PROBABILISTIC RELIABILITY ASSESSMENT

OF

CENTRAL VANCOUVER ISLAND TRANSMISSION PROJECT

(Expected Energy Not Supplied Assessment)

Report No. 2007-REL-03.1

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Regional System Planning,
System Planning and Performance Assessment
British Columbia Transmission Corporation

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Executive Summary

Central Vancouver Island 138 kV transmission circuits (1L115 and 1L116) are heavily loaded and are approaching their capacity limits during the high load in winter under system normal condition. Both 1L115 and 1L116 circuits are equipped with a Remedial Action Scheme (RAS) that is designed to open 1L115 and 1L116 at the JPT end if an overload on these circuits is detected, causing load to be served from VIT. This will result in overloads on the four 230/138 kV transformers at VIT if the RAS operates. The Central Vancouver Island Transmission project is intended to resolve thermal constraints on the 138 kV system in Central Vancouver Island (circuits 1L115 and 1L116) as well as at the four 230/138 kV transformers at Vancouver Island Terminal Substation (VIT).

Probabilistic reliability assessment for the CVIT project is presented in this report to provide a quantitative assessment of the expected energy not supplied (EENS) after the implementation of the CVIT project. The 230 kV to 138 kV injection option was considered, which can be further considered to three different sub-options designated as Options a.1 to a.3 (Looping, Tapping, and Station Options respectively). This study report is only focused on EENS study of these three options. The following findings are concluded in the report.

- *The EENS reductions (reliability improvement) of the three options are very significant when comparing with that of Do Nothing Option (EENS reductions are greater than 2,400 MWh/yr).*
- *The EENS differences between the three options fall within the 2.5% error tolerance and therefore are insignificant. Consequently, the EENS obtained using the three different options are considerably similar.*
- *The impact of the common cause of a tower structure failure was examined to quantify the risk of the low probability event but high consequence. The results indicate Option a.1 (Looping Option) will have a slightly little incremental EENS (risk) due to the common cause failure. Options a.2 (Tapping Option) will result in an incremental risk of approximately 100 MWh/yr while Option a.3 (Station Option) will not have the incremental risk due to the common cause failure.*
- *Although there are differences of incremental risks due to the common cause failure for the three options, these incremental risks are still not able to significantly differentiate the reliability benefits between the three options.*
- *Option a.1 (Looping Option) leads to unbalanced flows on the 230 kV circuits from DMR, and therefore this option does not permit the maximum utilization of the path whereas Options a.2 and a.3 allow balanced flows on the 230 kV circuits from DMR and therefore permit the 230 kV path utilization to be maximized.*

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Probabilistic Reliability Assessment of Central Vancouver Island Transmission Project

Prepared by: Wijarn Wangdee
Regional System Planning, SPPA
British Columbia Transmission Corporation

1. Introduction

Load growth in Central Vancouver Island has resulted in the transmission system experiencing thermal constraints in the following two areas; 1) The 138 kV circuits designated as 1L115 and 1L116 from Dunsmuir Substation (DMR) near Qualicum to Jingle Pot Substation (JPT) near Nanaimo, 2) The four 230/138 kV transformers at Vancouver Island Terminal (VIT) north of Duncan.

Central Vancouver Island 138 kV transmission circuits (1L115 and 1L116) are heavily loaded and are approaching their capacity limits during the high load in winter under system normal condition. Both 1L115 and 1L116 circuits are equipped with a Remedial Action Scheme (RAS) that is designed to open 1L115 and 1L116 at the JPT end if an overload on these circuits is detected, causing load to be served from VIT. This will result in overloads on the four 230/138 kV transformers at VIT if the RAS operates. The Central Vancouver Island Transmission project is intended to resolve thermal constraints on the 138 kV system in Central Vancouver Island (circuits 1L115 and 1L116) as well as at the four 230/138 kV transformers at Vancouver Island Terminal Substation (VIT).

Probabilistic reliability assessment for the Central Vancouver Island Transmission (CVIT) project is presented in this report to provide a quantitative assessment of the expected energy not supplied (EENS) due to the implementation of the CVIT project.

2. Study Conditions and Assumptions

The study conditions and assumptions used in the study are as follows:

- The Central and South Vancouver Island system is used in the study as shown in Figure A.1 (2008 – 2009) and Figure A.2 (2010 – 2011) in Appendix A. The study does not focus on the Northern Vancouver Island system as it does not have impact the flows through

1L115 and 1L116. The Northern Vancouver Island system is therefore modeled as an equivalent load and generator connected to DMR substation.

- The Central Vancouver Island Transmission (CVIT) project is assumed to be in-service in October 2010.
- The 1L10 and 1L11 thermal upgrade project is assumed to be in-service in 2007. The Retermination of Sidney to Keating project is assumed to be in-service in 2010.
- The Qualicum Substation Reconfiguration project (F09 project seeking for approval) is assumed to be in-service in October 2008. This project helps to equalize and therefore maximize the flows on 1L115 and 1L116 resulting in reduction of the likelihood of load curtailment due to an overload tripping by RAS under normal system condition.
- Load duration curve for Vancouver Island is shown in Appendix B, Figure B.1. The load profile was obtained from PI system based on 2006 data. The future VI load is assumed to have a similar pattern to that shown in Figure B.1.
- BC Hydro load forecast (2006/07 – 2016/17) was used in the study. Load growth beyond 2016/17 is assumed to have 1% load growth rate.
- Substation coincident factors for Vancouver Island system were considered in order to present the realistic situation in which all substation loads may not reach their peak loads at the same time. These substation coincident factors were calculated based on the hourly chronological substation load data in the past 3 years during the VI system peak period, which obtained from RDMS. The substation coincident factors for Vancouver Island system for winter and summer seasons are shown in Appendix C.
- Reliability data (failure rate and repair time) for transformers and transmission lines in Central and South Vancouver Island system are obtained from Reliability Database Management System (RDMS) during the past 10 years.
- The VITR (230kV AC cable) is assumed to be in service in 2008. HVDC Poles 1 and 2 are assumed to be decommissioned after VITR is in-service.
- The unavailability of Jordan River Generation (JOR-G1) is dependent on the water condition as it is the run-off-river generation. The unavailability due to the water condition dominates the unavailability due to a mechanical failure of the generator. In regional system planning perspective, JOR-G1 is a very important local energy source to supply South VI system. This study therefore utilizes the unavailability of the water condition for the JOR-G1 reliability modeling. Jordan River generation pattern is shown in Appendix D, Figure D.1. The probability of having zero megawatt output is 0.46 based on the historical operating data.

3. Reliability Modeling and Software

The study system as shown in Figures A.1 and A.2 composes of both generation and transmission facilities. Since the study is focused on Vancouver Island system, the supplies from the each terminal of 5L29, 5L31 and VITR on the Mainland are modeled as an equivalent generator connected to the end of each line. All the equivalent generators are assumed to be 100% reliable, and their maximum generation outputs are limited by the capacity of the lines where they are connected to, i.e. if 5L29 is out of service, the equivalent generator connected to 5L29 will have zero output, and the maximum power flows on the 5L31 will be limited at 1221 MW. Jordan River generation (JOR-G1) is a very important source for the local area, so it will model as a non-perfect reliability generator. The unavailability of JOR-G1 is 0.46 in this study.

All the transmission components (lines, cables and transformers) considered in this study are not 100% reliable. Their reliability data are obtained from the RDMS during the past 10 years.

The in-house software designated as MECORE Program [1] is used in this study to assess the composite generation and transmission system reliability. The MECORE Program utilizes a Monte Carlo Simulation approach associated with DC-based power flow and optimization techniques. The state sampling approach is used in the simulation process. The VI load duration curve is divided into 20 non-uniform steps. The number of samplings used in this study is 50,000 for each load step to achieve a coefficient of variation (error tolerance) less than 2.5%.

4. Study Results

The expected energy not supplied (EENS) index is mainly focused in the study in order to investigate the potential risk of load curtailments based on the existing system condition, and also to investigate the potential reduction of load curtailments after implementing the CVIT project.

4.1 Reliability Indices Based on the Existing System (Do Nothing Option)

Table 4.1 presents the likelihood of the risk in terms of the magnitude of unserved energy based on the existing Central and South Vancouver Island system. The results shown in Table 4.1 are based on Do Nothing Option and will be used to compare against those results based on the implementation of the CVIT project.

Table 4.1: Expected Energy Not Supplied (EENS) based on the existing system (Do Nothing Option)

Year	EENS for Do Nothing Option (MWh/year)
2010/11	4215
2011/12	4635
2012/13	4958
2013/14	5463
2014/15	5993
2015/16	6532
2016/17	7121
2017/18	7972
2018/19	8984
2019/20	10062
2020/21	11383

4.2 Reliability Indices Based on the Implementation of CVIT Project

There are several CVIT reinforcement options originally being considered. Four basic options together with rough cost estimates (-5% to +30% accuracy) are summarized as follows:

a) 230 kV to 138 kV Injection ($82.2 million)
b) Phase Shifting Transformers and Related Upgrades ($114.7 million)
c) Conversion of 2L123 and 2L128 to 500 kV operation and Related Upgrades ($153.0 million)
d) Rebuild 1L115 and 1L116 ($169.5 million)

Reinforcement Options b), c) and d) were eliminated by the management as they are not cost effective solutions. Option a) has been selected as a preferred option to resolve thermal constraints on the 138 kV system in Central Vancouver Island (1L115 and 1L116) as well as at the four 230/138 kV transformers at VIT.

There are three sub-options in Option a) 230 kV to 138 kV Injection being studied in this report. These sub-options are designated as follows: The three options are illustrated in Figure 4.1.

Option a.1 : Looping one of the 230 kV circuits to a new Harwood West Substation (HWW)
Option a.2 : Tapping both 230 kV circuits to a new Harwood West Substation (HWW)
Option a.3 : Constructing 230 kV station to supply a new Harwood West Substation (HWW)

Options a.1 and a.2 have been considered in details while Option a.3 is presented in this study for a reliability comparison purpose only.

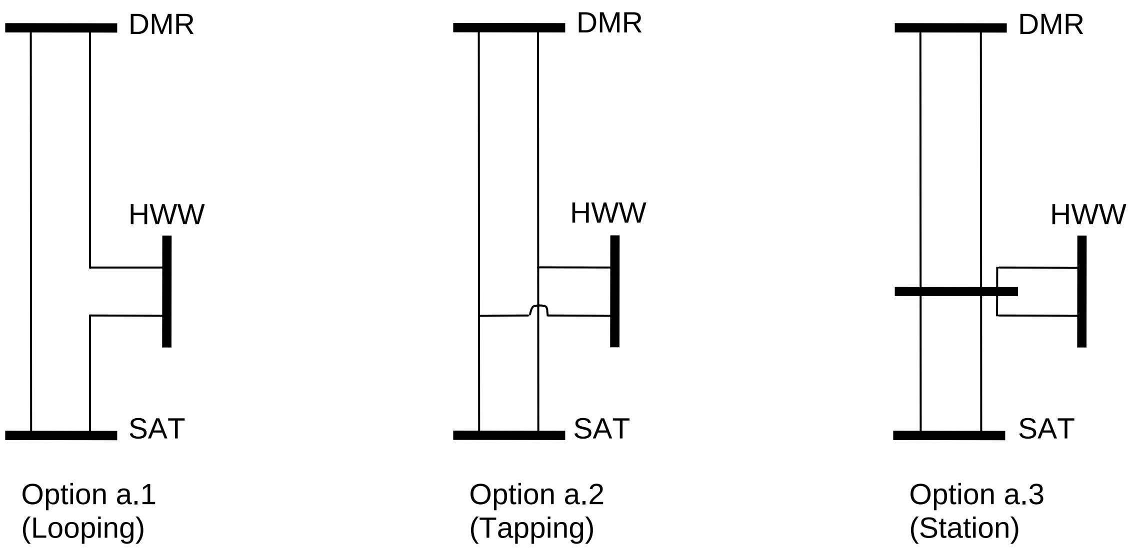


Figure 4.1: Simplified configurations for Reinforcement Options a.1 to a.3

Further assumptions:

- In Option a.1, when the 230 kV circuit section in the north that supplies to HWW is out-of-service under heavy load conditions, the overloads on 1L115 and 1L116 would occur and the RAS will open both 1L115 and 1L116 at JPT end.
- In Option a.2, when the either one of the 230 kV circuits supplying to HWW is out-of-service, the overloads on 1L115 and 1L116 could be expected and the RAS will open both 1L115 and 1L116 at JPT end.
- The double 230 kV circuit section supplying to HWW in Options a.1, a.2 and a.3 will be built on the same tower structure for 14 km in length. There is a possibility that a common cause due to a tower failure could happen, i.e. due to land slide etc. A likelihood of such event, which causes a common mode failure, is quite low as the transmission route is in a short distance. Although there are some hills in the area, the terrain that these circuits will pass through is not very rough. An appropriate route should also be selected to avoid events that could cause a tower failure. Therefore, this section will assume the common cause due to the tower failure that results in the loss of both 230 kV circuits supplied to HWW will be unlikely to occur.

Table 4.2 presents the expected energy not supplied (EENS) for Options a.1 to a.3 based on the study conditions noted earlier in Section 2 and further assumptions noted above. The results shown in Table 4.2 are graphically presented in Figure 4.2 against with those results shown in Table 4.1 for the base case (Do Nothing Option).

Table 4.2: EENS (MWh/yr) for Options a.1 to a.3 (excluding the common cause of tower failure)

Year	Looping Option (a.1)	Tapping Option (a.2)	Station Option (a.3)
2010/11	1567	1633	1623
2011/12	1598	1660	1650
2012/13	1625	1679	1668
2013/14	1663	1708	1697
2014/15	1702	1743	1730
2015/16	1752	1777	1764
2016/17	1787	1802	1788
2017/18	1841	1842	1828
2018/19	1906	1879	1863
2019/20	1974	1919	1902
2020/21	2044	1968	1950

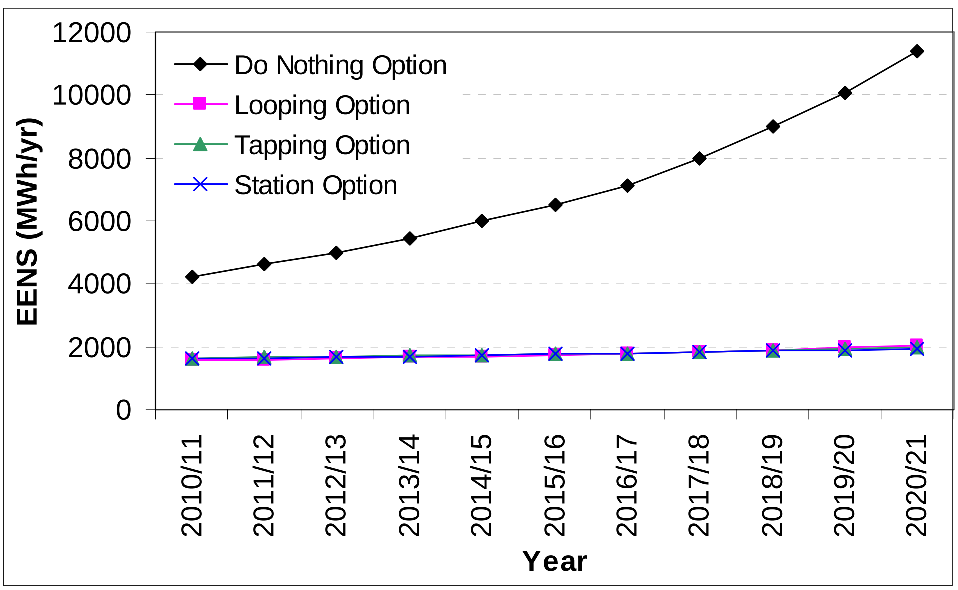


Figure 4.2: EENS comparisons (a common tower failure is not considered)

The results shown in Table 4.2 and Figure 4.2 indicate that the three options (Options a.1 to a.3) provide relatively similar reliability improvement. The EENS differences among the three options can be negligible as the fact that these numeric results fall within the 2.5% error tolerance as noted earlier in Section 3. The reliability benefits of these three options in a form of EENS reduction are, however, very significant when comparing with Do Nothing Option. The EENS for all the three options slightly little increase during the study period considered. This indicates these options are considerably efficient in dealing with Vancouver Island constraints in a long-term.

The results shown in Table 4.2 and Figure 4.2 were not taken into account the common cause of the tower structure failure. Although all the three options (Options a.1 to a.3) are exposed to the same probability of the common cause failure as the 14 km single structure strung with double circuits are common to all there options, this factor however tends to be a major concern for Option a.2 (Tapping Option) as the tower structure failure, i.e. due to lade slide in the specified section would result in a complete loss of the double 230 kV circuits from DMR to SAT, which will lead to significant load curtailment and therefore high consequence. Such an event with low probability but high consequence is examined based on a quantitative assessment using EENS as the measure index as shown in the following:

Common Cause Assumptions:

- Assume a rare event that causes the tower failure happens once in 50 year. Therefore, the probability of 0.02 per year could be expected.
- In Option a.1, the tower failure in the specified section will result in the loss of looped circuit from DMR to SAT. The restoration time of this circuit will depend on the repair or replacement of the damaged tower. The restoration time under this event is assumed to be 10 days for Option a.1.
- In Option a.2, the tower failure in the specified section will result in the complete loss of both 230kV circuits from DMR to SAT (and to HWW). The restoration time of these two circuits would take shorter time than that designated for Option a.1. The reason is because the tapped circuit section can be cut out, and then the remaining section (double circuits from DMR to SAT) can be restored while leaving the damaged tower under repair or replacement. The restoration time under this event is assumed to be 1 days for Option a.2.
- In Option a.3, the tower failure in the specified section will not result in the loss of any 230 kV circuits from DMR to SAT. The consequence due to the common cause failure of the tower structure is therefore insignificant.

Table 4.3 present the expected energy not supplied (EENS) for Options a.1 to a.3 based on the study conditions and assumptions noted earlier together with the common cause assumptions noted above. The results shown in Table 4.3 are graphically presented in Figure 4.3 against with those results shown in Table 4.1 for the base case (Do Nothing Option).

Table 4.3: EENS (MWh/yr) for Options a.1 to a.3 including the common cause of tower failure

Year	Looping Option (a.1)	Tapping Option (a.2)	Station Option (a.3)
2010/11	1571	1724	1623
2011/12	1602	1754	1650
2012/13	1630	1773	1668
2013/14	1669	1805	1697
2014/15	1710	1842	1730
2015/16	1761	1878	1764
2016/17	1797	1904	1788
2017/18	1852	1947	1828
2018/19	1920	1985	1863
2019/20	1991	2027	1902
2020/21	2064	2078	1950

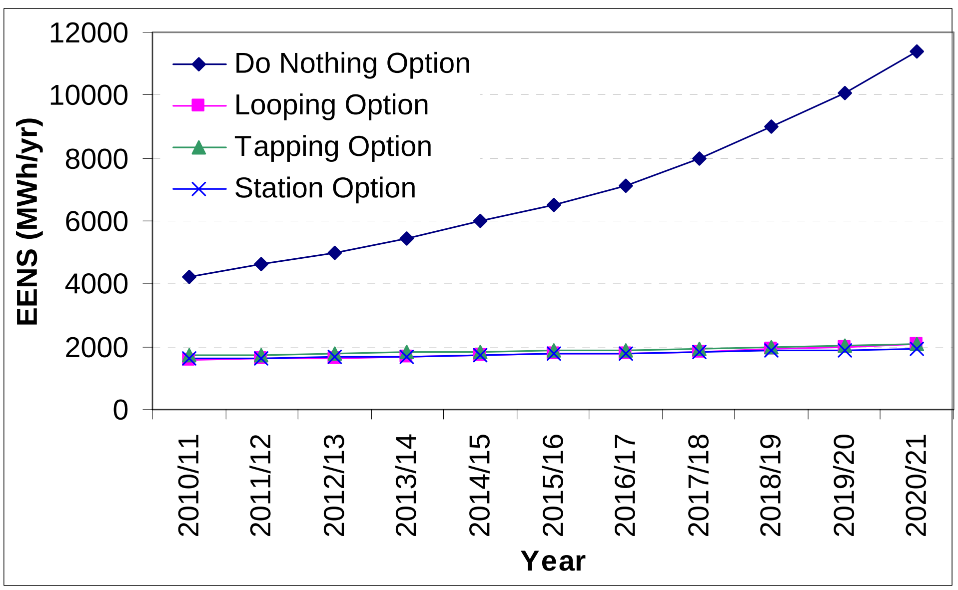


Figure 4.3: EENS comparisons (a common tower failure is considered)

Table 4.3 and Figure 4.3 indicate that the EENS differences for the three reinforcement options (Options a.1 to a.3) are still insignificant even though a common cause of the tower failure is taken into account. The common cause failure will be insignificant for Option a.3 and therefore the EENS for Option a.3 shown in Tables 4.2 and 4.3 are relatively the same. The EENS shown in Table 4.3 for Option a.1 are slightly higher than those of Option a.1 shown in Table 4.2 (when excluding the common cause failure). In Option a.2, the EENS differences between including and excluding the common cause failure (Tables 4.3 and 4.2 respectively) are approximately 100 MWh/yr. This 100

MWh/yr indicates the magnitude of the yearly distributed incremental risk due to a common cause failure throughout the study period. The EENS differences between Options a.1 and a.2 when including the common cause failure are still relatively similar.

It is important to note that the results shown in Table 4.3 and Figure 4.3 were based on the assumption of the low probability event of occurring once in 50 years. This single tower structure strung with double circuits are only 14 km in length, and this section will not pass through a very rough terrain. The probability of this common cause failure may be lower than the assumption used in the study, which would result in a lower incremental risk.

It is also worth noting that Option a.1 will create unbalanced flows on the 230 kV circuits from DMR. This will limit the transfer capability of the 230 kV circuits from the north to south. In other words, the 230 kV circuits from DMR cannot be maximized due to the uneven flows on the path. On the other hand, Options a.2 and a.3 allow the balanced flows on the 230 kV circuit from DMR and therefore permit a maximum utilization of the 230 kV path. Option a.3 may provide slightly little better reliability than Option a.2, but it involve with a higher investment cost than that of Option a.2.

5. Conclusions

The Central Vancouver Island Transmission (CVIT) project is intended to resolve thermal constraints on the 138 kV system in Central Vancouver Island (circuits 1L115 and 1L116) as well as at the four 230/138 kV transformers at Vancouver Island Terminal Substation (VIT). Probabilistic reliability assessment for the CVIT project is presented in the report to provide a quantitative assessment of the expected energy not supplied (EENS) after the implementation of the CVIT project. The 230 kV to 138 kV injection option was considered, which can be further considered to three different sub-options designated as Options a.1 to a.3 (Looping, Tapping, and Station Options respectively). This study report is only focused on EENS study of these three options. The reliability benefit/cost analysis for these three options can be conducted in a later stage when the cost estimates for different options become available. The study results indicate that the EENS obtained using the three different options are considerably similar. The EENS reductions (reliability improvement) of these three options are very significant when comparing with that of Do Nothing Option. The impact of the common cause of a tower structure failure was also examined to quantify the risk of the low probability event but high consequence. The results show there are some incremental risks due to the common cause failure, but these incremental risks still cannot significantly differentiate the reliability benefits between the three options.

References

[1] Wenyuan Li, "*MECORE Program: User's Manual*", BC Hydro, Canada, December 2001.

Appendix A: Central and South Vancouver Island System

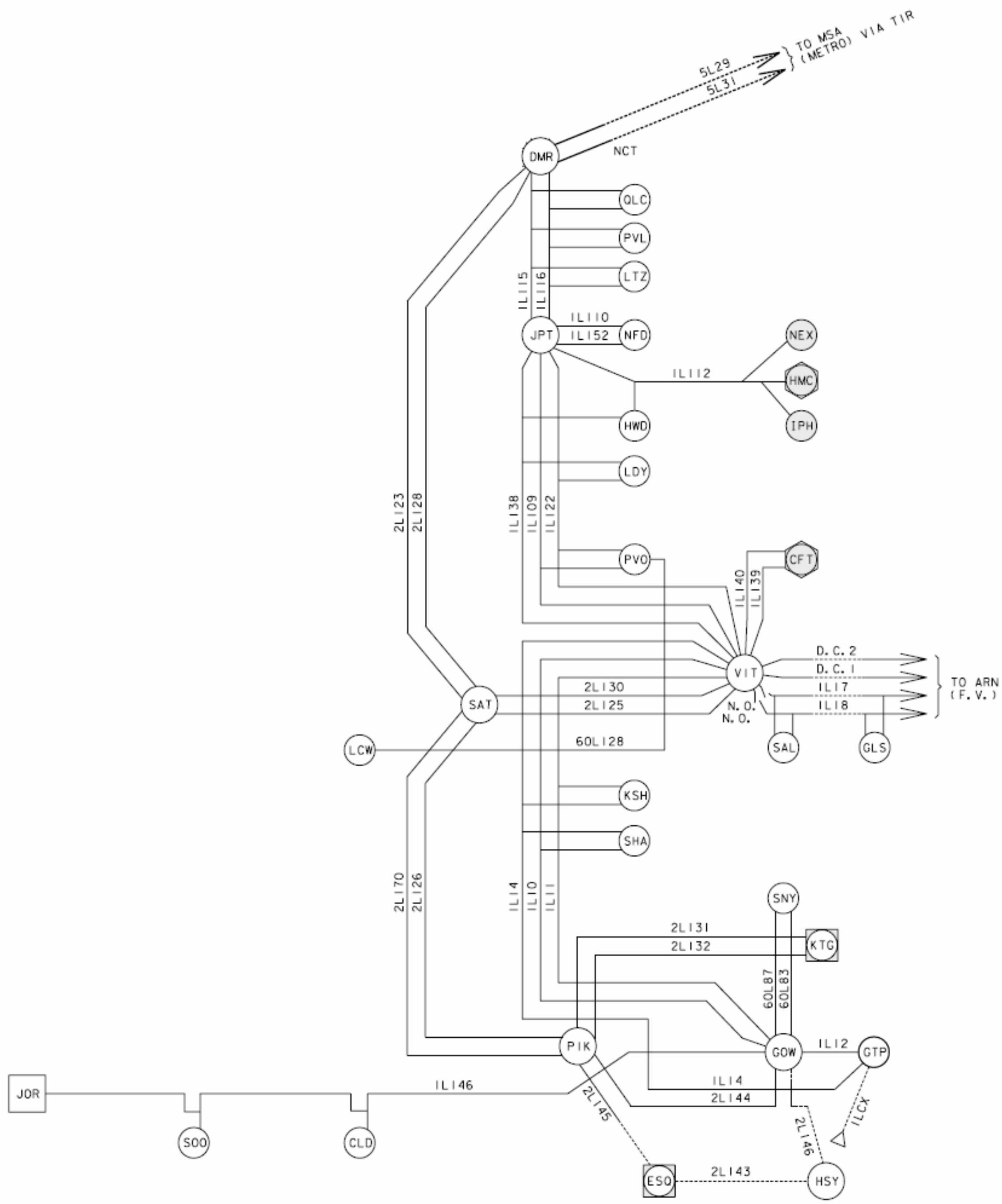


Figure A.1: Central and South Vancouver Island System Configuration (until 2009/10)

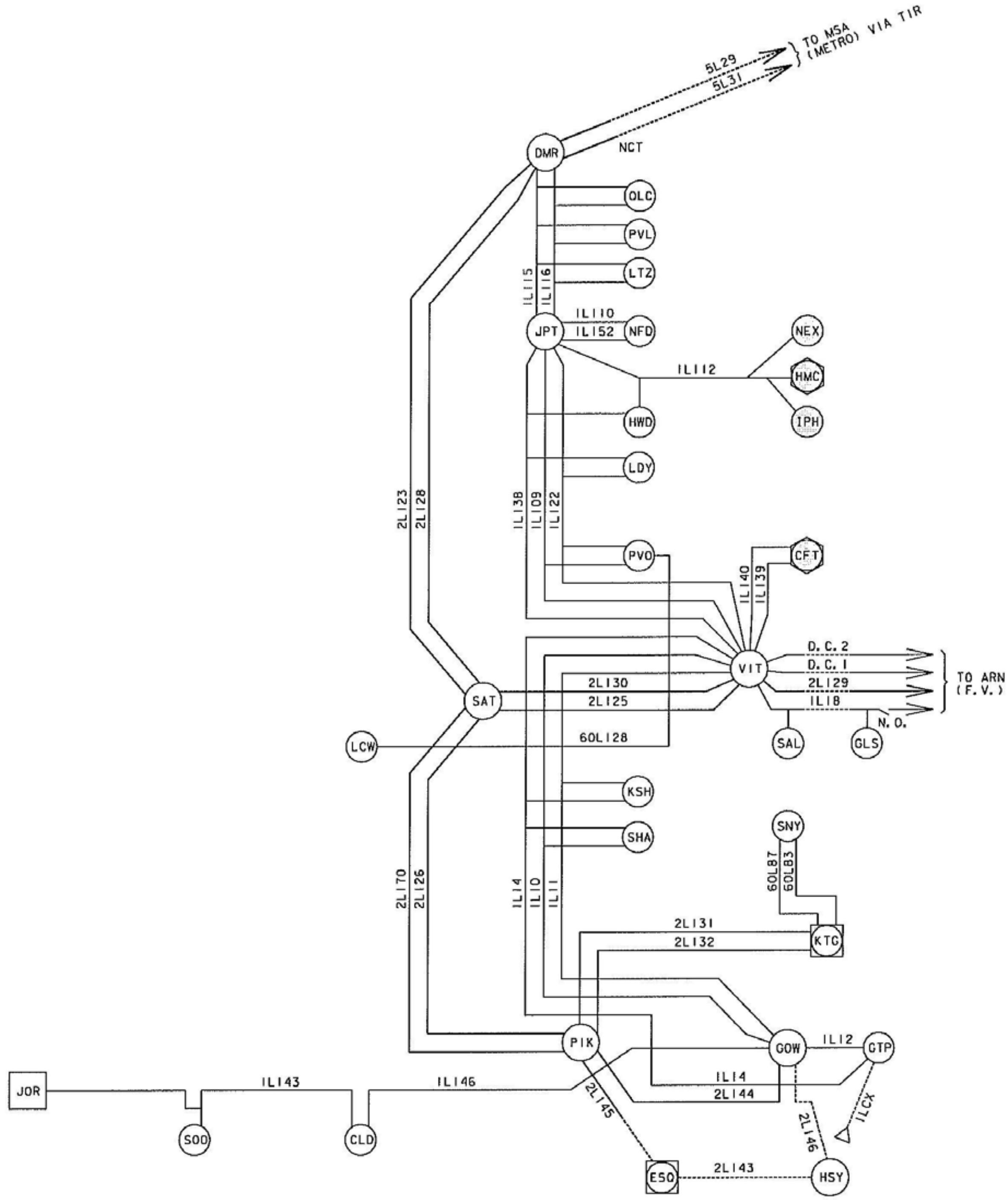


Figure A.2: Central and South Vancouver Island System Configuration (after 2010/11)

Appendix B: Vancouver Island Load Duration Curve

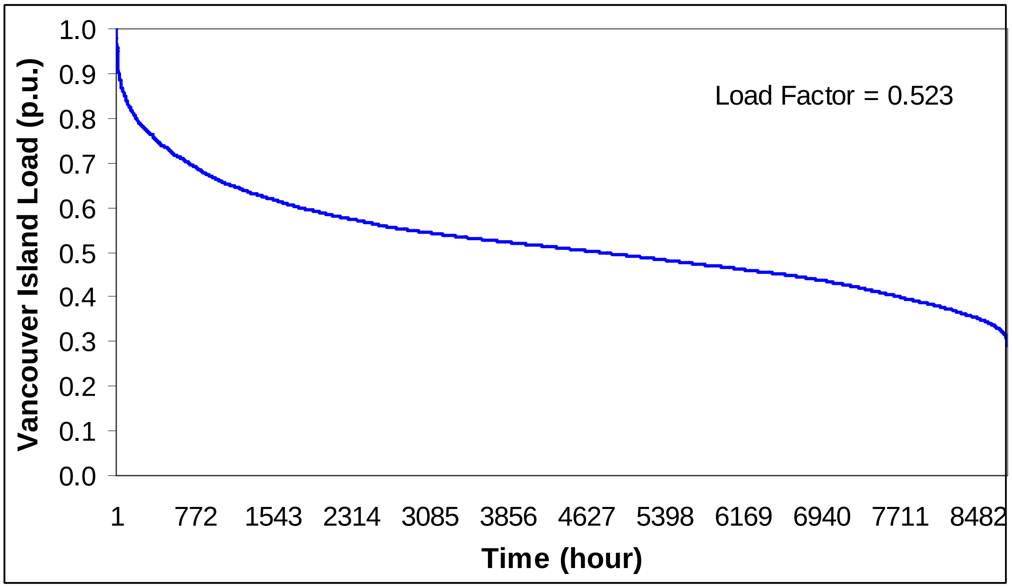


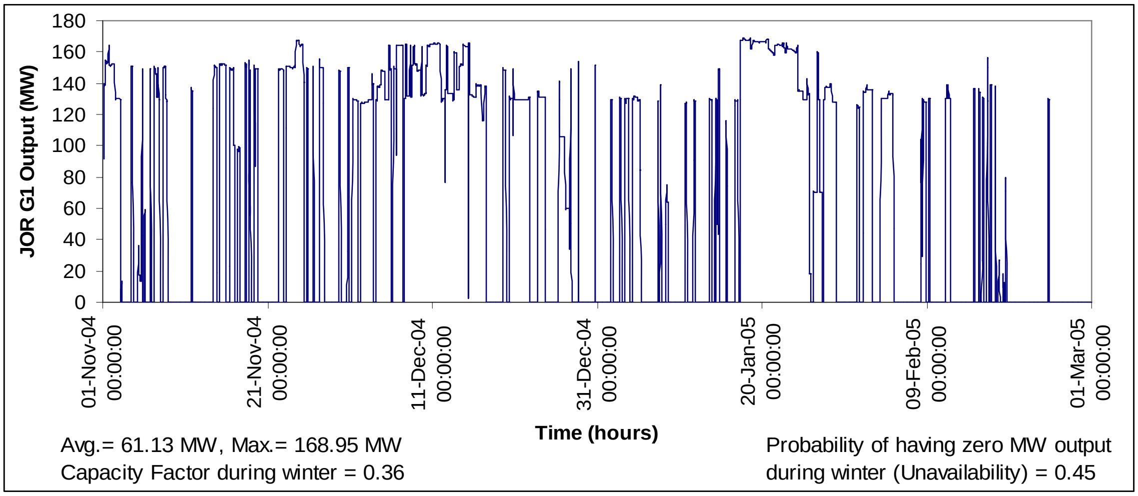
Figure B.1: Load duration curve for Vancouver Island System.

Appendix C: Substation Coincident Factors for Vancouver Island System

Table C1: Substation Coincident Factors for Winter and Summer Seasons

Bus Name (in RDMS)	Season Coincident Factors	
	Winter	Summer
APP138MA	0.9187	0.8707
BVC138SA	0.3204	0.3221
CBL25MA	0.9882	0.5647
CFT138MA	0.8550	0.8424
CLD25SA	0.9724	0.5538
CMX25MA	0.9849	0.9669
EFM138	0.8748	0.5212
ESQ12MA	0.9874	0.9058
GLD25MA	0.9472	0.6120
GLS25MA	0.8267	0.6120
GOW25MA	0.9637	0.4362
GRP138SA	0.8819	0.4123
GTP25MA	0.9852	0.5256
HMC138SA	0.3695	0.6744
HSY12MA	0.9809	0.5333
HSY25MB	0.9878	0.3509
HWD25MA	0.9846	0.6477
IPH138SA	0.2243	0.5282
JOR25MA	0.8722	0.5846
JUL138SB	0.9524	0.5644
JUL25SA	0.9439	0.4532
KGH25MA	0.9433	0.9528
KSH25MA	0.9404	0.4567
KTG25MA	0.9777	0.4566
LBH25SA	0.9397	0.6233
LBH25SB	0.9397	0.5136
LCW25SA	0.9661	0.4789
LDY25MA	0.9593	0.4789
LTZ25MA	0.9841	0.5614
NEX138SA	0.9823	0.6540
NFD25MA	0.9792	0.5410
OYR25MA	0.9807	0.9410
PAL25MA	0.9842	0.9836
PHY25SA	0.9474	0.5606
PML25SA	0.9474	0.5034
PUN25MA	0.9474	0.5953
PVL25MA	0.9897	0.4361
PVO25MA	0.9437	0.4362
QLC25MA	0.9730	0.4361
SAL25MA	0.9512	0.5222
SHA25MA	0.9719	0.4568
SNY25MA	0.9894	0.4782
SOO25SA	0.9437	0.5052
TSV25SA	0.9473	0.4757
WOS12SA	0.9489	0.5232

Appendix D: Jordan River Generation Pattern



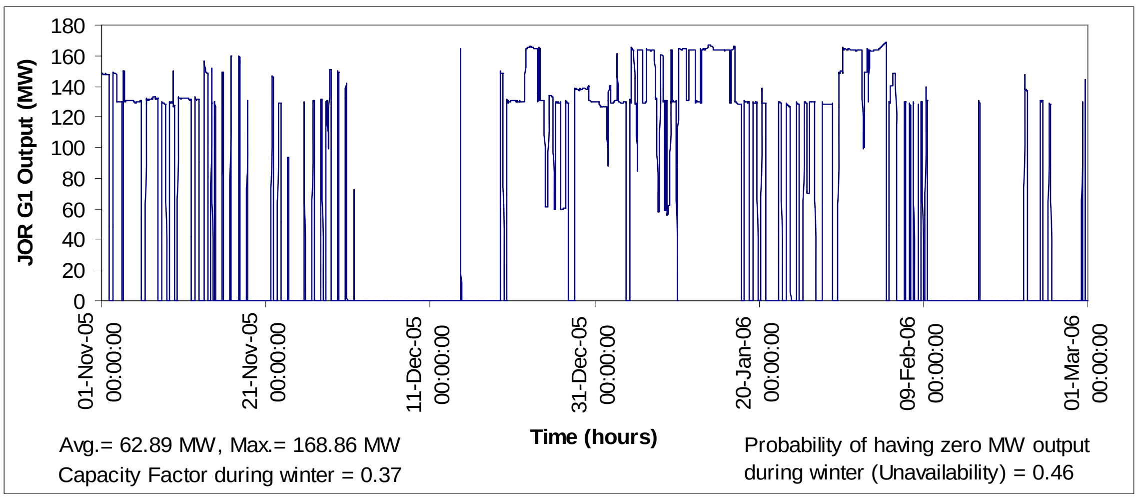


Figure D.1: MW Output of Jordan River generation during winter 2004/05 and 2005/06.