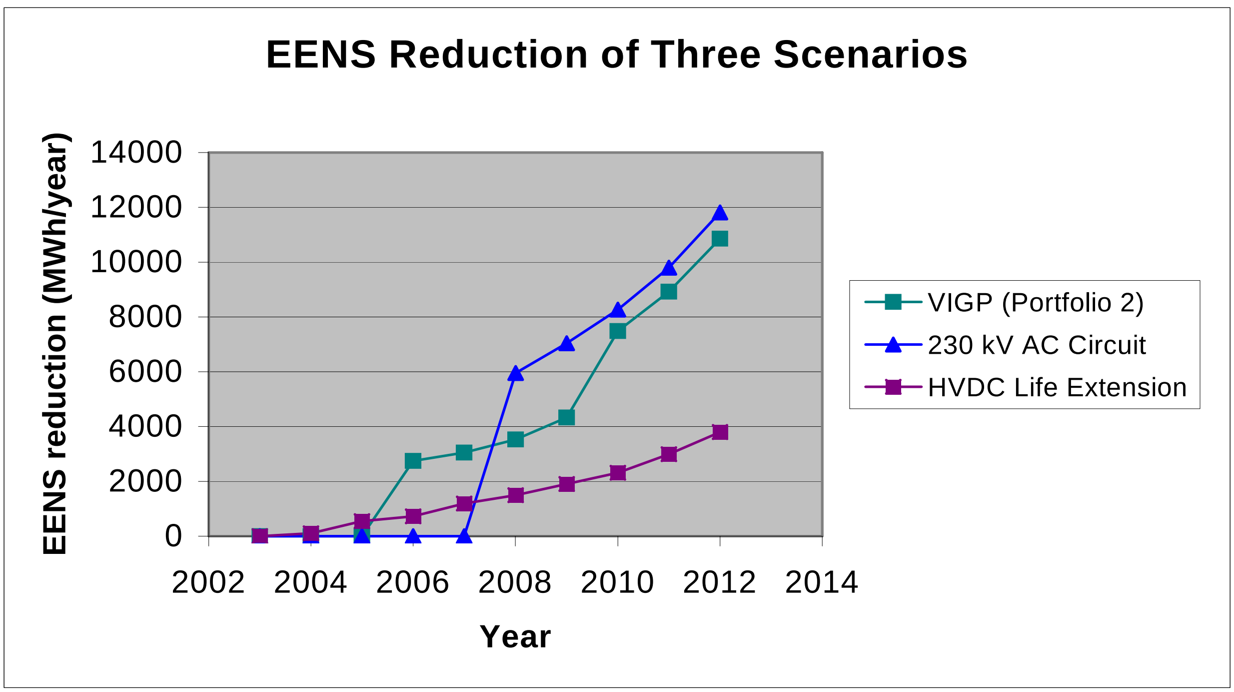

Figure 8 EENS Reduction of Three Scenarios With Reduced Unavailability of HVDC Pole 2

7.2 Results with Reduced ICP and VIGP Unit Unavailability

The EENS indices of the Island power supply system for the four scenarios under the assumption of the better performance of the ICP and VIGP generating units are shown in Table 6 and Figure 9. The EENS reductions for the three reinforcement scenarios are shown in Table 7 and Figure 10. The following observations can be drawn:

- The conclusions on the relative comparisons among the three scenarios that are obtained in the basic results still remain. In other word, a relatively large uncertainty on the unavailability of the ICP and VIGP generating units does not change the reliability ranking of the three reinforcement scenarios.

- Decreased unavailability of the ICP and VIGP units results in lower EENS indices for all the four scenarios. Although this effect is slightly larger than the VIGP scenario, it is still marginal.

- The EENS reductions (benefits) of the three reinforcement scenarios against the Do Nothing scenario under the assumption of the better ICP and VIGP unit performance are basically at the same levels as those in the original results. The cumulative EENS reductions for the three reinforcement scenarios are close to the values obtained under the basic data assumptions. This is mainly because the decreased unavailability of the ICP plays the same role for the three reinforcement scenarios and the “Do Nothing” option.

- The difference in the cumulative EENS reduction between the VIGP scenario and the 230 kV AC circuit scenario is 4.3% in the basic results and 1.9% in the case of decreased unavailability of the ICP and VIGP units. This indicates that the effect of a better ICP and VIGP performance is smaller for the 230 kV AC circuit scenario than for the VIGP scenario.

Table 6 EENS Indices for the Four Scenarios (MWh/year)
With Reduced Unavailability of ICP and VIGP Generating Units

Year	Do Nothing	VIGP (Portfolio 2)	230 kV AC Cables	HVDC Life Extension
2003	4,456	4,456	4,456	4,456
2004	4,923	4,923	4,923	4,741
2005	5,515	5,515	5,515	4,888
2006	6,276	3,177	6,276	5,469
2007	7,094	3,531	7,094	5,636
2008	8,040	3,916	1,437	6,257
2009	9,749	4,586	1,744	7,340
2010	11,762	2,781	2,089	8,560
2011	14,047	3,208	2,451	10,006
2012	17,135	3,730	2,904	11,957

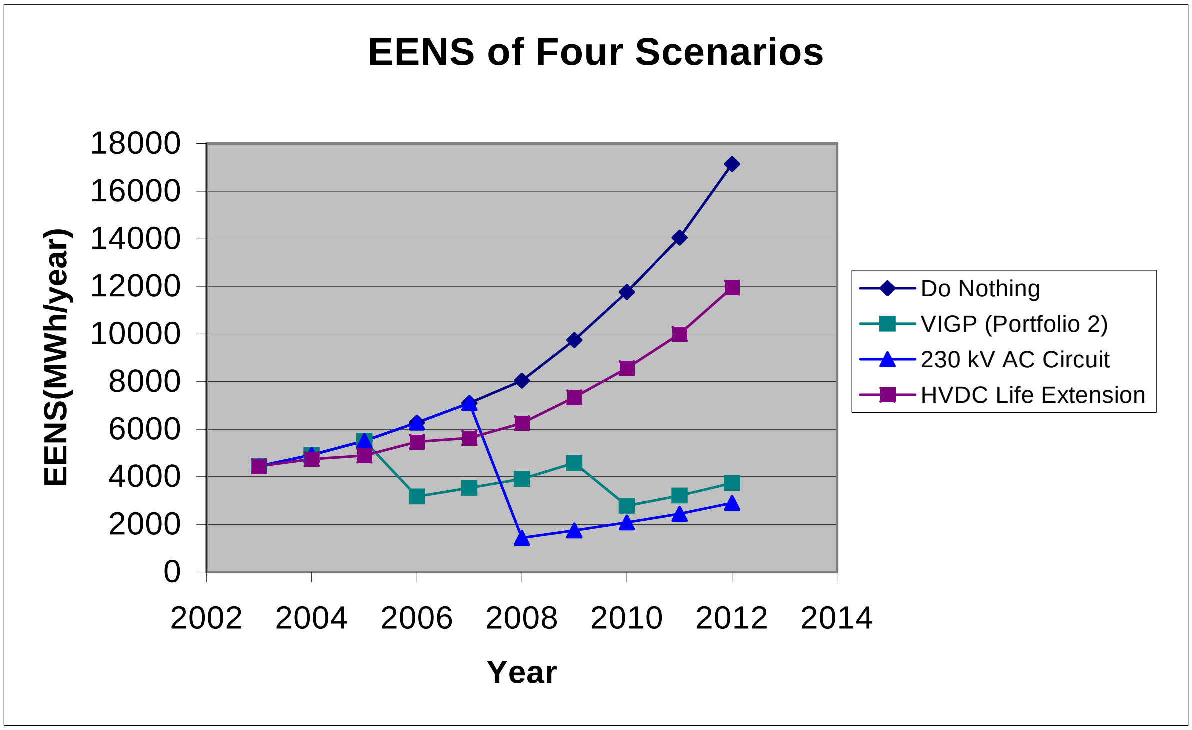

Figure 9 Comparison in EENS for the Four Scenarios With Reduced Unavailability of ICP and VIGP Generating Units

Table 7 EENS Reduction of Three Scenarios (MWh/year)
With Reduced Unavailability of ICP and VIGP Generating Units

Year	VIGP (Portfolio 2)	230 kV AC Circuit	HVDC life Extension
2003	0	0	0
2004	0	0	182
2005	0	0	627
2006	3,099	0	807
2007	3,563	0	1,457
2008	4,125	6,603	1,784
2009	5,163	8,005	2,409
2010	8,981	9,673	3202
2011	10,839	11,596	4,041
2012	13,404	14,230	5,177
Total	**49,174**	**50,107**	**19,686**

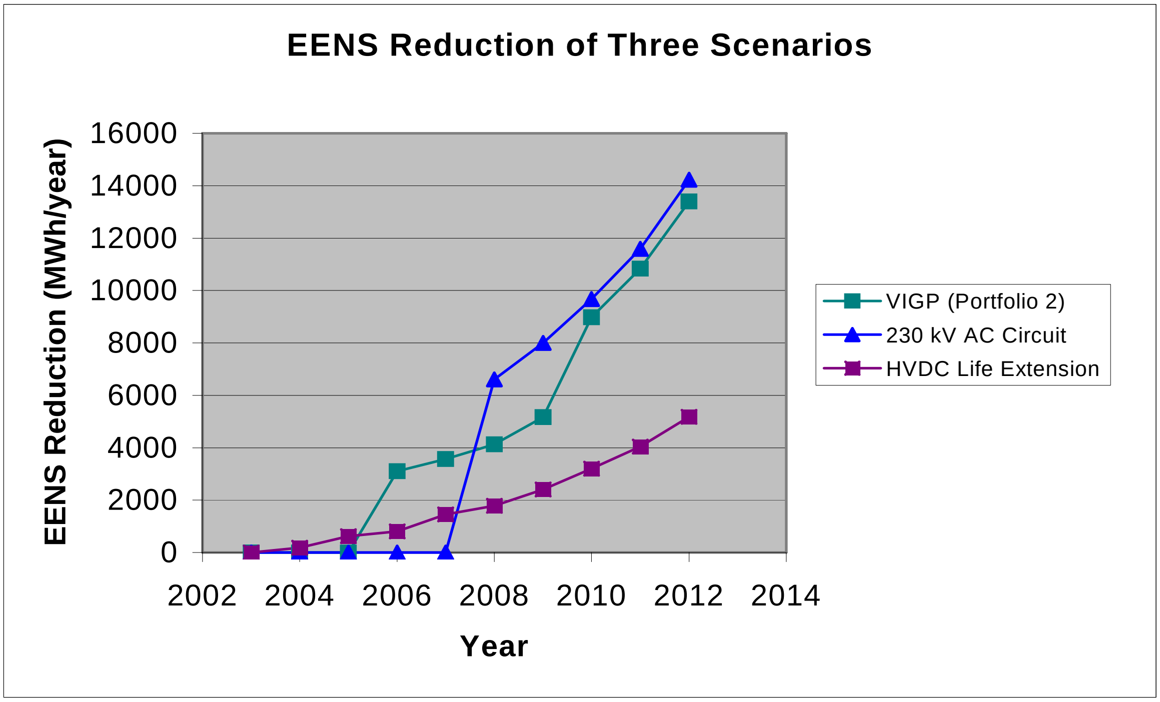

Figure 10 EENS Reduction Due to the Three Scenarios With Reduced Unavailability of ICP and VIGP Generating Units

8. Conclusions

The EENS study results indicate that the 230 kV AC circuit option provides the highest improvement to Vancouver Island power supply reliability over the study period. VIGP (Portfolio 2) provides the second highest reliability improvement. However, the difference in the cumulative EENS reduction between these two options is extremely close; i.e., in the order of only 1.9% to 4.3% over the study period.

The HVDC Pole 2 Life Extension can contribute some reliability improvement to Vancouver Island power supply. However, this contribution is much less than that of the 230 kV AC circuit or the VIGP scenario. A key reason is that the whole HVDC Pole 2 is aging. Refurbishing only a portion of major components cannot essentially resolve the problems due to the aging process.

A failure of the pipeline in the VIGP scenario would not significantly increase the overall risk to Vancouver Island power supply. This is mainly due to the fact that the failure probability of the pipeline is much smaller than failure probabilities of electric components in the Vancouver Island power supply system.

The sensitivity studies indicate that the uncertainty in the unavailability data of HVDC Pole 2 system, the ICP, and the VIGP generating units would not change the reliability ranking of the three scenarios, although the decreased unavailability of HVDC Pole 2 or ICP/VIGP units could reduce EENS indices of all the scenarios. The impact on the results due to the uncertainty in the unavailability data of ICP and VIGP units is marginal.

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Appendix A: Reliability Terms

(1) Reliability index – EENS (Expected Energy Not Served)

This index has been presented and used by the power industry for many years [2,12,13,14]. In some literatures, it is named EUE (Expected Unserved Energy). The definition of this index can be defined as follows [2]:

$$EENS = \sum_{i \in S} C_i F_i D_i$$

where C_i is the load curtailment in system state i (failure event i); F_i and D_i are the frequency and the duration of the system state i; and S is the set of all system states.

(2) General definitions of reliability and availability [1]

(i) Reliability is defined as “the probability of a component/device/system staying in the operating state without failure.”
(ii) Availability is defined as “ the probability of finding the component/device/system in the operating state at some time.”

(3) Several definitions associated with component data [1, 6]

(i) Forced outage rate (average unavailability due to forced outage)

FOR = down time / (down time + up time) = Forced outage hours / (service hours + forced outage hours)

(ii) Forced outage factor

FOF = forced outage hours/ period hours

(iii) Availability factor (total average availability)

AF = available hours/ period hours = (reserved shutdown hours + service hours)/period hours

Available hours = period hours – planned outage hours – maintenance hours – forced outage hours

(vi) Unavailability factor (total unavailability)

UF = 1- AF

(iv) Mean time to failure (MTTF) and failure rate (FR)

MTTF = service hours/ number of failures

FR = 1/ MTTF

(v) Mean time to repair (MTTR) and repair rate (RR)

MTTR = outage hours/ number of failures

RR= 1/MTTR

(vi) Mean time between failure (MTBF) and failure frequency (FF)

MTBF = (service hours + outage hours)/ number of failures

FF = 1/ MTBF

Appendix B: HVDC component reliability data

Data is based on expert engineering estimates, actual equipment condition and CIGRE report.
Cells with **RED TEXT** contain data with an uncertain range of values, see the associated notes

Reliability Data for Pole 1 on an Annual Basis.

Component	Year	MTTR (Hrs)	MTBF (Yrs)	Failure Rate (Fails/yr)	Age (Yrs)	Mean Life (Yrs)	Std Dev (Yrs)	Add'l outage time for construction (Hrs)	Notes:
HVDC Pole 1									
Cable 1/6	2002	2920.00	8.5	1.18E-01	33	60	10		- Without a spare cable section, the MTTR could be as little as
(600 Amp)	2003	2920.00	8.5	1.18E-01	34	60	10		5840 Hours (8 months)
	2004	2920.00	8.5	1.18E-01	35	60	10		- Without a spare cable section, the MTTR could be up to 13140
	2005	2920.00	8.5	1.18E-01	36	60	10		Hours (1.5 Years)
	2006	2920.00	8.5	1.18E-01	37	60	10		- With a spare cable section, the MTTR could be as little as 2920
	2007	2920.00	8.5	1.18E-01	38	60	10		Hours (4 months)
	2008	2920.00	8.5	1.18E-01	39	60	10		- With a spare cable section, the MTTR could be up to 4380 Hours
	2009	2920.00	8.5	1.18E-01	40	60	10		(6 months)
	2010	2920.00	8.5	1.18E-01	41	60	10		
	2011	2920.00	8.5	1.18E-01	42	60	10		
	2012	2920.00	8.5	1.18E-01	43	60	10		
Cable 2/7	2002	2920	8.5	1.18E-01	33	60	10		- Without a spare cable section, the MTTR could be as little as
(600 Amp)	2003	2920	8.5	1.18E-01	34	60	10		5840 Hours (8 months)
	2004	2920	8.5	1.18E-01	35	60	10		- Without a spare cable section, the MTTR could be up to 13140
	2005	2920	8.5	1.18E-01	36	60	10		Hours (1.5 Years)
	2006	2920	8.5	1.18E-01	37	60	10		- With a spare cable section, the MTTR could be as little as 2920
	2007	2920	8.5	1.18E-01	38	60	10		Hours (4 months)
	2008	2920	8.5	1.18E-01	39	60	10		- With a spare cable section, the MTTR could be up to 4380 Hours
	2009	2920	8.5	1.18E-01	40	60	10		(6 months)
	2010	2920	8.5	1.18E-01	41	60	10		
	2011	2920	8.5	1.18E-01	42	60	10		
	2012	2920	8.5	1.18E-01	43	60	10		
Cable Return	2002	2920	8.5	1.18E-01	33	60	10		- Without a spare cable section, the MTTR could be as little as
(600 Amp)	2003	2920	8.5	1.18E-01	34	60	10		5840 Hours (8 months)
	2004	2920	8.5	1.18E-01	35	60	10		- Without a spare cable section, the MTTR could be up to 13140
	2005	2920	8.5	1.18E-01	36	60	10		Hours (1.5 Years)
	2006	2920	8.5	1.18E-01	37	60	10		- With a spare cable section, the MTTR could be as little as 2920
	2007	2920	8.5	1.18E-01	38	60	10		Hours (4 months)
	2008	2920	8.5	1.18E-01	39	60	10		- With a spare cable section, the MTTR could be up to 4380 Hours
	2009	2920	8.5	1.18E-01	40	60	10		(6 months)
	2010	2920	8.5	1.18E-01	41	60	10		
	2011	2920	8.5	1.18E-01	42	60	10		
	2012	2920	8.5	1.18E-01	43	60	10		
Cable 4/9	2002	5840	8.5	1.18E-01	26	40	10	4380	- pole 2 cables have are less protected than pole 1 and have a
(900 Amp)	2003	5840	8.5	1.18E-01	27	40	10		lower life expectancy
	2004	5840	8.5	1.18E-01	28	40	10		- Without a spare cable section, the MTTR could be as little as
	2005	5840	8.5	1.18E-01	29	40	10		5840 Hours (8 months)
	2006	5840	8.5	1.18E-01	30	40	10		- Without a spare cable section, the MTTR could be up to 13140
	2007	5840	8.5	1.18E-01	31	40	10		Hours (1.5 Years)
	2008	5840	8.5	1.18E-01	32	40	10		- With a spare cable section, the MTTR could be as little as 2920
	2009	5840	8.5	1.18E-01	33	40	10		Hours (4 months)
	2010	5840	8.5	1.18E-01	34	40	10		- With a spare cable section, the MTTR could be up to 4380 Hours
	2011	5840	8.5	1.18E-01	35	40	10		(6 months)
	2012	5840	8.5	1.18E-01	36	40	10		- 2002 cable section repair/replacement initiated

Cable 5/10	2002	5840	8.5	1.18E-01	26	40	10	4380	- pole 2 cables have are less protected than pole 1 and have a lower life expectancy - Without a spare cable section, the MTTR could be as little as 5840 Hours (8 months) - Without a spare cable section, the MTTR could be up to 13140 Hours (1.5 Years) - With a spare cable section, the MTTR could be as little as 2920 Hours (4 months) - With a spare cable section, the MTTR could be up to 4380 Hours (6 months) - 2002 cable section repair/replacement initiated
(900 Amp)	2003	5840	8.5	1.18E-01	27	40	10		
	2004	5840	8.5	1.18E-01	28	40	10		
	2005	5840	8.5	1.18E-01	29	40	10		
	2006	5840	8.5	1.18E-01	30	40	10		
	2007	5840	8.5	1.18E-01	31	40	10		
	2008	5840	8.5	1.18E-01	32	40	10		
	2009	5840	8.5	1.18E-01	33	40	10		
	2010	5840	8.5	1.18E-01	34	40	10		
	2011	5840	8.5	1.18E-01	35	40	10		
	2012	5840	8.5	1.18E-01	36	40	10		
ARN P1 Filters	2002	1.56	2.7	3.70E-01	33	33	5		
	2003	1.56	2.7	3.70E-01	34	33	5		
	2004	1.56	2.7	3.70E-01	35	33	5		
	2005	1.56	2.7	3.70E-01	36	33	5		
	2006	1.56	2.7	3.70E-01	37	33	5		
	2007	1.56	2.7	3.70E-01	38	33	5		
	2008	1.56	2.7	3.70E-01	39	33	5		
	2009	1.56	2.7	3.70E-01	40	33	5		
	2010	1.56	2.7	3.70E-01	41	33	5		
	2011	1.56	2.7	3.70E-01	42	33	5		
	2012	1.56	2.7	3.70E-01	43	33	5		
VIT P1 Filters	2002	1.56	2.7	3.70E-01	33	33	5		
	2003	1.56	2.7	3.70E-01	34	33	5		
	2004	1.56	2.7	3.70E-01	35	33	5		
	2005	1.56	2.7	3.70E-01	36	33	5		
	2006	1.56	2.7	3.70E-01	37	33	5		
	2007	1.56	2.7	3.70E-01	38	33	5		
	2008	1.56	2.7	3.70E-01	39	33	5		
	2009	1.56	2.7	3.70E-01	40	33	5		
	2010	1.56	2.7	3.70E-01	41	33	5		
	2011	1.56	2.7	3.70E-01	42	33	5		
	2012	1.56	2.7	3.70E-01	43	33	5		
ARN MAV	2002	37	0.42	2.38E+00	33	33	5		
	2003	37	0.42	2.38E+00	34	33	5		
	2004	37	0.42	2.38E+00	35	33	5		
	2005	37	0.42	2.38E+00	36	33	5		
	2006	37	0.42	2.38E+00	37	33	5		
	2007	37	0.42	2.38E+00	38	33	5		
	2008	37	0.42	2.38E+00	39	33	5		
	2009	37	0.42	2.38E+00	40	33	5		
	2010	37	0.42	2.38E+00	41	33	5		
	2011	37	0.42	2.38E+00	42	33	5		
	2012	37	0.42	2.38E+00	43	33	5		
VIT MAV	2002	37	0.42	2.38E+00	33	33	5		
	2003	37	0.42	2.38E+00	34	33	5		
	2004	37	0.42	2.38E+00	35	33	5		
	2005	37	0.42	2.38E+00	36	33	5		
	2006	37	0.42	2.38E+00	37	33	5		
	2007	37	0.42	2.38E+00	38	33	5		
	2008	37	0.42	2.38E+00	39	33	5		
	2009	37	0.42	2.38E+00	40	33	5		
	2010	37	0.42	2.38E+00	41	33	5		
	2011	37	0.42	2.38E+00	42	33	5		
	2012	37	0.42	2.38E+00	43	33	5		

ARN MAV	2002	37	0.42	2.38E+00	33	33	5
	2003	37	0.42	2.38E+00	34	33	5
	2004	37	0.42	2.38E+00	35	33	5
	2005	37	0.42	2.38E+00	36	33	5
	2006	37	0.42	2.38E+00	37	33	5
	2007	37	0.42	2.38E+00	38	33	5
	2008	37	0.42	2.38E+00	39	33	5
	2009	37	0.42	2.38E+00	40	33	5
	2010	37	0.42	2.38E+00	41	33	5
	2011	37	0.42	2.38E+00	42	33	5
	2012	37	0.42	2.38E+00	43	33	5
VIT MAV	2002	37	0.42	2.38E+00	33	33	5
	2003	37	0.42	2.38E+00	34	33	5
	2004	37	0.42	2.38E+00	35	33	5
	2005	37	0.42	2.38E+00	36	33	5
	2006	37	0.42	2.38E+00	37	33	5
	2007	37	0.42	2.38E+00	38	33	5
	2008	37	0.42	2.38E+00	39	33	5
	2009	37	0.42	2.38E+00	40	33	5
	2010	37	0.42	2.38E+00	41	33	5
	2011	37	0.42	2.38E+00	42	33	5
	2012	37	0.42	2.38E+00	43	33	5
Tx1	2002	8760	33.333	3.00E-02	33	36	5
- VIT	2003	8760	33.333	3.00E-02	34	36	5
	2004	8760	33.333	3.00E-02	35	36	5
	2005	8760	33.333	3.00E-02	36	36	5
	2006	8760	33.333	3.00E-02	37	36	5
	2007	8760	33.333	3.00E-02	38	36	5
	2008	8760	33.333	3.00E-02	39	36	5
	2009	8760	33.333	3.00E-02	40	36	5
	2010	8760	33.333	3.00E-02	41	36	5
	2011	8760	33.333	3.00E-02	42	36	5
	2012	8760	33.333	3.00E-02	43	36	5
Tx2	2002	8760	33.333	3.00E-02	33	36	5
- VIT	2003	8760	33.333	3.00E-02	34	36	5
	2004	8760	33.333	3.00E-02	35	36	5
	2005	8760	33.333	3.00E-02	36	36	5
	2006	8760	33.333	3.00E-02	37	36	5
	2007	8760	33.333	3.00E-02	38	36	5
	2008	8760	33.333	3.00E-02	39	36	5
	2009	8760	33.333	3.00E-02	40	36	5
	2010	8760	33.333	3.00E-02	41	36	5
	2011	8760	33.333	3.00E-02	42	36	5
	2012	8760	33.333	3.00E-02	43	36	5
Tx5	2002	8760	33.333	3.00E-02	33	36	5
- ARN	2003	8760	33.333	3.00E-02	34	36	5
	2004	8760	33.333	3.00E-02	35	36	5
	2005	8760	33.333	3.00E-02	36	36	5
	2006	8760	33.333	3.00E-02	37	36	5
	2007	8760	33.333	3.00E-02	38	36	5
	2008	8760	33.333	3.00E-02	39	36	5
	2009	8760	33.333	3.00E-02	40	36	5
	2010	8760	33.333	3.00E-02	41	36	5
	2011	8760	33.333	3.00E-02	42	36	5
	2012	8760	33.333	3.00E-02	43	36	5

Tx6	2002	8760	33.333	3.00E-02	33	36	5
- ARN	2003	8760	33.333	3.00E-02	34	36	5
	2004	8760	33.333	3.00E-02	35	36	5
	2005	8760	33.333	3.00E-02	36	36	5
	2006	8760	33.333	3.00E-02	37	36	5
	2007	8760	33.333	3.00E-02	38	36	5
	2008	8760	33.333	3.00E-02	39	36	5
	2009	8760	33.333	3.00E-02	40	36	5
	2010	8760	33.333	3.00E-02	41	36	5
	2011	8760	33.333	3.00E-02	42	36	5
	2012	8760	33.333	3.00E-02	43	36	5
Rx1 - VIT	2002	672	50	2.00E-02	33	30	5
	2003	672	50	2.00E-02	34	30	5
	2004	672	50	2.00E-02	35	30	5
	2005	672	50	2.00E-02	36	30	5
	2006	672	50	2.00E-02	37	30	5
	2007	672	50	2.00E-02	38	30	5
	2008	672	50	2.00E-02	39	30	5
	2009	672	50	2.00E-02	40	30	5
	2010	672	50	2.00E-02	41	30	5
	2011	672	50	2.00E-02	42	30	5
	2012	672	50	2.00E-02	43	30	5
Rx1 - VIT	2002	672	50	2.00E-02	33	30	5
	2003	672	50	2.00E-02	34	30	5
	2004	672	50	2.00E-02	35	30	5
	2005	672	50	2.00E-02	36	30	5
	2006	672	50	2.00E-02	37	30	5
	2007	672	50	2.00E-02	38	30	5
	2008	672	50	2.00E-02	39	30	5
	2009	672	50	2.00E-02	40	30	5
	2010	672	50	2.00E-02	41	30	5
	2011	672	50	2.00E-02	42	30	5
	2012	672	50	2.00E-02	43	30	5

Data is based on actual CIGRE report data that has been reviewed and updated to reflect actual equipment condition.
Cells with **RED TEXT** contain data with an uncertain range of values, see the associated notes

Reliability Data for Pole 2 Life Extension Studies on an Annual Basis.

Component	Year	MTTR (Hrs)	MTBF (Yrs)	Failure Rate (Fails/yr)	Age (Yrs)	Mean Life (Yrs)	Std Dev (Yrs)	Add'l outage time for construction (Hrs)	Notes:
Scenario - Existing (do nothing)									
Cable 1/6	2002	2920.00	8.5	1.18E-01	33	60	10		- Without a spare cable section, the MTTR could be as little as 5840 Hours (8 months)
(600 Amp)	2003	2920.00	8.5	1.18E-01	34	60	10		
	2004	2920.00	8.5	1.18E-01	35	60	10		- Without a spare cable section, the MTTR could be up to 13140 Hours (1.5 Years)
	2005	2920.00	8.5	1.18E-01	36	60	10		
	2006	2920.00	8.5	1.18E-01	37	60	10		- With a spare cable section, the MTTR could be as little as 2920 Hours (4 months)
	2007	2920.00	8.5	1.18E-01	38	60	10		
	2008	2920.00	8.5	1.18E-01	39	60	10		- With a spare cable section, the MTTR could be up to 4380 Hours (6 months)
	2009	2920.00	8.5	1.18E-01	40	60	10		
	2010	2920.00	8.5	1.18E-01	41	60	10		
	2011	2920.00	8.5	1.18E-01	42	60	10		
	2012	2920.00	8.5	1.18E-01	43	60	10		
Cable 2/7	2002	2920	8.5	1.18E-01	33	60	10		- Without a spare cable section, the MTTR could be as little as 5840 Hours (8 months)
(600 Amp)	2003	2920	8.5	1.18E-01	34	60	10		
	2004	2920	8.5	1.18E-01	35	60	10		- Without a spare cable section, the MTTR could be up to 13140 Hours (1.5 Years)
	2005	2920	8.5	1.18E-01	36	60	10		
	2006	2920	8.5	1.18E-01	37	60	10		- With a spare cable section, the MTTR could be as little as 2920 Hours (4 months)
	2007	2920	8.5	1.18E-01	38	60	10		
	2008	2920	8.5	1.18E-01	39	60	10		- With a spare cable section, the MTTR could be up to 4380 Hours (6 months)
	2009	2920	8.5	1.18E-01	40	60	10		
	2010	2920	8.5	1.18E-01	41	60	10		
	2011	2920	8.5	1.18E-01	42	60	10		
	2012	2920	8.5	1.18E-01	43	60	10		
Cable Return	2002	2920	8.5	1.18E-01	33	60	10		- Without a spare cable section, the MTTR could be as little as 5840 Hours (8 months)
(600 Amp)	2003	2920	8.5	1.18E-01	34	60	10		
	2004	2920	8.5	1.18E-01	35	60	10		- Without a spare cable section, the MTTR could be up to 13140 Hours (1.5 Years)
	2005	2920	8.5	1.18E-01	36	60	10		
	2006	2920	8.5	1.18E-01	37	60	10		- With a spare cable section, the MTTR could be as little as 2920 Hours (4 months)
	2007	2920	8.5	1.18E-01	38	60	10		
	2008	2920	8.5	1.18E-01	39	60	10		- With a spare cable section, the MTTR could be up to 4380 Hours (6 months)
	2009	2920	8.5	1.18E-01	40	60	10		
	2010	2920	8.5	1.18E-01	41	60	10		
	2011	2920	8.5	1.18E-01	42	60	10		
	2012	2920	8.5	1.18E-01	43	60	10		
Cable 4/9	2002	5840	8.5	1.18E-01	26	40	10	4380	- pole 2 cables have are less protected than pole 1 and have a lower life expectancy
(900 Amp)	2003	5840	8.5	1.18E-01	27	40	10		
	2004	5840	8.5	1.18E-01	28	40	10		- Without a spare cable section, the MTTR could be as little as 5840 Hours (8 months)
	2005	5840	8.5	1.18E-01	29	40	10		
	2006	5840	8.5	1.18E-01	30	40	10		- Without a spare cable section, the MTTR could be up to 13140 Hours (1.5 Years)
	2007	5840	8.5	1.18E-01	31	40	10		
	2008	5840	8.5	1.18E-01	32	40	10		- With a spare cable section, the MTTR could be as little as 2920 Hours (4 months)
	2009	5840	8.5	1.18E-01	33	40	10		
	2010	5840	8.5	1.18E-01	34	40	10		- With a spare cable section, the MTTR could be up to 4380 Hours (6 months)
	2011	5840	8.5	1.18E-01	35	40	10		
	2012	5840	8.5	1.18E-01	36	40	10		- 2002 cable section repair/replacement initiated

Cable 5/10	2002	5840	8.5	1.18E-01	26	40	10	4380	- pole 2 cables have are less protected than pole 1 and have a
(900 Amp)	2003	5840	8.5	1.18E-01	27	40	10		lower life expectancy
	2004	5840	8.5	1.18E-01	28	40	10		- Without a spare cable section, the MTTR could be as little as
	2005	5840	8.5	1.18E-01	29	40	10		5840 Hours (8 months)
	2006	5840	8.5	1.18E-01	30	40	10		- Without a spare cable section, the MTTR could be up to 13140
	2007	5840	8.5	1.18E-01	31	40	10		Hours (1.5 Years)
	2008	5840	8.5	1.18E-01	32	40	10		- With a spare cable section, the MTTR could be as little as 2920
	2009	5840	8.5	1.18E-01	33	40	10		Hours (4 months)
	2010	5840	8.5	1.18E-01	34	40	10		- With a spare cable section, the MTTR could be up to 4380
	2011	5840	8.5	1.18E-01	35	40	10		Hours (6 months)
	2012	5840	8.5	1.18E-01	36	40	10		- 2002 cable section repair/replacement initiated
P2 Common	2002	2.9	0.625	1.60E+00	26	50	5		
	2003	2.9	0.625	1.60E+00	27	50	5		
	2004	2.9	0.625	1.60E+00	28	50	5		
	2005	2.9	0.625	1.60E+00	29	50	5		
	2006	2.9	0.625	1.60E+00	30	50	5		
	2007	2.9	0.625	1.60E+00	31	50	5		
	2008	2.9	0.625	1.60E+00	32	50	5		
	2009	2.9	0.625	1.60E+00	33	50	5		
	2010	2.9	0.625	1.60E+00	34	50	5		
	2011	2.9	0.625	1.60E+00	35	50	5		
	2012	2.9	0.625	1.60E+00	36	50	5		
V3 Aux.	2002	3.8	1.22	8.20E-01	26	50	5		
	2003	3.8	1.22	8.20E-01	27	50	5		
	2004	3.8	1.22	8.20E-01	28	50	5		
	2005	3.8	1.22	8.20E-01	29	50	5		
	2006	3.8	1.22	8.20E-01	30	50	5		
	2007	3.8	1.22	8.20E-01	31	50	5		
	2008	3.8	1.22	8.20E-01	32	50	5		
	2009	3.8	1.22	8.20E-01	33	50	5		
	2010	3.8	1.22	8.20E-01	34	50	5		
	2011	3.8	1.22	8.20E-01	35	50	5		
	2012	3.8	1.22	8.20E-01	36	50	5		
V4 Aux.	2002	3.8	1.22	8.20E-01	26	50	5		
	2003	3.8	1.22	8.20E-01	27	50	5		
	2004	3.8	1.22	8.20E-01	28	50	5		
	2005	3.8	1.22	8.20E-01	29	50	5		
	2006	3.8	1.22	8.20E-01	30	50	5		
	2007	3.8	1.22	8.20E-01	31	50	5		
	2008	3.8	1.22	8.20E-01	32	50	5		
	2009	3.8	1.22	8.20E-01	33	50	5		
	2010	3.8	1.22	8.20E-01	34	50	5		
	2011	3.8	1.22	8.20E-01	35	50	5		
	2012	3.8	1.22	8.20E-01	36	50	5		
V7 Aux.	2002	3.8	1.22	8.20E-01	26	50	5		
	2003	3.8	1.22	8.20E-01	27	50	5		
	2004	3.8	1.22	8.20E-01	28	50	5		
	2005	3.8	1.22	8.20E-01	29	50	5		
	2006	3.8	1.22	8.20E-01	30	50	5		
	2007	3.8	1.22	8.20E-01	31	50	5		
	2008	3.8	1.22	8.20E-01	32	50	5		
	2009	3.8	1.22	8.20E-01	33	50	5		
	2010	3.8	1.22	8.20E-01	34	50	5		
	2011	3.8	1.22	8.20E-01	35	50	5		
	2012	3.8	1.22	8.20E-01	36	50	5		

V8 Aux.	2002	3.8	1.22	8.20E-01	26	50	5	
	2003	3.8	1.22	8.20E-01	27	50	5	
	2004	3.8	1.22	8.20E-01	28	50	5	
	2005	3.8	1.22	8.20E-01	29	50	5	
	2006	3.8	1.22	8.20E-01	30	50	5	
	2007	3.8	1.22	8.20E-01	31	50	5	
	2008	3.8	1.22	8.20E-01	32	50	5	
	2009	3.8	1.22	8.20E-01	33	50	5	
	2010	3.8	1.22	8.20E-01	34	50	5	
	2011	3.8	1.22	8.20E-01	35	50	5	
	2012	3.8	1.22	8.20E-01	36	50	5	
ARN P2 Filters	2002	0.62	5	2.00E-01	6	33	5	- ARN filters were replaced in 1996
	2003	0.62	5	2.00E-01	7	33	5	
	2004	0.62	5	2.00E-01	8	33	5	
	2005	0.62	5	2.00E-01	9	33	5	
	2006	0.62	5	2.00E-01	10	33	5	
	2007	0.62	5	2.00E-01	11	33	5	
	2008	0.62	5	2.00E-01	12	33	5	
	2009	0.62	5	2.00E-01	13	33	5	
	2010	0.62	5	2.00E-01	14	33	5	
	2011	0.62	5	2.00E-01	15	33	5	
	2012	0.62	5	2.00E-01	16	33	5	
VIT P2 Filters	2002	0.62	5	2.00E-01	26	33	5	
	2003	0.62	5	2.00E-01	27	33	5	
	2004	0.62	5	2.00E-01	28	33	5	
	2005	0.62	5	2.00E-01	29	33	5	
	2006	0.62	5	2.00E-01	30	33	5	
	2007	0.62	5	2.00E-01	31	33	5	
	2008	0.62	5	2.00E-01	32	33	5	
	2009	0.62	5	2.00E-01	33	33	5	
	2010	0.62	5	2.00E-01	34	33	5	
	2011	0.62	5	2.00E-01	35	33	5	
	2012	0.62	5	2.00E-01	36	33	5	
V3	2002	136	3	3.33E-01	26	40	10	
- Low Voltage Valves	2003	136	3	3.33E-01	27	40	10	
- VIT	2004	136	3	3.33E-01	28	40	10	
	2005	136	3	3.33E-01	29	40	10	
	2006	136	3	3.33E-01	30	40	10	
	2007	136	3	3.33E-01	31	40	10	
	2008	136	3	3.33E-01	32	40	10	
	2009	136	3	3.33E-01	33	40	10	
	2010	136	3	3.33E-01	34	40	10	
	2011	136	3	3.33E-01	35	40	10	
	2012	136	3	3.33E-01	36	40	10	
V4	2002	136	3	3.33E-01	26	40	10	
- High Voltage Valves	2003	136	3	3.33E-01	27	40	10	
- VIT	2004	136	3	3.33E-01	28	40	10	
	2005	136	3	3.33E-01	29	40	10	
	2006	136	3	3.33E-01	30	40	10	
	2007	136	3	3.33E-01	31	40	10	
	2008	136	3	3.33E-01	32	40	10	
	2009	136	3	3.33E-01	33	40	10	
	2010	136	3	3.33E-01	34	40	10	
	2011	136	3	3.33E-01	35	40	10	
	2012	136	3	3.33E-01	36	40	10	

V7	2002	136	3	3.33E-01	26	40	10	
- Low Voltage Valves	2003	136	3	3.33E-01	27	40	10	
- ARN	2004	136	3	3.33E-01	28	40	10	
	2005	136	3	3.33E-01	29	40	10	
	2006	136	3	3.33E-01	30	40	10	
	2007	136	3	3.33E-01	31	40	10	
	2008	136	3	3.33E-01	32	40	10	
	2009	136	3	3.33E-01	33	40	10	
	2010	136	3	3.33E-01	34	40	10	
	2011	136	3	3.33E-01	35	40	10	
	2012	136	3	3.33E-01	36	40	10	
V8	2002	136	3	3.33E-01	26	40	10	
- High Voltage Valves	2003	136	3	3.33E-01	27	40	10	
- ARN	2004	136	3	3.33E-01	28	40	10	
	2005	136	3	3.33E-01	29	40	10	
	2006	136	3	3.33E-01	30	40	10	
	2007	136	3	3.33E-01	31	40	10	
	2008	136	3	3.33E-01	32	40	10	
	2009	136	3	3.33E-01	33	40	10	
	2010	136	3	3.33E-01	34	40	10	
	2011	136	3	3.33E-01	35	40	10	
	2012	136	3	3.33E-01	36	40	10	
T3	2002	16	36	2.78E-02	26	36	5	- Spare TX available on site
- VIT	2003	16	36	2.78E-02	27	36	5	- MTTR is the time to connect the onsite spare
	2004	16	36	2.78E-02	28	36	5	
	2005	16	36	2.78E-02	29	36	5	
	2006	16	36	2.78E-02	30	36	5	
	2007	16	36	2.78E-02	31	36	5	
	2008	16	36	2.78E-02	32	36	5	
	2009	16	36	2.78E-02	33	36	5	
	2010	16	36	2.78E-02	34	36	5	
	2011	16	36	2.78E-02	35	36	5	
	2012	16	36	2.78E-02	36	36	5	
T4	2002	16	36	2.78E-02	26	36	5	- Spare TX available on site
- VIT	2003	16	36	2.78E-02	27	36	5	- MTTR is the time to connect the onsite spare
	2004	16	36	2.78E-02	28	36	5	
	2005	16	36	2.78E-02	29	36	5	
	2006	16	36	2.78E-02	30	36	5	
	2007	16	36	2.78E-02	31	36	5	
	2008	16	36	2.78E-02	32	36	5	
	2009	16	36	2.78E-02	33	36	5	
	2010	16	36	2.78E-02	34	36	5	
	2011	16	36	2.78E-02	35	36	5	
	2012	16	36	2.78E-02	36	36	5	
T7	2002	16	36	2.78E-02	26	36	5	- Spare TX available on site
- ARN	2003	16	36	2.78E-02	27	36	5	- MTTR is the time to connect the onsite spare
	2004	16	36	2.78E-02	28	36	5	
	2005	16	36	2.78E-02	29	36	5	
	2006	16	36	2.78E-02	30	36	5	
	2007	16	36	2.78E-02	31	36	5	
	2008	16	36	2.78E-02	32	36	5	
	2009	16	36	2.78E-02	33	36	5	
	2010	16	36	2.78E-02	34	36	5	
	2011	16	36	2.78E-02	35	36	5	
	2012	16	36	2.78E-02	36	36	5	

T8	2002	16	36	2.78E-02	26	36	5	- Spare TX available on site
- ARN	2003	16	36	2.78E-02	27	36	5	- MTTR is the time to connect the onsite spare
	2004	16	36	2.78E-02	28	36	5	
	2005	16	36	2.78E-02	29	36	5	
	2006	16	36	2.78E-02	30	36	5	
	2007	16	36	2.78E-02	31	36	5	
	2008	16	36	2.78E-02	32	36	5	
	2009	16	36	2.78E-02	33	36	5	
	2010	16	36	2.78E-02	34	36	5	
	2011	16	36	2.78E-02	35	36	5	
	2012	16	36	2.78E-02	36	36	5	
Rx2 - VIT	2002	720	5	2.00E-01	26	33	5	- Spare Rx woukld have to be transported from ARN to VIT to be installed (causing the increased replacement time)
	2003	720	5	2.00E-01	27	33	5	
	2004	720	5	2.00E-01	28	33	5	
	2005	720	5	2.00E-01	29	33	5	
	2006	720	5	2.00E-01	30	33	5	
	2007	720	5	2.00E-01	31	33	5	
	2008	720	5	2.00E-01	32	33	5	
	2009	720	5	2.00E-01	33	33	5	
	2010	720	5	2.00E-01	34	33	5	
	2011	720	5	2.00E-01	35	33	5	
	2012	720	5	2.00E-01	36	33	5	
Rx2 - ARN	2002	8	46.3	2.16E-02	26	30	5	- Spare Rx is located at ARN
	2003	8	46.3	2.16E-02	27	30	5	- MTTR is a spare replacement time
	2004	8	46.3	2.16E-02	28	30	5	
	2005	8	46.3	2.16E-02	29	30	5	
	2006	8	46.3	2.16E-02	30	30	5	
	2007	8	46.3	2.16E-02	31	30	5	
	2008	8	46.3	2.16E-02	32	30	5	
	2009	8	46.3	2.16E-02	33	30	5	
	2010	8	46.3	2.16E-02	34	30	5	
	2011	8	46.3	2.16E-02	35	30	5	
	2012	8	46.3	2.16E-02	36	30	5	

Data is based on actual CIGRE report data that has been reviewed and updated to reflect actual equipment condition.
Cells with **GREEN TEXT** contain data adjusted from the existing data due to refurbishment, see the associated notes
Cells with **RED TEXT** contain data with an uncertain range of values, see the associated notes

Reliability Data for Pole 2 Life Extension Studies on an Annual Basis.

Component	Year	MTTR (Hrs)	MTBF (Yrs)	Failure Rate (Fails/yr)	Age (Yrs)	Mean Life (Yrs)	Std Dev (Yrs)	Add'l outage time for construction (Hrs)	Notes:
Scenario 2 - Major Refurbishments due to higher than expected failures									
Cable 1/6	2002	2920	8.5	0.118	33	60	10		- Without a spare cable section, the MTTR could be as little as
(600 Amp)	2003	2920	8.5	0.118	34	60	10		5840 Hours (8 months)
	2004	2920	8.5	0.118	35	60	10		- Without a spare cable section, the MTTR could be up to 13140
	2005	2920	8.5	0.118	36	60	10		Hours (1.5 Years)
	2006	2920	8.5	0.118	37	60	10		- With a spare cable section, the MTTR could be as little as 2920
	2007	2920	8.5	0.118	38	60	10		Hours (4 months)
	2008	2920	8.5	0.118	39	60	10		- With a spare cable section, the MTTR could be up to 4380
	2009	2920	8.5	0.118	40	60	10		Hours (6 months)
	2010	2920	8.5	0.118	41	60	10		
	2011	2920	8.5	0.118	42	60	10		
	2012	2920	8.5	0.118	43	60	10		
Cable 2/7	2002	2920	8.5	0.118	33	60	10		- Without a spare cable section, the MTTR could be as little as
(600 Amp)	2003	2920	8.5	0.118	34	60	10		5840 Hours (8 months)
	2004	2920	8.5	0.118	35	60	10		- Without a spare cable section, the MTTR could be up to 13140
	2005	2920	8.5	0.118	36	60	10		Hours (1.5 Years)
	2006	2920	8.5	0.118	37	60	10		- With a spare cable section, the MTTR could be as little as 2920
	2007	2920	8.5	0.118	38	60	10		Hours (4 months)
	2008	2920	8.5	0.118	39	60	10		- With a spare cable section, the MTTR could be up to 4380
	2009	2920	8.5	0.118	40	60	10		Hours (6 months)
	2010	2920	8.5	0.118	41	60	10		
	2011	2920	8.5	0.118	42	60	10		
	2012	2920	8.5	0.118	43	60	10		
Cable Return	2002	2920	8.5	0.118	33	60	10		- Without a spare cable section, the MTTR could be as little as
(600 Amp)	2003	2920	8.5	0.118	34	60	10		5840 Hours (8 months)
	2004	2920	8.5	0.118	35	60	10		- Without a spare cable section, the MTTR could be up to 13140
	2005	2920	8.5	0.118	36	60	10		Hours (1.5 Years)
	2006	2920	8.5	0.118	37	60	10		- With a spare cable section, the MTTR could be as little as 2920
	2007	2920	8.5	0.118	38	60	10		Hours (4 months)
	2008	2920	8.5	0.118	39	60	10		- With a spare cable section, the MTTR could be up to 4380
	2009	2920	8.5	0.118	40	60	10		Hours (6 months)
	2010	2920	8.5	0.118	41	60	10		
	2011	2920	8.5	0.118	42	60	10		
	2012	2920	8.5	0.118	43	60	10		
Cable 4/9	2002	5840	8.5	0.118	26	40	10	4380	- pole 2 cables have are less protected than pole 1 and have a
(900 Amp)	2003	5840	8.5	0.118	27	40	10		lower life expectancy
	2004	2920	8.5	0.118	28	40	10		- Without a spare cable section, the MTTR could be as little as
	2005	2920	8.5	0.118	29	40	10		5840 Hours (8 months)
	2006	2920	8.5	0.118	30	40	10		- Without a spare cable section, the MTTR could be up to 13140
	2007	2920	8.5	0.118	31	40	10		Hours (1.5 Years)
	2008	2920	8.5	0.118	32	40	10		- With a spare cable section, the MTTR could be as little as 2920
	2009	2920	8.5	0.118	33	40	10		Hours (4 months)
	2010	2920	8.5	0.118	34	40	10		- With a spare cable section, the MTTR could be up to 4380
	2011	2920	8.5	0.118	35	40	10		Hours (6 months)
	2012	2920	8.5	0.118	36	40	10		- 2002 cable section repair/replacement initiated

Cable 5/10	2002	5840	8.5	0.118	26	40	10	4380	- pole 2 cables have are less protected than pole 1 and have a
(900 Amp)	2003	5840	8.5	0.118	27	40	10		lower life expectancy
	2004	2920	8.5	0.118	28	40	10		- Without a spare cable section, the MTTR could be as little as
	2005	2920	8.5	0.118	29	40	10		5840 Hours (8 months)
	2006	2920	8.5	0.118	30	40	10		- Without a spare cable section, the MTTR could be up to 13140
	2007	2920	8.5	0.118	31	40	10		Hours (1.5 Years)
	2008	2920	8.5	0.118	32	40	10		- With a spare cable section, the MTTR could be as little as 2920
	2009	2920	8.5	0.118	33	40	10		Hours (4 months)
	2010	2920	8.5	0.118	34	40	10		- With a spare cable section, the MTTR could be up to 4380
	2011	2920	8.5	0.118	35	40	10		Hours (6 months)
	2012	2920	8.5	0.118	36	40	10		- 2002 cable section repair/replacement initiated
P2 Common	2002	2.9	0.625	1.600	26	50	5		
	2003	2.9	0.625	1.600	27	50	5		
	2004	2.9	0.625	1.600	28	50	5		
	2005	2.9	0.625	1.600	29	50	5		
	2006	2.9	0.625	1.600	30	50	5		
	2007	2.9	0.625	1.600	31	50	5		
	2008	2.9	0.625	1.600	32	50	5		
	2009	2.9	0.625	1.600	33	50	5		
	2010	2.9	0.625	1.600	34	50	5		
	2011	2.9	0.625	1.600	35	50	5		
	2012	2.9	0.625	1.600	36	50	5		
V3 Aux.	2002	3.8	1.22	0.820	26	50	5		
	2003	3.8	1.22	0.820	27	50	5		
	2004	3.8	1.22	0.820	28	50	5		
	2005	3.8	1.22	0.820	29	50	5		
	2006	3.8	1.22	0.820	30	50	5		
	2007	3.8	1.22	0.820	31	50	5		
	2008	3.8	1.22	0.820	32	50	5		
	2009	3.8	1.22	0.820	33	50	5		
	2010	3.8	1.22	0.820	34	50	5		
	2011	3.8	1.22	0.820	35	50	5		
	2012	3.8	1.22	0.820	36	50	5		
V4 Aux.	2002	3.8	1.22	0.820	26	50	5		
	2003	3.8	1.22	0.820	27	50	5		
	2004	3.8	1.22	0.820	28	50	5		
	2005	3.8	1.22	0.820	29	50	5		
	2006	3.8	1.22	0.820	30	50	5		
	2007	3.8	1.22	0.820	31	50	5		
	2008	3.8	1.22	0.820	32	50	5		
	2009	3.8	1.22	0.820	33	50	5		
	2010	3.8	1.22	0.820	34	50	5		
	2011	3.8	1.22	0.820	35	50	5		
	2012	3.8	1.22	0.820	36	50	5		
V7 Aux.	2002	3.8	1.22	0.820	26	50	5		
	2003	3.8	1.22	0.820	27	50	5		
	2004	3.8	1.22	0.820	28	50	5		
	2005	3.8	1.22	0.820	29	50	5		
	2006	3.8	1.22	0.820	30	50	5		
	2007	3.8	1.22	0.820	31	50	5		
	2008	3.8	1.22	0.820	32	50	5		
	2009	3.8	1.22	0.820	33	50	5		
	2010	3.8	1.22	0.820	34	50	5		
	2011	3.8	1.22	0.820	35	50	5		
	2012	3.8	1.22	0.820	36	50	5		

V8 Aux.	2002	3.8	1.22	0.820	26	50	5		
	2003	3.8	1.22	0.820	27	50	5		
	2004	3.8	1.22	0.820	28	50	5		
	2005	3.8	1.22	0.820	29	50	5		
	2006	3.8	1.22	0.820	30	50	5		
	2007	3.8	1.22	0.820	31	50	5		
	2008	3.8	1.22	0.820	32	50	5		
	2009	3.8	1.22	0.820	33	50	5		
	2010	3.8	1.22	0.820	34	50	5		
	2011	3.8	1.22	0.820	35	50	5		
	2012	3.8	1.22	0.820	36	50	5		
ARN P2 Filters	2002	0.62	5	0.200	6	33	5		- ARN filter capacitors replaced in 1996
	2003	0.62	5	0.200	7	33	5		
	2004	0.62	5	0.200	8	33	5		
	2005	0.62	5	0.200	9	33	5		
	2006	0.62	5	0.200	10	33	5		
	2007	0.62	5	0.200	11	33	5		
	2008	0.62	5	0.200	12	33	5		
	2009	0.62	5	0.200	13	33	5		
	2010	0.62	5	0.200	14	33	5		
	2011	0.62	5	0.200	15	33	5		
	2012	0.62	5	0.200	16	33	5		
VIT P2 Filters	2002	0.62	5	0.200	26	33	5		
	2003	0.62	5	0.200	27	33	5		
	2004	0.62	5	0.200	28	33	5		
	2005	0.62	5	0.200	29	33	5		
	2006	0.62	5	0.200	30	33	5	40	- VIT filter capacitor replacement
	2007	0.62	5	0.200	1	33	5		
	2008	0.62	5	0.200	2	33	5		
	2009	0.62	5	0.200	3	33	5		
	2010	0.62	5	0.200	4	33	5		
	2011	0.62	5	0.200	5	33	5		
	2012	0.62	5	0.200	6	33	5		
V3	2002	136	3	0.333	26	40	10		
- Low Voltage Valves	2003	136	3	0.333	27	40	10		
- VIT	2004	136	3	0.333	28	40	10		
	2005	136	3	0.333	29	40	10		
	2006	136	3	0.333	30	40	10		
	2007	136	3	0.333	31	40	10		
	2008	136	3	0.333	32	40	10		
	2009	136	3	0.333	33	40	10		
	2010	136	3	0.333	34	40	10		
	2011	136	3	0.333	35	40	10		
	2012	136	3	0.333	36	40	10		
V4	2002	136	3	0.333	26	40	10		
- High Voltage Valves	2003	136	3	0.333	27	40	10		
- VIT	2004	136	3	0.333	28	40	10		
	2005	136	3	0.333	29	40	10		
	2006	136	3	0.333	30	40	10		
	2007	136	6	0.167	1	40	10		- Valve Replacement
	2008	136	6	0.167	2	40	10		
	2009	136	6	0.167	3	40	10		
	2010	136	6	0.167	4	40	10		
	2011	136	6	0.167	5	40	10		
	2012	136	6	0.167	6	40	10		

V7	2002	136	3	0.333	24	40	10		
- Low Voltage Valves	2003	136	3	0.333	25	40	10		
- ARN	2004	136	3	0.333	26	40	10		
	2005	136	3	0.333	27	40	10		
	2006	136	3	0.333	28	40	10		
	2007	136	3	0.333	29	40	10		
	2008	136	3	0.333	30	40	10		
	2009	136	3	0.333	31	40	10		
	2010	136	3	0.333	32	40	10		
	2011	136	3	0.333	33	40	10		
	2012	136	3	0.333	34	40	10		
V8	2002	136	3	0.333	26	40	10		
- High Voltage Valves	2003	136	3	0.333	27	40	10		
- ARN	2004	136	3	0.333	28	40	10		
	2005	136	3	0.333	29	40	10		
	2006	136	3	0.333	30	40	10		
	2007	136	6	0.167	1	40	10		- Valve Replacement
	2008	136	6	0.167	2	40	10		
	2009	136	6	0.167	3	40	10		
	2010	136	6	0.167	4	40	10		
	2011	136	6	0.167	5	40	10		
	2012	136	6	0.167	6	40	10		
T3	2002	16	36	0.028	26	36	5		- 1 Spare TX available on site
- VIT	2003	16	36	0.028	27	36	5		- MTTR is the time to connect the onsite spare
	2004	16	36	0.028	28	36	5		- Additional VIT Spare
	2005	16	36	0.028	29	40	5	80	- Replace Gassing T3-B with new (remaining are now all good)
	2006	16	36	0.028	30	40	5		
	2007	16	36	0.028	31	40	5		
	2008	16	36	0.028	32	40	5		
	2009	16	36	0.028	33	40	5		- new TX (one phase)
	2010	16	36	0.028	34	40	5		
	2011	16	36	0.028	3	40	5		- new TX (All 3 phases are now replaced with new)
	2012	16	36	0.028	4	40	5		
T4	2002	16	36	0.028	26	36	5		- 1 Spare TX available on site
- VIT	2003	16	36	0.028	27	36	5		- MTTR is the time to connect the onsite spare
	2004	16	36	0.028	28	36	5		
	2005	16	36	0.028	29	36	5		
	2006	16	36	0.028	30	36	5		
	2007	16	36	0.028	31	36	5		
	2008	16	36	0.028	32	36	5		
	2009	16	36	0.028	33	36	5		
	2010	16	36	0.028	34	36	5		
	2011	16	36	0.028	35	36	5		
	2012	16	36	0.028	36	36	5		
T7	2002	16	36	0.028	26	36	5		- 1 Spare TX available on site
- ARN	2003	16	36	0.028	27	36	5		- MTTR is the time to connect the onsite spare
	2004	16	36	0.028	28	36	5		- TX spare repaired
	2005	16	36	0.028	29	36	5		
	2006	16	36	0.028	30	36	5		
	2007	16	36	0.028	31	36	5		
	2008	16	36	0.028	32	36	5		
	2009	16	36	0.028	33	36	5		
	2010	16	36	0.028	34	36	5		
	2011	16	36	0.028	35	36	5		
	2012	16	36	0.028	36	36	5		

T8	2002	16	36	0.028	26	36	5		- 1 Spare TX available on site
- ARN	2003	16	36	0.028	27	36	5		- MTTR is the time to connect the onsite spare
	2004	16	36	0.028	28	36	5		
	2005	16	36	0.028	29	36	5		
	2006	16	36	0.028	30	36	5		
	2007	16	36	0.028	31	36	5		
	2008	16	36	0.028	32	36	5		
	2009	16	36	0.028	33	36	5		
	2010	16	36	0.028	34	36	5		
	2011	16	36	0.028	35	36	5		
	2012	16	36	0.028	36	36	5		
Rx2 - VIT	2002	720	46.3	0.022	26	33	5		- Spare Rx would have to be transported from ARN to VIT to be installed (causing the increased replacement time)
	2003	720	46.3	0.022	27	33	5		
	2004	720	46.3	0.022	28	33	5	16	- Install new spare Rx
	2005	8	46.3	0.022	29	33	5		
	2006	8	46.3	0.022	30	33	5		
	2007	8	46.3	0.022	31	33	5		
	2008	8	46.3	0.022	32	33	5		
	2009	8	46.3	0.022	33	33	5		
	2010	8	46.3	0.022	34	33	5		
	2011	8	46.3	0.022	35	33	5		
	2012	8	46.3	0.022	36	33	5		
Rx2 - ARN	2002	8	46.3	0.022	26	30	5		- Spare Rx is located at ARN
	2003	8	46.3	0.022	27	30	5		- MTTR is a spare replacement time
	2004	8	46.3	0.022	28	30	5		
	2005	8	46.3	0.022	29	30	5		
	2006	8	46.3	0.022	30	30	5		
	2007	8	46.3	0.022	31	30	5		
	2008	8	46.3	0.022	32	30	5		
	2009	8	46.3	0.022	33	30	5		
	2010	8	46.3	0.022	34	30	5		
	2011	8	46.3	0.022	35	30	5		
	2012	8	46.3	0.022	36	30	5		

Appendix C: Local Hydro Generating Unit Reliability Data

Generating Unit	Capacity (MW)	FOR	Repair Time (hrs)
ASH	24	0.004	15.35
JHT-1	21	0.0795	926.51
JHT-2	20	0.0008	2.31
JHT-3	20	0.003	36.32
JHT-4	20	0.0026	7.84
JHT-5	20	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	33	0.0027	5.33
SCA-2	32	0.0218	28.26
JOR	165	0.0124	5.99
Total	448		

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 Report, "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

Appendix D: 500 kV and 230 kV Circuit Reliability Data

Circuit	Capacity (MW)	FOR	Repair time (hrs)
500 kV	1200	0.0293	137.81
500 kV	1200	0.0293	137.81
230 kV	600	0.0259	383.74
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 Report, "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 reliability data for the overhead portion of a new 230 kV circuit is based on the average of historical records of 230 kV circuits 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(acble)/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 E: ICP and VIGP Reliability Data

Unit	Capacity (MW)	FOR		Failure Frequency (f/year)		Repair Time (hrs)	
		Forced	Planned	Forced	Planned	Forced	Planned
ICP	240	0.03238	0.07407	13.22	5.32	21.46	122.0
VIGP #1	265	0.03238	0.07407	13.22	5.32	21.46	122.0
VIGP #2	265	0.03238	0.07407	13.22	5.32	21.46	122.0
Pipeline		0.00127		0.00507		2190	

Note:

1. The reliability data for the ICP and the VIGP 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.

2. The reliability data for the pipeline are based on the following information:

   Failure frequency f = 0.00507/year

   This estimate is obtained from the following document:

   [1] "Quantitative Risk Calculations for GSX Pipeline", Exhibit B-153, filed with the National Energy Board for "GSX Pipeline Project - Joint Review Panel Hearing Order GH-4-2001", downloadable from [http://www.gsxreg.com/pdfs/hearing/b-140_b-157.pdf]

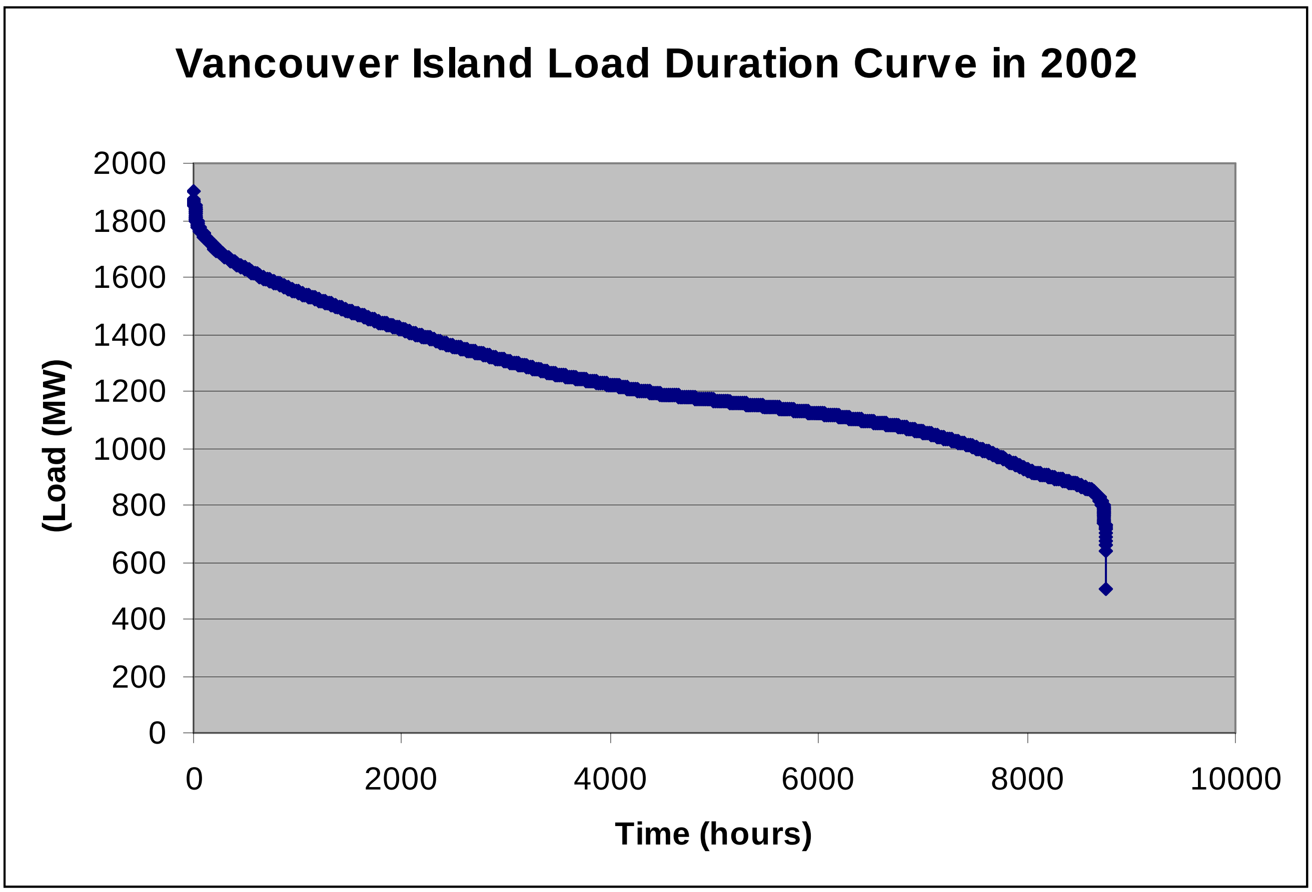
   Repair time r = 3 months = 2190 hours

   This estimate is the same as the repair time for the 230 kV submarine cable.

   FOR = fr/8760 = 0.00507x2190/8760 = 0.00127

Appendix F: Load Forecast for 2003/04 to 2012/13 and Load Duration Curve in 2002

Vancouver Island **Probable Load Forecast**	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
Energy Generation Requirements	10,835	10,811	11,131	11,269	11,389	11,568	11,699	11,863	12,027	12,198	12,433
Peak Demand Requirements with losses before PS	2,159	2,189	2,230	2,263	2,293	2,320	2,346	2,377	2,406	2,438	2,474
Energy Generation Requirments	10,794	10,690	10,931	10,979	11,031	11,157	11,236	11,354	11,461	11,571	11,771
with Power Smart	41	121	200	290	358	411	463	509	566	627	662
Peak Demand Requirements with losses	2,152	2,164	2,176	2,194	2,212	2,228	2,244	2,275	2,304	2,336	2,372
with Power Smart	7	25	54	69	81	93	102	102	102	102	102



Appendix G: Assumptions for HVDC Pole 2 Reliability Evaluation

- All HVDC Pole 2 models consider only major components. Failures of minor components are considered part of a “common” component.

- Both repairable and aging failure modes for all components have been considered.

- Maintenance and planned outages are not included.

- Cables 5 and 9 have their damaged sections repaired as planned by October 2003.

- Pole 2 full operating capacity is 476 MW and its firm capacity is 238 MW. These two main operational MW levels are modeled and any other possible levels that have very low possibility in operation are not considered.

- 1L17 metallic return and sea return are not an included option for HVDC current return.

- All Pole 1 cables have an in-service date of 1969 (2003 age = 34 yrs.)

- Pole 2 equipment original in-service date was 1976 (2003 age = 27 yrs.). Updates due to equipment replacement are annotated in the outage data tables in Appendix B.

- Mean component lives were obtained from expert engineering estimates based on historical data and equipment condition monitoring. These values have not been statistically verified.