



 Approved for Release	<u>Aug 25 2011</u> Date
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# PRELIMINARY TRANSMISSION SYSTEM ANALYSIS

## MUSKRAT FALLS TO CHURCHILL FALLS TRANSMISSION VOLTAGE

Date: November 2010

System Planning Department



## EXECUTIVE SUMMARY

Given the potential of development of Muskrat Falls prior to Gull Island, a preliminary transmission analysis is warranted to determine the appropriate transmission operating voltage for the Muskrat Falls to Churchill Falls transmission system. The purpose of this analysis is to provide guidance on the appropriate transmission voltage level for project costing.

Preliminary analysis indicates that at least four single conductor per circuit 230 kV transmission lines would be required between Muskrat Falls and Churchill Falls for stable operation of the power system during expected contingencies. Moving to a two conductor bundle at 230 kV results in a minimum of three 230 kV transmission lines between Muskrat Falls and Churchill Falls to provide reasonable assurances of stable system operation.

Alternatively, moving to the 362 kV transmission class indicates that a minimum of two 315 kV or two 345 kV transmission lines can be expected to provide reasonable system performance. There are advantages and disadvantages of each the 315 kV and 345 kV operating voltage.

For project costing it is recommended that two 345 kV transmission lines with a two conductor bundle of 795 MCM 26/7 ACSR “DRAKE” per phase be assumed. In addition, to ensure acceptable voltage control on line open end conditions four 345 kV, 45 MVAR shunt reactors (one per each transmission line end) be included.

Detailed stability studies in final design will be required to determine the technical applicability of moving to a 315 kV operating voltage level.

Further analysis is required to determine if application of on load tap changers on the 735/345 kV autotransformers can be sized to provide the necessary voltage control and eliminate the need for independent shunt reactors. This will ultimately be a decision of economics and operability in final project design.

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## INTRODUCTION

The Lower Churchill Project (LCP) consists of a 2250 MW hydroelectric generating station at Gull Island and an 824 MW hydroelectric generating station at Muskrat Falls. Gull Island and Muskrat Falls are located 225 km and 285 km downstream of the Upper Churchill hydro electric facility respectively. Once completed, the project is expected to include high voltage ac transmission lines between Churchill Falls and Gull Island, Gull Island and the Province of Québec, Gull Island and Muskrat Falls, Muskrat Falls and Happy Valley and an HVdc transmission line between Labrador and the Island of Newfoundland.

Given that the total project capacity exceeds the provincial requirements, project construction requires access to the electricity market in northeastern North America. The size of the combined market, and route(s) to those markets, will ultimately determine the timeline and which component(s) of the project are completed.

The purpose of this preliminary transmission system analysis is to determine an acceptable transmission voltage level between Muskrat Falls and Churchill Falls for project costing. The HVdc transmission line between Muskrat Falls in Labrador and Soldier's Pond on the Island of Newfoundland is assumed to be part of the Muskrat Falls first scenario.

Figure 1 provides an overview of the proposed transmission layout of the Muskrat Falls site. High voltage power cables will be used to connect the high voltage winding of the generator unit step up transformers to an ac switchyard on the south bank of the Churchill River. There will be two connections from the ac switchyard to the HVdc converter station, which will also be located on the south bank. An HVdc bipole transmission line will connect the Muskrat Falls Converter Station to the Soldiers Pond Converter Station on the Island of Newfoundland approximately 1100 km away. High voltage ac transmission lines will be used to connect the Muskrat Falls ac switchyard to the Labrador Interconnected Transmission System located on the north side of the Churchill River. A tap station is proposed on the north bank of the Churchill River for termination of the 138 kV transmission system to Happy Valley – Goose Bay. Location of this tap station on the north side of the river limits the number of ac transmission line crossings of the river, thereby minimizing line congestion on the relatively narrow crossing path. Ac transmission lines following the existing TL240 (L1301) route will connect the tap station on the north side of the river to Churchill Falls.

The analysis does not address the economics of Muskrat Falls before Gull Island, the constructability of such a concept, or any water management issues. The analysis is completed using the Siemens Power Technologies Int. software package PSS/E version 30.2.

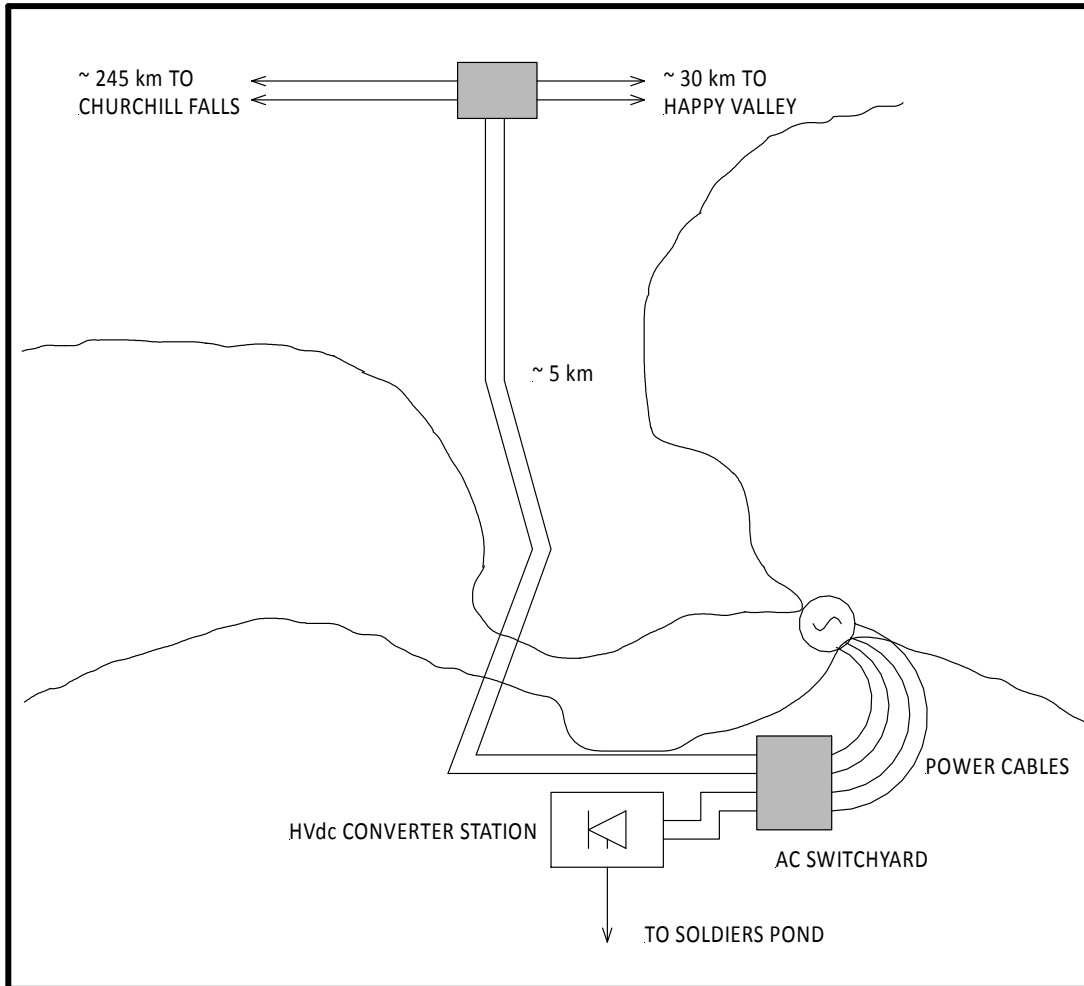


Figure 1 – Muskrat Falls Transmission Layout

## TRANSMISSION PLANNING CRITERIA

On at least two occasions in Newfoundland and Labrador Hydro (NLH) has been reviewed by independent consultants appointed by the Public Utilities Board of Newfoundland and Labrador. On each occasion the following list has been provided as summary of NLH's Transmission Planning Practices:

- NLH's bulk transmission system is planned to be capable of sustaining the single contingency loss of any transmission element without loss of system stability;
- In the event a transmission element is out of service, power flow in all other elements of the power system should be at or below normal rating;
- The NLH system is planned to be able to sustain a successful single pole reclose for a line to ground fault based on the premise that all system generation is available;
- Transformer additions at all major terminal stations (i.e. two or more transformers per voltage class) are planned on the basis of being able to withstand the loss of the largest unit;
- For single transformer stations there is a back-up plan in place which utilizes NLH's and/or Newfoundland Power's mobile equipment to restore service;
- For normal operations, the system is planned on the basis that all voltages be maintained between 95% and 105%; and
- For contingency or emergency situations voltages between 90% and 110% is considered acceptable.

## TRANSMISSION VOLTAGE LEVEL

Under normal operation it is expected that the HVdc transmission line to the Island of Newfoundland (the Island Link) will be loaded to near 824 MW during peak load periods. With the full capacity of the Muskrat Falls Generating Station being transmitted over the Island Link, the transmission system between Churchill Falls and Muskrat Falls would be required to deliver the peak load of the Happy Valley – Goose Bay area. The forecast peak for this region is on the order of 85 MW in the 2017 time frame assuming a 20 MW electric boiler load at 5 Wing Goose Bay. Given the relatively low load to be delivered by the transmission system between Churchill Falls and Muskrat Falls, one would assume that a relatively “slight” transmission system consisting of a single or double 230 kV transmission line would suffice. However, there are a number of factors that must be assessed in selecting the number of transmission lines and the transmission voltage level between Churchill Falls and Muskrat Falls.

With respect to the number of transmission lines between Churchill Falls and Muskrat Falls standard transmission planning criteria stipulate that one must be able to serve the load for loss of a single transmission element, such as a transmission line<sup>1</sup>. In the case of the Muskrat Falls interconnection, loss of a single transmission line between Churchill Falls and Muskrat Falls would mean a shortfall of 85 MW of capacity during peak load conditions. Either the load in Happy Valley - Goose Bay would have to be curtailed, or the deliveries to Newfoundland via the Island Link would have to be reduced. Should the deliveries to Newfoundland be used to meet firm load on the Island, the loss of a single transmission line between Churchill Falls and Muskrat Falls followed by a reduction in Island Link loading to continue supply to Happy Valley – Goose Bay would result in an inability to supply firm load on the Island. This, in turn, would be a violation of the transmission planning criteria. As there has been no decision as to whether or not power delivered via the Island Link will be considered non-firm delivery for, say the maritime market, the transmission in Labrador must be planned for firm deliveries with one transmission element out of service. Therefore, a minimum of two transmission lines will be required between Churchill Falls and Muskrat Falls.

In considering the power transfer capability between Churchill Falls and Muskrat Falls, one must look beyond the normal operation where only the peak load at Happy Valley – Goose Bay must be supplied. During an outage to a generating unit at Muskrat Falls (either forced or maintenance outage), it is expected that the 206 MW capacity reduction will be supplied by generation at Churchill Falls under a water management agreement. That being said, the transmission system between Churchill Falls and Muskrat Falls would need to be capable of delivering the 206 MW generation deficit at

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<sup>1</sup> NERC Standard TPL-002-0a – System Performance Following Loss of a Single BES Element Table I stipulates for Category B contingencies (events resulting in the loss of a single element – 2. Transmission circuit) there will be no loss of demand or curtailment of firm transfers. This criterion has been applied to the bulk system on the Island Interconnected Transmission System with the exception that loss of a generator will initiate under frequency load shedding given the isolated nature of the system.



Muskrat Falls plus the 85 MW peak load of Happy Valley – Goose Bay, or 291 MW in total.

Further, the Island Link is being designed and integrated into the transmission system on the Island of Newfoundland such that the Island Interconnected Transmission System will remain stable for a temporary pole-to-pole fault on the overhead HVdc transmission line. In the event of a temporary HVdc pole-to-pole fault the HVdc system will shutdown to clear the fault, then restart following a preset time to allow for the arc to extinguish and the air to de-ionize. The total time that the Island Link will be out of service is set at 350 msec (21 cycles). To ensure that the Island Interconnected Transmission System remains stable during this temporary outage, system upgrades including high inertia synchronous condensers are being added to maintain an acceptable voltage level and system frequency for restart of the converter station at Soldiers Pond. There will be a corresponding impact to the Labrador Interconnected Transmission System due to this temporary outage. With the shutdown of the Island Link for the 350 msec, there will be up to 824 MW of excess power on the Labrador Interconnected Transmission System that must be handled in the short term. With the Labrador Interconnected Transmission System being connected to the much larger Hydro Québec TransÉnergie (HQT) transmission system<sup>2</sup>, the HQT system will act as the dynamic “shock absorber” accepting the swing of 824 MW into its system for the 350 msec restart time. Clearly, if the Labrador Interconnected Transmission System is to remain stable during the temporary HVdc pole-to-pole fault, the transmission system between Churchill Falls and Muskrat Falls must be capable of dynamically delivering up to 824 MW into the 735 kV transmission system at Churchill Falls without loss of angular stability at Muskrat Falls.

A preliminary load flow analysis is used to assess the steady state angular displacement between the Muskrat Falls generators and both the Churchill Falls generators and the HQT system during the temporary HVdc pole-to-pole outage. Steady state angular displacements above 30° - 35° are indicative of conditions that may experience angular stability issues during dynamic events such as the temporary loss of the Island link.

For the preliminary analysis the Muskrat Falls generator terminal voltage is held at 15 kV (1.00 pu.), the Churchill Falls 735 kV bus voltage is held at 735 kV with the plant at 5428 MW and the Montagnais 735 kV bus voltage is held at 735 kV.

Given that the voltage levels in Churchill Falls are 230 kV and 735 kV, the analysis begins with single circuit, single conductor per phase 230 kV transmission lines. Typical conductor sizes for Newfoundland and Labrador Hydro range from 636 kcmil, 26/7 ACSR

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<sup>2</sup> The Hydro Québec System consists of approximately 30,000 MW of generation compared to the proposed 6252 MW Labrador System (5428 MW Churchill Falls Generating Station plus 824 MW Muskrat Falls Generating Station).

“GROSBEAK” to 1431 kcmil, 54/19 ACSR “PLOVER”. An 1192.5 kcmil, 54/19 ACSR “GRACKLE” conductor was selected for the single conductor per phase analysis.

The 1999 EHV Transmission Lines in Labrador report by RSW – EDM Joint Venture recommended that the 230 kV transmission system between Gull Island and Muskrat Falls consist of a double circuit line with a two conductor bundle of 1354 kcmil 48/7 ACSR “BERSFORT” per phase. As part of the preliminary analysis of transmission voltage versus steady state angular displacement, 230 kV transmission lines with a two conductor bundle consisting of 1354 kcmil 48/7 ACSR “BERSFORT” is included.

Beyond the 230 kV voltage level, the next voltage level is the 362 kV voltage class. HQT operates 315 kV transmission lines throughout its network including a 315 kV transmission line originating at its Montagnais Substation. Both NB Power and Nova Scotia Power operate 345 kV transmission lines in their respective transmission systems. For this preliminary analysis a two conductor bundle of 795 kcmil 26/7 ACSR “DRAKE” is used for the 362 kV class transmission lines.

Table 1 summarizes the results of the preliminary analysis considering single conductor 230 kV, two conductor bundle 230 kV, two conductor bundle 315 kV and two conductor bundle 345 kV transmission lines.

Table 1 Preliminary Analysis – Angular Displacement 824 MW from Muskrat Falls to Churchill Falls			
kV	Circuits	Angle MF to CF	Angle MF to HQT
230	Three 1C x 1192.5 kcmil ACSR “GRACKLE”	39.2°	56.6°
230	Four 1C x 1192.5 kcmil ACSR “GRACKLE”	28.0°	45.4°
230	Two 2C x 1354 kcmil ACSR “BERSFORT”	44.2°	61.6°
230	Three 2C x 1354 kcmil ACSR “BERSFORT”	26.9°	44.4°
315	Two 2C x 795 kcmil ACSR “DRAKE”	23.3°	40.8°
345	Two 2C x 795 kcmil ACSR “DRAKE”	19.1°	36.6°

The results indicate that at least four single conductor per phase 230 kV transmission lines, three double conductor bundle 230 kV transmission lines, or two 315/345 kV transmission lines are required to provide reasonable angular stability between Muskrat Falls and Churchill Falls.

Application of the St. Clair curve can be used to verify the preliminary results prior to detailed stability analysis. The St. Clair curve determines transmission line loadability using the surge impedance loading (SIL) of the line and the line length. For a 250 km long transmission line the St. Clair curve sets the load limit at approximately 1.4 times its

SIL. Table 2 summarizes the transmission requirements for the Muskrat Falls to Churchill Falls transmission route based upon the St. Clair curve.

Table 2 Muskrat Falls to Churchill Falls Transmission Requirements Based upon St. Clair Curve 824 MW Transfer Limit – 250 km			
Option	SIL MW	Max MW per circuit	Req'd # of circuits
230 kV – 1C x 1192.5 kcmil ACSR “GRACKLE”	140	196	4.2
230 kV – 2C x 1192.5 kcmil ACSR “GRACKLE”	194	272	3.0
315 kV – 2C x 795 kcmil ACSR “DRAKE”	328	459	1.8
345 kV – 2C x 795 kcmil ACSR “DRAKE”	393	550	1.5

Based upon the St. Clair curve an adequate stability margin should be obtainable with three double conductor bundle 230 kV transmission lines or two 315/345 kV transmission lines. To minimize the width of the transmission corridor between Muskrat Falls and Churchill Falls, the 362 kV class transmission solution is selected for further analysis. Both 315 kV and 345 kV each have advantages and disadvantages.

At 315 kV there is a 14.9% over voltage margin for 362 kV class station equipment, while at 345 kV there is a 4.9% margin. Consequently, one can expect tighter voltage operating limits at 345 kV.

The application of 315 kV leaves provisions for a 315 kV transmission system to Labrador West with future connection to HQT’s 315 kV system at Mount Wright.

Application of 315 kV results in higher phase currents and subsequently higher line losses assuming the same conductor and load transfer than 345 kV transfer. However, as the dominant transfer is via the HVdc Island Link and not the connection to Churchill Falls, a transmission line loss evaluation is not expected to be a deciding fact for the interconnection voltage.

The application of 315 kV for the Muskrat Falls interconnection will have lower transmission line charging (approximately 20 MVAR less per circuit than the corresponding 345 kV circuit) with corresponding lower open circuit line end voltages during restoration with potentially lower rated shunt reactors, if required. However the lower line charging results in a reduction in maximum power transfer as indicated by a 315 kV SIL of 328 MW versus a 345 kV SIL of 393 MW.

It is common practice to employ shunt reactors to assist in voltage control on 362 kV class transmission systems. At NB Power 37.5 MVAR shunt reactors are connected to the tertiary windings of 345 kV autotransformers to provide the necessary voltage

control on its 345 kV network. At Nova Scotia Power shunt reactors range in size from 25 MAR to 50 MVAR depending on the 345 kV line length. At HQT 315 kV shunt reactors on the north east axis are sized at 110 - 150 MVAR. Studies completed by SNC-Lavalin for the Lower Churchill Development Corporation in 1980 considered 40 MVAR shunt reactors for a 345 kV transmission system between Muskrat Falls and Churchill Falls. Preliminary analysis of energization of a single 345 kV line from the Churchill Falls end indicates that the Muskrat Falls 345 kV bus voltage will reach 370.8 kV (1.075 p.u.) without voltage reduction equipment. A nominal 45 MVAR shunt reactor at Muskrat Falls reduces the 345 kV bus voltage to 354.4 kV (1.027 p.u.), which is more acceptable for synchronizing the Muskrat Falls generators.

## CONCLUSIONS

Preliminary analysis indicates that at least four single conductor per circuit 230 kV transmission lines would be required between Muskrat Falls and Churchill Falls for stable operation of the power system during expected contingencies. Moving to a two conductor bundle at 230 kV results in a minimum of three 230 kV transmission lines between Muskrat Falls and Churchill Falls to provide reasonable assurances of stable system operation.

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