Report-BCTC-R009C

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

(Part III: Reliability Analysis for Power Supply to Gulf Islands)

December 30, 2005

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December 30, 2005

Expected Energy Not Served (EENS) Study for Vancouver Island Transmission Reinforcement Project (Part III: Reliability Analysis for Power Supply to Gulf Islands) (Executive Summary)

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As a part of the Vancouver Island Reinforcement Project, the power supply system to Gulf Islands will be reconfigured. The present supply system includes two 138 kV lines 1L17 and 1L18 with taps to Salt Spring and Galiano Island substations. When the 230 kV AC line is in service, 1L18 will be removed. Circuit 1L17 will be upgraded to the 230 kV construction (but operated at 138 kV) and the configuration of 1L17 will be changed to a “looped-in” connection with Salt Spring and Galiano Island substations. Under Sea Breeze’s HVDC Light VIC proposal, the configuration of 1L17 and 1L18 with taps to Salt Spring and Galiano Island substations will be kept but the sections between Galiano and Arnott substations will be removed and power would be supplied only from the VIT substation.

The purpose of this study is to conduct comparisons in power supply reliability among the three connections to Gulf Islands: the present configuration, the future configuration proposed by BCTC and the future configuration proposed by Sea Breeze Corp. The failure data are based on the historical statistics over the past 20 years. All switching actions are modeled in the reliability evaluation.

The results indicate that the future 1L17 looped-in connection proposed by BCTC is more reliable than the present 1L17&18 tap-connection although a few assumptions in the study are unfavourable to the 1L17 loop-in connection. This is due to the fact that the loop-in connection makes sections of the circuit separable and switchable and changing the normal supply point from the ARN end to the VIT end allows SAL and GLS substations to be supplied via shorter circuits with lower failure probabilities. The positive effects of the loop-in connection and smaller failure probability in separable sections of the circuit due to shorter lengths on the 1L17 loop-in connection system outweighs the positive effect of having two power sources from the VIT end on the 1L17&18 tap-connection. The 1L17 loop-in connection proposed by BCTC has a comparable reliability level with the 1L17&18 tap-connection proposed by Sea Breeze Corp. in terms of EENS index although the former can provide a lower failure frequency than the latter. The EENS indices for the present 1L17&18 tap-connection, 1L17 loop-in connection proposed by BCTC and 1L17&18 tap-connection proposed by Sea Breeze Corp. are 28.18, 11.13 and 10.19 MWh/year respectively. The Expected Frequency of Load Curtailment (EFLC) indices for the three connections are 1.008, 0.22 and 0.40 occurrences/year respectively.

It is worthy to note that this study is not a unique case where the double-line tap-connection arrangement has lower reliability than the single-line loop-in connection layout. A similar example has been investigated in Chapter 9 of a power system reliability book that was published by Institute of Electric and Electronic Engineers of USA in 2005 [2].

The normalized EENS indices for the power supply systems of Vancouver Island and Gulf Islands show that for each MW load, the average reliability level of Gulf Islands is much higher than that of Vancouver Island after the VIGR project is in service. The normalized EENS indices are, respectively, 1.197 MWh/year/MW for Vancouver Island and 0.183 MWh/year/MW for Gulf Islands.

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1. Introduction

As a part of the Vancouver Island Reinforcement Project, the power supply system to Gulf Islands will be reconfigured. The present supply system includes two 138 kV lines 1L17 and 1L18 with taps to Salt Spring and Galiano Island substations. When the 230 kV AC line is in service, 1L18 will be removed. Circuit 1L17 will be upgraded to the 230 kV construction (but operated at 138 kV) and the configuration of 1L17 will be changed to a "looped-in" connection with Salt Spring and Galiano Island substations. Under Sea Breeze's HVDC Light VIC proposal, the configuration of 1L17 and 1L18 with taps to Salt Spring and Galiano Island substations will be kept but the sections between Galiano and Arnott substations will be removed and power would be supplied only from the VIT substation.

The purpose of this study is to conduct comparisons in power supply reliability among the three connections: the present configuration, the future configuration proposed by BCTC and the future configurations proposed by Sea Breeze Corp. In the following discussion, the present configuration is called the 1L17&18 tap-connection, the future configuration proposed by BCTC is called the 1L17 loop-in connection and the configuration proposed by Sea Breeze Corp. is called the 1L17&18 tap-connection (Sea Breeze).

At the first glance, the present 1L17&18 tap-connection looks more reliable since it has 4 supply sources with two at the Lower Mainland side and other two at the Vancouver Island side whereas the 1L17 loop-in connection has only two supply sources with one at the Lower Mainland side and the other one at the Vancouver Island side. However, reliability of a transmission system depends on not only power sources but also configurations. Generally, a tap-connection structure has lower reliability than a loop-in connection structure [2]. This report provides a qualitative analysis on reliability of the three configurations first. Quantified reliability assessments, which are based on historical failure data of 1L17 and 1L18, are then performed.

The reliability evaluation model used in this part is more complex compared to the model in other parts of the report since switching actions associated with breakers and switches have to be modeled. The computing tool used in the study is still the MCGSR program that can handle switching actions. The failure data of overhead and cables in 1L17 and 1L18 are based on historical records in the past 20 years.

2. Qualitative reliability analysis

(1) Comparison between 1L17& 18 tap-connection and 1L17 loop-in connection configurations

The schematics of the present 1L17&18 tap-connection and future 1L17 loop-in connection proposed by BCTC are shown in Figures 1 and 2 respectively. The detailed single line diagrams of Salt Spring and Galiano Island stations are given in Appendix A.

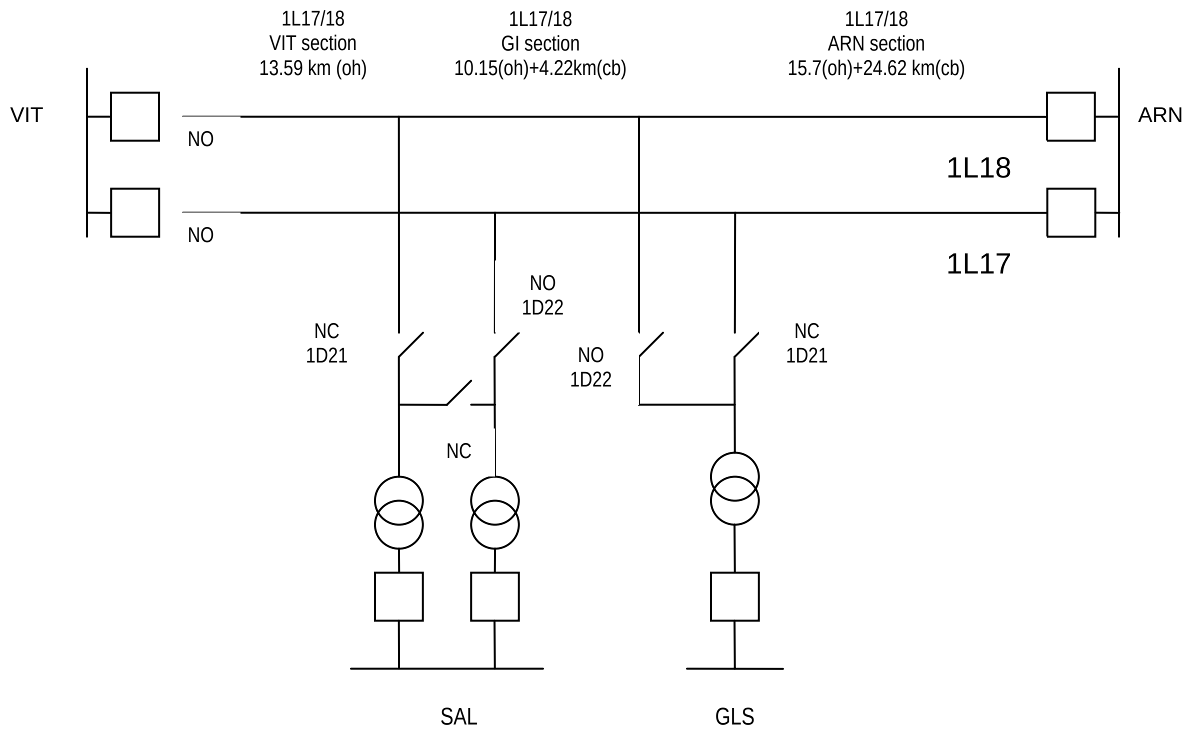


Figure 1 1L17&18 tap-connection

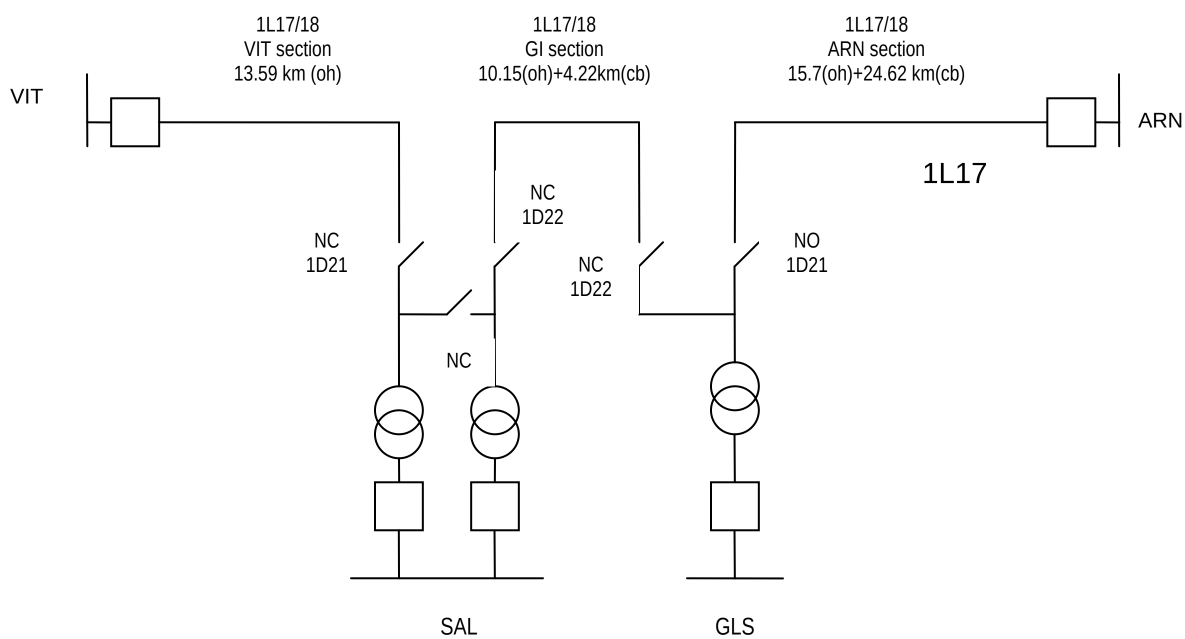


Figure 2 1L17 loop-in connection Proposed by BCTC

As mentioned earlier, at the first glance, the present 1L17&18 tap-connection looks more reliable since it has 4 supply sources. However, careful observations on the two configurations lead to an opposite judgment. The following observations can be made:

- The present configuration has two circuits 1L17 and 1L18. However, the two circuits must be opened at the VIT end because of two reasons: (1) If they were closed at both the ends of VIT and ARN, there would be an overloading problem on the two circuits due to power flow distribution; (2) There is a shortage of supply power from Vancouver Island before the VITR project. Under the existing connection, when 1L18 fails, the load at SAL substation will be switched to 1L17 by opening 1D21 and closing 1D22 at this substation. Similarly, when 1L17 fails, the load at GLS will be switched to 1L18. Only when both 1L17 and 1L18 fail at the same time, it is needed to make use of the other two sources at the VIT end. The probability of simultaneous failure of both 1L17 and 1L18 is very low. Moreover, it is not easy to make use of these two power sources in operation because of their tap connection structure. When there are simultaneous faults on both 1L17 and 1L18, two entire circuits are in outage. The breakers at the VIT end cannot be closed before an emergency crew is sent to fault locations and manually isolate faulted sections of the circuits. This process may take one day or even longer to complete. Therefore, only the two sources from ARN substation play a major role for power supply reliability of Gulf Islands whereas the improvement in power supply reliability of Gulf Islands that could be brought by other two power sources at the VIT end is limited due to the low probability and long switching time.
- In the future 1L17 loop-in connection configuration, there are two power sources with the one from the VIT end that is normally closed and the other one from the ARN end that is normally opened. Due to the loop-in connection, when a failure occurs on energized sections of the circuit, it is easy to perform a switching action. For example, when a fault happens on the section near VIT, both SAL and GLS can be switched and supplied from ARN through opening ID21 at SAL substation and closing ID21 at GLS substation. When a fault happens on the mid section (the Gulf Island section), GLS can be switched and supplied from ARN while SAL continues to be supplied from VIT. In other words, the loop connection structure makes failures on different sections of the circuit separable by switching. This type of switching may take only one hour or even shorter since a supervisory control can be easily implemented.
- In the present configuration, both SAL and GLS are supplied through a much longer distance from ARN substation compared to the future 1L17 loop-in connection configuration. The circuit sections between SAL and ARN include 54.47 km of overhead lines and submarine cables and the circuit sections between GLS and ARN include 40.32 km of overhead lines and submarine cables. In contrast, in the future 1L17 loop-in configuration, power will be supplied from the VIT end with a normal open point at the east of GLS. The section between the east of GLS and ARN is still normally energized from ARN to warm the cables (preventing corrosion) and also to produce VAR to the Lower Mainland system. The circuit sections between SAL and VIT have only 13.59 km of overhead lines and the circuit sections between GLS and VIT have only 27.96 km of overhead lines and submarine cables. The failure rate of a transmission circuit is generally proportional to its length. A longer circuit has more exposure to external environment (weather or water) which is the main source of failures.

- The difference in power supply reliability between the present and future transmission connection systems of supplying Gulf Islands is most likely dominated by effects of failure rates of circuit sections and different connection manners (tap-in or loop-in structures). In other words, the effect due to the number of power sources is secondary. This judgment will be verified using quantified reliability assessments in Section 4.

(2) Qualitative analysis on the 1L17& 18 tap-connection (Sea Breeze)

The schematic of the 1L17&18 tap-connection (Sea Breeze) is shown in Figure 3. Compared to the present 1L17&18 tap-connection in Figure 1, the only difference is that the sections between the ARN and GLS are removed and power will be supplied from VIT substation. The following observations can be made:

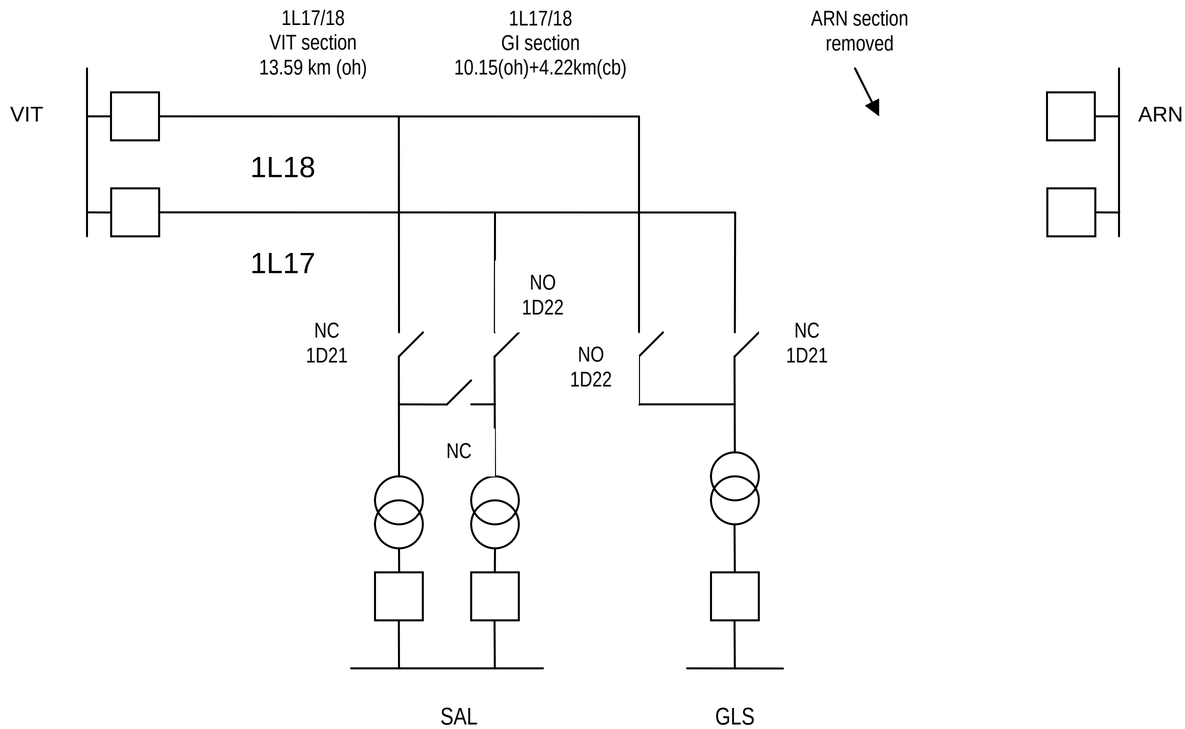


Figure 1 1L17&18 tap-connection (Sea Breeze)

- A merit of this configuration is that the supply distances for both SAL and GLS load points are shorter than the present 1L17&18 tap-connection. This will have a positive impact in the supply reliability compared to the present configuration.
- However, on the other hand, this configuration loses the power supply points from ARN substation. When both 1L17 and 1L18 fail at the same time, no backup power sources are available to switch in. This will have a negative impact in the supply reliability compared to the present configuration.
- Compared to the 1L17 loop-in connection proposed by BCTC, an essential difference is that it still keeps tap connection structure in which a fault on any place along the line will trip the whole line out. This means that the exposed distance for 1L17&18 tap-connection (Sea Breeze) is longer than the 1L17 loop-in connection. In other words, the demerit of tap-connection still remains.

- By considering positive and negative aspects of the 1L17&18 tap-connection (Sea Breeze), it should be more reliable than the existing 1L17&18 tap-connection and may provide a comparable reliability level with the 1L17 loop-in connection proposed by BCTC.

3. Data and assumptions

The failure data of 1L17 and 1L18 in Table 1 are based on the historical statistics in the past 20 years from Dec. 1985 to Nov. 2005. In this study, the following assumptions are used:

- Although failure statistics show that 1L17 has much lower failure probability (unavailability) than 1L18, the average failure probability of 1L17 and 1L18 is used in the reliability evaluation to mitigate uncertainty of statistics. This assumption is unfavourable to the future 1L17 loop-in connection in the comparison since a higher failure probability than that of 1L17 is used. For the present 1L17&18 tap-connection, the average failure probability is higher than that of 1L17 but lower than that of 1L18.
- The line-related failure probability is proportional to the length of circuits. The failure probabilities of the VIT section, Gulf Island section and ARN section are calculated in terms of the composition of overhead and cables and their lengths.
- It is assumed that the repair time for the entire circuit or for any section of the circuit is the same. The repair time for a circuit or a section of circuit with both overhead line and cable is assumed to be the average of the repair times for the overhead line and cable.
- The common cause failure of 1L17 and 1L18 (such as lightning on both circuits) is not considered because of lack of failure data although it can happen in real life conceptually since they are in the same right of way. This is another assumption unfavourable to the 1L17 loop-in connection in the comparison.
- Overlapping events of independent failures of 1L17 and 1L18 (in the 1L17&18 tap-connection) or any two sections (in the 1L17 loop-in connection) are modeled. The overlapping failure events always have a low probability of occurrence, which is the product of independent failure probabilities of two circuits or sections.
- The overlapping failure of three sections of circuit is omitted since its probability of occurrence is extremely low. Even if considered, it would not have any effective impact on results.
- The load forecast of Gulf Islands for 2008/2009 is used in reliability evaluation. The load forecast is based on MVA and a power factor of 0.98 is used to obtain the MW load. The total 60.86 MW for Gulf Islands is broken down into the loads for SAL and GLS substations. The 8760 hourly load records in 2004 are used to represent the annual load curve shape.
- All switching actions are modeled in the reliability evaluation for all the three configurations. The normal switching time of using disconnects is assumed to be 1 hour. The switching time required by sending a crew to the field in order to physically isolate faulted sections is assumed to be 24 hours.

Based on the above assumptions, the failure data used in the study are summarized in Table 2 and the peak loads in Table 3. The switching times are given in Table 4.

Table 1 Raw failure data of 1L17 and 1L18 based on historical records

Circuit	Length (km)	Repair time (hrs)	Unavailability
Overhead			
1L17	39.44	0.3	0.00001
1L18	39.44	185.39	0.00741
Overhead average		92.85	0.00371
Cable			
1L17	28.84	210.59	0.0046
1L18	28.84	58.57	0.00301
Cable average		130.08	0.00381

Table 2 Failure data of 1L17 and 1L18 used in the study

Circuit	Length (km)	Repair time (hrs)	Unavailability
1L17&18 tap-connection			
1L17	39.44(o/h) + 28.84 (cable)	111.47	0.00752
1L18	39.44(o/h) + 28.84 (cable)	111.47	0.00752
Both 1L17&1L18		55.74	0.000057
1L17 loop-in connection			
VIT section	13.59	92.85	0.001278
Gulf islands section	10.15 (o/h) + 4.22 (cable)	111.47	0.001512
ARN section	15.7 (o/h) + 24.62 (cable)	111.47	0.00473
Both VIT and Gulf Island sections		50.66	0.0000019
Both ARN and Gulf Island sections		55.74	0.0000072
Both VIT and ARN sections		50.66	0.0000061
1L17&18 tap-connection (Sea Breeze)			
1L17	23.74 (o/h) + 4.22 (cable)	111.47	0.00279
1L18	23.74 (o/h) + 4.22 (cable)	111.47	0.00279
Both 1L17&1L18		55.74	0.0000078

Table 3 Peak loads of Gulf Islands in 2008/009

Substation	Peak Load (MW)	Peak Load (MVA)	Power factor
SAL	50.72	51.75	0.98
GLS	10.14	10.35	0.98
Total	60.86	62.10	0.98

Table 4 Switching times

Switching type	Switching time
Using disconnects	1 hour
Physical isolation of sections	24 hours

4. Results

The MCGSR program was used to perform reliability evaluation for the three configurations – the 1L17&18 tap-connection (present configuration), 1L17 loop-in connection and 1L17&18 tap-connection (Sea Breeze). All switching actions were modeled. In the 1L17 loop-in connection, the ARN section (between ARN and GLS) is normally opened and both SAL and GLS are supplied from the VIT side. When a failure occurs on the VIT section or Gulf Island section, power supply is switched on the ARN section. After this switching, the ARN section can fail as well. This case was also modeled in the study.

(1) Comparison of the three configurations

The EENS (Expected Energy Not Supplied) and EFLC (Expected Frequency of Load Curtailment) indices are summarized in Tables 5, 6 and 7. In addition to the total indices, the indices are also broken down into contributions due to each failure event. The following observations can be made:

- The 1L17 loop-in connection is more reliable than the present 1L17/18 tap-connection in terms of both EENS and EFLC indices. As pointed out in the qualitative analysis given in Section 2, the positive effects of the loop-in connection structure and smaller failure probability in separable sections of the circuit due to shorter lengths on the 1L17 loop-in connection system outweighs the positive effect of two more power sources from the VIT end on the present 1L17&18 tap-connection.
- For the present 1L17&18 tap-connection, only when both 1L17 and 1L18 fail simultaneously, it is necessary to switch to the other two power sources at the VIT end. This switching action needs 24 hours since a crew has to be sent to the field to physically isolate faulted sections. However, even if it is assumed that this simultaneous failure would never occur or we could do this switching immediately, which means that the indices caused by the event of both 1L17 and 1L18 failures is taken away from the total indices, the EENS and EFLC indices for 1L17&18 tap-connection would be still higher than those for the 1L17 loop-in connection. This is because the probability of both 1L17 and 1L18 failures is low and it does not make a major contribution to the total indices.

- The 1L17&18 tap-connection proposed by Sea Breeze (removal of the section between ART and GLS) is also more reliable than the present 1L17/18 tap-connection mainly due to the shorter circuit distance which results in a lower failure probability on circuits.
- The 1L17 loop-in connection proposed by BCTC has a comparable EENS index with the 1L17&18 tap-connection proposed by Sea Breeze but a lower failure frequency index.
- The EENS contributed by the 1L18 failure event is higher than that by the 1L17 failure. This is not because 1L18 has a higher failure probability but because 1L18 provides power supply to SAL substation at which the load is five times higher than that at GLS substation. As mentioned in the data assumption, 1L18 and 1L17 are assumed to have the same failure probability. In fact, the frequency index of loss of load is the same for either 1L17 or 1L18 failure events.
- The merits of the loop-in connection structure can be further observed from the breakdown of the indices in Table 6. The main contributions are from two single section failure events. The overlapping failure events associated with two separated sections of the circuit make much smaller contributions to the total indices.

Table 5 Reliability indices for the present 1L17&1L18 tap-connection

Failure event	EENS (MWh/year)	EFLC (occurrences/year)
1L18 failure	17.27	0.54
1L17 failure	3.44	0.54
Both 1L17 and 1L18 failure	7.47	0.008
Total	28.18	1.008

Table 6 Reliability indices for the future 1L17 loop-in connection

Failure event	EENS (MWh/year)	EFLC (occurrences/year)
VIT section failure	4.22	0.109
Gulf Island failure	4.15	0.108
Failure of both VIT and Gulf Island sections	0.502	0.0003
Failure of both ARN and Gulf Island sections	0.39	0.001
Failure of both VIT and ARN sections	1.87	0.00096
Total	11.132	0.21926

Table 7 Reliability indices for the 1L17&1L18 tap-connection (Sea Breeze)

Failure event	EENS (MWh/year)	EFLC (occurrences/year)
1L18 failure	6.40	0.20
1L17 failure	1.28	0.20
Both 1L17 and 1L18 failure	2.51	0.00117
Total	10.19	0.40117

(2) Comparison between Gulf Islands and Vancouver Island supply reliability

It is worthy to compare the reliability levels between the power supply systems for VI Island and Gulf Islands. The loads in VI Island and Gulf Islands are about 40 times different and therefore it is impossible to compare them by directly using their absolute EENS indices. However, a normalized index of EENS divided by the peak load, which is the average energy loss per year for each MW of load, will make sense in the comparison for different supply systems with different load levels.

It is known from the Part I of the report [1] that after the 230 kV line is in service, the EENS for the VI power supply system in 2008/2009 is 2870 MWh/year while the peak load in Vancouver Island in the same year is 2397 MW. The normalized EENS index for the VI power supply system is:

2870/2397 = 1.197 MWh/year/MW

For the 1L17 loop-in connection to Gulf Island power supply proposed by BCTC, the EENS index and peak load in 2008/2009 are 11.132 MWh/year and 60.86 MW respectively. The normalized EENS index is:

11.132/60.86 = 0.183 MWh/year/MW

It can be seen that the average reliability level for Gulf Island power supply is even much better than that for Vancouver Island after the VITR project is in place.

5. Conclusions

This part of the report conducted qualitative and quantified comparisons in power supply reliability to the Gulf Islands among the present 1L17&18 tap-connection, future 1L17 loop-in connection proposed by BCTC and 1L17&18 tap-connection proposed by Sea Breeze. The failure data are based on the historical statistics in the past 20 years. All switching actions are modeled in the reliability evaluation.

The results indicate that the future 1L17 loop-in connection proposed by BCTC is more reliable than the present 1L17&18 tap-connection although a few assumptions in the study are unfavourable to the 1L17 loop-in connection. This is due to the fact that the loop connection structure makes sections of the circuit separable and switchable, and changing the normal supply point from the ARN end to the VIT end makes SAL and GLS substations to be supplied on shorter circuits with lower failure probabilities. The positive effects of the loop-in connection structure and smaller failure probability in separable sections of the circuit due to shorter lengths on the 1L17 loop-in connection system outweighs the positive effect of two more power sources from the VIT end on the 1L17&18 tap-connection. The 1L17 loop-in connection proposed by BCTC has a comparable reliability level with the 1L17&18 tap-connection proposed by Sea Breeze Corp. in terms of EENS index although the former can provide a lower failure frequency than the latter. The EENS indices for the present 1L17&18 tap-connection, 1L17 loop-in connection proposed by BCTC and 1L17&18 tap-connection proposed by Sea Breeze Corp. are 28.18, 11.13 and 10.19 MWh/year respectively. The EFLC indices for the three connections are 1.008, 0.22 and 0.40 occurrences/year respectively.

It is worthy to note that this study is not a unique case where the double-line tap-connection has lower reliability than the single-line loop-in connection. A similar example has been investigated in Chapter 9 of a power system reliability book that was published by Institute of Electric and Electronic Engineers of USA in 2005 [2].

The normalized EENS indices for the power supply systems of Vancouver Island and Gulf Islands show that for each MW load, the average reliability level of Gulf Islands is much higher than that of Vancouver Island after the VIGR project is in service. The normalized EENS indices are, respectively, 1.197 MWh/year/MW for Vancouver Island and 0.183 MWh/year/MW for Gulf Islands.

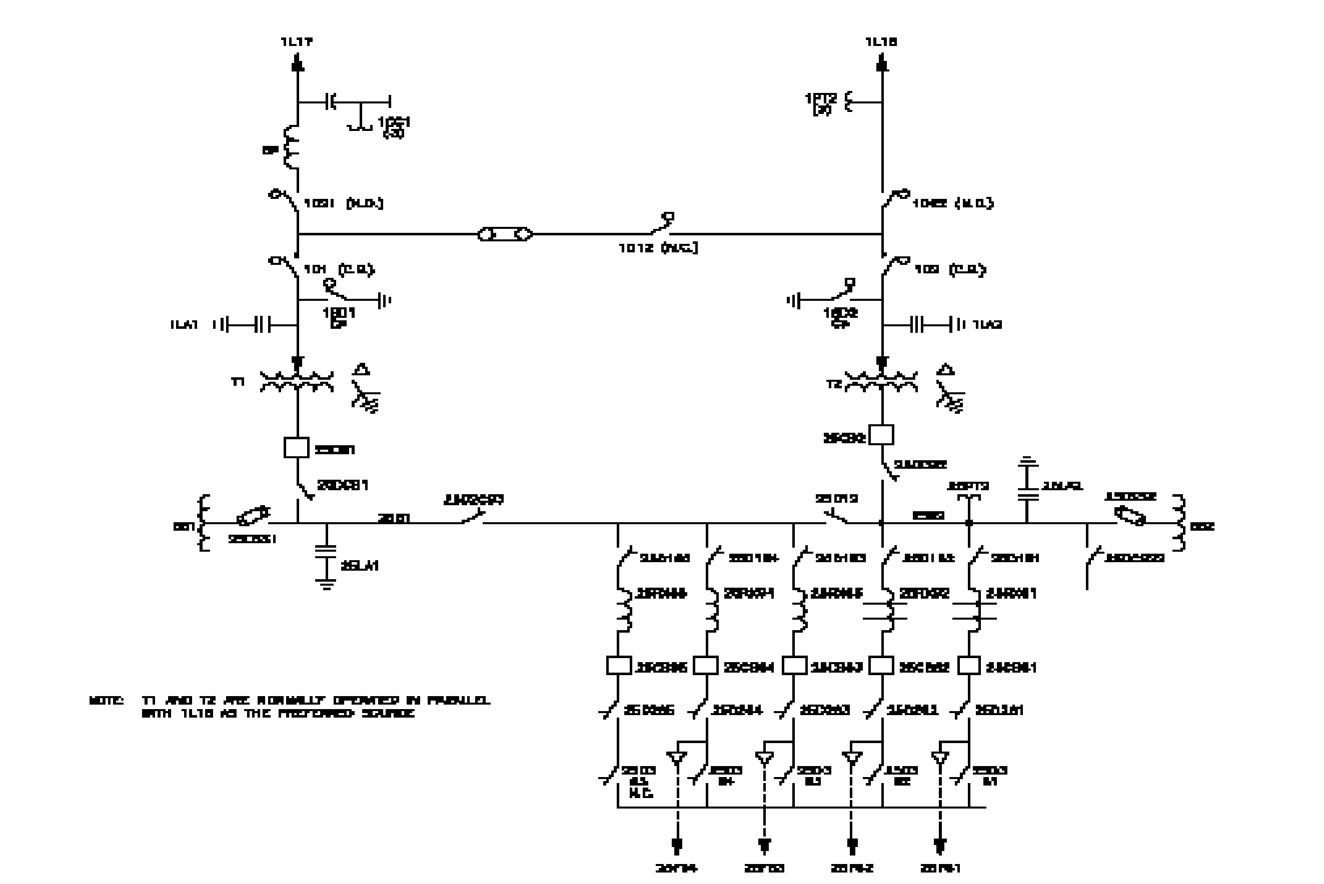
References

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

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

Appendix A: Single line diagrams of SAL and GLS substations

SAL substation



GLS substation