Manitoba Hydro International's Review of the Muskrat Falls and Labrador Island HVdc Link (LIL) and the Isolated Island Options

Prepared for:
Hon. Jerome Kennedy, Q.C.
The Minister of the Department of Natural Resources
Government of Newfoundland and Labrador

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1 HVdc, Electrode, and Collector Transmission System Review

Report by: G. Proteau, P. Eng.

1.1 Scope

Comment [plw1]: Gerry, as we discussed, please include some comments on the conductor selection.

The intent of this section is to conduct a high level review of the high voltage dc (HVdc) lines, the electrode sites, and the high voltage ac (HVac) ~~(~~collector transmission system~~)~~ Nalcor proposed at Decision Gate 3 (DG3) as compared to the configuration in place at Decision Gate 2 (DG2).

Cost estimates, construction schedules, and the design methodology undertaken by Nalcor in preparation for DG3 were examined and an assessment made of the reasonableness as inputs to a CPW analysis.

1.2 Schedule

Nalcor's proposed schedule for the HVdc and ac line designs, procurement, and construction were reviewed ~~in~~ through a series of interviews with key Nalcor personnel. ~~at o~~Only a high ~~strategic~~ level schedule for the existing ~~of~~ scope ~~as depicted in~~was provided in Nalcor's document "Project Schedule – Transmission."[1]

At ~~the time of this writing~~this time, detailed design of the transmission line structures is under way, and testing of critical line structures scheduled later this year. Nalcor ~~It is~~ projected ~~in the schedule~~ to extend detailed design right through to construction completion in the schedule. This is a prudent industry practice to support construction on large transmission projects with changing terrain necessitating field-specific design solutions.

Procurement activities have been staged to in the first quarter of 2012. Manitoba Hydro International (MHI) understands much legwork has been done to verify pricing and supply of the various transmission line materials pending official DG3 project sanction. To date, a total of 21 material procurement management packages are being prepared to fulfill the transmission requirements. To maintain the project construction schedule as planned, the majority of material contracts for long lead-time items such as towers, insulators, and conductors should be awarded by the end of 2012 for a fall 2013 or early 2014 construction start.

The construction window for all high voltage transmission line construction activities for the project complex has been allocated approximately four years with clearing activities starting in the second

[1] CE-12 Transmission Schedule

quarter of 2012. MHI ~~believes~~ finds the schedule to be reasonable and achievable provided construction work and equipment access is possible during all four seasons.

1.3 Cost Estimate Evaluation

Nalcor did not provide MHI access to the detailed cost elements, nor costing reports defining the DG3 estimate and ~~varience~~variance from the DG2 estimate for the transmission facilities. However, totals are provided and o~~O~~verall ~~however,~~ the DG3 estimate increased significantly from DG2. The DG2 estimates increased ~~(~~approximately 120% for the HVdc lines, and 45% for the HVac lines[2].

Nalcor described the methodology in preparing the DG3 estimate and MHI considers that it adequately reflects the costs forecasted for the ~~project~~construction of the transmission lines.

The DG3 estimate is based upon the following contributory factors:

- Costing from suppliers for detailed material breakdowns and known bulk quantities such as number of towers, insulators, and hardware.
- Transmission contractor budgetary feedback based upon the proposed schedule and construction methodology and timelines~~ factors~~.
- Engineering concepts that are virtually complete, and scope changes tracked and identified[3].
- Labour unit costing ~~determined~~ assuming a negotiated master labour agreement, equipment and commodity rates are identified.
- Productivity factors for labor, equipment, ~~and~~ while factoring in seasonal~~ity~~ impacts.

Comparing the DG3 cost estimate evaluated on a cost-per-line-km basis with other similar projects under way in Canada, MHI finds the Muskrat Falls ~~Transmission~~ transmission line complex costs are at an acceptable level and accuracy for this stage of the estimate. The costs are within an AACE Class 3 estimate accuracy congruent to the requirements of DG3.

1.4 Risk Assessment

Nalcor has identified the key areas of project risk in its project management strategy. At the current stage of project progress, the majority of major engineering decisions affecting ~~the~~ transmission line design and construction ~~which affect~~as to project scope have been made and costs estimated ~~in~~ for DG3. Nalcor has displayed appropriate controls and signing authority managing scope changes with the Transmission Deviation Alerts and the Change Notice document MHI reviewed in its ~~research~~review.

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[2] CE-31 Comparative Summary and Cost Growth Since DG2
[3] CE-25 Basis of Design Document

With the level of engineering complete to date and the tracking system in place, the probability of major scope changes to the design affecting cost and schedule is assessed as very low. At this stage minor route changes will not affect cost or schedule significantly. Nalcor has reserved the right of property expropriation in its final routing selection, to mitigate the risk of easement delays impacting the project schedule.

Comment [plw2]: Note: Al, the language here may have to be softened as not to alarm the public of Newfoundland.

Material costing has been calculated with estimated line quantities at current market values and as such is likely to only vary with the final tower optimization quantities. These variations ~~which~~ should not be~~vary~~ significant~~ly~~ from the quantities currently estimated.

At this stage, the major risks to be addressed for the transmission line complex remain with contractor cost and labour availability. There are several other high-profile transmission line and generation projects in the design stage in Canada set for construction in the same time frames~~lines~~ as Nalcor's Lower Churchill project. These, along with other natural resource projects, will act to attract skilled labour away from this project and create an inevitable cost escalation for contractor labour.

Comment [plw3]: Al, can you reword...

Nalcor has identified these issues as the major risks and has identified a strategy to attract skilled labour back into the province through a master labour agreement, training, and other self-development programs. While these programs and compensation levels were not identified in detail, MHI is aware of the issue of contractor availability in a very competitive skilled labour market. Should this event occur, there is a very high probability of cost escalation for construction activities.

1.5 Assessment of Line Routes

MHI has reviewed the general route corridor provided in Google Earth format. The route corridor MHI reviewed is the publically available 2-km-wide corridor running from Muskrat Falls across the Strait of Belle Isle ~~(SOBI)~~ to the Soldiers Pond Converter Station[4]. The 60-metre-wide final transmission line alignment remains confidential to Nalcor until it ~~recovers~~ receives final permitting, and completes its property acquisition~~,~~ and easement process. As the detailed routing alignment is not available, MHI's assessment will be limited to only the route suitability in the most general terms.

1.5.1 ~~+/- 350 kVdc~~HVdc Transmission Line Route

The route selected for the HVdc line is reasonably optimal considering the primary criteria required for an efficient bulk point-to-point transmission line. ~~It~~ The line has been designed to be as straight as possible between the source and load stations, minimizing angle locations where possible. The route navigates the more difficult areas of Labrador, by-passing the numerous large lakes, ponds, and swampy terrain with a minimal number of line angles. All water crossings appear achievable with minimal custom site designs typified as shown in Figure 1.

[4] CE-24 Lower Churchill Project –Asset Schematic by Project (Excluding Maritime Link)

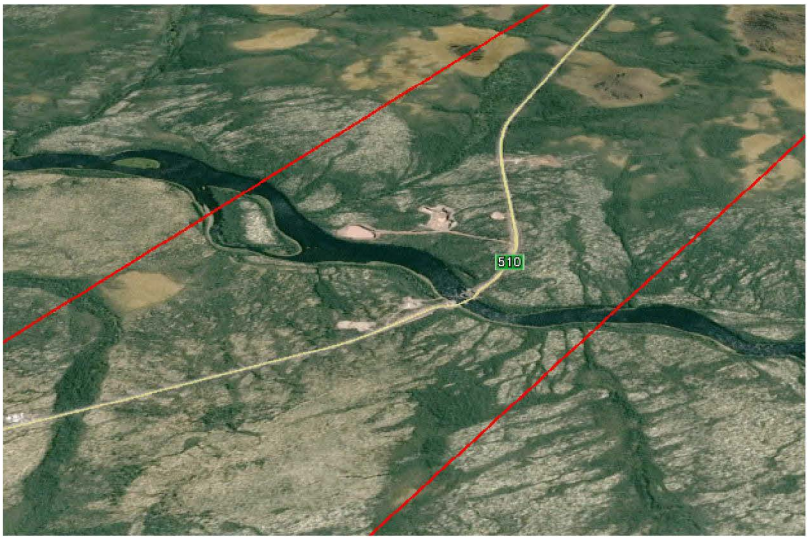


Figure 1:HVDC ~~Labrador~~ Transmission Line Route Water and Highway Crossing

Field Code Changed

The above figure shows a typical water crossing and the river crossing spans are achievable with the given design basis.

The route proceeds as directly as possible through the Long Range Mountain Ridge before it turns east heading through the Newfoundland Island to the Soldiers Pond Converter Station.

Portions of the route are adjacent to major roads such as the Trans-Canada and Trans-Labrador highways. This will help facilitate access to clearing, construction of the line, maintenance, and with planning an emergency response scenario. A review of the corridor displayed numerous access trails which enables fairly good access to the line in most seasons. Once the route is finalized, other access trails should be constructed for future line access.

Comment [plw4]: This sounds like a recommendation. Include in the key findings.

The route corridor through ~~the~~ Labrador ~~portion~~ is ~~frozen (~~finalized~~)~~ with the island portion of the corridor set for public input and approval. ~~shortly.~~ Nalcor has expressed confidence that final approval is forthcoming with minimal unforeseen changes to the routing. While MHI does not have access to information and cannot comment on local issues which may affect the final routing, the route appears to be well ~~chosen~~ suited for its purpose.

1.5.2 ~~315 kVac~~AC Transmission Line Routing

The routing for the two 315 kVac lines connecting Churchill Falls to Muskrat falls essentially follows the corridor of existing 138 kV transmission line TL 240. The corridor is well established and will be widened to an appropriate width to contain the additional two lines. MHI reviewed the Google Earth transmission line corridor and does not foresee any difficulties with this planned corridor addition. Nalcor still needs to obtain appropriate approvals and easements.

1.5.3 Electrode Line Routing

Detailed routing for the small lengths of electrode line to the Labrador and Newfoundland Electrode sites were not made available for this review, and as such MHI cannot comment as to the appropriateness of the routing. These small lengths of electrode line have a small cost when compared to the overall project and thus would not have a material impact.

1.6 Structure Families

MHI reviewed Nalcor's proposed structure families for the new ~~proposed~~ transmission lines ~~systems~~ in meetings with Nalcor's Principal Design Engineer and reviewed formal and informal printed documentation from design files. Final design drawings are neither complete nor available in an appropriate format for detailed review.

Nalcor's design philosophy used to determine the structure families for the ac and dc transmission lines follows an industry-accepted practice of apportioning out structures into "families" classified by their function along the transmission line. Structure families proposed in the designs include tangent suspension structures, various degrees of angle structures, heavy angle, and termination structures used to sectionalize the line.

The tangent suspension towers Nalcor has selected for both ac and dc systems are composed of guyed lattice steel mast-type structures modifiable by height extensions to maximize tower utilization in the rolling terrain common along the entire corridor. These types of structures are the best economical choice given the variety of geophysical soil conditions, terrain to be crossed, and remoteness of the route selected. Use of these structure types is common throughout the industry, and there are many other examples of these towers successfully installed throughout North America.

Other structures proposed are lattice steel self-supporting towers typically positioned at angle locations and other sections in the line for termination purposes or boundaries between weather-loading ~~cases~~zones. Critical to the performance and maintenance of self-supporting structures is suitable foundations for the terrain type. Nalcor has identified these tower locations for detailed geotechnical exploration which is acceptable methodology for structures of these types. MHI concurs with the selection made on structure families and types for use in this project.

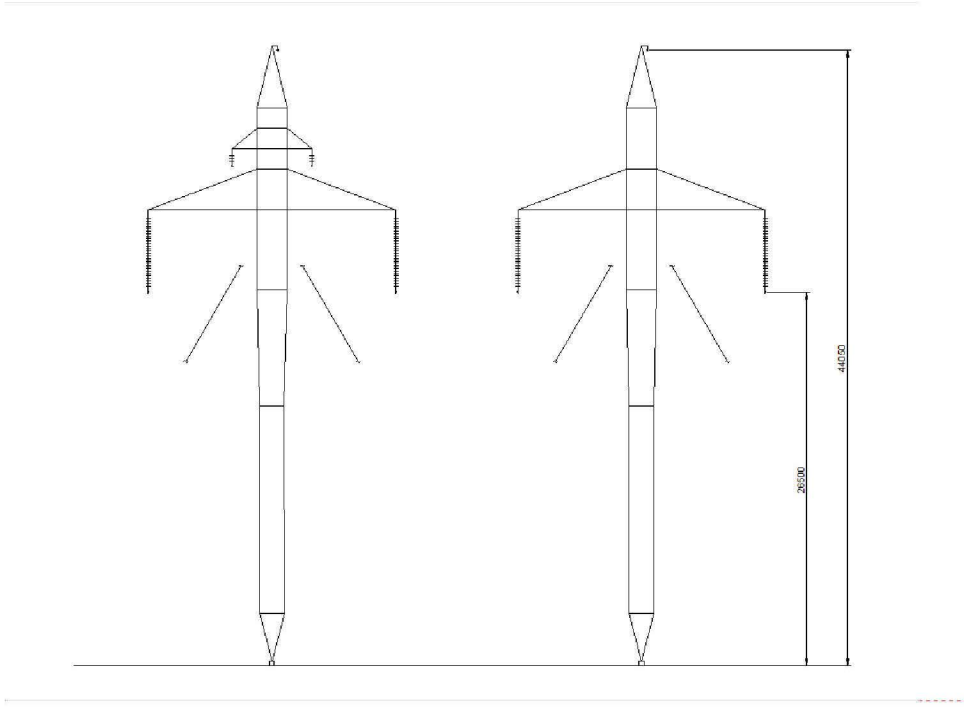
1.6.1 ~~+/- 350 kVdc~~HVdc Transmission Line Structure Family

MHI reviewed Nalcor documents[5] "+/- 350 kV HVdc Tower Design Criteria A1 Dec 14, 2011" and "+/- 350 kV HVdc Transmission Line Design Criteria A1 Dec 2, 2011" which summarized Nalcor's design approach in determining the tower window geometry, span spacings, load capacity, and other detailed engineering criteria pertinent to the proposed HVdc transmission system. From extensive meteorological research, Nalcor determined that the transmission line would require 16 unique weather zones to adequately model the ice-and-wind loading on line structures.

[5] Exhibit documents ~~not available~~were presented at the meetings with Nalcor, but MHI was not allowed to retain copies.

Engineering work is in progress to complete the detailed design for the HVdc line. Nalcor has defined 12 structure families, with a total of 25 structure types[6], required to economically construct the line. Wherever possible, an effort was made to use common structures in the various loading zones in an effort to minimize the number of unique, custom structures which mitigates design and construction cost.

*Figure 2: Typical HVdc **Transmission Guy Tangent** Structures*



HVdc Segment 1 (with electrode) HVdc Segment 2 (without electrode)

Comment [plw5]: Gerry, please specify tower width, extend the guys and specify that width, and note the units.

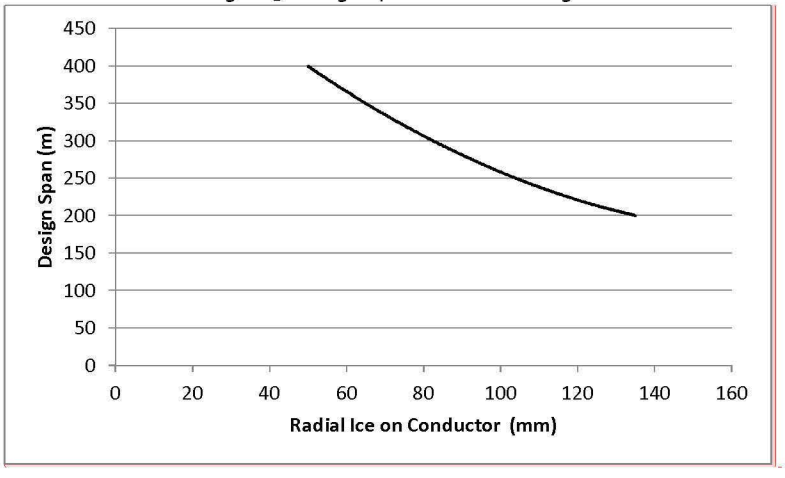
Typical guy tangent tower which comprise approximately 85% of the towers in the Labrador Island HVdc transmission line.

Comment [plw6]: Gerry, please confirm this number.

Nalcor's design controlled the various combined ice-and-wind loading to the line structures by reducing or increasing the ruling span in the 16 weather-zone regions. Generally, as the ice-and-wind-combined loading increased, the design ruling span was reduced accordingly as depicted in Figure 3. It is an acceptable approach to control as much as possible the structure size and weight, and ultimately construction and logistics costs.

[6] CE-07 350 kV HVdc Tower Types

Figure 3: Design Spans for Ice Loading



Comment [plw7]: Gerry, can you please send me the original so I can reformat the presentation.

MHI has reviewed the various ice-and-wind loading cases and required structure families and has determined Nalcor's design approach, given the severity and wide range of weather cases found along the transmission line route, is a reasonable and cost-effective methodology.

1.6.2 ~~315 kVac~~AC Transmission Line Structure Family

MHI reviewed Nalcor documents[7] "+/- 315 kV HVac Tower Design Criteria B2 March 23, 2012" and "+/- 315 kV HVac Transmission Line Design Criteria B2 February 2, 2012" which summarized Nalcor's design approach in determining the tower window geometry, span spacings, load capacity, and other detailed engineering criteria pertinent to the proposed HVac transmission system running from the Churchill Falls Switching Station to the Muskrat Falls Switching Station.

Two 315-kVac lines are proposed, and Nalcor has advised that only one structure family with five different tower types is required for the route. The structure family is composed of guyed steel lattice structures with self-supporting angle and termination structures. As this line is predominantly in one weather-loading zone, MHI concurs with Nalcor's decision in selecting this structure family design.

1.6.3 Electrode Line

For reasons of life-cycle economics and reliability, the electrode line on the Labrador portion of the HVdc line was recently moved from individual wood pole structures located along the right-of-way

[7] Exhibit documents were presented at the meetings with Nalcor, but MHI was not allowed to retain copies. ~~not available~~

edge to a position on the HVdc line structures from Muskrat Falls to Forteau point. MHI finds it is a prudent decision to consolidate the HVdc pole and electrode conductors onto one supporting structure in the Labrador transmission line section. There are considerable cost savings in construction effort, material, and the long-term maintenance required of wood pole structures by proceeding with this design.

From Forteau point to the Labrador Electrode site at L'Anse-au-Diable, and from the Soldiers Pond Converter Station to the Dowden Point electrode site, the electrode line is suspended on standard wood pole structures of similar size to a distribution pole system. MHI concurs with the design methodology that Nalcor selected for the electrode line system.

1.7 Assessment of Transmission Line Reliability

Nalcor made several prudent decisions to the detailed transmission line design to reduce the probability of an outage, and failure or progression of failures in line structures with the intent to increase the line's overall reliability. The following salient points highlight these decisions:

1. The guyed structure configuration will naturally resist failure from cascading events and is more stable in the rugged terrain found along the route.

2. Provision of special anti-cascade towers every 10 to 20 structures to contain and isolate failures and prevent them from impacting large sections of line.

3. In sections of the transmission line with the most severe combined ice-and-wind loading, the spans have been shortened appropriately to reduce structure loading to manageable levels.

4. Selection of a single large conductor in place of a multi-bundled conductor arrangement. This prevents ice accumulations bridging across sub-conductors to form large shapes which would transfer high wind loads to structures.

5. Insulator purchase is limited only to vendors with international reputations for quality, operational reliability who have established distribution networks to comply with delivery schedules.

6. Due to the effect the rolling terrain has on tower locations and optimization, the average tower strength utilization on tangent towers will be somewhat less than the designed capacity, with utilization possibly averaging between 75% and 85% of the ultimate strength. This has the effect of increasing tower resistance and stability during extreme weather events thus increasing overall reliability.

7. Selection of the final alignment within the route corridor attempted to minimize exposure to the extreme climatic-loading regions such as Long Range Mountain Ridge, and to avoid areas where the terrain acts to accelerate and funnel the wind.

8. Tower window dimensions and spans are designed to comply with the most up-to-date theory predicting conductor motion in extreme wind and ice events. This will reduce or eliminate outages during these events, increasing the overall transmission line reliability.

9. Tower prototype testing on the most common line structures to affirm capacity and behavior under loading

MHI finds Nalcor has completed a thorough assessment of the various climatic regions impacting the +/- 350 kV HVdc line from Muskrat Falls to the Soldiers Pond transmission line route and past meteorological research resulting with the line being apportioned into 11 sections each with a unique zone-specific climatic loading[8].

The climatic loadings for each line section selected on a 1:50-year return period based on Nalcor's past research studies, as outlined in document "Muskrat Falls Project –Exhibit 97, Appendix A Revision 1," are approximately equivalent to the climatic loading calculated assuming a Canadian Standards Association (CSA) 1:500-year return period.

There are additional recommendations in CAN/CSA C22.3 which recommend a greater reliability of design to 1:150-year or 1:500-year return periods for lines of voltages greater than 230 kV which are deemed of critical importance to the electrical system. The +/- 350 kVdc and 315 kVac lines proposed and configured for the Lower Churchill Project will, once operating, operate as a critical backbone for Newfoundland's electrical supply in the foreseeable future. These lines should, in MHI's opinion, be classified in the critical importance category due to their operating voltage and role in Nalcor's long term strategic plan for its transmission system.

Nalcor is aware of these additional reliability recommendations, and the decisions made in other provinces considering similar HVdc projects such as in Alberta and Manitoba; however, through its own internal design policy, it has elected to not incorporate them in this project.

By selecting a 1:50-year climatic return, Nalcor only meets the minimum reliability requirements outlined in CAN/CSA C22.3 for high voltage transmission lines.

Comment [plw8]: Al, these two paragraphs need to be reworded to be more politically astute and palatable. Can you tackle this.

1.8 Emergency Response Plan

MHI is not aware of any formalized emergency response plan that Nalcor has made for an HVdc outage scenario. Informal discussions with key Nalcor staff were held on the topic to determine what, if any formalized ~~planning on~~ emergency restoration is planned. Emergency response times to restore the line to normal operating conditions are very difficult to predict due to the remoteness of the transmission line and levels of failure possible. Outage periods up month or greater in remote line sections are possible.

[8] CE-22 Muskrat Falls Project –Exhibit 97, Appendix A Revision 1

The items addressed for possible follow-up in a restoration plan may include:

- Purchase and strategic storage of material caches. Material for caching may be purchased with the primary material orders to take advantage of bulk costing.
- Development of access and restoration trail-way system. This may be done during primary construction.
- Design of temporary emergency structures and anchoring which may be flown to tower sites.

Since Nalcor has selected the minimum reliability period of 1:50 years ~~in~~ as its design basis, MHI recommends Nalcor undertake an additional ~~parallel design~~ study for the various ~~an~~ emergency response scenarios.

Comment [plw9]: Gerry, what exactly is your recommendation here. I may have butchered it.

1.9 Summary of Key Findings

The following is a summary of the key findings from the review of the information gathered and interviews held with the Nalcor project team.

- The Nalcor project management team is utilizing an experienced consultancy firm to prepare the detailed design, material, and construction cost estimate taken forward to DG3. Nalcor is utilizing highly professional staff with engineering and project management backgrounds to manage, track, and direct the consultant using accepted project management practices.
- The transmission line structures and routes selected for all transmission facilities are very cost-effective considering the terrain, route, and climatic loading expected. From the review of the written documentation provided, design methodology, and information recorded in the Nalcor staff interviews, MHI is satisfied the DG3 estimate for all transmission facilities was prepared with high skill and diligence and is expected to be accurate to AACE International Class 3 level (+30% to -20%).
- The design and construction schedule proposed by Nalcor is achievable provided there are no major changes to the project scope, unusual weather encountered during construction seasons, and adequate contractors retained with resources available.
- The risk of cost escalation during the construction stage is high considering very competitive labor rates and compensation will be required to attract qualified contractors and personnel. This escalation risk may not be fully accounted in the DG3 estimate.
- In MHI's opinion, Nalcor undertook extensive due diligence in its design methodology designing the transmission line to withstand the many unique and severe climatic loading regions along its line length. However, by Nalcor assessing and selecting only a 1:50-year climatic return period, the HVdc line will only meet the minimum reliability requirements for high voltage transmission line. This contradicts standard industry practice of a utility designing critical

transmission infrastructure to a higher level of reliability compared to the rest of its electrical system.