Q. **Reference Application Rev. 1, Volume 1, Section D: Projects Over $200,000 but less than $500,000, Replace Voltage Regulator – Happy Valley Gas Turbine, pages D-21 to D-26**

Please quantify the probability of failure of the 138 kV transmission line connected at Muskrat Falls Terminal Station #2 followed by the subsequent failure of the Happy Valley Gas Turbine regulator.

A. The 138 kV transmission line connected at Muskrat Falls Terminal Station 2 (L1302) is not yet in service and therefore has no operational outage statistics. The estimated unavailability of this line was calculated in "Reliability Assessment for the 138 kV Lines Supplying Labrador East," provided as CA-NLH-048, Attachment 1. The unavailability of the Happy Valley Gas Turbine Automated Voltage Regulator ("AVR") was calculated based on a five-year average of the outages related specifically to the AVR. The unavailability of L1302 and the Happy Valley Gas Turbine AVR separately and concurrently are included in Table 1.

Table 1: Reliability Statistics for Happy Valley Assets

	Five Year Average Unavailability	Hours Unavailable per Year
Calculated Loss of New Line (L1302)	0.290%	25.40
Happy Valley Gas Turbine AVR Outage	0.042%	3.70
New Line (L1302) and Gas Turbine AVR Concurrent Outage	**0.00012%**	**0.01**

Table 1 indicates that the probability of a total outage to the Labrador East transmission system due the simultaneous loss of both the primary and backup sources of supply is low. However, if the Happy Valley Gas Turbine AVR is not replaced, a failure would result in an extended outage to the unit. With the unit unavailable, regional supply would be entirely dependent on the availability of the 138 kV transmission line. If an outage to the transmission line were to occur while the gas turbine is not available, the expected duration of the forced total system outage would be approximately 17 hours, as per CA-NLH-048, Attachment 1.

Reliability Assessment for the 138 kV Lines Supplying Labrador East

October 2018

A Report to the Board of Commissioners of Public Utilities

newfoundland labrador hydro
a nalcor energy company

Table of Contents

List of Appendices

1 Objective

The purpose of this document is to provide a recommended plan of replacement of wood pole plant assets and estimate the planned maintenance outage duration to ensure that this is included in determining the unavailability of the L1301 and L1302, respectively. The document will also address the specific request as stated in Board Order No. P.U. 9(2018)[1] *"… iv) the condition of existing assets and an estimate of remaining life…"*

2 Asset Maintenance – Wood Pole Transmission Lines

Newfoundland and Labrador Hydro initiated a proactive Wood Pole Line Management ("WPLM") program 15 years ago to address four specific items as follows:

1) Inspect poles and associated line components such as conductor, hardware and insulators;
2) Treat all poles;
3) Develop and implement an electronic data collection system to facilitate field data collection and subsequent data analysis; and
4) Make data based, optimized decisions to rehabilitate, or replace poles and associated hardware.

The aim of the program is to ensure that deteriorated poles are identified and retreated for life extension, and identify in a timely manner poles requiring replacement before failures occur in service, thereby avoiding more expensive repairs, service outages, and danger to line workers.

3 Design Criteria

The basic supporting structures in this line are wood pole braced H-frame single circuit configuration type. Two continuous overhead shield wires were installed for approximately 1.5

[1] Board Order No. P.U. 9(2018), page 9, lines 34 to 35.

to 3 kilometers out from Churchill Falls Substation and 1.5 kilometers approaching Happy Valley Substation.

Traditional design load for a high voltage (HV) overhead line is based on the appropriate selection of a return period. Typically, line of this voltage class will be designed for a 50-year return period. Because the importance of the line at the time was identified as somewhat lower,[2] the design return period selected was 25 years. However, the line has survived for 42 years. The line is also designed to meet *CSA C22.3 - 1970 Specification - for Grade 1 Construction - Under Heavy Loading Conditions*.

4 Life Data Analysis

Based on the current projection (solid red curve), the data used in this analysis indicates that the expected mean life for the L1301/L1302 wood pole plant asset is approximately 103 years (Figure 1), which is significantly higher than the conventional economic life of 40 years historically used in the industry.[3] The typical Iowa curve assumes an expected asset life of 50 years. Similarly, the expected mean life for the X-arm shows that the asset life is 63 years (Figure 2).

[2] L1301 was originally a temporary construction power line during the construction of the Gull Island Project in the mid-1970s.
[3] M. Mankowski, M, E. Hansen, and J.Morrell "Wood Pole Purchasing, Inspection and Maintenance: A Survey of Utility Practices", *Forest Product Journal,* Vol. 52, No. 11/12, 2002, p.43-50.

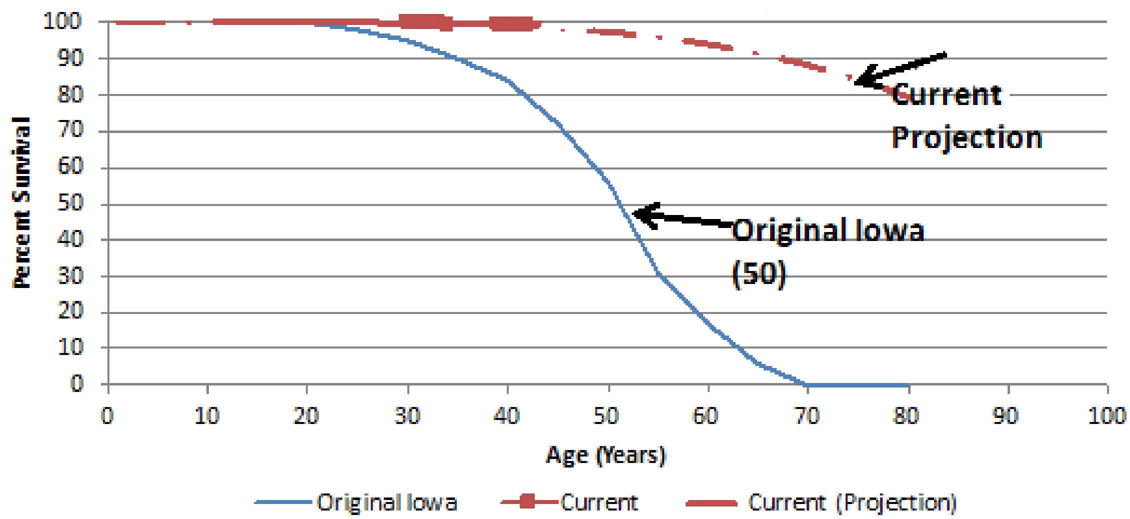

Figure 1: L1301 – Survival Plot for Pole Plant Asset

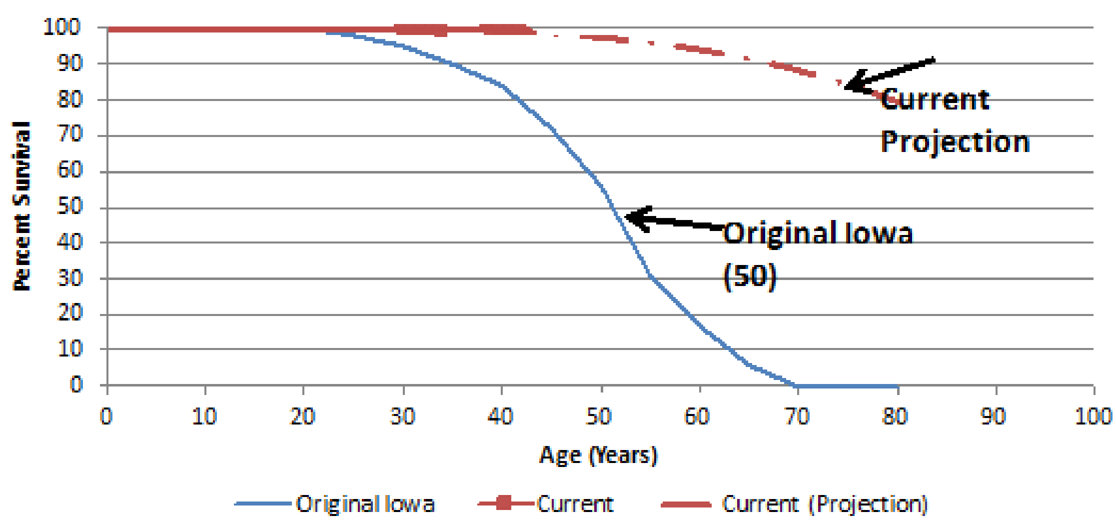

Figure 2: L1301 – Survival Plot for X-arm

5 Survival Probability in Future Years (Replacement Rate)

Based on Figure 1 and Figure 2, the probability of replacement in the future years was calculated as conditional probability given that both pole plant assets and X-arms have survived for 42 years. The results are shown in Figures 4 and 5, respectively.

1 **5.1 Pole Asset**

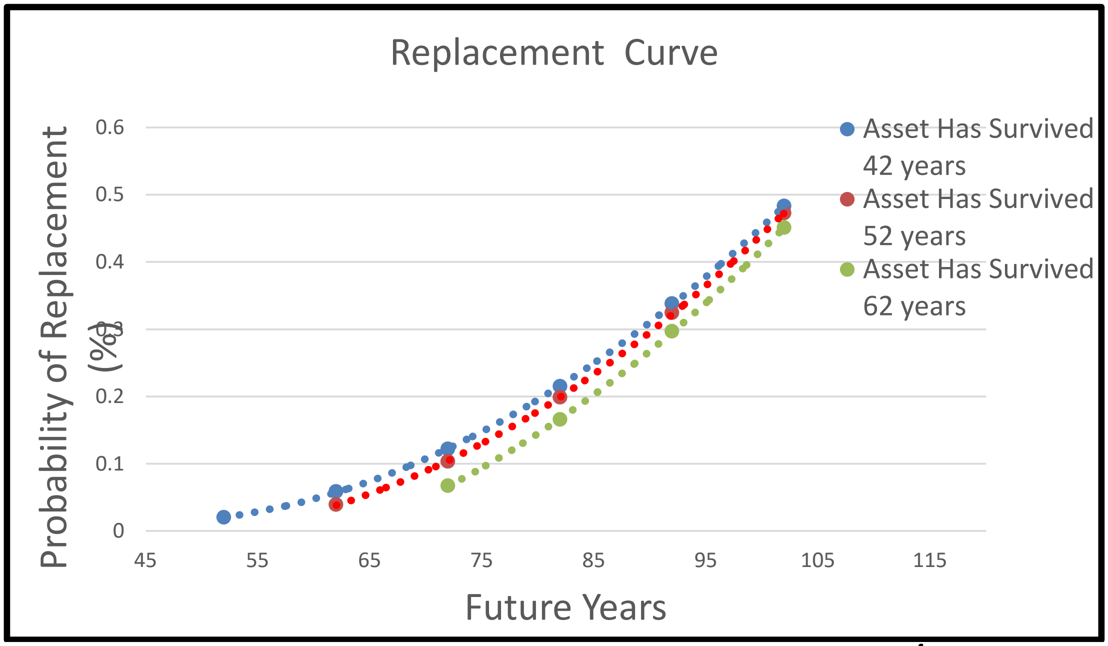

Figure 3: Replacement Probability of the Pole Plant Assets[4]

2 **5.2 X-Arm Asset**

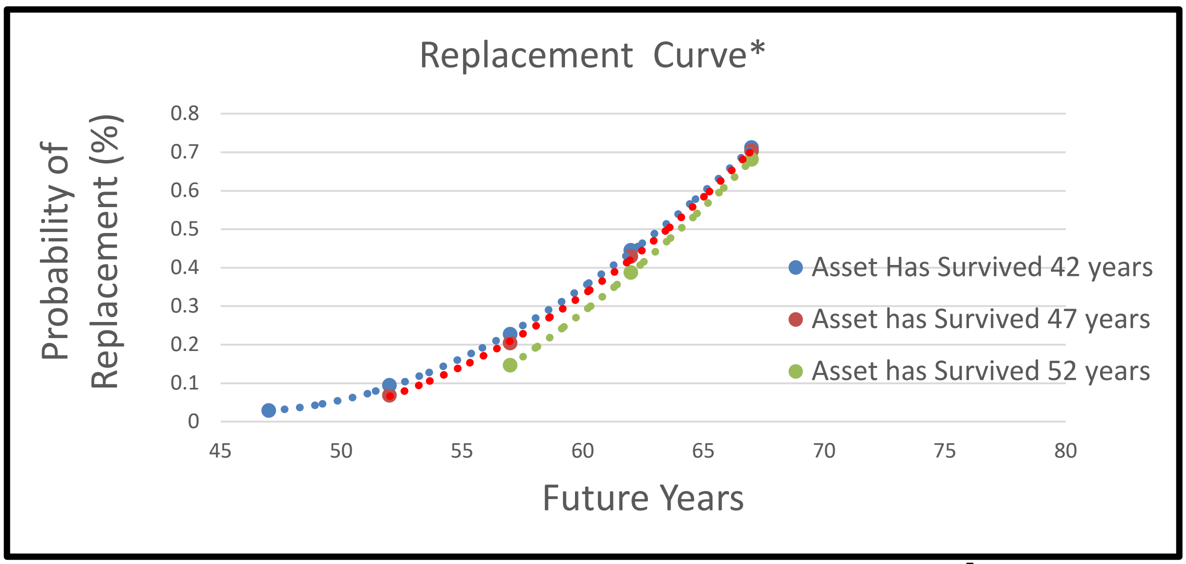

Figure 4: Replacement Probability of the X-Arm Plant Assets[5]

[4] Given that the asset has survived a T-year period.
[5] Given that the Asset Has Survived a T-year period.

6 Recommendations for Replacement Rate and Initial Costs

Based on the asset life data analysis, it is estimated from Figure 3 that the replacement rate of the pole plant asset for L1301 for the next 20-year planning horizon would be 0.30 percent per year given that it has survived for 42 years of operation. Similarly, this replacement rate for the X-arm asset would be 2.3 percent per year (Figure 4). Accordingly, the annualized cost data for replacement of poles and X-arms and inspection cost are included in the cost benefit analysis.

7 Summary and Conclusions

Results of the data analysis clearly demonstrate that the expected life of the wood pole for L1301 is estimated as 103 years while the X-arm is estimated as 63 years. The line has survived 42 years of operations. The overall pole replacement rate per year is well below the published industry data. Based on the current rejection rate, it is estimated that Hydro may be required to replace 0.30 percent of pole plant asset per year for the planning horizon considered in this study. For the X-arm, this replacement rate would be 2.3 percent per year. Planned maintenance outage duration for L1301 is estimated to be seven days in each year of future operation to support this replacement rate and the number of poles and X-arms that need to be replaced per year. The planned maintenance outage duration should be pro-rated for L1302 in terms of line length. This maintenance outage data is provided in Appendix A of this document for unavailability and expected energy not supplied ("EENS") calculations. Annualized cost of replacement of pole plant assets and X-arms and inspection costs are provided in the cost benefit section and are developed based on the information provided in this section. This cost data is later used in the cost benefit analysis presented in the main section of this report.

Appendix A

Unavailability and Expected Energy Not Supplied ("EENS")

Availability Calculations for Options 1 and 2

Option 1

The proposed plan for Alternative 1 is to offload L1301/L1302 under peak conditions through the interruption of customer load and the operation of back-up generation on the Happy Valley–Goose Bay system.

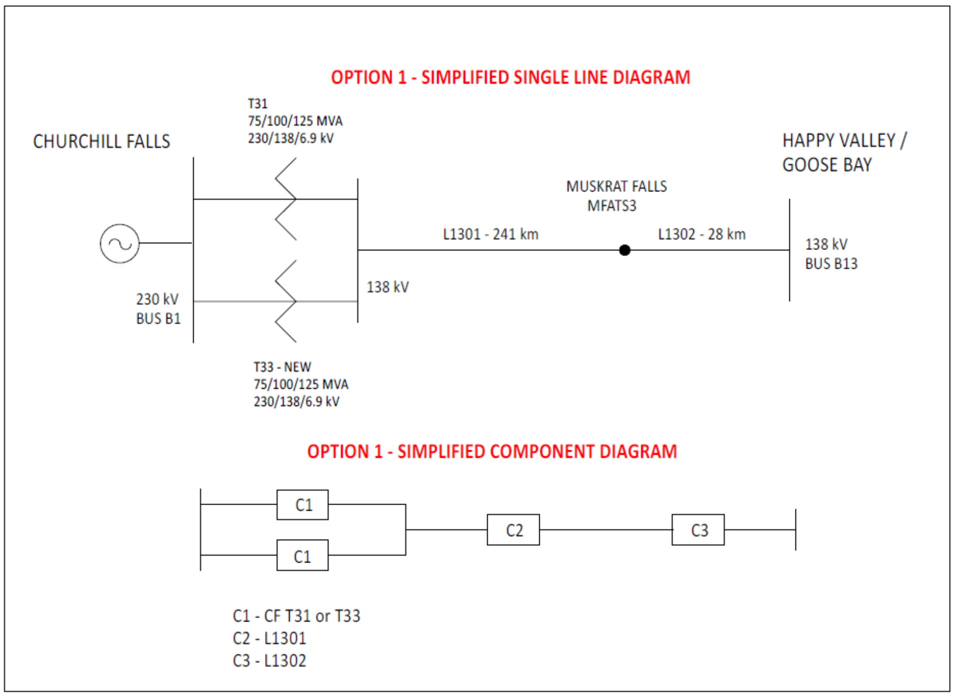

Figure A1: Option 1 – Simplified Single-Line/Component Diagram

Table A1: Option 1 – Component Unavailability

Sustained Outage Data

Component	Description	Freq (f)	Mean Time to Repair (r)		Unavailability
		occur/year	(hours)	(Years)	U (f × r)
C1	CF T31 or T33	0.1431	254.35	0.02904	0.00416
C2	L1301	2.1353[6]	16.85	0.00192	0.00411
C3	L1302	0.2481[7]	16.85	0.00192	0.00048

Maintenance Outage Data

Component	Description	Freq (f)	Mean Time to Repair (r)		Unavailability
		occur/year	(hours)	(Years)	U (f × r)
C2	L1301	1	168[8]	0.01918	0.01918
C3	L1302	1	19.52[9,10]	0.00223	0.00223

Unavailability for Option 1 is derived by calculating the unavailability of the parallel combination of C1 and C1, in series with C2 in series with C3 as follows:

$U_{C1C1pa} = U_{C1} \times U_{C1} = 0.00416 \times 0.00416 = 0.0000173$

$U_{C2C3se} = U_{C2} + U_{C3} - U_{C2}xU_{C3} = 0.004588$

$U1 = U_{C1C1pa} + U_{C2C3se} - (U_{C1C1pa} \times U_{C2C3se}) = 0.00460$

(Unavailability of Option 1 without Maintenance Outage Included)

Unavailability due to Maintenance of L1301 (WPLM) $U_{C2M} = \lambda \text{ x r} = 1 \text{ x } \frac{168}{8760} = 0.01918$

Unavailability due to Maintenance of L1302 (WPLM) $U_{C3M} = \lambda \text{ x r} = 1 \text{ x } \frac{19.52}{8760} = 0.00223$

Unavailability of $U_{C2} = U_{C2E} + U_{C2M} - U_{C2E}\,U_{C2M} = 0.00411 + 0.01918 - 0.00411 * 0.01918 = 0.02321$

Unavailability of $U_{C3} = U_{C3E} + U_{C3M} - U_{C3E}\,U_{C3M} = 0.00048 + 0.00223 - 0.00048 * 0.00223 = 0.00270$

$U_{C2C3se} = UC_2 + U_{C3} - U_{C2} * U_{C3} = 0.02321 + 0.00270 - 0.02321 \text{x } 0.00270 = 0.02579$

$U1 = U_{C1C1pa} + U_{C2C3se} - (U_{C1C1pa} \times U_{C2C3se}) = 0.0000173 + 0.02579 - 0.0000173 \times 0.02579 = 0.0258$

$U_1 = 0.0258$ (Unavailability of Option 1)

[6] L1301 = (0.886 occurrences / 100km.a) × 241 km = 2.1353.
[7] L1302 = (0.886 occurrences / 100km.a) × 28 km = 0.2481.
[8] Outage data is derived from the Life Data Analysis.
[9] L1302 = (168/ 241km) × 28 km = 19.52.
[10] Outage duration for C3 is prorated based on line length.

Option 2

This project proposes tapping transmission line L1302 at the Muskrat Falls 138/25 kV Tap Station ("MFATS3") and the addition of a 6 km segment of 138 kV wood pole transmission line constructed to the Muskrat Falls 315 kV Terminal Station ("MFATS2").

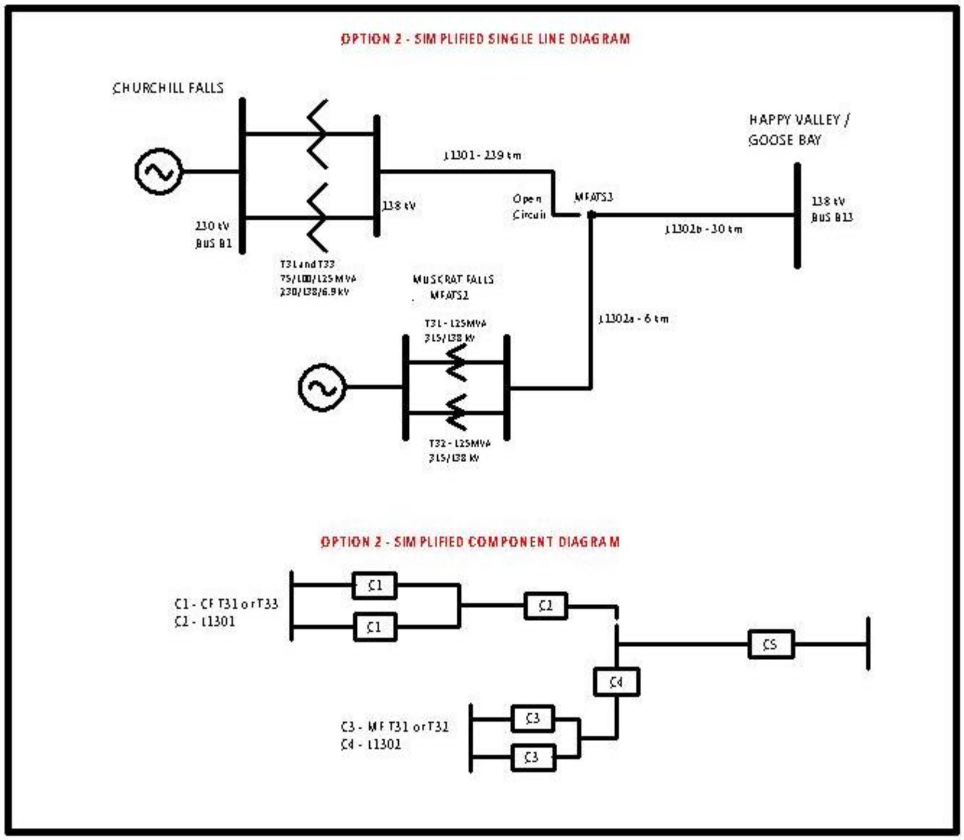

Figure A2: Option 2 – Simplified Single-Line/Component Diagram

Table A2: Option 2 – Component Unavailability

Sustained Outage Data

Component	Description	Freq (f)	Mean Time to Repair (r)		Unavailability
		occur/year	(hours)	(Years)	U (f x r)
C1	CF T31 or T33	0.1431	254.35	0.02904	0.00416
C2	L1301	2.11754[11]	16.85	0.00192	0.00407
C3	MF T31 or MF T32	0.2020	477.0	0.05445	0.01100
C4	L1302a (6km)	0.05316[12]	16.85	0.00192	0.000102
C5	L1302b (30km)	0.2658[13]	16.85	0.00192	0.00051

Maintenance Outage Data

Component	Description	Freq (f)	Mean Time to Repair (r)		Unavailability
		occur/year	(hours)	(Years)	U (f x r)
C2	L1301 (239km)	1	166.9[14]	0.0190	0.0190
C4	L1302a (6km)	N/A	N/A[15]	N/A	N/A
C5	L1302 (30km)	1	20.92[16]	0.00239	0.00239

Unavailability due to Maintenance, C2M = λ x r = 1 x $\frac{166.9}{8760}$ = 0.0190

Unavailability due to Maintenance, C5M = λ x r = 1 x $\frac{21.09}{8760}$ = 0.00241

Option 2 unavailability is derived by calculating the unavailability of the combination of:

i) Parallel combination of C1 and C1, in series C2.

$U_{C1C1pa} = U_{C1} \times U_{C1} = 0.00416 \times 0.00416 = 0.0000173$

[11] L1301 = (0.886 occurrences / 100km.a) x 239 km = 2.11754.
[12] L1302a = (0.886 occurrences/100km.a) x 6 km = 0.05316.
[13] L1302b = (0.886 occurrences/100km.a) x 30 km = 0.2658.
[14] L1301 = (168/ 241km) x 239 km = 166.
[15] L1302a = (168/ 241km) x 6 km = N/A.
[16] L1302b = (168/ 241km) x 30 km = 20.92.

Adjusting the C2 unavailability due to maintenance

$U_{C2} = U_{C2E} + U_{C2M} - U_{C2E} \times U_{C2M} = 0.00407 + 0.0190 - 0.00407 \times 0.019 = 0.2301$

$U_{C1C1paC2se} = U_{C1C1pa} + U_{C2} – U_{C1C1pa} \times U_{C2} = 0.0000173 + 0.2301 – 0.2301 \times 0.0000173 = 0.02303$

ii) Parallel combination of C3 and C3, in series C4.

$U_{C3C3pa} = U_{C3} \times U_{C3} = 0.011 \times 0.011 = 0.000121$

$U_{C3C3paC4se} = U_{C3C3pa} + U_{C4} – U_{C3C3pa} \times U_{C4} = 0.000223$

iii) Parallel combination of items I and ii in series with C5.

$UiUiipa = Ui \text{ x } Uii = 0.02303 \times 0.000223 = 0.00000513$

Adjusting the C5 unavailability due to maintenance

$U_{C5} = U_{C5E} + U_{C5M} - U_{C5E} \times U_{C5M} = 0.00051 + 0.00239 - 0.00051 \times 0.00239= 0.00290$

$UiUii_{pa\ C5se} = UiUii_{pa} + U_{C5} – UiUii_{pa} \times U_{C5} = 0.00000513 + 0.00290 -0.00000513 \times 0.00290 = 0.00290$

$U_2 = UiUiipa + U_{C5} - (U_iU_{iipa} \times U_{C5}) = 0.00290$

U_2 =0.00290 (Unavailability of Option 2)

Expected Energy Not Supplied ("EENS")

Table A3: Unavailability/EUE Comparison of Options

Interconnection Option	Calculated Unavailability (U)	Calculated Expected Unserved Energy (MWh)[17]
1	0.0258	8,570
2	0.00290	960

Based on the revised analysis, it appears that the unavailability is increased by fivefold and so as the EENS when one considers the planned maintenance outage in the unavailability analysis (0.00406 for Option 1 and 0.00051 for Option 2 without planned maintenance outage). Also, the unavailability of Option 2 appears to be approximately one tenth of that of the one computed for Option 1 indicating that Option 2 is significantly reliable compared to Option 1.

A time history plot of the EENS for the planning horizon can be created by multiplying the energy forecast data for Happy Valley-Goose Bay by the numbers in Table A3. Once this is developed, the cost of unsupplied energy can be determined and the value of EENS can be estimated over the planning horizon. A separate analysis not shown here was carried out using the sustained outage data for L1301 and L1302 from Churchill Falls database. The results showed that the unavailability data for Options 1 and 2 were comparable to those obtained from CEA data presented in Table A3.

[17] Based upon the Happy Valley-Goose Bay 2020 annual energy requirement of 332 GWh.