REGISTERED PROFESSIONAL ENGINEER P. THOMAS SIGNATURE Jan 25, 2018 PROVINCE OF NEWFOUNDLAND	Electrical
	Mechanical
	Civil
	Protection & Control
	Transmission & Distribution
	Telecontrol
	System Planning

Muskrat Falls to Happy Valley Interconnection

July 2017

Revised August 30, 2017

Revised January 25, 2018

A Report to the Board of Commissioners of Public Utilities

newfoundland labrador hydro

a nalcor energy company

Summary

Hydro provides electricity to approximately 5300 interconnected customers in Happy Valley-Goose Bay, Mud Lake, Northwest River and Sheshatshiu (Upper Lake Melville area). The load continues to increase in this area. Analysis shows that the existing electrical system can support an Upper Lake Melville area peak load of 77 MW. Loads beyond 77 MW will cause system voltages to deteriorate, ultimately resulting in system voltage collapse and customer outages. Hydro projects the load for Upper Lake Melville area to grow from 79.8 MW in 2017 to 104 MW in 2042, including received service applications for new data centres, and a Department of National Defense conversion to electric boilers in 2020.

Five power supply options for the Upper Lake Melville area were analyzed from both a technical and cost benefit point of view. It was shown that while maintaining long term supply from Churchill Falls (status quo) with an additional 125 MVA transformer added at Churchill Falls, a 67 MVAR capacitor bank, and 50MVA transformer at Happy Valley – Goose Bay, had the lowest initial capital cost, it did not have the lowest cumulative net present value. Connection of the Upper Lake Melville to Muskrat Falls via construction of a six km long transmission line from the existing 138 kV right of way to the Muskrat Falls site had the lowest cumulative net present value of the five options. In addition, the reliability analysis indicates that by connecting the 138 kV transmission system in Eastern Labrador to the Muskrat Falls site the unavailability is reduced to 0.051% compared to 0.46% if supply is maintained via the 269 km transmission line to Churchill Falls (Status Quo). Further, the expected unsupplied energy is reduced from 1,747 MWh to 194 MWh by connecting to Muskrat Falls. Therefore connection to the 138 kV bus at the Muskrat Falls site is recommended to support the forecast load growth in the Upper Lake Melville area and improve overall reliability of supply to the customers.

This project will tap L1301/L1302, the 138 kV transmission line from the Churchill Falls Terminal Station to the Happy Valley Terminal Station (Happy Valley), at the Muskrat Falls Tap Station with a 6 km transmission line which will terminate in a Hydro constructed

partial ring bus in the Muskrat Falls 315 kV Terminal Station. The partial ring bus will also accept two 138 kV supplies from Muskrat Falls via two 315/138kV, 125 MVA transformers. As this project will increase the maximum fault level at Happy Valley, five reclosers and one circuit breaker will be replaced with six new circuit breakers. A new control building will be constructed to house the new Happy Valley protection and control infrastructure required. In addition, due to projected load increases, a new 138/25kV, 50 MVA transformer will be required at Happy Valley.

Once this interconnection project is complete and construction power from Hydro is no longer needed for the Muskrat Falls Project, the firm capacity of the electrical system supplying the Upper Lake Melville area will be approximately 104 MW.

The cost of this proposed project is estimated at $19,978,500 with the transmission line infrastructure in service by December 2018, while the 50 MVA transformer will be in service by December 2019.

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1.0 Introduction

Hydro provides electricity to approximately 5300 interconnected customers in Happy Valley-Goose Bay, Mud Lake, Northwest River, and Sheshatshiu (Upper Lake Melville area). The load continues to increase in this area. Analysis shows that the existing electrical system can support an Upper Lake Melville area peak load of 77 MW. Loads beyond 77 MW will cause system voltages to deteriorate, ultimately resulting in system voltage collapse and customer outages. Hydro projects the load for Upper Lake Melville area to grow from 79.9 MW in 2017 to 104 MW in 2042. To support loading levels beyond 77 MW the capacity of the Upper Lake Melville area transmission system must be increased.

For the 2017-2018 winter peak Hydro temporarily utilized one of the new 315 kV transmission lines between Churchill Falls and Muskrat Falls through the strategic location of jumpers such that a section of 315 kV transmission line could be operated at 138 kV. The 315 kV line with two conductors per phase resulted in a reduction in 138 kV transmission system losses such that the Happy Valley load could be supplied. Commissioning of the Labrador – Island HVdc Link in the Spring of 2018 requires that both 315 kV lines between Churchill Falls and Muskrat Falls are in service. Consequently, a permanent 138 kV transmission solution is required for reliable supply of the load in Eastern Labrador.

Figure 1 shows the configuration of the Upper Lake Melville area electrical system upon completion of the Muskrat Falls Project. Two 250 km, 315 kV transmission lines will connect Churchill Falls and Muskrat Falls.

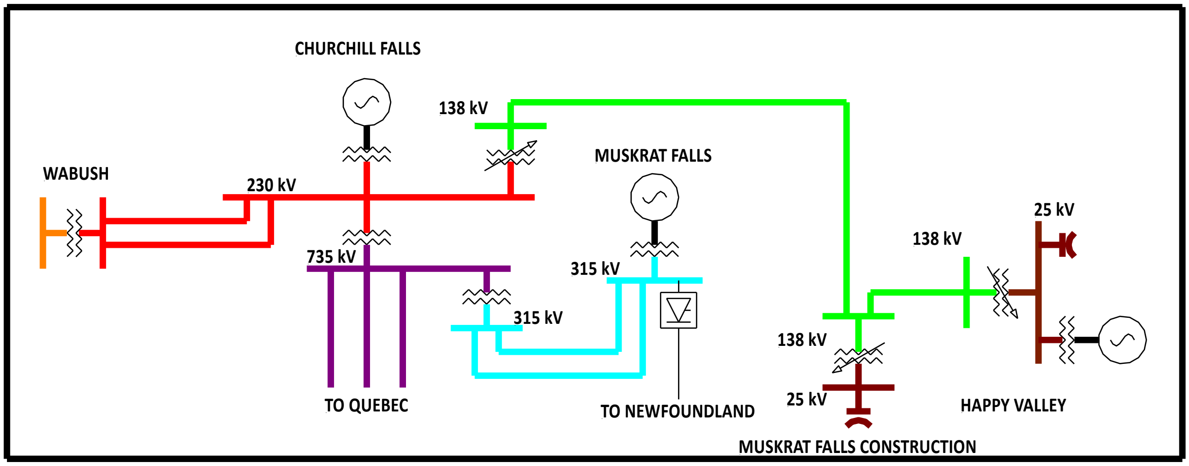

Figure 1 Labrador Interconnected System with Muskrat Falls Complete

Hydro's vision to ensure a reliable, flexible electrical system for the Upper Lake Melville area is a two-phased approach.

1. Phase I is the proposed splitting of transmission line L1302 at Muskrat Falls, as shown in Figure 2.

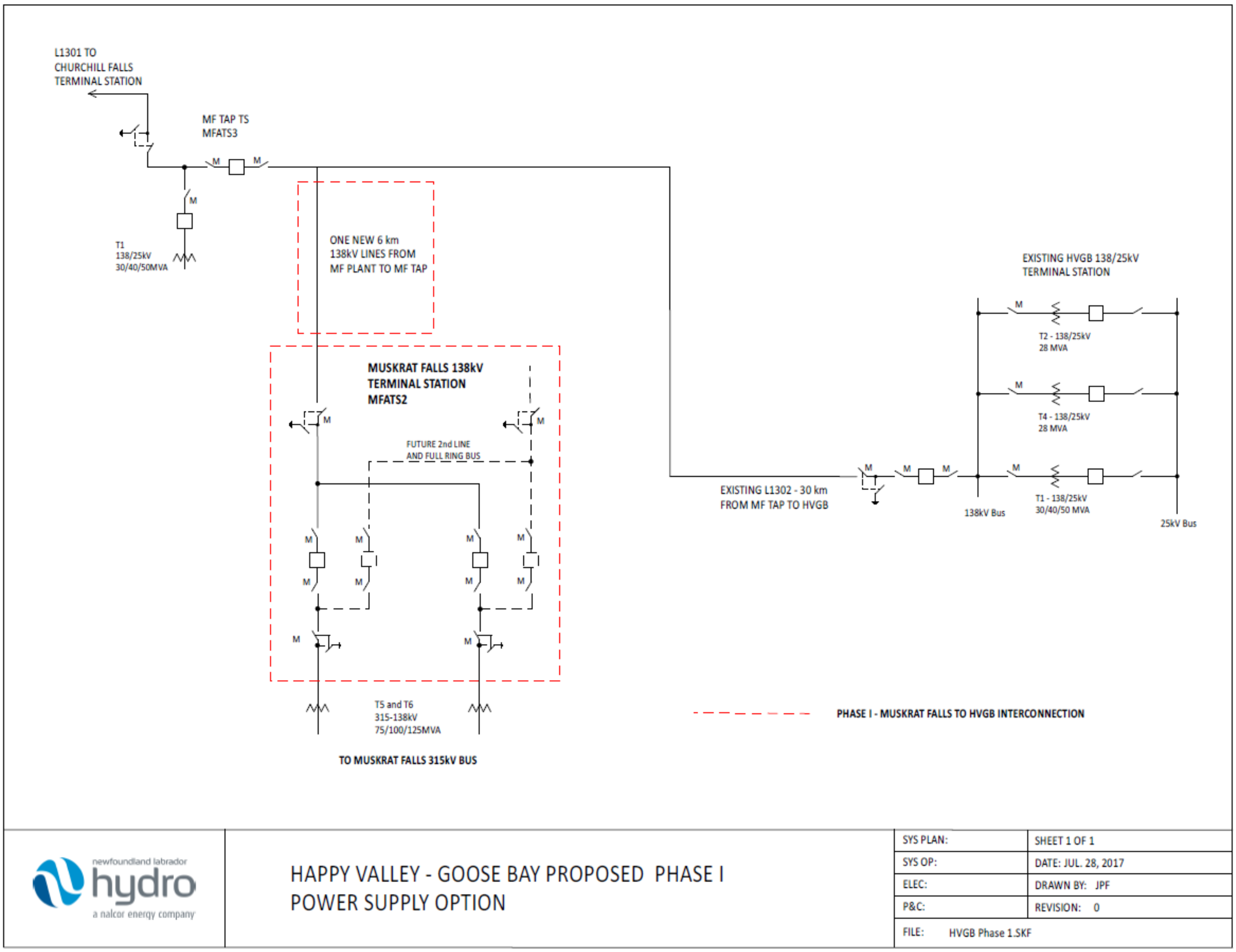

Figure 2 Electrical System for Upper Lake Melville Area – Phase I

The firm capacity of Phase I is approximately 104 MW. The overall reliability and capacity of the system will be improved from the existing configuration due to a reduction of the primary supply location being approximately 36 km from the Happy Valley Terminal Station (Happy Valley), as compared to approximately 269 km for supply from the Churchill Falls Terminal Station. Reliability analysis indicates that the expected unsupplied energy will be reduced from 1,747 MWh for continued supply via the existing transmission from Churchill Falls, to 194 MWh when interconnected to the Muskrat Falls Terminal Station.

It is recognized that load growth beyond the firm capacity of 104 MW could occur fairly quickly depending on industrial load growth, such as increased numbers of data centers in the area. For loads beyond 104 MW, Phase II could be implemented.

2. Phase II, when required, proposes the installation of a second 138/25 kV terminal station in the Upper Lake Melville area and through use of existing transmission lines and newly constructed transmission lines, a looped electrical system would be established interconnecting the new terminal station, the Happy Valley Terminal Station, the Muskrat Falls 315 kV Terminal Station, and the Churchill Falls Terminal Station. At the end of Phase II, the area would have a flexible, robust electrical system with a firm transmission capacity of 125 MVA for contingency event of loss of one 315/138 kV transformer at Muskrat Falls; however, Phase II would only be proposed when load forecasts for the Upper Lake Melville area approach 104 MW, or if increased reliability is deemed necessary. It should also be noted that the work that is proposed in Phase I as part of this Capital Budget Application will be utilized in Phase II, and that there is no disadvantage to executing this project in two phases. See Figure 3.

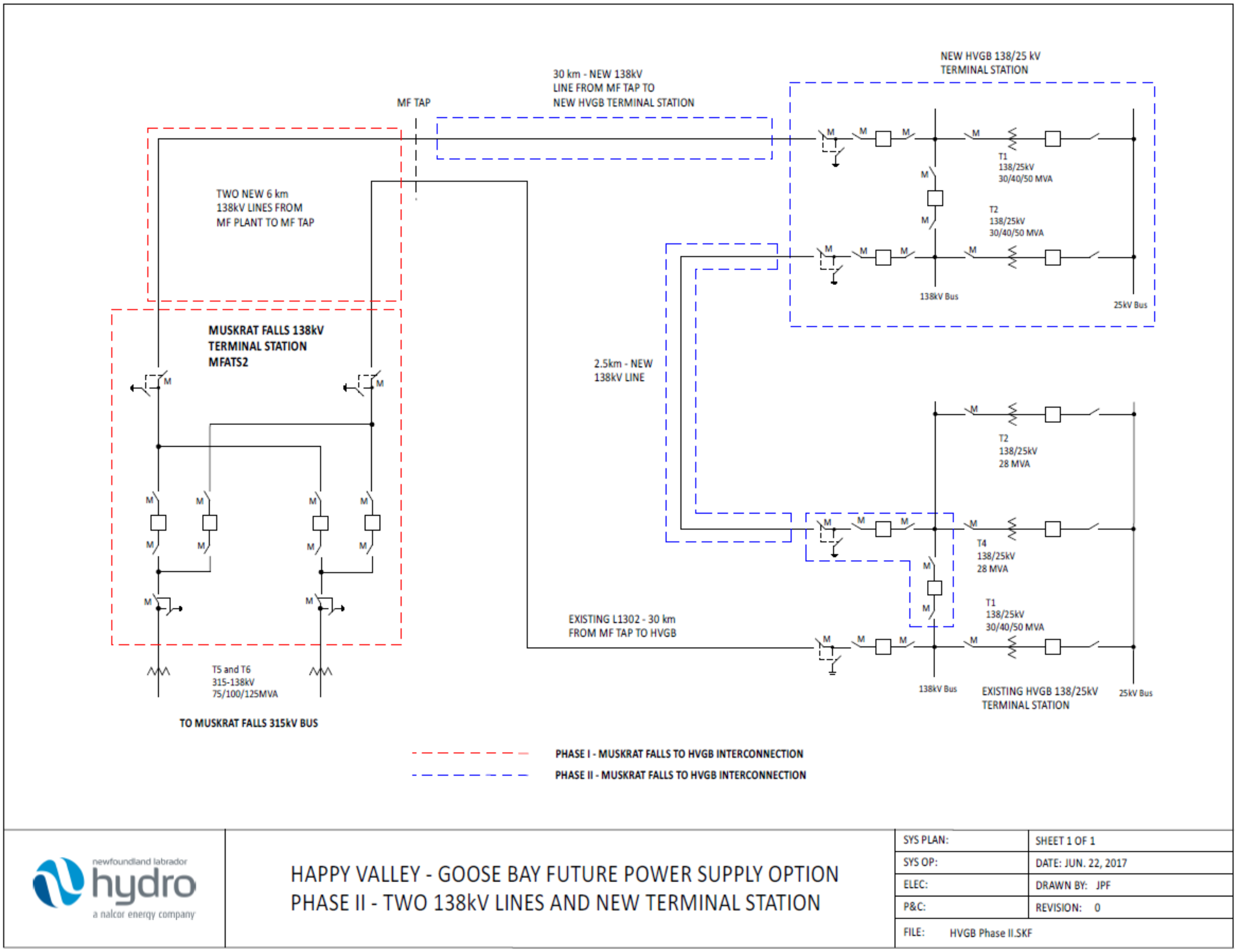

Figure 3 Electrical System for Upper Lake Melville Area – Phase II

2.0 Project Description

This project (Phase I) proposes tapping transmission line L1302 at a location close to the Muskrat Falls 138kV/25 kV Tap Station (MFATS3) and the addition of a six km segment of 138 kV wood pole transmission line that will be constructed to the Muskrat Falls 315 kV Terminal Station. The Muskrat Falls 315 kV Terminal Station is being constructed to provide Hydro with two 138 kV supply connections via 315/138kV, 125 MVA transformers. At these connections, Hydro will install a partial ring bus to accept the two 138 kV supplies from Muskrat Falls and to terminate the new six km segment to L1302.

As this project will increase the maximum fault level at the Happy Valley Terminal Station, five reclosers and one circuit breaker will be replaced with six new circuit breakers. A new 138/25kV, 50 MVA transformer will be required to allow for the projected load increase. To house the new Happy Valley protection and control infrastructure that will be required, a new control building will be constructed.

In addition to the proposed option, several other options were analyzed as alternatives to this project, as detailed in the new report entitled "Eastern Labrador Transmission System Planning Report", included as Appendix A.

The budget estimate for this project is $19,978,500.

3.0 Justification

Analysis of the present 138 kV transmission system configuration serving the Upper Lake Melville area indicates that the system is capable of delivering 77 MW to the Happy Valley 25 kV bus when the system is no longer providing construction power to the Muskrat Falls Project. For load levels beyond 77 MW, system voltages will deteriorate ultimately resulting in system voltage collapse and customer outages. The projected peak load for the area is expected to increase from 79.9 MW in 2017 to 104 MW in 2042. To support load levels beyond 77 MW in the Upper Lake Melville area, the capacity of the transmission system supplying the area must be increased. Refer to Appendix A, Eastern Labrador Transmission System Planning Report.

3.1 Existing System

The transmission system in Upper Lake Melville area is part of the larger Labrador Interconnected System, which is presented in Figure 4. The Upper Lake Melville area is interconnected to the Churchill Falls Terminal Station via L1301/L1302 with a total length of approximately 269 km. In 1977, transmission line L1301 was constructed to provide

1 electricity to the Gull Island Construction Site and was extended to the town of Happy
2 Valley-Goose Bay.

Figure 4 Labrador Interconnected System

3 Figure 5 provides a simplified diagram of the existing Labrador Interconnected System.

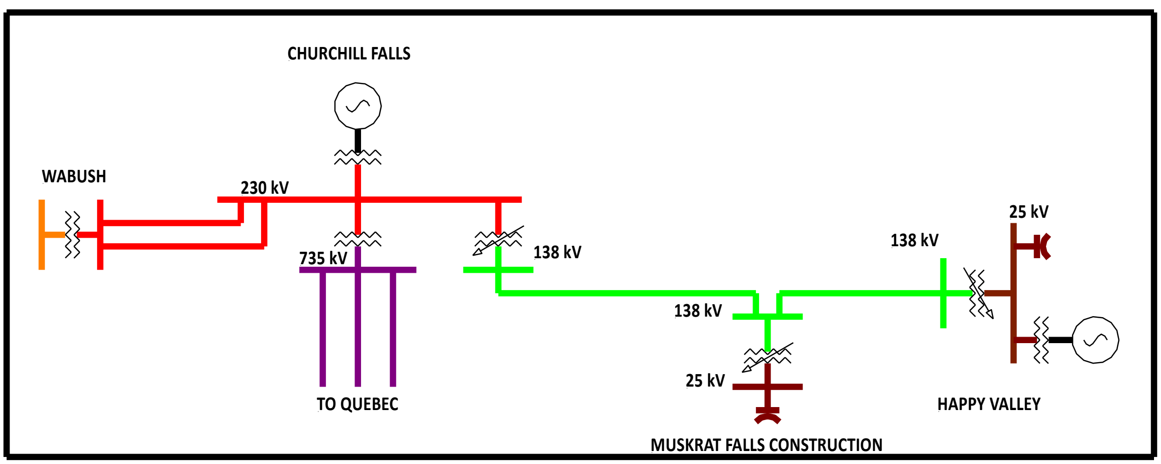

Figure 5 Existing Labrador Interconnected System

The L1301 transmission line was tapped to establish a terminal station to supply construction power to the Muskrat Falls Project[1]. Due to increase in load demand from both the Muskrat Falls Project and the Upper Lake Melville area, 21.6 MVAR of capacitor banks were added to this tap station to improve power transfer capability and to maintain acceptable voltages.

At Churchill Falls, transmission line L1301 is connected to a 230/138 kV, 75/100/125 MVA autotransformer which is equipped with an on load tap changer to provide 138 kV system voltage regulation. The configuration of the Churchill Falls Terminal Station includes a standby 42 MVA, 230/138 kV transformer.

At the Happy Valley Terminal Station, there are three 138/25 kV transformers, all equipped with on-load tap-changers that provide voltage regulation for the Happy Valley Distribution System. There are also 11.4 MVAR of switched shunt capacitor banks and a 25 MW gas turbine, with synchronous condenser capabilities. The shunt capacitors and the synchronous condenser provide reactive power support to maintain acceptable voltages.

At the North Side Diesel Plant, there is approximately 5 MW of diesel generation, but due to the deteriorating condition of the plant, it is not reliable. Recognizing that the North Side Diesel Plant may not be available and with the loss of the 125 MVA transformer at the Churchill Falls Terminal Station, the maximum load that can be supplied to the area from Happy Valley Terminal Station, with the Churchill Falls Terminal Station's 42 MVA transformer and Happy Valley's 25 MW gas turbine, is 62 MW.

3.2 Forecast Customer Growth

Table 1 outlines the expected long-term forecast demand for the Happy Valley Terminal Station.

[1] Following tapping of L1301 the transmission line numbering became L1301 (Churchill Falls to Muskrat Falls Tap) and L1302 (Muskrat Falls tap to Happy Valley)

Table 1 Happy Valley Long Term Forecast

Year	Spring 2017 Forecast, MW
2017	79.9
2018	80.6
2019	81.4
2020	93.9
2021	94.5
2022	94.8
2023	95.3
2024	95.8
2025	96.3
2026	96.8
2027	97.3
2028	97.8
2029	98.2
2030	98.7
2031	99.2
2032	99.6
2033	100.0
2034	100.5
2035	100.9
2036	101.3
2037	101.7
2038	102.2
2039	102.6
2040	103.1
2041	103.5
2042	104.0

4.0 Conclusion

Analysis shows that the existing electrical system, servicing the Upper Lake Melville area, can support peak load of 77 MW. Loads beyond 77 MW will cause system voltages to deteriorate, ultimately resulting in system voltage collapse and customer outages. Hydro projects the load for Upper Lake Melville area to grow from 79.9 MW in 2017 to 104 MW in 2042. To support loading levels beyond 77 MW, the capacity of the Upper Lake Melville area transmission system must be increased.

Five power supply options for the Upper Lake Melville area were analyzed from both a technical and cost benefit point of view. It was shown that while maintaining long term supply from Churchill Falls (status quo) with an additional 125 MVA transformer added at Churchill Falls, a 67 MVAR capacitor bank, and 50MVA transformer at Happy Valley – Goose Bay, had the lowest initial capital cost, it did not have the lowest cumulative net present value. Connection of the Upper Lake Melville to Muskrat Falls via construction of a six km long transmission line from the existing 138 kV right of way to the Muskrat Falls site had the lowest cumulative net present value of the five options. In addition, the reliability analysis indicates that by connecting the 138 kV transmission system in Eastern Labrador to the Muskrat Falls site the unavailability is reduced to 0.051% compared to 0.46% if supply is maintained via the 269 km transmission line to Churchill Falls (Status Quo). Further, the expected unsupplied energy is reduced from 1,747 MWh to 194 MWh by connecting to Muskrat Falls. Therefore connection to the 138 kV bus at the Muskrat Falls site is recommended to support the forecast load growth in the Upper Lake Melville area and improve overall reliability of supply to the customers.

Once this interconnection project is complete and construction power from Hydro is no longer needed for the Muskrat Falls Project, the firm capacity of the electrical system supplying the Upper Lake Melville area will be approximately 104 MW.

4.1 Project Estimate

A budget estimate for the project is provided in Table 2.

Table 2 Project Budget Estimate

Project Cost: *($ x1,000)*	**2018**	**2019**	**Beyond**	**Total**
Material Supply	1,370.2	0.0	0.0	1,370.2
Labour	2,419.0	275.0	0.0	2,694.0
Consultant	114.6	0.0	0.0	114.6
Contract Work	10,132.6	1,500.0	0.0	11,632.6
Other Direct Costs	266.6	0.0	0.0	266.6
Interest and Escalation	567.9	117.0	0.0	684.9
Contingency	2,860.6	355.0	0.0	3,215.6
TOTAL	**17,731.5**	**2,247.0**	**0.0**	**19,978.5**

4.2 Project Schedule

The project schedule is provided in Table 3. The transmission interconnection would be in-service by December 2018 while the installation and commissioning of the 50 MVA transformer in Happy Valley will be completed by December 2019.

Table 3 Project Schedule

Activity		Start Date	End Date
Planning	Planning	January 2018	February 2018
Design	Engineering Design	February 2018	May 2018
Procurement	Procurement of Material and Hardware	February 2018	May 2018
Construction	Project Construction	May 2018	September 2019
Commissioning	Commissioning	September 2018	October 2019
Closeout	Project Closeout	November 2019	December 2019

4.3 Future Plans

Hydro will continue to monitor load growth in the Upper Lake Melville area and will submit a capital budget application for further construction (Phase II) when the load forecast indicates that loads will exceed the capacity of the Phase I interconnection.

Appendix A

Eastern Labrador Transmission System Planning Report

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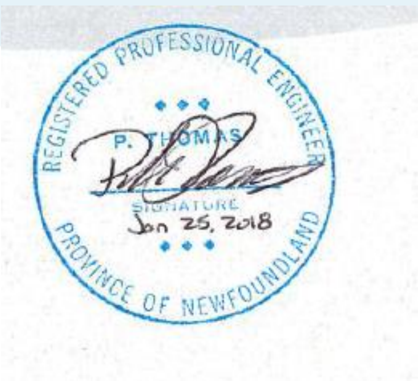
<tr><td rowspan="7">
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<tr><td>Transmission & Distribution</td></tr>
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<tr><td>System Planning</td></tr>
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Eastern Labrador Transmission System – Planning Report

August 21, 2017

Revised January 25, 2018

A Report to the Board of Commissioners of Public Utilities

newfoundland labrador hydro
a nalcor energy company

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List of Appendices

1.0 Purpose

The purpose of this report is to recommend a course of action for the future reliable supply of power to the interconnected transmission system in Eastern Labrador. This report provides an overview of the existing system (Section 3), future supply alternatives (Section 5), a cost benefit analysis of technically viable alternatives (Section 8), reliability assessment of preferred alternatives (Section 9), and a recommended course of action (i.e. the preferred alternative) (Section 10).

2.0 Introduction

The transmission system in Eastern Labrador is part of the larger Labrador Interconnected System (see Figure 1). The eastern portion of the transmission system connects the Upper Lake Melville area to the Churchill Falls Generating Station. The communities served by the transmission system in Eastern Labrador include Happy Valley-Goose Bay, North West River, Mud Lake, and Sheshatshiu.

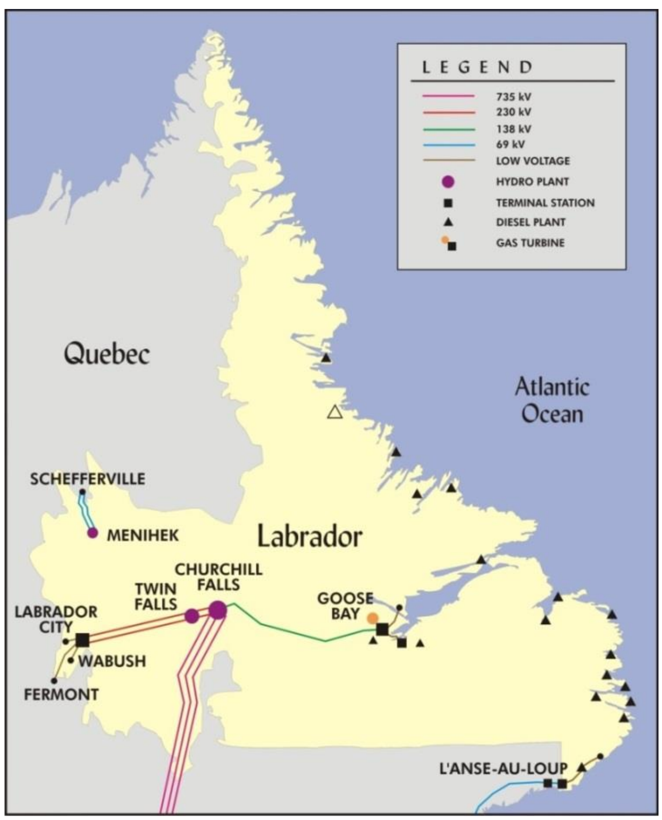


Figure 1 Labrador Interconnected System

The development of, and planning for, the transmission system in Eastern Labrador has been intrinsically linked to the development of the Lower Churchill River from its very inception. With the 138 kV transmission line connecting Churchill Falls and Happy Valley, development plans for the lower Churchill River have included the relocation of the 230/138 kV transformers from Churchill Falls to Gull Island, once Gull Island was completed, and further relocation of the 230/138 kV transformers from Gull Island to Muskrat Falls, once Muskrat Falls was completed. Each step reduced the length of 138 kV transmission line and brought the generation source closer to Happy Valley, thereby improving overall reliability to the load center.

3.0 Existing Transmission System Eastern Labrador

Eastern Labrador is presently interconnected to the Churchill Falls Terminal Station via a single 269 km long, 138 kV transmission line.

In the early 1970's the Gull Island Power Company initiated construction of 196 km of 138 kV transmission line from Churchill Falls eastward to provide construction power for Gull Island. Two 230/138 kV, 25/33.3/42 MVA autotransformers (T31 and T32) were installed at Churchill Falls. Unfortunately, markets for Gull Island could not be secured and the development of Gull Island was put on hold. The 138 kV construction power line was extended an additional 73 km to the Happy Valley Terminal Station (HVY), completing supply to the upper Lake Melville area in 1977. The local diesel plant in Happy Valley – Goose Bay remained as a stand by source. The 138 kV line (L1301) has an expected service life of 60 years from its completion date. The HVY station consisted of two 138/25 kV, 15/20/25//28 MVA transformers (T1 and T2) with on-load tap changers to provide voltage regulation to the local distribution system.

In 1982, Public Works Canada (now Department of National Defense) installed two 12 MW electric boilers and a 9 MVAR, 25 kV switched shunt capacitor bank to offset the fuel costs for heating of the Canadian Forces Base Goose Bay through a secondary energy sales contract with Hydro. The transmission system had a stated transfer capacity of 40 MW with all equipment in service.

By 1989 load in the region had grown to the level that system reinforcement was required. To meet the forecast load growth Hydro installed 11.4 MVAR of 25 kV switched shunt capacitors on the 25 kV bus at Happy Valley and added a 25 MW gas turbine with synchronous condenser capability in 1991. In normal mode of operation the gas turbine would operate as a synchronous condenser enabling the transmission system to deliver up to 63 MW to Happy Valley. For loss of either T31 or T32 at Churchill Falls, or T1 or T2 at HVY, operation of the gas turbine for MW provided the necessary back up transformer capacity in the near term.

In 2004 the HVY 138/25 kV transformer T1 (28 MVA) was replaced with a larger 138/25 kV, 30/40/50 MVA transformer due to load growth. The original T1 (15/20/25//28 MVA) unit remained on site as a spare.

With the sanction of the Lower Churchill Project (LCP) in 2012 and requirement for construction power at Muskrat Falls (MF), the 138 kV transmission line was tapped and a new 138/25 kV terminal station established near the Muskrat Falls Site, designated as MFATS3. Due to increase in load demand from both Muskrat Falls and the Eastern Labrador Interconnected System, 21.6 MVAR of capacitor banks were added to this new station to improve power transfer capability and voltage support in the area. With the tapping of L1301 the section from Churchill Falls to MFATS3 was identified as L1301 and the section from MFATS3 to Happy Valley identified as L1302.

At Churchill Falls the combined loads in Eastern Labrador were forecast to exceed the two 230/138 kV, 42 MVA transformer capacity. As a result, one unit (T31) was removed and replaced with a new 230/138 kV, 75/100/125 MVA autotransformer complete with an on-load tap changer. The displaced 42 MVA unit remained on site as a spare transformer. The new 125 MVA unit (T31) with on-load tap changer is used as the primary supply for the 138 kV transmission system, with the on-load tap changer providing limited voltage regulation capability[1]. The remaining 42 MVA unit (T32) remains in service as a “hot” standby with its 138 kV disconnect

[1] The Churchill Falls T31 on-load tap changer is limited to a maximum tap position of tap 3 (235,750 V – tap ratio 1.025) so that sudden loss of load at Happy Valley results in 138 kV system voltages that do not exceed 110%.

switch open.

In 2015 Hydro re-installed the spare 138/25 kV, 15/20/25//28 MVA transformer at the Happy Valley Terminal Station as T4 to provide sufficient installed transformer capacity for loss of the largest (50 MVA) unit with the gas turbine running at 25 MW. Today the HVY station consists of three 138/25 kV transformers (two x 28 MVA plus one x 50 MVA), all with on-load tap changers to provide the necessary voltage regulation for the Happy Valley-Goose Bay Distribution System. In addition, this terminal station has 11.4 MVAR of switched shunt capacitor banks and a 25 MW combustion turbine with synchronous condenser capability, which provides reactive power support. At the North Side Diesel Plant, there is approximately 5 MW of diesel generation available, but due to the deteriorating condition of the plant, it is assumed that the diesel generation is not available for the purpose of this study and will not be part of the long term solution for Happy Valley-Goose Bay.

Figure 2 provides a diagram of the existing Labrador Interconnected System.

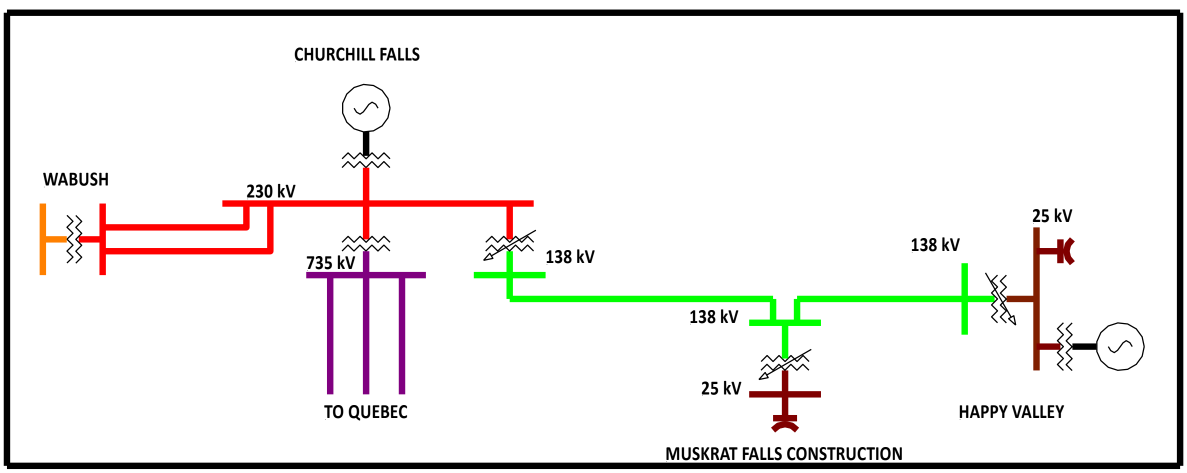


Figure 2 Existing Labrador Interconnected System

Analysis of the existing 138 kV transmission system in Eastern Labrador indicates that it is capable of delivering 77 MW to the Happy Valley 25 kV bus, with Muskrat Falls construction completed[2].

[2] The Churchill Falls sending end 230 kV bus voltage is held at 239.2 kV (1.04 p.u.) consistent with the minimum expected 230 kV bus voltage for proper voltage regulation on the 735 kV transmission network.

At this load level, Happy Valley T1, T2, and T4 transformers are loaded to 85% of rating. T1, T2, and T4 on-load tap changers are near maximum tap position (Tap 33 – 117300 V - tap ratio 0.85) providing the minimum acceptable voltage to the 25 kV bus[3] as shown in Figure 3. The transmission system in Eastern Labrador is approaching voltage collapse at this load level and requires additional voltage support for loading levels beyond 77 MW.

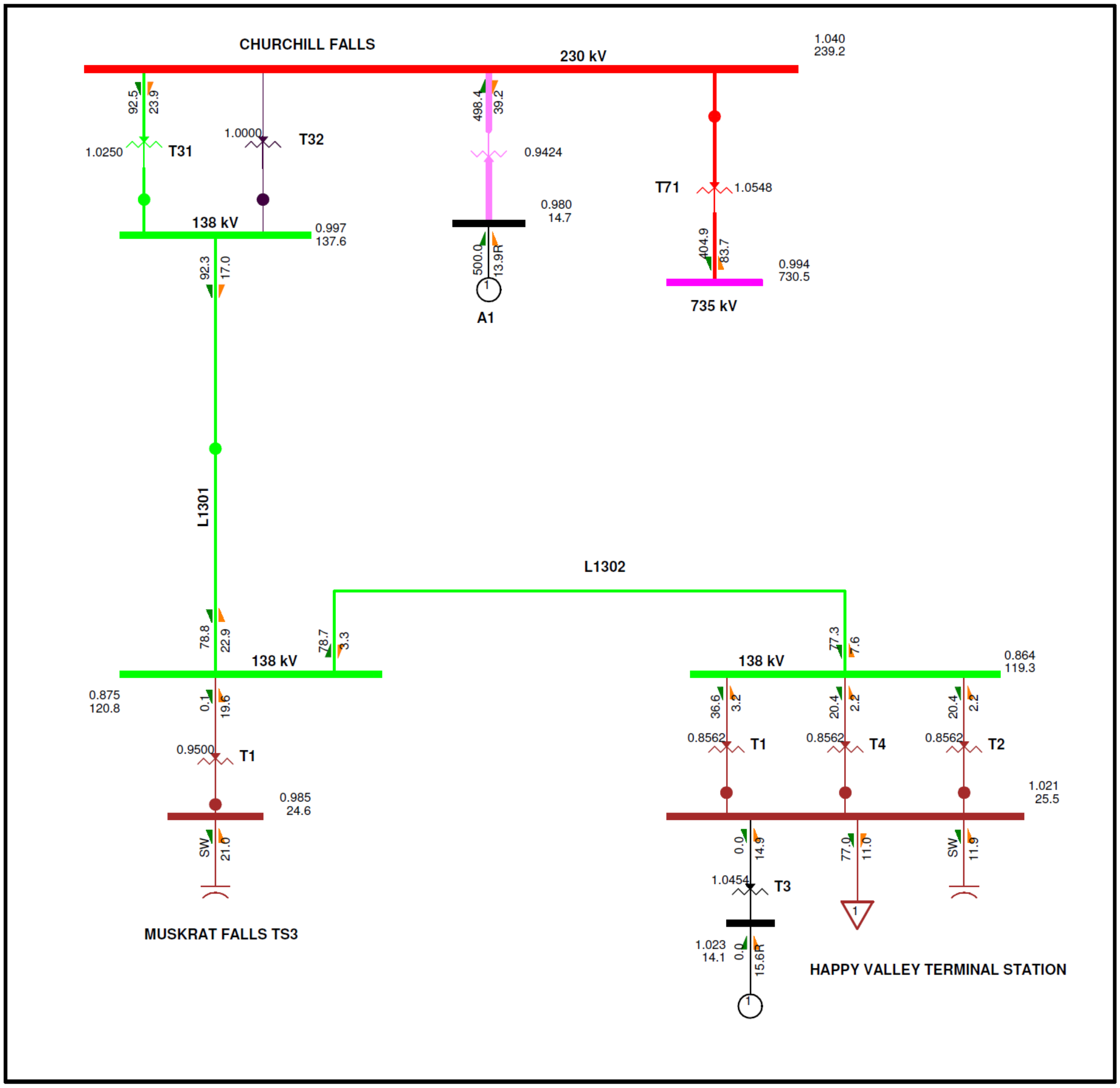


Figure 3 Maximum Transfer Capacity 77MW with Churchill Falls at 239.2 kV

[3] The Happy Valley 25 kV bus voltage is held between 25.5 kV (1.02 p.u.) and 26.1 kV (1.044 p.u.) under normal operation to provide acceptable voltages to customers on the remote ends of the 25 kV distribution feeders.

Given that construction at Muskrat Falls will continue until 2020, the combined Happy Valley and construction power load was forecast to exceed the transfer capacity of the existing system beginning in the 2017-2018 winter peak. To ensure adequate transfer capacity for the 2017-2018 peak, Hydro utilized a section of the recently constructed 315 kV circuit L3102 between Churchill Falls and Muskrat Falls. In essence, the existing 138 kV transmission line L1301 between Churchill Falls and MFATS3 was removed from service by removal of jumpers on strategically located transmission line structures and L3102 (a 315 kV circuit) inserted into the transmission path and operated at 138 kV. The 315 kV line section with two conductors per phase reduced transmission line losses permitting the 2017-2018 peak load to be delivered. Figure 4 provides a diagram of the Labrador Interconnected System for the 2017-2018 peak load period.

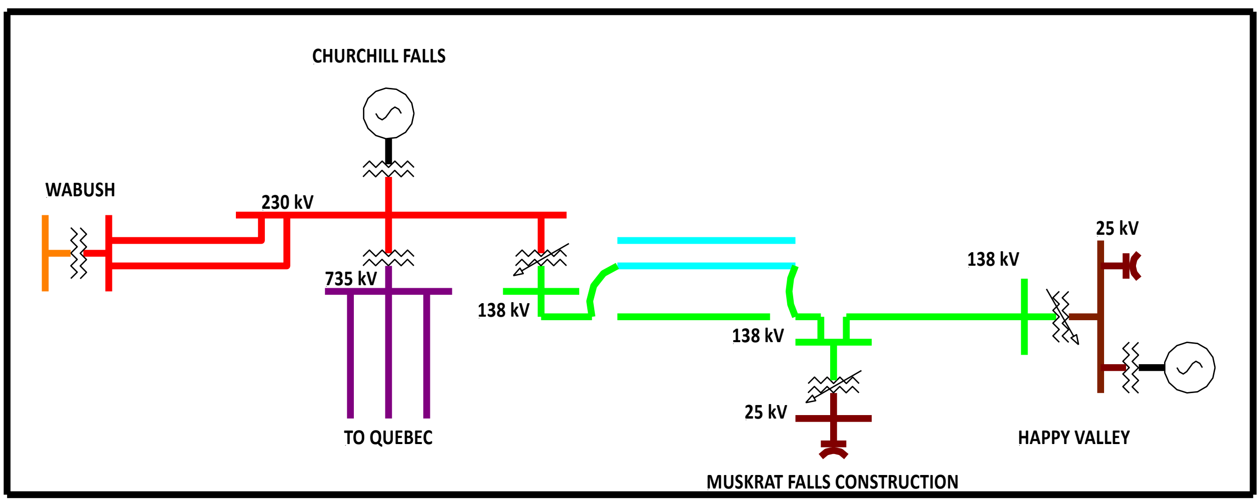


Figure 4 Labrador Interconnected System 2017-18 Peak[4]

Commissioning of the Labrador – Island HVdc Link in 2018 requires the operation of both new 315 kV lines (L3101 and L3102) at 315 kV. With both 315 kV lines operating at 315 kV, the Muskrat Falls construction power load will be supplied from the tertiary winding of the 315/138 kV autotransformers at Muskrat Falls in the fall of 2018. To this end, supply of Happy Valley must be returned to the existing 138 kV line L1301 between Churchill Falls and MFATS3 in the spring of 2018. Given the limited transfer capacity of the existing transmission system in Eastern Labrador

[4] Line crossings removed for clarity.

and the continued load growth in the area, a permanent solution to the transmission constraints is required. Further, supply to Happy Valley is dependent upon a 269 km long 138 kV transmission line, continued operation of capacitor banks at MFATS3 and HVYTS, and the Happy Valley gas turbine in synchronous condenser mode. Failure of any one component results in Hydro's inability to supply all load in the area.

4.0 Long Term Forecast Demand Happy Valley-Goose Bay

Table 1 outlines the expected Long Term Forecast Demand for Happy Valley-Goose Bay. This study assumes a 25-year study period for which the 2042 load is estimated to be 104.0 MW. This forecast does not include demand for the Muskrat Falls Construction Project, which is assumed to be completed in 2020 for this study, given that Muskrat Falls construction power will be delivered to the project site on the 315 kV system in 2018, and will no longer be dependent upon the 138 kV transmission. This table outlines the variability of the load forecast. Within the last year there has been a 29% increase in the 2042 forecast (from the Fall 2016 forecast to the revised forecast in the Summer 2017).

The load increases over the past year reflect data center load requests received prior to July 7, 2017, and the Department of National Defence conversion to all-electric boilers at Canadian Forces Base Goose Bay. The 7.6 MW increase in the 2017 forecast is a direct result of service applications for new data centers. The three data centers that make up the 7.6 MW of load are in service. The load increase of approximately 12.5 MW in 2020 is largely attributed to the Department of National Defense (DND) conversion to all-electric boilers.

[…]

Table 1 Happy Valley Long Term Forecast

Year	Fall 2016 Forecast (MW)	Spring 2017 Forecast (MW)	Summer 2017 Forecast (MW)
2017	72.3	79.8	79.9
2018	72.6	80.1	80.6
2019	73.0	80.5	81.4
2020	73.3	80.8	93.9
2021	73.6	81.1	94.5
2022	74.0	81.5	94.8
2023	74.4	81.9	95.3
2024	74.7	82.2	95.8
2025	75.1	82.6	96.3
2026	75.5	83.0	96.8
2027	75.9	83.3	97.3
2028	76.2	83.7	97.8
2029	76.5	84.0	98.2
2030	76.9	84.4	98.7
2031	77.2	84.7	99.2
2032	77.5	85.0	99.6
2033	77.8	85.3	100.0
2034	78.1	85.6	100.5
2035	78.4	85.9	100.9
2036	78.7	86.2	101.3
2037	79.0	86.5	101.7
2038	79.3	86.8	102.2
2039	79.6	87.1	102.6
2040	79.9	87.4	103.1
2041	80.2	87.7	103.5
2042	80.5	88.0	104.0
Source: Market Analysis Section, System Planning			

The Cost Benefit Analysis undertaken as part of this report is based on the Summer 2017 Load Forecast outlined in Table 1, which was released in July 2017. [...]

5.0 Transmission System in Eastern Labrador Post 2019

Commissioning of the 315 kV transmission between Churchill Falls and Muskrat Falls (MFATS2) is scheduled to be completed in 2018. Commissioning of the Labrador – Island HVdc Link will begin in 2018 with monopolar operation and continue with full power bipole testing once the Muskrat Falls Generating Station is completed. The Muskrat Falls Generating Station is scheduled to be completed in 2020. At that time there will be a 315 kV connection between Churchill Falls and Muskrat Falls (2 x 250 km, 315 kV lines), a 315/735 kV station at Churchill Falls, an 824 MW hydro-electric generating facility at Muskrat Falls and a ±350 kV, 900 MW HVdc link between Muskrat Falls and the Island of Newfoundland (See Figure 5).

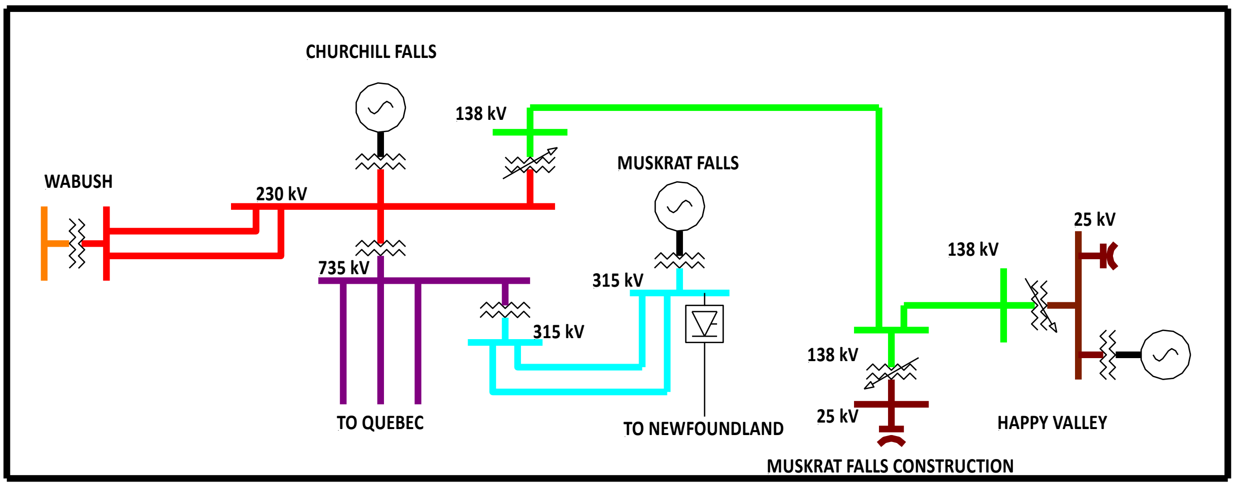


Figure 5 2020 Labrador Interconnected System with Muskrat Falls Complete

The Muskrat Falls Generating Station, its associated 315 kV terminal station and the HVdc converter station are located on the south side of the Churchill River. The 315 kV transmission lines cross the Churchill River to the north side and generally follow the existing 138 kV right-of-way to the Churchill Falls 315/735 kV Station. Provisions are being made during design and construction phases of the Muskrat Falls development to ensure that the 315 kV terminal station can be connected to Eastern Labrador to provide future power requirement. The 315 kV terminal station and HVdc converter station at Muskrat Falls require two 315/25 kV station service transformers. These transformers have been modified and have been designed and built with a 138 kV winding rated 125 MVA (i.e. 315/138 kV autotransformer with 25 kV Delta tertiary winding), such that the 138 kV system in Eastern Labrador can be connected to the Muskrat Falls Facility at a future date. As well, the 315 kV transmission line structures at the river crossing were designed and built as double-circuit river-crossing structures to accommodate one 315 kV and one future 138 kV transmission line per structure.

With respect to transformer contingencies, loss of the 125 MVA unit at Churchill Falls leaves the 42 MVA "hot" standby unit in service to supply the Happy Valley Load. Combined, the 42 MVA unit at Churchill Falls and the Happy Valley 25 MW combustion turbine provide a maximum power delivery of 62 MW[5] when the 42 MVA T32 load reaches 100% of rating, as shown in Figure 6. Under this contingency, the 2018 winter peak load would exceed system capacity.

[5] This value becomes 67 MW if the North Side Diesel Plant is considered.

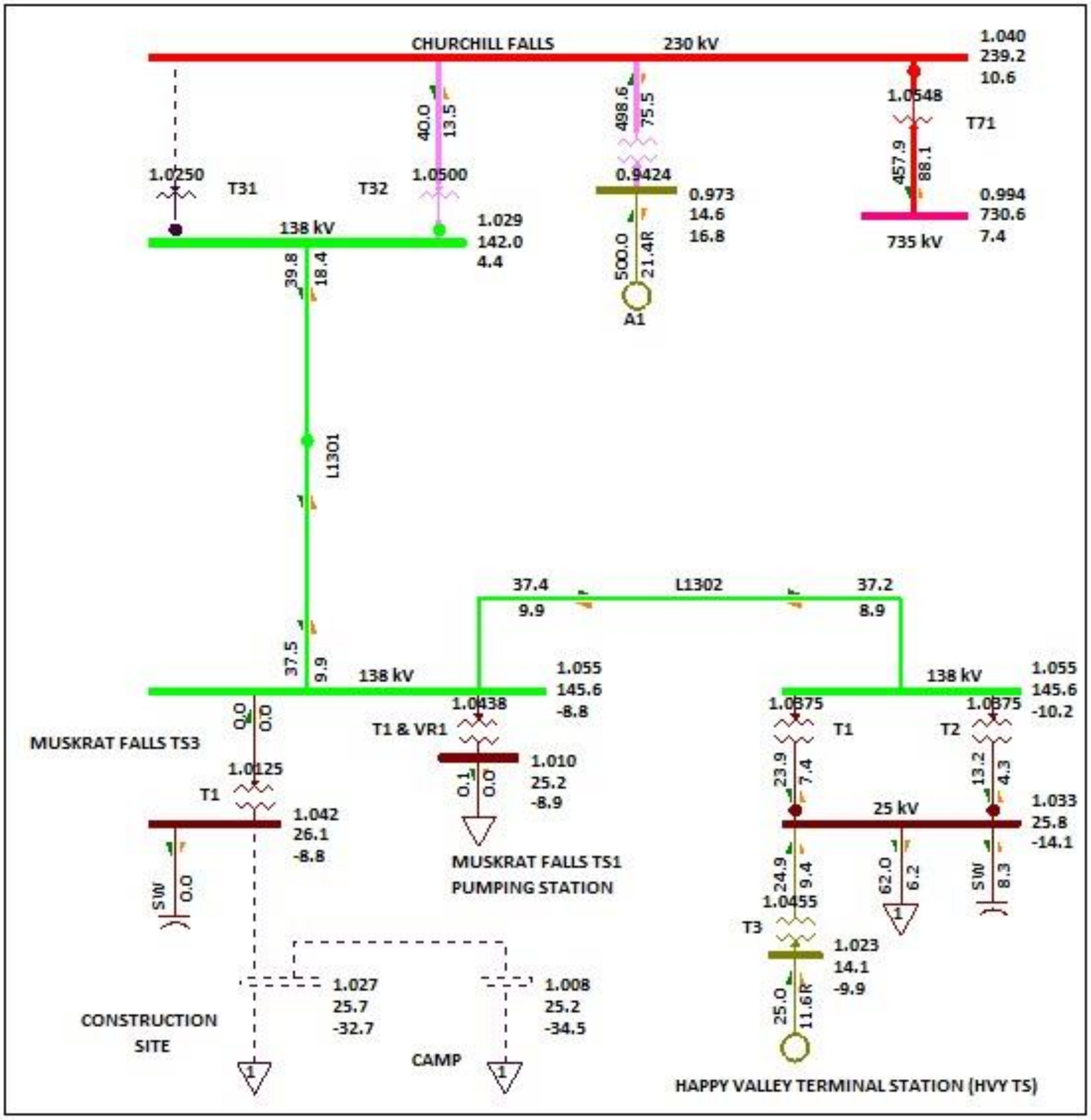


Figure 6 62 MW Transfer with Churchill Falls T31 Out of Service

For continued supply of the Upper Lake Melville area via the 138 kV transmission line from Churchill Falls, additional transformer capacity is required at Churchill Falls to meet existing loading requirements for the loss of the 125 MVA unit. Therefore, a second 230/138 kV, 75/100/125 MVA unit is warranted at Churchill Falls to provide transformer redundancy.

Analysis of the 138 kV transmission system in Eastern Labrador, with a second 125 MVA transformer at Churchill Falls, indicates that the system is capable of delivering 79 MW to the

Happy Valley 25 kV Bus. At this load level the Happy Valley 138/25 kV transformers are loaded to 88% of rating. The T1, T2, and T4 on-load tap changers are at maximum tap position (Tap 33 – 117300 V - tap ratio 0.85) providing the minimum acceptable voltage to the 25 kV bus[6] as shown in Figure 7. The system in Eastern Labrador is approaching voltage collapse at this load level and requires additional voltage support for loading levels beyond 79 MW. Note that the 79 MW transfer capacity is exceeded given the 2018 peak load forecast of 80.6 MW.

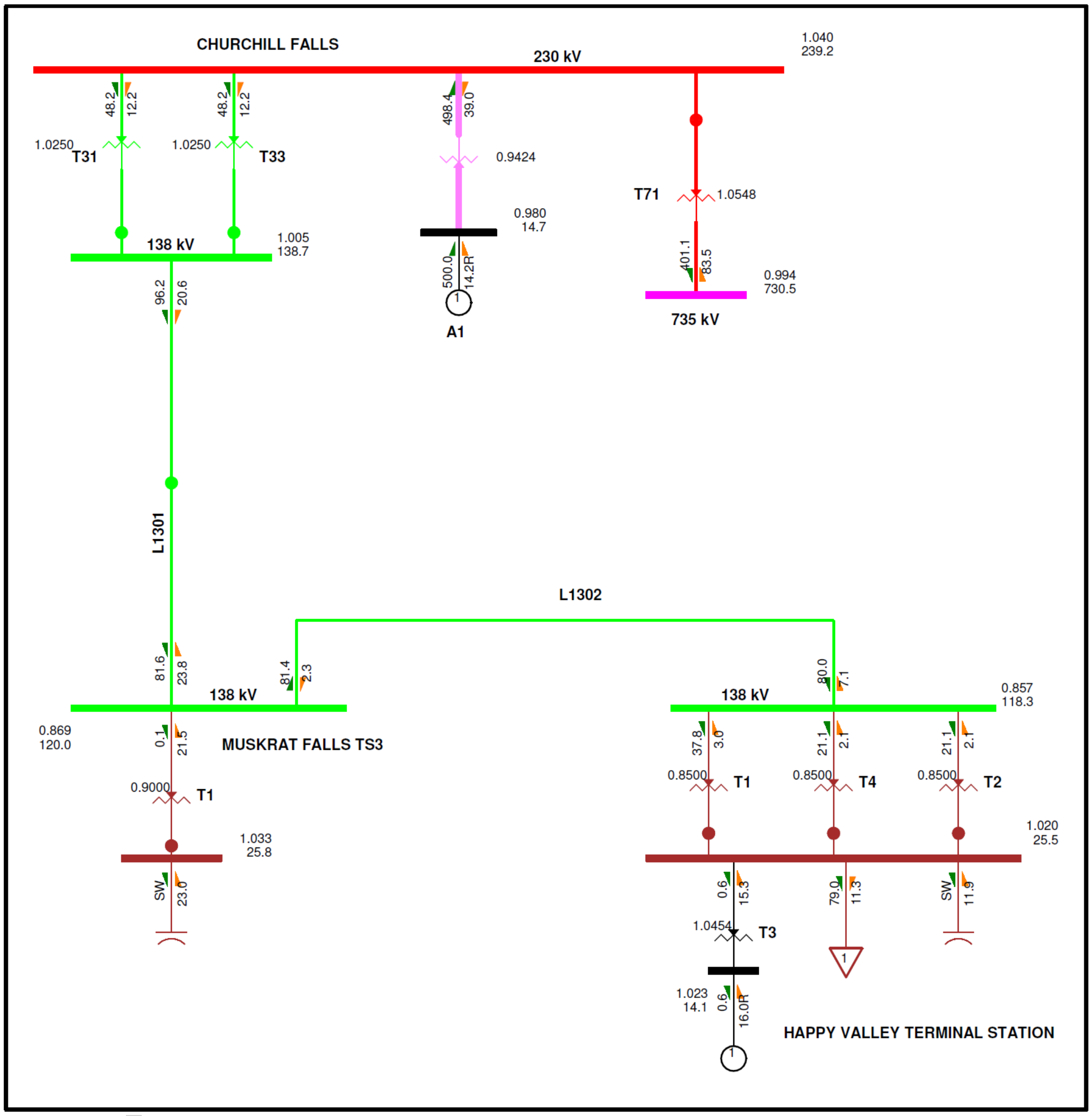


Figure 7 79 MW Transfer with Additional Churchill Falls 125 MVA Transformer

[6] The Happy Valley 25 kV bus voltage is held between 25.5 kV (1.02 p.u.) and 26.1 kV (1.044 p.u.) under normal operation to provide acceptable voltages to customers on the remote ends of the 25 kV distribution feeders.

Analysis demonstrates that an additional 67 MVAR of reactive compensation on the 138 kV bus and an additional 138/25 kV, 50 MVA transformer at the Happy Valley Terminal Station are required in order to serve the future load forecast of 104.0 MW (including DND conversion to all electric) at the end of the study period.

The addition of new transformer capacity at Happy Valley is required due to the fact that loss of the largest unit (T1-50MVA) combined with operation of the gas turbine at 25 MW would provide 81 MW of transfer capacity. The load forecast shows that the 81 MW transfer capacity with the largest transformer out of service will be exceeded in 2019, prior to the proposed DND conversion to all-electric. Addition of a 50 MVA unit (T5) will provide a firm capability of 104 MW in the event of loss of the largest transformer at the Happy Valley Terminal Station and would not require the start-up of the gas turbine for back-up for this contingency. Figure 8 outlines the load flow simulation results of this solution with one 50 MVA transformer out-of-service and 67 MVAR of 138 kV shunt capacitors on the 138 kV bus at Happy Valley Terminal Station.

It must be noted that in order to achieve the transfer capacity up to 104 MW on the 138 kV transmission system connected to Churchill Falls, continued operation of the MFATS3 switched shunt capacitor banks are required. Total reactive power shunt compensation for the 104 MW transfer totals 100 MVAR (MFATS3 at 21.6 MVAR, Happy Valley 11.4 MVAR at 25 kV and 67 MVAR at 138 kV).

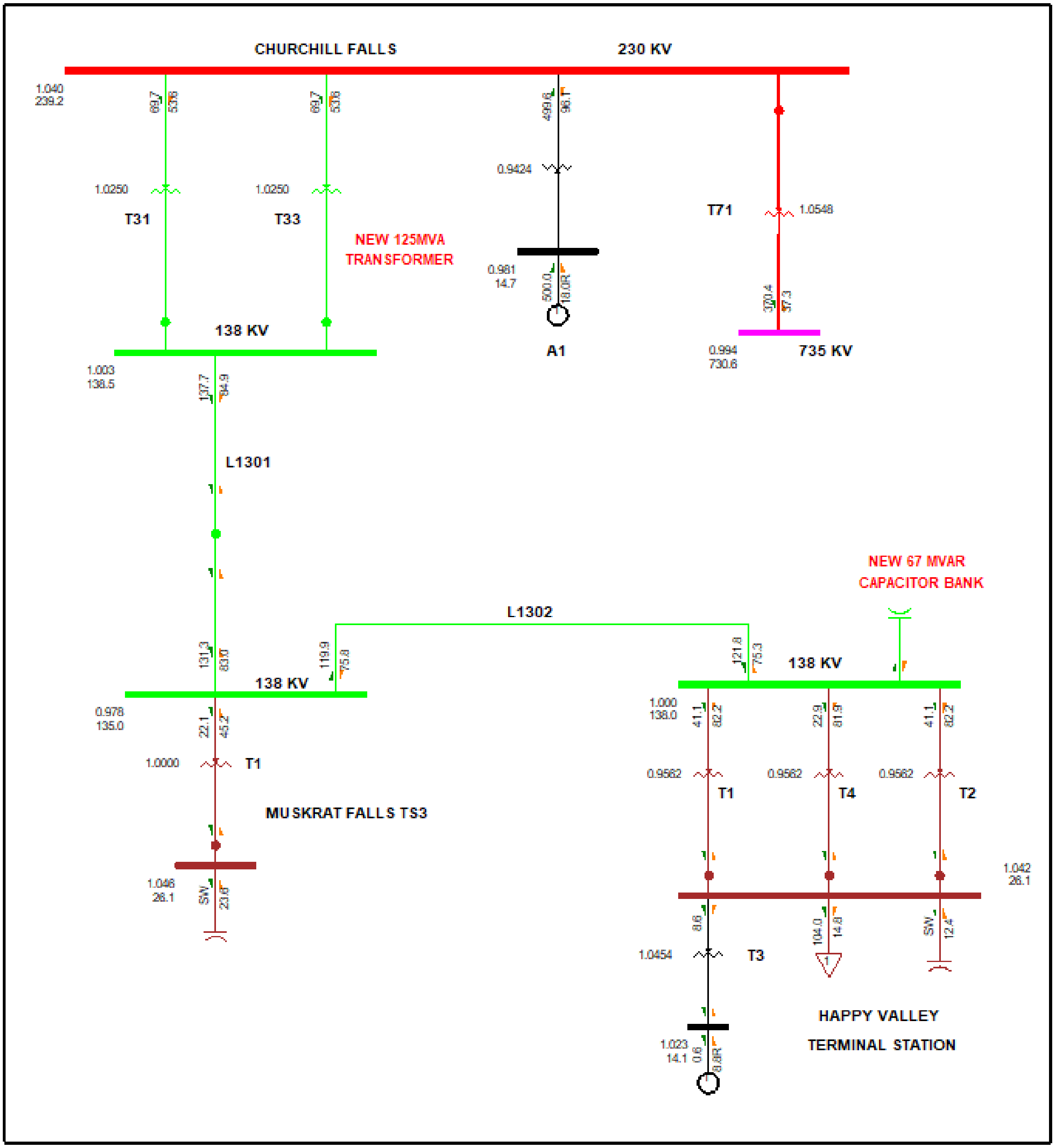


Figure 8 104MW Transfer with Additional 67 MVAR Capacitor Banks at Happy Valley with one 138/25 kV, 30/40/50 MVA Transformer Out of Service

Preliminary transmission system analysis was conducted in 2017 to assess potential long term transmission solutions for the region. Seven technically viable alternatives are presented below for consideration of the future supply requirements.

5.1 Option 1 – […] 125 MVA Transformer at Churchill Falls, 67 MVA Capacitor Bank and New 50 MVA Transformer at Happy Valley

This option calls for the continued use of the 138 kV transmission path connecting Churchill Falls and Happy Valley. The option requires the addition of a second 230/138 kV, 75/100/125 MVA autotransformer at Churchill Falls to meet the transformer back up criteria, the addition of 67 MVAR capacitor banks to provide the necessary voltage support, and the addition of a new 138/25kV, 50 MVA transformer at the Happy Valley Terminal Station to meet the transformer back up criteria. The continued operation of the Happy Valley gas turbine in synchronous condenser mode is also required as part of this option. As a result, for Option 1, as is the case today, failure of the gas turbine system to start the synchronous condenser function would mean rotating outages in the winter season. The proposed additions will increase the overall transfer capacity to 104 MW during normal operation, which satisfies the current load forecast until 2042. The estimated capital cost of adding a second transformer at Churchill Falls is $4.05M, new capacitor banks and new transformers at Happy Valley will cost $5.0M and $3.8M respectively.

Associated with this option is the continued Wood Pole Line Management (WPLM) Program on 138 kV transmission lines L1301[7] and L1302 and maintenance associated with the Churchill Falls and MFATS3 Terminal Stations. The WPLM program is estimated to cost approximately $407k per year, the Churchill Falls station maintenance cost approximately $27.7k per year and the MFATS3 maintenance cost approximately $15.3k per year for a total cost of approximately $450K per year until the end of the study period. The WPLM program includes an annual transmission line cross arm replacement component, which requires a one to two week outage of L1301/L1302 and subsequent operation of the 25 MW gas turbine at Happy Valley to supply local load. For the purpose of this study, a one week line outage has been assumed during the lightest loading period of the summer.

Figure 9 shows the lightest summer loading for 2016 with 7.6 MW added to account for expected

[7] L1301 and L1302 collectively are also known as TL 240 in the Newfoundland and Labrador Hydro line numbering system.

2017 Data Center load. A review of the figure shows that it is possible for Happy Valley load to be curtailed as the expected load profile could exceed 25 MW (the gas turbine rating).

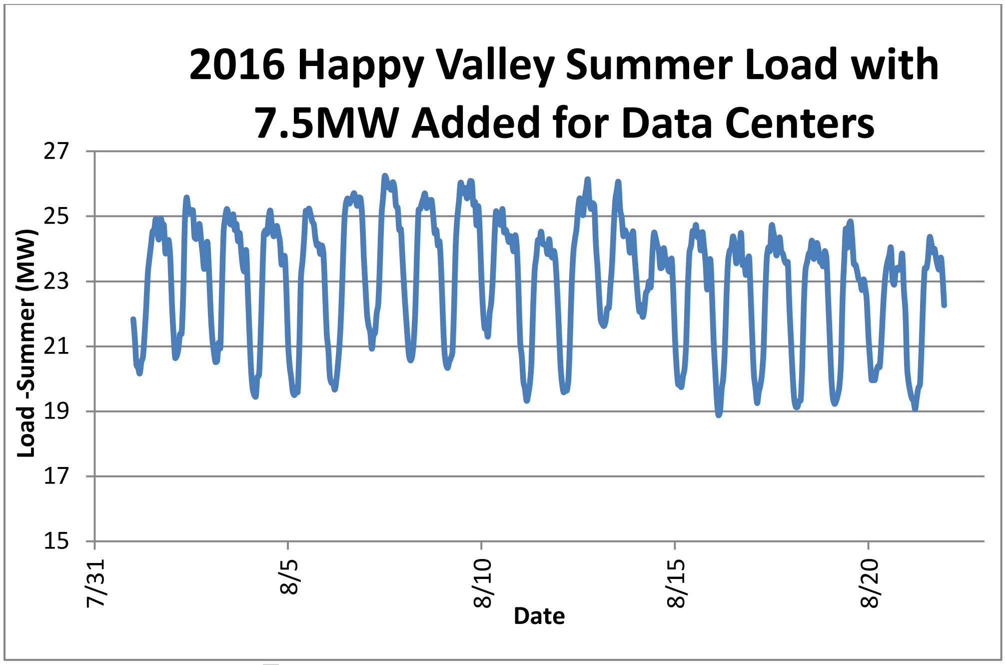


Figure 9 Expected 2017 Light Load Summer Profile

For a one week period, the expected energy to be supplied from the gas turbine has been estimated at 3,856,000 kWh. The amount of fuel estimated to be burned during that time frame, with a gas turbine efficiency of 3.3 kWh/L, is approximately 1.17 million liters per year at an estimated cost of approximately $1.33M in 2018 per week. Appendix A provides the single-line diagram associated with this option.

5.2 Option 2 – One Single 138 kV Circuit from Muskrat Falls to Happy Valley – (Add One New 6km 138 kV Transmission Section)

This option results in one single 138 kV circuit from Muskrat Falls 315/138 kV Terminal Station (MFATS2) to Happy Valley Terminal Station. The option requires the construction of the following:

i) One 6 km 138 kV transmission line from Muskrat Falls 315 kV/138 kV Terminal Station (MFATS2) to L1302, where the lines will be joined to provide one single 138 kV circuit to Happy Valley.

ii) Partial 138 kV ring bus located at MFATS2 to accommodate one transmission line and connection to two existing 315/138 kV autotransformers, with future expansion possible for a second 138 kV transmission line.

iii) Modification to the Happy Valley Terminal Station, including upgrade of reclosers and circuit breakers due to fault level increases, and addition of a new 138/25kV – 50 MVA transformer and a new control building.

The total capital cost of this option is estimated at $20.0M. Associated with this option is the continued Wood Pole Line Management (WPLM) Program on L1301 ($361.6k per year) and L1302 ($54.6k per year) and maintenance associated with Churchill Falls ($15.3k per year), Muskrat Falls 138 kV Tap Station (MFATS3) ($27.7k per year) and MFATS2 ($10.8k per year) terminal stations, which are estimated to cost approximately $470k per year until the end of the study period.

The WPLM Program for L1301 between Churchill Falls and MFATS3 does not require operation of the Happy Valley gas turbine as discussed in Option One. In Option Two the Happy Valley load is connected to the MFATS2 and therefore L1301 cross arm replacement can be accomplished without an outage to Happy Valley customers. However, cross arm replacement on L1302 between MFATS2 and Happy Valley will require operation of the gas turbine to avoid an outage to customers. The operation of the gas turbine for cross arm replacement for one week is prorated based upon line length. As a result operation of the gas turbine for cross arm replacement on L1302 is estimated to cost approximately $165.8k per year.

For this option, L1301 will be maintained in service for the short term, but open-circuited at MFATS3. This configuration with normal supply via MFATS2 and L1302 with L1301 open circuit at MFATS2 will provide a level of reliability and back-up supply to the Muskrat Falls connection. Recall a maximum of 77 MW can be delivered to Happy Valley from Churchill Falls (Figure 3). The long term viability of the line L1301 would be reviewed at a later date. See Figure 10.

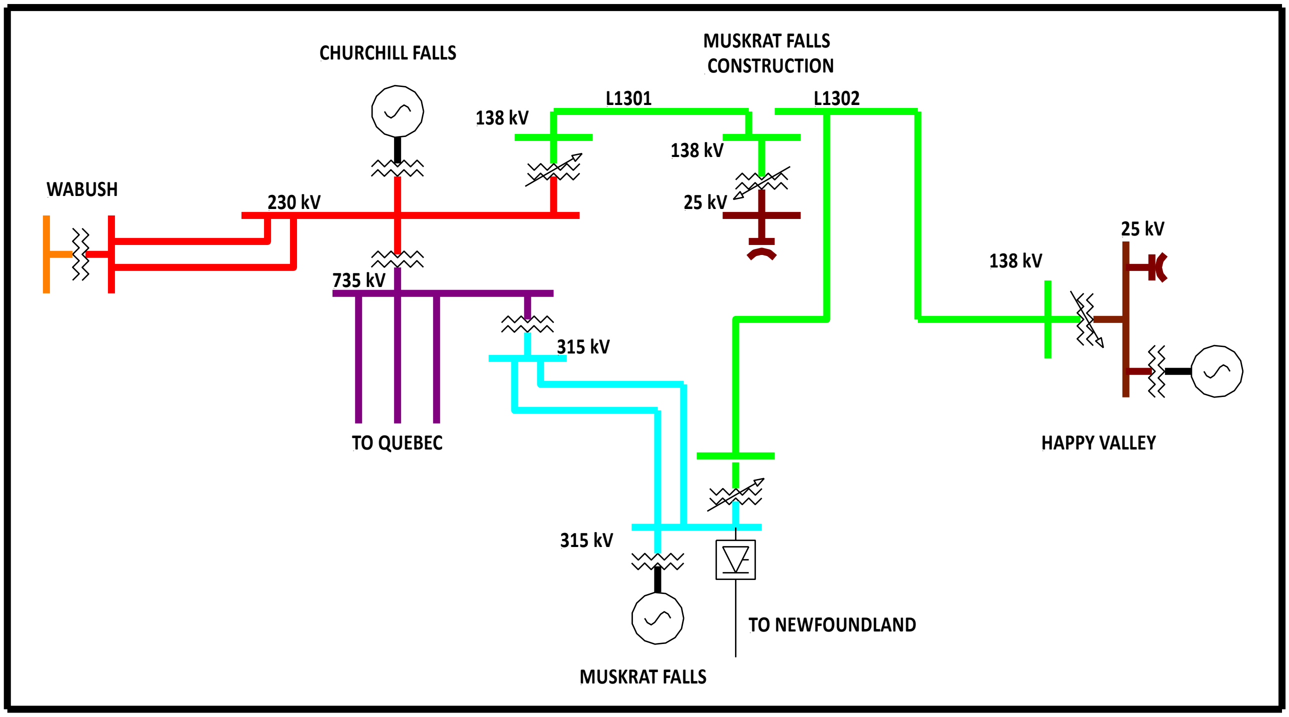


Figure 10 Option 2 Transmission Configuration

The overall firm transfer limit for various contingencies are as follows:

i) 129 MW for single contingency of loss of a 50MVA transformer at Happy Valley and the gas turbine available for 25 MW. (Overloading of remaining Happy Valley transformers).

ii) 142 MW for single contingency of loss of a 125MVA transformer at MFATS2 and the gas turbine available for 25 MW (Overloading of remaining MFATS2 transformers).

iii) 77 MW for the single contingency loss of the first 6 km section of L1302 at MFATS2 through operation of L1301 and connection to Churchill Falls (voltage constraint)

iv) 25 MW for the single contingency loss of L1302 between MFATS2 and Happy Valley Terminal Station (rating of gas turbine).

v) 104 MW for double contingency of loss of a 50MVA transformer at Happy Valley and the gas turbine out of service. (Overloading of remaining HV-GB transformers)

vi) 116 MW for double contingency of loss of a 125MVA transformer at MFATS2 and the gas turbine out of service (Overloading of remaining MFATS2 transformers).

Included in the cost benefit analysis are the estimated cost savings from reduction in transmission losses associated with this option as opposed to the status quo of providing power from Churchill Falls. It is estimated that reduction in losses are on the order of between 31 – 56 GWh per year, as outlined in Section 6 and Appendix G and would provide a Cumulative Net Present Worth savings of approximately $1 Million as outlined in Appendix H. These savings are a direct benefit to the NLH customer as recall power is purchased at the 230kV bus in Churchill Falls and a reduction in losses would reduce the power purchase expense.

Appendix B provides the single line diagram associated with this option.

5.3 Option 3 – One Single 138 kV Circuit from Churchill Falls to Muskrat Falls to Happy Valley (Two New 6km 138 kV Transmission Sections)

This option has been included at this time for completeness given that it was the original proposal submitted in the 2018 Capital Budget Application. Option 2, as outlined in Section 5.2 above, is considered an acceptable and less costly alternative to this Option.

Option 3 includes one single 138 kV circuit from Churchill Falls to MFATS2 and a second 138 kV circuit from MFATS2 to the Happy Valley Terminal Station. In essence, L1301 and L1302 are terminated at the 138 kV bus in MFATS2. This option requires the construction of the following:

i) Two 6 km 138 kV transmission lines from MFATS2 to the L1301/L1302 right of way near MFATS3 tap station. One new 138 kV line would be connected to L1301, which will be maintained in service for the short term, but open circuited at MFATS3. […] The second 138 kV line would be connected to L1302 to provide one single circuit to Happy Valley.
ii) Full 138 kV ring bus located at MFATS2 to accommodate both transmission lines.
iii) Happy Valley Terminal Station modifications, including upgrade of reclosers and circuit breakers due to fault level increases, and addition of a new 138/25kV – 50 MVA transformer and a new control building.

This configuration with normal supply via MFATS2 and L1302 with L1301 open circuit at MFATS2 will provide a level of reliability and back-up supply to the Muskrat Falls connection. Recall a maximum of 77 MW can be delivered to Happy Valley from Churchill Falls (Figure 3). The long term viability of the line L1301 would be reviewed at a later date. See Figure 11.

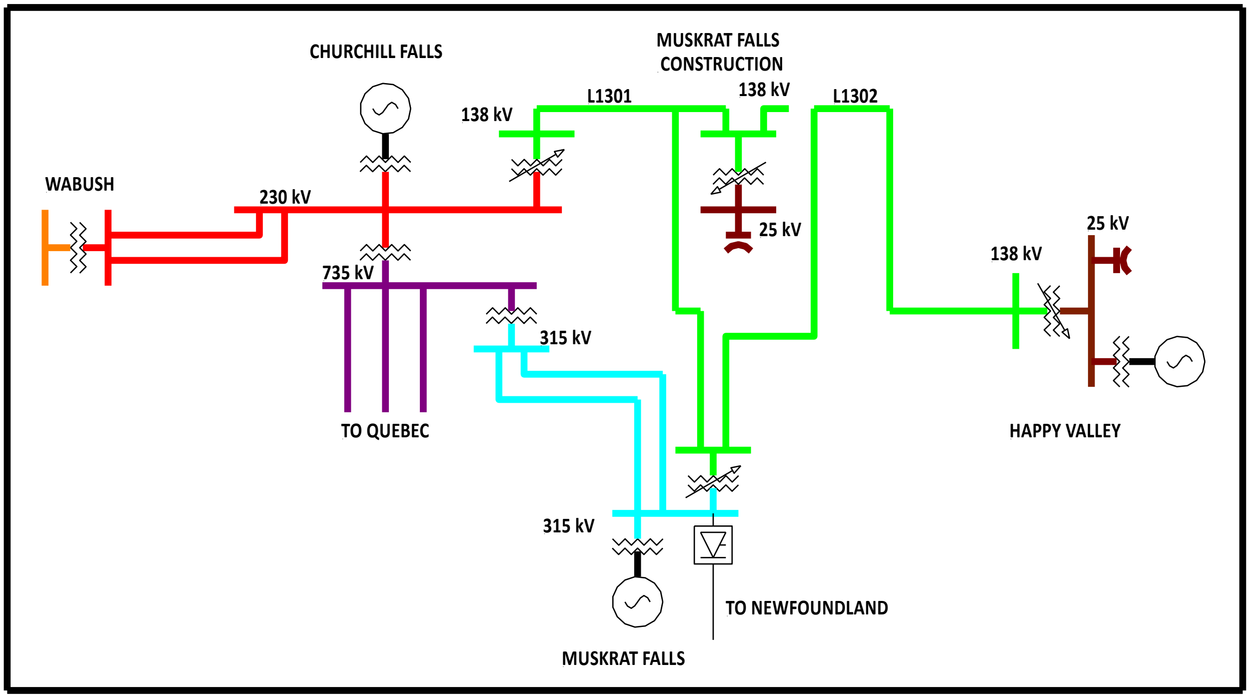


Figure 11 Option 3 Transmission Configuration

The total capital cost of this option is estimated at $28.3M. Associated with this option is the continued Wood Pole Line Management (WPLM) Program on L1301 ($367.5k per year) and L1302 ($54.5k per year) and maintenance associated with Churchill Falls Terminal Station ($15.3k per year), MFATS3 ($27.7k per year) and MFATS2 ($17.4k per year), which are estimated to cost approximately $482.4k per year until the end of the study period.

The WPLM Program for L1301 between Churchill Falls and MFATS3 does not require operation of the Happy Valley gas turbine as discussed in Option One. In Option Three the Happy Valley load is connected to the MFATS2 and therefore L1301 cross arm replacement can be accomplished without an outage to Happy Valley customers. However, cross arm replacement on L1302 between MFATS2 and Happy Valley will require operation of the gas turbine to avoid an outage to customers. The operation of the gas turbine for cross arm replacement for one week is prorated based upon line length. As a result operation of the gas turbine for cross arm replacement on L1302 is estimated to cost approximately $165.8k per year.

The overall firm transfer limit for various contingencies are as follows:

i) 129 MW for single contingency of loss of a 50MVA transformer at Happy Valley and the gas turbine available for 25 MW. (Overloading of remaining Happy Valley transformers).

ii) 142 MW for single contingency of loss of a 125MVA transformer at MFATS2 and the gas turbine available for 25 MW (Overloading of remaining MFATS2 transformers).

iii) 77 MW for the single contingency loss of the first 6 km section of L1302 at MFATS2 through operation of L1301 and connection to Churchill Falls (voltage constraint)

iv) 25 MW for the single contingency loss of L1302 between MFATS2 and Happy Valley Terminal Station (rating of gas turbine).

v) 104 MW for double contingency of loss of a 50MVA transformer at Happy Valley and the gas turbine out of service. (Overloading of remaining HV-GB transformers)

vi) 116 MW for double contingency of loss of a 125MVA transformer at MFATS2 and the gas turbine out of service (Overloading of remaining MFATS2 transformers).

Included in this analysis are the estimated cost savings from reduction in transmission losses associated with this option as opposed to the status quo of providing power from Churchill Falls. It is estimated that reduction in losses are on the order of between 31 – 56 GWh per year, as outlined in in Section 6 and Appendix G and could provide a Cumulative Net Present Worth savings of approximately $1 Million as outlined in Appendix H. These savings are a direct benefit to the Hydro Customer as recall power is purchased at the 230kV bus in Churchill Falls and a reduction in losses would reduce the power purchase expense.

Appendix C provides the single line diagram associated with this option.

5.4 Option 4 – Two Single 138 kV Circuits From Muskrat Falls to Happy Valley

This option includes two single 138 kV circuits from MFATS2 to the Happy Valley Terminal Station. This option requires the construction of the following:

i) One 6 km 138 kV transmission line from MFATS2 to L1302, where the lines will be joined to provide one single 138 kV circuit from MFATS2 to Happy Valley.
ii) One 36 km 138 kV transmission line from MFATS2 to the Happy Valley Terminal Station.
iii) Full 138 kV ring bus located at MFATS2 to accommodate both transmission lines.
iv) Happy Valley Terminal Station modifications, including upgrade of reclosers and circuit breakers due to fault level increases, expansion of terminal station to accommodate the second transmission line, tie breaker, a new 138/25kV – 50 MVA transformer, and new control building.

The total capital cost of this option is estimated at $57.2M. Associated with this option is the continued Wood Pole Line Management (WPLM) Program on L1301 ($361.6k per year), L1302 ($54.5k per year) and L1303 (the new line at $54.5k per year) and maintenance associated with CF ($15.3k per year), MFATS3 ($27.7k per year) and new MFATS2 ($17.4k per year) terminal stations, which are estimated to cost approximately $531K per year until the end of the study period.

The WPLM Program for L1301 between Churchill Falls and MFATS3 does not require operation of the Happy Valley gas turbine as discussed in Option One. Further, given that there are two 138 kV lines between MFATS2 and Happy Valley, cross arm replacement can be accomplished without operating the gas turbine as a generator. Therefore the gas turbine operating cost for WPLM is not required in Option Four.

This configuration has normal supply of Happy Valley via MFATS2 by two 138 kV lines (L1302 and a new 36 km long line) with L1301 open circuit at MFATS2 will provide a level of reliability and back-up supply to the Muskrat Falls connection. The long term viability of the line L1301 would be reviewed at a later date. See Figure 12.

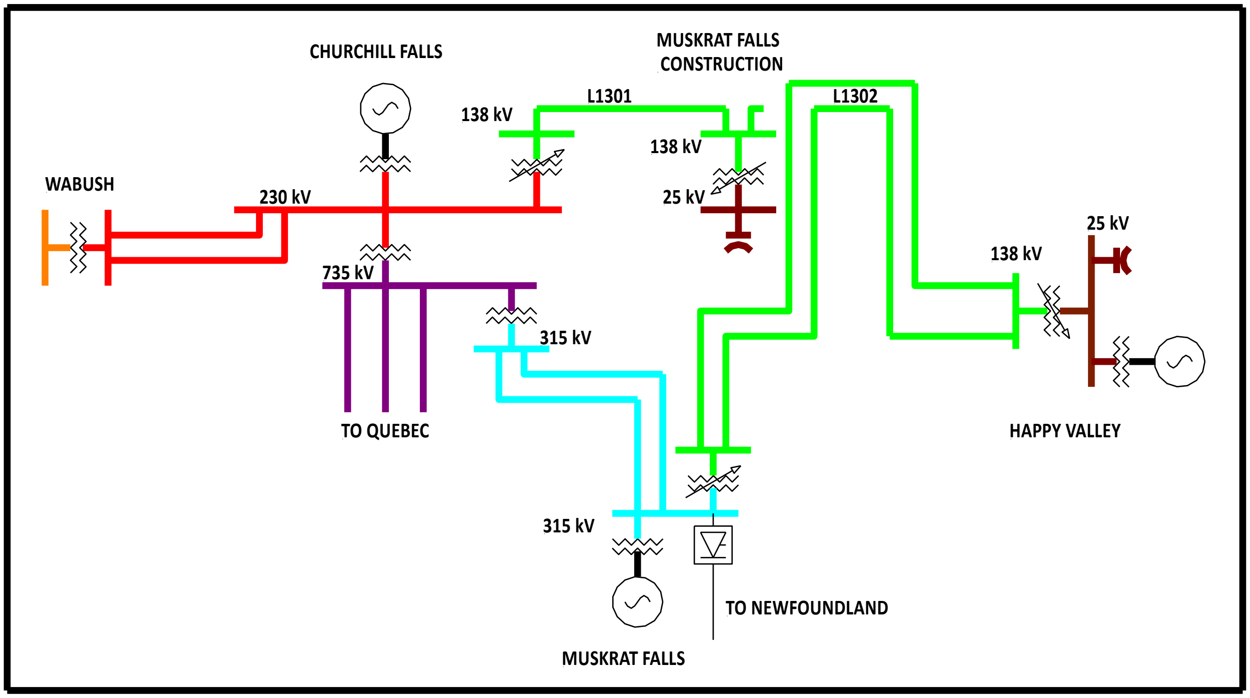


Figure 12 Option 4 Transmission Configuration

[...]

The overall firm transfer limit for various contingencies are as follows:

i) 129 MW for single contingency of loss of a 50MVA transformer at Happy Valley and the gas turbine available for 25 MW. (Overloading of remaining Happy Valley transformers).

ii) 142 MW for single contingency of loss of a 125MVA transformer at MFATS2 and the gas turbine available for 25 MW (Overloading of remaining MFATS2 transformers).

iii) 104 MW for double contingency of loss of a 50MVA transformer at Happy Valley and the gas turbine out of service. (Overloading of remaining HV-GB transformers)

iv) 116 MW for double contingency of loss of a 125MVA transformer at MFATS2 and the gas turbine out of service (Overloading of remaining MFATS2 transformers).

v) With one 138 kV line out of service the transfer is limited by the thermal rating of the remaining 138 kV line: 89.1 MVA at 30 °C ambient, 130.8 MVA at 15°C ambient and 161.7 MVA at 0°C ambient.

This option provides Happy Valley with a higher degree of reliability with a redundant 138kV feed from Muskrat Falls. Appendix D provides the single line diagrams associated with this option.

Included in this analysis are the estimated cost savings from reduction in transmission losses associated with this option as opposed to the status quo of providing power from Churchill Falls. It is estimated that reduction in losses are on the order of between 31-56 GWh per year, as outlined in Section 6 and Appendix G and could provide a Cumulative Net Present Worth savings of approximately $1 Million as outlined in Appendix H. These savings are a direct benefit to the Hydro Customer as recall power is purchased at the 230kV bus in Churchill Falls and a reduction in losses would reduce the power purchase expense.

5.5 Option 5 – Two Single 138 kV Circuits and Two Terminal Stations - Muskrat Falls to Happy Valley-Goose Bay

This option includes two single 138 kV circuits from MFATS2 to the Labrador East area and the addition of a second 138/25 kV terminal station. This option requires the construction of the following:

i) One 6 km 138 kV transmission line from MFATS2 to L1302, where the lines will be joined to provide one single 138 kV circuit to the existing Happy Valley Terminal Station.
ii) One 36 km 138 kV transmission line from MFATS2 to a new Happy Valley Terminal Station.
iii) One 2.5 km 138 kV transmission line from the existing Happy Valley Terminal Station to a new second Happy Valley Terminal Station.
iv) Full 138 kV ring bus located at MFATS2 to accommodate both transmission lines.
v) Happy Valley Terminal Station modifications, including upgrade of reclosers and circuit breakers due to fault level increases, expansion of terminal station to accommodate the second transmission line, tie breaker, and new control building.
vi) One new 138/25 kV terminal station located approximately 2.5 km from the existing terminal station. This station is to include the following major equipment:
    1. Two 138/25 kV, 50 MVA transformers;

2. Three 138 kV circuit breakers; and
3. Two 25 kV circuit breakers.

The total capital cost of this option is estimated at $76M. Associated with this option is the continued Wood Pole Line Management (WPLM) Program on L1301 ($361.6k per year),L1302 ($54.5k per year), L1303 (new line MFATS2 to new station at $58.3k per year) and L1304 (new line between Happy Valley and new station ($3.8k per year) and maintenance associated with Churchill Falls Terminal Station ($15.3k per year), MFATS3 ($27.7k per year), MFATS2 ($17.4k per year) and the new Happy Valley terminal station ($30.4k per year), which are estimated to cost approximately $569k per year until the end of the study period.

The WPLM Program for L1301 between Churchill Falls and MFATS3 does not require operation of the Happy Valley gas turbine as discussed in Option One. Further, given that there are two 138 kV lines between MFATS2 and Happy Valley, cross arm replacement can be accomplished without operating the gas turbine as a generator. Therefore the gas turbine operating cost for WPLM is not required in Option Five.

This configuration has normal supply of Happy Valley via MFATS2 by two 138 kV lines (L1302 and a new 36 km long line) with L1301 open circuit at MFATS2 will provide a level of reliability and back-up supply to the Muskrat Falls connection. The long term viability of the line L1301 would be reviewed at a later date. See Figure 13.

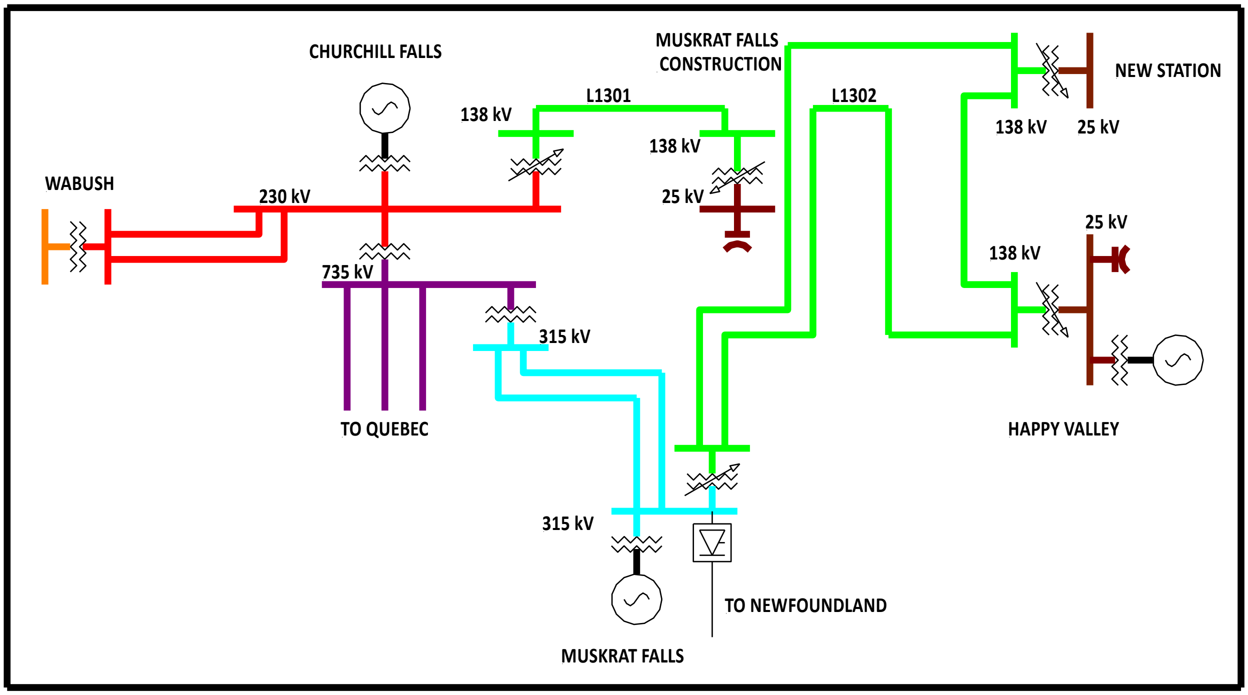


Figure 13 Option 5 Transmission Configuration

[…]The overall firm transfer limit of this option approximately 150 MW, based on loss of one 315/138 kV, 125MVA transformer at MFATS2 and operation of the Happy Valley gas turbine for 25MW. This option provides Happy Valley-Goose Bay with the highest degree of reliability with a redundant 138 kV feed from Muskrat Falls. Appendix E provides the single line diagrams associated with this option.

Included in this analysis are the estimated cost savings from reduction in transmission losses associated with this option as opposed to the status quo of providing power from Churchill Falls. It is estimated that reduction in losses are on the order of between 31-56 GWh per year, as outlined in Section 6 and Appendix G and could provide a Cumulative Net Present Worth savings of approximately $1 Million as outlined in Appendix H. These savings are a direct benefit to the Hydro Customer as recall power is purchased at the 230kV bus in Churchill Falls and a reduction in losses would reduce the power purchase expense.

5.6 Option 6 – Addition of 60 MW Gas Turbine at the Happy Valley Terminal Station

This option calls for the addition of a second gas turbine rated for at least 60 MW. This would provide full back up to the Happy Valley-Goose Bay System with the existing 25 MW gas turbine until the year 2032, should the existing transmission line L1301/L1302 fail for an extended period of time. A class five budget estimate for this alternative is approximately $90M. No consideration has been given to operational costs associated with fuel usage or maintenance.

This option has been immediately discounted due to the high capital cost in relation to the alternatives already presented. Appendix F provides the single line diagrams associated with this option.

5.7 Option 7 – Addition of Mobile Diesels

The option of adding mobile diesels was reviewed at the initial stage of the analysis. A typical mobile diesel utilized by Hydro has a rating of 2,000 kW, or 2 MW. Mobile diesels are viewed as a short-term or temporary solution. The load forecast indicates that the 2018 peak load will equal 80.6 MW, which is a 3.6 MW shortfall from the 77 MW transfer capacity of the system. This shortfall would require a minimum of 2 mobile diesels, fuel storage, fuel supply, staffing, maintenance, interconnection costs and permitting. Continuing to 2019, the peak load is forecast to equal 81.4 MW, a shortfall of 4.6 MW, which in turn would require a total of three mobile diesels and fuel storage, fuel supply, staffing, maintenance, interconnection costs and permitting. The number of units and associated costs continue to increase as load grows. The ultimate requirement for a transmission solution with improved reliability of supply to Happy Valley would result in the removal of the mobile diesels at a future date as they would no longer be required. Given that a transmission solution can be constructed in time to meet the winter 2018-2019 peak, the application of mobile diesels was ruled out as being inappropriate in this situation.

5.8 Options for Review

Of the seven options presented above, five alternatives were chosen for further review, they are as follows:

Option 1 – 125 MVA Transformer at Churchill Falls, 67 MVA Capacitor Bank and New 50 MVA Transformer at Happy Valley – Section 5.1

This option calls for the addition of a 125 MVA transformer at Churchill Falls, 67 MVARs capacitor bank at the Happy Valley Terminal Station and a 50 MVA transformer at Happy Valley for a capital investment of approximately $12.85M. This alternative offers the least capital cost up front, but does not provide the most reliable source of power due to the length of transmission line (refer to Section 9) and the requirement to maintain the gas turbine as a synchronous condenser for load transfer. Load requirements can be satisfied up to 104 MW until 2042, the end of the study period. This option includes an estimated one week per year line outage of L1301 and subsequent operation of the Happy Valley gas turbine at a considerable fuel cost.

Option 2 – One Single 138 kV Circuit from Muskrat Falls to HV-GB (One 6km Line Section Addition) – Section 5.2

This option calls for the interconnection of L1302 to MFATS2 (Muskrat Falls 138 kV Terminal Station) via a 6km transmission line, partial ring bus at MFATS2 and modifications to the Happy Valley Terminal Station including a new 50 MVA transformer for a capital investment of approximately $20.0M. This alternative offers the best compromise of minimizing up front capital cost, increasing reliability by minimizing 138 kV transmission distance from 269 to 36 km, removal of the requirement for load transfer support from the gas turbine synchronous condenser function, and providing a significant reduction in transmission losses by utilizing the 315 kV transmission system.

Option 3 – One Single 138 kV Circuit from Muskrat Falls to HV-GB (Two 6km Line Section Additions) – Section 5.3

This option calls for the interconnection of L1301 to MFATS2 (Muskrat Falls 138 kV Terminal Station) via a 6 km transmission line and L1302 to MFATS2 by a second 6 km transmission line, full ring bus at MFATS2 and modifications to the Happy Valley Terminal Station including a new 50 MVA transformer for a capital investment of approximately $28.3M.

Option 4 – Two Single 138 kV Circuits from Muskrat Falls to HV-GB – Section 5.4

This option calls for the interconnection of MFATS2 to the Happy Valley Terminal Station with two single 138kV transmission lines. This includes construction of a 6 km transmission line from MFATS2 to L1302, a 36km 138 kV line from MFATS2 to Happy Valley Terminal Station, full 138 kV ring bus at MFATS2 and modifications to Happy Valley Terminal Station, including a new 50 MVA transformer, for a capital investment of approximately $57.2M. A parallel circuit will provide a higher degree of reliability than the current situation.

Option 5 – Two Single 138 kV Circuits from Muskrat Falls to HV-GB and New Terminal Station – Section 5.5

This option calls for the interconnection of MFATS2 to the Happy Valley Terminal Station with two single 138kV transmission lines and an additional 138/25kV terminal station 2.5 km from the existing station. This includes construction of a 6km transmission line from MFATS2 to L1302, a 36 km 138 kV line from MFATS2 to the new Happy Valley Terminal Station, 2.5 km 138 kV transmission line between the two stations, full 138 kV ring bus at MFATS2 and modifications to the Happy Valley Terminal Station for a capital investment of approximately $76M. The parallel circuit and second station will provide a higher degree of reliability, flexibility and operability for the area.

6.0 Transmission System Loss Impacts

Re-terminating the 138 kV transmission system in Eastern Labrador at the Muskrat Falls 315/138 kV Station (MFATS2) reduces the length of the 138 kV transmission path to the Happy Valley Terminal Station by approximately 234 km and replaces it with two 250 km long 315 kV transmission lines. This change in transmission path has a significant impact on overall transmission system losses in Eastern Labrador. At present, Hydro purchases power from CF(L)Co at a recall rate of approximately 2 cents per kWh, based on delivery from the 230kV bus at Churchill Falls. If Happy Valley-Goose Bay is supplied from the Muskrat Falls interconnection, then Hydro will still purchase power at the 230kV bus at Churchill Falls for the recall rate of 2 cents per kWh, but power will be transmitted over the two 315kV lines to Muskrat Falls. The overall reduction in losses on the transmission system is a direct benefit to the Hydro Customer and is therefore used in the Cumulative Net Present Value analysis for the interconnection options.

6.1 Transmission System Losses Churchill Falls to Happy Valley

A transmission system loss evaluation has been completed to assess the value of transmission system losses for the period 2019 to 2042 for both continued supply of Happy Valley via Churchill Falls and supply from Muskrat Falls via the 315 kV transmission lines. Appendix G provides a summary of the annual energy losses associated with both scenarios as well as the difference between the two, which can be used to provide an annualized cost savings. Losses can be reduced on the order of between 31-56 GWh per year. During the peak load of 104 MW in 2042, the loss difference between status quo and Muskrat Falls interconnection is approximately 20 MW. This power can be utilized by either the Labrador Interconnected customers or be used as additional recall power for the island portion of the Province.

6.2 Transmission System Loss Valuation

Analysis was performed to assess transmission system loss impacts for alternatives involving the continued supply of Happy Valley via Churchill Falls and those involving an alternate supply via Muskrat Falls.

Appendix H provides a summary of the cumulative net present worth of the cost of the transmission system losses for continued supply of Happy Valley via Churchill Falls for the period 2019 to 2042. The analysis uses a marginal cost of $2/MWh for the entire study period, corresponding to the recall rate.

The analysis indicates that the reduction in transmission losses have a value of approximately $1M, which is used in the cost benefit analysis.

7.0 Operation and Maintenance Cost Assumptions

A comparison was performed to assess the maintenance costs associated with the alternatives to supply Happy Valley. Appendix I includes the analysis of the various terminal station and transmission line maintenance costs that were used in the cost benefit analysis. Within the various options operation and maintenance costs for L1301, MFATS3 and the Happy Valley gas turbine have been included where required and as appropriate. Decisions regarding the eventual removal of these assets and the subsequent impact on reliability will be addressed in a future abandonment of plant application, as deemed required; however, abandonment of these assets and the subsequent changes in total operation and maintenance costs do not change the selected preferred alternative as proposed in this report. In addition, there may be an alternate future for the gas turbine (see Section 12), but this will also be addressed as required, taking into account the benefits to the system as a whole.

8.0 Cost Benefit Analysis

A cost benefit analysis has been completed to assess the least cost alternative for supplying Happy Valley in the long term. As outlined in Section 5.7, five options were chosen for review. These are as follows:

i) **Option 1** – 125 MVA Transformer at Churchill Falls, 67 MVA Capacitor Bank and New 50 MVA Transformer at Happy Valley Terminal Station for a capital investment of approximately $12.85M.

The O&M costs for this alternative include:

- L1301/L1302 WPLM at a cost of $450K in 2017 dollars
- switchyard maintenance of
  - $15.3K for Churchill Falls and
  - $27.7K for MFATS3.
- Estimated remaining NBV on CF T33 and 67 MVAR cap banks and T3 at HVY at end of study period.
- Estimated gas turbine fuel expense as a result of operating the GT for one week per year for WPLM program.

ii) **Option 2** – One Single 138 kV Circuit from Muskrat Falls to Happy Valley. This option calls for the termination of L1302 at MFATS2 (Muskrat Falls 315/138 kV Terminal Station) via a 6 km transmission line, partial ring bus at the MFATS2 Terminal Station and modifications to the Happy Valley Terminal Station for a capital investment of approximately $20.0M.

The O&M costs for the alternative include:

- L1301/L1302 WPLM at a cost of $469.9K in 2017 dollars.
- $9.1K for WPLM of new 6km transmission line connection L1302 to MFATS2
- switchyard maintenance of
  - $15.3K for Churchill Falls
  - $27.7K for MFATS3 and
  - $10.8K for MFATS2 partial ring bus
- Remaining NBV on 2018 Interconnection assets at end of study period.
- Estimated gas turbine fuel expense as a result of operating the GT for L1302 WPLM program.
- Estimated loss savings assuming 2cents/kwh.

iii) **Option 3** – One Single 138 kV Circuit from Muskrat Falls to Happy Valley (two new 6 km lines). This option calls for the termination of L1301 at MFATS2 via a 6 km line and the termination of L1302 at MFATS2 via a second 6km transmission line, full ring bus at MFATS2 and modifications to the Happy Valley Terminal Station, including a 50 MVA transformer, for a capital investment of approximately $28.3M.

The O&M costs for the alternative include:

- L1301/L1302 WPLM Estimated cost of $482.5K in 2017 dollars.
- $18.2K for WPLM for two new 6km transmission lines connection L1301 and L1302 to MFATS2.
- switchyard maintenance of
  - $15.3K for Churchill Falls
  - $27.7K for MFATS3 and
  - $17.8K for MFATS2 full ring bus
- Remaining NBV of 2018 interconnection assets at end of study period.

- Estimated gas turbine fuel expense as a result of operating the GT for L1302 WPLM program.
- Estimated loss savings assuming 2cents/kwh.

iv) **Option 4** – Two Single 138 kV Circuits from Muskrat Falls to Happy Valley. This option includes construction of a 6 km transmission line from MFATS2 to L1302, a 36 km 138 kV line from MFATS2 to the Happy Valley Terminal Station, full 138 kV ring bus at MFATS2 and modifications to the Happy Valley Terminal Station, including a 50 MVA transformer, for a capital investment of approximately $57.2M.

The O&M costs for this alternative include:

- L1301/L1302 WPLM at a cost of $450K in 2017 dollars.
- L1303 (new 138 kV line MFATS2 to HVY) WPLM at a cost of $54.5K
- WPLM cost of $9.1K for 6km of new line associated with L1302 at MFATS2
- Switchyard maintenance of
  - $15.3K for Churchill Falls
  - $27.7K for MFATS3 and
  - $17.5K for MFATS2
- Remaining NBV of 2018 interconnection assets at end of the study period.
- Estimated loss savings assuming 2cents/kwh.

v) **Option 5** – Two Single 138 kV Circuits from Muskrat Falls to Happy Valley and new terminal station 2.5 km from existing Happy Valley Terminal Station. This includes construction of a 6 km transmission line from MFATS2 to L1302, a 38.6 km 138 kV line from MFATS2 to the new Happy Valley Terminal Station, 2.5 km 138 kV transmission line between the two stations, full 138 kV ring bus at MFATS2 and modifications to the Happy Valley Terminal Station for a capital investment of approximately $76M.

The O&M costs for this alternative include:

- L1301/L1302 WPLM at a cost of $450K in 2017 dollars
- L1303 (MFTATS2 to new station) WPLM at a cost of $58.3K

- 6km of new 138 kV for L1302 at MFATSS2 WPLM at a cost of$9.1K
- 2.5 km tie line between Happy Valley and new station WPLM at a cost of $3.8K
- Switchyard maintenance of
  - $15.3K for Churchill Falls
  - $27.7K for MFATS3
  - $17.5K for MFATS2 and
  - $30.4K for new Happy Valley station.
- Remaining NBV of 2018 interconnection assets at end of study period.
- Estimated loss savings assuming 2cents/kwh.

Tables J.1, J.2, J.3, J.4 and J.5 in Appendix J outline the cash flow stream of each option for the study period. The results of the preliminary cost benefit analysis are summarized in Table 2.

Table 2 CPV Summary of Options Considered

Long Term Supply of Happy Valley		
Alternative Comparison *Cumulative Net Present Value* *To The Year* **2017**		
Alternatives	**Cumulative Net Present Value (CPV)**	**CPV Difference between Alternatives and the Least Cost Alternative**
Option 1- [...] Continued Supply From CF (New 125 MVA Transformer at CF + 22 MVAR Capacitor Bank at HV-GB)	$ 33,478,915	+ $ 9,901,254
Option 2 – One Single 138 kV Circuit from Muskrat Falls to HV-GB (back-up from L1301) – One 6 km section added	$ 23,577,661	0
Option 3 – One Single 138 kV Circuit from Muskrat Falls to HV-GB (back-up from L1301) – Two 6 km sections added	$ 30,281,004	+ $ 6,703,343
Option 4- Two Single Circuit Supply from Muskrat Falls to HV-GB	$ 51,090,211	+ $ 27,512,550
Option 5- Two Single Circuit Supply from Muskrat Falls to HV-GB and New Terminal Station in HV-GB	$ 66,485,624	+ $ 42,907,963

9.0 Reliability Analysis of Options Considered

Reliability analysis was completed on a simplified component model of all five options presented in Section 5.7. Each model only consists of transmission lines and transformers up to the 138 kV bus at the Happy Valley Terminal Station. For this analysis, CEA's "2015 Annual Report – Forced Outage Performance of Transmission Equipment" data was used for transmission line and transformer components. CEA's 2015 Annual Report is based on data for the period January 1, 2011 to December 31, 2015.

Table 3 outlines the CEA summary of transmission line statistics for line-related sustained forced outages for 138 kV and 315 kV transmission lines. Table 4 outlines the CEA summary of transformer bank statistics for forced outages involving integral subcomponents and terminal equipment.

Table 3 Transmission Line Sustained Forced Outage Statistics

Voltage Classification (kV)	Sustained Outage Frequency (Per 100 km·a)	Mean Duration (h)
138	0.8860	16.85
315	0.3123	334.04

Table 4 Transformer Forced Outage Statistics Involving Integral Subcomponents and Terminal Equipment

Voltage Classification (kV)	Sustained Outage Frequency (Per a)	Mean Duration (h)
230	0.1431	254.35
315	0.2020	477.00
735	0.1198	625.13

Reliability is the probability that a component has not failed as of a given time point whereas availability is the probability that a component is found available at a given time point although it may have experienced failures and repairs before this point. For the reliability analysis, the concept of Unavailability will be used to compare the three alternatives. For each component in a system, the Unavailability (U) can be calculated as per equation below.

Unavailability (U) = f x r , where:

f = outage frequency (occurrences per year), and

r = mean time to repair (years)

For reliability evaluation, components are said to be in series if only one needs to fail for the network failure. Components are said to be in parallel if they must all fail for the network failure.

For a series network comprising of two repairable components, 1 and 2, the unavailability of the system is mathematically described as follows:

$U_{se} = U_1 + U_2 - U_1U_2$

For a parallel network comprising of two repairable components, 1 and 2, the unavailability of the system is mathematically described as follows:

$U_{pa} = U_1U_2$

Unavailability has been calculated for each considered option as detailed below.

9.1 Unavailability of Option 1 – 125 MVA Transformer at Churchill Falls, 67 MVA Capacitor Bank and New 50 MVA Transformer at Happy Valley

Figure K.1 in Appendix K outlines a simplified single line diagram of the Churchill Falls to Happy Valley supply, which can be simplified to a simple four element network with components C1 and C1 in parallel, in series with components C2 and C3. Table K.1 in Appendix K outlines each of the component's unavailability followed by the overall unavailability calculation for Option 1. The overall unavailability of Option 1 is estimated to be on the order of 0.00460 or 0.46%.

9.2 Unavailability of Option 2 – Single Circuit from Muskrat Falls to Happy Valley with Churchill Falls as Backup

Figure K.2 in Appendix K outlines a simplified single line diagram of the Churchill Falls to MFATS3 backup and single line from MFATS2 to Happy Valley, which can be simplified to a simple seven element network with components C1 to C5. Table K.2 in Appendix K below outlines each component's unavailability followed by the overall unavailability calculation for Option 2. The overall unavailability of Option 2 is estimated to be on the order of 0.00051 or 0.051%.

9.3 Unavailability of Option 3 – Single Circuit from Muskrat Falls to Happy Valley with Churchill Falls as Backup

Figure K.3 in Appendix K outlines a simplified single line diagram of the Churchill Falls to MFATS3 backup and single line from MFATS2 to Happy Valley, which can be simplified to a simple six element network with components C1 to C4. Table K.3 in Appendix K below outlines each component's unavailability followed by the overall unavailability calculation for Option 3. The overall unavailability of Option 3 is estimated to be on the order of 0.00061 or 0.061%.

9.4 Unavailability of Option 4 – Two Circuits from Muskrat Falls to Happy Valley

Figure K.4 in Appendix K outlines a simplified single line diagram of the Muskrat Falls to Happy Valley supply, which can be simplified to a four element network with components C1 and C1 in parallel in series with parallel components C2 and C2. Table K.3 in Appendix K outlines each component's unavailability followed by the overall unavailability calculation for Option 4. The overall unavailability of Option 4 is estimated to be on the order of 0.000121 or 0.0121%.

9.5 Unavailability of Option 5 – Two Circuits from Muskrat Falls to Happy Valley with Two Terminal Stations in Happy Valley-Goose Bay Region

Figure K.5 in Appendix K outlines a simplified single line diagram of the Muskrat Falls to Happy Valley supply, which can be simplified to a five element network with components C1 and C1 in parallel in series with parallel components C2 and C3. Table K.4 in Appendix K outlines each component's unavailability followed by the overall unavailability calculation for Option 5. The overall unavailability of Option 5 is estimated to be on the order of 0.000121 or 0.0121%.

9.6 Unavailability and EUE Comparison of Alternatives

Table 5 below outlines the comparative Unavailability of the three alternative options to interconnection of Happy Valley as well as quantifies the amount of Expected Unserved Energy (EUE) of each alternative using the reliability analysis of the previous sections. The EUE is based on annual Unavailability of energy to Happy Valley using an approximation of 379.8 GWh for the 2020 Energy requirement of Happy Valley.

Table 5 Unavailability/EUE Comparison of Options

Interconnection Option	Calculated Unavailability (U)	Calculated Expected Unserved Energy (MWh) [1]
1	0.00460	1747
2	0.00051	194
3	0.00061	232
3	0.000121	46
4	0.000121	46
1. Based upon HV-GB 2020 annual energy requirement of 379.8 GWh.		

Based on this analysis, Options 4 and 5 offer the most reliable system when considering sustained forced outages of major components of the alternatives. While no reliability criteria exists for radial transmission system supply, particularly in Labrador, Hydro's business continuity criteria of no more than 300 GWh of unserved energy for an outage on the Island system can be used as a measure. That being said, Options 2 through 5 provide the reliability levels that meet the continuity criteria of 300 GWh. This demonstrates the overall improvement in reliability to the customers of the Upper Lake Melville area. Options 2 to 5 therefore align with Hydro's business continuity rationale on the Island.

10.0 Preferred Alternative Selection

Table 6 below outlines a relative comparison of the five options considered with respect to cumulative present value (least cost alternative), expected unserved energy (reliability) and transfer capability (technically acceptable).

Table 6 Overall Comparison of Options

Option	CPV Difference ($M)	Calculated Unavailability (U)		Estimated HV-GB Transfer Capability (MW)
		(%)	EUE (MWh)	
1	+ 9.9	0.460	1747	104[1] / 106[2]
2	0	0.051	194	104[1] / 149[2]
3	+ 6.7	0.061	232	104[1] / 149[2]
4	+ 27.5	0.0121	46	116[3] / 152[4]
5	+ 42.9	0.0121	46	116[3] / 152[4]

1. Limitation based on overload of transformer at HV-GB on loss of 50MVA transformer at HV-GB, GT in SC Mode.
2. Limitation based on overload of transformer at HV-GB, no outages, GT in SC Mode.
3. Limitation based on overload of transformer at MFATS2, T31 outage, GT off.
4. Limitation based on overload of transformer at HV-GB, no outages, GT off.

Based upon the summarized results of Table 6, Option 2 meets all criteria and has been chosen as the preferred interconnection alternative as it offers a significant reliability improvement from the existing system, while improving the transfer capability immediately. An increase of the transfer capability from 77 to 104MW will provide the Happy Valley-Goose Bay region with additional room for future economic developments. This option also improves the voltage profile at Happy Valley thus giving the system better operability and full 104 MW transfer capacity with the Happy Valley synchronous condenser and capacitor banks out of service. The Cumulative Net Present Value of Option 2 is superior than the closest alternative of Option 3, while providing similar technical capabilities.

11.0 Future Long Term Supply Configuration

As outlined in this report, the load in the Happy Valley area will exceed the transfer capacity of the transmission system in Eastern Labrador in 2018. The analysis indicates that the preferred alternative improves the total capacity of the Happy Valley Terminal Station to approximately 149 MW with no transmission line or transformer outage conditions, and 104 MW with loss of the largest transformer at the Happy Valley Terminal Station and the gas turbine out of service. The overall reliability and capacity of the region will be improved from the existing configuration by reduction of transmission line length of 269 km to roughly 36 km. The reliability analysis indicates that by connecting the 138 kV transmission system in Eastern Labrador to MFATS2 the unavailability is reduced to 0.051% compared to 0.46% if supply is maintained via 269 km and Churchill Falls. Further, the expected unsupplied energy is reduced from 1,747 MWh to 194 MWh by connecting to MFATS2. It must be noted that load growth beyond the capacity of 104 MW could occur fairly quickly depending on industrial load growth, such as increased numbers of data centers.

Hydro's long term vision for power supply to the Happy Valley-Goose Bay area is a two phased approach. Phase I is the proposed configuration of interconnection to Muskrat Falls using existing 138 kV transmission line L1302 by construction of one 6 km segment as outlined in Figure 14. Phase II, as outlined in Figure 15, would include a second 138 kV transmission feed from Muskrat Falls and a second 138/25 kV terminal station in Happy Valley, see Figure 16 for location of second terminal station. The two Happy Valley terminal stations would be tied together via a 2.5 km 138 kV transmission line. The new terminal station will have two 50 MVA transformers. This configuration will provide a firm transmission capacity of 125 MVA for contingency event of loss of one 315/138 kV transformers at Muskrat Falls. This configuration will provide a very high level of reliability and operability due to a parallel transmission path from Muskrat Falls.

As can be seen from Figure 14, the proposed additions of Phase I, single transmission path from Muskrat Falls, will be required for completion of Phase II, thus the current proposal will be fully utilized in the ultimate system configuration. Given that Phase II utilizes all of the equipment proposed in Phase I, Phase II is viewed as a logical complement to the Phase I addition.

The decision on proceeding with Phase II is based upon future load growth and requirement for further enhancements to reliability of supply. Hydro will continue to monitor load growth in Labrador and will submit a capital budget application for the construction of Phase II when load forecasts indicate loads will exceed the capacity of the Phase I interconnection.

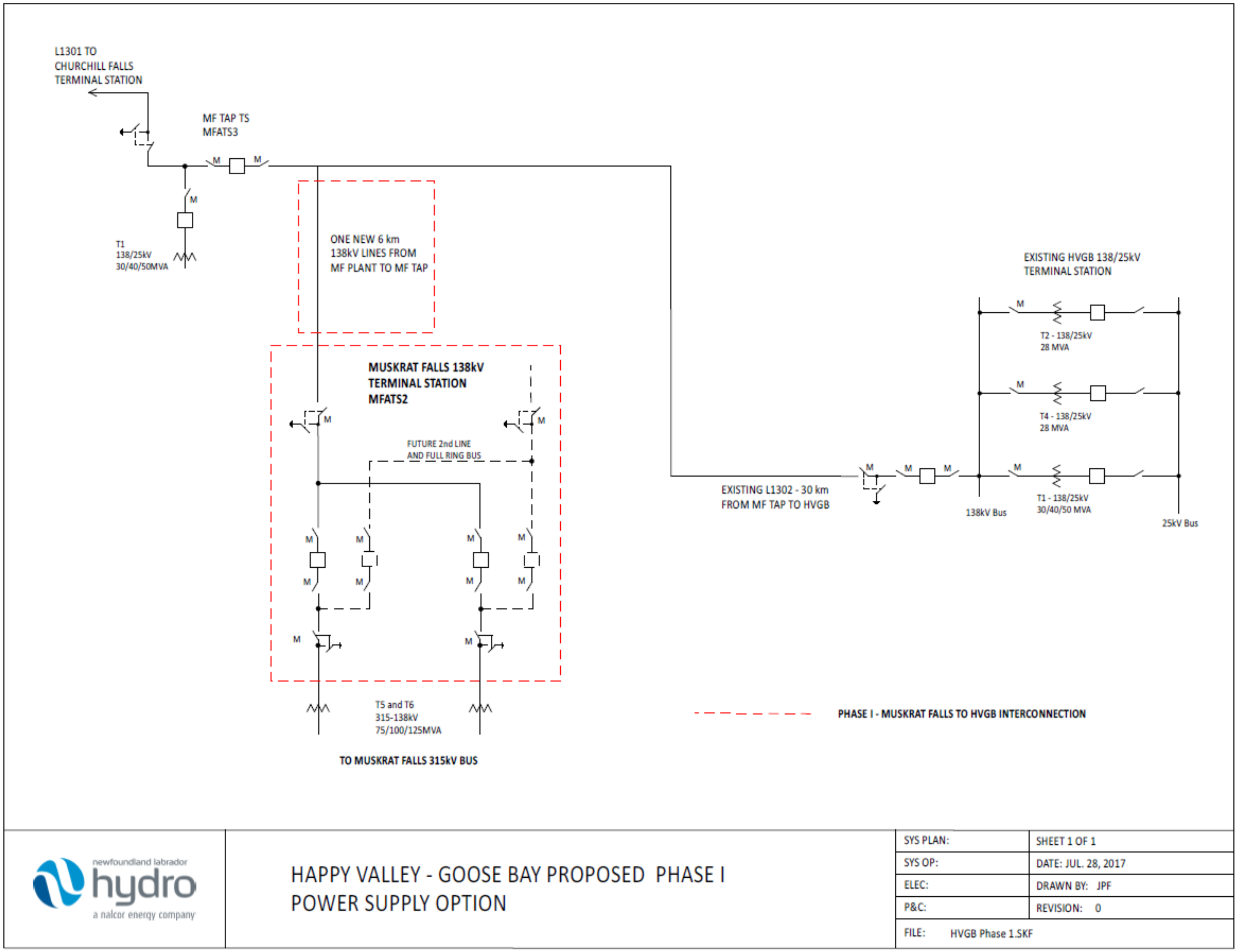


Figure 14 Phase I – Single 138kV Transmission Interconnection to Happy Valley-Goose Bay

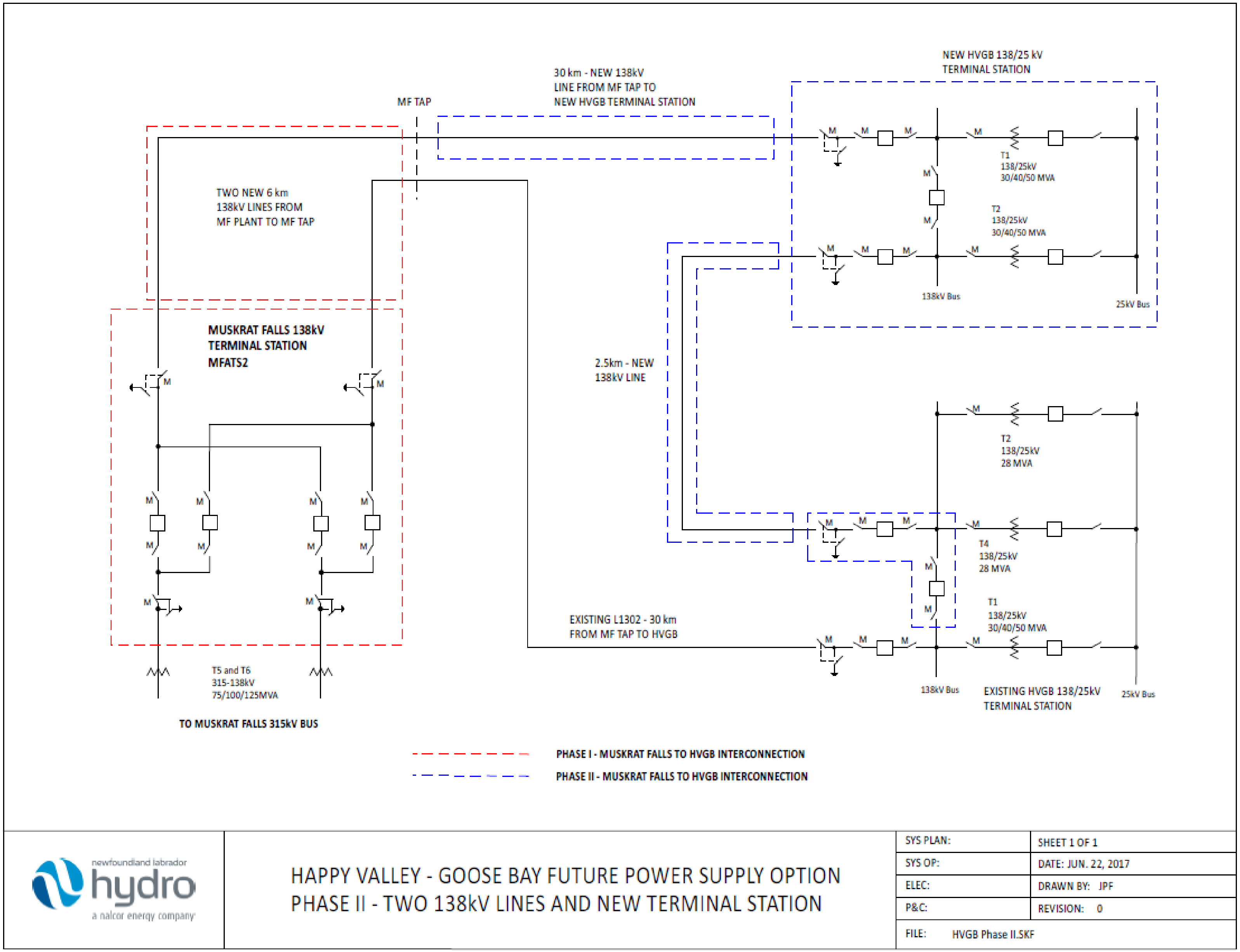


Figure 15 Phase II – Double 138kV Transmission Interconnection to Happy Valley-Goose Bay

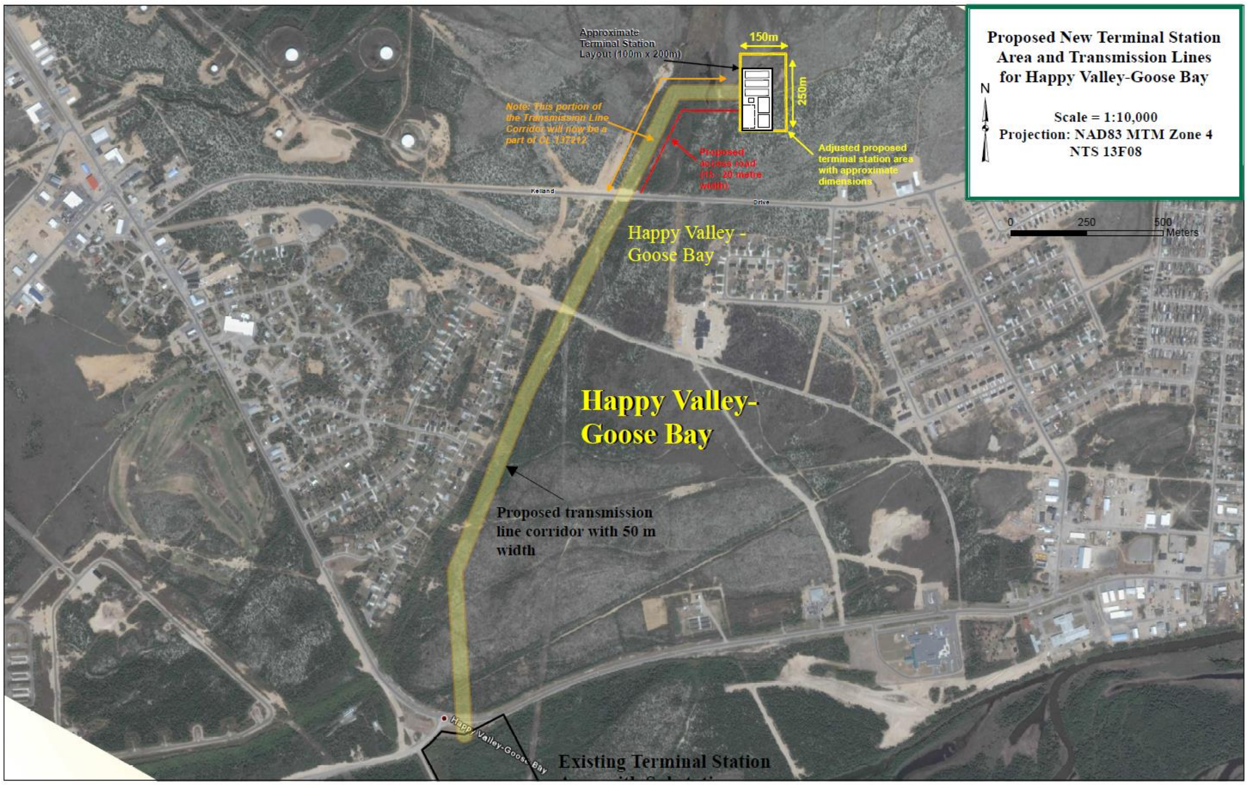


Figure 16 Proposed Location of Second 138/25kV Terminal Station

12.0 Treatment of the Happy Valley Gas Turbine

The Happy Valley gas turbine was added in 1991 as part of a project to increase the transfer capacity of the 138 kV transmission system in Eastern Labrador from 40 MW to 63 MW, as a reasonable means of supplying loads in the Upper lake Melville area until the developments on the lower Churchill River were completed. Since installation the gas turbine has normally operated in synchronous condenser mode to provide the necessary reactive power support for transmission system. In generate mode it provides up to 25 MW of capacity for line outages, both planned and unplanned. In completing the cost benefit analysis of the transmission capacity increase options, the ongoing operational cost of the gas turbine was excluded from the analysis with the exception of the fuel cost associated with the Wood Pole Line Management (WPLM) Program. Fuel costs for WPLM were included as the various transmission options provided for differing line lengths and requirement to operate the gas turbine during WPLM driven line outages.

It is true that, from the strict perspective of transmission supply to Happy Valley, alternatives involving the connection of the 138 kV system to the Muskrat Falls site (MFATS2) will reduce the need for the gas turbine to operate in synchronous condenser mode due to the significant shortening of the transmission system (36 km versus 269 km) and voltage regulating capability of the 315/138 kV autotransformers at Muskrat Falls. An estimate of the cumulative net present value of the life cycle cost for continued operation of the gas turbine at its historical levels for the study period is $21.3 million. One would further argue that as a result, transmission options reducing the need for the gas turbine should benefit from a reduction in overall cumulative net present value. At a high level, if one assumes no operational cost for the gas turbine moving forward in options with a connection to MFATS2, then Option One would see its cumulative net present value increase from $33.5M to $51.8M while the cumulative net present value of remaining Options would not change. The cost benefit analysis would still recommend Option 2 as the least cost alternative. Similarly, if one proposed that Options Two and Three having only one 138 kV transmission line to Happy Valley would require the gas turbine be maintained and operated at historical levels while Options Four and Five with two lines do not require the gas turbine at all, adding the $21.3M cumulative net present value to Options Two and Three would not change the cost benefit recommendation as Option Four has an existing cumulative net present value difference of $27.5M compared to Option Two (a net $6.2M preference for Option Two with the $21.3M added), and Option Five has an existing cumulative net present value difference of $42.9M compared to option Two (a net $21.6M preference for Option Two with the $21.3M added).

With the connection of the Labrador and Island Interconnected Systems via the Labrador – Island HVdc Link in 2018, operation of the Happy Valley gas turbine must be considered in the broader, system wide context. With the interconnection, the Happy Valley gas turbine can be used to support both the Labrador and Island Interconnected Systems. As a result, there may be little change in its operational cost as the purpose moves to larger system support. The long term requirements of the Happy Valley gas turbine can only be fully assessed as part of the larger generation planning exercise, which is beyond the scope of this analysis and load driven issue at hand. As a result, operational cost for the Happy Valley gas turbine was purposefully excluded from the transmission planning exercise. From a historical perspective, the St. Anthony Diesel Plant was not shut down following the interconnection of the St. Anthony – Roddickton System to the Island Interconnected System as it was found that the diesel plant provided overall benefit to the larger Island Interconnected System. This possibility exists for the Happy Valley gas turbine.

13.0 Conclusions and Recommendations

The load in the Happy Valley area will exceed the transfer capacity of the transmission system in Eastern Labrador in 2018. Although utilization of one of the new 315 kV lines, operated at 138 kV, has allowed for the load to be served during the winter of 2017-2018, this was a short term solution that cannot be sustained for the following winter season. Five power supply options for Happy Valley-Goose Bay area were analyzed from both a technical and cost benefit point of view. It was shown that while Option 1, […] with additional 125 MVA transformer added at Churchill Falls, 67 MVAR capacitor bank and 50MVA transformer at HV-GB, had the lowest initial capital cost, it did not have the lowest cumulative net present value. As well it is technically inferior to the other supply options in both overall transfer capability and reliability to the customer. Option 4 and 5, two 138 kV circuits from Muskrat Falls to Happy Valley are the best technical supply options from a transfer capability and reliability point of view. However, these options require an initial capital investment of approximately $57.2 and $76 million respectively. Options 2 and 3, interconnection of a single 138 kV line from Muskrat Falls to Happy

Valley-Goose Bay, provide identical transfer capabilities and very similar reliability indices. Option 2 has the lowest cumulative net present value of the five options, while providing a technically superior alternative to […] Option 1. The reliability analysis indicates that by connecting the 138 kV transmission system in Eastern Labrador to MFATS2 (Option 2) the unavailability is reduced to 0.051% compared to 0.46% if supply is maintained via 269 km and Churchill Falls. Further, the expected unsupplied energy is reduced from 1,747 MWh to 194 MWh by connecting to MFATS2.

Therefore, Option 2 is recommended as the preferred method of supplying future power to Happy Valley-Goose Bay area. This option calls for one single 138 kV circuit from the Muskrat Falls 315/138 kV Terminal Station to the Happy Valley Terminal Station. This consists of the construction of the following:

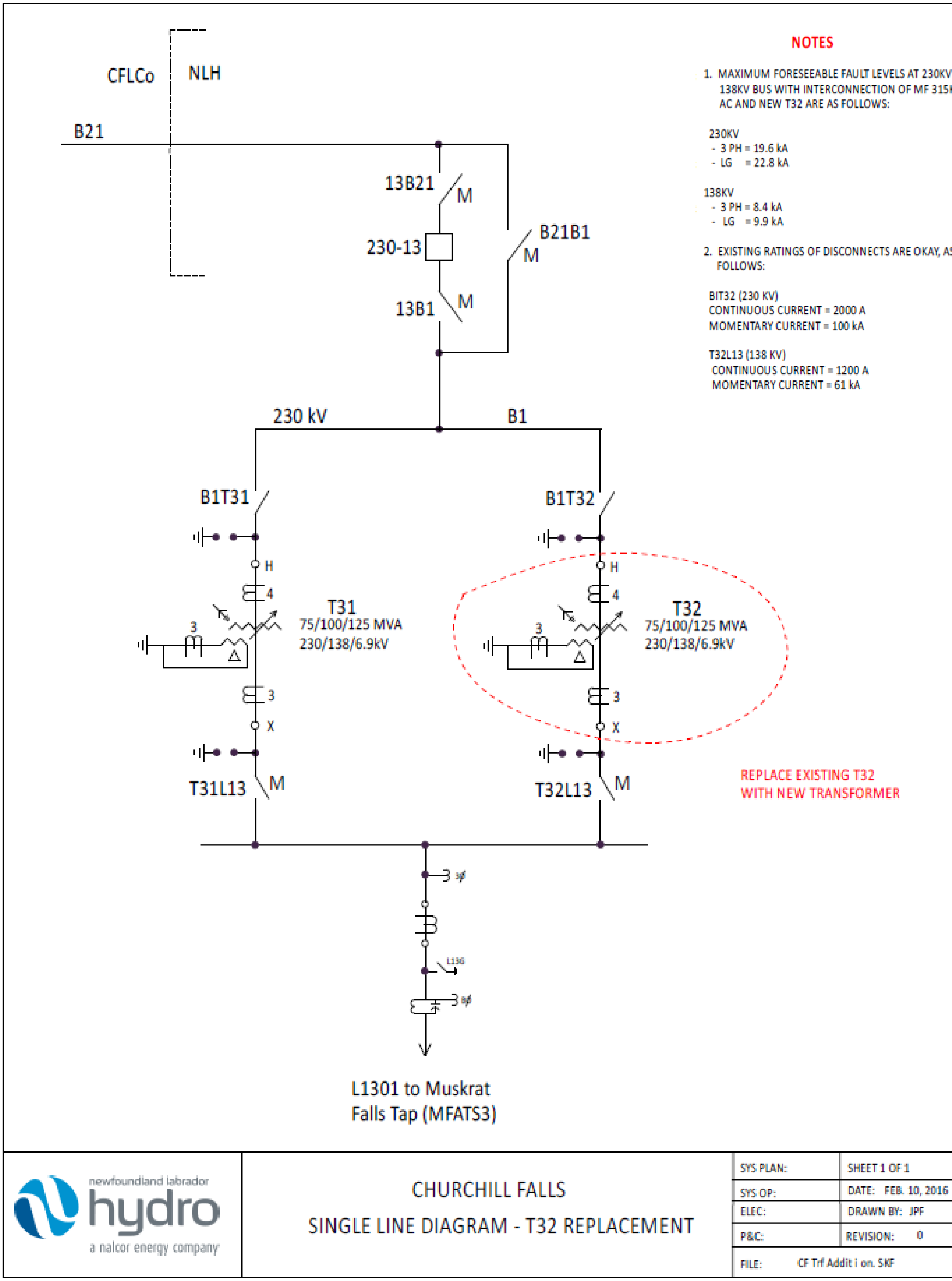
i) One 6 km 138 kV transmission line from MFATS2 to L1302, where they will be joined to provide one single circuit to Happy Valley.
ii) Partial 138 kV ring bus located at MFATS2 to accommodate one transmission line, with future expansion possible for a second.
iii) Happy Valley Terminal Station modifications, including upgrade of reclosers and circuit breakers, as indicated in Appendix B due to fault level increases, a new control building and a new 50MVA transformer.

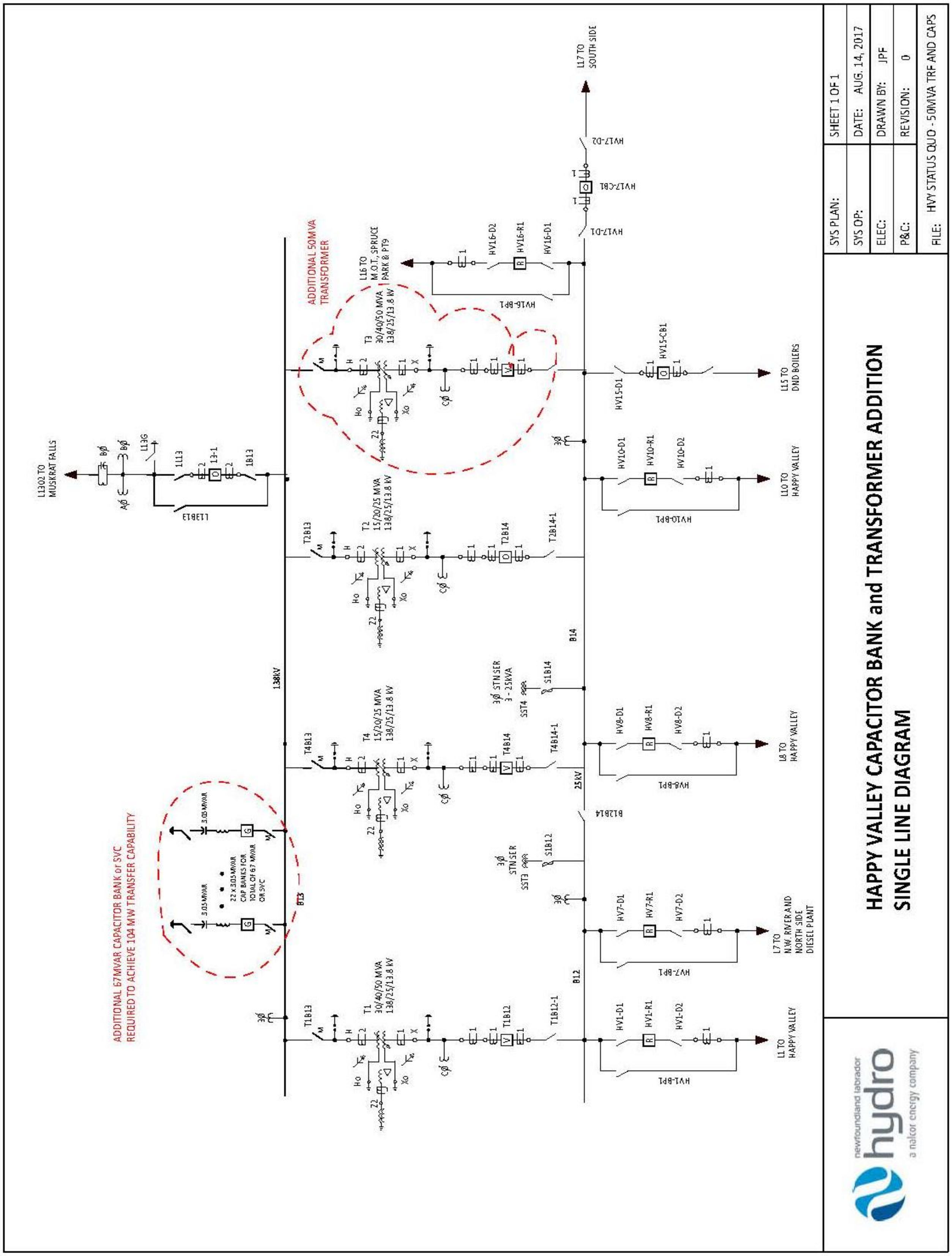
The total capital cost of this option is estimated at $20.0M and will provide increased transfer capability to 104 MW to Happy Valley-Goose Bay region, with no outages.

The proposed project improves the reliability of supply by reducing the Expected Unsupplied Energy (EUE) served from 1747 MWh to 194 MWh when compared to the Option 1. Finally, this option gives the Happy Valley-Goose Bay region room in its transfer capacity for future economic development.

Appendix A

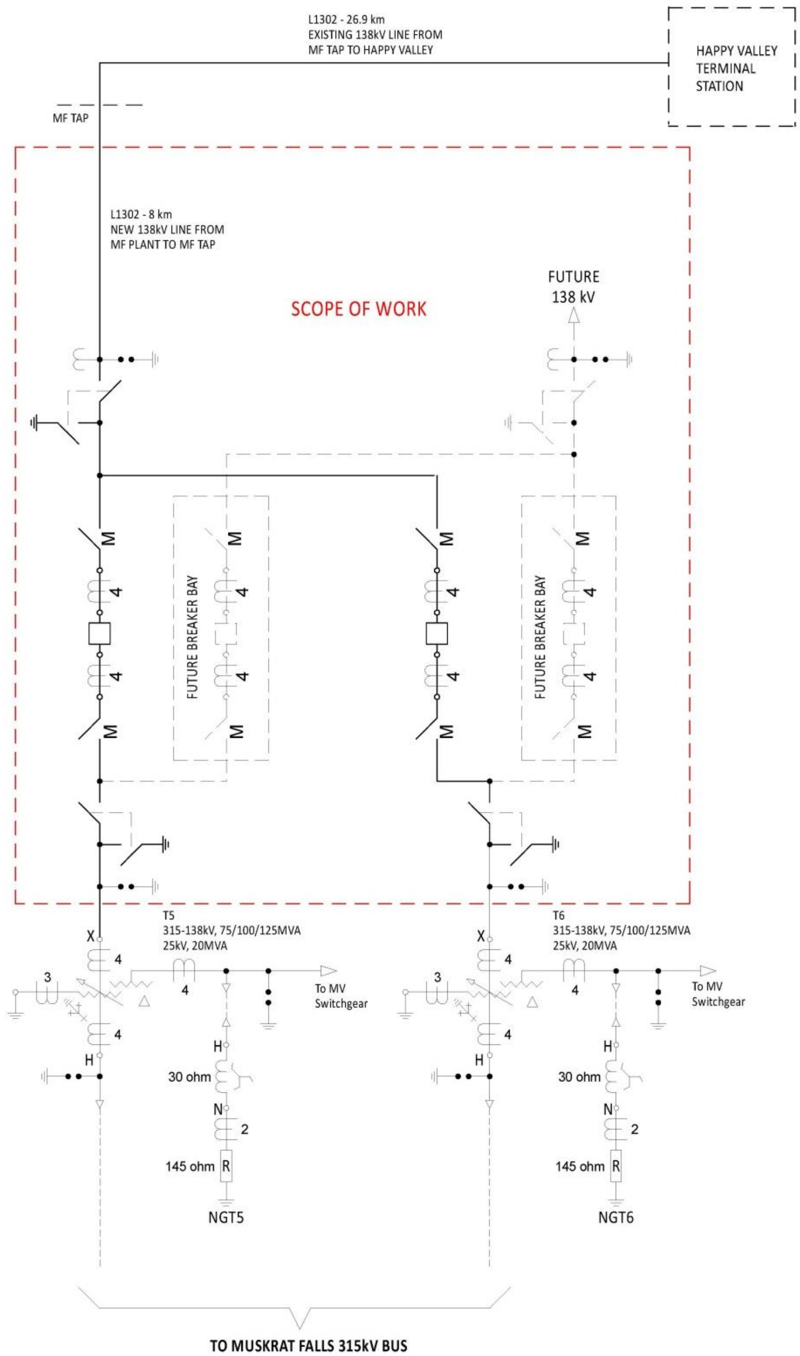
Option 1: […]
Addition of 125 MVA Transformer at Churchill Falls
and
67 MVAR Capacitor and 50MVA Transformer at Happy Valley-Goose Bay


CFLCo
NLH
B21
13B21
M
230-13
B21B1
M
13B1
M
230 kV
B1
B1T31
B1T32
H
4
T31
75/100/125 MVA
230/138/6.9kV
3
3
X
T32
75/100/125 MVA
230/138/6.9kV
T31L13
M
T32L13
M
REPLACE EXISTING T32
WITH NEW TRANSFORMER
NOTES
1. MAXIMUM FORESEEABLE FAULT LEVELS AT 230KV and 138KV BUS WITH INTERCONNECTION OF MF 315KV AC AND NEW T32 ARE AS FOLLOWS:
230KV
- 3 PH = 19.6 kA
- LG = 22.8 kA
138KV
- 3 PH = 8.4 kA
- LG = 9.9 kA
2. EXISTING RATINGS OF DISCONNECTS ARE OKAY, AS FOLLOWS:
BIT32 (230 KV)
CONTINUOUS CURRENT = 2000 A
MOMENTARY CURRENT = 100 kA
T32L13 (138 KV)
CONTINUOUS CURRENT = 1200 A
MOMENTARY CURRENT = 61 kA
L1301 to Muskrat
Falls Tap (MFATS3)
newfoundland labrador
hydro
a nalcor energy company
CHURCHILL FALLS
SINGLE LINE DIAGRAM - T32 REPLACEMENT
SYS PLAN:
SHEET 1 OF 1
SYS OP:
DATE: FEB. 10, 2016
ELEC:
DRAWN BY: JPF
P&C:
REVISION: 0
FILE: CF Trf Addit i on. SKF


HAPPY VALLEY CAPACITOR BANK and TRANSFORMER ADDITION
SINGLE LINE DIAGRAM
SYS PLAN:
SYS OP:
ELEC:
P&C:
FILE: HVY STATUS QUO - 50MVA TRF AND CAPS
SHEET 1 OF 1
DATE: AUG. 14, 2017
DRAWN BY: JPF
REVISION: 0
ADDITIONAL 67MVAR CAPACITOR BANK or SVC
REQUIRED TO ACHIEVE 104 MW TRANSFER CAPABILITY
ADDITIONAL 50MVA
TRANSFORMER
L1302 TO
MUSKRAT FALLS
L17 TO
SOUTH SIDE
L16 TO
M.O.T., SPRUCE
PARK & PT9
L15 TO
DND BOILERS
L10 TO
HAPPY VALLEY
L8 TO
HAPPY VALLEY
L7 TO
N.W. RIVER AND
NORTH SIDE
DIESEL PLANT
L1 TO
HAPPY VALLEY
T3
30/40/50 MVA
138/25/13.8 kV
T2
15/20/25 MVA
138/25/13.8 kV
T4
15/20/25 MVA
138/25/13.8 kV
T1
30/40/50 MVA
138/25/13.8 kV
138kV
25kV
B12
B13
B14
hydro
a nalcor energy company

Appendix B

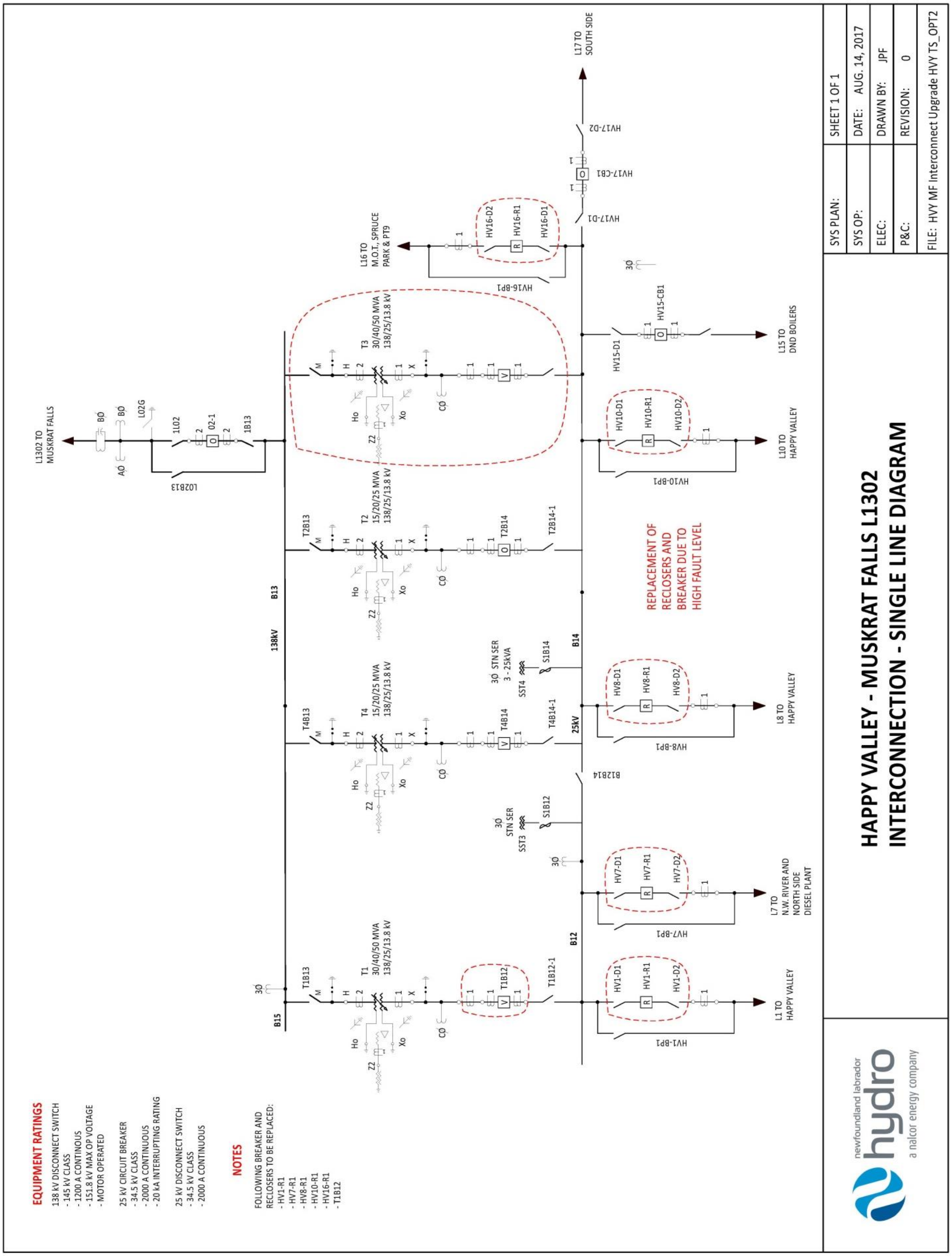
Option 2
Muskrat Falls to Happy Valley-Goose Bay
One Single 138 kV Circuit



newfoundland labrador hydro
a nalcor energy company

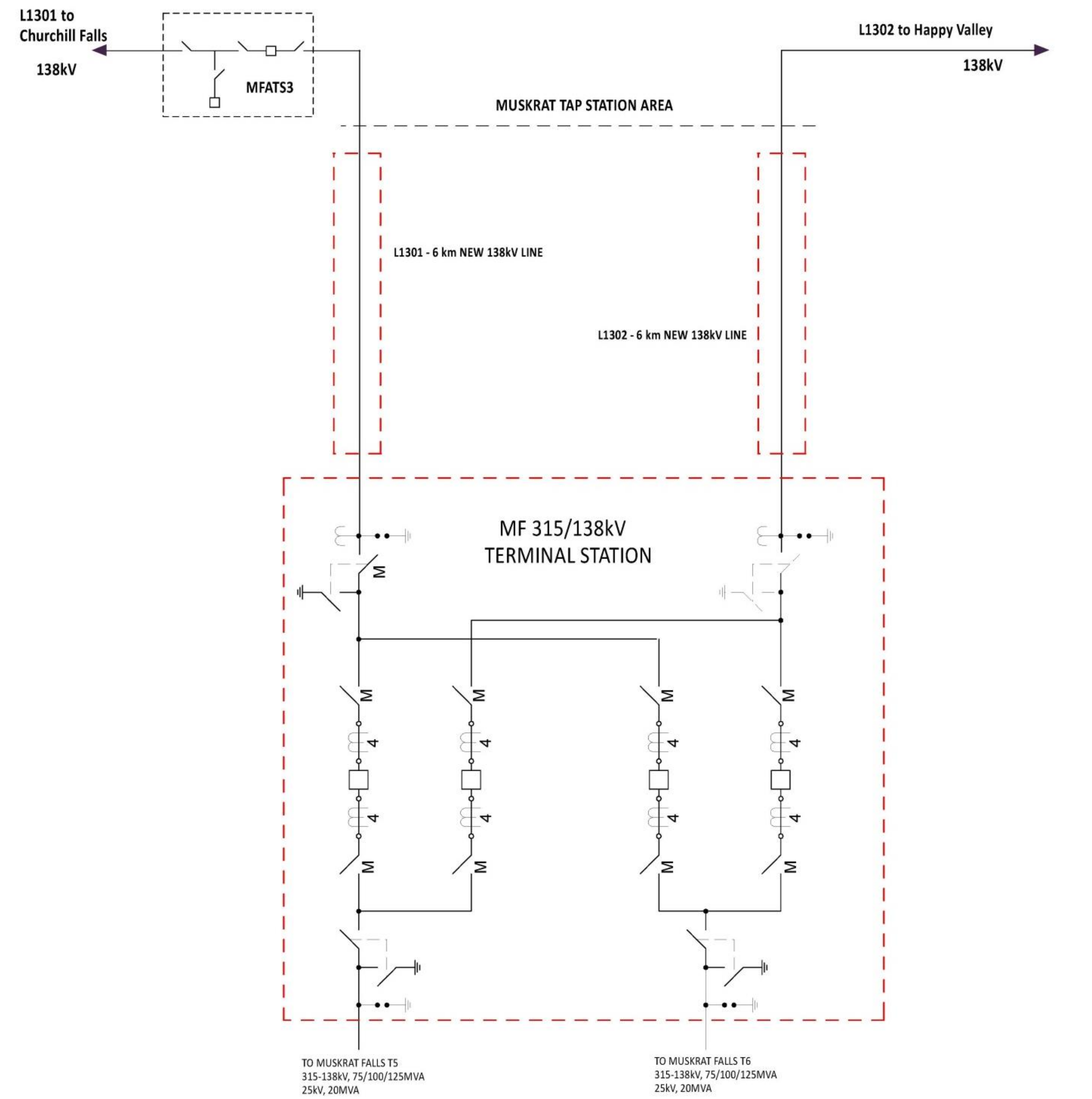
MUSKRAT FALLS TERMINAL STATION
HAPPY VALLEY 138kV INTERCONNECTION
PARTIAL RING BUS - 1 LINE

SYS PLAN:	SHEET 1 OF 1
SYS OP:	DATE: FEB. 11, 2016
ELEC:	DRAWN BY: JF
P&C:	REVISION: 0
FILE: MFATS - PARTIAL RING.SKF	


HAPPY VALLEY - MUSKRAT FALLS L1302
INTERCONNECTION - SINGLE LINE DIAGRAM
EQUIPMENT RATINGS
138 kV DISCONNECT SWITCH
- 145 kV CLASS
- 1200 A CONTINOUS
- 151.8 kV MAX OP VOLTAGE
- MOTOR OPERATED
25 kV CIRCUIT BREAKER
- 34.5 kV CLASS
- 2000 A CONTINUOUS
- 20 kA INTERRUPTING RATING
25 kV DISCONNECT SWITCH
- 34.5 kV CLASS
- 2000 A CONTINUOUS
NOTES
FOLLOWING BREAKER AND RECLOSERS TO BE REPLACED:
- HV1-R1
- HV7-R1
- HV8-R1
- HV10-R1
- HV16-R1
- T1B12
REPLACEMENT OF RECLOSERS AND BREAKER DUE TO HIGH FAULT LEVEL
L1302 TO MUSKRAT FALLS
L17 TO SOUTH SIDE
L16 TO M.O.T., SPRUCE PARK & PT9
L15 TO DND BOILERS
L10 TO HAPPY VALLEY
L8 TO HAPPY VALLEY
L7 TO N.W. RIVER AND NORTH SIDE DIESEL PLANT
L1 TO HAPPY VALLEY
T1 30/40/50 MVA 138/25/13.8 kV
T2 15/20/25 MVA 138/25/13.8 kV
T3 30/40/50 MVA 138/25/13.8 kV
T4 15/20/25 MVA 138/25/13.8 kV
3Ø STN SER 3 - 25kVA
138kV
25kV
B12
B13
B14
B15
SYS PLAN:
SHEET 1 OF 1
SYS OP:
DATE: AUG. 14, 2017
ELEC:
DRAWN BY: JPF
P&C:
REVISION: 0
FILE: HVY MF Interconnect Upgrade HVY TS_OPT2
newfoundland labrador hydro
a nalcor energy company

Appendix C

Option 3
Muskrat Falls to Happy Valley-Goose Bay
One Single 138 kV Circuit
(Two 6km Sections)



SCOPE OF WORK

1. CONSTRUCTION OF TWO X 6KM OF 138KV TRANSMISSION LINE FROM MF 315/138KV TERMINAL STATION TO MFATS3 TAP STATION. NEW LINES TO TIE INTO EXISTING L1301 AND L1302.

2. INSTALLATION OF FULL RING BUS AT MF 315/138KV TERMINAL STATION
   - FOUR 138KV CIRCUIT BREAKERS COMPLETE WITH MOTOR OPERATED DISCONNECT SWITCHES AND CT'S.
   - 138KV DISCONNECT SWITCHES (MOTORIZED) COMPLETE WITH GROUND SWITCHES
   - THREE PHASE PT'S AND LIGHTNING ARRESTERS

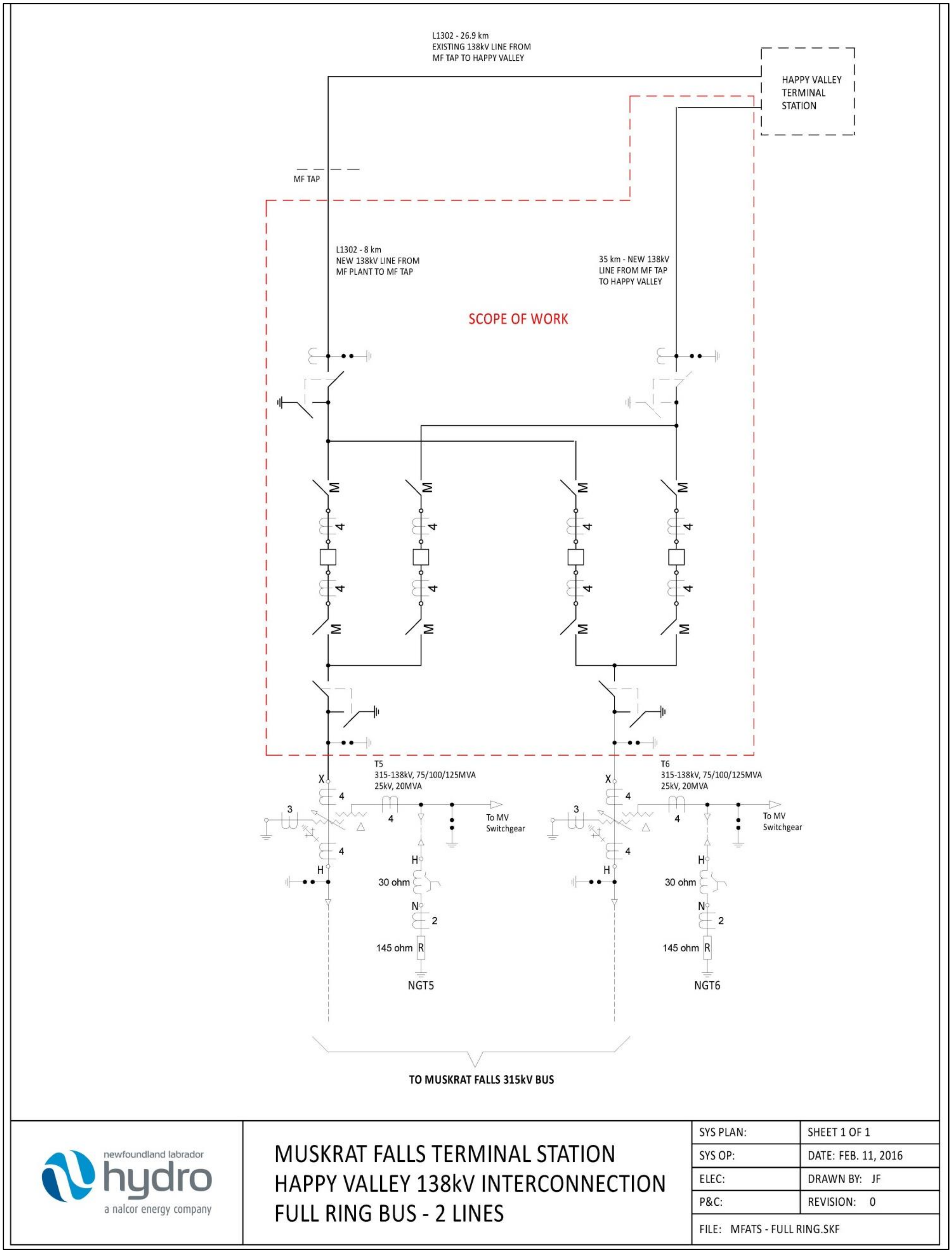
newfoundland labrador hydro
a nalcor energy company

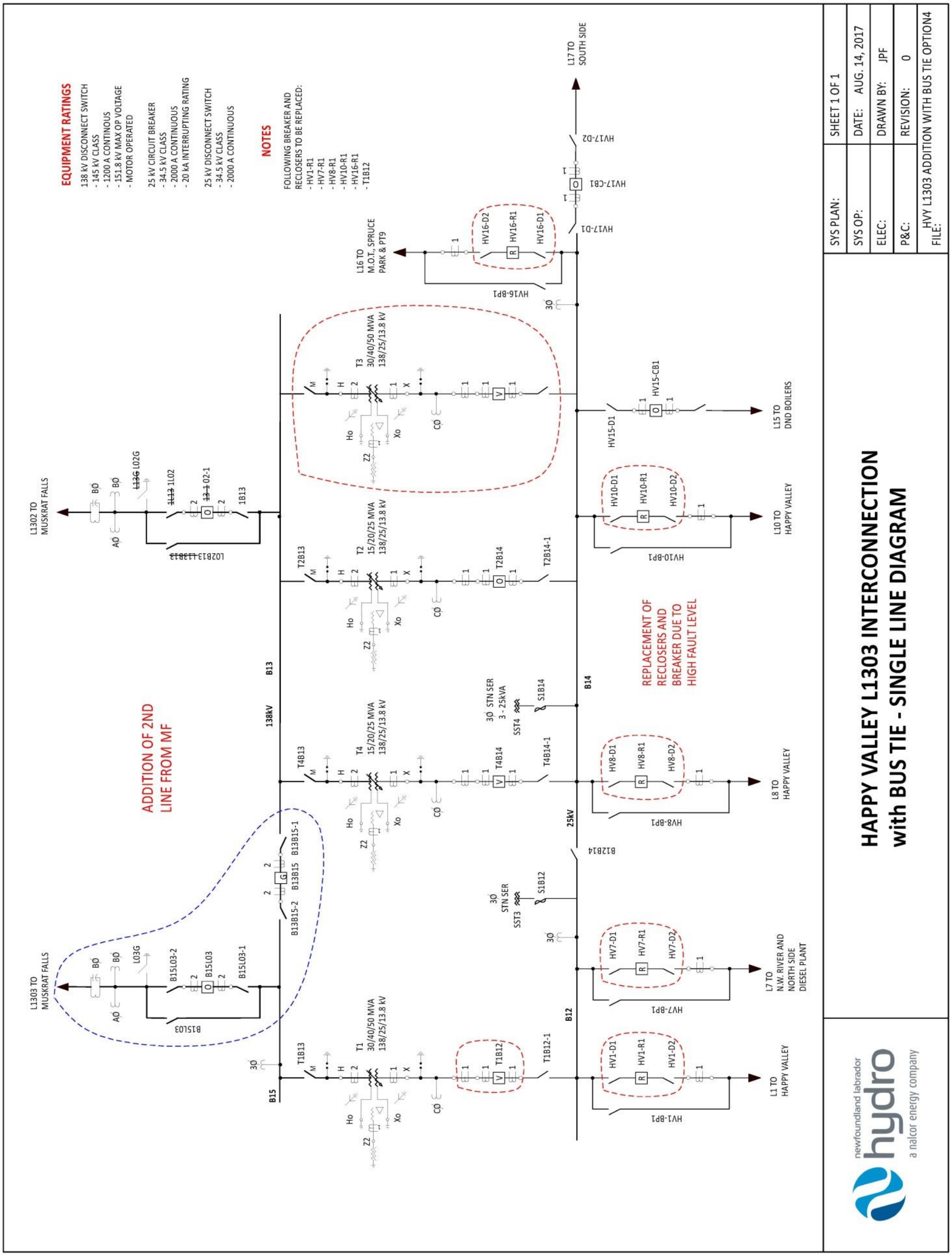
MUSKRAT FALLS TAP TERMINAL STATION TS3
HAPPY VALLEY 138kV INTERCONNECTION
OPTION 3

SYS PLAN:	SHEET 1 OF 1
SYS OP:	DATE: AUG. 14, 2017
ELEC:	DRAWN BY: JPF
P&C:	REVISION: 0
FILE:	OPTION3-CF MF - 1 LINE FROM MF_ KEEP MFATS3.SKF

Appendix D

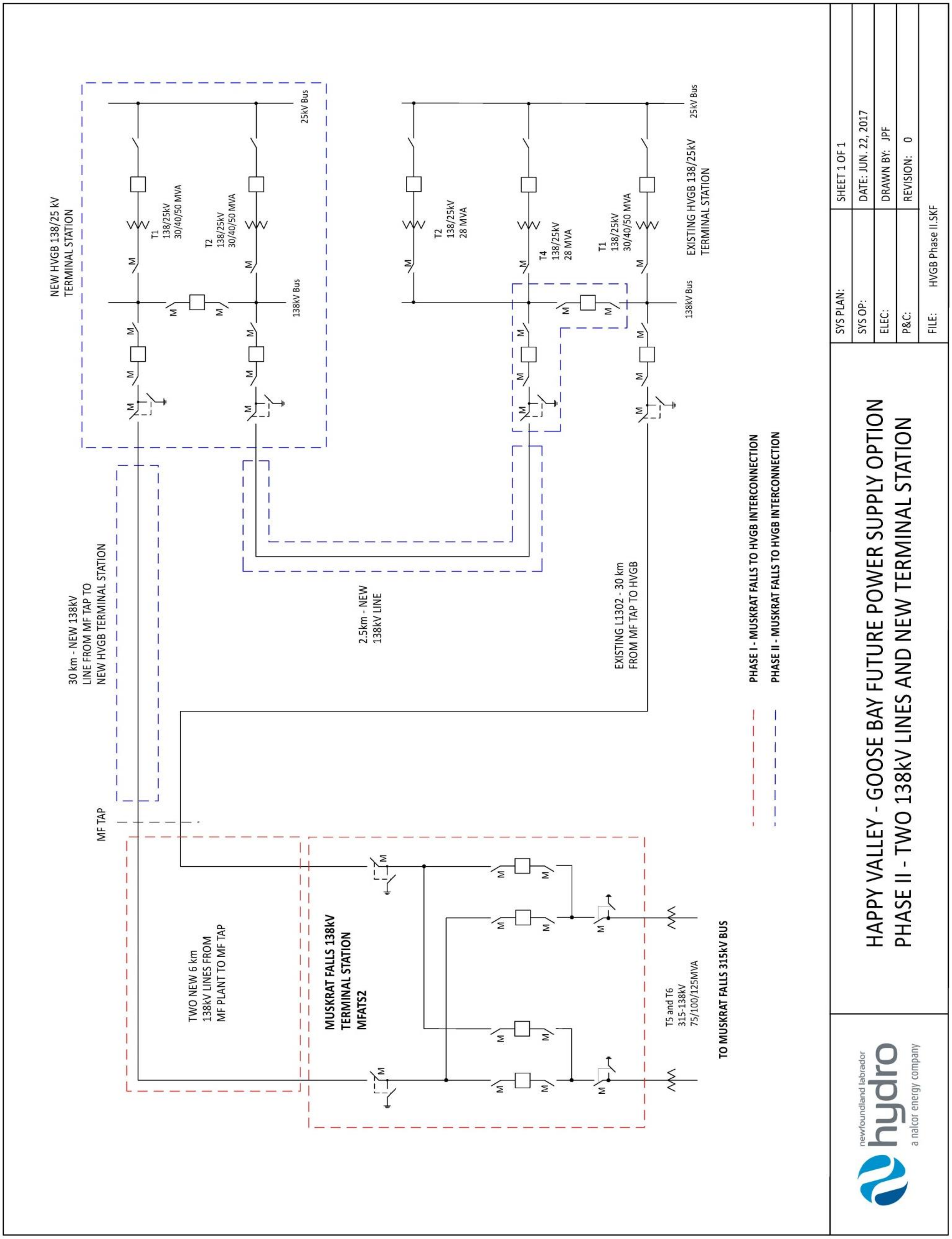
Option 4
Muskrat Falls to Happy Valley-Goose Bay
Two Single 138 kV Circuits


L1302 - 26.9 km
EXISTING 138kV LINE FROM
MF TAP TO HAPPY VALLEY
HAPPY VALLEY
TERMINAL
STATION
MF TAP
L1302 - 8 km
NEW 138kV LINE FROM
MF PLANT TO MF TAP
35 km - NEW 138kV
LINE FROM MF TAP
TO HAPPY VALLEY
SCOPE OF WORK
T5
315-138kV, 75/100/125MVA
25kV, 20MVA
To MV
Switchgear
30 ohm
145 ohm
NGT5
T6
315-138kV, 75/100/125MVA
25kV, 20MVA
To MV
Switchgear
30 ohm
145 ohm
NGT6
TO MUSKRAT FALLS 315kV BUS
newfoundland labrador
hydro
a nalcor energy company
MUSKRAT FALLS TERMINAL STATION
HAPPY VALLEY 138kV INTERCONNECTION
FULL RING BUS - 2 LINES
SYS PLAN:
SHEET 1 OF 1
SYS OP:
DATE: FEB. 11, 2016
ELEC:
DRAWN BY: JF
P&C:
REVISION: 0
FILE: MFATS - FULL RING.SKF


EQUIPMENT RATINGS
138 kV DISCONNECT SWITCH
- 145 kV CLASS
- 1200 A CONTINOUS
- 151.8 kV MAX OP VOLTAGE
- MOTOR OPERATED
25 kV CIRCUIT BREAKER
- 34.5 kV CLASS
- 2000 A CONTINUOUS
- 20 kA INTERRUPTING RATING
25 kV DISCONNECT SWITCH
- 34.5 kV CLASS
- 2000 A CONTINUOUS
NOTES
FOLLOWING BREAKER AND RECLOSERS TO BE REPLACED:
- HV1-R1
- HV7-R1
- HV8-R1
- HV10-R1
- HV16-R1
- T1B12
L1302 TO MUSKRAT FALLS
L1303 TO MUSKRAT FALLS
ADDITION OF 2ND LINE FROM MF
138kV
B13
B15
B14
B12
25kV
T1 30/40/50 MVA 138/25/13.8 kV
T2 15/20/25 MVA 138/25/13.8 kV
T3 30/40/50 MVA 138/25/13.8 kV
T4 15/20/25 MVA 138/25/13.8 kV
3Ø STN SER 3 - 25kVA
REPLACEMENT OF RECLOSERS AND BREAKER DUE TO HIGH FAULT LEVEL
L16 TO M.O.T., SPRUCE PARK & PT9
L17 TO SOUTH SIDE
L15 TO DND BOILERS
L10 TO HAPPY VALLEY
L8 TO HAPPY VALLEY
L7 TO N.W. RIVER AND NORTH SIDE DIESEL PLANT
L1 TO HAPPY VALLEY
HAPPY VALLEY L1303 INTERCONNECTION with BUS TIE - SINGLE LINE DIAGRAM
SYS PLAN:
SYS OP:
ELEC:
P&C:
SHEET 1 OF 1
DATE: AUG. 14, 2017
DRAWN BY: JPF
REVISION: 0
FILE: HVY L1303 ADDITION WITH BUS TIE OPTION4
newfoundland labrador hydro
a nalcor energy company

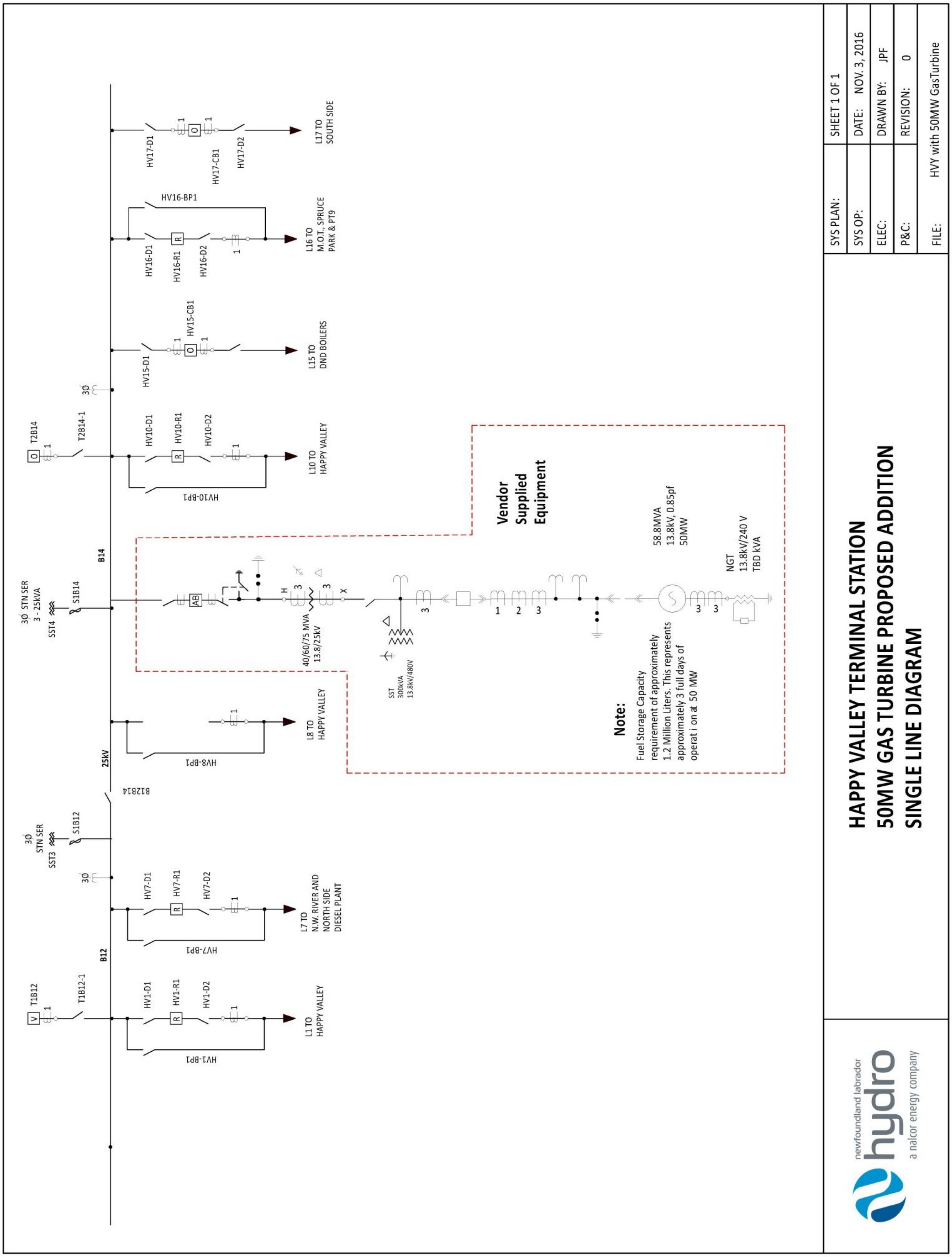
Appendix E

Option 5
Muskrat Falls to Happy Valley-Goose Bay
Two Single 138 kV Circuits + Second Terminal Station


HAPPY VALLEY - GOOSE BAY FUTURE POWER SUPPLY OPTION
PHASE II - TWO 138kV LINES AND NEW TERMINAL STATION
SYS PLAN:
SYS OP:
ELEC:
P&C:
FILE: HVGB Phase II.SKF
SHEET 1 OF 1
DATE: JUN. 22, 2017
DRAWN BY: JPF
REVISION: 0
newfoundland labrador hydro
a nalcor energy company
NEW HVGB 138/25 kV TERMINAL STATION
25kV Bus
138kV Bus
T1 138/25kV 30/40/50 MVA
T2 138/25kV 30/40/50 MVA
EXISTING HVGB 138/25kV TERMINAL STATION
T2 138/25kV 28 MVA
T4 138/25kV 28 MVA
T1 138/25kV 30/40/50 MVA
30 km - NEW 138kV LINE FROM MF TAP TO NEW HVGB TERMINAL STATION
2.5km - NEW 138kV LINE
EXISTING L1302 - 30 km FROM MF TAP TO HVGB
PHASE I - MUSKRAT FALLS TO HVGB INTERCONNECTION
PHASE II - MUSKRAT FALLS TO HVGB INTERCONNECTION
MF TAP
TWO NEW 6 km 138kV LINES FROM MF PLANT TO MF TAP
MUSKRAT FALLS 138kV TERMINAL STATION MFATS2
T5 and T6 315-138kV 75/100/125MVA
TO MUSKRAT FALLS 315kV BUS
M

Appendix F

Option 6
Addition of 50 MW Gas Turbine


HAPPY VALLEY TERMINAL STATION
50MW GAS TURBINE PROPOSED ADDITION
SINGLE LINE DIAGRAM
SHEET 1 OF 1
DATE: NOV. 3, 2016
DRAWN BY: JPF
REVISION: 0
FILE: HVY with 50MW GasTurbine
SYS PLAN:
SYS OP:
ELEC:
P&C:
newfoundland labrador hydro
a nalcor energy company
Vendor Supplied Equipment
58.8MVA
13.8kV, 0.85pf
50MW
NGT
13.8kV/240 V
TBD kVA
40/60/75 MVA
13.8/25kV
SST
300kVA
13.8kV/480V
Note:
Fuel Storage Capacity requirement of approximately 1.2 Million Liters. This represents approximately 3 full days of operat i on at 50 MW
L17 TO SOUTH SIDE
L16 TO M.O.T., SPRUCE PARK & PT9
L15 TO DND BOILERS
L10 TO HAPPY VALLEY
L8 TO HAPPY VALLEY
L7 TO N.W. RIVER AND NORTH SIDE DIESEL PLANT
L1 TO HAPPY VALLEY
B14
B12
25kV
B12B14
S1B14
S1B12
SST4
SST3
T2B14
T2B14-1
T1B12
T1B12-1

Appendix G

Annual Marginal Difference in Transmission Losses Between 138 kV Churchill Falls Supply vs. Muskrat Falls 315 kV Supply

Annual Marginal Difference in Transmission Losses
Between 138 kV Churchill Falls Supply vs. Muskrat Falls 315 kV Supply

Year	Annual Energy Losses, MWh		
	CF Supply via 138 kV	MF Supply via 315 kV[1]	Marginal Difference
2019	34,192	3,035	31,157
2020	46,901	3,049	43,852
2021	47,600	3,063	44,537
2022	47,953	3,082	44,871
2023	48,547	3,101	45,446
2024	49,148	3,116	46,032
2025	49,754	3,135	46,620
2026	50,368	3,154	47,214
2027	50,989	3,173	47,815
2028	51,616	3,188	48,428
2029	52,123	3,202	48,921
2030	52,763	3,222	49,541
2031	53,410	3,236	50,174
2032	53,933	3,251	50,682
2033	54,461	3,265	51,195
2034	55,127	3,280	51,847
2035	55,666	3,295	52,371
2036	56,209	3,310	52,899
2037	56,758	3,325	53,433
2038	57,450	3,340	54,110
2039	58,010	3,355	54,655
2040	58,716	3,370	55,346
2041	59,288	3,385	55,903
2042	60,009	3,400	56,609

1. Based on 2027 Monthly average on peak/off peak load flow on LTA from 2010 Hydraulic Model, with HV-GB load added.

Appendix H

CPW of Transmission System Losses to NLH

CPW of Transmission System Losses to NLH
(Benefit to NLH for Reduced System Losses)

Year	Marginal Losses (MWh)	Marginal $/MWh[1]	Energy Value$	PW 2017 $	CPW 2017 $
2019	31,157	2.0	62,314	51,587	51,587
2020	43,852	2.0	87,704	68,174	119,761
2021	44,537	2.0	89,074	65,013	184,774
2022	44,871	2.0	89,742	61,503	246,278
2023	45,446	2.0	90,892	58,490	304,767
2024	46,032	2.0	92,064	55,628	360,395
2025	46,620	2.0	93,240	52,900	413,295
2026	47,214	2.0	94,428	50,304	463,599
2027	47,815	2.0	95,630	47,835	511,435
2028	48,428	2.0	96,856	45,492	556,926
2029	48,921	2.0	97,842	43,150	600,076
2030	49,541	2.0	99,082	41,030	641,106
2031	50,174	2.0	100,348	39,018	680,124
2032	50,682	2.0	101,364	37,008	717,132
2033	51,195	2.0	102,390	35,101	752,232
2034	51,847	2.0	103,694	33,378	785,610
2035	52,371	2.0	104,742	31,658	817,268
2036	52,899	2.0	105,798	30,025	847,293
2037	53,433	2.0	106,866	28,477	875,770
2038	54,110	2.0	108,220	27,078	902,848
2039	54,655	2.0	109,310	25,681	928,530
2040	55,346	2.0	110,692	24,419	952,948
2041	55,903	2.0	111,806	23,159	976,108
2042	56,609	2.0	113,218	22,020	998,128

[1] Marginal Cost projection based on estimated recall energy rate from CFLCo.

Appendix I

Operation and Maintenance Cost Assumptions

7.1 Terminal Station Maintenance

Terminal station equipment maintenance costs for analysis purposes are summarized as follows:

Terminal Station Maintenance Costs and Period by Unit Type – 2017$				
Maintenance Unit Type	**Preventive Maintenance**		**Corrective Maintenance**	
	$/unit	**Period years**	**$/unit**	**Period years**
Transformers	5,121	6	2,504	1
Circuit Breakers	8,466	6	1,325	1
Disconnect Switches	1,167	6	104	1
Instrument Transformers (CT, PT, CVT)	1,167	6	52	1
Station Visual Inspections			1000	0.333

Each of the terminal stations are considered in turn.

7.2 Churchill Falls Terminal Station

O&M costs associated with the Churchill Falls Terminal Station equipment supplying Happy Valley are summarized as follows:

Summary of Churchill Falls O&M Costs – 2017 $					
Maintenance Unit Type	**# of Maint. Units**	**Preventive Maintenance**		**Annual Corrective Maintenance**	
		$/Unit	**Six Year Cost**	**$/Unit**	**Annual Cost**
Transformers	2	5,121	10,241	2,504	5,008
Circuit Breakers	1	8,466	8,466	1,325	1,325
Switches	8	1,167	9,332	104	832
CT, PT, CVT	2	1,167	2,334	52	104
Station Inspections	3			1,000	3,000
Total			30,373		10,269

Given that the 230/138 kV, 75/100/125 MVA T31 replacement at Churchill Falls was installed in 2012, it is assumed that its first transformer preventive maintenance will occur in 2018. Given the requirement for a second 230/138 kV, 75/100/125 MVA transformer in Churchill Falls in 2019, it is assumed that the preventive maintenance cycles of T31 and T33 will align with each other for simplification purposes.

The six year preventive maintenance costs for Churchill Falls have been annualized at $5,062 and added to the corrective maintenance of $10,269 to arrive at a combined O&M cost of $15,331.

7.3 Muskrat Falls Construction Power Station – MFATS3

Given that the Muskrat Falls Construction Power Station (MFATS3) is required to assist in power transfer to Happy Valley in the supply from Churchill Falls alternative, O&M costs associated with this station must be considered. The O&M costs are summarized as follows:

Summary of MFATS3 O&M Costs – 2017 $

Maintenance Unit Type	# of Maint. Units	Preventive Maintenance		Annual Corrective Maintenance	
		$/Unit	Six Year Cost	$/Unit	Annual Cost
Transformers	1	5,121	5,121	2,504	2,504
Circuit Breakers	9[1]	8,466	50,796	1,325	7,950
Switches	8	1,167	9,336	104	832
CT, PT, CVT	3	1,167	3,501	52	156
Capacitor Bank[2]	6	1,167	7,002	104	624
Station Inspections	3			1000	3000
Total			75,756		15,066

[1]. Three SF_6 circuit breakers (2 x 138 kV 1 x 25 kV) at full O&M cost, six 25 kV vacuum circuit breakers assumed at one half O&M cost.
[2]. Capacitor banks assumed at disconnect switch rates

Given that the Muskrat Falls construction power station was installed in late 2011, the first preventive maintenance cycle is assumed to occur in 2017.

The six year preventive maintenance costs for MFATS3 have been annualized at $12,626 and added to the corrective maintenance of $15,066 to arrive at a combined O&M cost of $27,692.

7.4 Muskrat Falls 315/138 kV Terminal Station – MFATS2 (Full Ring Bus)

The O&M costs associated with the supply of Happy Valley via the new 315/138 kV station at Muskrat Falls (MFATS2) are summarized as follows:

Summary of MFATS2 O&M Costs – 2017 $					
Maintenance Unit Type	# of Maint. Units	Preventive Maintenance		Annual Corrective Maintenance	
		$/Unit	Six Year Cost	$/Unit	Annual Cost
Transformers[1]	0	5,121	0	2,504	0
Circuit Breakers	4	8,466	33,864	1,325	5,300
Switches	11	1,167	12,837	104	1,144
CT, PT, CVT	1	1,167	1,167	52	52
Station Inspections	3			1000	3000
Total			47,868		9,496

1. The 315/138/25 kV transformers at MFATS2 are assumed to be part of the Labrador Transmission Assets and maintenance associated with these transformers would be included in any tariff applied to Hydro's use of the 315 kV transmission between Churchill Falls and Muskrat Falls.

The six year preventive maintenance costs for MFATS2 full ring bus have been annualized at $7,978 and added to the corrective maintenance of $9,496 to arrive at a combined O&M cost of $17,474.

7.5 Muskrat Falls 315/138 kV Terminal Station – MFATS2 (Partial Ring Bus)

The O&M costs associated with the supply of Happy Valley via the new 315/138 kV station at Muskrat Falls (MFATS2) are summarized as follows:

Summary of MFATS2 O&M Costs – 2017 $					
Maintenance Unit Type	# of Maint. Units	Preventive Maintenance		Annual Corrective Maintenance	
		$/Unit	Six Year Cost	$/Unit	Annual Cost
Transformers[1]	0	5,121	0	2,504	0
Circuit Breakers	2	8,466	16,932	1,325	2,650
Switches	7	1,167	8,169	104	728
CT, PT, CVT	1	1,167	1,167	52	52
Station Inspections	3			1000	3000

Total			26,268		6,430
1. The 315/138/25 kV transformers at MFATS2 are assumed to be part of the Labrador Transmission Assets and maintenance associated with these transformers would be included in any tariff applied to Hydro's use of the 315 kV transmission between Churchill Falls and Muskrat Falls.					

The six year preventive maintenance costs for MFATS2 partial ring bus have been annualized at $4,378 and added to the corrective maintenance of $6,430 to arrive at a combined O&M cost of $10,808.

7.6 Happy Valley Terminal Station

For analysis purposes the Happy Valley Terminal Station maintenance is excluded as it is the same in all alternatives.

7.7 New Second Happy Valley Terminal Station

The O&M costs associated with the supply of Happy Valley via a second new 138/25 kV station in HV-GB area are summarized as follows:

Summary of New HV-GB Terminal Station O&M Costs – 2017 $					
Maintenance Unit Type	**# of Maint. Units**	**Preventive Maintenance**		**Annual Corrective Maintenance**	
		$/Unit	**Six Year Cost**	**$/Unit**	**Annual Cost**
Transformers	2	5,121	10,242	2,504	5,008
Circuit Breakers	5	8,466	42,330	1,325	6,625
Switches	12	1,167	14,004	104	1,248
CT, PT, CVT	14	1,167	16,338	52	728
Station Inspections	3			1000	3000
Total			82,914		16,609

The six year preventive maintenance costs for a new 138/25 kV station in HV-GB have been annualized at $13,819 and added to the corrective maintenance of $16,609 to arrive at a combined O&M cost of $30,428.

7.8 Transmission Line Maintenance

Hydro's Wood Pole Line Management Program for L1301 / L1302 is estimated to cost approximately $407,000 per year for the 269 km length, or roughly $1.51k/km. This cost would include annual cross arm replacement. Annual maintenance of each section of line for this study period has been based on $1.5K/km as follows:

- Existing L1301 (239 km) = $ 361.6k
- L1301 terminated at MFATS2 (245 km) = $ 367.5k
- Existing L1302 (30 km) = $ 45.4k
- L1302 terminated at MFATS2 (36 km) = $54.5k
- New 36 km Line MFATS2 to Happy Valley Terminal Station = $54.5k
- New 38.5 km Line MFATS2 to new Happy Valley Station = $58.3k
- New 2.5 km Line Happy valley Terminal Station to new station = $3.8k

Appendix J

Cash Flow for Options Considered for CPW Analysis

Table J.1 Option 1 Cash Flow ($ Escalated to Current Year) [...]

Year	Annual O&M ($)	Expense 1 ($)	Expense 2 ($)
2017			
2018	460,004[1]	8,171,600[2]	1,238,610[4]
2019	470,961	4,679,000[2]	1,332,090
2020	481,879		1,483,995
2021	492,929		1,542,420
2022	504,389		1,542,420
2023	516,116		1,542,420
2024	528,116		1,542,420
2025	540,395		1,542,420
2026	552,959		1,542,420
2027	565,815		1,542,420
2028	578,970		1,542,420
2029	592,431		1,542,420
2030	606,205		1,542,420
2031	620,300		1,542,420
2032	634,722		1,542,420
2033	649,479		1,542,420
2034	664,579		1,542,420
2035	680,031		1,542,420
2036	695,841		1,542,420
2037	712,020		1,542,420
2038	728,574		1,542,420
2039	745,514		1,542,420
2040	762,847		1,542,420
2041	780,583		1,542,420
2042	798,731	(6,775,892)[3]	1,542,420

1. L1301/L1302 WPLM Estimated cost of $450K in 2017 dollars, including transmission line cross arm replacement program requiring a one to two outage of L1301 each year. This estimate also includes switchyard maintenance of $15.3K for CF and $27.7K for MFATS3.
2. CF T33 transformer addition in 2018 for estimated $4.05M, 67 MVAR capacitor addition at HVY TS for estimated $5.0M and new 50MVA transformer T3 in HV-GB for estimated $3.8M in 2017 dollars.
3. Estimated remaining NBV on CF T33 and 67 MVAR cap banks and T3 at HVY.
4. Estimated gas turbine fuel expense as a result of operating the GT for one week per year for WPLM program.

Table J.2 Option 2 Cash Flow ($ Escalated to Current Year)

Year	Annual O&M ($)	Expense 1 ($)	Expense 2 ($)	Expense 3 ($)
2017				
2018	460,004[1]	17,731,500[2]	165,762[5]	
2019	491,893[3]	2,247,000[2]	178,272	(62,314)[6]
2020	503,296		198,601	(87,704)
2021	514,836		206,420	(89,074)
2022	526,806		206,420	(89,742)
2023	539,055		206,420	(90,892)
2024	551,588		206,420	(92,064)
2025	564,412		206,420	(93,240)
2026	577,535		206,420	(94,428)
2027	590,962		206,420	(95,630)
2028	604,702		206,420	(96,856)
2029	618,762		206,420	(97,842)
2030	633,148		206,420	(99,082)
2031	647,868		206,420	(100,348)
2032	662,931		206,420	(101,364)
2033	678,345		206,420	(102,390)
2034	694,116		206,420	(103,694)
2035	710,254		206,420	(104,742)
2036	726,768		206,420	(105,798)
2037	743,665		206,420	(106,866)
2038	760,995		206,420	(108,220)
2039	778,647		206,420	(109,310)
2040	796,751		206,420	(110,692)
2041	815,275		206,420	(111,806)
2042	834,231	(10,433,760)[4]	206,420	(113,218)

1. L1301/L1302 WPLM Estimated cost of $450K in 2017 dollars, including transmission line cross arm replacement program. This estimate also includes switchyard maintenance of $15.3K for CF and $27.7K for MFATS3.
2. One single 6 km, 138 kV transmission line from MFATS2 to MFA Tap. Includes partial 138 kV ring bus at MFATS2 and terminal station upgrades at HVY, including new 50MVA transformer.
3. L1301/L1302 WPLM Estimated cost of $469.9K in 2017 dollars. This estimate also includes switchyard maintenance of $15.3K for CF, $27.7K for MFATS3 and $10.8K for MFATS2 partial ring bus and $9.1K for new 6km transmission line.
4. Remaining NBV on 2018 Interconnection assets of one 6km 138kV line, partial ring bus at MFATS2, HVY TS breaker upgrades and new HVY transformer.
5. Estimated gas turbine fuel expense as a result of operating the GT for L1302 WPLM program.
6. Estimated loss savings assuming 2cents/kwh.

Table J.3 Option 3 Cash Flow ($ Escalated to Current Year)

Year	Annual O&M ($)	Expense 1 ($)	Expense 2 ($)	Expense 3 ($)
2017				
2018	460,004[1]	26,423,700[2]	165,762[5]	
2019	504,972[3]	1,899,100[2]	178,272	(62,314)[6]
2020	516,678		198,601	(87,704)
2021	528,526		206,420	(89,074)
2022	540,814		206,420	(89,742)
2023	553,388		206,420	(90,892)
2024	566,254		206,420	(92,064)
2025	579,419		206,420	(93,240)
2026	592,891		206,420	(94,428)
2027	606,676		206,420	(95,630)
2028	620,781		206,420	(96,856)
2029	635,214		206,420	(97,842)
2030	649,983		206,420	(99,082)
2031	665,095		206,420	(100,348)
2032	680,558		206,420	(101,364)
2033	696,381		206,420	(102,390)
2034	712,572		206,420	(103,694)
2035	729,139		206,420	(104,742)
2036	746,092		206,420	(105,798)
2037	763,439		206,420	(106,866)
2038	781,189		206,420	(108,220)
2039	799,351		206,420	(109,310)
2040	817,936		206,420	(110,692)
2041	836,953		206,420	(111,806)
2042	856,412	(14,765,838)[4]	206,420	(113,218)

1. L1301/L1302 WPLM Estimated cost of $450K in 2017 dollars. This estimate also includes switchyard maintenance of $15.3K for CF and $27.7K for MFATS3.
2. Two single 138 kV transmission line option from MFATS2 to HVY TS. Includes full 138 kV ring bus at MFATS2 and terminal station upgrades at HVY.
3. L1301/L1302 WPLM Estimated cost of $482.5K in 2017 dollars. This estimate also includes switchyard maintenance of $15.3K for CF, $27.7K for MFATS3 and $17.8K for MFATS2 full ring bus and $18.2K for two new 6km transmission line.
4. Remaining NBV of 2018 interconnection assets.
5. Estimated gas turbine fuel expense as a result of operating the GT for L1302 WPLM program.
6. Estimated loss savings assuming 2cents/kwh.

Table J.4 Option 4 Cash Flow ($ Escalated to Current Year)

Year	Annual O&M ($)	Expense 1 ($)	Expense 2 ($)
2017			
2018	460,004[1]	55,307,700[2]	
2019	555,839[3]	1,899,100[2]	(62,314)[5]
2020	568,724		(87,704)
2021	581,765		(89,074)
2022	595,291		(89,742)
2023	609,132		(90,892)
2024	623,294		(92,064)
2025	637,786		(93,240)
2026	652,614		(94,428)
2027	667,787		(95,630)
2028	683,314		(96,856)
2029	699,201		(97,842)
2030	715,457		(99,082)
2031	732,091		(100,348)
2032	749,112		(101,364)
2033	766,529		(102,390)
2034	784,351		(103,694)
2035	802,587		(104,742)
2036	821,247		(105,798)
2037	840,341		(106,866)
2038	859,879		(108,220)
2039	879,872		(109,310)
2040	900,329		(110,692)
2041	921,261		(111,806)
2042	942,681	(30,294,349)[4]	(113,218)

1. L1301/L1302 WPLM Estimated cost of $450K in 2017 dollars. This estimate also includes switchyard maintenance of $15.3K for CF and $27.7K for MFATS3.
2. Two single 138 kV transmission line option from MFATS2 to HVY TS. Includes full 138 kV ring bus at MFATS2, TS upgrades at HVY, and new 50MVA transformer at HVY.
3. Additional annual maintenance costs of $81.1K for L1303 ($54.5K), 6km new for L1302 ($9.1K) and MFATS2 ($17.5K).
4. Remaining NBV of 2018 interconnection assets.
5. Estimated loss savings assuming 2cents/kwh.

Table J.5 – Option 5 Cash Flow ($ Escalated to Current Year)

Year	Annual O&M ($)	Expense 1 ($)	Expense 2 ($)
2017			
2018	460,004[1]	76,000,000[2]	
2019	595,635[3]		(62,314)[5]
2020	609,443		(87,704)
2021	623,418		(89,074)
2022	637,912		(89,742)
2023	652,744		(90,892)
2024	667,920		(92,064)
2025	683,449		(93,240)
2026	699,339		(94,428)
2027	715,599		(95,630)
2028	732,237		(96,856)
2029	749,261		(97,842)
2030	766,681		(99,082)
2031	784,507		(100,348)
2032	802,746		(101,364)
2033	821,410		(102,390)
2034	840,508		(103,694)
2035	860,050		(104,742)
2036	880,046		(105,798)
2037	900,507		(106,866)
2038	921,444		(108,220)
2039	942,868		(109,310)
2040	964,789		(110,692)
2041	987,221		(111,806)
2042	1,010,173	(39,520,000)[6]	(113,218)

1. L1301/L1302 WPLM Estimated cost of $450K in 2017 dollars. This estimate also includes switchyard maintenance of $15.3K for CF and $27.7K for MFATS3.
2. Two single 138 kV transmission line option from MFATS2 to HVY TS. Includes full 138 kV ring bus at MFATS2,TS upgrades at HVY, new 2nd TS in HV-GB, new 2.5km line between TS's.
3. Additional annual maintenance costs of $119.1K for L1303 ($58.3K), 6km new for L1302 ($9.1K), 2.5km line ($3.8K), MFATS2 ($17.5K) and new TS ($30.4K).
4. Remaining NBV of 2018 interconnection assets.
5. Estimated loss savings assuming 2cents/kwh.

Appendix K

Reliability Analysis of Considered Options

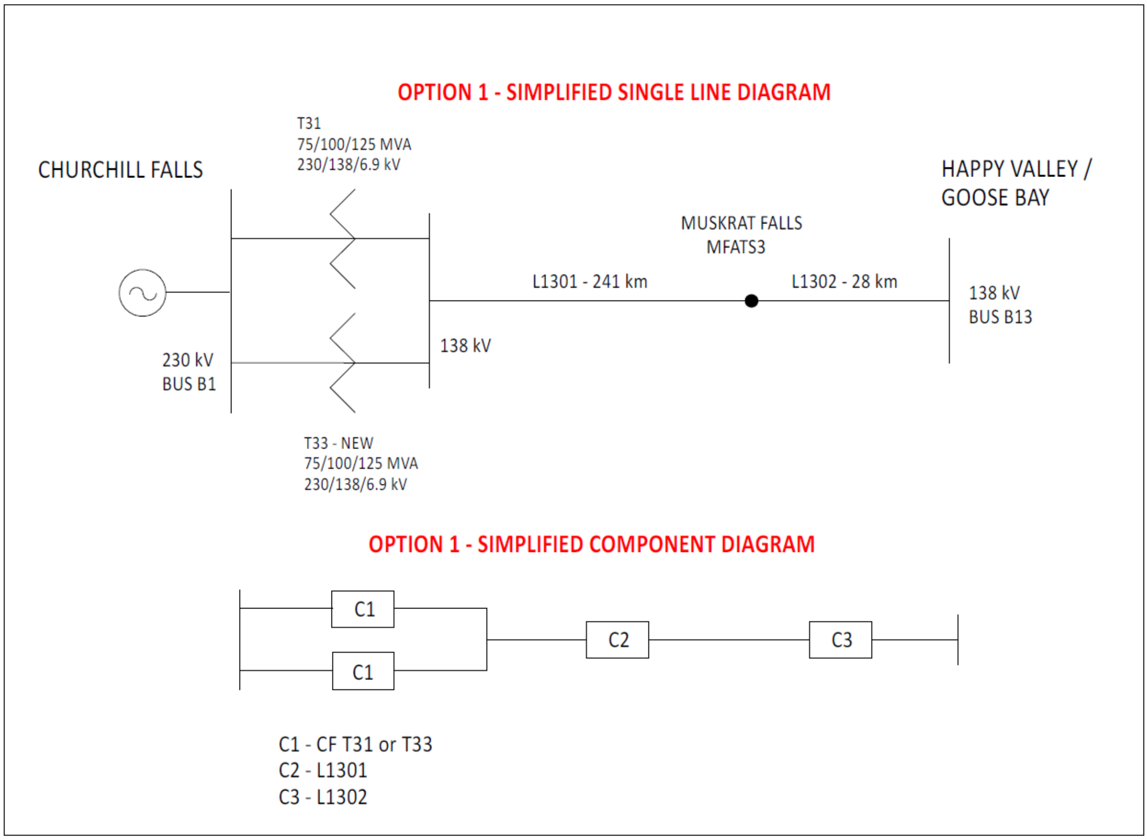


Figure K.1 Option 1 Simplified Single Line/Component Diagram

Table K.1 Option 1 Component Unavailability

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

1. L1301 = (0.886 occurrences / 100km.a) x 241 km = 2.1353
2. L1302 = (0.886 occurrences / 100km.a) x 28 km = 0.2481

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

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

$U_{C2C3se} = U_{C2} + U_{C3} - U_{C2} \times U_{C3} = 0.004588$

$U1 = U_{C1C1pa} + U_{C2C3se} - (U_{C1C1pa} \times U_{C2C3se}) = 0.00460$ (Unavailability of Option 1)

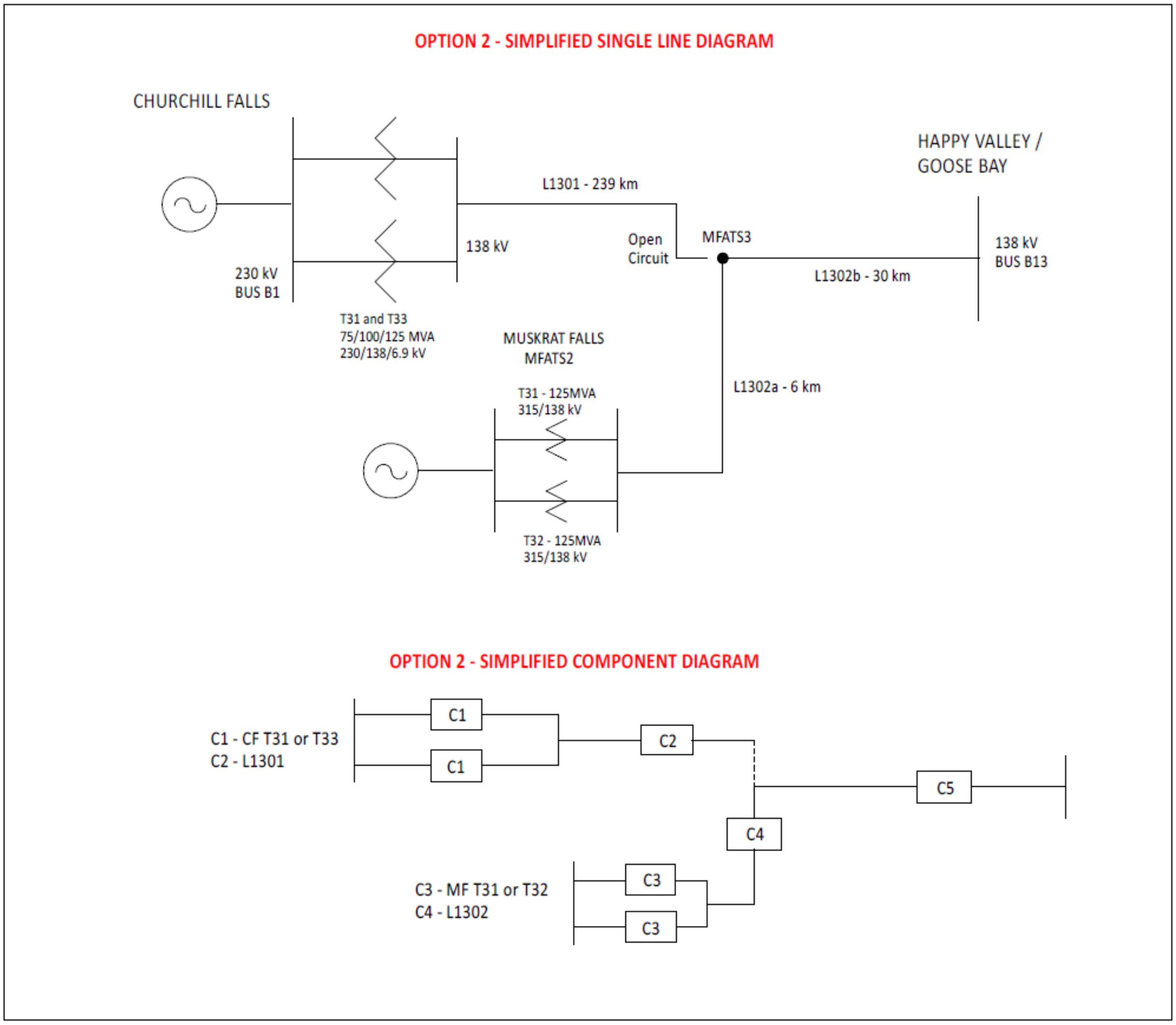


Figure K.2 Option 2 Simplified Single Line/Component Diagram

Table K.2 Option 2 Component Unavailability

Component	Description	Freq (f) Occur/year	Mean Time to Repair (r) (hours)	Mean Time to Repair (r) (Years)	Unavailability U (f x r)
C1	CF T31 or T33	0.1431	254.35	0.02904	0.00416
C2	L1301	2.11754 [1]	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 [2]	16.85	0.00192	0.000102
C5	L1302b (30km)	0.2658 [3]	16.85	0.00192	0.00051

1. L1301 = (0.886 occurrences / 100km.a) x 239 km = 2.11754
2. L1302a = (0.886 occurrences/100km.a) x 6 km = 0.05316
3. L1302b = (0.886 occurrences/100km.a) x 30 km = 0.2658

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

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

$U_{C1C1pa} = U_{C1} \times U_{C1} = 0.00416 \times 0.00416 = 0.0000173$
$U_{C1C1paC2se} = U_{C1C1pa} + U_{C2} – U_{C1C1pa} x U_{C2} = 0.004087$

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

$U_{C3C3pa} = U_{C3} \times U_{C3} = 0.011 \times 0.011 = 0.000121$
$U_{C3C3paC4se} = U_{C3C3pa} + U_{C4} – U_{C3C3pa} x U_{C4} = 0.000223$

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

$UiUii_{pa} = Ui \times Uii = 0.004087 \times 0.000223 = 0.000000495$
$UiUii_{pa\ C5se} = UiUii_{pa} + U_{C5} – UiUii_{pa} x U_{C5} = 0.00022$

$U_2 = U_i U_{iipa} + U_{C5} - (U_i U_{iipa} \times U_{C5}) = 4.95 \times 10^{-7} + 0.00051 – (4.95 \times 10^{-7} \times 0.00051)$

$U_2 = 0.00051$ (Unavailability of Option 2)

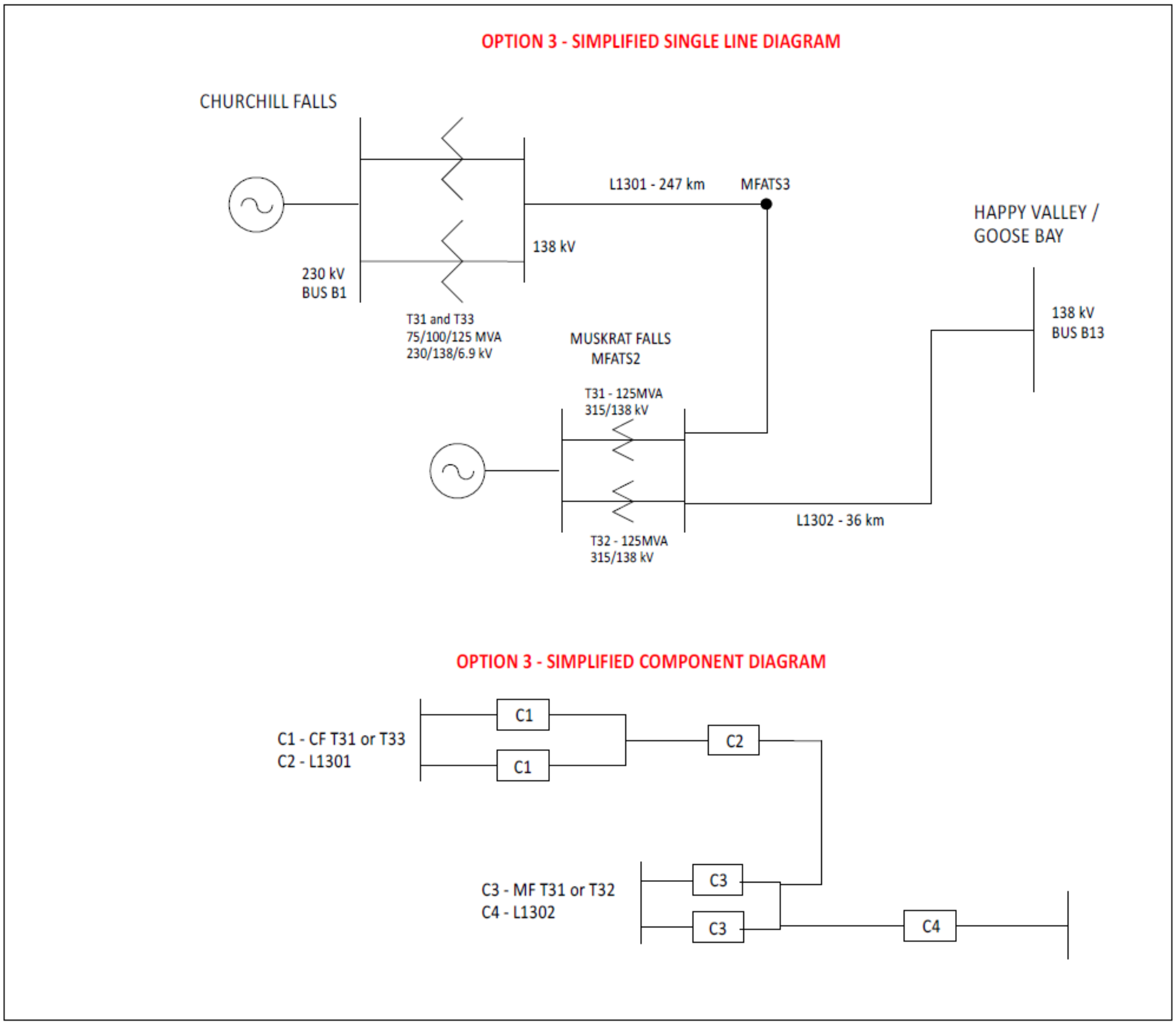


Figure K.3 Option 3 Simplified Single Line/Component Diagram

Table K.3 Option 3 Component Unavailability

Component	Description	Freq (f) Occur/year	Mean Time to Repair (r) (hours)	Mean Time to Repair (r) (Years)	Unavailability U (f x r)
C1	CF T31 or T33	0.1431	254.35	0.02904	0.00416
C2	L1301	2.1884 [1]	16.85	0.00192	0.00420
C3	MF T31 or MF T32	0.2020	477.0	0.05445	0.01100
C4	L1302	0.3190 [2]	16.85	0.00192	0.00061

1. L1301 = (0.886 occurrences / 100km.a) x 247 km = 2.1884
2. L1302 or L1303 = (0.886 occurrences/100km.a) x 36 km = 0.3190

Option 3 unavailability is derived by calculating the unavailability of the combination of the following:

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

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

$U_{C1C1paC2se} = U_{C1C1pa} + U_{C2} - U_{C1C1pa} \times U_{C2} = 0.004217$

ii) Parallel combination of the following; C3 in parallel with C3 and item i).

$U_{C3C3pa} = U_{C5} \times U_{C5} = 0.01100 \times 0.01100 = 0.0001210$

$U_{ii} = U_{C3C3pa} \times U_{i} = 0.0001210 \times 0.004217 = 5.1 \times 10^{-7}$

iii) Series combination of items ii and C4.

$\mathbf{U_3 = U_{ii} + U_{C4} - (U_{ii} \times U_{C4}) = 5.1 \times 10^{-7} + 0.00061 - (5.1 \times 10^{-7} \times 0.00061)}$

U_3 = 0.000611 **(Unavailability of Option 3)**

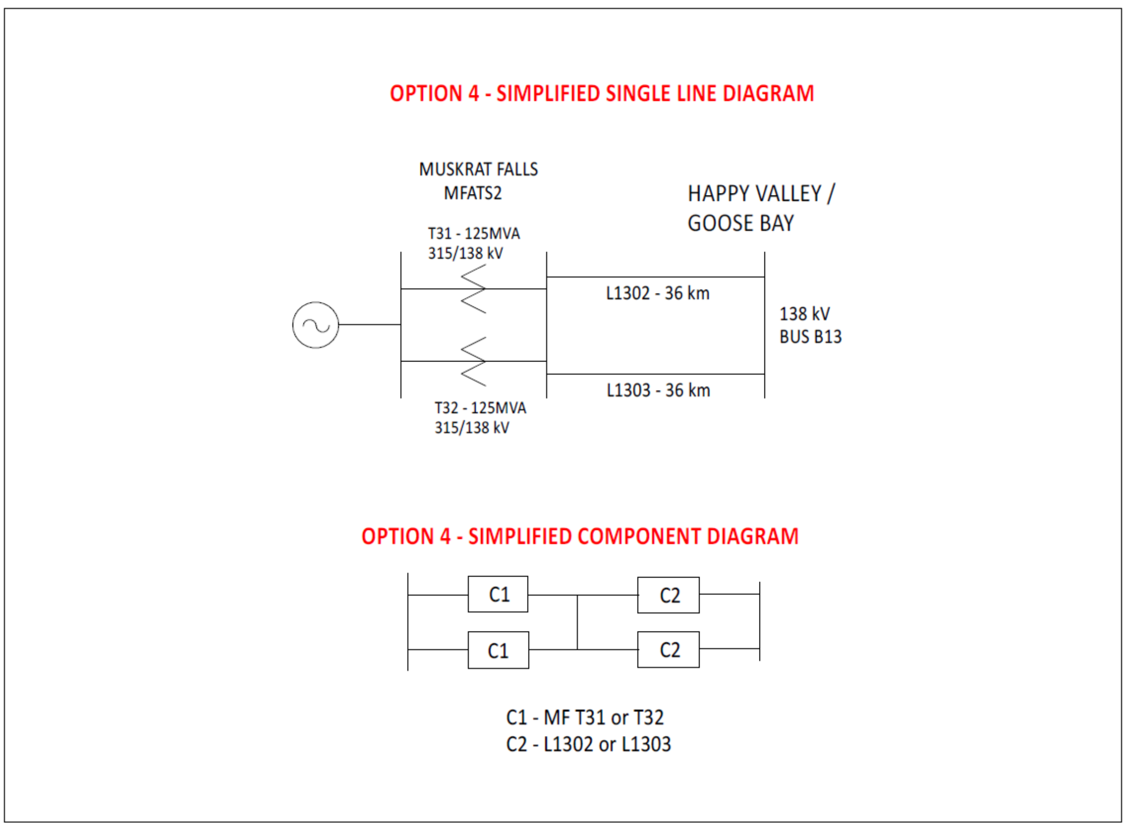


Figure K.4 Option 4 Simplified Single Line/Component Diagram

Table K.4 Option 4 Component Unavailability

Component	Description	Freq (f) Occur/year	Mean Time to Repair (r) (hours)	(Years)	Unavailability U (f x r)
C1	MF T31 or MF T32	0.2020	477.0	0.05445	0.01100
C2	L1302 or L1303	0.3190 [1]	16.85	0.00192	0.00061

1. L1302 or L1303 = (0.886 occurrences/100km.a) x 36 km = 0.3190

Option 4 unavailability is derived by calculating the unavailability of the parallel combination of C1 and C1 in series with parallel components C2 and C2 as follows:

$U_{C1C1pa} = U_{C1} \times U_{C1} = 0.01100 \times 0.01100 = 0.0001210$
$U_{C2C2pa} = U_{C2} \times U_{C2} = 0.00061 \times 0.00061 = 0.0000004$
$(U_{C1C1pa}\ U_{C2C2pa})_{se} = U_{C1C1pa} + U_{C2C2pa} - U_{C1C1pa} \times U_{C2C2pa} = 0.000121$
U4 = 0.000121 (Unavailability of Option 4)

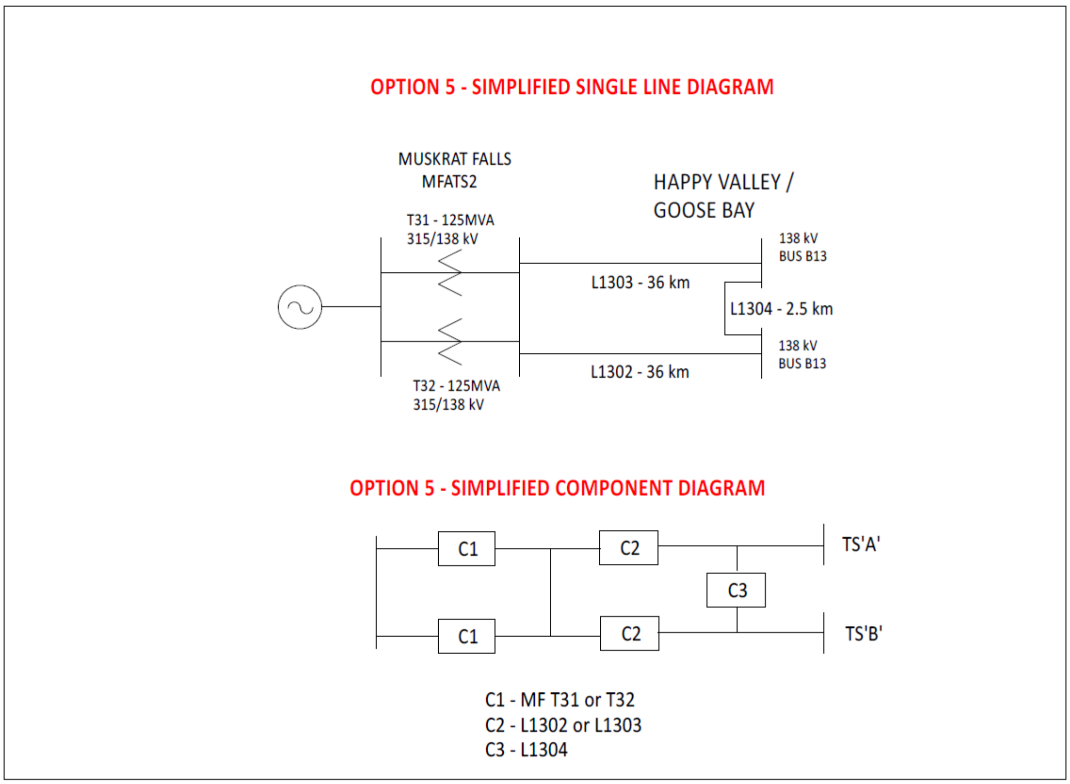


Figure K.5 Option 5 Simplified Single Line/Component Diagram

Table K.5 Option 5 Component Unavailability

Component	Description	Freq (f) Occur/year	Mean Time to Repair (r)		Unavailability U (f x r)
			(hours)	(Years)	
C1	MF T31 or MF T32	0.2020	477.0	0.05445	0.01100
C2	L1302 or L1303	0.3190 [1]	16.85	0.00192	0.00061
C3	L1304	0.02215 [2]	16.85	0.00192	0.000043

1. L1302 or L1303 = (0.886 occurrences/100km.a) x 36 km = 0.3190
2. L1304 = (0.886 occurrences/100km.a) x 2.5 km = 0.02215

For purposes of the analysis, it is assumed that both Terminal Stations in HV-GB region, TS'A' and TS'B' in Figure K.5 above, are assumed to be loaded evenly and unavailability at one Terminal Station will be identical to the other, as per the following calculation.

Loss of supply to TS'A' is derived by calculating the unavailability of the parallel combination of C1 and C1 in series with the parallel combination of components C2 and C2 / C3 as follows:

$U_{C1C1pa} = U_{C1} \times U_{C1} = 0.01100 \times 0.01100 = 0.0001210$
$U_{C2C3se} = U_{C2} + U_{C3} - U_{C2}\, U_{C3} = 0.00061 + 0.000043 – (0.00061 \times 0.000043) = 0.000653$
$U_{C2}(U_{C2C3se})_{pa} = U_{C2} \times U_{C2C3se} = 0.00061 \times 0.000653 = 3.98 \times 10^{-7}$

U5 = U_{C1C1pa} **+** $U_{C2}(U_{C2C3se})_{pa} - (U_{C1C1pa} \times U_{C2}(U_{C2C3se})_{pa})$
U5 = 0.000121 + 3.98x10^{-7} – (0.000121 x 3.98x10^{-7})
U5 = 0.000121

(Unavailability of Option 5)