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THE Lower Churchill PROJECT

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DC1020 - HVdc System Integration Study

Volume 2 - Power Flow and Short Circuit Analysis

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Executive Summary

Steady state analysis of the Lower Churchill multi-terminal HVdc project has been completed. The following conclusions can be made:

1. The steady state reactive power requirements are as follows:
    - Soldiers Pond 230 kV bus – 450 MVAr filters, 150 MVAr synchronous condenser
    - Sunnyside 230 kV – 200 MVAr capacitance

The reactive power support is required to compensate the HVdc converter reactive power absorption, to prevent voltage collapse under heavily loaded Island conditions particularly on 230 kV lines between Bay d'Espoir and Soldiers Pond, and to maintain the minimum effective short circuit ratio (ESCR) at the Soldiers Pond bus to 2.5.

2. HVdc losses in bipolar operation at nominal rating:
    - Operating at a dc voltage of 500 kV per pole with Gull Island producing nominal rated 1600 A per pole current, a total power of 765.8 MW is injected at Soldiers Pond and a total power of 763.4 MW is injected at Salisbury, resulting in losses of 34.2 MW and 36.6 MW at Soldiers Pond and Salisbury respectively.
3. HVdc losses in monopolar operation:
    - The losses increase when operating in monopolar mode, requiring up to 2611 A (1.66 pu current) at Gull Island to simultaneously supply the 10-minute 100% overload requirement at Soldiers Pond (2.16 pu current) and the continuous 10% overload at Salisbury (1.1 pu current), and up to 2149 A (1.34 pu) at Gull Island to supply the continuous 50% and 10% overloads at Soldiers Pond (1.58 pu current) and Salisbury (1.1 pu current) respectively.

4. Maximum fault levels at the following stations are increased by the listed percentages with the addition of a synchronous condenser at Soldiers Pond and the five new combustion turbines (CTs) at Holyrood:
    - Come by Chance - 10.1 – 37.6%
      Western Avalon – 12.0 – 37.3%
      Long Harbour – 23.5 – 97.8 %
      Sunnyside – 13.2 – 46.6%
      Oxen Pond – 7.3 – 41.4%
      Hardwoods – 8.1 – 69.1%
      Holyrood – 12.6-74.2%
    - At the Holyrood 230 kV station, nine breakers rated for 5100 MVA (B12B15, B3L18, B12L42, B3B13) and 5430 MVA (B2L42, B12L17, B1L17, B1B11, B2B11) would require replacement as their ratings are exceeded. No other breaker ratings are exceeded at other stations despite the increase in fault levels.
5. The minimum ESCR at the Soldiers Pond bus occurs during the minimum Island generation case for loss of Holyrood unit #3 resulting in the following ESCRs:

- ESCR = 1.9 (1967 MVA) without a synchronous condenser at Soldiers Pond
- ESCR = 2.5 (2545 MVA) with 150 MVAr synchronous condenser at Soldiers Pond

Therefore a synchronous condenser is required at Soldiers Pond to meet the minimum desired ESCR of 2.5.

6. Due to very heavy west to east power flow along the 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond, made worse by a proposed new refinery load near Piper's Hole, several 230 kV lines were observed to be overloaded particularly for loss of one of the 230 kV lines in that corridor. The overloads are worst during cases of low DC infeed at Soldiers Pond and especially when exporting from Soldiers Pond, but can also occur to a lesser degree for the maximum DC infeed cases. The following line upgrades could be implemented to significantly reduce the amount of overloads observed:

Line		Current Rating (MVA)	New Rating (MVA)	Upgrade
TL202	Bay d'Espoir-Piper's Hole	199.3/297.7/369.5	341.8/402.4/453.8	Thermal uprate to 75 degrees C.
TL206	Piper's Hole – Sunnyside	199.3/297.7/369.5	341.8/402.4/453.8	Thermal uprate to 75 degrees C.
TL203	Sunnyside – Western Avalon	261.7/307.8/347.0	355.8/411.5/459.6	Rebuild with 804 MCM AACSR/TW conductor.
TL217	Western Avalon-Soldiers Pond	199.3/297.7/369.5	341.8/402.4/453.8	Recent review indicates can operate at 75 degrees C
TL201	Western Avalon-Soldiers Pond	175.5/260.2/322.2	355.8/411.5/459.6	Rebuild with 804 MCM AACSR/TW conductor.
TL201	Soldiers Pond-Hardwoods	175.5/260.2/322.2	355.8/411.5/459.6	Rebuild with 804 MCM AACSR/TW conductor.
TL207	Sunnyside – Come by Chance	355.8/411.5/459.6	-	Requires detailed review by Transmission Design.
TL237	Come By Chance-Western Avalon	355.8/411.5/459.6	-	Requires detailed review by Transmission Design.

Several overloads still exist after the line upgrades listed above are implemented, however the overloads only occur during cases of minimum DC infeed or during DC export. Generation re-dispatch in which the DC infeed power is increased and generation in the west is decreased can be used to relieve the remaining overloaded lines.

7. The need for a fast HVdc power run-up and run-down has been identified as follows:
   - Depending on whether the Soldiers Pond converter is importing or exporting power, a fast HVdc power run-up or run-down will be required to either increase the power being imported into Soldiers Pond or to decrease the power being exported in order to off-load the 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond to prevent a voltage collapse scenario for loss of one of the parallel 230 kV lines between Bay d'Espoir and Piper's Hole. Power flow cases in which the DC infeed is operating at minimum power of 80 MW and cases in which the DC is exporting can result in pre-contingency power flows of greater than 300 MW on both of the Bay d'Espoir to Piper's Hole lines. It appears that if this pre-contingency power flow is greater than approximately 225-250 MW a fast DC run-up (when importing) and run-down (when exporting) is required to prevent system voltage collapse for loss of one of the 230 kV lines between Bay d'Espoir to Piper's Hole. Corresponding generation in the west would require transfer tripping.

8. It should be noted that a portion of the Island system upgrades identified in this report, in particular the need for reactive power support at Sunnyside and the extensive thermal upgrades required on 230 kV transmission between Bay d'Espoir and Soldiers Pond, are largely due to approximately 255 MW of new industrial load (refinery and smelter) which is planned to be installed along the heavily loaded transmission corridor. The major NLH Island load centre is located east of Bay d'Espoir on the Avalon Peninsula, while the majority of the generation is located west of Bay d'Espoir. This can result in heavy west to east power flow on the 230 kV transmission system, in particular between Bay d'Espoir, Sunnyside, Western Avalon and Soldiers Pond, with further increased loading due to the new industrial loads. As a general result this can cause voltage depression and thermal overloading in the area. The HVdc infeed into Soldiers Pond generally has a positive impact on the Island transmission system as it off-loads this west to east power flow by injecting power closer to the load centre. Many of the issues discussed are not necessarily due to the HVdc infeed but are due to the lack of transmission linking the generation in the west to the load in the east. For example, without the new refinery load, the reactive power requirement at Sunnyside reduces to approximately 50 MVAr from 200 MVAr. It will be important for further system impact studies involving the loads to define more exact requirements of connecting the new loads separate from the impacts of the HVdc infeed into Soldiers Pond.

1. Introduction

This report describes the steady state analysis portion of the WTO DC1020, the DC system integration studies for the Lower Churchill Project (LCP), including the power flow and short circuit studies. The purpose of the steady state analysis is to determine new facilities including steady state reactive power requirements and upgrades to existing facilities that are required within the Newfoundland and Labrador Hydro (NLH) transmission system in order to interconnect the 800 MW HVdc link while ensuring that the NLH criteria for acceptable power system operation is maintained.

The steady state analysis is performed using the PSS/E version 30.2 software package.

Also, this study assumes that New Brunswick (NB) transmission system is able to wheel through 760 MW from Salisbury 345 kV substation to the northern Maine area. This assumption has been validated in a separate study and the summary results are included in Appendix 6 – New Brunswick Power Injection Assessment. The load flow and transient stability study was carried out using PSS/E version 29.4 since the dynamic model was available in this format."

1.1 Objectives

The objectives of the steady state analysis are to determine:

1. The total steady state reactive power supply requirements at the converter stations, including the harmonic filter requirements for the converter stations in Labrador and Newfoundland and the potential need for any synchronous condenser(s) to provide additional reactive power support and/or to increase the effective short circuit ratio at the Soldiers Pond bus.
2. The requirements for any other reactive power supply elsewhere in the NLH transmission system to meet steady state voltage criteria.
3. The losses for the proposed HVdc solutions and associated configurations.
4. Any other equipment requirements such as new equipment or upgrades to existing NLH transmission system equipment required to meet thermal loading and steady state voltage criteria.
5. The pre-HVdc system strengths.
6. The impacts of adding the HVdc system including reactive power compensation additions on existing circuit breaker ratings to determine the need for any breaker replacements.
7. The range of ESCR at the Soldiers Pond bus for the various power system configurations and the reactive power compensation of the HVdc system.
8. Preliminary HVdc design parameters, including typical converter transformer impedances, ranges required for alpha and gamma at each station in each operating mode, and tap changer ranges for the converter transformers.
9. The required HVdc operating modes, considering the bi-directional nature of each terminal and the need to provide frequency control in Newfoundland.

1.2 Procedure

The steady state analysis is carried out using the following procedure:

1. Create power flow cases for the various NLH generation and load dispatches and for the various multi-terminal HVdc configurations and operating points. This involves merging the NLH power flow cases with the New Brunswick area power flow cases via a multi-terminal HVdc model.
2. Perform power flow studies by performing steady state contingency analysis on the NLH power system using the various power flow cases to determine the steady state reactive power requirements of the converters and to ensure that the steady state criteria, including voltage and thermal loading, is met for all operating conditions in the NLH system.
3. Perform short circuit studies by applying faults at key NLH system buses to determine the maximum short circuit levels and impacts to existing circuit breakers and to determine the range of minimum ESCRs at the Soldiers Pond bus using the reactive power supply requirements as determined from the power flow analysis.

2. Multi-terminal HVdc Information

2.1 Ratings, Losses and Equipment Data

The multi-terminal HVdc system consists of a three-terminal link connecting Labrador, Newfoundland and New Brunswick. The proposed HVdc system is bipolar with normal operation having Labrador as rectifier and Newfoundland and New Brunswick as inverters; however, each converter station is capable of operating as either rectifier or inverter.

The HVdc system will operate at a rated dc voltage of +/-500 kV. The Labrador terminal is connected to the Gull Island 230 kV bus and has a nominal rating of 1600 MW, or 1600 A. The Newfoundland terminal is connected to the Soldiers Pond 230 kV bus and has a nominal rating of 800 MW, or 800 A. The New Brunswick terminal is connected to the Salisbury 345 kV bus and has a nominal rating of 800 MW, or 800 A.

The HVdc infeed into Soldiers Pond will be a major source of power to the NLH Island and will provide frequency control. The converters at Soldiers Pond will require a 10-minute 2.0 pu and a continuous 1.5 pu overload capability in order to maintain supply to the Island during loss of an HVdc pole. The 10-minute overload capability will provide NLH operators time to turn on other Island generation in the event of a HVdc pole outage. The converters at Salisbury are assumed to have a typical 10% current overload capability. The 1.5 pu and 2.0 pu overload ratings at Soldiers Pond refer to nominal power (not current) injected at Soldiers Pond after losses when Gull Island is supplying rated 800 MW to the Island. The special overload capabilities at Soldiers Pond will require each pole at Gull Island to have a 1.66 pu current rating and at Soldiers Pond to have a 2.16 pu current rating.

The rectifier and inverter control modes used in a multi-terminal HVdc link are different than in a typical two-terminal HVdc link. In a multi-terminal link, the inverters will operate in current control mode and the rectifier will operate in voltage control mode. This is because stable current sharing between the two inverters is best achieved if both inverters are operating in current control. An additional reason to operate the inverters in current control is because a long section of the HVdc line from the tap at Taylors Brook to New Brunswick is an HVdc cable. The large capacitance and discharge current associated with a long HVdc cable can cause significant transient overcurrents into an inverter during even remote AC inverter faults. The operation of an inverter at the end of a long HVdc cable is most stable in current control mode. In order for the inverters to be able to control their current, they need to be able to adjust their dc voltage in order to maintain the ordered current. This requires the inverters to operate somewhere above minimum gamma, which is typically 16 to 18 degrees in a two-terminal link, in order that the current controller has enough dynamic range in its firing angle to be able to adjust its dc voltage and subsequently control its dc current. The gamma range at the inverters in this multi-terminal HVdc link will be approximately 22 to 24 degrees. The impact of operating at a higher gamma is that the converter consumes slightly more reactive power. The rectifier is then left to control the dc voltage.

The bipolar multi-terminal HVdc link is represented by the configuration shown below in Figure 1. The DC line extends from Gull Island to a tap at Taylors Brook, at which point the line splits to terminate at Soldiers Pond on the NLH Island system and at Salisbury in the New Brunswick system. The Gull Island terminal is grounded through a 407 km electrode line and the Salisbury terminal is grounded through a 100 km electrode line.

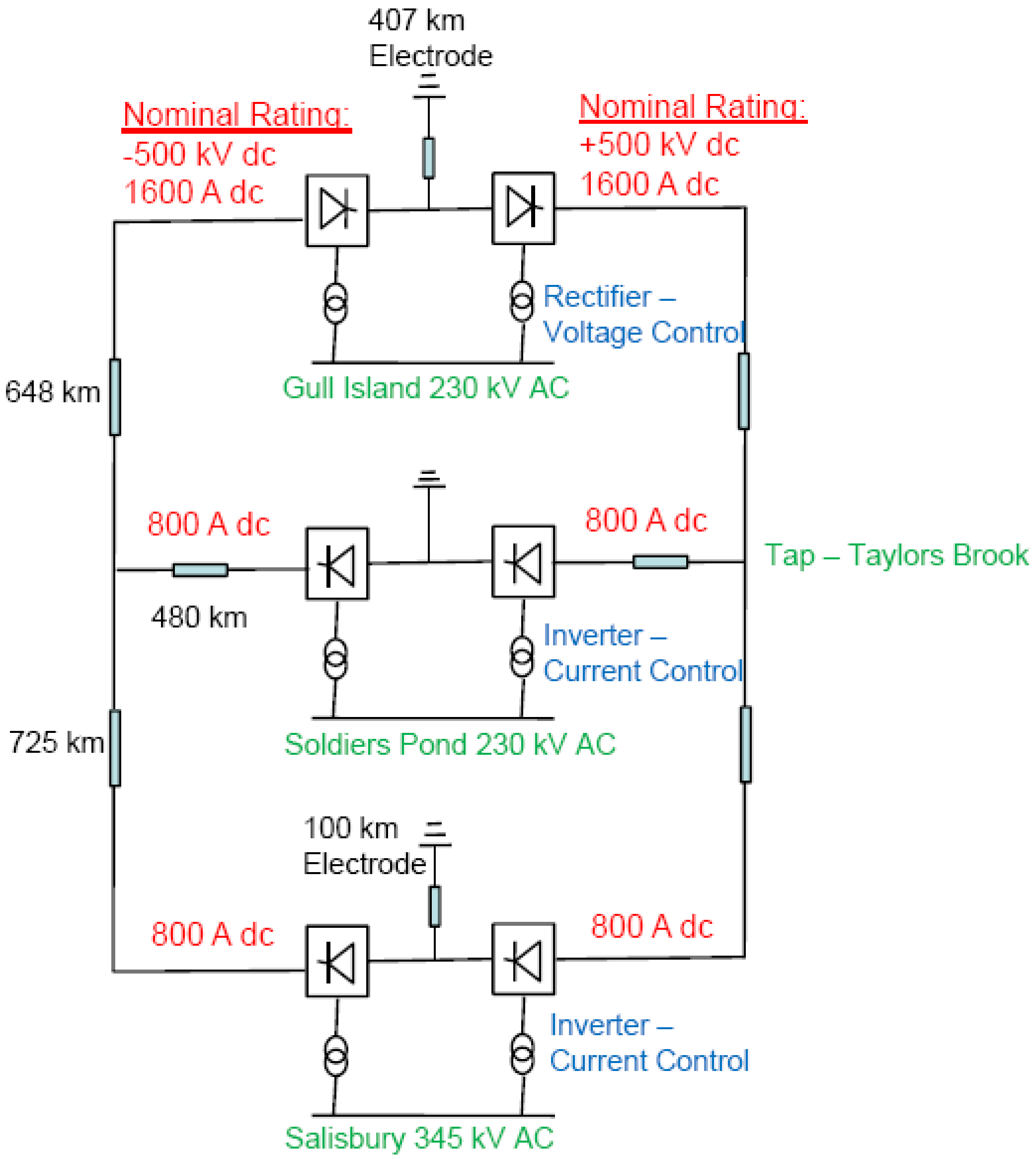

Figure 1 – Multi-terminal HVdc link and line lengths

Table 1 summarizes the DC line lengths and resistances used in the steady state analysis. As the DC conductor optimization and route selection was not finalized prior to carrying out the power flow and short circuit analysis, the conductor type, geometry and line lengths used in the studies were based on the preliminary data available at the time. Although final transmission line and cable parameters may differ from those used in this study, the overall impact on results should be minimal. Please refer to Appendix 2 for further information on the DC line conductor assumptions.

Table 1
DC Line Lengths and Resistances

DC Line Section	Length (km)	DC Resistance per pole (ohms)
Gull Island - Tap	648.7	9.17
Tap - Soldiers Pond	480.0	6.94
Tap - Salisbury	725.0	8.77
Gull Island Electrode	407.0	6.39 (includes 0.5 ohm sea resistance)
Salisbury Electrode	100.0	1.94 (includes 0.5 ohm sea resistance)

In determining preliminary parameters for the HVdc system, typical industry practice was followed by assuming a commutating reactance of 0.14 pu for the converter transformers. The commutating reactance would not usually be higher than this value, and if it is lower then it will absorb less reactive power. Therefore the assumption of 0.14 pu for the commutating reactance will provide a reasonable estimate for the steady state reactive power requirements.

The power flow studies assumed an initial converter transformer tap changer range of 0.9 to 1.1. An alpha firing angle range of 12 to 20 degrees was assumed at the rectifier. Gamma was set to be 25 degrees for the purposes of power flow studies although its range will likely be closer to 22 to 24 degrees. The assumption of operating at a higher gamma draws slightly more reactive power into the converter, also providing a conservative estimate when determining the steady state reactive power requirements for the HVdc system.

The HVdc parameters used in this study are preliminary values and are subject to change during later phases of more detailed design such as the pre-specification studies.

The nominal operating points of the HVdc system in bipolar and monopolar operating modes along with the HVdc system parameters used in the power flow analysis are summarized below in Tables 2 and 3. Current normal industry practice is to supply a single twelve pulse valve group per pole at each station for HVdc transmission systems with power ratings similar to that being considered. Each twelve pulse valve group is connected to the ac system either through two three phase, two winding, converter transformers or three, single phase, three winding converter transformers to provide the necessary wye:wye and wye:delta connections. Please refer to Appendix 2 for further information related to the converter transformers.

Table 2
Converter Transformer Data

Converter	Rating (MVA)	Voltage (kV)	Tap Changer Range	Commutating Reactance (pu)
Gull Island	2 x 585 per pole	230–208.6	0.9-1.1	0.14 pu
Soldiers Pond	2 x 351 per pole	230–208.6	0.9-1.1	0.14 pu
Salisbury	2 x 234 per pole	345–208.6	0.9-1.1	0.14 pu

Table 3
Nominal Operating Points

Converter	Per Pole Parameters	Nominal Bipolar	10-min Overload Monopolar	Continuous Monopolar
Gull Island	Vdc (kV)	500	481.7	485
	Pdc (MW)	1600	1258	1042
	Idc (A)	1600 (1.0 pu)	2611 (1.66 pu)	2149 (1.34 pu)
	Qdc (MVAr)	823.8	693.6	532.8
	Alpha (deg)	19.1	14.6	14.9
Soldiers Pond	Vdc (kV)	478.7	444.2	455.2
	Pdc (MW)	765.8	765.8	574.4
	Idc (A)	800 (1.0 pu)	1724 (2.16 pu)	1262 (1.58 pu)
	Qdc (MVAr)	456.2	558.6	380.4
	Gamma (deg)	25.0	25.0	25.0
Salisbury	Vdc (kV)	477.1	448.6	456.3
	Pdc (MW)	763.4	394.8	401.6
	Idc (A)	800 (1.0 pu)	880 (1.1 pu)	880 (1.1 pu)
	Qdc (MVAr)	492.8	263.5	271.4
	Gamma (deg)	25.0	25.0	25.0

During nominal bipolar operation, the Gull Island converter supplies a rated current of 1600 A (1.0 pu). The total power injected at Soldiers Pond is 765.8 MW and at Salisbury is 763.4 MW, resulting in losses of 34.2 MW and 36.6 MW at Soldiers Pond and Salisbury respectively.

The losses increase when operating in monopolar mode, requiring up to 2611 A (1.66 pu current) at Gull Island to supply the 10-minute 100% overload requirement at Soldiers Pond (2.16 pu current) and the continuous 10% overload at Salisbury (1.1 pu current), and up to 2149 A (1.34 pu) at Gull Island to supply the continuous 50% and 10% overloads at Soldiers Pond (1.58 pu current) and Salisbury (1.1 pu current) respectively.

2.2 Reactive Power Requirements

HVdc converters typically consume reactive power in the approximate amount of 55% of their real power output. The exact amount of reactive power consumed depends on the commutating reactance of the converter transformers, the tap position of the converter transformers and the firing angle of the converter. For the purposes of this study, the commutating reactances of the converter transformers were held constant throughout the tap changer ranges. The power flow studies assumed a minimum reactive power compensation of 450 MVAr at Soldiers Pond and Salisbury and 900 MVAr at Gull Island.

As a first assumption and start to the power flow analysis, the reactive power compensation at each station is assumed to be supplied by a combination of filters and shunt capacitors. Power flow analysis is used to determine the total reactive power requirements based on NLH system voltages during contingency analysis. Short circuit analysis is then used to determine if a portion of that total reactive power requirement should be in the form of a synchronous condenser to increase the short circuit strength at the Soldiers Pond bus. At rated power output, minimum filter requirements would be approximately 250 MVAr at Soldiers Pond and Salisbury and 500 MVAr at Gull Island in order to meet harmonic performance requirements.

2.3 ESCR Requirements

Beyond the basic consideration of power transfer, there are a number of ways which the dc and associated ac systems interact at the converter stations. As the strength of the ac system reduces, both in normal operation and as a result of contingencies, certain interactions tend to become more pronounced.[1] These interactions include:

- Recovery from ac and dc Faults: For acceptable performance it is required that the dc system should recover from ac or dc faults without subsequent commutation failures. As a general guide, recovery to 90% of pre-disturbance power transfer within 100 to 300ms is desirable. As the Short Circuit Level (SCL) of the ac systems decreases, the effects of magnetizing inrush currents can become more pronounced, resulting in a slower recovery. Attempting to increase the speed of recovery can sometimes lead to the dc system drawing excessive reactive power from the ac network, resulting in a prolonged depression of the ac network voltage, particularly as the Short Circuit Ratio (SCR) of the ac systems decreases.
- Temporary Overvoltages: Temporary ac system overvoltages can occur at the dc terminals due to converter blocking, ac fault inception and clearing, dc faults, and other disturbances. The severity of these overvoltages increases as the SCR of the ac systems decreases.
- While it may be an issue for ac systems with higher SCRs also, the capacitive shunt compensation at the converter bus and the relatively high system inductance for low SCR ac systems typically results in a parallel resonance at second harmonic. Such a resonance can result in harmonic voltages which are substantial relative to the magnitude of the fundamental during disturbances.
- Commutation Failures: It is a general requirement that the converter does not experience commutation failures for frequently occurring changes in the associated ac systems such as small voltage and phase deviations. As the SCR decreases, the likelihood of commutation failures occurring increases.
- Converter Reactive Power Element Switching: As the SCR decreases the voltage sensitivity to changes in the reactive power increases and creates the potential for voltage changes within the ac network in the vicinity of the converter station when reactive power elements are switched.
- System Inertia: In addition to characterizing the ac system as having sufficient SCR, it is also necessary to consider the overall inertia of the system. In cases where overall system inertia is low,

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[1] Guide for Planning DC Links Terminating at AC system Locations Having Low Short-Circuit Capacities, Part II: Planning Guidelines. CIGRE Working Group 14.07, IEEE Working Group 15.05.05, December 1997.

synchronous compensators can be used to increase the system SCR and help maintain ac system voltage and frequency.

Effective short circuit ratio (ESCR) is defined as follows:

ESCR = (Short circuit MVA at AC bus – MVA rating of filters)/Rated DC power

The CIGRE Guide for Planning DC Links Terminating at AC System Locations Having Low Short Circuit Capacities identifies the following categories of ESCR:

High	ESCR >2.5
Low	2.5 > = ESCR > = 1.5
Very Low	ESCR <1.5

Based on industry experience it can be stated that low or very low SCR in itself is not a technical limitation in the evaluation of an HVdc transmission option, but it must be recognized that decreasing SCR (and ESCR) results in overall decreased performance of the interconnected ac/dc systems. The effects of reducing ESCR on overall performance becomes even more pronounced for long HVdc cables.

As such, it is recommended that a minimum ESCR of 2.5 for the inverter ac systems be maintained. Dynamic performance studies will further validate this minimum ESCR value, however for the purposes of the power flow analysis the goal is to design the reactive power requirements such that the ESCR at the Soldiers Pond bus is at least 2.5.

The HVdc system itself does not contribute to the short circuit strength of the system, however a synchronous condenser installed with the HVdc system will increase the short circuit strength if deemed necessary by the short circuit studies.

3. Study Power Flow Models

Steady state analysis is performed using a range of power flow cases that represent various generation and load dispatches in the NLH Island system for various years, seasons and times of day. For each of these power flows, various HVdc infeed amounts are considered for several combinations of HVdc monopolar and bipolar configurations. The power flow cases represent a range of weak to strong system conditions in the NLH Island system. Although the power flow models include the New Brunswick and large surrounding area system connected via the multi-terminal HVdc link, the focus of the steady state analysis is solely on the NLH system, with particular attention to the Island system.

3.1 AC System Representations

3.1.1 NLH Island System

The full NLH Island AC system PSSE model is used for the power flow analysis. Eleven (11) Island power flow configurations are represented, ranging from minimum generation light summer night loading to maximum generation future peak winter loading along with various ranges of infeed levels at Soldiers Pond from minimum DC power (80 MW) to maximum DC power (800 MW). One configuration is also represented in which the Island is exporting power. All power flow cases represent year 2016, with the exception of the future peak maximum load case. Table 4 below provides a brief description of the base cases. For more detailed information on the Island dispatch please refer to Appendix 1.

Table 4
Power Flow Base Cases

NO.	NLH System Load	Soldiers Pond	Island Generation	Labrador (Gull)	NB
BC1	Peak (1600 MW)	Full Import (800 MW)	economic dispatch	Weak	Peak load
BC2	Peak (1600 MW)	Reduced Import (600 MW)	max economic dispatch	Weak	Peak load
BC3	Future Peak (1800 MW)	Full Import (800 MW)	max generation	Weak	Peak load
BC4	Summer Night (550 MW)	Reduced Import (255 MW)	min generation	Weak	Peak load
BC5	Summer Night (550 MW)	Minimum Import (80 MW)	economic dispatch	Weak	Peak load
BC6	Intermediate (1000 MW)	Full Import (800 MW)	economic dispatch	Weak	Peak load
BC7	Intermediate (1000 MW)	Minimum Import (80 MW)	max economic dispatch	Weak	Peak load
BC8	200 MW (550 MW)	Export	dispatch	Weak	Peak load
BC9	Peak (1600 MW)	Full Import (800 MW)	economic dispatch	Weak	Weak, Peak load
BC10	Peak (1600 MW)	Full Import (800 MW)	economic dispatch	Weak	Light load
BC11	Peak (1600 MW)	Full Import (800 MW)	economic dispatch	Weak	Strong, Light load
BC12	Summer Night (550 MW)	Minimum Import (80 MW)	economic dispatch	Normal	Peak load
BC13	Future Peak (1800 MW)	Reduced Import (600 MW)	max generation	Weak	Peak load

Note that base cases BC9 and BC11 are greyed out because they were not studied. Originally it was thought that these cases would test variations of strong and weak New Brunswick systems with light and peak loads, however only two New Brunswick power flow cases were available – a strong case with peak load and a weak case with light load, therefore cases BC9 and BC11 were dropped from the original scope. However, two cases were added, BC12 to test the Labrador system for overvoltages when operating at minimum power, and BC13 to test the future peak maximum load case when operating with a 600 MW monopolar infeed at Soldiers Pond.

The year 2016 and future peak Island power flow cases have several significant modifications when compared to the existing system today:

1. A new large refinery load (175 MW, 85 MVAr) is planned to be in-service near Piper's Hole, between Bay D'Espoir and Sunnyside. As well, a nickel smelter load (83 MW, 40 MVAr) is planned for the Long Harbour area. The internal NLH studies for the additions of these loads have not yet been completed, therefore it is expected that system impacts due the loads will be observed in this HVdc feasibility study.

2. NLH is planning to convert units #1 to #3 at Holyrood to synchronous condensers as part of the Lower Churchill Project to meet ESCR requirements. In addition NLH is planning to install five 50 MW combustion turbines (CT) at Holyrood to meet load requirements between 2010 and the HVdc 2015 in-service date. These CTs will be specified with the capability to operate in synchronous condenser mode. The Holyrood station will have a total of eight (8) synchronous condensers available for voltage control and in support of ESCR with the following ratings:
    a. Unit #1 – 142/-72 MVAr
    b. Unit #2 – 142/-72 MVAr
    c. Unit #3 – 150/-69 MVAr
    d. CT Units #1-5: 63.5 MVA at 0.85 power factor leading

    In addition, a 54 MW CT at Hardwoods is capable of operation as a synchronous condenser with a +28/-25 MVAr rating.

3. The 24 MVAr capacitor bank at Long Harbour is removed.

4. The 50 MVAr capacitor bank at Western Avalon is in-service.

The major NLH load centre is located on the Avalon Peninsula (east side of the Island) while the majority of the generation is located in the west. The Island terminal of the HVdc link will be located at Soldiers Pond which is between Holyrood, Hardwoods and Oxen Pond stations. The HVdc terminal will normally be operated as an inverter, with a nominal rated infeed of 765.8 MW (800 MW minus losses). One power flow case is setup with Soldiers Pond in rectifier operation to test the Island's export capability. The HVdc infeed is located nearer to the load centre (i.e. more to the east) than the majority of the other Island generation and should help to off-load heavy west to east flows.

3.1.2 Labrador System

For all power flow cases, the Labrador system is represented by a weak system configuration. As shown in Figure 2, this weak configuration is achieved by removing the Muskrat Falls generating station, a 230 kV line from Gull Island to Muskrat Falls and a 735 kV line from Churchill Falls to Gull Island Generating Station.

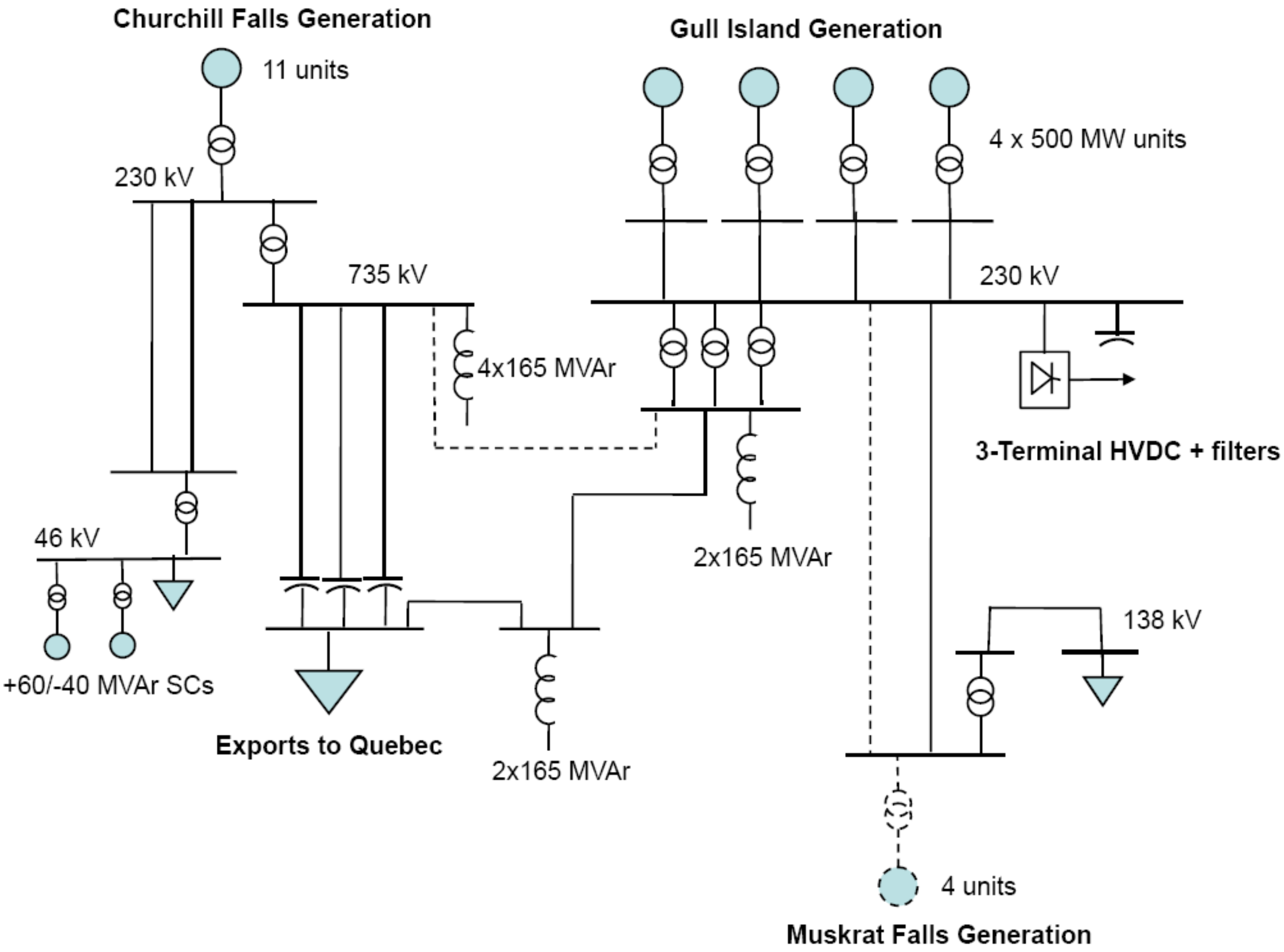

Figure 2 – Labrador System in Weak Configuration

There is one power flow case in which the Labrador system is represented with the 230 kV Gull Island-Muskrat Falls and the 735 kV Churchill Falls-Gull Island lines in-service. This case is used to determine the worst case steady state overvoltages in the Labrador System when operating at minimum power.

The Labrador terminal of the HVdc system will normally operate as the rectifier, supplying power to Newfoundland Island and to New Brunswick, although a few power flow cases represent the terminal as an inverter. When the power level into the HVdc link is adjusted at Gull Island for the various power flow cases, the offsetting power adjustment is made to the equivalent load which represents power exports to Quebec. This Quebec equivalent load is adjusted to maintain the Churchill Falls generation at 5428 MW.

3.1.3 New Brunswick System

For all power flow cases, the New Brunswick system power flow conditions represent the winter peak load case, with the exception of one case that represents summer light load conditions.

The New Brunswick system is contained in a reduced system model of approximately 1000 buses.

The New Brunswick terminal of the HVdc system will normally operate as an inverter, although one power flow case represents the system operating as a rectifier. The offsetting power adjustments from the HVdc infeed are scheduled to a bus at Orrington which is the first 345 kV bus south of the Maine-New Brunswick border.

3.2 Multi-terminal HVdc Link Representation

The Gull Island terminal will normally be operated as the rectifier with the Island and New Brunswick terminals operating as inverters, although the DC link will be designed such that any terminal could be a rectifier or inverter. In addition, the link will normally run as a bipole however situations may occur in which an entire pole or any section of a pole could be out of service (i.e. forced outage or scheduled maintenance). Taking this information into consideration, various DC configurations are studied as listed in Table 5.

Table 5
HVdc Configurations

NO.	Gull Island	Soldiers Pond	Salisbury	Description
DC1	REC - BP	INV - BP	INV - BP	Normal
DC2	REC - MP	INV – MP (overload)	INV - MP	Loss of 1 pole at Gull Island
DC3	REC - MP	INV – MP(continuous)	INV - MP	Loss of 1 pole at Gull Island
DC4	REC - BP	INV – MP (overload)	INV - BP	Loss of 1 pole at Soldiers Pond
DC5	REC - BP	INV – MP (continuous)	INV - BP	Loss of 1 pole at Soldiers Pond
DC6	REC - BP	INV - BP	INV - MP	Loss of 1 pole at Salisbury
DC7	OFF	INV - BP	REC - BP	2-terminal
DC8	OFF	REC - BP	INV - BP	2-terminal
DC9	INV - BP	REC - BP	OFF	2-terminal
DC10	REC – BP	REC – BP	OFF	2-terminal

3.3 PSSE Multi-terminal DC Line Power Flow Model

The HVdc link is modeled in PSSE using two separate multi-terminal DC line models, one line to represent each pole of the bipole. The HVdc link could have been represented as one bipole line containing both poles however it was found that this setup did not provide adequate flexibility when configuring the model in certain monopolar configurations.

The PSSE model requires that one of the inverters be in voltage control mode, although this is likely not consistent with how the actual HVdc link will operate. In order to populate the data for the PSSE multi-terminal DC line models, the operating points of the HVdc link for both poles were calculated for each of the HVdc configurations listed in Table 5 for appropriate base case power flows listed in Table 4. The combinations of HVdc configurations and base case power flows that were studied are listed in Table 6 of upcoming section 4.3. The detailed set of HVdc operating points for each of these power flow cases containing the DC voltages, currents and powers for both poles at all three terminals can be found in Appendix 2. These operating points including a positive current or power order at the rectifier, a positive voltage at the voltage-controlling inverter and a negative current or power order at the other inverter. These values are entered into the SETVAL field of the converter data for both poles of the HVdc link in order to change the operating point of the HVdc system. The remainder of the data that populate the model, including parameters such as DC line resistances, converter transformer data, firing angle ranges and such remain the same when changing operating points, unless a mode change from rectifier to inverter is made, then the firing angle limits must be modified appropriately.

For further detailed information regarding multi-terminal DC models in PSSE, please refer to PSSE Application Guide Volume II section 6.4.9.

3.4 Set of Final Power Flow Models

A total of nineteen (19) power flow cases representing various combinations of Island, Labrador, New Brunswick and HVdc configurations were created as listed below in Table 6. Unless otherwise stated, Gull Island is operating as the rectifier and Soldiers Pond and Salisbury are operating as inverters. BP stands for bipole, MP stands for monopole. Appendix 5 contains a set of power flow diagrams for each of these cases listed in Table 6.

Table 6
Complete set of power flow cases for steady state analysis

Base Case	DC	Soldiers Pond	Salisbury	Gull Island
BC1	DC1	800 BP	800 BP	1600 BP
	DC6	800 BP	400 MP	1200 BP
	DC7[2]	800 BP	800 BP–REC	OFF
BC2	DC1	600 BP	800 BP	1400 BP
	DC3	600 MP	400 MP	1000 MP
	DC5	600 MP	800 BP	1400 BP
BC3	DC1	800 BP	800 BP	1600 BP
	DC4	800 MP	400 MP	1000 MP
BC4	DC1	255 BP	800 BP	1055 BP
	DC3	255 MP	400 MP	655 MP
BC5	DC1	80 BP	800 BP	880 BP
BC6	DC1	800 BP	800 BP	1600 BP
BC7	DC1	80 BP	800 BP	880 BP
BC8[3]	DC8	200 BP–REC	800 BP–INV	OFF
	DC9	200 BP–REC	OFF	800 BP–INV
BC9[4]	DC1	800 BP	800 BP	1600 BP
	DC6	800 BP	400 MP	1200 BP

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[2] Cannot solve this power flow when NB system is at peak load. Instead case BC10-DC7 was created in which the NB system is at light load.

[3] Can only get approximately 200 MW out of Island system base case, further export would require Island system upgrades.

[4] These base cases were not created as TGS did not have a strong/weak peak/light load for NB system; only a peak and light load case were available.

Base Case	DC	Soldiers Pond	Salisbury	Gull Island
BC10[5]	DC1	800 BP	800 BP	1600 BP
	DC6	800 BP	400 MP	1200 BP
	DC7	800 BP	800 BP–REC	OFF
BC11[3]	DC1	800 BP	800 BP	1600 BP
	DC6	800 BP	400 MP	1200 BP
BC12	DC10	80 BP	OFF	80 BP
BC13	DC3	600 MP	400 MP	1000 MP

3.5 Assumptions

The following assumptions were made for each of the power flow cases:

1. One large synchronous condenser (unit #3 - 150 MVA) at Holyrood and one small synchronous condenser (50 MW CT running as synchronous condenser) are out of service for maintenance.

3.6 Contingencies

Table 7 lists the Island contingencies that are studied.

Table 7
Contingencies for Steady State Analysis

Contingency	Description
C1	Soldiers Pond to Holyrood 230 kV line
C2	Soldiers Pond to Hardwoods 230 kV line
C3	Soldiers Pond to Oxen Pond 230 kV line
C4	Soldiers Pond to Western Avalon 230 kV line
C5	Western Avalon to Come By Chance 230 kV line
C6	Come By Chance to Sunnyside 230 kV line
C7	Western Avalon to Sunnyside 230 kV line
C8	Sunnyside to Piper's Hole 230 kV line
C9	Piper's Hole to Bay d'Espoir 230 kV line
C10	Hardwoods gas turbine in synchronous condenser mode
C11	150 MVAr synchronous condenser

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[5] Represents NB light load system, all other base cases represent NB peak load system.

4. Power Flow Analysis

The purpose of the power flow analysis is to determine the total steady state reactive power requirements of the Island system such that the steady state voltage requirements are met, and to determine any network upgrades to the existing Island system that are required to relieve thermal overloading.

4.1 Study Procedure

Steady state AC contingency analysis (PSS/E activity ACCC) is used to assess the impact of the HVdc link on the NLH Island system. It tests the adequacy of the Island transmission system to transfer the additional 800 MW of power from the HVdc infeed and determines the worst-case contingencies.

Buses and branches in the NLH system are monitored. Contingencies, as defined in Table 7, are applied for all power flow cases described in Table 6. The purpose is to find any contingencies that result in a thermal overload of a transmission line or transformer or that result in a steady state voltage violation or voltage collapse scenario. If a problem is discovered, mitigation in the form of extra reactive power support, transmission line upgrades or generation re-dispatch are evaluated.

4.2 Criteria

The following steady state NLH system criteria are used to determine the steady state transmission solution:

1. Steady state voltages should be within the following ranges:
   a. 0.95 pu – 1.05 pu – System Intact
   b. 0.90 pu – 1.10 pu – Contingency (N-1)

2. Thermal loading on a transmission line or transformer should not exceed 100% of:
   a. Rate A – Summer season (30 degrees C ambient) – light load
   b. Rate B – Spring/Fall season (15 degrees C ambient) – intermediate load
   c. Rate C – Winter season (0 degrees C ambient) – peak load

Within the NLH Island system, if during a contingency the thermal loading of a transmission line or transformer is found to exceed 100% of its rating, it is deemed acceptable mitigation practice to use a generation re-dispatch to correct the issue as long as there is sufficient Island generation available and if the re-dispatch reduces the loading on all transmission lines and transformers to at or below 100% of their thermal ratings.

4.3 Study Results

The major NLH Island load centre is located east of Bay d'Espoir on the Avalon Peninsula, while the majority of the generation is located west of Bay d'Espoir. This can result in heavy west to east power flow on the 230 kV transmission system, in particular between Bay d'Espoir, Sunnyside, Western Avalon and Soldiers Pond. In addition, approximately 255 MW of new industrial load (refinery and smelter) is planned to be installed along this heavily loaded west to east corridor, which serves to increase the loading on these 230 kV lines. As a general result this can cause voltage depression and thermal overloading in the area. The HVdc infeed into Soldiers Pond generally has a positive impact on the Island transmission system as it off-loads this west to east power flow by injecting power closer to the load centre. Many of the issues that will be discussed are not necessarily due to the HVdc infeed but are due to the lack of transmission linking the generation in the west to the load in the east. The results discuss solutions that use the HVdc infeed to assist in mitigating the problems.

The discussion of the power flow results is split into three sections – the first section defines the total reactive power requirements of the NLH system and is based on the steady state voltage criteria; the second section discusses any potential for overvoltages on the Labrador system when operating at minimum power; and the third section defines the transmission line overloads on the Island and possible mitigation measures.

4.3.1 Island - Total Steady State Reactive Power Requirements

As a starting point, the HVdc converter at Soldiers Pond was assumed to provide its full reactive power compensation in the form of 450 MVAr of filters and shunt capacitors. It was quickly discovered that if the HVdc infeed was operating in its 2.0 pu monopolar configuration, a voltage collapse would occur even without any outages in the Island system. The heavy west-east flow and the new refinery load at Piper's Hole, combined with the increased reactive power consumption of the HVdc inverter at Soldiers Pond (559 MVAr monopolar compared to 462 MVAr bipolar), depressed the system voltage enough to cause system wide voltage collapse that begins around the Sunnyside and Piper's Hole area, very near to the new refinery load. Significant improvement in voltage is achieved with the addition of local area reactive power supply at the Sunnyside 230 kV bus.

In terms of maintaining acceptable steady state voltages on the Island, the worst case power flows were found to be the future peak load cases, in particular:

- BC3-DC1 – 1800 MW future peak Island loading, 800 MW bipolar infeed at Soldiers Pond
- BC3-DC3 – 1800 MW future peak Island loading, 600 MW monopolar infeed at Soldiers Pond
- BC3-DC4 – 1800 MW future peak Island loading, 800 MW 10-minute overload monopolar infeed at Soldiers Pond

The worst case corresponding contingencies were found to be:

- C9 – Loss of 230 kV line from Bay d'Espoir to Piper's Hole
- C11 – Loss of synchronous condenser unit #3 at Holyrood

These two contingencies were the determining cases for total reactive power requirements for the Island. Again, the absolute worst power flow case was the 10-minute 2 pu overload scenario in which the HVdc inverter at Soldiers Pond is in monopolar operation (BC3-DC4). This is due to the fact that the HVdc converter's reactive power absorption is highest in this case at 559 MVAr compared to 462 MVAr in the bipolar case.

The result of losing either the Bay d'Espoir-Piper's Hole line or the Holyrood unit #3 synchronous condenser with insufficient reactive power support in the system is voltage collapse. Combinations of reactive power supply at Holyrood, Soldiers Pond and Sunnyside were tested. As additional reactive power supply, a 150 MVAr synchronous condenser at Soldiers Pond is tested as one of the alternatives. For the purposes of power flow analysis, a single 150 MVAr synchronous condenser at Soldiers Pond was assumed because of the close proximity to Holyrood unit #3, an outage of either of these two units could likely be considered a similar outage and would require a similar reactive power requirement at Sunnyside. Several scenarios of reactive power sources required to avoid voltage collapse are summarized in Table 8 below.

Table 8
Reactive Power Solutions to Avoid Voltage Collapse

Scenario	Contingency	Holyrood #3 (150 MVAr)	Soldiers Pond Synchronous Condenser (150 MVAr)	Soldiers Pond Filters (MVAr)	Sunnyside (MVAr)
0	C9	Out	None	450	300
1	C11	In (but lose)	Out	450	200
1	C9	In	Out	450	150
2	C9	Out	In	450	165

Scenario 0 assumes no additional reactive power support (aside from 450 MVAr filters) is installed at Soldiers Pond. This would require at least 300 MVAr of steady state reactive power supply at Sunnyside, which is a substantial amount of reactive power support and could not all be supplied in the form of shunt capacitors.

Scenarios 1 and 2 assume a 150 MVAr synchronous condenser is installed at Soldiers Pond in addition to the 450 MVAr filters. As a base case assumption it is assumed that either one of these 150 MVAr units at Holyrood or Soldiers Pond could be out of service for maintenance. The defining case for the total reactive power requirement at Sunnyside then becomes loss of the in-service 150 MVAr synchronous condenser, which requires a minimum of 200 MVAr of steady state reactive power support at Sunnyside to avoid system voltage collapse.

The preferred solution for the total Island reactive power supply is as follows:

- 450 MVAr filters at Soldiers Pond
- 150 MVAr synchronous condenser at Soldiers Pond
- 200 MVAr capacitive reactive power support at Sunnyside

At this point in the steady state analysis, the split of total reactive power requirements at Soldiers Pond cannot necessarily be determined. It is not desirable to add the extra supply in the form of more filters as this could cause overvoltage problems and also would further reduce the ESCR. Please refer to the discussion of Short Circuit Analysis to see the justification for the 150 MVAr synchronous condenser at Soldiers Pond.

The entire contingency analysis was performed on all power flow cases with the above reactive power solution modeled, taking into account a base case maintenance outage of one of the CT units at Holyrood plus a base case maintenance outage of either of the 150 MVAr synchronous condensers at Holyrood or Soldiers Pond. With this reactive power solution, no further voltage violations or voltage collapse scenarios were observed, with the exception of contingency C9, loss of 230 kV line from Bay d'Espoir to Piper's Hole during BC7 when the HVdc infeed at Soldiers Pond is at minimum power or during BC8 when the HVdc converter is exporting power. These scenarios will require a fast DC run-up (when importing) and run-down (when exporting) to prevent system voltage collapse. A corresponding transfer trip of generation in the west would be required to offset the increase in HVdc infeed. The voltage collapse seems to occur if there is more than approximately 225-250 MW flowing from west to east on both of the Bay d'Espoir to Piper's Hole lines. If it would not be desired to perform a fast dc power run-up or run-down, then it would likely be possible to develop an operating guideline to limit steady state power flow on the circuits between Bay d'Espoir and Piper's Hole by re-dispatching generation to avoid the voltage collapse scenario in the first place. This would require further study to determine if this is in fact possible and what the power flow limit would be. Dynamic performance analysis could look further into this scenario.

4.3.2 Labrador – Total Steady State Reactive Power Requirements

The Gull Island station is connected to a strong network with a minimum short circuit strength of 5851 MVA, corresponding to an ESCR of 3.1. The steady state reactive power requirement can be fulfilled by the use of filters and shunt capacitors, no synchronous condensers are required. A total of 900 MVAr of reactive power support is modeled at the 1600 MW Gull Island converter.

A minimum power case at Gull Island was checked to ensure that overvoltages in the Labrador system would not be too high. This power flow case, as shown in Figure 3, modeled all transmission lines in-service which were previously taken out-of-service for the weak representation in other power flow cases. Muskrat Falls generating station was kept out-of-service. In order to find the worst condition for high voltages, one of the two 735 kV 165 MVAr reactors at Gull Island was taken out-of-service as were generating units #2 to #4 at Gull Island. The Gull Island rectifier was supplying 80 MW of power to Soldiers Pond with 250 MVAr of filters connected. The steady state 230 kV voltage observed on the Gull Island bus was 1.047 pu. The single Gull Island generating unit still had approximately 65 MVAr room left for further reactive power absorption. Overvoltages are therefore not expected to be a problem.

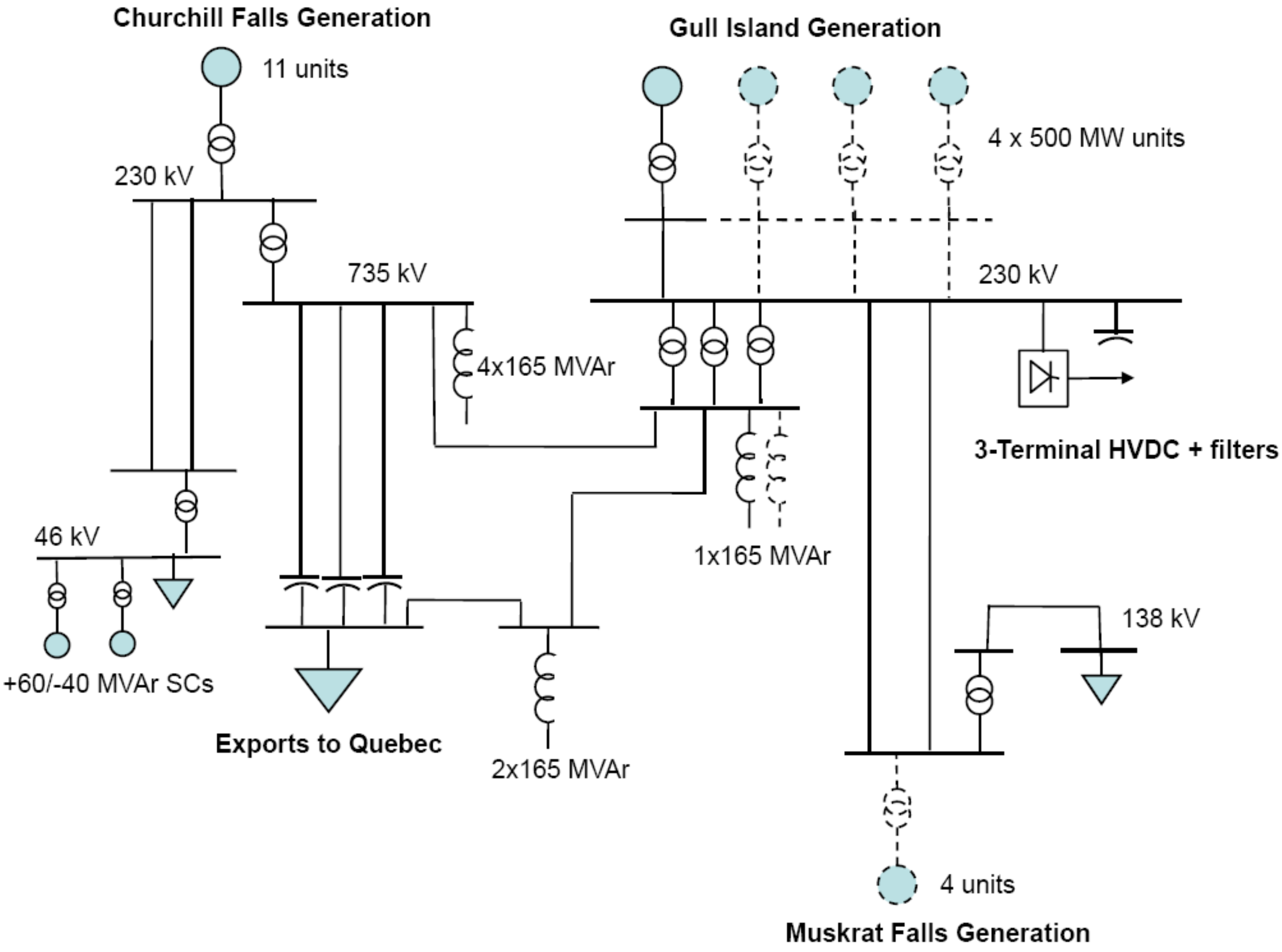


Figure 3 - Labrador system used for checking for overvoltages

4.3.3 *Island - Thermal Overloads and Mitigation*

The heavily loaded 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond not only results in voltage problems as discussed and mitigated in section 5.5.1, but also results in thermal overloading on several 230 kV lines in the area.

Generally the worst overloading occurs when the Soldiers Pond DC infeed is operating at lower power levels, or even worse if it is exporting power. This results in the need for more Island generation in the west to serve the major load centre in the east, in addition to the new refinery load at Piper's Hole, causing several 230 kV transmission lines to be significantly overloaded under certain power flow conditions. NLH currently operates their Island system with a guideline to re-dispatch generation to mitigate overloaded lines.

Without applying any line upgrades to the Island system the export power flow case (BC8) was able to export 200 MW with the Island load at summer night light loading (550 MW). However, it was found that in order to relieve system intact base case overloads during this power flow, all 250 MW of generation from the Holyrood CTs must be on-line. In the event of a contingency, the DC export must be reduced below 200 MW as necessary to bring loading on all lines to below 100%. However, overloads are high – in the range of 150-200%.

The import power flow cases can also use this generation re-dispatch method to mitigate all but one of the overloaded lines (the exception is line TL201 from Soldiers Pond to Hardwoods which is discussed in the next paragraph). For power flows in which the HVdc infeed was not operating at its maximum, the DC infeed power was increased and generation in the west was decreased (Bay d'Espoir generation was the swing bus for this study) to mitigate overloads. If the HVdc was already importing maximum power, then Holyrood CTs were turned on as needed to mitigate the overloads. This method was successful for mitigating all of the 230 kV line overloads between Bay d'Espoir and Soldiers Pond. Case BC13-DC3, the future peak load case (1800 MW) with the DC infeed operating as a 600 MW monopole requires the last 50 MW of generation from the Holyrood CTs to be turned on in order to relieve overloading on parallel lines from Piper's Hole-Bay d'Espoir lines TL202 and TL206 for loss of the parallel line. This case has 200 MW of generation being supplied by the Holyrood CTs pre-contingency. There is no further generation in the east that could be utilized beyond this amount for this power flow case.

Line TL201 from Soldiers Pond to Hardwoods becomes overloaded for contingency C2, loss of the parallel Soldiers Pond to Hardwoods line. This overload only occurs during the future peak load (1800 MW) case. It occurs due to high loading on the underlying 138 kV system radially connected to Hardwoods and Oxen Pond stations. The overload is worst (115%) if the two 25 MW wind farms connected to this radial system are turned off. 54 MW of generation can be turned on at Hardwoods, which reduces the overload to 103.5% (rate C) assuming the wind farms are off. Upgrading this line would require a rebuild using the 804 AACSR/TW conductor type.

Table 9 lists the thermal overloads for all power flow cases without network upgrades and the post-contingency generation re-dispatch that would be required to eliminate the listed overload.

Table 9
Thermal Overloads Before Any Upgrades are Implemented

Overloaded Line	Contingency	Rate	Power Flow	Overload (%)	Pre-Contingency HVdc Infeed (MW)	Post-Contingency Redispatch (MW)
Piper's Hole-Bay d'Espoir TL202, TL206	C9	C	BC2-DC1	117.8	600 BP	+60 DC infeed
		C	BC2-DC3	122.2	600 MP	+70 Holyrood
		C	BC2-DC5	123.3	600 MP	+75 Holyrood
		C	BC3-DC1	107.4	800 BP	+25 Holyrood
		C	BC3-DC4	110.9	800 MP	+35 Holyrood
		A	BC5-DC1	169.8	80 BP	+175 DC infeed
		A	BC12-DC10	174.0	80 BP	+160 DC infeed
		C	BC13-DC3	106.9	600 MP	+50 Holyrood
	Base, all	A	BC8	162.1-169.9	-200 BP	0 DC export +225 Holyrood
Sunnyside-Western Avalon TL203	C5	B	BC6-DC1	118.4	800 BP	-50 DC infeed
	C6	B	BC7-DC1	126.7	80 BP	+100 DC infeed
	C4,C5,C6	A	BC8	202.6	-200 BP	0 DC export +50 Holyrood
Piper's Hole-Sunnyside TL202	C8	A	BC5-DC1	113.3	80 BP	+25 DC infeed
		B	BC7-DC1	147.6	80 BP	+150 DC infeed
		A	BC12-DC10	117.1	80 BP	+35 DC infeed
		A	BC8	128.6	-200 BP	0 DC export +120 Holyrood
Western Avalon-Soldiers Pond TL201	C4	B	BC6-DC1	146.5	800 BP	-175 DC infeed
		A	BC8	197.8	-200 BP	0 DC export
Hardwoods-Soldiers Pond TL201	C2	C	BC3-DC1	108.1	800 BP	+54 Hardwoods
		C	BC3-DC4	108.0	800 MP	+54 Hardwoods
		C	BC13-DC3	107.3	600 MP	+54 Hardwoods
Piper's Hole-Sunnyside TL206	Base, all	A	BC8	128.6-133.6	-200 BP	+250 Holyrood in base case
Sunnyside-Come By Chance TL207	C7	A	BC8	150.5	-200 BP	+35 DC import
Come By Chance-Western Avalon TL237	C7	A	BC8	142.9	-200 BP	-130 DC export
Western Avalon-Soldiers Pond TL217	C5,C6,C7	A	BC8	103.2	-200 BP	-110 DC export

As an alternative to relying on generator re-dispatch to relieve overloads, especially because some of the overloads are extremely high, the overloaded lines were considered to be upgraded as detailed below and the contingency analysis was re-run.

1. **TL202 and TL206 – Bay d'Espoir to Piper's Hole and Piper's Hole to Sunnyside**
   These lines could be upgraded to 75 degrees C with the addition of a few mid span structures.

	Current Rating (MVA)	Upgraded Rating (MVA)	Rating Increase (%)
Rate A	199.3	341.8	71.5 %
Rate B	297.7	402.4	35.2 %
Rate C	369.5	453.8	22.8 %

2. **TL203 – Sunnyside to Western Avalon**
   This line is an H-frame wood pole design with multiple conductor types. Upgrading this line is not considered at viable option but instead the circuit would need to be replaced. The NLH standard would be to rebuild TL203 using steel structures and the 804 MCM AACSR/TW conductor.

	Current Rating (MVA)	Upgraded Rating (MVA)	Rating Increase (%)
Rate A	261.7	355.8	35.9 %
Rate B	307.8	411.5	33.7 %
Rate C	347.0	459.6	32.4 %

3. **TL207 – Sunnyside to Come By Chance**
   This line was upgraded to use the 804 MCM AACSR/TW conductor. The maximum conductor temperature was set at 80 deg C to match the hot conductor sag to the maximum ice load sag. This line would require further review by NLH transmission design. For the purposes of this study the current thermal ratings will be assumed.

	Current Rating (MVA)	Upgraded Rating (MVA)	Rating Increase (%)
Rate A	355.8	n/a	n/a
Rate B	411.5	n/a	n/a
Rate C	459.6	n/a	n/a

4. **TL237 – Come by Chance to Western Avalon**
   Same comments as for line TL207.

5. **TL217 – Western Avalon to Soldiers Pond**
   This line was upgraded using the 804 MCM AACSR/TW conductor except for two 5km sections that had been rebuilt following a previous ice storm. The two 5km sections consist of 795 MCM ACSR DRAKE conductor. A recent review by NLH Transmission Design has indicated that this section can be operated at a 75 deg C conductor temperature without violating ground clearance requirements. Therefore the ratings on this circuit are higher than what exists in the original PSSE model.

	Current Rating (MVA)	Upgraded Rating (MVA)	Rating Increase (%)
Rate A	199.3	341.8	71.5 %
Rate B	297.7	402.4	35.2 %
Rate C	369.5	453.8	22.8 %

6. **TL201 – Western Avalon to Soldiers Pond and Soldiers Pond to Hardwoods**

   This line is an H-frame wood pole construction and consists of multiple conductor types. Uprating of the existing line is not viewed as a viable option. Instead the line would need to be rebuilt using the 804 AACSR/TW conductor type.

	Current Rating (MVA)	Upgraded Rating (MVA)	Rating Increase (%)
Rate A	175.5	355.8	102.7 %
Rate B	260.2	411.5	58.1 %
Rate C	322.2	459.6	42.6 %

With the line upgrades in place, most of the overloads are mitigated. The remaining overloads are summarized below in Table 10. They can all be mitigated by re-dispatching generation following the contingency.

Table 10
Thermal Overloads After Line Upgrades are Implemented

Overloaded Line	Contingency	Rate	Power Flow	Overload (%)	Pre-Contingency HVdc Infeed (MW)	Post-Contingency Redispatch (MW)
Piper's Hole-Bay d'Espoir TL202, TL206	C9	A	BC12-DC10	101.4	80 BP	+10 DC import
		B	BC7*		80 BP	+175 DC import
		A	BC8*		-200 BP	0 DC export +75 Holyrood
		C	BC2-DC5	100.3	600 MP	n/a
Sunnyside-Western Avalon TL203	C5,C6	A	BC8	146.7	-200 BP	-125 DC export
Piper's Hole-Sunnyside TL202	C8	A	BC8	148.6	-200 BP	-160 DC export
		B	BC7-DC1	108.9	80 BP	+35 DC import
Sunnyside-Come By Chance TL207	C7	A	BC8	150.3	-200 BP	-130 DC export
Come By Chance-Western Avalon TL237	C7	A	BC8	142.7	-200 BP	-110 DC export

**These contingencies require fast dc run-up (if importing into Soldiers Pond) or fast dc run-down (if exporting from Soldiers Pond) as described in section 5.3.1.*

4.3.4 Impacts of New Refinery Load and New 230 kV Transmission East of Bay d'Espoir

The worst cases were chosen to analyze sensitivity to the New Refinery load as well as to look at potential benefits of adding a new 230 kV line from Bay d'Espoir that would terminate at some point east of Bay d'Espoir. The two key issues noted are impacts to the amount of reactive power support required at Sunnyside and impacts to the export capability at Soldiers Pond.

New Refinery Load Not Connected

If the New Refinery load is not connected, the reactive power requirement at Sunnyside reduces to 50 MVAr from 200 MVAr. The defining case is voltage collapse following loss of a Bay d'Espoir – Piper's Hole line during the future peak load case when the DC infeed is 600 MW monopolar (BC13-DC3).

With 50 MVAr at Sunnyside and the load not connected, the export capability at Soldiers Pond increases to 300 MW, limited by 0.95 pu system intact voltages. With 75 MVAr at Sunnyside, the export capability increases to 350 MW, limited by 0.95 pu system intact voltages and thermal limits on the two circuits between Bay d'Espoir and Piper's Hole. In both of these export cases, DC run-back to 100 MW is required during loss of a Bay d'Espoir-Piper's Hole line. There is 447 MW of generation available for export if the load is not connected, and assuming Holyrood CTs are off-line because its generation would be too expensive to export.

New 230 kV Line from Bay d'Espoir East

If a new 230 kV line is built between Bay d'Espoir and Sunnyside (with New Refinery load connected), then the reactive power requirement at Sunnyside reduces to 100 MVAr from 200 MVAr. The defining case is voltage collapse following loss of Bay d'Espoir – Piper's Hole line or loss of a 150 MVAr synchronous condenser during the future peak load case when the DC infeed is 800 MW monopolar (BC3-DC4).

Extending the new line to Western Avalon or to Soldiers Pond does not have much impact on the 100 MVAr requirement at Sunnyside for this same worst case power flow and contingency.

The new 230 kV line out of Bay d'Espoir has more of an impact on export capability, in particular the closer the line termination is to Soldiers Pond the higher the export capability. Table 11 below summarizes the impact on export capability. The limiting factor is the 0.95 pu system intact voltage criteria. A fast DC run-back scheme would be required following certain contingencies. Please note that there is only 272 MW available for export in this particular case, assuming the Holyrood CTs are not producing any power.

Table 11
Export Capability with new 230 kV line out of Bay d'Espoir

Sunnyside (MVAr)	Generation Available for Export (MW)	Export Capability for Various Line Terminations (MW)		
		Sunnyside	Western Avalon	Soldiers Pond
0	272	240	265	300
100	272	325	350	375

To get a feel for the maximum possible export capability at Soldiers Pond (assuming generation is coming from west Bay d'Espoir and not from Holyrood), if the New Refinery load is not connected and a new line is built from Bay d'Espoir to Soldiers Pond, without any reactive power support at Sunnyside, the Soldiers Pond export capability is 485 MW, the limiting condition being 0.95 pu system intact voltages. This particular scenario (without the New Refinery load) has 447 MW of generation available for export, again assuming the Holyrood CTs are not producing any power.

5. Short Circuit Analysis

The purpose of the short circuit analysis is to quantify impacts to existing maximum fault levels particularly near to the HVdc system bus and to identify any circuit breakers whose ratings are exceeded due to increased fault levels. Another purpose of the short circuit analysis is to quantify the minimum short circuit level at the Soldiers Pond bus and identify the need for synchronous condenser(s) to ensure a minimum ESCR of 2.5.

5.1 ESCR Requirements of the HVdc Link

As described in Section 3.3 ESCR Requirements, it is recommended that a minimum ESCR of 2.5 be maintained at the Soldiers Pond bus. Dynamic performance studies will further validate this minimum ESCR value, however for the purposes of the power flow analysis, the goal is to design the reactive power requirements such that the ESCR at the Soldiers Pond bus is at least 2.5.

The HVdc system itself does not contribute to the short circuit strength of the system, however a synchronous condenser installed with the HVdc system will increase the short circuit strength if deemed necessary by the short circuit studies.

5.2 Study Procedure

Fault application (PSSE activity ASCC) is used to determine the three-phase and line-to-ground fault levels at a particular bus. All NLH power flow cases contain sequence data, therefore the same cases as used for the power flow analysis are used in the short circuit analysis.

Power flow cases representing the minimum short circuit levels are used to determine the short circuit MVA level and the corresponding ESCR at the Soldiers Pond bus. The power flow cases use the base assumption stated earlier which assumes that one 150 MVAr synchronous condenser and one Holyrood CT synchronous condenser are out of service for maintenance. Then the ESCRs are determined for system intact and contingency conditions.

Power flow cases representing the maximum short circuit levels are used to determine the fault levels at key buses, particularly near to the Soldiers Pond and Gull Island buses. These power flow cases represent system intact conditions with maximum generation and all available synchronous condensers in service. The fault levels at each bus are then compared with the existing fault level and nearby breaker ratings to determine if any breaker ratings will be exceeded. If so, mitigation such as breaker replacement is required.

5.3 Criteria

The following criteria must be met:

1. Fault levels at all buses must not exceed circuit breaker ratings, otherwise mitigation such as breaker replacement is required.
2. The minimum ESCR at the Soldiers Pond bus should be 2.5.

5.4 Study Results

5.4.1 Minimum Short Circuit Levels – ESCR

Power flow analysis determined the total reactive power requirement to be 600 MVAr at Soldiers Pond (450 MVAr filters and 150 MVAr synchronous condenser was assumed) and 200 MVAr at Sunnyside in addition to the eight synchronous condensers at Holyrood.

As a starting point in order to determine whether a synchronous condenser is actually required at Soldiers Pond, the minimum ESCR was found assuming no synchronous condenser is installed at Soldiers Pond. This results in a minimum ESCR of 1.9 (1967 MVA) during minimum generation power flow case BC4 for contingency C11, loss of Holyrood unit #3. This ESCR is below the desired minimum of 2.5. With the single 150 MVAr synchronous condenser at Soldiers Pond, the minimum ESCR is increased to 2.5 (2545 MVA) for this worst case contingency.

Therefore, the short circuit analysis verifies the fact that Soldiers Pond will require one 150 MVAr synchronous condenser to maintain the desired minimum ESCR. Dynamic performance studies will verify this requirement based on dynamic performance results.

For a complete listing of ESCR results for all power flows and all contingencies, please refer to Appendix 3.

5.4.2 Maximum Short Circuit Levels – Breaker Ratings

Maximum fault levels were tested with power flow cases BC1, BC2, BC3, BC7 and BC8 which represent the power flow cases with most Island generation in-service. In addition, all synchronous condensers at Holyrood and Soldiers Pond were placed in-service. Power flow cases BC1 and BC3 were found to produce very similar results and represented the highest fault levels.

Stations near Soldiers Pond and Holyrood saw the largest increase in fault levels. This is due to the addition of a synchronous condenser at Soldiers Pond and the five CTs at Holyrood. Table 11 below summarizes all stations in which the fault level is increased by more than 10%. Please note that existing fault level data and breaker ratings were not available for all buses, only buses for which this data was available were compared to the new increased fault levels in Table 12.

For a complete listing of fault levels with the new facilities in service please refer to Appendix 3.

Table 12
Stations with fault levels increases greater than 10%

Station	Existing Fault Level (MVA)		New Fault Level (MVA)				Breaker Ratings
	3P	LG	3P	Increase	LG	Increase	
Come By Chance 230	2019	1831	2520	24.8%	2520	37.6%	7960
Come By Chance 13.8	301	317	335	11.3%	349	10.1%	Customer-owned
Western Avalon 230	2152	2349	2954	37.3%	3182	35.5%	4980, 5600
Western Avalon 138	1281	1531	1600	24.9%	1882	22.9%	4780
Western Avalon 66	465	324	540	16.1%	363	12.0%	1430, 1500
Long Harbour 230	1653	1439	2151	30.1%	1777	23.5%	None
Long Harbour 46	423	464	807	90.8%	918	97.8%	1590
Sunnyside 230	2164	2084	2701	24.8%	3055	46.6%	5600
Sunnyside 138	1386	1630	1569	13.2%	1933	18.6%	2510
Oxen Pond 230	2396	3335	3387	41.4%	3577	7.3%	5600
Oxen Pond 66	1441	1337	2017	40.0%	1696	26.9%	2380
Hardwoods 230	2223	2605	3758	69.1%	4149	59.3%	5430, 7560, 13360
Hardwoods 66	1628	1625	2285	40.4%	2060	26.8%	2380, 2360, 2850, 3600
Holyrood 230	2657	3307	4629	74.2%	**5754**	74.0%	**5100**, **5430**,7570,12550
Holyrood 138	1377	1690	1839	33.6%	2212	30.9%	5020
Holyrood 66	542	501	629	16.1%	564	12.6%	4570
Holyrood 16	1827	0	2200	20.4%	0	-	None
Holyrood 16	1773	0	2099	18.4%	0	-	None
Holyrood 16	1598	0	1928	20.7%	0	-	None

Despite the increase in fault levels, the only station in which breaker ratings were exceeded was Holyrood. The maximum fault level seen at Holyrood station was 4629 MVA three-phase and 5754 MVA line-to-ground. Nine breakers at Holyrood rated for 5100 MVA (B12B15, B3L18, B12L42, B3B13) and 5430 MVA (B2L42, B12L17, B1L17, B1B11, B2B11) would require replacement.

6. Conclusions

6.1 Steady State Reactive Power Requirements

The minimum steady state reactive power support requirements are as follows:

- Soldiers Pond – 450 MVAr filters, 150 MVAr synchronous condenser
- Sunnyside 230 kV – 200 MVAr of capacitance

The determining contingencies for the steady state reactive power requirements were C9, loss of one of the Bay d'Espoir to Piper's Hole lines, and C11, loss of Holyrood unit #3, during the future peak Island load (1800 MW) BC3-DC4 power flow case in which the HVdc inverter at Soldiers Pond was operating in the 10-minute 2.0 pu monopolar mode. In this case the inverter at Soldiers Pond is absorbing 559 MVA compared to the 462 MVAr during bipolar operation. Without the additional reactive power support of the synchronous condenser at Soldiers Pond and the 200 MVAr at Sunnyside, the result of either of these contingencies would be system wide voltage collapse.

The synchronous condensers at Holyrood control their own bus voltage and are not VAR-limited during these worst contingencies because the voltage problems occur too far west of Holyrood for the reactive power support at Holyrood to be significantly useful in these voltage collapse scenarios. Therefore the synchronous condenser required for Soldiers Pond should be located right at the converter and not at Holyrood as local support will be required at Soldiers Pond. It is unlikely that fewer than 450 MVAr of filters will be required at Soldiers Pond because of the voltage depression occurring west of Soldiers Pond. If filters were removed at Soldiers Pond then a similar amount of reactive power support as was removed would be required at Sunnyside. It comes down to determining a reasonable split and location of total system reactive power requirements. With Sunnyside already requiring 200 MVAr, it would be undesirable to move some of the filter requirements from Soldiers Pond to Sunnyside. It would more likely be possible to lower the filter requirements at Soldiers Pond if the Holyrood synchronous condensers were located directly at Soldiers Pond.

Even with the above described reactive power support, it should be noted that for power flow cases BC7 with the HVdc infeed at minimum power of 80 MW and for case BC8 when the DC is exporting 200 MW, a fast HVdc run-up (minimum 50 MW when importing) and run-down (minimum 100 MW when exporting) is required to prevent system voltage collapse for contingency C9, loss of a Bay d'Espoir to Piper's Hole. A corresponding transfer trip of generation in the west would be required to offset the increase in generation in the east. The voltage collapse seems to occur if there is more than approximately 225-250 MW flowing from west to east on both of the Bay d'Espoir to Piper's Hole lines. If it would not be desired to perform a fast dc power run-up or run-down, then it would likely be possible to develop an operating guideline to limit steady state power flow on the circuits between Bay d'Espoir and Piper's Hole by re-dispatching generation to avoid the voltage collapse scenario in the first place. This would require further study to determine if this is in fact possible and what the exact power flow limit would be. Dynamic performance studies could investigate this issue further.

Dynamic performance studies will verify these requirements, whether one synchronous condenser at Soldiers Pond is sufficient, and whether there are any dynamic reactive power requirements at the Sunnyside 230 kV station.

6.2 NLH Network Upgrades

All but one of the thermal overloads on the Island occur on the heavily loaded west to east 230 kV transmission corridor between Bay d'Espoir and Soldiers Pond.

The exception to this corridor is 230 kV line TL201 from Soldiers Pond to Hardwoods. This line becomes overloaded only during the future peak Island load (1800 MW) power flow case due to load serving requirements on the radial 138 kV system underlying Hardwoods and Oxen Pond stations. The overload is worse, up to 115%, if the two 25 MW wind farms are not in-service. This line will need to be upgraded and will require a rebuild with 804 MCM AACSR/TW conductor as stated in upcoming Table 13.

For the remaining 230 kV lines between Bay d'Espoir and Soldiers Pond, the highest overloads occur when the HVdc system is exporting power from the Island, and the next worst situation is when the HVdc system is importing low power. However, some overloads still occur even when the HVdc system is importing its maximum rated power. It is possible to mitigate all of these overloads by re-dispatching Island generation, first by increasing the HVdc import if there is room available (or lowering the HVdc export) and then by turning on generation from the CTs at Holyrood when there is no more room left on the HVdc. This effectively reduces the west to east power flow and reduces loading on the affected 230 kV lines.

Many of these overloads are quite high however, and instead of relying on generator re-dispatch to mitigate the overloads, line upgrades could be implemented as described in Table 13.

Table 13
230 kV Transmission Line Upgrades

Line		Current Rating (MVA)	New Rating (MVA)	Upgrade
TL202	Bay d'Espoir-Piper's Hole	199.3/297.7/369.5	341.8/402.4/453.8	Thermal uprating to 75 degrees C.
TL206	Piper's Hole – Sunnyside	199.3/297.7/369.5	341.8/402.4/453.8	Thermal uprating to 75 degrees C.
TL203	Sunnyside – Western Avalon	261.7/307.8/347.0	355.8/411.5/459.6	Rebuild with 804 MCM AACSR/TW conductor.
TL217	Western Avalon-Soldiers Pond	199.3/297.7/369.5	341.8/402.4/453.8	Recent review indicates can operate at 75 degrees C as is.
TL201	Western Avalon-Soldiers Pond	175.5/260.2/322.2	355.8/411.5/459.6	Rebuild with 804 MCM AACSR/TW conductor.
TL201	Soldiers Pond-Hardwoods	175.5/260.2/322.2	355.8/411.5/459.6	Rebuild with 804 MCM AACSR/TW conductor.

Lines TL207 from Sunnyside to Come By Chance and TL237 from Come By Chance to Western Avalon have already been upgraded to use 804 MCM AACSR/TW conductor. These lines would require further review by NLH Transmission Design if the ratings were to be increased.

If the line upgrades listed in Table 13 are built, a few overloads still remain but only during cases with very low HVdc infeed power or when the HVdc is exporting power from the Island. These cases are summarized below in Table 14. These overloads can be mitigated by increasing HVdc imports or decreasing HVdc exports post-contingency.

Table 14
Overloads After Line Upgrades are Implemented

Overloaded Line	Contingency	Rate	Power Flow	Overload (%)	Pre-Contingency HVdc Infeed (MW)	Post-Contingency Re-dispatch (MW)
Piper's Hole-Bay d'Espoir TL202, TL206	C9	A	BC12-DC10	101.4	80 BP	+10 HVdc import
		B	BC7*		80 BP	+175 HVdc import
		A	BC8*		-200 BP	0 HVdc export +75 Holyrood
		C	BC2-DC5	100.3	600 MP	-
Sunnyside-Western Avalon TL203	C5,C6	A	BC8	146.7	-200 BP	-125 HVdc export
Piper's Hole-Sunnyside TL202	C8	A	BC8	148.6	-200 BP	-160 HVdc export
		B	BC7-DC1	108.9	80 BP	+35 HVdc import
Sunnyside-Come By Chance TL207	C7	A	BC8	150.3	-200 BP	-130 HVCD export
Come By Chance-Western Avalon TL237	C7	A	BC8	142.7	-200 BP	-110 HVdc export

**These scenarios require a fast HVdc run-up or run-down as described in section 7.1.*

6.3 HVdc System Losses

During normal bipolar operation, the Gull Island converter supplies a rated current of 1600 A. The power injected at Soldiers Pond is 765.8 MW and at Salisbury, 763.4 MW, resulting in losses of 34.2 MW and 36.6 MW respectively.

The losses increase when operating in monopolar mode, requiring up to 2611 A (1.66 pu current) at Gull Island to supply the 10-minute 100% overload requirement at Soldiers Pond (2.16 pu current) and the continuous 10% overload at Salisbury (1.1 pu current), and up to 2149 A (1.34 pu) at Gull Island to supply the continuous 50% and 10% overloads at Soldiers Pond (1.58 pu current) and Salisbury (1.1 pu current) respectively.

6.4 Minimum ESCR at Soldiers Pond

Soldiers Pond requires one 150 MVAr synchronous condenser to increase the minimum ESCR at the Soldiers Pond 230 kV bus up to 2.5 (2545 MVA) from 1.9 (1967 MVA) if no synchronous condenser is installed. The minimum ESCR occurs during the minimum Island generation base case (BC4) with contingency C11, loss of Holyrood unit #3. The base case assumes maintenance outages of the Soldiers Pond synchronous condenser and one Holyrood CT synchronous condenser.

6.5 Impacts to Maximum Fault Levels

Despite the increase in fault levels at various nearby stations, the only station with breakers whose ratings were exceeded was Holyrood. The maximum fault level seen at Holyrood station was 4629 MVA three-phase and 5754 MVA line-to-ground. Nine breakers at Holyrood rated for 5100 MVA (B12B15, B3L18, B12L42, B3B13) and 5430 MVA (B2L42, B12L17, B1L17, B1B11, B2B11) would require replacement.

6.6 Impacts of New Refinery Load

It should be noted that a portion of the Island system upgrades identified in this report, in particular the need for reactive power support at Sunnyside and the extensive thermal upgrades required on 230 kV transmission between Bay d'Espoir and Soldiers Pond, are largely due to approximately 255 MW of new industrial load (refinery and smelter) which is planned to be installed along the heavily loaded transmission corridor. The major NLH Island load centre is located east of Bay d'Espoir on the Avalon Peninsula, while the majority of the generation is located west of Bay d'Espoir. This can result in heavy west to east power flow on the 230 kV transmission system, in particular between Bay d'Espoir, Sunnyside, Western Avalon and Soldiers Pond, with further increased loading due to the new industrial loads. As a general result this can cause voltage depression and thermal overloading in the area. The HVdc infeed into Soldiers Pond generally has a positive impact on the Island transmission system as it off-loads this west-to-east power flow by injecting power closer to the load centre. Many of the issues discussed are not necessarily due to the HVdc infeed but are due to the lack of transmission linking the generation in the west to the load in the east. For example, without the new refinery load, the reactive power requirement at Sunnyside reduces to approximately 50 MVAr from 200 MVAr. It will be important for further system impact studies involving the loads to define more exact requirements of connecting the new loads separate from the impacts of the HVdc infeed into Soldiers Pond.

Appendix A

Newfoundland Island Generation Dispatch for Base Cases

WTO DC 1020
HVDC System Integration Study
Generation Dispatch for Base Case Scenarios

	Base Cases									
	BC1	BC2	BC3	BC4	BC5	BC6	BC7	BC8	BC12	BC13
NLH System Load (MW)	1584.5	1584.5	1750.5	625	625	990.1	990.1	625	625	1750.5
Generation Dispatch										
HVDC at Soldiers Pond	765.9	578.4	765.9	248.8	78.5	765.9	78.5	-200.0	79.8	574.2
NLH - Hydro										
Bay d'Espoir Unit 1	57.8	67.8	69	61.6	60.6	58.5	71.2	59.1	59.2	67.6
Bay d'Espoir Unit 2	58.2	68.3	69.5	off	off	off	69.7	58	off	68.1
Bay d'Espoir Unit 3	58.2	68.3	69.5	off	60.8	off	69.7	58	60.8	68.1
Bay d'Espoir Unit 4	58.2	68.3	69.5	off	off	off	69.7	58	off	68.1
Bay d'Espoir Unit 5	58.2	68.3	69.5	off	60.8	off	69.7	58	60.8	68.1
Bay d'Espoir Unit 6	58.2	68.3	69.5	off	off	off	69.7	58	off	68.1
Bay d'Espoir Unit 7	135	154	154	135	135	sc	154	154	135	154
Cat Arm Unit 1	35	65	65	35	35	sc	60	65	35	65
Cat Arm Unit 2	35	65	65	sc	35	sc	60	65	35	65
Upper Salmon	75	84	84	64	75	70	75	84	75	84
Hinds Lake	67	75	75	off	off	off	67	75	off	75
Granite Canal	25	40	40	22	30	25	35	40	30	40
Paradise River	8	8	8	off	8	off	8	8	8	8
NLH - Thermal										
Hardwoods	sc	sc	sc	sc	sc	sc	sc	sc	sc	sc
Stephenville	sc	sc	sc	sc	sc	sc	sc	sc	sc	sc
Holyrood CT1	sc	30	sc	sc	sc	sc	sc	sc	sc	50
Holyrood CT2	sc	sc	sc	sc	sc	sc	sc	sc	sc	50
Holyrood CT3	sc	sc	sc	sc	sc	sc	sc	sc	sc	50
Holyrood CT4	sc	sc	sc	sc	sc	sc	sc	sc	sc	50
Holyrood CT5	sc	sc	sc	sc	sc	sc	sc	sc	sc	sc
NUGS										
Star Lake	17.9	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4
Rattle Brook	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
CBP&P	15	15	15	15	15	15	15	15	15	15
Exploits	32	32	32	32	32	32	32	32	32	32
Wind										
St. Lawrence	25	25	25	0	0	12	12	0	0	25
Fermuse	25	25	25	0	0	12	12	0	0	25
Goulds	25	25	25	0	0	12	12	0	0	25
Total Generation	1638.2	1651.7	1816.4	634.4	646.7	1023.4	1061.2	708.1	646.6	1816.3

Appendix B

HVdc Operating Points for all Base Cases

Portion of Appendix B removed from Public version

Includes data parameters for PSSE multi-terminal line model.

Corresponds to Table 6 of the report.

Line Conductor Details

As the dc conductor optimization and route selection were not finalized prior to carrying out the power flow and short circuit analysis, the conductor type, geometry and line lengths used in the studies were based on the preliminary data available at the time. Although final transmission line and cable parameters may differ from those used in this study, the overall impact on results should be minimal.

Overhead line portions assumed 2-conductor symmetrical bundle with a dc resistance of 0.02892 ohms/km. Cable portions assumed a single conductor. Line lengths were as follows:

Gull Island to Strait of Belle Isle	407 km overhead line
Strait of Belle Isle	40.7 km of submarine cable
Strait of Belle Isle to Taylors Brook	201 km of overhead line
Taylors Brook to Soldiers Pond	480 km of overhead line
Taylors Brook to Cape Ray	300 km of overhead line
Cape Ray to Salisbury	325 km of submarine cable
Cape Ray to Salisbury	100 km of overhead line

Converter Transformer Details

Current normal industry practice is to supply a single twelve pulse valve group per pole at each station for HVdc transmission systems with power ratings similar to that being considered. Each twelve pulse valve group is connected to the ac system either through two three phase, two winding, converter transformers or three, single phase, three winding converter transformers to provide the necessary wye:wye and wye:delta connections. For PSSE modeling purposes, the transformers connected to each pole have been lumped together into one equivalent transformer connected to a single bridge.

When calculating the values for the equivalent converter transformers, the commutating reactance value in ohms is referred to the secondary side of the transformer. Because these transformers are connected in series (one to each 6-pulse bridge) the secondary voltage for the equivalent transformer is double, as is the MVA rating. For example, at Gull Island:

Equivalent transformer rating = 2 * 585 = 1170 MVA
Equivalent transformer secondary voltage = 2*208.6 = 417.2 kV
Xc (ohms) = 0.14 pu * (417.2 kV*417.2 kV)/1170 MVA = 20.827 ohms

Converter Transformer Data

Converter	Rating (MVA)	Voltage (kV)	Tap Changer Range	Commutating Reactance Xc (pu)	Equivalent Transformer Rating (MVA)	Equivalent Transformer Voltage (kV)	Equivalent Transformer Xc (ohms)
Gull Island	2 x 585 per pole	230–208.6	0.9-1.1	0.14 pu	1170 per pole	230-417.2	20.827
Soldiers Pond	2 x 351 per pole	230–208.6	0.9-1.1	0.14 pu	702 per pole	230-417.2	34.712
Salisbury	2 x 234 per pole	345–208.6	0.9-1.1	0.14 pu	468 per pole	345-417.2	52.068

Appendix C

Effective Short Circuit Ratios at Soldiers Pond

ESCR and Short Circuit MVA at Soldiers Pond 230 kV Bus

Assuming Synchronous Condenser at Soldiers Pond does not exist

	BC1		BC2		BC3		BC4		BC5		BC6		BC7		BC8		BC10		BC12		BC13	
Contingency	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**
Base Case	3.2	2989	3.2	2989	3.2	2989	2.5	2453	2.6	2504	2.9	2807	3.1	2900	2.9	2734	3.2	2989	2.8	2689	3.2	2989
C1	3.1	2929	3.1	2929	3.1	2929	2.4	2395	2.5	2446	2.9	2748	3.0	2840	2.8	2664	3.1	2929	2.7	2619	3.1	2929
C2	3.2	2985	3.2	2985	3.2	2985	2.5	2453	2.6	2504	2.9	2804	3.1	2896	2.9	2734	3.2	2985	2.8	2689	3.2	2985
C3	3.2	2985	3.2	2985	3.2	2985	2.5	2453	2.6	2504	2.9	2804	3.1	2897	2.9	2734	3.2	2985	2.8	2689	3.2	2985
C4	3.0	2871	3.0	2871	3.0	2871	2.4	2370	2.4	2408	2.8	2718	2.9	2785	2.7	2625	3.0	2871	2.7	2592	3.0	2871
C5	3.1	2897	3.1	2897	3.1	2897	2.4	2387	2.5	2426	2.9	2736	2.9	2807	2.7	2646	3.1	2897	2.7	2611	3.1	2897
C6	3.1	2897	3.1	2897	3.1	2897	2.4	2387	2.5	2426	2.9	2736	2.9	2807	2.7	2646	3.1	2897	2.7	2611	3.1	2897
C7	3.0	2872	3.0	2872	3.0	2872	2.4	2368	2.4	2405	2.8	2716	2.9	2781	2.7	2622	3.0	2872	2.7	2589	3.0	2872
C8	3.2	2984	3.2	2984	3.2	2984	2.5	2449	2.6	2499	2.9	2803	3.1	2894	2.8	2728	3.2	2984	2.8	2684	3.2	2984
C9	3.0	2823	3.0	2823	3.0	2823	2.3	2319	2.4	2352	2.8	2677	2.9	2732	2.6	2561	3.0	2823	2.6	2536	3.0	2823
C10	2.6	2505	2.6	2505	2.6	2505	1.9	1967	2.0	2018	2.3	2322	2.5	2414	2.3	2255	2.6	2505	2.2	2209	2.6	2505

Assumptions:

1 Synchronous Condenser at Soldiers Pond does not exist
2 Holyrood unit #3 and a Holyrood CT synchronous condensers out of service (all other Holyrood SCs in service)
3 No reactive power support at Sunnyside
4 450 MVAR switched capacitors at Soldiers' Pond (does not contribute to short circuit current)

ESCR and Short Circuit MVA at Soldiers Pond 230 kV Bus

Assuming 150 MVAR Synchronous Condenser exists at Soldiers Pond
Soldiers Pond synchronous condenser out-of-service

	BC1		**BC2**		**BC3**		**BC4**		**BC5**		**BC6**		**BC7**		**BC8**		**BC10**		**BC12**		**BC13**	
Contingency	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**
Base Case	3.7	3409	3.7	3409	3.7	3409	3.0	2875	3.1	2925	3.5	3228	3.6	3320	3.4	3149	3.7	3409	3.3	3104	3.7	3409
C1	3.6	3320	3.6	3320	3.6	3320	2.9	2788	3.0	2839	3.4	3140	3.5	3232	3.2	3049	3.6	3320	3.2	3004	3.6	3320
C2	3.7	3404	3.7	3404	3.7	3404	3.0	2875	3.1	2925	3.5	3225	3.6	3316	3.4	3149	3.7	3404	3.3	3104	3.7	3404
C3	3.7	3405	3.7	3405	3.7	3405	3.0	2875	3.1	2925	3.5	3225	3.6	3317	3.4	3149	3.7	3405	3.3	3104	3.7	3405
C4	3.5	3290	3.5	3290	3.5	3290	2.9	2790	3.0	2828	3.4	3138	3.4	3205	3.2	3039	3.5	3290	3.2	3006	3.5	3290
C5	3.6	3317	3.6	3317	3.6	3317	2.9	2808	3.0	2848	3.4	3157	3.5	3227	3.3	3061	3.6	3317	3.2	3027	3.6	3317
C6	3.6	3317	3.6	3317	3.6	3317	2.9	2808	3.0	2848	3.4	3157	3.5	3227	3.3	3061	3.6	3317	3.2	3027	3.6	3317
C7	3.6	3292	3.6	3292	3.6	3292	2.9	2789	3.0	2826	3.4	3137	3.4	3202	3.2	3037	3.6	3292	3.2	3005	3.6	3292
C8	3.7	3404	3.7	3404	3.7	3404	3.0	2870	3.1	2920	3.5	3224	3.6	3314	3.4	3143	3.7	3404	3.3	3099	3.7	3404
C9	3.5	3244	3.5	3244	3.5	3244	2.9	2740	2.9	2773	3.3	3098	3.4	3153	3.2	2977	3.5	3244	3.1	2952	3.5	3244
C10	3.4	3195	3.4	3195	3.4	3195	3.0	2875	3.1	2925	3.2	3004	3.3	3096	3.4	3149	3.4	3195	3.3	3104	3.4	3195
C11	3.2	2989	3.2	2989	3.2	2989	2.5	2454	2.6	2504	2.9	2808	3.1	2900	2.9	2734	3.2	2989	2.8	2689	3.2	2989

Assumptions:

1. Synchronous Condenser at Soldiers' Pont out of service
2. A Holyrood CT synchronous condenser out of service (all other Holyrood SCs in service)
3. 200 MVAR SVC at Sunnyside (does not contribute to short circuit current)
4. 450 MVAR switched capacitors at Soldiers' Pond (does not contribute to short circuit current)

ESCR and Short Circuit MVA at Soldiers Pond 230 kV Bus

Assuming 150 MVAR Synchronous Condenser exists at Soldiers Pond

Holyrood unit #3 synchronous condenser out-of-service

	BC1		BC2		BC3		BC4		BC5		BC6		BC7		BC8		BC10		BC12		BC13	
Contingency	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**	**ESCR**	**MVA**
Base Case	4.0	3625	4.0	3625	4.0	3625	3.3	3098	3.4	3145	3.8	3450	3.9	3536	3.7	3372	4.0	3625	4.1	3745	4.0	3625
C1	3.9	3564	3.9	3564	3.9	3564	3.2	3039	3.3	3086	3.7	3390	3.8	3476	3.6	3301	3.9	3564	4.0	3644	3.9	3564
C2	4.0	3621	4.0	3621	4.0	3621	3.3	3098	3.4	3145	3.7	3447	3.9	3533	3.7	3372	4.0	3621	4.1	3745	4.0	3621
C3	4.0	3621	4.0	3621	4.0	3621	3.3	3098	3.4	3145	3.7	3447	3.9	3533	3.7	3372	4.0	3621	4.1	3745	4.0	3621
C4	3.8	3497	3.8	3497	3.8	3497	3.2	3003	3.2	3038	3.6	3350	3.7	3411	3.5	3252	3.8	3497	4.0	3636	3.8	3497
C5	3.8	3524	3.8	3524	3.8	3524	3.2	3021	3.3	3058	3.6	3369	3.7	3434	3.5	3274	3.8	3524	4.0	3658	3.8	3524
C6	3.8	3524	3.8	3524	3.8	3524	3.2	3021	3.3	3058	3.6	3369	3.7	3434	3.5	3274	3.8	3524	4.0	3658	3.8	3524
C7	3.8	3497	3.8	3497	3.8	3497	3.2	3000	3.2	3034	3.6	3346	3.7	3407	3.5	3248	3.8	3497	4.0	3634	3.8	3497
C8	4.0	3620	4.0	3620	4.0	3620	3.3	3094	3.4	3140	3.7	3446	3.9	3531	3.6	3366	4.0	3620	4.1	3740	4.0	3620
C9	3.8	3470	3.8	3470	3.8	3470	3.2	2972	3.2	3003	3.6	3329	3.7	3379	3.5	3210	3.8	3470	3.9	3603	3.8	3470
C10	3.7	3411	3.7	3411	3.7	3411	3.3	3098	3.4	3145	3.5	3225	3.6	3311	3.7	3372	3.7	3411	4.1	3745	3.7	3411
C11	3.2	3026	3.2	3026	3.2	3026	2.6	2498	2.6	2545	3.0	2850	3.1	2937	2.9	2773	3.2	3026	3.4	3145	3.2	3026

Assumptions:

1 Holyrood synchronous condenser unit #3 out of service
2 A Holyrood CT synchronous condenser out of service
3 200 MVAR SVC at Sunnyside (does not contribute to short circuit current)
4 450 MVAR switched capacitors at Soldiers' Pond (does not contribute to short circuit current)

Appendix D

Maximum Short Circuit Levels

Maximum NLH Fault Levels
Before and After HVDC System Addition

Area	Bus No	Bus Name	Station	Bus Volt kV	Rating MVA	Existing		BC1-DC1		BC2-DC1		BC3-DC1		BC7-DC1		BC8-DC8	
						3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA
1	211	NLREFINERY	New Refinery	230	Proposed Station			2469	3018	2430	2972	2464	3009	2306	2835	2238	2781
1	227	CBC B1B2	Come-By-Chance	230	7960	2019	1831	2520	2520	2480	2477	2517	2507	2347	2369	2276	2328
1	228	CBC T1	Come-By-Chance	13.8	Customer-owned	301	317	335	349	328	342	330	343	321	334	320	334
1	229	WAV B1B3	Western Avalon	230	4980/5600	2152	2349	2954	3182	2908	3120	2964	3177	2711	2935	2622	2884
1	230	LHR B1	Long Harbour - VBN	230	New breakers	1653	1439	2151	1777	2112	1738	2147	1761	1993	1662	1947	1650
1	231	LHR B3B4	Long Harbour - VBM	46	1590	423	464	807	918	789	897	798	906	760	867	756	864
1	234	HRD TS	Holyrood	230	5100/5400/7570/12550	2657	3307	4537	5668	4517	5622	4629	5754	4123	5175	3843	4896
1	236	HWD B1B2	Hardwoods	230	5430/7560/13360	2223	2605	3694	4100	3664	4039	3758	4149	3335	3701	3055	3502
1	237	HWD G1	Hardwoods	13.8	720	961	0.14	1039	0	1026	0	1033	0	1013	0	360	0
1	238	OPD B1	Oxen Pond	230	5600	3104	2396	3335	3533	3301	3472	3387	3577	3005	3157	2773	3022
1	308	BLK NPT3	Blaketown	66	Customer-owned			527	493	515	482	523	490	483	458	488	465
1	309	BRB T2T3	Bay Roberts	66	Customer-owned			460	515	447	500	454	508	419	477	432	493
1	310	BLK NP	Blaketown	138	Customer-owned			1323	1134	1297	1104	1320	1123	1220	1052	1209	1062
1	311	WAV B4	Western Avalon	138	4780	1281	1531	1600	1882	1571	1843	1595	1870	1483	1751	1457	1735
1	334	OPD B2B5	Oxen Pond	66	2380	1441	1337	2004	1694	1973	1655	2017	1696	1813	1541	1647	1473
1	335	HWD B7B8	Hardwoods	66	2380/2630/2850/3600	1628	1625	2271	2058	2239	2016	2285	2060	2052	1880	1736	1705
1	336	WAV B2	Western Avalon	66	1430/1500	465	324	540	363	527	355	534	359	502	341	507	348
1	337	HRD B6B7	Holyrood	66	1500/4570	542	501	629	564	616	552	623	557	591	541	585	543
1	338	HRD B8	Holyrood	138	5020	1377	1690	1839	2212	1803	2164	1840	2207	1690	2039	1663	2023
1	340	HOL NP	Holyrood Town	138	Customer-owned			1415	1152	1384	1121	1411	1141	1303	1069	1294	1078
1	347	SCV NP	Seal Cove	66	Customer-owned			649	552	635	539	644	546	605	521	596	523
1	348	KEL NP	Kelligrews	66	Customer-owned			763	513	746	500	759	508	707	481	688	482
1	349	CHA NP	Chamberlains	66	Customer-owned			1332	886	1305	863	1331	880	1217	822	1119	801
1	352	SCV GEN	Seal Cove	2.4	Customer-owned			53	30	52	30	53	30	36	0	37	0
1	353	SPF NP	Springfield	138	Customer-owned			1176	849	1149	825	1171	839	1080	788	1077	801
1	354	COL NP	Colliers	138	Customer-owned			1211	876	1183	852	1206	866	1114	815	1111	827
1	357	BRB NP	Bay Roberts	138	Customer-owned			1170	875	1143	849	1165	864	1070	810	1066	823
1	428	CBC T2	Come-By-Chance	13.8	Customer-owned			335	349	329	342	330	343	321	334	320	334
1	434	HRP G1	Holyrood	16	No Unit Breakers	1827	0.12	2175	0	2154	0	2200	0	2025	0	2059	0
1	435	HRP G2	Holyrood	16	No Unit Breakers	1773	0.12	2077	0	2057	0	2099	0	1938	0	1974	0
1	436	HRP G3	Holyrood	16	No Unit Breakers	1598	0.12	1907	0	1886	0	1928	0	1770	0	1802	0
1	444	HRD CT1	Holyrood	13.8	Proposed Unit			873	0	859	0	880	0	817	0	838	0
1	445	HRD CT2	Holyrood	13.8	Proposed Unit			873	0	863	0	880	0	817	0	838	0
1	446	HRD CT3	Holyrood	13.8	Proposed Unit			873	0	863	0	880	0	817	0	838	0
1	447	HRD CT4	Holyrood	13.8	Proposed Unit			873	0	863	0	880	0	817	0	838	0
1	448	HRD CT5	Holyrood	13.8	Proposed Unit			873	0	863	0	880	0	817	0	838	0
1	507	ILC NP	Islington	66	Customer-owned			323	280	314	272	318	275	296	259	305	267
1	511	GOU WIND	Goulds	66	Customer-owned			735	923	723	908	733	920	644	822	518	683
1	512	GOU WIND	Goulds	13.8	Customer-owned			294	202	292	201	294	202	286	199	161	0
1	580	FER WIND	Fermuse	66	Customer-owned			229	227	228	226	229	227	193	201	112	132
1	581	FER WIND	Fermuse	34.5	Customer-owned			212	252	212	252	212	252	200	241	76	101
1	2301	CHF A1 B21	Churchill Falls	230	15000			7239	8436	7211	8400	7239	8436	7154	8329	7121	8279
1	2302	CHF A2 & A3	Churchill Falls	230	15000			8602	10374	8572	10336	8602	10374	8512	10258	8473	10201
1	2303	CHF A4 & A5	Churchill Falls	230	15000			8616	10407	8586	10369	8616	10407	8526	10291	8487	10233
1	2304	CHF A6 & A7	Churchill Falls	230	15000			8584	10357	8555	10319	8584	10357	8494	10241	8456	10184
1	2305	CHF A8& A9	Churchill Falls	230	15000			8633	10424	8603	10386	8633	10424	8543	10308	8504	10250
1	2306	CHF B23	Churchill Falls	230	15000			9059	10809	9030	10772	9059	10809	8971	10697	8937	10644
1	2490	SOL B1	Soldiers Pond	230	Proposed Station			4375	5534	4359	5492	4467	5622	3971	5043	3659	4722
1	2491	SOL SC1	Soldiers Pond	13.8	Proposed Station			2338	1676	2310	1652	2362	1686	2112	1443	2077	1440
2	112	IRV B1	Indian River	138	628	523	340	532	345	528	342	527	341	520	338	527	344
2	113	SPL B1	Springdale	138	1490	515	322	525	327	520	324	519	323	514	322	520	327
2	145	BWT L60	Bottom Waters	138	287	216	120	223	121	221	120	220	120	218	120	222	123
2	146	BWT B1	Bottom Waters	25	Reclosers			94	109	94	108	93	108	93	108	94	110
2	151	BUC B2	Buchans	66	4570			427	325	423	323	421	321	423	323	425	325
2	214	SOK T1	South Brook	25	Reclosers			63	65	63	65	63	64	63	65	63	66

Maximum NLH Fault Levels
Before and After HVDC System Addition

Area	Bus No	Bus Name	Station	Bus Volt kV	Rating MVA	Existing		BC1-DC1		BC2-DC1		BC3-DC1		BC7-DC1		BC8-DC8	
						3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA
2	215	BUC B1	Buchans	230	5430/7970	1824	1736	1773	1735	1759	1720	1759	1718	1736	1710	1729	1707
2	216	STB B1B2	Stony Brook	230	4780/9960	2444	2640	2433	2649	2411	2624	2417	2629	2379	2600	2359	2582
2	217	STB B3	Stony Brook	138	2480/2630	1508	1836	1512	1853	1495	1832	1492	1828	1471	1809	1466	1806
2	218	PIPERS_HOLE	Pipers Hole	230	Proposed Station			2680	3071	2638	3022	2677	3062	2497	2882	2416	2821
2	219	SOK L22	South Brook	138	Circuit Switcher	538	335	548	341	543	337	542	337	538	336	542	340
2	222	SSD B1	Sunnyside	230	5600	2164	2084	2701	3055	2661	3007	2701	3048	2515	2864	2431	2802
2	223	SSD B2B3	Sunnyside	138	2510	1386	1630	1569	1933	1541	1898	1558	1917	1471	1821	1396	1745
2	226	SSD T5	Sunnyside	25	Customer-owned			195	202	191	198	192	199	187	194	188	196
2	296	GWD NP	Glenwood	138	No Breaker	701	507	710	516	699	508	700	509	693	508	691	509
2	297	GWD NPT1	Glenwood	25	Customer-owned			68	70	67	68	67	68	68	70	68	70
2	300	RUS NP	Rusty Pond	66	Customer-owned			211	170	209	168	209	168	210	170	211	171
2	301	NWB NP	Northwest Brook	138	Customer-owned			1118	948	1097	929	1108	937	1057	905	1019	882
2	302	RBK NP	Rattling Brook	66	Customer-owned			164	184	162	182	162	182	163	183	165	186
2	303	RBK NP G	Rattling Brook	6.9	Customer-owned			86	0	85	0	85	0	86	0	87	0
2	304	GAN NP	Gander	138	Customer-owned			727	619	715	611	718	615	703	601	698	601
2	305	GAM NP	Gambo	138	Customer-owned			618	402	606	394	609	395	596	392	590	393
2	306	CLV NP	Clarenville	138	Customer-owned			1063	913	1043	893	1053	904	1006	873	968	828
2	312	NWB NPT1	Northwest Brook	25	Customer-owned			93	97	91	95	92	95	90	94	91	95
2	315	COB NP	Cobbs Pond	138	Customer-owned			757	619	745	610	748	614	732	603	727	603
2	316	COB NPT2	Cobbs Pond	66	Customer-owned			210	232	205	226	202	223	212	235	213	237
2	320	GLV NP	Glovertown	138	Customer-owned			621	391	609	384	612	385	597	382	591	381
2	321	TNS NP	Terra Nova	138	Customer-owned			656	415	643	406	647	408	630	403	622	400
2	323	PBD NP	Port Blandford	138	Customer-owned			676	432	662	423	667	425	648	419	638	415
2	324	SBK NP	Sandy Brook	66	Customer-owned			159	154	157	152	157	152	159	154	161	156
2	325	SBK GEN	Sandy Brook	6.9	Customer-owned			59	0	58	0	58	0	59	0	59	0
2	326	GFS NP	Grand Falls	138	Customer-owned			1192	1190	1177	1175	1177	1174	1163	1168	1159	1167
2	327	GFS NPT1	Grand Falls	66	Customer-owned			224	175	221	173	221	173	222	175	223	176
2	341	BFS NP	Bishops Falls	138	Customer-owned			1155	1116	1141	1102	1140	1101	1127	1096	1124	1095
2	342	BFS NPT1	Bishops Falls	25	Customer-owned			179	241	176	238	176	238	177	240	177	240
2	344	GAN NPT2	Gander	66	Customer-owned			190	144	187	142	188	142	187	142	188	144
2	380	GAM NPT2	Gambo	66	Customer-owned			202	230	198	226	198	225	198	227	199	228
2	381	HBS NP	Hare Bay	66	Customer-owned			137	122	134	120	134	119	135	121	137	122
2	382	TRN NP	Trinity	66	Customer-owned			104	96	102	94	101	93	103	95	104	96
2	383	GPD NP	Greens Pond	66	Customer-owned			80	89	79	87	78	86	80	88	81	89
2	384	WES NP	Wesleyville	66	Customer-owned			70	93	69	91	69	90	70	92	71	93
2	385	WES GEN	Wesleyville	13.2	Customer-owned			53	0	52	0	52	0	53	0	53	0
2	395	NDJ NP	Notre Dame Junction	66	Customer-owned			158	132	156	130	156	130	156	132	157	134
2	397	LEW NP	Lewisporte	66	Customer-owned			126	89	125	88	125	88	125	90	126	92
2	410	CLK NP	Clarks Head	66	Customer-owned			110	75	108	73	107	73	109	74	110	76
2	411	BOY NP	Boyds Cove	66	Customer-owned			84	51	83	50	83	50	84	51	85	52
2	412	FHD L54	Farewell Head	66	No Breaker			72	42	71	41	71	41	72	42	72	43
2	413	FHD T1	Farewell Head	25	n/a			51	66	50	65	50	65	50	65	51	66
3	103	DLK B2	Deer lake	66	1430/2380/2390			683	709	681	708	681	707	677	704	679	708
3	104	SCR NP	Seal Cove Road	138	Customer-owned	271	154	278	156	275	155	275	154	272	154	276	158
3	108	MMT NP	Marble Mountain	66	No Breaker			809	410	806	408	806	409	802	408	804	410
3	111	DLK B1	Deer lake	138	4300/7530	936	957	923	957	918	951	916	949	897	932	911	948
3	114	PAS B1	Pasadena	66	No Breaker			537	286	536	285	536	285	534	285	536	286
3	115	MDR B2B3	Massey Drive	66	1430/1490			758	736	752	732	750	731	740	723	741	724
3	135	DLK B3	Deer lake	230	12550	1353	1196	1311	1170	1298	1158	1297	1154	1271	1137	1274	1143
3	136	CAT L47	Cat Arm	230	9960	988	1130	971	1113	963	1103	961	1100	928	1063	931	1068
3	137	CAT G1	Cat Arm	13.8	No Unit Breaker	777	47	776	47	774	47	775	47	736	45	737	45
3	138	CAT G2	Cat Arm	13.8	No Unit Breaker	777	47	776	47	774	47	775	47	736	44	737	44
3	152	MDR B4	Massey Drive	66	Customer-owned			1357	768	1351	766	1350	766	1339	764	1342	766
3	200	PAB NP	Port Aux Basques	66	Customer-owned			108	117	108	116	108	116	89	101	88	101
3	201	DLS B1	Doyles	66	1500			138	182	137	182	137	182	119	160	119	160

Maximum NLH Fault Levels
Before and After HVDC System Addition

Area	Bus No	Bus Name	Station	Bus Volt kV	Rating MVA	Existing		BC1-DC1		BC2-DC1		BC3-DC1		BC7-DC1		BC8-DC8	
						3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA
3	202	DLS L14	Doyles	138	No Breaker			189	161	188	161	189	161	170	152	169	153
3	203	BBK B2	Bottom Brook	138	1490			364	432	362	430	362	430	343	411	342	411
3	204	SVL B2	Stephenville	66	1430			544	587	542	585	541	584	512	562	509	560
3	205	BBK B1	Bottom Brook	230	5430	1392	1473	1250	1255	1241	1248	1243	1252	1214	1236	1213	1235
3	206	SVL B1	Stephenville	230	15930	1219	1458	1063	1062	1056	1056	1056	1061	1034	1054	1035	1056
3	208	MDR B1B5	Massey Drive	230	5600/12550	1703	1693	1622	1631	1612	1622	1620	1628	1589	1605	1582	1601
3	209	SVL G1	Stephenville	13.8	650			593	0	592	0	592	0	566	0	557	0
3	210	HLY L51	Howley	69	2200			115	122	115	121	114	121	113	120	115	122
3	212	HLY B1	Howley	138	4300	863	827	868	839	864	835	863	833	843	817	863	836
3	213	HLK L43	Hinds Lake	138	No Breaker	790	972	803	992	800	988	799	987	778	961	800	989
3	250	HLK G1	Hinds Lake	13.8	1000			791	31	790	31	790	31	761	30	789	31
3	252	HDN L51	Hampden	69	No Breaker			82	68	81	68	81	68	80	67	82	69
3	253	JAM L52	Jacksons Arm	69	No Breaker			69	72	69	71	69	71	68	71	69	72
3	254	HDN B1	Hampden	12.5	Reclosers			31	35	31	35	31	35	31	35	31	36
3	255	JAM B1	Jacksons Arm	12.5	Reclosers			42	52	42	51	42	51	41	51	42	52
3	260	ACS SVL	Abitibi Consol. Stephenville	230	No Breaker	1210	1452	1054	1045	1047	1039	1047	1044	1026	1037	1026	1039
3	275	GBY NP	Grand Bay	66	2500			115	130	115	130	115	130	93	111	93	111
3	276	LGL NP	Long Lake	66	Customer-owned			94	93	93	93	93	93	80	84	79	84
3	278	CAM L53	Coney Arm	69	No Breaker			65	67	65	67	65	67	64	66	66	68
3	279	CAM B1	Coney Arm	12.5	Reclosers			29	34	29	34	29	34	29	34	30	35
3	281	RBH NP	Rose Blanche	25	Customer-owned			50	63	50	63	50	63	49	62	49	63
3	285	GBY NPT1	Grand Bay	12.5	Customer-owned			85	94	85	94	85	94	57	70	57	70
3	287	RBH GEN	Rose Blanche	6.9	Customer-owned			57	0	57	0	57	0	56	0	56	0
3	319	DLK NP	Deer Lake	66	No Breaker			714	759	712	757	712	757	707	753	709	757
3	328	STG NPT2	St. Georges	33	Customer-owned			136	132	136	131	136	132	115	118	115	118
3	329	BBK T2	Bottom Brook	66	1500			108	120	108	120	108	120	106	118	106	118
3	330	WHE NP	Wheelers	66	Customer-owned			85	74	85	73	85	74	83	72	83	73
3	331	HAR NP	Harmon	66	Customer-owned			445	402	443	401	443	401	424	391	423	391
3	332	STX NP	Stephenville Crossing	66	Customer-owned			414	356	412	355	412	355	389	344	388	344
3	333	STG NP	St. Georges	66	Customer-owned			263	221	262	221	262	221	243	212	244	212
3	343	LBK NP	Lookout Brook	33	Customer-owned			85	95	85	95	85	95	61	73	61	73
3	350	GAL NP	Gallants	66	Customer-owned			426	381	425	379	424	380	407	371	406	371
3	603	BBK B3	Bottom Brook	138	9560			338	393	336	390	335	390	333	388	334	389
3	604	GBK L50	Grandy Brook	138	No Breaker			163	111	162	110	162	110	161	111	161	111
3	605	GBK NREG	Grandy Brook	25	No Breaker			72	84	72	84	72	84	72	84	72	84
3	609	GBK REG	Grandy Brook	25	Reclosers			69	80	69	80	68	79	70	82	70	82
3	610	BUR NREG	Burgeo	25	No Breaker			35	26	35	26	35	25	35	26	35	26
3	611	BUR REG	Burgeo	25	No Breaker			34	25	34	25	33	24	35	26	35	27
3	612	BURGEO	Burgeo	25	Reclosers			30	21	30	21	30	21	31	22	31	23
3	867	RBK L53	Rattle Brook	69	4570			69	75	69	75	69	75	68	74	69	76
3	870	SLK L80	Star Lake	66	4780			184	219	183	218	183	217	184	218	185	219
3	871	SLK G1	Star Lake	13.8	Customer-owned			162	0	161	0	161	0	161	0	162	0
4	224	BLA L12	Bay L'Argent	138	No Breaker	439	375	435	375	427	368	430	370	416	363	387	351
4	225	LLK NP	Linton Lake	138	Customer-owned	440	466	423	451	416	443	419	446	402	434	363	405
4	232	MKS L12	Monkstown	138	No Breaker	542	464	558	476	548	468	552	470	533	460	510	452
4	282	MKS NPT1	Monkstown	25	No Breaker	124	168	127	171	125	168	125	169	124	168	125	169
4	283	PRV L58	Paradise River	25	Reclosers	74	88	77	92	77	91	77	92	76	91	77	92
4	284	PRV G1	Paradise River	4.2	Reclosers	67	0.01	71	0	70	0	70	0	70	0	71	0
4	359	MSY NP	Marystown	138	Customer-owned	445	481	425	461	418	453	421	456	404	442	362	411
4	360	MSY NPT1	Marystown	12.5	Customer-owned			151	191	152	191	147	185	150	190	149	190
4	361	SPT NP	Salt Pond	66	Customer-owned			277	320	272	315	271	313	271	317	220	269
4	362	LAU NP	Laurentian	66	Customer-owned			212	158	210	157	209	156	202	154	140	127
4	363	GRH NP	Greenhill	12.5	Customer-owned			87	107	86	105	86	106	84	103	76	95
4	364	GRH NP	Greenhill	66	Customer-owned			158	189	156	187	156	187	152	183	123	155
4	365	GAR NP	Garnish	66	Customer-owned			198	175	195	173	195	173	194	172	162	156

Maximum NLH Fault Levels
Before and After HVDC System Addition

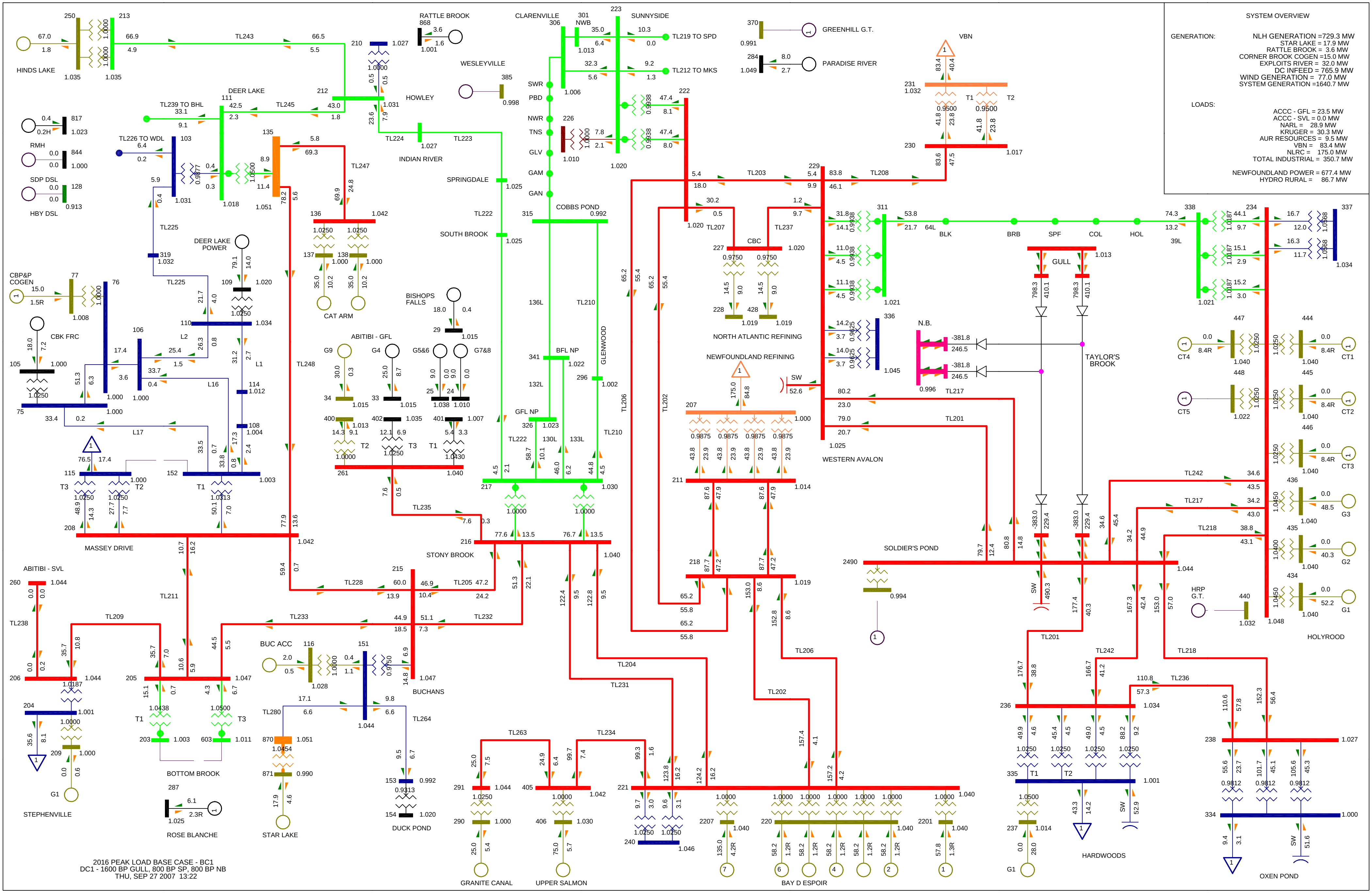
Area	Bus No	Bus Name	Station	Bus Volt kV	Rating MVA	Existing		BC1-DC1		BC2-DC1		BC3-DC1		BC7-DC1		BC8-DC8	
						3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA
4	366	WEB NP	Webbers Cove	66	Customer-owned			181	148	179	147	179	146	174	144	130	123
4	370	GRT GEN	Greenhill	13.8	Customer-owned			91	0	90	0	90	0	88	0	79	0
4	371	SPO NP	Salt Pond	138	Customer-owned	461	498	432	462	425	455	429	457	410	443	362	406
4	372	STL WIND	St. Lawrence Wind	66	Customer-owned			205	143	203	142	202	142	196	140	133	116
4	373	STL WIND	St. Lawrence Wind	25	Customer-owned			181	212	180	211	179	210	179	210	82	105
5	100	BHL B1	Berry Hill	138	5970	385	277	358	266	356	264	354	263	349	262	356	266
5	101	BHL T1	Berry Hill	66	1500			107	153	107	152	106	152	106	151	107	152
5	102	RHR B1	Rocky Harbour	12.5	Reclosers			45	53	45	53	45	53	45	53	45	53
5	107	CHD T1	Cow Head	12.5	Reclosers			36	44	36	44	36	44	36	44	36	44
5	119	CHD B1	Cow Head	66	1490			72	62	71	62	71	62	71	62	72	62
5	120	DHR B1B2	Daniels Harbour	66	1500			85	114	85	114	85	114	83	112	84	113
5	121	PBN B2	Peter's Barren	66	4570	104	149	89	128	88	127	88	127	87	125	87	126
5	124	PPD L27	Parsons Pond	66	No Breaker			68	66	67	66	68	66	67	66	67	66
5	125	HBY B1	Hawke's Bay	66	1500			59	66	59	66	59	66	58	65	58	65
5	127	HBY B2B3	Hawke's Bay	12.5	Reclosers			41	56	41	56	41	56	41	55	40	55
5	129	WDL B1	Wiltondale	66	1430			209	119	208	118	208	118	208	119	209	120
5	130	GLB L29	Glenburnie	66	No Breaker			116	60	115	60	115	60	115	60	116	61
5	132	PPT B2	Plum Point	12.5	Reclosers			61	71	60	71	60	71	60	70	60	71
5	133	PPT B1	Plum Point	138	9560			130	106	129	106	128	106	128	105	131	106
5	134	BCV B1	Bear Cove	138	9560			118	98	117	97	116	98	115	97	118	98
5	139	DHR B3B4	Daniels Harbour	12.5	Reclosers			24	27	24	27	24	27	24	27	24	27
5	140	BCV B2	Bear Cove	12.5	Reclosers			58	68	58	68	58	68	57	68	57	68
5	141	PBN B1	Peter's Barren	138	9560	232	173	200	158	199	157	197	156	195	156	199	158
5	143	PPD T1	Parsons Pond	12.5	Reclosers			15	16	14	16	15	16	14	16	14	16
5	144	WDL T1	Wiltondale	12.5	Reclosers			14	14	14	14	13	14	14	14	14	14
5	147	GLB B1	Glenburnie	12.5	Reclosers			34	38	34	38	34	38	34	38	34	39
5	148	SCV L27	Sally's Cove	66	No Breaker			89	96	89	96	89	96	89	96	89	96
5	150	RHR B1	Rocky Harbour	66	No Breaker			108	58	108	57	107	57	108	58	108	59
5	807	RWC B3	Reddickton Wood Chip	12.5	Reclosers			31	39	31	39	31	39	32	41	31	40
5	808	RWC T2	Reddickton Wood Chip	12.5	Reclosers			32	42	32	41	32	42	32	41	32	41
5	809	RWC B1	Reddickton Wood Chip	69	2630			46	59	45	58	46	59	45	58	45	58
5	815	RMH TAP	Reddickton Mini Hydro	12.5				19	21	19	20	19	20	20	21	20	21
5	816	RMH HV	Reddickton Mini Hydro	12.5	Reclosers			18	19	18	19	18	19	19	20	19	20
5	818	MBK L57	Main Brook	69	No Breakers			52	63	52	62	52	63	51	62	52	63
5	822	STA B1	St. Anthony Airport	69	2380/4570			63	92	63	92	64	93	62	90	63	92
5	846	SDP B1	St. Anthony Diesel Plant	25	Reclosers			40	59	40	58	40	59	40	59	39	58
5	848	SDP L61	St. Anthony Diesel Plant	69	No Breaker			49	59	49	59	49	59	48	58	48	58
5	850	STA L56	St. Anthony Airport	138	No Breaker			102	87	101	87	101	87	100	87	103	87
6	221	BDE TS	Bay d'Espoir	230	5130/5600/5710	3845	4576	4025	4794	3987	4747	4000	4757	3935	4696	3896	4661
6	240	BDE B9	Bay d'Espoir	69	1430	289	299	296	304	291	299	289	296	292	300	294	304
6	241	CRV L20	Conne River	69	No Breaker	201	155	207	159	205	158	204	157	205	158	206	160
6	242	EHW L20	English HR. West	69	No Breaker	113	70	118	71	117	71	117	70	117	71	117	72
6	243	BCX L20	Barachoix	69	No Breaker	100	60	105	62	104	61	103	61	104	62	104	62
6	244	CRV T1	Conne River	12.5	Reclosers			31	33	30	33	30	33	30	33	31	33
6	245	EHW T1	English HR. West	25	Reclosers	42	50	44	52	44	52	44	51	44	52	45	52
6	246	BCX T1	Barachoix	25	Reclosers	62	78	65	82	64	81	64	81	64	81	65	82
6	247	BDE B14	Bay d'Espoir	24	Reclosers			100	115	99	114	99	114	99	114	99	115
6	290	GCL G1	Granite Canal	13.8	1506	414	0.04	417	0	430	0	429	0	424	0	419	0
6	291	GCL L63	Granite Canal	230	No Breaker	861	762	887	779	888	779	887	778	882	775	877	771
6	405	USL L34	Upper Salmon	230	12550/15935	1683	1600	1741	1656	1732	1647	1732	1646	1719	1637	1709	1629
6	406	USL G1	Upper Salmon	13.8	920	861	0.2	884	0	885	0	885	0	874	0	863	0
6	407	USL T2	Upper Salmon	25	Reclosers			94	104	94	104	94	104	93	102	92	101
6	2201	BDP G1	Bay d'Espoir G1	13.8	No Unit Breaker	984	0.13	1025	0	1021	0	1021	0	1025	0	1028	0
6	2207	BDP G7	Bay d'Espoir G7	13.8	No Unit Breaker	2095	0.27	2181	0	2174	0	2176	0	2181	0	2186	0
7	27	ACG GFL	Abitibi Cons. Grand Falls	66	Customer-owned			209	242	208	240	207	239	208	241	209	242

Maximum NLH Fault Levels
Before and After HVDC System Addition

						Existing		BC1-DC1		BC2-DC1		BC3-DC1		BC7-DC1		BC8-DC8	
Area	Bus No	Bus Name	Station	Bus Volt kV	Rating MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA	3P MVA	LG MVA
7	28	ACG BFL	Abitibi Cons. Bishop Falls	66	Customer-owned			184	219	183	219	183	218	184	219	184	220
7	261	ACG GFL	Abitibi Cons. Grand Falls	230	No Breaker	2419	2614	2409	2623	2388	2599	2393	2603	2357	2576	2337	2558
7	400	ACG T2	Abitibi Cons. Grand Falls	13.8	1055			542	19	540	19	541	19	540	19	543	19
8	75	CBPP E	Corner Brook Pulp & Paper	66	Customer-owned			1442	983	1437	980	1436	980	1427	977	1429	979
8	76	CBPP B	Corner Brook Pulp & Paper	66	Customer-owned			1451	984	1446	981	1445	982	1436	979	1439	981
8	106	CBPP D	Corner Brook Pulp & Paper	66	Customer-owned			1445	959	1440	956	1439	956	1429	954	1432	956
8	109	DLP G1-7	Deer Lake Power	6	Customer-owned			686	0	685	0	686	0	683	0	683	0
8	110	DLP B1B4	Deer Lake Power	66	Customer-owned			754	865	752	863	753	863	748	858	750	861
9	153	DPD L64	Duck Pond	66	No Breaker			143	73	141	73	141	72	142	73	143	73
10	2101	CHF A1	Churchill Falls	15	No Unit Breaker			5072	0	5056	0	5072	0	5022	0	4991	0
10	2102	CHF A2	Churchill Falls	15	No Unit Breaker			5386	0	5371	0	5386	0	5338	0	5306	0
10	2103	CHF A3	Churchill Falls	15	No Unit Breaker			5386	0	5371	0	5386	0	5338	0	5306	0
10	2104	CHF A4	Churchill Falls	15	No Unit Breaker			5326	0	5311	0	5326	0	5279	0	5247	0
10	2105	CHF A5	Churchill Falls	15	No Unit Breaker			5326	0	5311	0	5326	0	5279	0	5247	0
10	2106	CHF A6	Churchill Falls	15	No Unit Breaker			5321	0	5306	0	5321	0	5274	0	5242	0
10	2107	CHF A7	Churchill Falls	15	No Unit Breaker			5383	0	5368	0	5383	0	5335	0	5303	0
10	2108	CHF A8	Churchill Falls	15	No Unit Breaker			5329	0	5314	0	5329	0	5282	0	5250	0
10	2109	CHF A9	Churchill Falls	15	No Unit Breaker			5392	0	5376	0	5392	0	5344	0	5311	0
10	2110	CHF A10	Churchill Falls	15	No Unit Breaker			5512	0	5497	0	5512	0	5466	0	5436	0
10	2111	CHF A11	Churchill Falls	15	No Unit Breaker			5448	0	5434	0	5448	0	5403	0	5373	0
10	2115	MUSK G1-4	Muskrat Falls	15	Proposed Station			1725	0	1682	0	1725	0	1586	0	1448	0
10	2121	GUL G1	Gull Island	15	Proposed Station			4784	3709	4682	3629	4784	3709	4454	3451	4395	3313
10	2122	GUL G2	Gull Island	15	Proposed Station			3325	1454	3230	1412	3325	1454	3018	1319	2937	1222
10	2123	GUL G3	Gull Island	15	Proposed Station			3325	1454	3230	1412	3325	1454	3018	1319	2937	1222
10	2124	GUL G4	Gull Island	15	Proposed Station			3325	1454	3230	1412	3325	1454	3018	1319	2937	1222
10	2131	CHF L1301	Churchill Falls	138	No Breaker			688	764	685	760	688	764	678	752	671	744
10	2133	MUSKRAT	Muskrat Falls	138	No Breaker			710	390	694	380	710	390	659	359	599	328
10	2134	MUSKRAT	Muskrat Falls	25	Reclosers			38	0	38	0	38	0	36	0	32	0
10	2135	HVY B13	Happy Valley	138	2637			545	492	534	480	545	492	510	454	467	423
10	2136	HVY B11 B12	Happy Valley	25	1448			379	495	374	488	379	495	362	471	335	438
10	2137	HVY G1	Happy Valley	13.8	n/a			342	267	339	264	342	267	332	258	320	250
10	2141	WTS SC1	Wabush	13.8	n/a			763	539	762	538	763	539	761	538	760	537
10	2142	WTS SC2	Wabush	13.8	n/a			756	544	755	543	756	544	754	542	753	542
10	2307	WABUSH TS	Wabush	230	3500			1758	481	1755	480	1758	481	1749	478	1744	477
10	2308	GUL 230	Gull Island	230	Proposed Station			6124	7829	5969	7631	6124	7829	5620	7182	5784	7196
10	2309	MFA 230	Muskrat Falls	230	Proposed Station			2140	1385	2087	1351	2140	1385	1967	1273	1815	1138
10	2341	GUL T1	Gull Island	230	Proposed Station			5784	6976	5641	6803	5784	6976	5316	6408	5392	6304
10	2342	GUL T2	Gull Island	230	Proposed Station			5542	6746	5400	6573	5542	6746	5079	6180	5140	6072
10	2343	GUL T3	Gull Island	230	Proposed Station			5542	6746	5400	6573	5542	6746	5079	6180	5140	6072
10	2344	GUL T4	Gull Island	230	Proposed Station			5542	6746	5400	6573	5542	6746	5079	6180	5140	6072
10	2461	WTS BUS 1	Wabush	46	1500/2000/2510/1992			1404	0	1402	0	1404	0	1398	0	1396	0
10	2462	WTS BUS 2	Wabush	46	1500/2000/2510/1992			1199	0	1197	0	1199	0	1193	0	1191	0
10	2700	CHF TS	Churchill Falls	735	25000			21922	24565	21879	24496	21922	24565	21831	24386	22088	24536
10	2704	GUL TS	Gull Island	735	Proposed Station			6249	7397	6100	7219	6249	7397	5759	6813	5777	6627

Appendix E

Power Flow Case Diagrams



SYSTEM OVERVIEW

GENERATION:

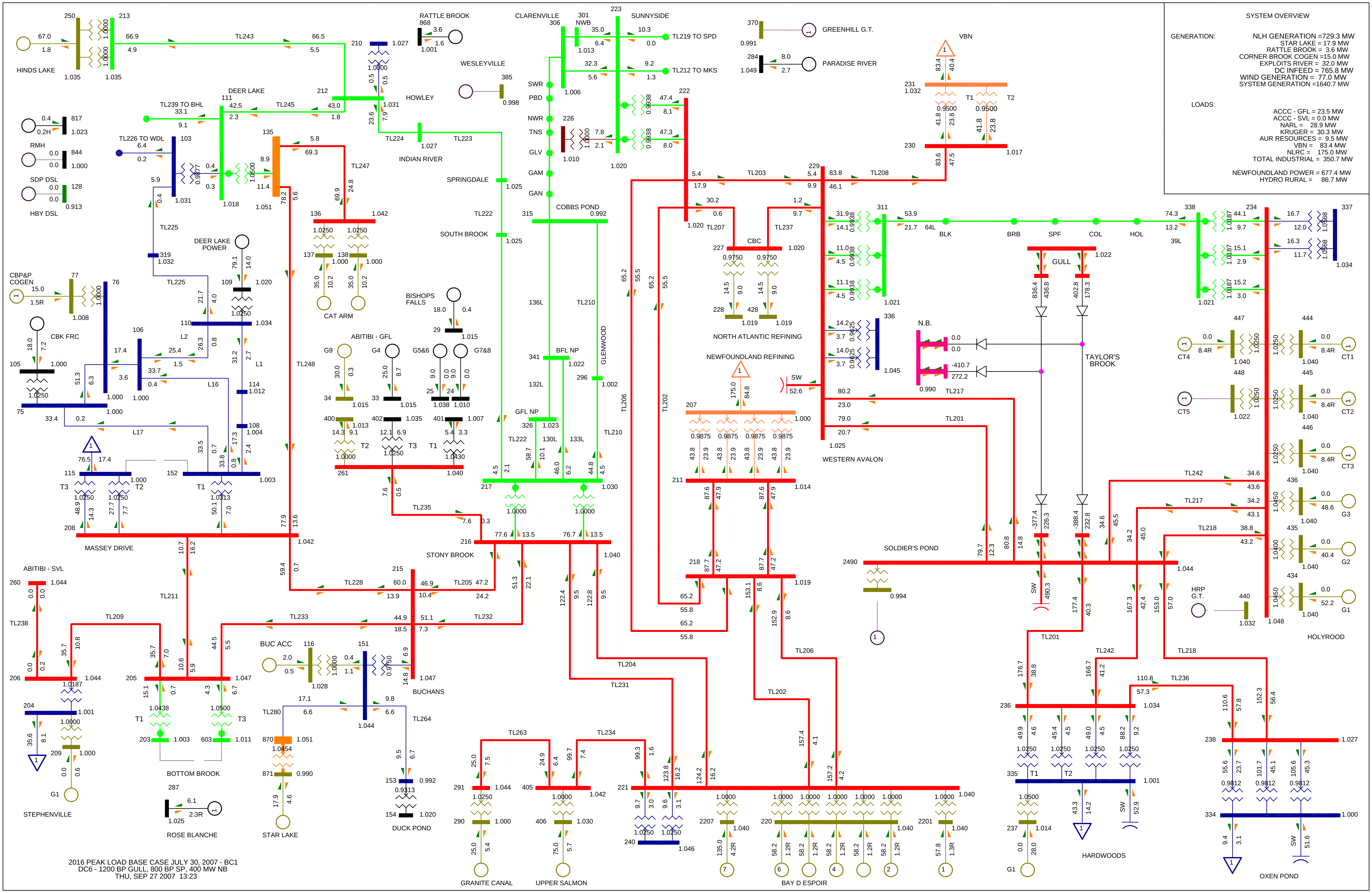
NLH GENERATION =729.3 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 765.9 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1640.7 MW

LOADS:

ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.3 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.7 MW

NEWFOUNDLAND POWER = 677.4 MW
HYDRO RURAL = 86.7 MW

2016 PEAK LOAD BASE CASE - BC1
DC1 - 1600 BP GULL, 800 BP SP, 800 BP NB
THU, SEP 27 2007 13:22



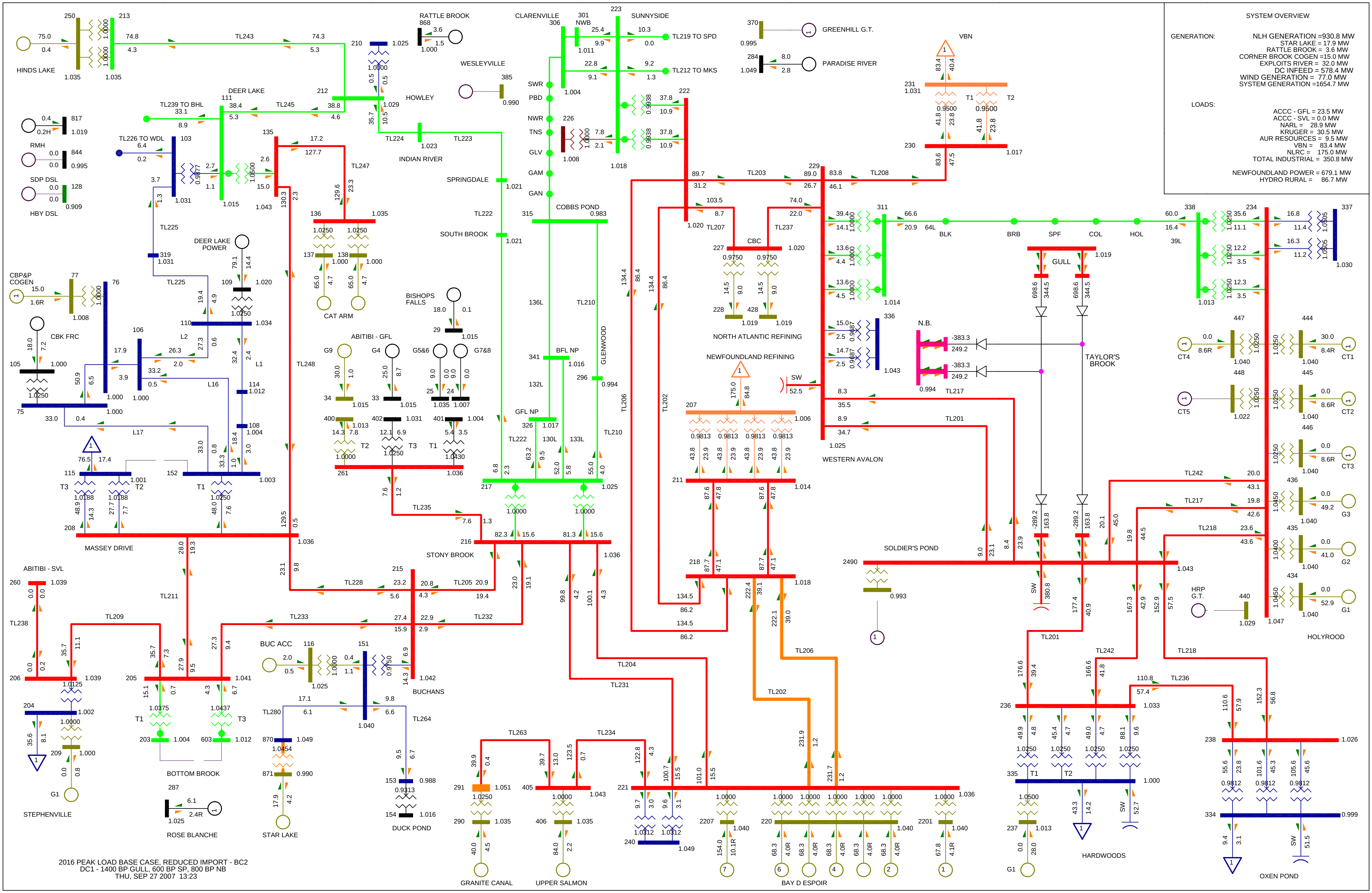
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =729.3 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 765.8 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1640.7 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.3 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.7 MW

NEWFOUNDLAND POWER = 677.4 MW
HYDRO RURAL = 86.7 MW

2016 PEAK LOAD BASE CASE JULY 30, 2007 - BC1
DC6 - 1200 BP GULL, 800 BP SP, 400 MW NB
THU, SEP 27 2007 13:23



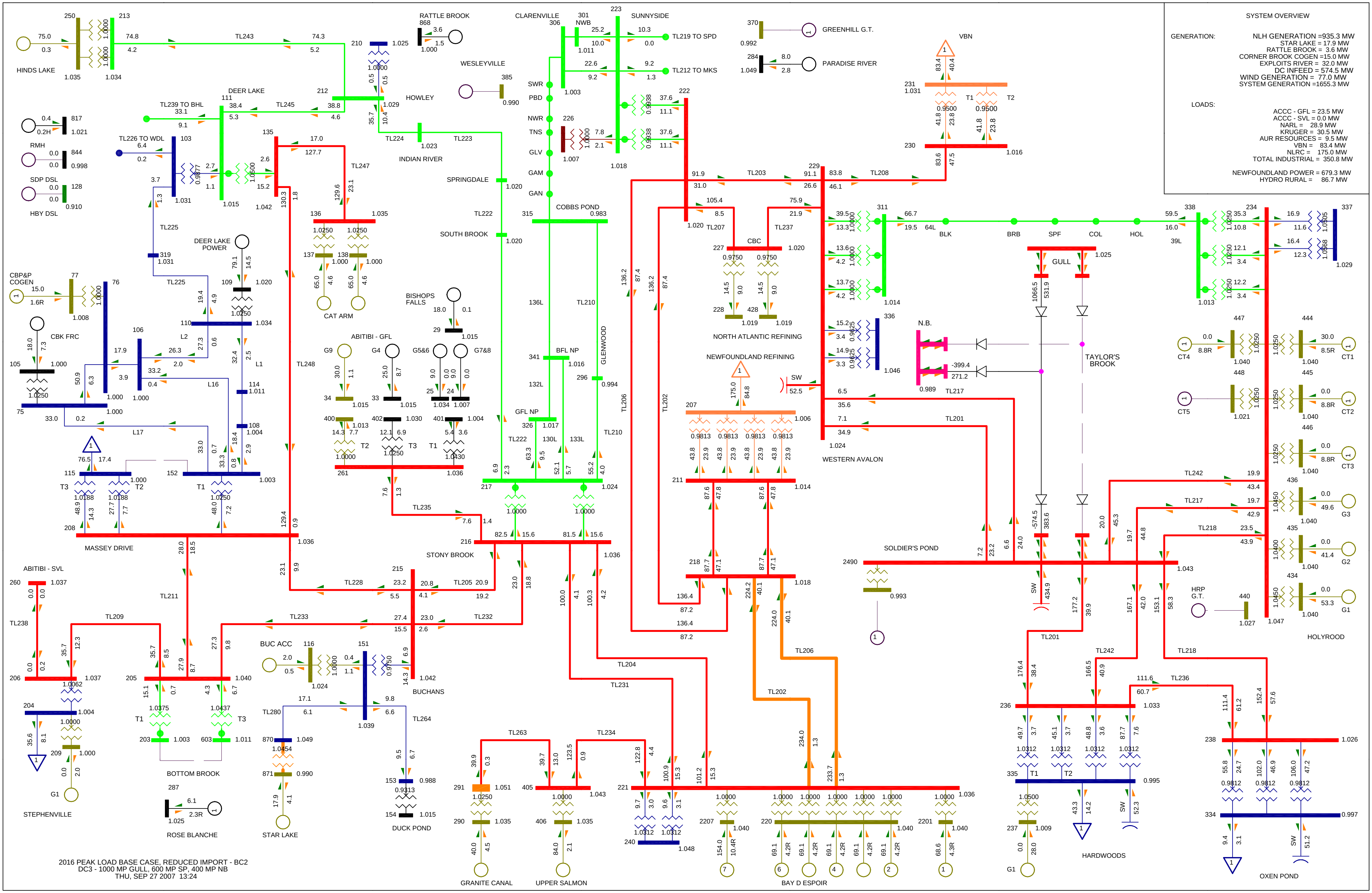
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =930.8 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 578.4 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1654.7 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.5 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.8 MW

NEWFOUNDLAND POWER = 679.1 MW
HYDRO RURAL = 86.7 MW

2016 PEAK LOAD BASE CASE, REDUCED IMPORT - BC2
DC1 - 1400 BP GULL, 600 BP SP, 800 BP NB
THU, SEP 27 2007 13:23



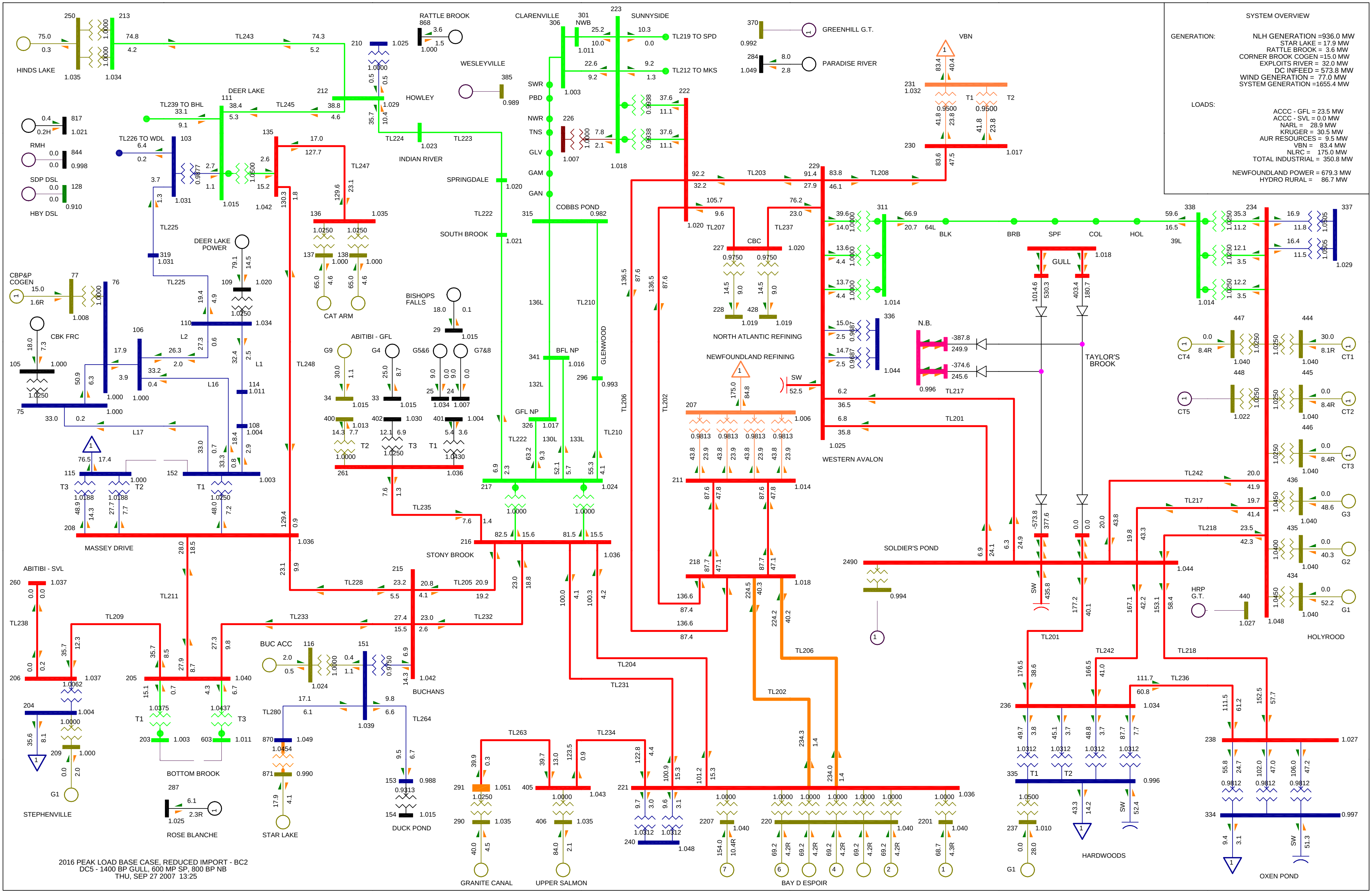
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =935.3 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 574.5 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1655.3 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.5 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.8 MW

NEWFOUNDLAND POWER = 679.3 MW
HYDRO RURAL = 86.7 MW

2016 PEAK LOAD BASE CASE, REDUCED IMPORT - BC2
DC3 - 1000 MP GULL, 600 MP SP, 400 MP NB
THU, SEP 27 2007 13:24



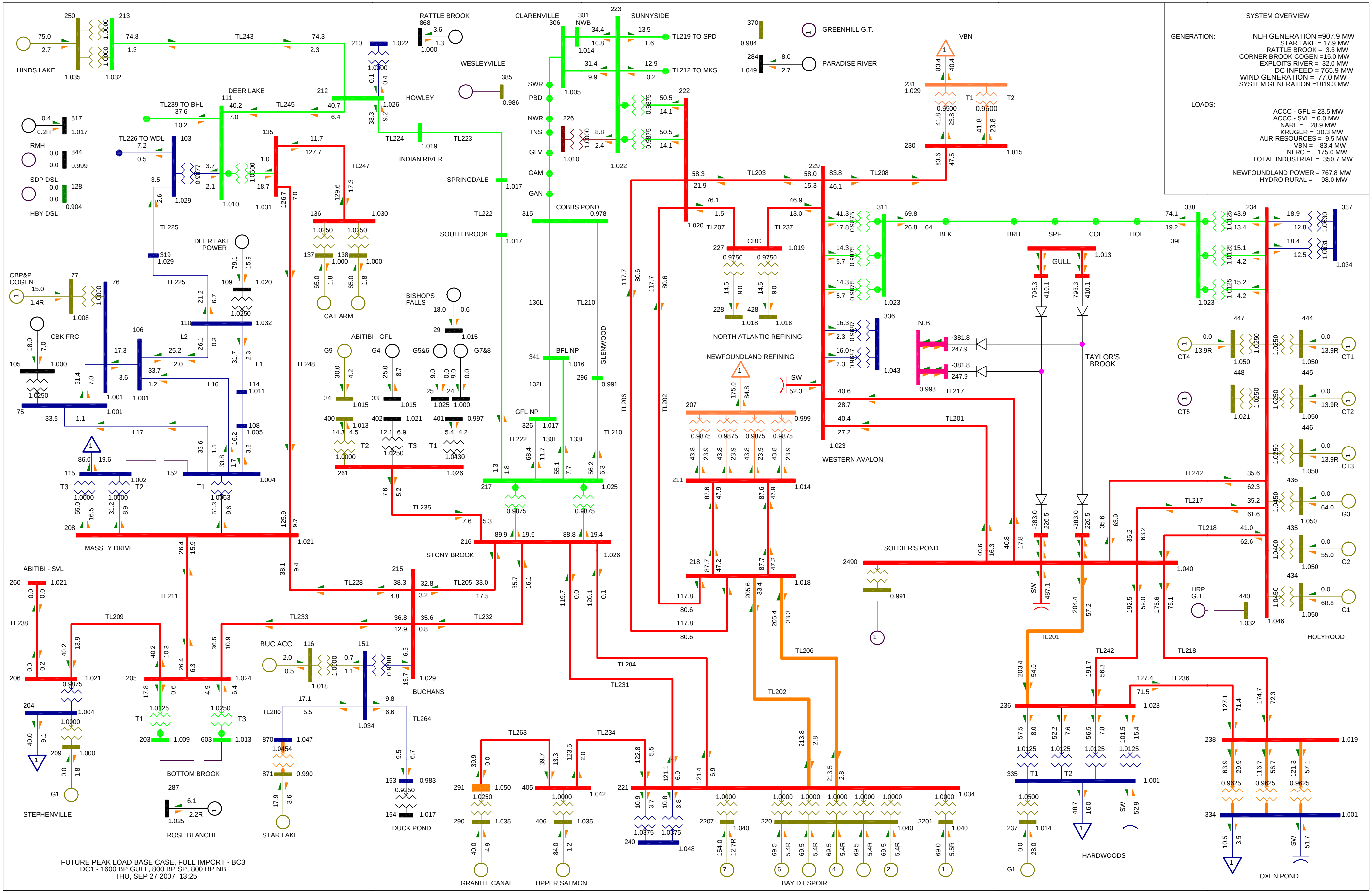
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =936.0 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 573.8 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1655.4 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.5 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.8 MW

NEWFOUNDLAND POWER = 679.3 MW
HYDRO RURAL = 86.7 MW

2016 PEAK LOAD BASE CASE, REDUCED IMPORT - BC2
DC5 - 1400 BP GULL, 600 MP SP, 800 BP NB
THU, SEP 27 2007 13:25



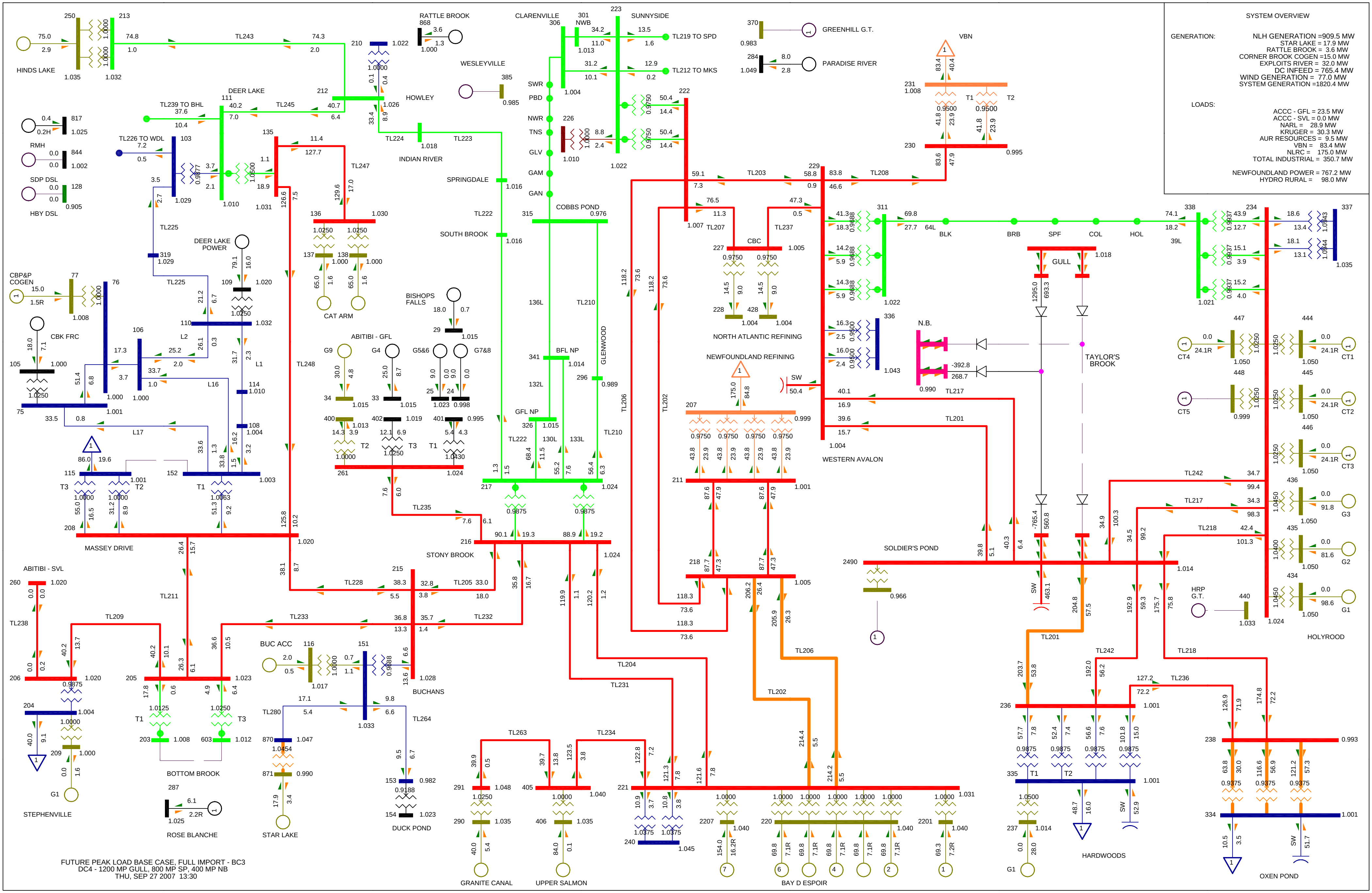
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =907.9 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 765.9 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1819.3 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.3 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.7 MW

NEWFOUNDLAND POWER = 767.8 MW
HYDRO RURAL = 98.0 MW

FUTURE PEAK LOAD BASE CASE, FULL IMPORT - BC3
DC1 - 1600 BP GULL, 800 BP SP, 800 BP NB
THU, SEP 27 2007 13:25

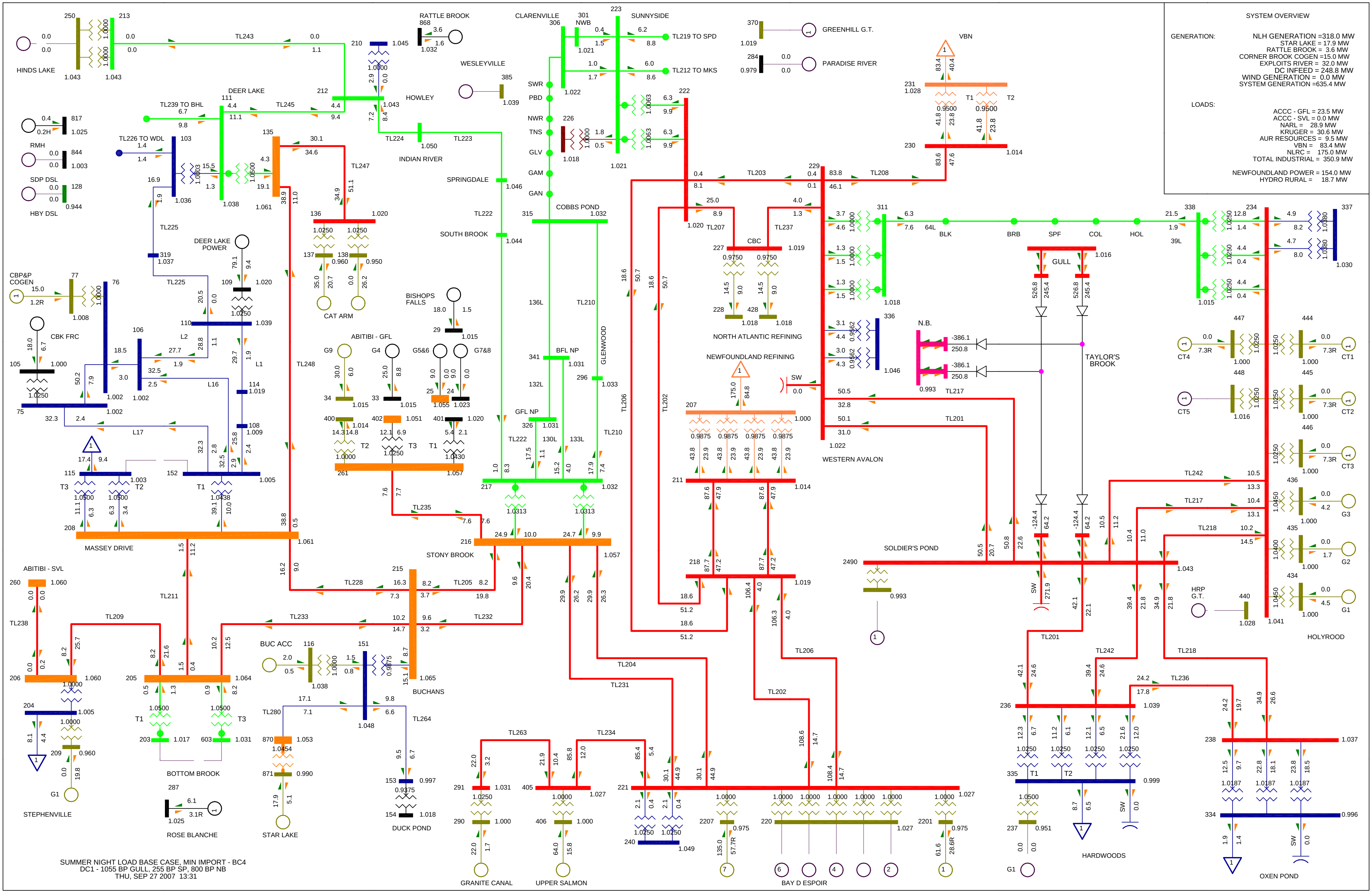


SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =909.5 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 765.4 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1820.4 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.3 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.7 MW

NEWFOUNDLAND POWER = 767.2 MW
HYDRO RURAL = 98.0 MW



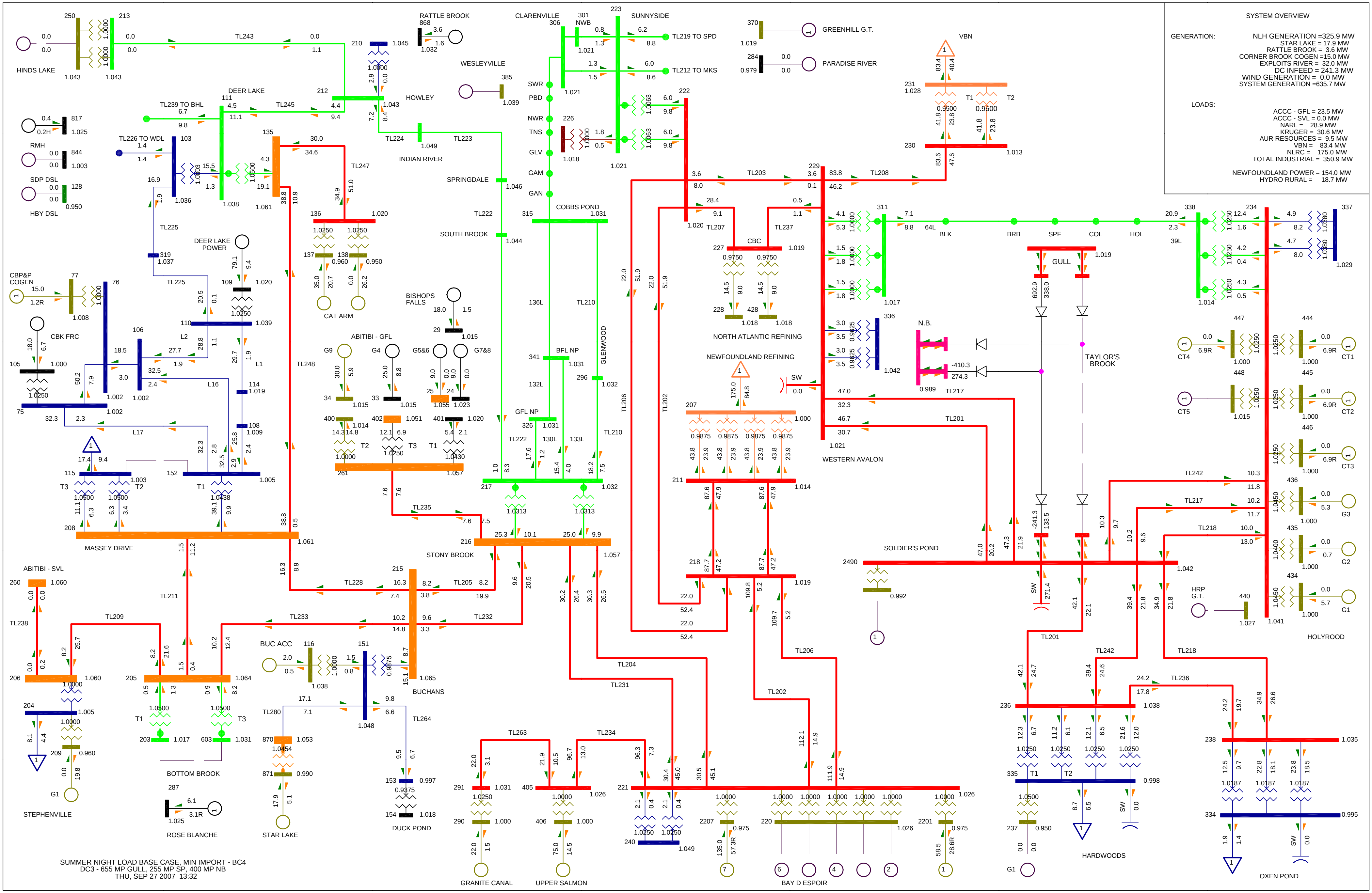
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =318.0 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 248.8 MW
WIND GENERATION = 0.0 MW
SYSTEM GENERATION =635.4 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.6 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.9 MW

NEWFOUNDLAND POWER = 154.0 MW
HYDRO RURAL = 18.7 MW

SUMMER NIGHT LOAD BASE CASE, MIN IMPORT - BC4
DC1 - 1055 BP GULL, 255 BP SP, 800 BP NB
THU, SEP 27 2007 13:31



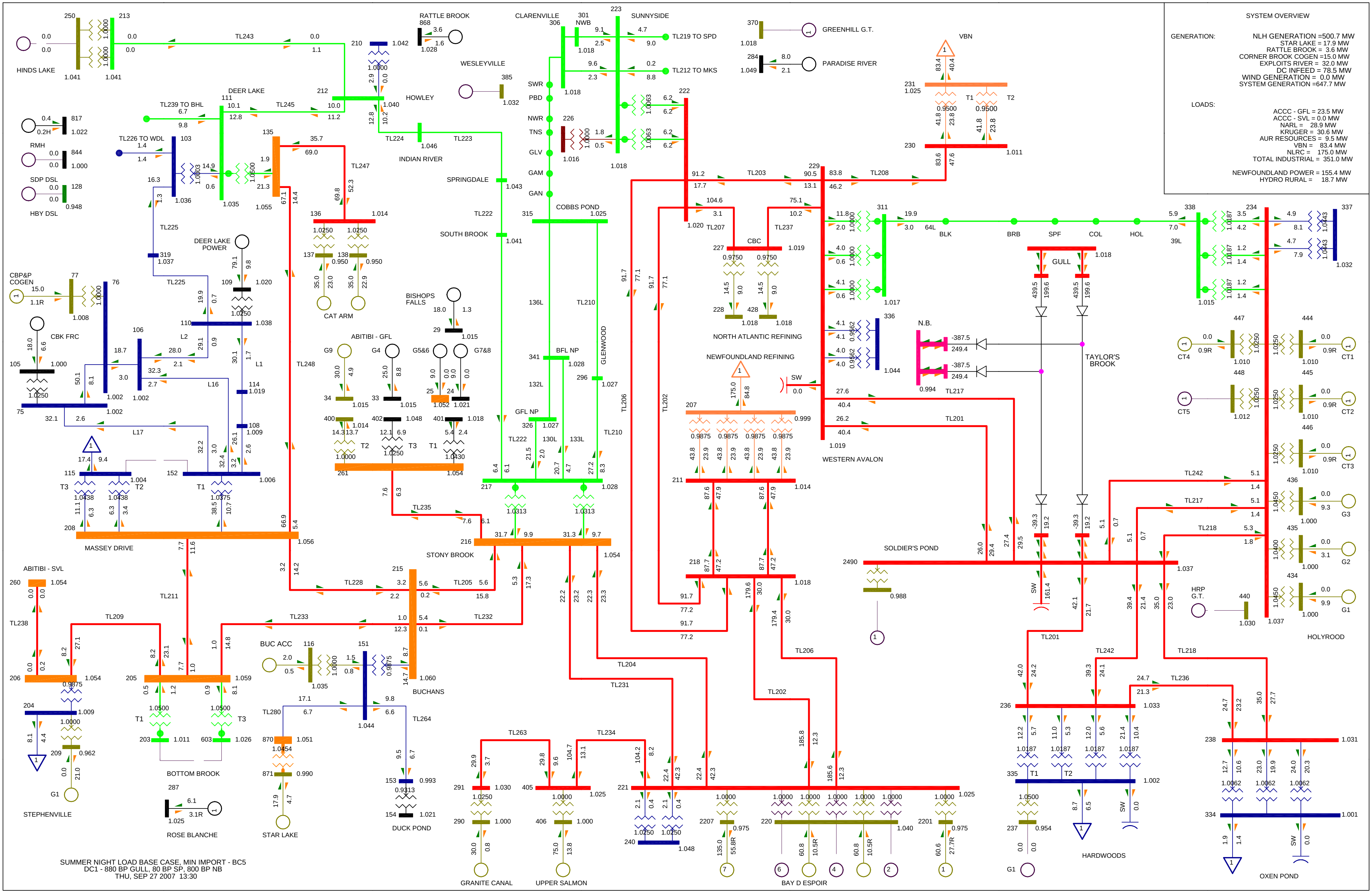
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =325.9 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 241.3 MW
WIND GENERATION = 0.0 MW
SYSTEM GENERATION =635.7 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.6 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.9 MW

NEWFOUNDLAND POWER = 154.0 MW
HYDRO RURAL = 18.7 MW

SUMMER NIGHT LOAD BASE CASE, MIN IMPORT - BC4
DC3 - 655 MP GULL, 255 MP SP, 400 MP NB
THU, SEP 27 2007 13:32



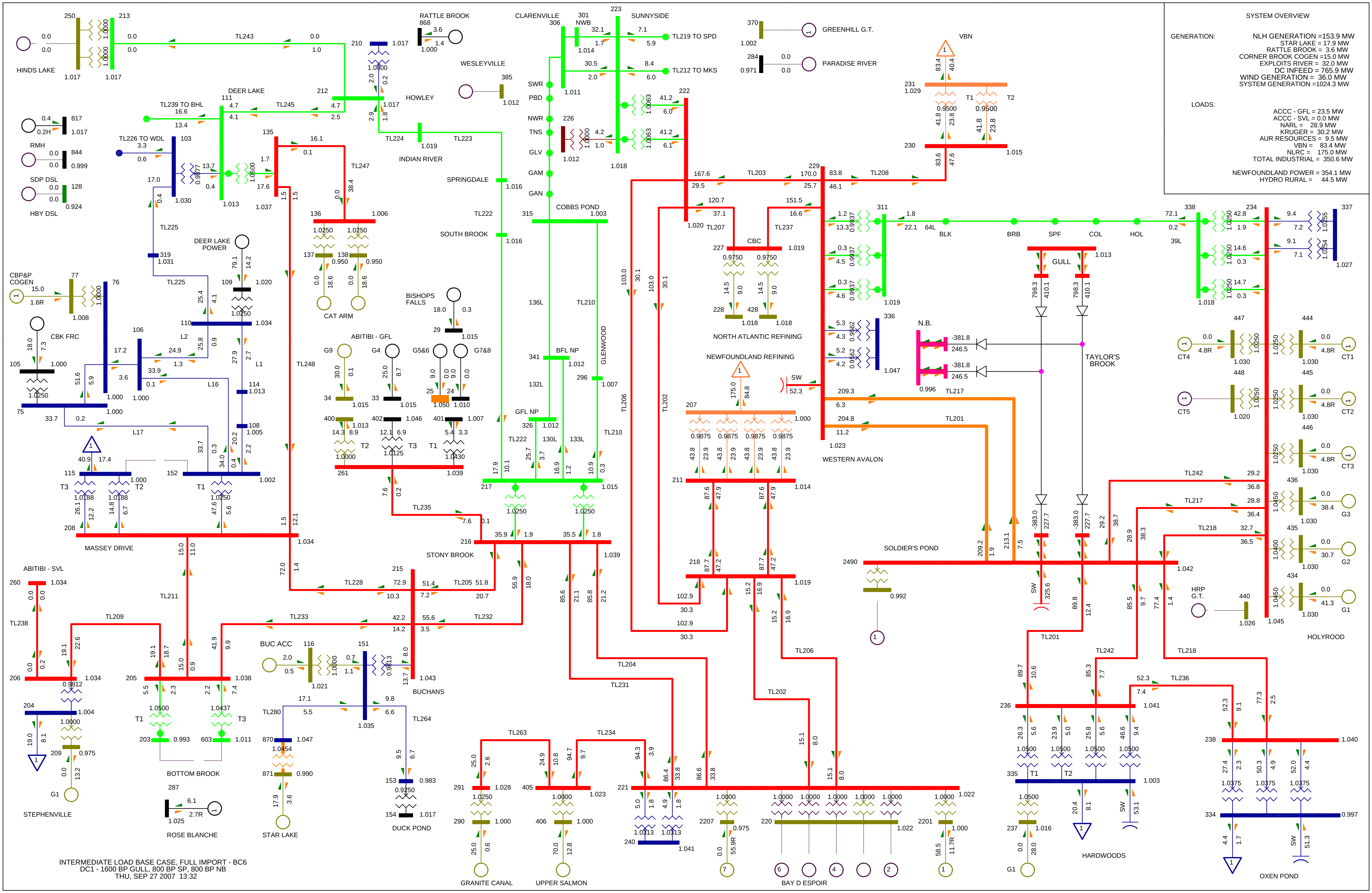
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =500.7 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 78.5 MW
WIND GENERATION = 0.0 MW
SYSTEM GENERATION =647.7 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.6 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 351.0 MW

NEWFOUNDLAND POWER = 155.4 MW
HYDRO RURAL = 18.7 MW

SUMMER NIGHT LOAD BASE CASE, MIN IMPORT - BC5
DC1 - 880 BP GULL, 80 BP SP, 800 BP NB
THU, SEP 27 2007 13:30



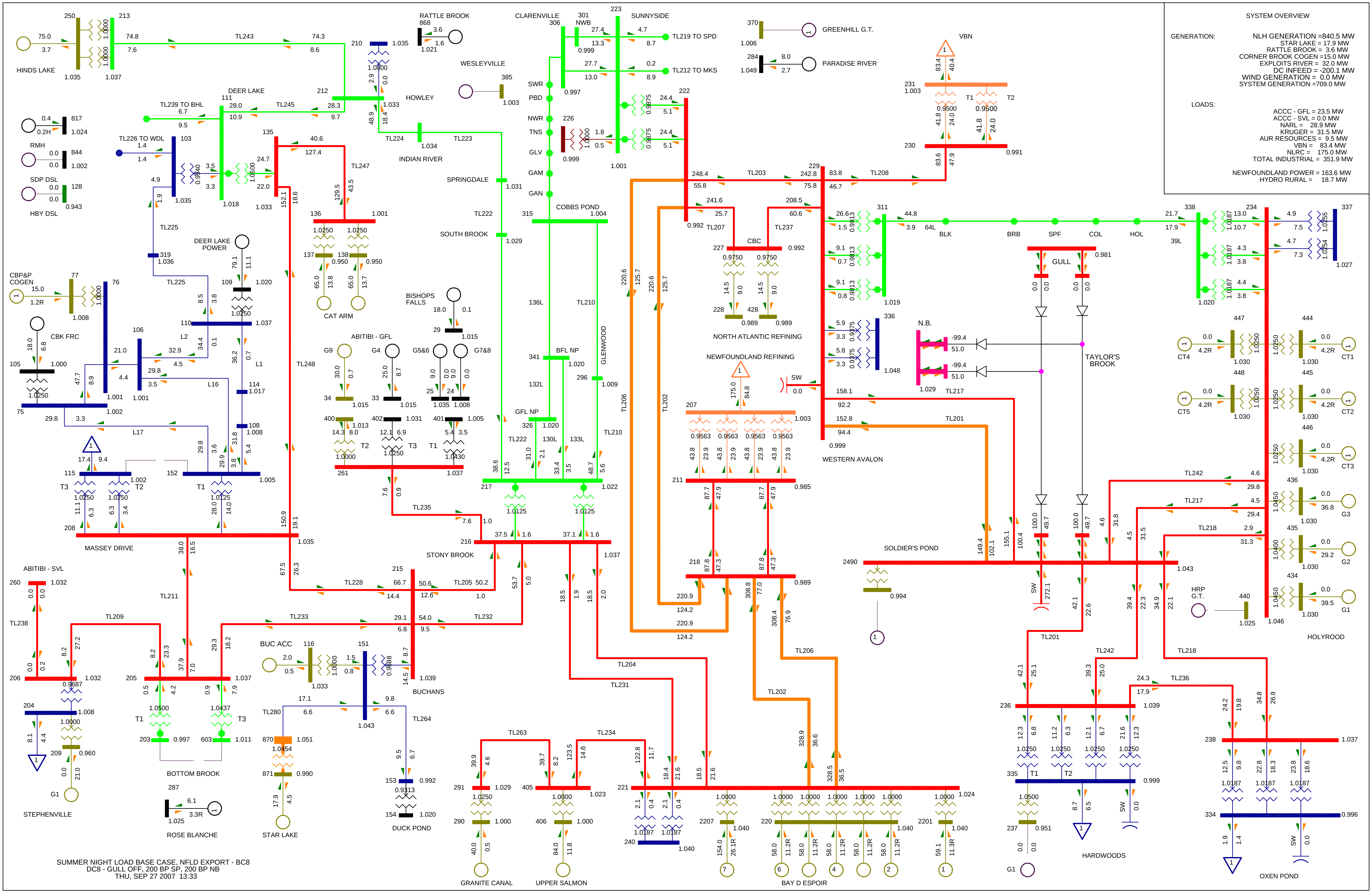
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =153.9 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 765.9 MW
WIND GENERATION = 36.0 MW
SYSTEM GENERATION =1024.3 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.2 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.6 MW

NEWFOUNDLAND POWER = 354.1 MW
HYDRO RURAL = 44.5 MW

INTERMEDIATE LOAD BASE CASE, FULL IMPORT - BC6
DC1 - 1600 BP GULL, 800 BP SP, 800 BP NB
THU, SEP 27 2007 13:32



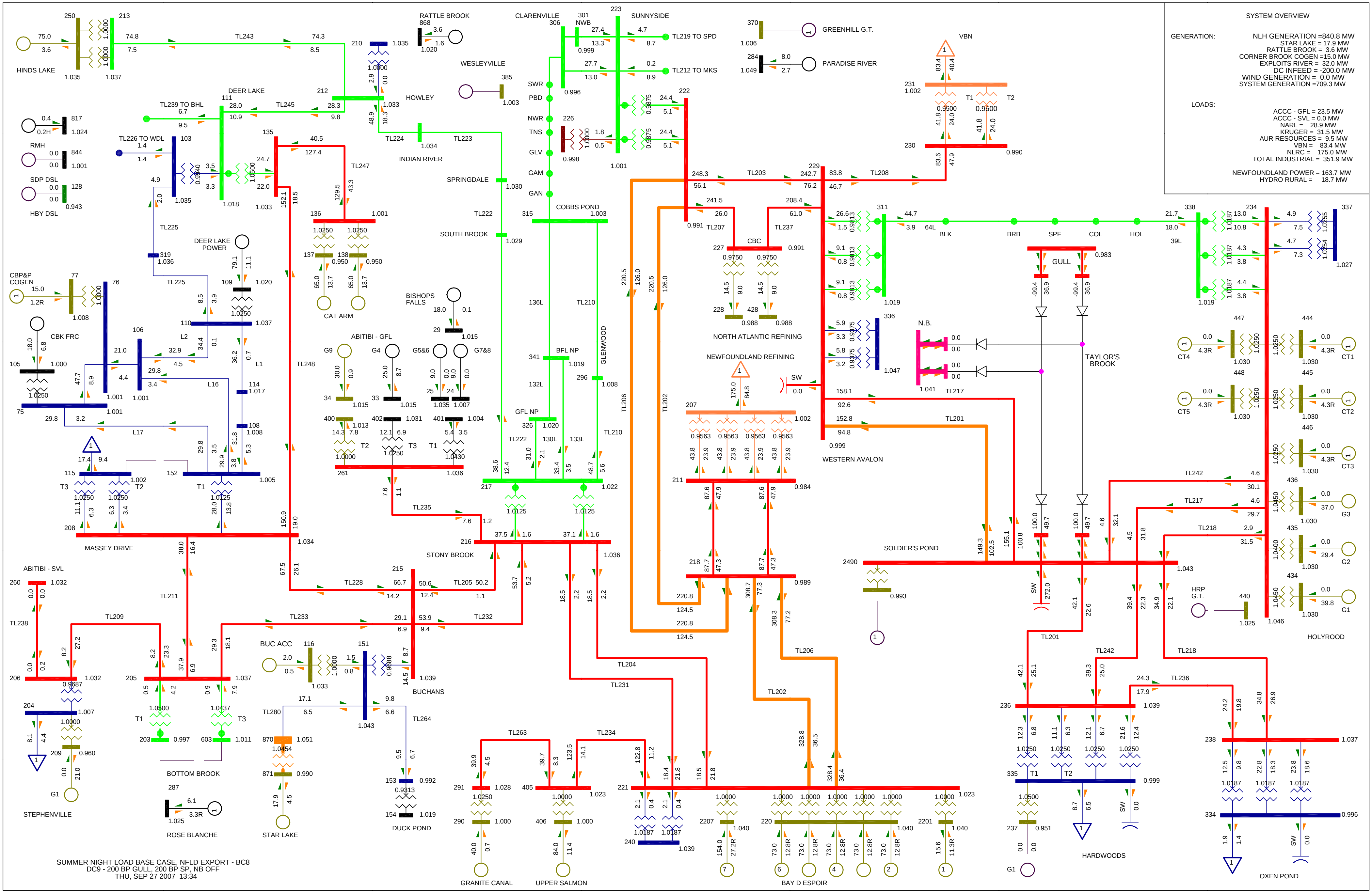
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =840.5 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = -200.1 MW
WIND GENERATION = 0.0 MW
SYSTEM GENERATION =709.0 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 31.5 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 351.9 MW

NEWFOUNDLAND POWER = 163.6 MW
HYDRO RURAL = 18.7 MW

SUMMER NIGHT LOAD BASE CASE, NFLD EXPORT - BC8
DC8 - GULL OFF, 200 BP SP, 200 BP NB
THU, SEP 27 2007 13:33



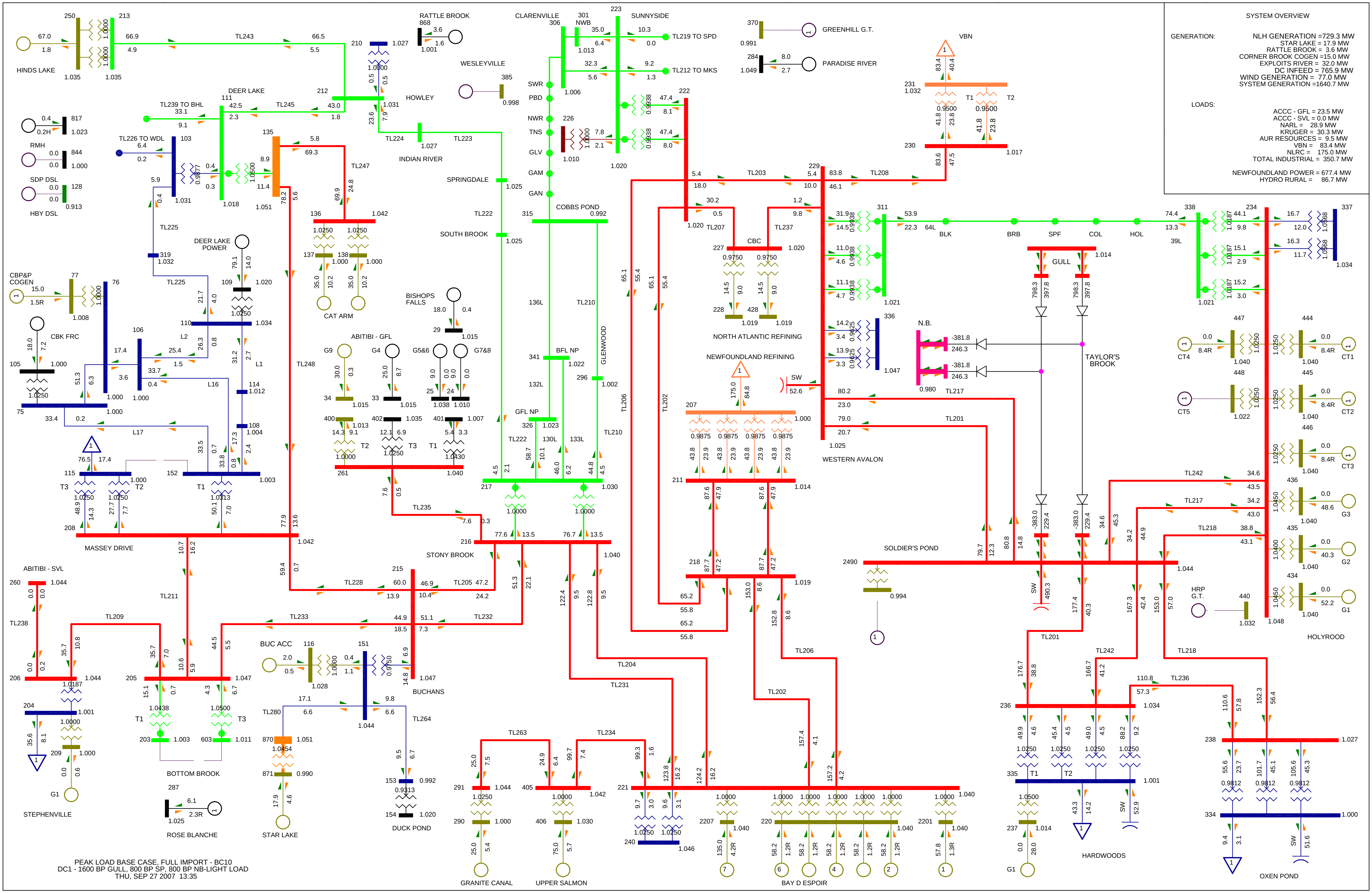
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =840.8 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = -200.0 MW
WIND GENERATION = 0.0 MW
SYSTEM GENERATION =709.3 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 31.5 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 351.9 MW

NEWFOUNDLAND POWER = 163.7 MW
HYDRO RURAL = 18.7 MW

SUMMER NIGHT LOAD BASE CASE, NFLD EXPORT - BC8
DC9 - 200 BP GULL, 200 BP SP, NB OFF
THU, SEP 27 2007 13:34



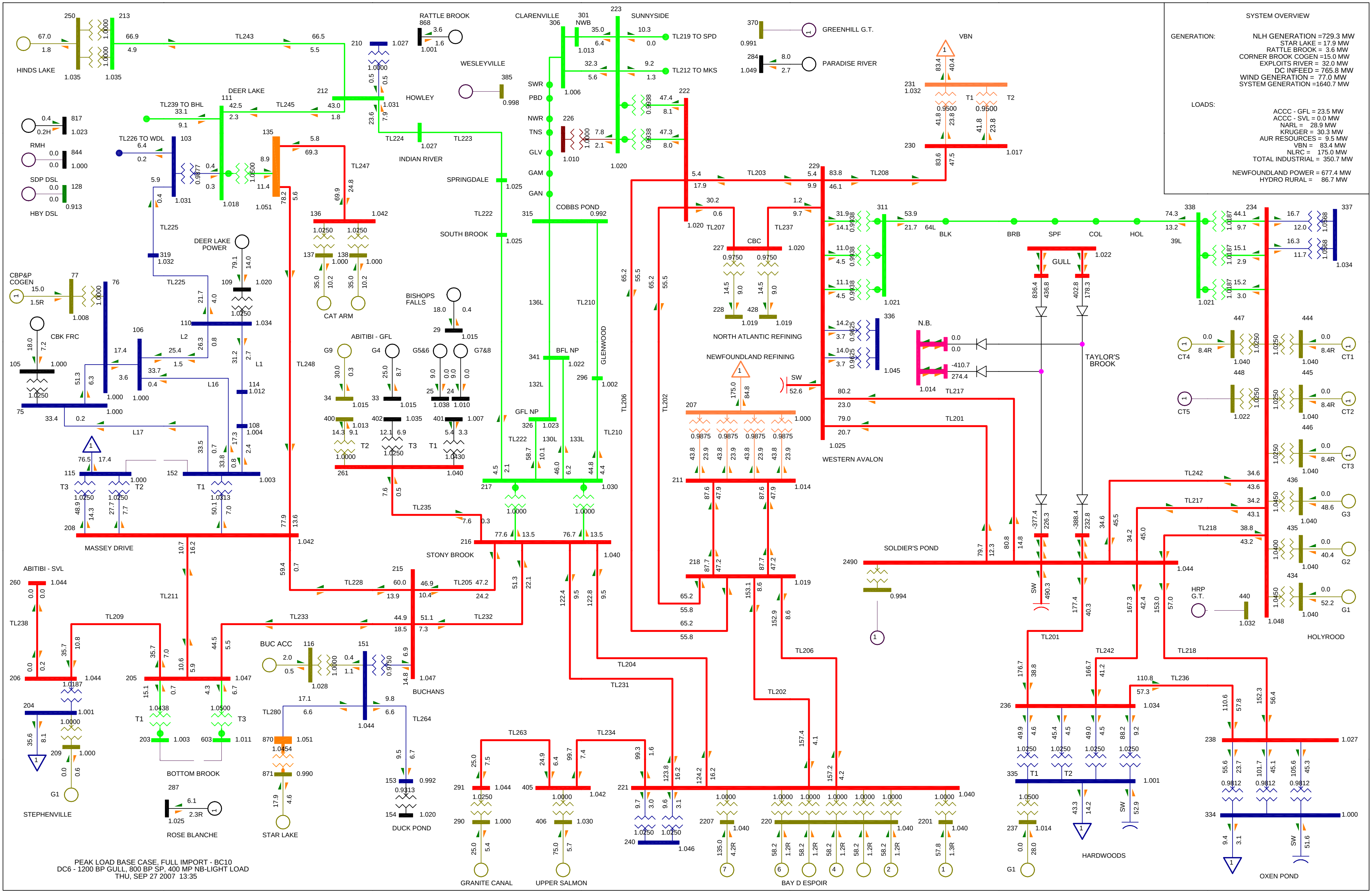
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =729.3 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 765.9 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1640.7 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.3 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.7 MW

NEWFOUNDLAND POWER = 677.4 MW
HYDRO RURAL = 86.7 MW

PEAK LOAD BASE CASE, FULL IMPORT - BC10
DC1 - 1600 BP GULL, 800 BP SP, 800 BP NB-LIGHT LOAD
THU, SEP 27 2007 13:35



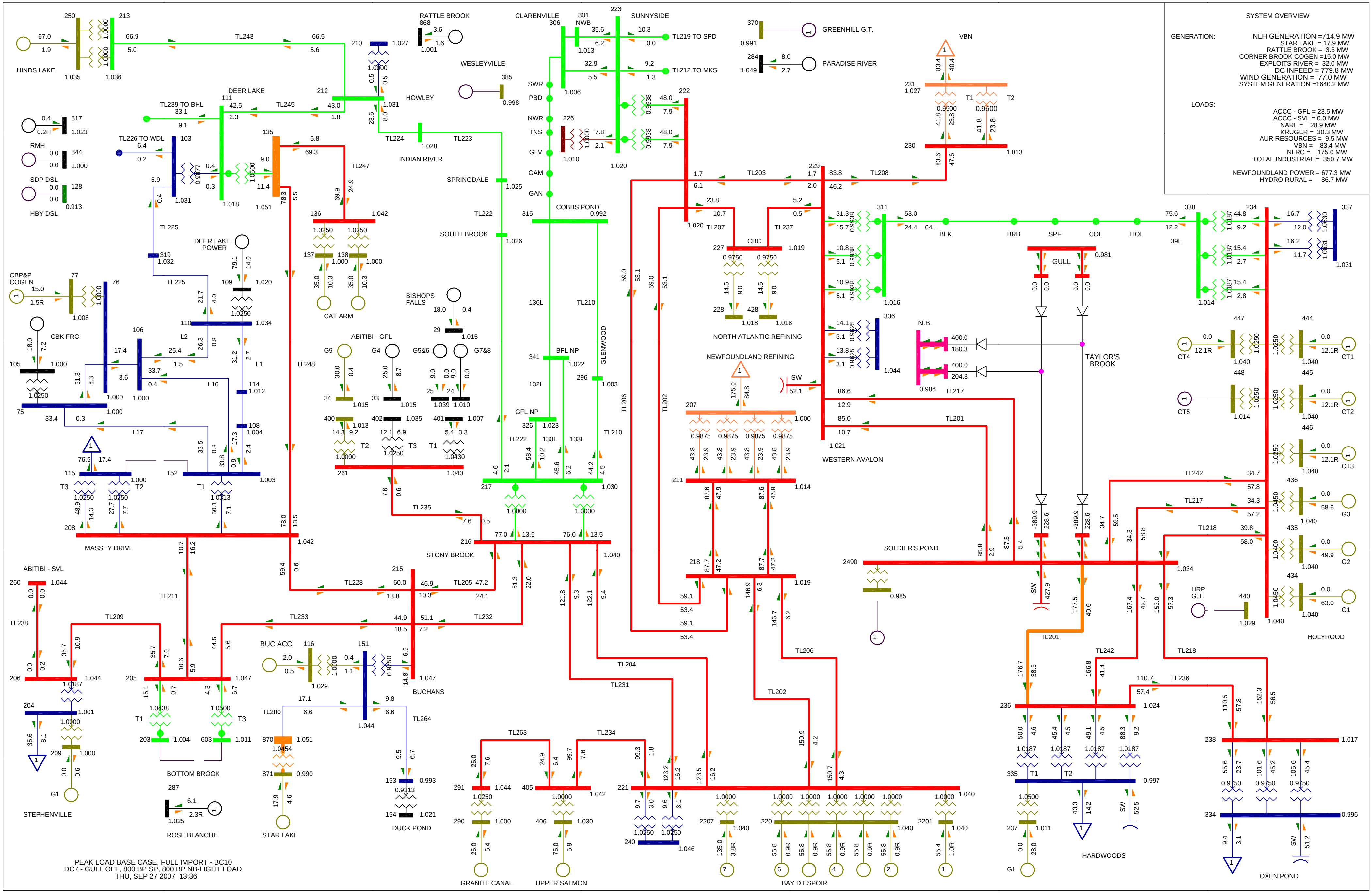
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =729.3 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 765.8 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1640.7 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.3 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.7 MW

NEWFOUNDLAND POWER = 677.4 MW
HYDRO RURAL = 86.7 MW

PEAK LOAD BASE CASE, FULL IMPORT - BC10
DC6 - 1200 BP GULL, 800 BP SP, 400 MP NB-LIGHT LOAD
THU, SEP 27 2007 13:35



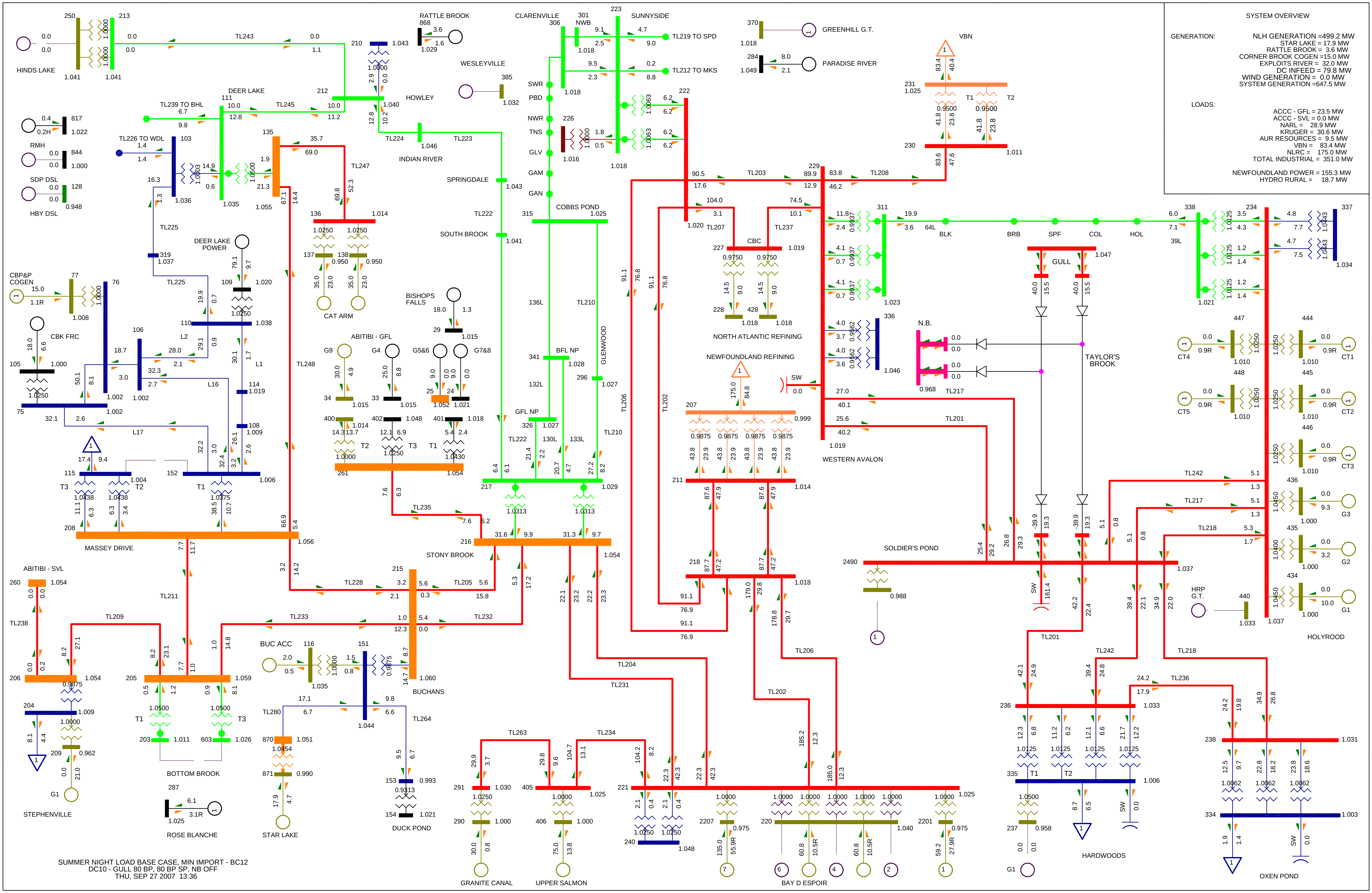
SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =714.9 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 779.8 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1640.2 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.3 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.7 MW

NEWFOUNDLAND POWER = 677.3 MW
HYDRO RURAL = 86.7 MW

PEAK LOAD BASE CASE, FULL IMPORT - BC10
DC7 - GULL OFF, 800 BP SP, 800 BP NB-LIGHT LOAD
THU, SEP 27 2007 13:36



SYSTEM OVERVIEW

GENERATION:

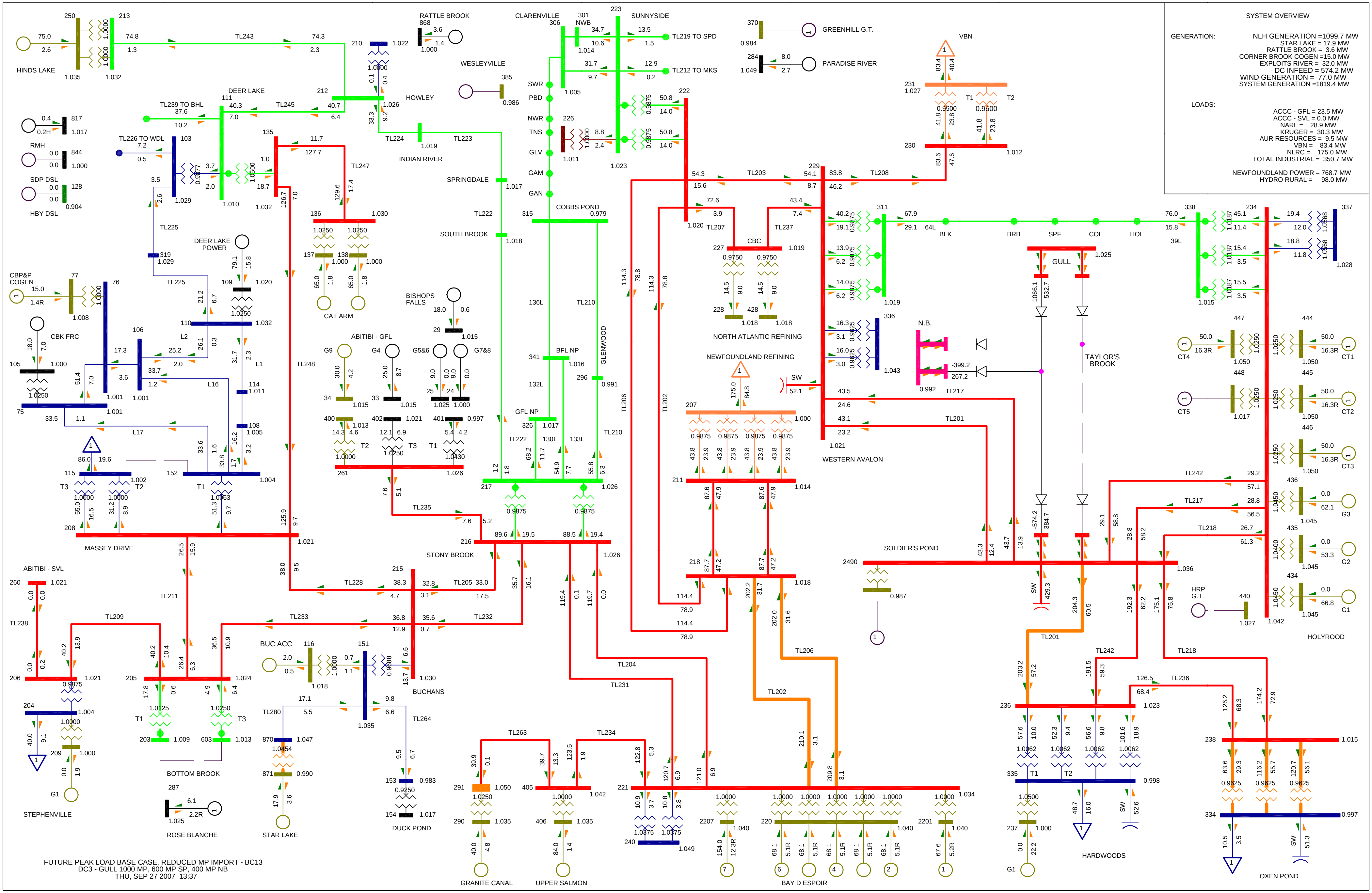
NLH GENERATION =499.2 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 79.8 MW
WIND GENERATION = 0.0 MW
SYSTEM GENERATION =647.5 MW

LOADS:

ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.6 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 351.0 MW

NEWFOUNDLAND POWER = 155.3 MW
HYDRO RURAL = 18.7 MW

SUMMER NIGHT LOAD BASE CASE, MIN IMPORT - BC12
DC10 - GULL 80 BP, 80 BP SP, NB OFF
THU, SEP 27 2007 13:36



SYSTEM OVERVIEW

GENERATION:
NLH GENERATION =1099.7 MW
STAR LAKE = 17.9 MW
RATTLE BROOK = 3.6 MW
CORNER BROOK COGEN =15.0 MW
EXPLOITS RIVER = 32.0 MW
DC INFEED = 574.2 MW
WIND GENERATION = 77.0 MW
SYSTEM GENERATION =1819.4 MW

LOADS:
ACCC - GFL = 23.5 MW
ACCC - SVL = 0.0 MW
NARL = 28.9 MW
KRUGER = 30.3 MW
AUR RESOURCES = 9.5 MW
VBN = 83.4 MW
NLRC = 175.0 MW
TOTAL INDUSTRIAL = 350.7 MW

NEWFOUNDLAND POWER = 768.7 MW
HYDRO RURAL = 98.0 MW

FUTURE PEAK LOAD BASE CASE, REDUCED MP IMPORT - BC13
DC3 - GULL 1000 MP, 600 MP SP, 400 MP NB
THU, SEP 27 2007 13:37

Appendix F

New Brunswick Power Injection Assessment

(Please refer to Attachment 1 for the corresponding set of plots.)

Results on New Brunswick system not included in Public version

Attachment 1

Set of Plots Corresponding to Appendix F