

**Historical Summary of the Labrador-Island HVdc System
Configuration for the Lower Churchill Project
(1974-Present)**

Technical Note

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1.0 Introduction

The purpose of this document is to provide a historical summary of the proposed configurations for the Labrador-Island HVdc link that have been investigated as part of the Lower Churchill Project. The document includes a summary of system design from previous project iterations in 1974, 1980, and 1998, as well as the configuration from the current basis of design.

2.0 Definition of Terms

| | |
|----------------------------------|--|
| Bipole | An HVdc transmission system that consists of two conductors. One conductor is at a positive polarity, while the other is at a negative polarity. |
| Combustion Turbine | A generator that derives electrical energy from the combustion of fossil fuels. |
| Converter Station | Equipment that converts power from ac to dc (rectifier) or dc to ac (inverter). |
| Hybrid Line Configuration | A situation when HVdc and HVac transmission lines share a common right of way. |
| Mass Impregnated | The electrical insulation method used for power cables. The conductor is tightly wrapped with porous paper and saturated with oil, installed under pressure, to provide electrical insulation. |
| Multi-Terminal HVdc | An HVdc transmission system that interconnects more than two terminal stations. |
| Overhead Ground Wire | Provides lightning protection for the power conductors. When used, direct lightning strikes are minimized, and potential disturbances due to lightning are reduced. |
| Overload Capacity | The capacity of a system component to deliver power in excess of its nameplate rating. |

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| Reactive Power | The storage of electrical energy by system components in the form electric and magnetic fields (measured in vars). System components that have inductive properties absorb <i>reactive power</i> , while components that have capacitive properties generate <i>reactive power</i> . A deficit of <i>reactive power</i> may lead to undervoltages, while an excess of <i>reactive power</i> may lead to overvoltages. |
| Return Period | A measure of the reliability of a transmission line based on the robustness of tower and conductor design. A line design with a twenty-five year <i>return period</i> would be expected to withstand the ice/wind loads associated with a one-in-twenty-five-year weather event. |
| Series Compensation | The addition of capacitors to reduce the amount of <i>reactive power</i> consumed by a transmission line. |
| Synchronous Condenser | A rotating machine that may be controlled to absorb or generate <i>reactive power</i> . |
| Static Var Compensator | A machine that may be controlled to absorb or generate <i>reactive power</i> . |
| Under-Frequency Load Shedding Scheme | A protection scheme that ensures that sections of Shedding Scheme load disconnected from a power system if there is insufficient generation. Such a scheme helps to avoid system collapse. |
| Voltage Source Converter | A specific type of HVdc technology that relies on specialized switches known as IGBT's. VSC technology has a potential advantage in that the system may be implemented without additional reactive support. |

3.0 List of Acronyms

| | |
|-------------|---|
| A | Ampere |
| ac | alternating current |
| AASC | Aluminum Alloy Stranded Conductor |
| ACSR | Aluminum Conductor, Steel Reinforced |
| dc | direct current |
| HVac | High-Voltage alternating current |
| HVdc | High-Voltage direct current |
| IGBT | Insulated-Gate Bipolar Transistor |
| LCP | Lower Churchill Project |
| MI | <i>Mass Impregnated</i> |
| PSSE | Power System Simulation for Engineering |
| RFP | Request for Proposals |
| SOBI | Strait of Belle Isle |
| V | Volt |
| var | voltampere reactive |
| VSC | <i>Voltage Source Converter</i> |
| W | Watt |

4.0 Previous Studies

4.1 HVdc System - 1974

Initial investigations of the HVdc line were completed in 1974 with the assistance of Teshmont Consultants Ltd. The HVdc link would provide an inherent solution to challenges such as maintaining synchronism between the generating sources on the Island and in Labrador as well as issues surrounding the use of submarine cables. The proposed system would consist of two ± 400 kV, 800 MW *bipoles* where one *bipole* would run from Gull Island to Stony Brook, while the other would run to from Gull Island to Soldiers Pond. Transmission lines were specified based on towers with a twenty-five year *return period* and a single ACSR conductor. The lines would have no *overhead ground wire*. The proposed SOBI crossing would involve six oil-filled, paper-insulated cables.

4.2 HVdc System - 1980

In 1980, the LCP was revisited with the assistance of SNC-Lavalin. The proposed HVdc system in this iteration would involve the installation of a ± 400 kV, 800 MW *bipole* that would connect Gull Island to Soldiers Pond, with the possibility of a second ± 400 kV,

800 MW *bipole* that would run from Gull Island to Onslow, Nova Scotia. The investigation specified that provisions be made such that the Soldiers Pond and Nova Scotia systems could be interconnected in the event of an emergency. It was therefore proposed that a switching station be installed at Taylors Brook, where the two *bipoles* would diverge.

4.3 HVdc System - 1998

The next HVdc investigation was completed with the assistance of Teshmont Consultants, Inc. in 1998 and involved a series of technical modifications to previously proposed systems. These modifications involved the inclusion of an *overload capacity* for the HVdc system. Given the magnitude of the HVdc in-feed relative to the Island system and its subsequent impact on system performance, the HVdc in-feed would be rated with a 2.0 p.u. *overload capacity* (800 MW) on each pole for 10 minutes and a 1.5 p.u. (600 MW) *overload capacity* per pole continuously. The rationale for the pole ratings was that in the event of the loss of one pole, the healthy pole would instantaneously deliver the full power for ten minutes so that there would be no frequency dip on the Island and no need to initiate underfrequency load shedding. In the intervening ten minutes there would be realization that there was a permanent pole failure and NLH would start generation on the Island to unload the HVdc In-feed and reposition the available NLH generating fleet. The continuous 1.5 p.u. overload capability is intended to limit the amount of fast start combustion turbine generation that would have to be added to the Island system.

Other design considerations for the system included of an *overhead ground wire* on the HVdc line to provide lightning protection. A single 54 mm AASC conductor was proposed for this system and MI SOBI cables were specified for the overload current rating of 1500 A. An extensive power system study was completed as part of this investigation and Island System upgrades were proposed. These upgrades include three 150 MVAR *synchronous condensers* at Soldiers Pond, as well as some *reactive power* compensation in the Western Avalon Area.

5.0 Current Project Iteration

5.1 Original Labrador-Island HVdc System Configuration

The original configurations of the Labrador-Island HVdc system in the current iteration of the LCP were similar to previously proposed systems. Two transmission scenarios were investigated including an 800 MW scenario involving a transmission system from Gull Island to Soldiers Pond and a transmission system that would transmit 1600 MW from Gull Island to 800 MW converter stations at Soldiers Pond and Salisbury, New Brunswick. Based on the 1998 study, it was assumed that each pole would be capable of an *overload capacity* of 200% (800 MW) for 10-minutes and 150% (600 MW)

continuously.

Voltages of ± 400 , ± 450 and ± 500 kV dc, were considered and MI cables were specified for the SOBI and Cabot Strait crossings. Generic tower designs were used to estimate the tower costs and it was determined during detailed studies completed in association with Hatch and RSW in 1998 that optimal configurations would involve a ± 400 kV, 50.4 mm diameter conductor solution for the 800 MW scenario and a ± 450 kV, 58 mm diameter conductor solution for the 1600 MW scenario.

5.2 Proposed Upgrades to the Island Interconnected System

An extensive interconnection study for the proposed HVdc system was completed in May of 2008 with assistance from Hatch and TransGrid Solutions. Major study tasks included power flow, short circuit, and transient stability analyses; a cursory evaluation of alternative HVdc configurations; and the development of a *multi-terminal HVdc* model for future PSSE studies.

The systems analyses allowed for the identification of required Island upgrades including the conversion of Holyrood units to *synchronous condensers*, the installation of five *combustion turbines* at the Pipers Hole, the installation of one (plus one spare) 300 MVAR high-inertia *synchronous condenser* at Soldiers Pond and at Pipers Hole, the installation of 50% *series compensation* on transmission lines TL202 and TL206, the upgrade of a number of 230 kV lines and circuit breakers, the modification of the existing underfrequency load shedding scheme, and the implementation of a special protection schemes.

In August of 2010, system models were modified to account for the cancellation of the proposed refinery at Pipers Hole. Performance criteria were also revisited as it was proposed that the system should not be required to withstand a three-phase fault at Bay d'Espoir. This contingency was noted as being particularly severe as it would isolate significant portions of generation while suppressing ac system voltages to such a degree that commutation failures would occur in the Labrador-Island HVdc link. This event was deemed an exceptional contingency as it was determined that the number of upgrades required to withstand such a contingency would be too costly, particularly as the existing Island Interconnected System would not be able to withstand such an event.

Modified system models also considered the use of new high-inertia *synchronous condenser* models that would potentially improve system performance while reducing the required number of units.

Results of the study indicate that Island system upgrades would be limited to include two (plus one spare) 150 MVAR high-inertia *synchronous condensers* installed at Soldiers Pond as well as a new 230 kV transmission line from Bay d'Espoir to Western Avalon

Terminal Station. As an alternative to the new 230 kV circuit, upgrades could include a 300 MVAR *static var compensator* at Sunnyside and 50% *series compensation* on transmission lines TL202 and TL206. Analysis was performed to investigate the upgrades that would be required to survive a three-phase fault at Bay d'Espoir. These upgrades would include a new 230 kV transmission line from Bay d'Espoir to Western Avalon Terminal Station, 50% *series compensation* on this new circuit, as well as transmission lines TL202 and TL206 and two (plus one spare) 300 MVAR high-inertia *synchronous condensers*.

An investigation was also performed to investigate the impacts of the loss of both poles of the HVdc system. The results indicate significant modifications would have to be made to the existing *under-frequency load shedding schemes* and that approximately 750 MW would have to be shed in the event of such a contingency.

5.3 Development of the Muskrat Falls Hydroelectric Facility Before Gull Island

In 2010, Newfoundland and Labrador Hydro was faced with a decision relating to generation expansion for the Island Interconnected System for the timeframe ranging from 2015 to 2020. As ensuing analysis indicated that the least-cost expansion option would involve a Labrador-Island HVdc infeed, it was determined that priority should be given to the Muskrat Falls Development. This development would be sufficient to meet forecasted demand in for the Island Interconnected System, while providing some additional capacity for potential export to the Maritimes.

Based on this change, the proposed 1600 MW multi-terminal HVdc scheme would be replaced with a smaller point-to-point system from Muskrat Falls to Soldiers Pond. With an estimated annual plant capability of 4.9 TWh at Muskrat Falls and up to 300 MW of available recall capacity from the Upper Churchill, it was determined that the HVdc link should be sized for 900 MW.

Analysis confirmed that a 900 MW HVdc link between Labrador and the Island would require a minimum operating voltage of ± 320 kV. System upgrades associated with this alternative include: two (plus one spare) 150 MVAR high-inertia *synchronous condensers* installed at Soldiers Pond, conversion of Units 1 & 2 at Holyrood to synchronous condenser operation and a number of 230 kV and 138 kV circuit breaker upgrades.

5.4 The Maritime HVdc Link

The transmission system on the Island of Newfoundland may be characterized as having significant hydroelectric resources in the West and main load centres in the East. This results in a significant West-to-East power flow, with the main load centre at St. John's being supported by a 450 MW thermal plant at Holyrood. The termination of the

Labrador-Island HVdc Link at Soldiers Pond would therefore allow for the replacement of the thermal plant, while alleviating the need to push power across the Island. Another consequence of this would be that hydroelectric resources in the western portion of the Island System would become available for export. It was therefore proposed that a ± 200 kV, 500 MW HVdc link be connected from Bottom Brook Terminal Station to Nova Scotia. Bottom Brook Terminal Station was chosen as the terminus of the Maritime HVdc Link, as it represents the southwestern-most corner of the 230 kV system and is closest to the export path. For loss of the HVdc system between Labrador and the Island, the HVdc link to the Maritimes would also be capable of delivering up to 500 MW to the Island in the post contingency period.