WHENEVER. WHEREVER.
We'll be there.

NEWFOUNDLAND POWER
A FORTIS COMPANY

DELIVERED BY HAND

October 14, 2016

Board of Commissioners
of Public Utilities
P.O. Box 21040
120 Torbay Road
St. John's, NL A1A 5B2

Attention: G. Cheryl Blundon
Director of Corporate Services
and Board Secretary

Ladies and Gentlemen:

Re: The Board's Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System - Phase Two

Please find enclosed the original and 12 copies of the expert report of Mr. Elias Ghannoum filed on behalf of Newfoundland Power.

If you have any questions regarding the enclosed, please contact the undersigned at your convenience.

Yours very truly,

Gerard M. Hayes
Senior Counsel

Enclosures

Newfoundland Power Inc.
55 Kenmount Road • P.O. Box 8910 • St. John's, NL A1B 3P6
PHONE (709) 737-5609 • FAX (709) 737-2974 • ghayes@newfoundlandpower.com

c. Tracey Pennell
Newfoundland and Labrador Hydro

Paul Coxworthy
Stewart McKelvey Stirling Scales

Danny Dumaresque

Thomas Johnson, QC
O'Dea Earle Law Offices

Roberta Frampton Benefiel
Grand Riverkeeper Labrador, Inc.

Newfoundland Power Inc.
55 Kenmount Road • P.O. Box 8910 • St. John's, NL A1B 3P6
PHONE (709) 737-5609 • FAX (709) 737-2974 • **ghayes@newfoundlandpower.com**

Reliability Assessment of the Labrador Island Link

October 14, 2016

Prepared by: Elias Ghannoum

Contents

Annexes

Annex 1: Summary of Select Exhibits, Muskrat Falls Review

Annex 2: Elias Ghannoum CV

1. Introduction

I have been asked by Newfoundland Power (NP) to review the design of the HVdc Labrador Island Link ("LIL") to be built as part of the Muskrat Falls hydroelectric project in Labrador (the "Project"), with particular emphasis on the reliability of the overhead transmission line portion of the LIL. The overhead portion of the LIL consists of an 1,100 km long ±350 kV bi-pole line. The LIL also incorporates a submarine cable crossing under the Strait of Belle Isle.

Nalcor Energy ("Nalcor"), the owner of the Project, is a provincial Crown corporation of the Government of Newfoundland and Labrador, headquartered in St. John's, Newfoundland. The Project, when completed, will provide Newfoundland and Labrador Hydro's ("Hydro") largest single source of electricity supply to the Island Interconnected system ("IIS"). For this reason, an assessment of the reliability of the LIL is essential to any assessment of the reliability of the IIS.

The objective of my review is to provide the Board of Commissioners of Public Utilities (the "Board") with an expert assessment of the expected reliability of the LIL in its investigation of the post-Muskrat Falls reliability of the IIS. In preparing my opinion, I have reviewed a large number of reports and exhibits made available to me by NP, and analyzed numerous Hydro responses to Requests for Information ("RFIs"). The information sources I have relied upon are referenced in this report.

The applicable Canadian standard for the design of overhead transmission lines is the *National Standard of Canada CAN/CSA-C22.3 No. 60826-10 Design criteria of overhead transmission lines* (the "CSA Standard"), which is an adoption, with Canadian deviations, of the identically titled CEI/IEC (International Electrotechnical Commission) Standard 60826 (third edition, 2003-10) (the "CEI/IEC Standard"). In completing my assessment of the reliability of the LIL, I have focused principally on the use and application of the CSA Standard in the design of the overhead portion of the LIL.

2. Overview

2.1 Overhead Transmission Lines

Once electricity is generated, it has to be transmitted and distributed to end users. In North America, the bulk movement of electrical energy from a generating plant to an electrical substation, from which it is then distributed to users, is typically accomplished by means of overhead transmission lines ("OTL").

An OTL generally consists of one or more uninsulated conductors suspended on steel towers or wooden poles. As with all power line design, a major goal of OTL design is to provide reliable support for the conductors. Another objective of OTL design is to maintain adequate clearance between energized conductors and the ground so as to prevent dangerous contact with the line. Such lines must be designed to be resilient to all potential causes of damage, including storms, ice load, lightning, earthquakes and other perils.

Engineers design networks of transmission lines to transport generated power as efficiently as feasible, while at the same time taking into account economic factors, network safety and redundancy.

Transmission infrastructure is expensive. A transmission line may cost in excess of $1 million per kilometer. It is not practically and economically feasible to build transmission lines that will never fail. It is therefore important to build redundancy into the system. Typically, a transmission line is built to transport power from a single generating station to the network or to provide an alternative transmission route in the event another line is out of order. If a line or a generator fails, the redundancy built into the system ensures customers are not deprived of their electricity supply for an extended period.

2.2 Transmission Line Design Considerations

There are many considerations that need to be taken into account when designing a transmission line. Some of these design considerations include (i) reliability level, (ii) redundancy and backup options, (iii) route selection, (iv) distance from the load, and (v) climatic conditions.

2.2.1 Reliability Level

An OTL can be designed for different reliability levels depending on its function within a supply network. The function of the line within a supply network determines the level of reliability required. OTLs that are of critical importance in a supply network should be designed to a higher standard than those that are of secondary or lesser importance. Typically, a higher OTL reliability level corresponds to a higher initial direct cost.

2.2.2 Redundancy and Back-up Options

Redundancy is incorporated in the design of OTL systems to either prevent or recover from the failure of a specific component or system. Redundancy can take the form of a parallel line, another source of power supply, back-up generation, or other alternatives.

In the case of the Project, adding redundancy to the LIL could involve construction of a parallel line (preferably in a different corridor), or adding generation on the Island where the majority of load is located. The Maritime Link can be considered as a potential source of back-up generation as long as the overhead lines required to carry power to the St. John's area are available, that it is possible to reverse the flow of power as and when required, and that the power will be available when needed.

2.2.3 Route Selection

The selection of the route is an important matter to be considered in the design of an OTL. A shorter line will generally be less costly than a longer line. However, the shortest route may not be feasible for a number of reasons. In addition to such basic considerations as land availability and the suitability of terrain for construction, matters of interest to the general public (e.g. environmental issues, aesthetic concerns) must be considered.

Route selection may be constrained by the presence of other infrastructure, including other electrical system infrastructure. In addition, the selection of the route may be influenced by weather loads. In the case of the LIL, for example, parts of the route have been selected so as to minimize exposure to severe icing. Icing is a hazard that can result, and has resulted, in line failure in Newfoundland and Labrador.

Accessibility is also an important issue with respect to maintenance and repairs. Transmission lines should be, to the extent possible, sited in locations that have good accessibility. Relative ease of access will tend to minimize maintenance costs and emergency response times.

2.2.4 Distance from Load

Ideally the power generation should be as close as possible to end users. Shorter transmission lines are less costly to build and maintain. Power losses increase with the length of the line. In addition, exposure to hazards, such as climatic and weather loads, increases with the length of an OTL. This is particularly important for the LIL.

2.2.5 Climatic Conditions

The exposure to climatic and weather loads is of prime importance in OTL design because weather conditions such as high winds, ice accretion on towers and conductors, exposure to corrosive effects of sea salt near the sea, and frost penetration in the ground, can cause deterioration and lead to failure of OTL conductors, towers and other components.

Engineers have to consider all of these effects and must design line components to ensure reliable and safe operation. The impact on line cost may be significant when anticipated weather conditions are severe.[1]

Heavy accumulation of ice on OTL components is a safety concern. When it accumulates on conductors, it causes them to sag. If the accumulation of ice exceeds design values, the reduced ground clearance

[1] The LIL is exposed to one of the most severe climates in North America.

increases the risk of electrical shocks and short circuits to objects underneath the line, as well as electrocution hazard to the general public. Icing above the design value also increases the mechanical tension in the conductor and can sometimes lead to its rupture and cascading failures of support structures that might extend to tens of towers.[2]

Climatic and weather loads for OTL design are selected on the basis of the "return period" of specific weather conditions. For example, a specified level of radial ice accumulation on a transmission line conductor may be determined on the basis of scientific evaluation to occur once, on average, every 50 years. In that case, the specified ice accumulation is said to have a return period of 50 years.

2.3 Transmission Line Standards

The CEI/IEC Standard is the internationally accepted standard for determining design criteria for overhead transmission lines.[3] The CSA Standard incorporates appropriate Canadian deviations from the CEI/IEC Standard.[4,5] The CSA Standard provides a methodical approach to determining design criteria for overhead transmission lines in Canada.

2.3.1 CSA and CEI/IEC Standard Approach

The CSA and CEI/IEC standards specify the loading and strength requirements of overhead lines derived from reliability based design principles. The reliability based design approach develops design criteria that meet a target reliability level or return period.[6] It recognizes that design loads can be exceeded, potentially leading to failures of line components and unavailability of the OTL.

The CSA and CEI/IEC standards provide for a minimum reliability level or return period of 50 years for OTL design. In other words, the standards aim to provide for the design of an OTL that will withstand maximum design loads that are expected to be encountered, on average, once in 50 years. In areas where OTLs are subjected to significant ice loading, the minimum requirements may be augmented based on local evidence. For example, in Newfoundland and Labrador and Quebec, there exist meteorological research studies and measurements of ice loadings in addition to those provided in the CSA Standard.

---

2 Most severe cascading cases occurred as a consequence of heavy icing such as during the January 1998 ice storm in Quebec where one line lost approximately 80 towers after conductors ruptured due to ice.

3 See Page 11 of the CEI/IEC Standard.

4 The CSA Standard is entitled *CAN/CSA-C22.3 No. 60826-10 Design criteria of overhead transmission lines.* The Canadian policy regarding national standards is to adopt, inasmuch as possible, international standards, and to augment these standards with such deviations or particularities that are appropriate for Canadian circumstances. Weather loads and their combinations are a good example of such deviations.

5 The writer is the Chair of the CSA Sub-Committee responsible for CAN/CSA-C22.3 No. 60826-10 Standard, as well as the chair of the IEC/TC11 working group that wrote the international standard IEC/TC11/MT1.

6 See Clause 5.1.1.1, Pages 33-34 of the CEI/IEC Standard for a full description of reliability levels and return periods.

2.3.2 CSA and CEI/IEC Standard Concepts

System Design

The methodology outlined in the CSA and CEI/IEC standards is based on the concept that an OTL is a system composed of a number of components. This approach enables the designer to coordinate the strength of components within the system. It recognizes that an OTL is a series of components where the failure of any component could lead to the loss of power transmitting capability. This system design approach is expected to lead to an overall economic design without undesirable mismatch in the reliability of individual components.[7] The reliability of the line is controlled by that of the least reliable component.[8]

In this system design approach, the selected design loads are applied to all line design elements, including the following:

- Major components: structures, foundations, conductors and ground wire, insulators, and hardware.
- Clearances: Above ground and obstacles; between phases and ground wire.
- Swing angle of insulators and corresponding clearances.

The various design elements are interrelated. For instance, if towers are able to withstand more than the design loads but, due to conductor sagging, the specified ground clearance is not maintained under such loads, this would be an unacceptable result.

System Reliability

The CSA and CEI/IEC standards provide a methodology to determine OTL design criteria on the basis of weather related loads. These weather related loadings are used to determine strength requirements of components that would result in a safe and reliable OTL. However, other conditions such as material defects can also impact system reliability and are not covered by the standards.

---

7 The goal of the system design concept is to avoid overdesigning specific line components for a reliability that is substantially different from other components, because a transmission line is a series system whose reliability depends on the weakest component. For example, if we assume that a line section having 90% of all towers in the line are designed for a 150-year ice and wind load, and the remaining section of 10% are designed for, say 25-year ice loads, the overall reliability could be as low as a 25-year return period, particularly when each of the two sections are exposed to uncorrelated weather systems.

8 See Clause 4.2, Page 29 of the CEI/IEC Standard.

3. The Labrador Island Link

3.1 Description of the Labrador Island Link (LIL)

The LIL is a 900 MW HVdc transmission system currently under construction between Muskrat Falls in Labrador and Soldiers Pond on the Island portion of the Province.[9] The primary purpose of the LIL is to transmit power from the 824 MW Muskrat Falls hydroelectric plant to service load on the Island Interconnected System, particularly on the Avalon Peninsula. The LIL will also provide an interconnection between the Upper Churchill Falls plant and the Island Interconnected System. The LIL will also facilitate the export of power from the Muskrat Falls plant to Nova Scotia.[10]

The LIL is comprised of a number of components and systems that each contribute to its overall reliability. These systems include (i) OTLs, (ii) submarine insulated cables, (iii) transition stations from the overhead line to the submarine cables, (iv) converter stations, (v) electrodes and overhead electrode lines, and (vi) and communications systems.[11] The scope of this report is to review the OTLs associated with the LIL.

3.2 LIL Overhead HVdc Transmission Details

The LIL overhead HVdc transmission line has the following attributes:[12]

- The LIL is a bipolar HVdc transmission line operating at ±350 kV. Each transmission line tower will contain two poles (conductors), one positive pole and one negative pole.
- The nominal power capacity of the LIL in bi-pole mode is 900 MW (2 x 450 MW, 1406 A per pole) at Muskrat Falls. The nominal power capacity at Soldiers Pond is 807.9 MW. Peak losses on the line are 92.1 MW.[13]
- The power capacity of the LIL in mono-polar mode is 450 MW with 100% overload capacity for ten minutes and 50% overload capacity for continuous operation.
- Each transmission line tower will support an optical power ground wire (OPGW). The OPGW is made of a combination of steel wires and fiber optic cable.[14]
- The LIL overhead HVdc transmission line will traverse approximately 1,100km from Muskrat Falls to Soldiers Pond. This includes approximately 388km in Labrador and approximately 680km on the island of Newfoundland.[15]

---

9 Muskrat Falls is located on the Churchill River in Labrador. Soldiers Pond is located approximately 35 km outside St. John's on the island of Newfoundland.

10 The LIL is currently expected to be completed in 2018. The 824MW Muskrat Falls hydroelectric plant is expected to be completed in 2020.

11 A full description of the LIL is provided in Attachment 1 of the response to Request for Information PUB-NLH-221.

12 See Page 3 of the response to Request for Information PUB-NLH-221.

13 See Attachment 1, Page 12 of the response to Request for Information PUB-NLH-212.

14 See the response to Request for Information CA-NLH-051.

15 See the response to Request for Information PUB-NLH-577.

- The elevation of the LIL will vary from 0m (Sea Level) to approximately 450m in the Long Range Mountains and 500m in the Highlands of St. John on the Great Northern Peninsula.[16]
- A counterpoise grounding system is installed on the LIL from Muskrat Falls to Soldiers Pond.[17]
- The pole and electrode conductors that will be used for the LIL and electrode lines are Aluminum Conductor Steel Reinforced (ACSR) conductors.[18]
- The LIL will consist of over 3,000 towers constructed of galvanized lattice steel. The tower family for the LIL includes 11 different tower types.[19]
- The Labrador section of the LIL is to carry two electrode conductors from the Muskrat Falls Converter Station to Forteau Point on southern Labrador. The majority of the electrode line in Labrador (370km) will be built on the ±350 kV HVdc steel transmission towers above the pole conductors and below the tower's single OPGW. The remainder of the electrode line in Labrador will be supported by wood poles.[20]
- An electrode line carrying two conductors will generally follow the existing transmission right-of-way from Soldiers Pond to Conception Bay. It will be supported by wood poles.[21]

---

16 See Pages 27-28 of the response to Request for Information NP-NLH-004.

17 Counterpoise refers to a continuous bare metallic grounding cable installed underground and connected to steel towers. This counterpoise dissipates lightning surges in the ground and mitigates induced currents in the towers.

18 See the response to Request for Information NP-NLH-027.

19 See the response to Request for Information NP-NLH-089.

20 See Attachment 1, Page 3 of the response to Request for Information PUB-NLH-221.

21 See Attachment 1, Pages 5-6 of the response to Request for Information PUB-NLH-221.

- Figure 1 shows a map of the LIL transmission line route from Muskrat Falls to Soldiers Pond.

Figure 1, LIL route from Muskrat falls to Soldiers Pond[22]

- Figure 2 shows a typical LIL transmission tower under construction.

Figure 2, Photograph of a guyed suspension structure used in LIL, conductors were not yet strung[23]

22 See Page 7 of the response to Request for Information NP-NLH-004.

23 See Attachment 1, Page 8 of the response to Request for Information CA-NLH-089.

- Figure 3 shows a cross section of a typical LIL transmission tower adjacent to a 230 kV transmission structure.

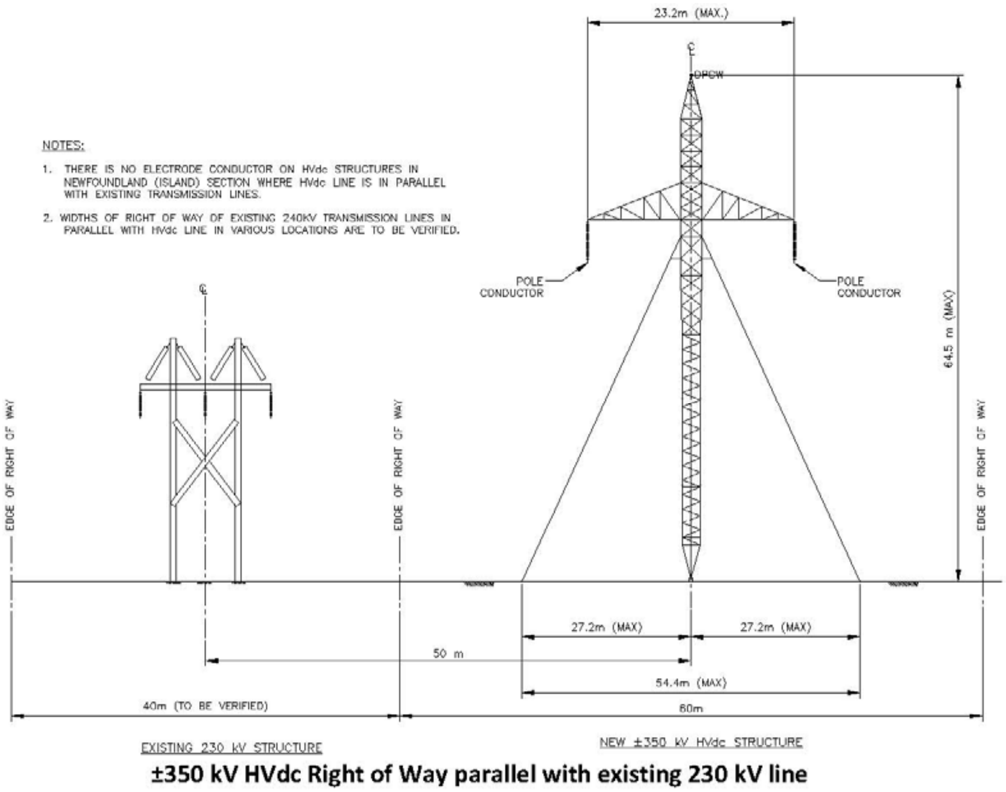


Figure 3, HVdc Segment 1 (with electrode) and HVdc Segment 2 (without electrode)[24]

3.3 Review of Exhibits from the Board's Muskrat Falls Review

The idea of a Labrador-Island transmission line that would bring power from a hydroelectric generation station on the Lower Churchill River in Labrador to the service load on the Island of Newfoundland has been the subject of many studies that span several decades. Many of these studies were presented as exhibits in the Board's Muskrat Falls Review in 2011-2012.[25] These exhibits cover a wide range of issues including (i) details of the design criteria for the LIL, (ii) meteorological studies relied upon in the development of the LIL design criteria, (iii) evaluations of previous transmission line failures in Hydro's service territory, and (iv) Hydro's own reviews and conclusions regarding the impact of the LIL on IIS reliability.

---

24 See Page 2 of the response to Request for Information PUB-NLH-268.

25 These exhibits can be found on the Board's website: http://www.pub.nf.ca/applications/MuskratFalls2011/nalcordocs.htm

These exhibits inform my conclusions in relation to the LIL and its expected reliability. Specifically, the information in these exhibits facilitated my understanding of how wind and icing data was used in the development of the design criteria for the LIL and how an appropriate return period was determined. I have summarized the contents of the principal exhibits I considered in preparing this report in Annex 1. These exhibits are shown in Table 1.

Table 1

Exhibit #	Title	Prepared by:	Date
Exhibit 85	Reliability Study of Transmission Lines on the Avalon and Connaigre Peninsulas	Asim Haldar Ph.D., P.Eng	Apr, 1996
Exhibit 92	DC1070 – Preliminary Meteorological Load Review	Hatch	Aug, 2008
Exhibit 95	Evaluation of in-cloud icing in the Long Range Mountain Ridge	Landsvirkjun Power	Dec, 2010
Exhibit 96	Evaluate Extreme Ice Loads from Freezing Rain for Newfoundland and Labrador Hydro	Kathleen F. Jones	Jan, 2010
Exhibit 106	Technical Note: Labrador – Island HVdc Link and IIS Reliability	System Planning Department, Newfoundland and Labrador Hydro	Oct, 2011

3.4 Design Criteria of the Labrador Island Link

The design criteria for ice (glaze and rime), wind, and combined wind/ice loading was presented to the Board in its Muskrat Falls Review.[26] The design criteria for the LIL OTL was also presented in the Board's Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System (the "Investigation").

To develop the criteria, Nalcor quantified the expected ice and wind loadings for various return periods, starting with the 50-year minimum return period specified by the CSA Standard and taking into account numerical modelling, full scale test structures and operational experience.[27] Design criteria were developed for 16 separate meteorological design zones, each having a specific design criteria for ice (glaze or rime), wind, and combined wind/ice loading.[28] The criteria are shown in Table 2.

[26] The design criteria for the LIL overhead transmission line was provided in Appendix A, Revision 1 of the Nalcor Energy *Review of Existing Meteorological Studies Conducted on the Labrador Island Transmission Link* submitted to the Board as Exhibit 97 in the Board's review.

[27] See Page 3 of Exhibit 97.

[28] The design criteria for the LIL is shown on Page 10 of the response to Request for Information NP-NLH-004.

Table 2 Design Criteria for the Labrador Island Link						
Weather Zone	**Zone**	**Region**	**Maximum Ice**[29]	**Maximum Wind**	**Combined Ice and Wind**	**% of total line length**[30]
Normal	1	Inner Labrador	50 mm (Glaze)	105 km/h	25 mm (Glaze) and 60 km/h	23%
	3	Labrador Coast	50 mm (Glaze)	120 km/h	25 mm (Glaze) and 60 km/h	2%
	4	Northern Peninsula Coast	50 mm (Glaze)	120 km/h	25 mm (Glaze) and 60 km/h	4%
	6	Northern Peninsula	50 mm (Glaze)	120 km/h	25 mm (Glaze) and 60 km/h	7%
	8a	Central-West Newfoundland	50 mm (Glaze)	120 km/h	25 mm (Glaze) and 60 km/h	1%
	8b	Central-West Newfoundland	50 mm (Glaze)	105 km/h	25 mm (Glaze) and 60 km/h	8%
	9	The Birchy Narrows	75 mm (Glaze)	130 km/h	45 mm (Glaze) and 60 km/h	1%
	10	Central-East Newfoundland	50 mm (Glaze)	105 km/h	25 mm (Glace) and 60 km/h	20%
Eastern	11	Eastern Newfoundland	75 mm (Glaze)	130 km/h	45 mm (Glaze) and 60 km/h	18%
Alpine	2a	Alpine Labrador	115 mm (Rime)	135 km/h	60 mm (Rime) and 95 km/h	1%
	2b	Alpine Labrador	135 mm (Rime)	135 km/h	70 mm (Rime) and 95 km/h	7%
	2c	Alpine Labrador	115 mm (Rime)	135 km/h	60 mm (Rime) and 95 km/h	2%
	5	Highlands of St. John	115 mm (Rime)	150 km/h	60 mm (Rime) and 105 km/h	3%
	7a	Long Range Mountains Crossing	115 mm (Rime)	180 km/h	60 mm (Rime) and 125 km/h	1%
	7b	Long Range Mountains Crossing	135 mm (Rime)	180 km/h	70 mm (Rime) and 125 km/h	1%
	7c	Long Range Mountains Crossing	115 mm (Rime)	180 km/h	60 mm (Rime) and 125 km/h	1%

Table 2, Summary of weather loads used by Nalcor for designing the LIL (ref. Exhibit 97-revision A)[31]

---

29 The unshaded rows represent glaze icing zones with a glaze ice density of 900 kg/m^3. The shaded rows represent rime icing zones with a rime ice density of 500 kg/m^3.

30 The percentages provided are approximate values estimates based on the review of maps and was not in the original table from Hydro.

31 Hydro's climatic design criteria are provided in Appendix A, Revision 1 of Exhibit 97. The same climatic design criteria was provided on Page 10 of the response to Request for Information NP-NLH-004.

The Board's Muskrat Falls Review was undertaken prior to the completion of detailed engineering for the LIL. It considered feasibility study inputs rather than completed engineering work. Further, the availability of the Maritime Link as a support for an alternate supply source was not a consideration in the review. The design of the LIL has since been completed and the line is currently under construction.[32]

Hydro confirmed it used multiple sources of data to establish load conditions for the LIL as listed below:[33]

a) Reference wind and ice loading as provided in the CSA standard.
b) A study undertaken by Kathleen Jones of the Cold Regions Research and Engineering Laboratory.
c) Hydro's applicable nearly 50-year operating history along the transmission line route, particularly on the Avalon Peninsula; and
d) A study undertaken by Landsvirkjun Power which evaluated rime (or in-cloud) ice loadings, which are a design consideration along the LIL route, but are not addressed by the CSA Standard.

Hydro indicates that the 'as-designed' structures for the LIL OTL meet or exceed the following loadings:

a) CSA 150-year ice loadings for the line section off the Avalon Peninsula.
b) CSA 500-year ice loadings for the route on the Avalon Peninsula.
c) CSA 150-year wind loadings for the line section off the Avalon Peninsula.
d) CSA 500-year wind loadings for the line section on the Avalon Peninsula.[34]

This determination was made after comparing the LIL, 'as-designed', to Hydro's application of the CSA Standard.

3.4.1 Design Criteria Determination

Hydro indicates that the design criteria for the LIL were developed following principles outlined in the CSA Standard.[35] This standard includes a recommended methodology for designing transmission lines.[36] One of the first requirements of the methodology is to select a reliability level in terms of return periods of limit loads.[37] A higher return period corresponds to a more reliable transmission line.[38] Following the determination of a reliability level, appropriate weather load values need to be determined in order to achieve the desired reliability level.

32 See Page 1 of the response to Request for Information NP-NLH-004.
33 See Pages 4-5 of the response to Request for Information NP-NLH-004.
34 See Pages 1-3 of the response to Request for Information NP-NLH-004.
35 See Page 2 of the response to Request for Information NP-NLH-004.
36 See Clause 5.1, Page 31 of the CEI/IEC Standard.
37 Guidance on reliability levels is provided for on Page 33 and Pages 125-127 of the CEI/IEC Standard.
38 Return periods for climatic loading on transmission lines are categorized as 50, 150, or 500-year return periods in the CSA Standard.

The principal guidance in the determination of an appropriate reliability level is the importance of the line within a supply network.[39] The CSA Standard indicates that lines should at least meet the requirements of a reliability level characterized by a 50-year return period. The standard suggests use of a return period of 150 years for lines above 230 kV. A return period of 500 years is suggested for lines, mainly above 230 kV, which constitute the principal or perhaps the only source of supply to a particular electrical load.

Hydro selected a 50-year return period for climatic loads for the LIL.[40]

3.4.2 LIL Design Criteria for Ice and Wind

For the purpose of designing the LIL, 16 different line segments were evaluated. As can be seen in Table 2, nine of those line segments are governed by severe glaze icing (or freezing rain) and seven segments are governed by severe in-cloud (rime icing).

---

39 See Page 125 of the CEI/IEC Standard.

40 See Page 11 of the Manitoba Hydro International *Report on Two Generation Expansion Alternatives for the Island Interconnected System (http://muskratfalls.nalcorenergy.com/wp-content/uploads/2014/07/MHI-Report-VolumeI.pdf).* See also Page 32 of Exhibit 106 and the response to Request for Information PUB-Nalcor-13 filed in relation to the Board's Muskrat Falls Review.

Figure 4 shows the 16 different line segments used in the development of the design criteria for the LIL.

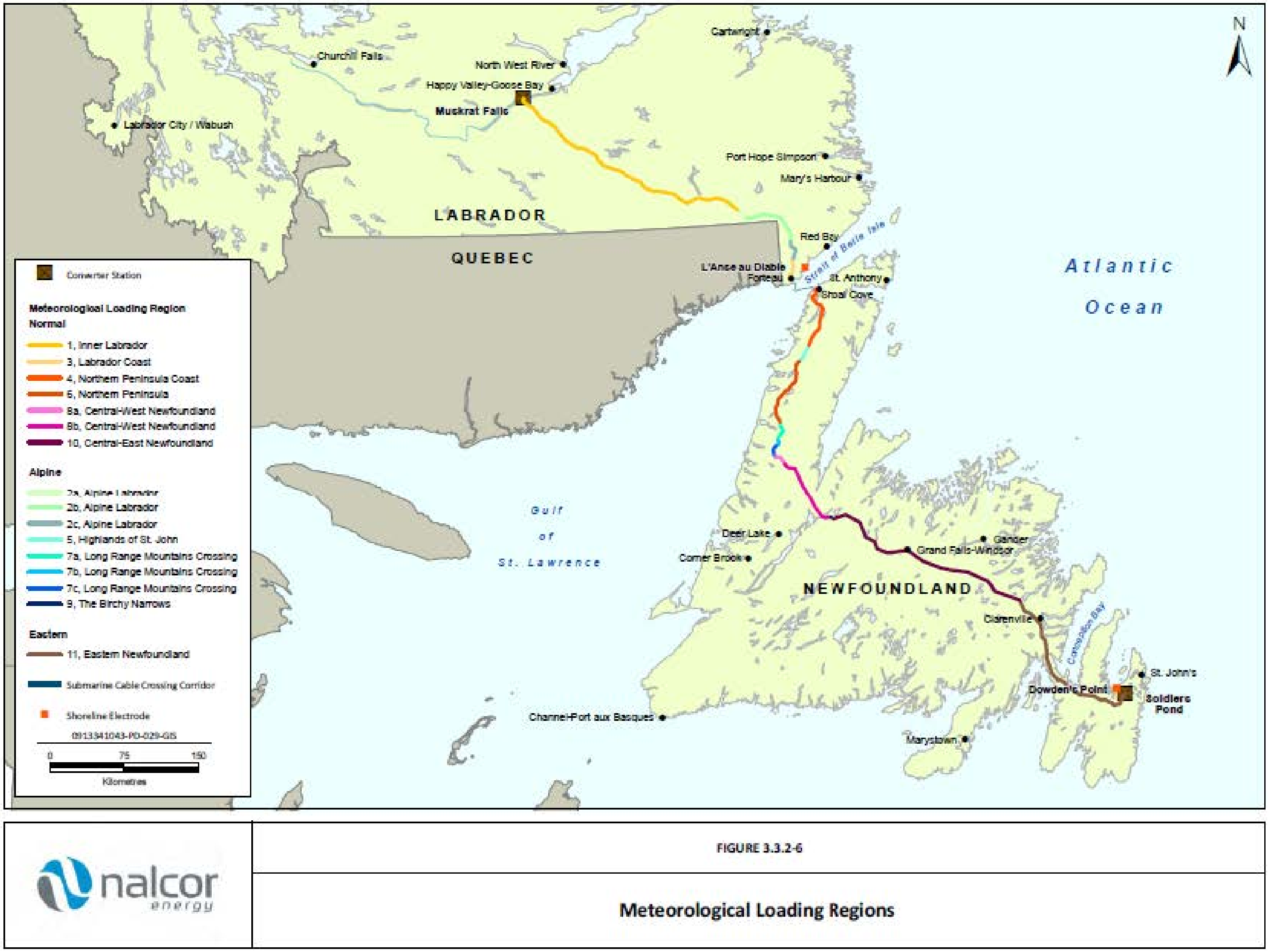


Figure 4, Map showing the LIL route with various weather zones identified by Nalcor (the intensity of weather data in each zone is provided in Table 2)

4. Analysis

In order to assess the reliability of the LIL, I reviewed the design criteria in light of the evidence filed with the Board in relation to Phase II of the Investigation, including responses to Requests for Information. In addition, I reviewed the evidence regarding the LIL filed in relation to the Board's Muskrat Falls Review.

Due to the limited information available to me, I could not perform a complete quantitative assessment of the reliability of the LIL. However, based on the available information, I was able to make an estimate of the overall reliability of the line. This estimate is principally based on my evaluation of the design criteria for the LIL in light of the climatic loads to which the line will be subjected.

In addition, I have included in this report some further observations regarding the applicability of relevant provisions of the CSA Standard to an evaluation of the reliability of the LIL.

4.1 Application of the CSA Standard

The LIL, as-designed, was evaluated against 150 and 500-year return period ice and wind loadings that were determined by Hydro. Using my own experience with the CSA Standard, I have reviewed this evaluation to the extent possible, and provide the following observations and opinions.

4.1.1 Use of Local Data

The CSA Standard States:

> *"Requirements have been updated so that the climatic data in the Standard may be augmented by reliable local data."*[41]
>
> and,
>
> *"The icing data given in Figures CA.10 and CA.11 are based on model simulations at weather stations. When reliable direct measurement data exist, these may be used as a substitute for the values given in these figures."*[42]

Hydro indicated that reliable information exceeding applicable CSA loads has not been identified.[43] Hydro further indicated that while meteorological loads could have been increased beyond the CSA Standard with commensurate increases in project cost and electricity rates, a decision was taken to use the approved Canadian standard as a basis, and to ensure that the line could also withstand loadings as identified in previous studies.[44]

41 See CSA Preface (b), Page CSA/8 of the CSA Standard.
42 See Clause 5.1, Page CSA/11 of the CSA Standard.
43 See the response to Request for Information NP-NLH-053.
44 See Page 4 of the response to Request for Information NP-NLH-100.

It is my opinion that climatic data provided in the CSA Standard should be considered as minimum values for transmission line design in Canada when reliable local data is not available.[45] Local data should be considered more reliable when determining appropriate climatic loads. A more detailed discussion of the use of local data, as it applies to the LIL, is provided in Section 4.2.

4.1.2 Terrain Roughness

The CSA Standard States:

> *"Terrain type B is representative of the majority of lines and should lead to acceptable results in all areas except in flat coastal areas, where a terrain type A should be used."*[46]

Hydro indicates that Terrain Category C was selected for all glaze ice zones. Terrain Category C is described as terrain with numerous small obstacles of low height (hedges, trees, and buildings). Terrain Category B was maintained in rime ice zones. Terrain Category B is described as open country with very few obstacles, for example airports or cultivated fields with few trees or buildings.[47]

It is my opinion that terrain type B should be used throughout the LIL as indicated in the CSA Standard.[48] There are two main reasons why the CSA sub-committee included this clause.[49] First, it eliminates subjective judgments when selecting the type of terrain roughness applicable to a given project. Secondly, where terrain types C or D are selected, localized amplification factors should be applied to wind speeds used for design. Since these amplification factors are difficult to evaluate without special studies, selecting type B is a reasonable and conservative assumption compared to type C or type D. Selecting type C terrain without taking into account any amplification factors or funneling of wind has a negative effect on reliability.

The selection of type C instead of type B terrain roughness leads to a reduction of about 15-17% in the wind forces that the line components are designed to withstand. This reduction is approximately equivalent to a reduction in return periods of wind speeds from 100 to 50, 200 to 100, or from 500 to 200-year return periods.[50]

---

45 Weather data applicable to Newfoundland and Labrador is provided in Figures CA.1, CA.3 and CA.10.

46 See Clause 6.2.2, Page CSA/12 of the CSA Standard.

47 See Pages 32-33 of the response to Request for Information NP-NLH-004.

48 For the same reference wind speed considered for the design of a line, wind forces on towers and conductors will decrease starting with type A to type D terrains.

49 The CSA Standard includes Canadian deviations to the harmonized IEC Standard and reflect mostly exceptions to IEC rules based on Canadian experiences and/or weather conditions. These deviations have priority over the corresponding CEI/IEC clauses, and reflect the consensus of the CSA sub-committee that was responsible for the CSA Standard.

50 These return period estimations are based on factors used to convert between CSA return period values found in Table CA.2, Page CSA/37 of the CSA Standard.

4.1.3 Amplification of Wind due to Topography

The CSA Standard States:

> *"Furthermore, the effects of acceleration due to funneling between hills or due to sloping grounds are not covered and may require specific studies to assess such influences"*[51]

Hydro indicates that it has not identified locations along the LIL route where funneling between hills or due to sloping grounds would be expected and that the LIL conforms to the general conditions summarized in the CSA standard.[52]

Without evidence acquired through specific studies, I would not discount the effects of acceleration of wind due to funneling between hills or due to sloping grounds. Such effects could increase wind loading on the LIL beyond design loadings. The amplification factors due to funneling can increase wind loads by 10% to 40% or more. If these factors are not applied as they should, this would result in a reduction in the reliability level of the line.

4.1.4 Amplification of Ice due to Topography

The CSA Standard States:

> *"This clause does not cover areas where in-cloud icing can occur and be amplified due to topographical features of the terrain. If such cases are suspected, it is suggested to undertake a study that could highlight the amount of increase in ice loads due to these special terrain features.*
>
> *Wind speed localized effects can also increase ice loads and the total combined loads, particularly when a low density of ice is considered"*[53]

Hydro's design criteria for sections of the LIL governed by rime ice, also referred to as "in-cloud icing" in the CSA Standard, is based on information provided in Exhibit 95.[54] This exhibit does not specifically address amplification of ice loads on the LIL route due to topographical features of the terrain.

It is my opinion that such topographical features are likely to exist and do require consideration. Amplification of ice due to topography was considered in Exhibit 92. However, amplification of ice due to topography was not included in the evaluation of the LIL as designed.[55]

---

51 See Clause 6.2.1, Page 43 of the CEI/IEC Standard.
52 See the response to Request for Information NP-NLH-057.
53 See Clause 6.3.1, Page CSA/13 of the CSA Standard.
54 See the response to Request for Information NP-NLH-077.
55 See Section 5.3.3 – Amplification due to Topography, and Appendix D – Influence of Topography of Exhibit 92.

4.1.5 Estimating Ice Accretion in Canada

The CSA Standard States:

> *"It is essential to note that extremes of rime ice greater than values indicated in Figures CA.10 and CA.11 can occur on hill, mountain, and ridge topes, especially in coastal areas. Local experience and knowledge should be used in determining design ice thickness in such locations."*[56]

Hydro indicates that relevant long term data should be used where available, and that available data was used along with relevant operational history of existing structures. Hydro also states that in areas where long-term data does not exist, design criteria were increased to address model uncertainties and that this was particularly the case with rime ice loading in the Long Range Mountains.[57]

Exhibit 92 provides information that includes local experience and knowledge of rime ice accretion. However, this information was not used by Hydro in the evaluation of the LIL as designed.

4.1.6 Ground Wire Icing

The CSA Standard States:

> *"The experience of some Canadian utilities is that in some locations the ground wire (GW) accretes as much radial ice weight as the larger-diameter conductors. This is partly due to the higher elevation of the GW, the higher temperatures of the phase conductor, and possibly the comparative torsional stiffness. In such locations, it is recommended to design the GW for the same linear unit weight of ice as for the phase conductor."*[58]

Hydro indicates that the general application recommendations in the standard have been followed, and that it has designed for a uniform radial ice thickness around conductors, ground wires, and optical ground wires. Hydro further asserts that the statement above is not a general application recommendation, but rather an exception to general practice to be applied under specific circumstances.[59]

It is my opinion that failure to comply with the CSA Standard recommendation to design the ground wire for the same weight of ice as the conductor can lead to (i) the ground wire being at risk of failure in advance of the phase conductors, and (ii) clearance issues between the ground wire and the phase conductors.

---

56 See Clause CA.3, Page CSA/18 of the CSA Standard.
57 See the response to Request for Information NP-NLH-080.
58 See Clause 6.3.2, Page CSA/13 of the CSA Standard.
59 See the response to Request for Information NP-NLH-022.

This recommendation of the CSA Standard is the result of the CSA Subcommittee consensus and is supported by the Canadian experience. There are several reasons for this recommendation. These are as follows:

(i) In many countries with severe icing, the icing variable is not the ice thickness, but the unit weight of ice per meter of conductor. In such cases, the ice weight corresponding to a return period of, say 50 years, is applied to all cables including phase conductors, GW, and OPGW as in the above CSA Standard recommendation.

(ii) The ground wire has a lower rotational stiffness than the phase conductors. This has the effect of increasing the ice thickness around the ground wire because of the rotation of the ice covered conductor and usually leads to a cylindrical form of icing.

(iii) In many measurement icing sites worldwide, the thickness of ice cannot be directly measured, but only the ice weight in a span. The thickness is only a reverse calculation from the unit weight obtained from the testing sites.

(iv) The CEI/IEC Standard recognizes the unit weight of icing as the statistical variable, in addition to ice thickness and provides all the equations to switch from unit weight to unit thickness.[60]

In locations where the phase conductor is designed for 75mm ice thickness, the CSA Standard recommends the ground wire be designed for approximately 89mm ice thickness. If the ground wire is designed for the same ice thickness as the phase conductor, it will be under-designed by approximately 16%. Similarly, if the phase conductor design ice thickness was 50mm instead of 75mm, the ground wire would be under-designed by about 20%.

The effect of this under-design will lower the reliability of the GW (and the line) from a 500-year return period to approximately a 150 to 200-year return period, or from a 150-year return period to an approximate 50 to 100-year return period.[61]

4.1.7 Wind Velocity Associated with Icing Episodes

The CSA Standard states:

> *"Wind velocities associated with icing episodes can be calculated from data, if available or, when there is little or no data, from the following assumptions. In the latter case, the reference wind speed is multiplied by a reduction factor B_i [0.4–0.5] as indicated below..."*[62]

---

60 See Clause 6.3.2, Page 61 of the CEI/IEC Standard.

61 The reduction in the GW (and line) reliability is an approximation using Table CA.2 on Page CSA/37 of the CSA Standard of the effect of under-designing GW ice thickness by about 16-20% mentioned in the previous paragraph.

62 See Clause 6.4.4.1, Page 73 of the CEI/IEC Standard.

Hydro indicates that it selected a reduction factor of 0.4 as it was within the range stated in the standard. Hydro further indicates that it did not use information presented in Exhibit 95 which shows that using a 50% reference wind speed may be appropriate.[63] [64]

It is my opinion that using a 50% (0.5) reference wind speed factor confirmed by testing and measurements in Exhibit 95 would have been more appropriate since it is based on real data obtained from a study that Hydro has relied upon. Exhibit 95 shows many possible combinations of wind and ice that support use of a higher wind speed factor than the default 40%.[65]

4.1.8 Use of CSA Standard Contour Lines

The CSA Standard includes maps of wind and icing conditions throughout Canada. Differences in climatic data (wind and ice) are delineated using contour lines.[66] In its evaluation of the CSA Standard on the LIL as-designed, Hydro appears to use averages or interpolations of adjacent contour lines for determining wind and ice loading in the areas between the lines.[67]

Where a transmission line route crosses multiple contour lines of icing and wind, it is more appropriate, in my opinion, to use the wind and ice loadings indicated by the highest value contour line applicable to each segment, and not an average or interpolated value.[68]

4.2 Selection of Design Criteria

The LIL will be subjected to two types of ice accumulation throughout its 1,100 km route between Muskrat Falls and Soldiers Pond. Some sections of the LIL are designed based on the amount of glaze ice that can be expected to occur, while rime ice is the governing consideration in the remaining sections. A review of the LIL design criteria for glaze ice and rime ice follows.

4.2.1 Glaze Ice

Glaze ice is a smooth, transparent and homogeneous ice coating occurring when freezing rain or drizzle hits a surface. The relative density of glaze ice is approximately 900 kg/m^3. Glaze ice accretion is a hazard to which overhead power lines are regularly exposed in Newfoundland and Labrador.

The following observations summarize the findings of my review of the LIL criteria with respect to glaze ice:

1. Hydro indicated that data used in Exhibit 96 predicted estimated loadings that are lower than those in the CSA Standard, but that no reductions to the design loadings were considered.[69]

---

[63] See the response to Request for Information NP-NLH-062.
[64] See Figure 53 and related text on Page 50 of Exhibit 95.
[65] See Figure 53 of Exhibit 95.
[66] See, for example, Figure CA.10, Page CSA/47 of the CSA Standard.
[67] See the first table on Page 16 of the response to Request for Information NP-NLH-004 as compared to Figures A-1, A-2, A-3 on Pages 52-54 of the same Request for Information.
[68] See the first table on Page 16 and Appendices A and B of the response to Request for Information NP-NLH-004.

The 200-year return period ice and wind values for the Avalon Peninsula are higher in Exhibit 96 than the CSA Standard values. A comparison of the return period data is provided in Table 3.

Table 3		
Return Period (years)	**Minimum CSA Standard**[70]	**Exhibit 96**
	CSA ice (mm) + wind (km/h)	**ice (mm) + wind (km/h)**[71]
50	60mm[72] + 65 km/h	57mm + 91[73] km/h[74]
200	76mm + 65 km/h	87mm + 91 km/h

Hydro indicates that the 'as-designed' structures on the Avalon Peninsula were evaluated against CSA 500-year return period ice and wind loadings.[75] This corresponds to 85mm of ice with 65 km/h wind. The 500-year return period ice and wind loadings used by Hydro to evaluate the structures on the Avalon Peninsula are lower than the 200-year return period values estimated in Exhibit 96.

2. Three separate Hydro studies between 1996 and 2011 indicate that 75mm of glaze ice on the Avalon Peninsula corresponds with a 50-year return period.[76]

3. As indicated in section 4.1.1, the CSA Standard contemplates the use of local data when reliable measurements exist.[77] Hydro indicated that reliable information exceeding applicable CSA loads was not identified.

---

69 See Page 13, Lines 6-11 of the response to Request for Information NP-NLH-004.

70 Conversion factors for ice having different return periods is taken from CSA table CA.2. These factors apply to CSA Standard values only.

71 Ice is taken from Table 5, Page 59 and wind from Figure 13 divided by 1.38 (CSA Fig. A.7) to convert from Gust to 10 min. wind.

72 Ice of 60mm is taken from Figure CA.10 of the CSA Standard (40mm x 1.5 = 60mm) and wind is taken from Figure CA.1 of the CSA Standard multiplied by a B_i of 0.5. (the value of 0.5 is supported with data deducted from Figure 53 of Exhibit 95).

73 A range of gust wind of 95 to 125 km/h concurrent with ice was shown on Figure 13, Page 45 of Exhibit 96. The value of 125 km/h gust wind was selected for the Avalon because this area has the highest wind speed in all Newfoundland and Labrador.

74 It is true that icing in Exhibit 96 is slightly less than minimum CSA Standard values, but the combined ice and wind is more critical to towers than the CSA Standard for a 50-year load. Note that when the return period increases, icing in Exhibit 96 increases much more than CSA Standard values. This is due to the difference in statistical models between the CSA Standard and that used in Exhibit 96.

75 See Page 2, Lines 13-20 of the response to Request for Information NP-NLH-004.

76 See Page 4 of Exhibit 85; Page 10 of Exhibit 106; and Page 26 of Exhibit 92.

77 Clause 4.1, Page CSA/11 of the CSA Standard.

In my opinion, the above references, including Hydro's own reports, lead to the conclusion that ice and wind loads on the Avalon Peninsula are higher than weather data in the CSA Standard.[78] Three Hydro reports indicate that glaze ice loads on the Avalon Peninsula consist of 75mm of ice for a 50-year return period.

If local data and measurements confirm ice and wind loads in excess of the CSA Standard, they should be used. The CSA standard suggests a 50-year return period of 60mm.[79] In my opinion, local data indicates the appropriate 50-year return period value for glaze ice on the Avalon Peninsula is 75mm.[80]

In my opinion, while the towers may be able to withstand 85mm of ice, the 85mm does not correspond to a 500-year return period. Rather, it corresponds to a 100-year return period.[81] A more appropriate 500-year return period value for glaze ice loading would be 106.5mm, which is based on factors used in the CSA Standard.[82]

4.2.2 Rime Ice

Rime ice is a white ice that forms when water droplets in fog or cloud freeze to the outer surfaces of objects. The following observations summarize the findings of my review of the LIL criteria with respect to rime ice:

1. Hydro relies on Exhibit 95 to establish its design criteria for rime ice accretion on the LIL.[83] Modeling in Exhibit 95 was also used to aid in line routing to avoid locations that are exposed to high levels of rime ice in the Long Range Mountains.[84] The authors of the report caution against using the results of their evaluation and indicate a need for further testing and validation of their models.[85]

2. The climatic modelling presented in Exhibit 95 uses data from a weather station in Daniel's Harbour collected between 1966 and 2010 to model ice accretion in the Long Range Mountains. Hydro confirmed that the surrounding topography and elevation above sea level for the Daniel's Harbour weather station are quite different than conditions that can be expected in the Long Range Mountains.[86]

---

78 The CSA Standard uses values of ice accretion obtained by Environment Canada using the Chaine model. See Clause 6.3.4.1, Page CSA/13 for a description of the weather data used in the CSA Standard.

79 See Figure CA.10, Page CSA/47 of the CSA Standard. The value directly obtained from this figure is 40mm of ice and represents point loads. The CSA Standard confirms that, for designing lines, the value shall be multiplied by 1.5 (See CSA Standard Clause 6.3.4.1).

80 The 50-year return period icing value of 75mm of glaze ice was also confirmed in Exhibit 106.

81 The 500-year value should have been 106.5mm (75mm x 1.42 = 106.5mm) with wind and not the claimed value of 85mm of ice. The ratio of Hydro's 500 year return period of 85mm to my 50-year return period of 75mm is 1.13 (85mm / 75mm = 1.13). Using Table CA.2 of the CSA standard, this ratio corresponds to a 100-year return period.

82 Conversion factor of 1.42 from Table CA.2 of the CSA Standard (75mm x 1.42 = 106.5mm).

83 See Page 2, Lines 21-24 of the response to Request for Information NP-NLH-004.

84 See Page 24 of the response to Request for Information NP-NLH-004.

85 See Summary of Exhibit 95 in Annex 1.

86 See the response to Request for Information NP-NLH-078.

3. Exhibit 95 includes a review of icing in Labrador.[87] Figure 2 in Annex 1 shows a picture of heavy icing that was taken in Labrador in 1977 near the LIL route. Additional data showing heavy ice accumulations in Labrador is also provided.[88] Exhibit 95 recommends that a field study of the line route on the Labrador side of the LIL be conducted.[89]

4. Exhibit 92 is a review of climatological knowledge of rime icing in Canada combined with data from locations near the LIL route. Some of the information reviewed in this exhibit is included in Hydro-Quebec's design criteria and rime icing maps, particularly, the amplification factors of rime ice due to slopes.[90]

5. Exhibit 92 includes a review of ice monitoring programs conducted between 1977 and 2002. The results of these monitoring programs show rime ice accumulations that exceed the design criteria of the LIL.[91]

6. Exhibit 92 was not used by Hydro in the determination of the LIL design criteria. The decision not to use the Exhibit 92 results was based on concerns that the study used a comparatively simple icing model that was no longer in general use, and that the loadings generated by the model were overestimated.[92]

In my opinion, Exhibit 92 provides the best available information on rime icing on the LIL. Exhibit 92 provides detailed information on monitoring programs that measured actual rime ice accumulations over the period 1977-2002. The age and relative simplicity of the weather model employed in Exhibit 92 are not sufficient reasons to disqualify its results. Further, the authors of Exhibit 95 caution against using the results without further testing and validation.

Hydro indicates that the design criteria for rime ice accretion are beyond 500-year return period loads of 85mm predicted by rime ice accretion models developed in Exhibit 95.[93] Hydro's design criteria reaches a maximum of 135mm of rime ice in both the Long Range Mountains and in Labrador.

---

87 See Pages 59-57 of Exhibit 95.
88 See Table 10, Page 59 of Exhibit 95.
89 See Page 81 of Exhibit 95.
90 Hydro-Quebec calls these ZAG (in French: Zones d'Amplification de Givre) and these are frequent in the North shore near the Labrador border.
91 See Pages 15-19 of Exhibit 92.
92 See the response to Request for Information NP-NLH-012. See also Page 71 of Exhibit 95.
93 See Page 2 and Page 29 of the response to Request for Information NP-NLH-004.

In my review of rime icing I have compared the results of Exhibit 95 with those of Exhibit 92. A summary is provided in Table 4.

Table 4		
Rime Icing Loads in mm on the Long Range Mountains		
Return Period (Years)	**Exhibit 95[94]**	**Exhibit 92[95]**
50	60	100
150	72	120
500	85	140
Amplification range due to topography for 50-year reference	-	100 – 200

Based on the information in Exhibit 92, the LIL criteria for rime icing of 135mm corresponds to a 50-year return period, when amplification due to topography is accounted for.[96]

I agree with the recommendation of Exhibit 92 to route the LIL to avoid locations where maximum rime ice is likely to occur. However, the degree to which the LIL can be effectively sheltered from rime ice is uncertain.

The design criteria for the LIL indicates that the controlling icing in inner Labrador is glaze icing, while the data presented in Exhibit 92 indicates rime icing to be more critical than glaze icing.[97] In my analysis, I did not identify in detail the reliability impact of selecting glaze ice loading conditions in inner Labrador as opposed to rime icing conditions. However, I did observe that the 50mm glaze ice loading for the LIL is approximately equivalent to a 50-year return period according to data from Exhibit 92 and once the difference between glaze ice and rime ice densities is taken into consideration.[98]

94 See Page 29 of the response to Request for Information NP-NLH-004.

95 See Table 2, Page 7 of Exhibit 92. The Long Range Mountains correspond to section C3 as shown in the map on Figure 1 of Exhibit 92.

96 See column C3 of Table 2, Page 7 of Exhibit 92. The Long Range Mountains correspond to section C3 as shown in the map on Figure 1 of Exhibit 92.

97 Compare Climatic Region C1 in Table 1 and Table 2, Page 7 of Exhibit 92 with Zone 1 on Table 2 of this report.

98 The LIL glaze ice design criteria for Inner Labrador is 50mm. Table 2 of Exhibit 92 shows a 50-year return period value of rime ice to be 70mm (equivalent in weight to 48mm of glaze ice). The LIL combined ice and wind design criteria for Inner Labrador is 25mm of glaze ice + 60 km/h wind. Table 5 of Exhibit 92 shows 50-year return period values of 39mm of rime ice + 70 km/h wind. My calculations confirm that return period values for rime ice lead to higher transverse loads on towers than what is used in the LIL design criteria. If an amplification range, as in Table 2 of Exhibit 92 is used, it would indicate 50-year return period loads higher than the LIL design criteria.

4.3 Reliability Assessment

4.3.1 Return Periods on the Avalon Peninsula

A complete quantitative assessment of the reliability of each segment of the LIL, including in-cloud icing zones, would require detailed calculations based on information, including PLS-CADD/TOWER files, that was not available to me.

Thus, I have relied on an approximation using glaze icing design loads for the Avalon Peninsula. Hydro claims that its towers resist an icing of 85mm and that this icing corresponds to a 500-year return period. This claim is based on weather data provided within the CSA Standard that indicated a 50-year return period load for glaze ice of 60mm. However, since Exhibit 85 demonstrates that the 50-year return period for glaze ice on the Avalon Peninsula is 75mm, then the design criteria of 85mm for the LIL on the Avalon Peninsula corresponds to a 100-year return period.[99] Using an important line section on the Avalon Peninsula, I conclude that even if the as-designed structures can withstand 85mm of ice, the LIL reliability level for that line segment is only a 100-year return period, and not the 500-year return period claimed by Hydro.

4.3.2 Other Factors Affecting Reliability

Independent Climatic Zones

The LIL is approximately 1,100 km long and will traverse at least four different climatic zones where the occurrence of maximum icing and wind appears to be uncorrelated.[100] For example, extreme wind and icing conditions can occur in Labrador when similar conditions are not being experienced on the Avalon Peninsula. The LIL is a series system consisting of a single chain of transmission towers from Muskrat Falls to Soldiers Pond. The failure of one tower anywhere on the line will therefore result in an outage of the entire line. Because the icing and wind conditions in the various climatic zones are not correlated, the overall reliability level for the complete LIL will be lower than indicated by the return period of the lowest individual line segment.

With four totally uncorrelated line segments having 150-year return periods, for example, a return period of 38 years would be expected.[101] If each segment was designed for a 500-year return period, the overall reliability would be that of a line designed for a 125-year return period. To the extent that there is some correlation of weather conditions between the 4 zones, the described effect on the overall equivalent return period would not be as great.

This issue is not addressed by either the CSA or IEC Standard. However, the CSA Standard is not intended to be a complete line design manual. In my opinion, a conservative approach is indicated in establishing weather loads and factors in such circumstances.

Ground Clearance

Hydro indicates that span by span ground clearances were not verified as part of the as-designed evaluation against the CSA Standard, as the intent of the process was to confirm the capability of the structures to withstand loads consistent with the stated return period. Hydro further indicates that

---

[99] See Footnote 81.

[100] These zones include the Avalon Peninsula, the Long Range Mountains, Coastal-Labrador and Northern Newfoundland, and Inner Labrador. See Figure 11, Page 42 of Exhibit 96.

[101] This value is approximately equal to 1/(1-(1-1/150)^4) = 38 years.

conductor tensions were confirmed not to exceed maximum allowable limits and that sags did not increase significantly.[102]

Tower strength compliance is only one component of checking whether or not a transmission line meets CSA Standard reliability levels. The risk of infringing clearances is serious; it could preclude the ability of the structures to resist larger loads.

4.4 Conclusion

The LIL climatic design criteria was provided in information filed with the Board in the Muskrat Falls Review in 2011. It was based on a 50-year return period. The same climatic design criteria was confirmed in information provided to the Board in Phase II of the Investigation. The LIL has since been designed and is currently under construction.

Once the LIL design was completed, it was compared to Hydro's application of the CSA Standard and ice accretion models developed by Landsvirkjun Power. Hydro concluded that the LIL, as designed, met or exceeded CSA 500-year return period glaze ice and wind loadings on the Avalon Peninsula, and CSA 150-year return period values elsewhere. For rime icing zones, Hydro concluded that the LIL, as designed, exceeded 500-year return period rime icing loads predicted by Landsvirkjun Power and CSA 500-year return period loads for wind.

In my opinion, the analysis conducted by Hydro does not demonstrate that the LIL meets or exceeds the return periods claimed.

In this report, I have reviewed the detailed information relating to ice and wind loads on the Avalon Peninsula. Based on Hydro's data and experience, 75mm of glaze ice corresponds to a 50-year return period. Hydro used a 50-year return period equivalent to 60mm of glaze ice in its as-designed reliability analysis. As a result, Hydro's estimate of a 500-year return period load was 85mm of glaze ice. My analysis concludes that 85mm of glaze ice corresponds to a 100-year return period, and not the 500-year return period ice loading determined by Hydro.

I also reviewed the LIL climatic design criteria associated with rime icing. Hydro based its rime icing criteria on work conducted by Landsvirkjun Power in Exhibit 95. The information in this report does not appear to be reliable enough to serve as a basis for the LIL rime icing criteria. Further, the report was not able to draw any conclusions regarding rime ice in Labrador. In my opinion, information presented in Exhibit 92 is more reflective of rime ice conditions on the LIL, as it includes rime ice modeling, a review of actual rime ice measurements, and amplification factors for ice due to wind. Based on my review of rime icing, the reliability level associated with rime icing zones is approximately equivalent to a 50-year return period.

102 See the response to Request for Information NP-NLH-038.

I have reviewed Hydro's application of the CSA Standard in their selection of design criteria and subsequent evaluation of reliability, and disagree with certain aspects. These include (i) the use of local data and knowledge, (ii) selection of terrain roughness category, (iii) amplification of wind and ice due to topography, (iv) ice loads on the ground wire, (v) wind velocities associated with icing episodes, and (vi) the use of averages or interpolations with regards to contour lines shown on CSA Standard weather maps. In my opinion, Hydro's approach to these issues raises additional concerns regarding the reliability of the LIL.

The LIL is approximately 1,100 km long and traverses multiple climatic zones. The weather conditions in these climatic zones appear to be uncorrelated. The overall reliability of the LIL will therefore be lower than indicated by the return period of loads for the lowest individual segment. In this case, that is less than 50 years.

In addition, a large portion of the LIL traverses terrain, such as the Long Range Mountains, where transmission lines have never existed before. The extent to which this will detract from the overall reliability of the line is uncertain.

Having considered all of these factors, I conclude that the reliability level of the LIL is equivalent to a return period of no greater than 50 years.

Annex 1:

Summary of Select Exhibits
Muskrat Falls Review

Exhibit 85: Reliability Study of Transmission Lines on the Avalon and Connaigre Peninsulas
Author: Asim Haldar, Ph.D. P.Eng
Date: April 1996

The *Reliability Study of Transmission Lines on the Avalon and Connaigre Peninsulas* provided (i) a detailed assessment of the ultimate mechanical strength of the transmission lines on the Avalon and Connaigre Peninsulas, (ii) an estimate of 25-year and 50-year design ice loads based on available historical data duly adjusted for various line failures since 1965, (iii) reliability analyses of various line components treating the whole line as a system, and (iv) a cost-benefit analysis to justify and select a particular option for future upgrading work.[103]

Exhibit 85 recognizes that the transmission lines on the Avalon Peninsula are highly exposed, particularly to glaze ice load due to severe freezing precipitation coupled with some in-cloud icing. Since 1965 Hydro observes that there were at least four (4) major line failures on the Avalon Peninsula. The failures occurred in 1970, 1984, 1988 and 1994, respectively.[104] During the 1970 storm, Hydro's observed ice loadings were 6 inch (150mm) diameter plus icicles.[105]

Combining the annual failure rates derived from the past and recent failure data with the results of an earlier meteorological study, new probabilistic ice loads were estimated for 10-year, 25-year and 50-year return period values.[106] Exhibit 85 indicates that Hydro's commonly accepted target design loading is a 50-year return period and that the 50-year return period for icing on the Avalon Peninsula is 3.0 inches (75mm) radial of glaze ice.[107]

Exhibit 85 was not mentioned specifically as a source of data used to establish load conditions for the LIL, but presumably was considered as part of Hydro's applicable nearly 50-year operating history along the LIL transmission line route.[108]

Exhibit 92: DC1070 – Preliminary Meteorological Load Review
Author: Hatch
Date: August 2008

Exhibit 92 provides 2008 estimates of 50, 150, and 500-year return periods for wind and ice loading for the LIL from Gull Island to Soldiers Pond and to Cape Ray. The estimates were developed from previous studies, measurements of icing by Hydro, meteorological loading criteria used by Hydro in previous designs near the Labrador border, and data from Environment Canada. A reliability based design (RBD) approach, as described in Canadian Standards Association (CSA) and International Electrotechnical

103 See Page 3 of Exhibit 85.
104 For a detailed summary of damage and duration of transmission line outages associated with these events, please see Pages 39-41 of Exhibit 85.
105 See Page 56 of Exhibit 85.
106 See Page 4 of Exhibit 85.
107 See Page 4 of Exhibit 85.
108 See Page 4, Line 35 to Page 5, Line 8 of the response to Request for Information NP-NLH-004.

Commission (IEC) guidelines, was used in the development of the estimates.[109] Hydro did not use data from Exhibit 92 to establish load conditions for the LIL.[110]

The 50-year return period loads developed in Exhibit 92 are generally higher than Hydro's current design criteria.[111] Exhibit 92 concludes that the design loading in parts of the route through the Long Range Mountains will be due to a combination of rime ice and wind and that the maximum combined load for the reference 50-year return period is 200mm of ice and 105 km/h of wind.[112] This compares to Hydro's current design criteria for the Long Range Mountains section of the LIL which reflects combined wind and ice loadings of 70mm of rime ice and 125 km/h wind.[113]

The ice and wind design data that resulted from this study was accompanied by amplification factors due to slopes and special terrain features. Hydro's design data did not include any such amplification factors in the design of the LIL.[114]

The review observes that parts of the LIL may experience icing that is unprecedented for major transmission lines worldwide; that it will be necessary to carefully route the line to minimize such loads, and that de-icing methods may have to be employed.[115,116] The report recommends that, prior to final design, wind measurements should be acquired to improve the understanding of topographic effects in the more critical, localized areas and thereby improve the confidence in the values chosen for design purposes.

Exhibit 95: Evaluation of In-Cloud Icing in the Long Range Mountain Ridge
Author: Landsvirkjun Power
Date: December 2010

Hydro indicates that data used in Exhibit 95, which evaluated rime (or in-cloud) ice loadings, was used to develop the design criteria for the LIL.[117] Exhibit 95 provides an evaluation of icing measurements at two test sites on the Long Range Mountains during the winter of 2009-2010, and attempts to model the results using wind speed data from a weather station located in Daniel's Harbour. The evaluation also attempts to assess rime ice accumulation in Labrador.

---

109 See Page 6 of Exhibit 92.
110 See Pages 4-5 of the response to Request for Information NP-NLH-004 and the response to Request for Information NP-NLH-012.
111 Hydro's current climatic design criteria for the LIL are provided in Table 1 in the response to Request for Information NP-NLH-004. Return period loads from Exhibit 92 are provided in Tables 1, 2, 3, 4 and 5 of Exhibit 92.
112 See Page 7 of Exhibit 92.
113 See Table 1, Page 10 of the response to Request for Information NP-NLH-004.
114 Hydro Quebec's current standard includes such amplification factors due to topography and slopes, particularly on the North Shore and near Labrador.
115 See Page 6 of Exhibit 92.
116 Hydro indicates in the response to Request for Information NP-NLH-031 that no investigation of de-icing methods applicable to the LIL have been undertaken.
117 See Page 5, Lines 6-8 of the response to Request for Information NP-NLH-004.

The climatic modelling presented in Exhibit 95 uses data from a weather station in Daniel's Harbour over a period of 1966 to 2010.[118] The surrounding topography and elevation above sea level for the Daniel's Harbour weather station are quite different than conditions that can be expected on the Long Range Mountains.[119] In addition, the report indicates that observations from Daniel's Harbour should give a good description of the source of icing when the icing direction is from the west, while care should be taken when the icing direction is from the east.[120] The report recommends further study is required to model severe icing cases that were known to occur in the past, and to continue to analyze test span icing events to get a better understanding of the impact of ice accumulations that develop from the Gulf of St. Lawrence area (SW-W).

Exhibit 95 provides photographs that demonstrate the level of rime icing that can be experienced on the Long Range Mountains. Figure 1 shows test sites on the Long Range Mountains during a site visit on January 19, 2010.[121] Figures 2 and 3 show ice accumulations from Hydro test sites in the 1970s.[122]

Figure 1

Figure 2

Figure 3

Exhibit 95 states that there is a clear inconsistency between the results of its two modelling techniques for the section of the LIL that crosses Labrador. It recommends that rime icing on that section be the subject of a separate study as it is very difficult to draw conclusions from the results.[123]

118 See Page 36 of Exhibit 95.
119 See the response to Request for Information NP-NLH-078.
120 See Pages 29-30 of 96 of Exhibit 95.
121 See Figure 6 of Exhibit 95.
122 See Figures 36 and 62 of Exhibit 95.
123 See Page 67 of Exhibit 95.

Exhibit 95 contains numerous cautions regarding the use of the evaluation results without further testing and verification.[124]

Exhibit 96: Evaluate Extreme Ice Loads from Freezing Rain for Newfoundland and Labrador Hydro
Author: Kathleen F. Jones
Date: January 11, 2010

Kathleen Jones of the Cold Regions Research and Engineering Laboratory, US Army Corp of Engineers, was engaged to provide an estimate of extreme ice and wind loading values for Newfoundland and Labrador, and to compare her results with a study conducted in 1973.[125] Hydro indicates that Exhibit 96 was one of the sources of data used for the development of the design criteria for the LIL overhead transmission line.[126] Hydro also indicates that, while the analysis predicted estimated loadings that are lower than those in the CSA standard, no reductions to the LIL design loadings were considered.[127]

The basis for the analysis provided in Exhibit 96 was weather data from 28 weather stations in Newfoundland and Labrador and nearby Quebec. This data was used to model wind and ice loads and to determine climatic return periods.[128] The model results were checked against ice storms reported in historical newspaper articles to determine the footprint of each ice storm where ice loads and wind-on-ice loads damaged overhead lines, telecommunication towers, and trees.[129]

The climatic model employed in Exhibit 96 is based on the 2005 revision of ASCE (American Society of Civil Engineers) Standard 7, *Minimum Design Loads for Buildings and other Structures (2005).*[130] This model is different from the model employed in the CSA Standard. A key difference between models is the factors used to extrapolate 150 to 500-year return periods from 50-year return period estimates. The use of the ASCE model can produce higher combined wind and ice values than determined by the CSA Standard for these longer return period ranges.[131]

---

124 For example, see the following passages at Page 58:
"More cases from the following winters need to be studied in order to draw conclusions about the quality of icing predictions for Newfoundland and surrounding areas" and *"Further conclusions cannot be drawn until we have analyzed some events with winds coming from the Gulf of St. Lawrence area (SW-W)."*

125 The 1973 study is entitled *Meteorological Study of the Gull Island-Stephenville-Holyrood Transmission Line. Routes* was conducted by Meteorology Research, Inc. and was filed as Exhibit 71 in the Board's Muskrat Falls Review. Page (i) of the study indicates that Maximum accumulations of glaze icing are expected to reach four radial inches in a 25-year period near the isthmus to the Avalon Peninsula and along the ridge of the Long Range Mountains. Table 4 of Exhibit 96 provides a comparison of return periods calculated by Kathleen Jones and those calculated in the 1973 study.

126 See Page 5 of the response to Request for Information NP-NLH-004

127 See Page 13, Lines 6-11 of the response to Request for Information NP-NLH-004.

128 See Page 9 of Exhibit 96.

129 See Page 8 of Exhibit 96.

130 See Page 8 of Exhibit 96.

131 The CSA Standard uses factors of 1.2 and 1.42 to determine 150 and 500-year return periods from 50-year return periods. The ASCE uses factors of 1.5 and 1.85 to determine the same.

The analysis provides commentary on some of the issues associated with determining appropriate wind and ice loads specific to Newfoundland and Labrador. The analysis addresses ice accretion from freezing rain and does not estimate values for in-cloud icing.[132] The analysis also indicates that winds occurring with freezing rain in Newfoundland and Labrador tend to be higher than in other areas. Further, the ice that accretes on a wire may last for days or even weeks after the freezing rain ends, as long as the weather remains cold. This has the effect of ice-laden transmission lines being subjected to higher winds after the initial ice storm has subsided.[133]

Table 5 of Exhibit 96 shows the ice thickness from freezing rain for a 50-year return period with concurrent gust speeds. The table shows a 50-year return period spatial ice thickness of 57mm for the Avalon Peninsula, with concurrent 10 minute wind speeds estimated at 69 to 91 km/hr.[134] Hydro's combined wind and ice loading criteria for the Avalon Peninsula is 45mm of glaze ice with 60 km/hr of wind.[135]

Exhibit 96 provides analysis that takes into consideration the spatial effect of transmission line design.[136] The results of this analysis show an 87mm ice load that corresponds to a 200-year return period on the Avalon Peninsula.[137]

Exhibit 106: Technical Note: Labrador – Island HVdc Link and IIS Reliability
Author: System Planning Department, Newfoundland and Labrador Hydro
Date: October 30, 2011

The purpose of Exhibit 106 was to provide an overview of Island Interconnected System reliability, the interrelationships between the areas which affect system reliability and, finally, the impact that the proposed HVdc transmission line addition will have on system reliability.[138]

Exhibit 106 indicates that a 50-year return period is Hydro's standard for new 230 kV transmission lines and addresses the question of whether or not a 50-year return period is appropriate for the LIL.[139,140] A

132 On Page 26 of Exhibit 96, it states "In cloud icing is known to cause large ice loads on towers and wires in the Long Range Mountains, and may also contribute to significant icing elsewhere in the province."
133 See Page 20 of Exhibit 96.
134 See Table 5, Page 59 of Exhibit 96. See Page 22 of Exhibit 96 and Figure 13, Page 45 of Exhibit 96 where concurrent (gust) wind speed of 95 to 125 km/h were mentioned. These values are converted to a reference wind speed of 10 minutes using a factor of 1.38 according to Figure A.7 of the CEI/IEC Standard.
135 See Page 10 of the response to Request for Information NP-NLH-004.
136 See Page 22 of Exhibit 96. Spatial effect refers to the variability of ice accumulations along a transmission line. For example, one section of the line may experience moderate icing levels, while another section may experience more severe ice accumulations.
137 See Table 5 of Exhibit 96 for 50 and 200-year return period estimates that take spatial and point loads into consideration. See also the response to Request for Information NP-NLH-079.
138 See Page 4 of Exhibit 106.
139 See Page 10 of Exhibit 106. Hydro has adopted a 1:50 year return period for new 230kv transmission line designs
140 See Page 31 of Exhibit 106.

500-year return period for the LIL is dismissed and the need for a 150-year return period is considered questionable based on an alternate supply from the Maritime Link.[141]

Exhibit 106 also considers the selection of an appropriate return period for the LIL in the context of return periods of Hydro's existing 230 kV transmission system. The report states that building the HVdc line to a very high reliability level (i.e. 1:500 year return period) while the connected AC transmission system has a lower reliability level (i.e. 1:25 year return period) is problematic, as a 1:50 year weather loading will result in failures to the ac transmission system while the HVdc line is unaffected.[142] It further states that while it may appear desirable to increase the return period for the LLIL, the entire 230 kV grid east of Bay d'Espoir would need to be upgraded to a similar return period in order to achieve the desired reliability improvement.[143]

The summary of Exhibit 106 estimates that a 14-day outage to the HVdc transmission system would result in maximum unserved energy of less than 1% of the total annual load on the system. Although the impact of such an outage could be further mitigated by additional combustion turbines, Nalcor has opted to apply load rotation and other means to minimize customer impact. The summary indicates this decision was made to minimize overall cost to customers, in light of the low probability of such events and the minimal impact on unsupplied energy.

[141] See Page 31 of Exhibit 106.

[142] The HVdc transmission line and converter station requires access to an AC transmission system of sufficient capacity and strength in order to transmit power to load centers.

[143] See Page 31 of Exhibit 106.

Annex 2:
Elias Ghannoum CV

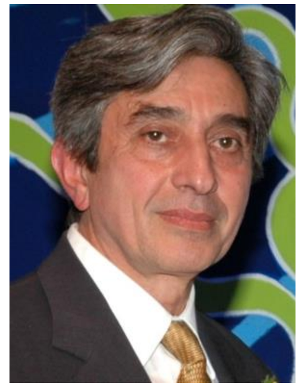
Name: **GHANNOUM, Elias**

Experience: 45 years in
Overhead Transmission Lines (Engineering, Design, Specifications, Construction, and Failure analyses)

Nationality: Canadian

Membership of Technical-Professional Societies-Standardization Committees: 15

Reports and Publications in International Journals and Conferences: more than 55



EDUCATION

1971	Master's degree in Civil Engineering (structural) M.A.Sc. University of Sherbrooke, Canada
1963 to 1968	Bachelor in Civil Engineering
1974, 1984, 1995	Courses in project management University of Montreal, and other seminars

EMPLOYMENT RECORD

Since 1998 **CONSULTANT**

Newfoundland Power: Review of the reliability of the HVDC and AC lines connecting Muskrat fall in Newfoundland to the St-John's (ongoing project since 2014)

Manitoba Hydro: Consultancy services for the design and optimization of 1350 km of ±500 KV HVDC Bipole III (ongoing work started in 2008), assignments include the selection of reliability levels, weather loads, conductors, structure types, loading cases, specifications, detailed design of structures, tower spotting, OPGW, etc.)

PowerGrid Corporation of India: Technical advisor and consultant for the design and optimization of the following projects:

- UHVDC ± 800 kV,
- 1200 kV UHVAC,
- Double circuit 800 kV AC lines
- Optimization and Design of 1600m long central span of the Hoogly river crossing. Assignment includes selection of crossing location, clearance above high water levels, conductor and OPGW optimization and selection, design criteria and structure loading cases, preliminary design of suspension and anchor towers, etc. (ongoing project started in 2009).
- Failure investigations of line failures,

Transelec-Chile: Engineering of 1200 km of 500 kV HVDC line and 230 kV double circuit AC lines for the Energy Austral project in South Chile. Work includes review and validation of Consultant work and proposals of special engineering solutions for extreme weather and access locations of this project. (2010 to 2012)

Mills Shirley: Expert witness for litigation between CenterPoint Utilities (Texas) and American Electric Power (2012-2014)

National Electric Power Company (NEPCO), Jordan: Design of steel towers and specialized courses in overhead line and lattice tower designs. (2011-2012)

SNC-Lavalin: transmission line and software courses in Toronto and Calgary (2011-2012) and review of specifications for Togo-Benin transmission line (2011)

Nova Scotia Power: Review of the design of a 138 kV line (in 2010) and related technical support

Transelec (Chile): Technical advisor and consultant for the design and optimization of a 2100 km HVDC ± 500 line (assignment form early 2008 to end of 2009).

Hidro-Aysen (Chile): Audit of detailed design of 500 kV AC lines (2009)

ESKOM, South Africa, Design of double circuit 800 kV AC structures and lines (2007-2008). Review of the proposed South African design standard of overhead lines (2009); Consultancy services for lines located in high wind areas (2009-2010)

Canadian Electricity Association Technologies Inc. (CEATI). CEATI REPORT No. T063700-3335: Comparison between unbalanced ice loads and security loads and assessment of their impact on line/structure designs

Transmission line courses on design of overhead lines and use of PLS-CADD, TOWER and PLS-POLE software: Vatech (Austria), EOS and BKW (Switzerland) Terna (Italy), Dubai, Abu Dhabi, Sonelgaz, France (EDF/RTE, Transel, Hecla, etc.), Electricity Authority of Cyprus, Sonelgaz (Algeria), Egypt EEC), Manitoba Hydro, Serbia, Spain, Malaysia, Bangladesh, STEG (Tunisia), ONE (Morocco), Saudi Arabia, Germany, Canada (BBA, Hydro-Quebec, Hydro-One, Teshmont, Manitoba Hydro), USA (San-Antonio, Oklahoma city), Courses in Montreal almost on a yearly basis, etc. since 1998.

Power Line Systems (USA), Technical support for line software such as PLS-CADD, TOWER, PLS-POLE since 1998

ESKOM, South Africa, Audit of design and construction practices and standards of TransAfrica Projects (ESKOM engineering branch), and Failure investigation of Matimba line (2006)

Principal Lecturer in Workshops: Belgrade (2002) on Transmission lines revitalization and Netherlands (2004) on Integration of Laser airborne survey techniques (LiDAR) in the design of overhead lines. (2005)

World Bank, Review of the design and construction of 161 kV line in Sierra Leone, (2005)

Canadian Electricity Association Technologies Inc. (CEATI). Comparison of Wind Load Methodologies for Lattice Transmission Line Towers, PROJECT NO.: T053700 – 3324 (2005),

Hydro-Quebec TransÉnergie, Canada, various consultancy works and expertise, contributor to the 2004 Revision of HQ transmission line design standard (2000-2004)

CHILE, Technical audit of 220 kV line Quillota - Los Piuquenes in Chili (2004)

Electricité de France (EDF/RTE), Review of the Utility's design criteria in the wake of the 1999 wind storms and application of probabilistic methods on three transmission projects, Failure investigation of lines that failed in 1999 wind storms and recommendations for improving reliability of the Network (2002)

Electricité de France (EDF/RTE), Assessment of security of 90 kV lines with concrete pole and assessment of means to increase the reliability and security of these lines (2003-2004)

KEC (India), Investigation of 400 kV tower failures (2002-2003)

World Bank: Umpire of a Disputes Review Board for a major 800 kV World Bank transmission project in India (1998-2002)

Hydro-Quebec Distribution: Basic and advanced course on design of distribution lines (2004)

ESKOM, South Africa, review of design practices and advanced courses on design and optimization of lines and towers. (2003)

University of Sherbrooke, Canada, first Chairperson (2002), "Hydro-Quebec Chair on design of Overhead Transmission Lines**" (2002)**

Hydro-Quebec, Canada, "Principal investigator of the 114 transmission lines that failed during the 1998 ice storm in North-America" and Principal Author of the official Diagnostic Report. Submitted to the Warren Committee and the Nicolet Commission (1998-1999)

Law firm Ogilvy-Renault, Canada, Expert witness in a major litigation involving transmission line failures due to the 1998 ice storm in Canada (1999-2001)

Canadian Electricity Association (CEA), Technical Coordinator in charge of the Interest Group composed of 15 major utilities on mitigation of Ice storm effects on overhead lines (1999-2000)

RSW, Canada, "Feasibility Studies of UHV lines in Labrador". (1999)

Phillips-Fitel, Canada, "Expertise related to OPGW and its installation". (1999)

HQI, Canada, "Specialized studies on overhead lines in North-Africa" (1999)

PTI/GAI, USA, "Expertise related to line failure in Argentina**" (1999)**

1977 to 2012: **UNIVERSITY OF MONTREAL (École Polytechnique)**

Lecturer graduate level (Master's and Ph.D. level), Engineering Faculty, course title "Structural analysis of transmission lines"

Lecturer of a course on basic design of overhead lines (2005-2006)

Lecturer of a course on advanced design of overhead transmission line (2005-2006)

Lecturer of a two-part course on design and construction of overhead transmission lines

1971 to 1998 **HYDRO-QUÉBEC**

1989 to 1998 *Transmission line Specialist*

Project Director of the Interconnection between Tunisia and Libya ($\approx$ 80 millions USD project): Responsible for technical studies, optimization, preparation of technical specifications, General/Special Contract documents, Invitation to Bidders, Bids analysis, contract negotiations, etc.

Transmission Line expertise in international projects: involves design, technical studies, optimization, and specifications of international transmission line projects. Partial list: $\pm$ 500 kV Chandrapur-Padghe, India, Chili 220 kV, Libya 230 kV and 400 kV, Tunisia 230 kV, Interconnection studies (transmission lines) of 5 Middle-Eastern countries (Turkey, Iraq, Syria, Jordan, Egypt), 500 kV Ertan project in China, 765 kV Venezuela, 500 kV Colombia, Mali, Burkina Faso (analysis of tower failures), etc.

Consultant to the World Bank for review of transmission line projects and tender documents.

Technical spokesperson for Hydro-Quebec during the Jan. 1998 ice storm.

Technical advisor to Electric Power Research Institute (EPRI), USA, for projects 1352 (reliability based design of overhead lines) and 1277 (wind loads).

Research projects on line rehabilitation and upgrading, compact conductors, wind loads on transmission lines.

Transmission Line Expert representing Hydro-Quebec in a Supreme Court litigation in Canada.

Optical ground wire (OPGW) studies, design, testing and installation of OPGW on 2000 km of 120 kV to 735 kV transmission lines.

Principal Lecturer-and Organizer of Technical seminars in various countries, namely: Brazil, Morocco, Columbia, Argentina, USA, Thailand, China, etc.

Principal Author of Hydro-Quebec's transmission lines design standard.

1983 to 1989 *Group Leader*

Design of towers and foundations Design of 1100 km of ± 450 kV DC line for 6th James Bay line.

Design of ± 500 kV, 1000 km Rihand-Delhi line in India (Project leader, responsible for optimization all technical studies and specifications related to overhead lines).

International consultant for various transmission lines projects.

1977 to 1983 *Division Head (Chief Engineer)*
Transmission Lines, Engineering Department.

Design criteria for line components based on reliability concepts.

Design of transmission towers, voltage levels from 120 kV to 735 kV such as chainette tower, suspension tower, long span tower, anti-cascade tower, angle and anchor tower, for the 735 kV Bay James Project.

Supervise the work of Hydro-Quebec's engineers in the design of towers, foundations, conductors and hardware.

Preparation of supply and construction specifications for transmission lines.

1971 to 1976 *Project Engineer*

Responsible for numerous projects covering all transmission voltage levels (69 kV, 120 kV, 161 kV, 230 kV, 345 kV, 735 kV). Work involves selection of line routes of transmission lines, soil studies for foundations, budgeting, design of structures (wood and steel), tower spotting and supervision of construction. Specialized engineering studies, supervision of technical work performed by consulting firms and technical assistance during construction. Project Engineer of 735 kV river crossing over the St. Lawrence River, using 600 tons self-supporting towers of a height of 185 m.

LANGUAGES

	Spoken	*Read*	*Written*
French	Excellent	Excellent	Excellent
English	Excellent	Excellent	Excellent
Arabic	Excellent	Excellent	Excellent
Spanish	Fair	good	-
Italian	-	Fair	-
German	(some knowledge)		

PROFESSIONAL ASSOCIATIONS

- Chair of the International Electrotechnical Commission (IEC), Technical Committee 7 "Overhead Conductors"

- Fellow, Institute of Electrical and Electronics Engineers (IEEE) since 1994
- Chair of Subcommittee of Canadian Standards Committee CSA-C22.3 on reliability based design of overhead transmission lines
- Chair of Canadian Committee of IEC TC-11, sponsored by the Standards Council of Canada
- Past-Convenor (1988-2000) and currently member, of CIGRÉ WG 6 of Committee B2 "Overall line Design". Also member of the Strategic advisory group of B2 Committee
- Chair of Working Group MT1 of IEC/TC11 "Loading and Strength of Overhead Transmission Lines"
- Past Chair of Working Group MT4 of IEC/TC7 "Aluminum and Aluminum alloy stranded Conductors"
- Past Chair of the Canadian Standards Committee on IEC/TC86A "Fiber Optic Cables"
- Member and past Chairman of IEEE Task Force "Line Assessment-Service Experience" (1995-2001)
- Past Convenor of CIGRÉ Task on High surge impedance loading lines
- Member of (4) IEEE Sub-Committees, "Loading and strength of overhead lines", Construction of lines", "Line Assessment", "Towers, Poles and Conductors".
- Member of Canadian Standards Committee CSA-C49
- Member of the Canadian Electrical Association
- Member of the Order of Engineers of Quebec
- Registered professional engineer in the province of Manitoba

AWARDS

2016 IEC Award for outstanding contributions to international standards

2010 IEC Award for outstanding contributions to international standards

2004, Award of Merit from the Canadian Standards Association "For his dedication, expertise and leadership of more than 25 years that were instrumental in writing national and international standards in the areas of overhead line design and overhead electrical conductors"

1997 CIGRÉ (Conférence Internationale des Grands Réseaux Electriques) Technical Award for outstanding contributions to technical work on overhead lines.

1993 The Institute of Electrical and Electronic Engineers, IEEE FELLOW "For contributions to the reliability-based design and leadership in international standardization of transmission line design".

1984 IEEE Transmission and Distribution Award for the best Technical Paper.

PUBLICATIONS (PARTIAL LIST)

CIGRE paper B2-205, Paris 2016, "A New Model for Developing, Constructing, Financing and Operating Major Transmission Projects in Alberta", Ghannoum, Elias, Elizabeth Moore, Pauline McLean, C. Killoran.

CIGRE, Green Book "Overhead lines", author of an 85 page chapter on line design, 2014

Ghannoum, E., Gopal Ji, Kumar, R., "Selection of Conductors and OPGW for the Hoogly River Crossing in India". To be presented to CIGRE B-2 session, New Delhi, Oct. 2013

Kieloch, Z, Ghannoum, E., Design of the ±500 kV HVDC Bipole III line in Manitoba, Canada, CIGRE paper B2-101, Paris, Aug. 2012

Ghannoum, E., Zibby Kieloch, "Use of Modern Technologies and Software to Deliver Efficient Design and Optimization of 1380 km Long Bipole III ± 500 kV HVDC Transmission Line, Manitoba, Canada", IEEE Transmission and Distribution conference, May 9, 2012

Rogier, E., Fronek, Ghannoum, E., and WG B2-06, "Tower Top Geometry and Mid Span Clearances", CIGRE Brochure 348, CIGRE 2008

Rogier, E., Ghannoum, E., and WG B2-06, “Reliability Based Design Methods for Overhead Lines, Advantages, Applications, and Comparisons”, CIGRE Brochure 344, CIGRE 2008

Ghannoum, E., -- Assessment of the impacts of increasing structural reliability and security by designing lines for longitudinal broken conductor and unbalanced icing loads, CIGRE Paper B2-204, Aug. 2008

Ghannoum, E., “Tutorial on Cascading Structure Failures”, IEEE Tower, Poles, and Conductors, Las-Vegas, Jan. 2008

Ghannoum, E., “Comparison Between Unbalanced Ice Loads and Security Loads and Assessment of their Impact on Line/Structure Designs”, CEATI Publication T063700 3335, 2008

Ghannoum, E. and al., “Reliability Based Design Methods for Overhead Lines Advantages, Applications and Comparisons”, CIGRE Brochure 289, Working Group 22-06, 2006

Ghannoum, E., “Comparison of Wind Load Methodologies for Lattice Transmission Line Towers”, CEATI Publication T053700 3324, 2005

Ghannoum, E. “Increasing structural Reliability and Security Using IEC 60826 Principles”, CIGRÉ Symposium on line revitalization, Belgrade, Serbia, May 2003.

Ghannoum, E., “Evolution of IEC 60826 -Loading and Strength of Overhead Lines-”, ASCE, 2002 Omaha conference.

GHANNOUM et Al., "Use of Reliability Techniques in the Design of Hydro-Quebec's 1100 km Radisson-Nicolet-Des Cantons ±450kV DC Line", CIGRÉ Paris Meeting, Sept. 1996.

GHANNOUM et Al., "Fiber Optic Ground Wire for Hydro-Québec's Telecommunication Network", IEEE, Winter Power Meeting, 1995.

GAUDRY, M., GHANNOUM, E., "Increasing power transfer of overhead lines by using homogenous compact conductors", CIGRÉ, Paris, Sept. 1998.

GHANNOUM, E., "State of the Art Report on Compact Conductors", CEA, June, 1992.

GHANNOUM, E., YAACOUB, S.J., "Optimization of Transmission Towers and Foundations Based on Their Minimum Installed Cost", IEEE/PES 1988 Winter Meeting, Paper 88 WM 072-1.

GHANNOUM, E., Orawski, G., "Reliability Based Design of Transmission Lines According to Recent Advances by IEC and CIGRÉ", International Symposium of Probabilistic Design of Transmission Lines, Toronto, June 1986.

GHANNOUM, E., et al, "The Use of Probability Techniques in the Design and Uprating of Transmission Lines in Hydro-Québec", Symposium on Probabilistic Design of transmission lines, Toronto, June 1986.

GHANNOUM, E., and Tupula, F., "The Design of 500 kV HVDC Rihand-Delhi Transmission Line", Symposium on Trends in Transmission Line Technology, Delhi, 1985.

GHANNOUM, E., and Lamarre, M., "Hydro-Québec's Experience with the Design and Construction of 1500 km of 735 kV Chainette Transmission Lines", IEEE, Vol. PAS-104, no. 10, October 1985.

GHANNOUM, E., "Reliability and Security Concepts Applied to Structural - Design of Transmission Lines", 1983, International Symposium on Reliability, Availability and Maintainability, Montréal, June 1983.

GHANNOUM, E., "Probabilistic Design of Transmission Lines - Part I : Probability Calculations and Structural Reliability", IEEE/PES 1983 Winter Meeting, New-York.

GHANNOUM, E., "Probabilistic Design of Transmission Lines - Part II : Design Criteria Corresponding to a Target Reliability", IEEE/PES 1983 Winter Meeting, New-York.

GHANNOUM, E., "Improving Transmission Line Design by Using Reliability Techniques", IEEE/PES 1984 Winter Meeting, Dallas. (Award Winning Paper)

GHANNOUM, E., "Hydro-Québec Designs 735 kV Towers", Transmission and Distribution, December 1982.

GHANNOUM, E., "Design of 450 kV Des Cantons - New England DC Transmission Lines", CEA, Mars 1985.

GHANNOUM, E., "Design Criteria of Transmission Lines in Icing Areas", CHINA-HYDRO-QUÉBEC Symposium, Beijing' November 1981.

GHANNOUM, E., "A Rational Approach to Structural Design of Transmission Lines", IEEE Power Engineering Society, Winter Meeting, Atlanta, February 1981, and IEEE Transaction on Power Apparatus and Systems, PAS-100, July 1981, pp. 3506-3511.

GHANNOUM, E. et Al, "Discussion of Hydro-Québec's Design Approach to Structural Design of Transmission Lines", Canadian Electrical Association, March 1981.

GHANNOUM, E. "Une Nouvelle Approche de la Conception des Pylônes des Lignes de Transport d'Énergie", Canadian Structural Engineering Conference, Montreal, February 1980.

ELLYN F. and GHANNOUM, E. "An assessment of reliability of structures", Transactions of the Engineering Institute of Canada, Feb. 1972.

OFFICE ADDRESS

Elias Ghannoum, Consultant
6100 Deacon Rd. appt. 6F
Montreal, Québec
Canada H3S 2V6
Tel. 1-514-344 4127
email: elias@ghannoum.com