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# System Impact Assessment Report

## CONNECTION ASSESSMENT & APPROVAL PROCESS

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Issue 1.0

**Final Report**

**Project:** Cornwall Interconnection

**Applicant:** Canadian Niagara Power Inc.

*CAA ID 2004-176*

Transmission Assessments & Performance Department

February 15, 2008

**REPORT**

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**SYSTEM IMPACT ASSESSMENT REPORT**  
**For**  
**Cornwall Interconnection**

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**System Impact Assessment Report**

115 kV Interconnection between Cornwall and Hydro One

**Acknowledgement**

The IESO wishes to acknowledge the assistance of Hydro One in completing this assessment.

**Disclaimers**

**IESO**

This report has been prepared solely for the purpose of assessing whether the connection applicant's proposed connection with the IESO-controlled grid would have an adverse impact on the reliability of the integrated power system and whether the IESO should issue a notice of approval or disapproval of the proposed connection under Chapter 4, section 6 of the Market Rules.

Approval of the proposed connection is based on information provided to the IESO by the connection applicant and the transmitter(s) at the time the assessment was carried out. The IESO assumes no responsibility for the accuracy or completeness of such information, including the results of studies carried out by the transmitter(s) at the request of the IESO. Furthermore, the connection approval is subject to further consideration due to changes to this information, or to additional information that may become available after the approval has been granted. Approval of the proposed connection means that there are no significant reliability issues or concerns that would prevent connection of the proposed facility to the IESO-controlled grid. However, connection approval does not ensure that a project will meet all connection requirements. In addition, further issues or concerns may be identified by the transmitter(s) during the detailed design phase that may require changes to equipment characteristics and/or configuration to ensure compliance with physical or equipment limitations, or with the Transmission System Code, before connection can be made.

This report has not been prepared for any other purpose and should not be used or relied upon by any person for another purpose. This report has been prepared solely for use by the connection applicant and the IESO in accordance with Chapter 4, section 6 of the Market Rules. The IESO assumes no responsibility to any third party for any use, which it makes of this report. Any liability which the IESO may have to the connection applicant in respect of this report is governed by Chapter 1, section 13 of the Market Rules. In the event that the IESO provides a draft of this report to the connection applicant, you must be aware that the IESO may revise drafts of this report at any time in its sole discretion without notice to you. Although the IESO will use

its best efforts to advise you of any such changes, it is the responsibility of the connection applicant to ensure that it is using the most recent version of this report.

## **HYDRO ONE**

### **Special Notes and Limitations of Study Results**

The results reported in this study are based on the information available to Hydro One, at the time of the study, suitable for a preliminary assessment of a new generation or load connection proposal.

The short circuit and thermal loading levels have been computed based on the information available at the time of the study. These levels may be higher or lower if the connection information changes as a result of, but not limited to, subsequent design modifications or when more accurate test measurement data is available.

This study does not assess the short circuit or thermal loading impact of the proposed connection on facilities owned by other load and generation (including OPGI) customers.

In this study, short circuit adequacy is assessed only for Hydro One breakers and does not include other Hydro One facilities. The short circuit results are only for the purpose of assessing the capabilities of existing Hydro One breakers and identifying upgrades required to incorporate the proposed connection. These results should not be used in the design and engineering of new facilities for the proposed connection. The necessary data will be provided by Hydro One and discussed with the connection proponent upon request.

The ampacity ratings of Hydro One facilities are established based on assumptions used in Hydro One for power system planning studies. The actual ampacity ratings during operations may be determined in real-time and are based on actual system conditions, including ambient temperature, wind speed and facility loading, and may be higher or lower than those stated in this study.

The additional facilities or upgrades which are required to incorporate the proposed connection have been identified to the extent permitted by a preliminary assessment under the current IESO Connection Assessment and Approval process. Additional facility studies may be necessary to confirm constructability and the time required for construction. Further studies at more advanced stages of the project development may identify additional facilities that need to be provided or that require upgrading.

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# SIA Findings

## Summary

Canadian Niagara Power Inc. is proposing to establish a parallel operation of the IESO-controlled grid, Cornwall Electric, New York and Cedars systems. Canadian Niagara Power intends to accomplish this with phase shifter(s) between St. Lawrence and Rosemount that will limit the flow to 100 MW.

This System Impact Assessment has examined the impact of parallel operation of the IESO-controlled grid, Cornwall Electric, New York and Cedars systems on the reliability of the IESO-controlled grid for an Ontario-Cornwall interconnection. Three possible interconnection configurations were evaluated: (1) single phase shifter in series with L5C interconnection, (2) single phase shifter in series with upgraded L5C interconnection and (3) double phase shifter interconnection.

The IESO has completed all necessary studies based on the preliminary information provided by the proponent. The IESO will proceed with a Post System Impact Assessment at the discretion of the proponent once more project details become available.

## Conclusions

The following are the conclusions for a single phase shifter in series with L5C interconnection:

1. The proposed configuration would result in a reduction in transfer capability at St. Lawrence during high L33P/L34P imports and exports. A special protection scheme rejecting L5C for the loss of L33P and L34P would be required to address the transfer capability reduction. The phase shifting transformer for this configuration must be rated at no less than 100 MVA and must be able to provide an operating angle range of at least  $\pm 40^\circ$ .

To prevent overloads on L5C for loss of L33P or loss L34P (single contingency), flows on L5C would need to be limited pre-contingency.

The following is the conclusion for a single phase shifter in series with an upgraded L5C interconnection:

1. Upgrading L5C to a 1192.5 ACSR 54/19 conductor with a continuous rating of 275 MVA in series with a transformer would allow full range of operation on L5C and L33P and L34P. The upgrade in L5C will require a phase shifter with a continuous rating of at least 275 MVA and angle range of at least  $\pm 40^\circ$ .

The following is the conclusion for a double phase shifter interconnection:

1. Configuring a two phase shifter two line interconnection consisting of the existing L5C line and a new L6C line of conductor type 605 ACSR 54/7, continuously rated for 200 MVA, would allow full range operation on the Cornwall interconnection and L33P and L34P. This configuration would require L5C and L6C phase shifters with continuous ratings of at least 100 MVA and 200 MVA respectively and angle ranges of at least  $\pm 40^\circ$ .

## **IESO's Requirements**

The following are required to initiate the Post-System Impact Assessment process with the IESO:

1. The connection applicant is required to provide the IESO a committed in-service date.
2. The connection applicant is to inform the IESO on a committed phase shifter configuration.
3. The connection applicant is required to provide new equipment specifications and design information to be used in the Post SIA studies.

The following are *tentative* requirements for connection should the Post System Impact Assessment process be initiated. A finalized list of requirements would be developed in the Post System Impact Assessment report.

1. The connection applicant is required to provide data necessary for the short circuit studies to be performed by Hydro One at the request of the IESO.
2. The connection applicant is required to initiate the Customer Impact Assessment process with Hydro One.
3. The connection applicant is required to verify ratings of the existing circuits from Cedars-Dennison lines to Rosemount and upgrade the circuits if necessary.
4. The connection applicant is required to ensure that the performance of the equipment that is eventually supplied and installed is similar or exceeds the predicted performance observed in the simulation results.
5. The connection applicant must ensure that all equipment and facilities being connected to the IESO-controlled grid adhere to the reliability standards set forth in the Market Rules regarding frequency and voltage variations. All equipment shall be capable of continuously operating in the range between 59.5 Hz - 60.5 Hz and equipment must be able to operate in the range 113 kV – 127 kV.
6. Phase Shifting Transformer(s) must have a continuous rating greater or equal to the continuous rating of the line it is connected to in series. The phase shifting transformer(s) must provide an operating range of at least  $\pm 40$  degrees. Operation of the phase shifter must be directed by the IESO only. Therefore, tap changes are not permissible unless directed by the IESO.
7. If a decision is made to configure the existing L5C line in series with a transformer, a cross-tripping scheme is required to trip L5C for the loss of L33P and L34P under high import/export scenarios. In order to comply with IESO criteria, this special protection scheme will have to be fully redundant and with separate communication paths. The scheme will need to meet the 'Special Protection System Criteria', as detailed in the NPCC Document A-11. Any SPS will require concurrence from New York. Studies by NYISO will be required as well as an agreement from both Ontario and New York.
8. Prior to connection, the connection applicant must demonstrate to the satisfaction of the IESO that the proposed connection will not result in any existing equipment in Ontario exceeding its rating.
9. Prior to connection, the connection applicant must demonstrate to the satisfaction of the IESO that any required changes to the IESO-Canadian Niagara Power Operating Agreement have been acquired.

10. Prior to connection, the connection applicant must demonstrate to the satisfaction of the IESO that all required permits for parallel operation between the IESO and the New York ISO have been obtained from the National Energy Board (NEB).
11. Prior to connection, the connection applicant must successfully complete the IESO's market entry process. All necessary permits and operating agreements must be in place prior to making this new parallel between Ontario, Quebec and New York.
12. The registration of the new facilities will need to be completed through the IESO facility registration process before any part of the facility can be placed in-service. It is required that the applicant initiates the facility registration process with the IESO at least six months prior to connection. It must be noted that if the data supplied for the registration of the facilities materially differ from those that were used for the assessment, then some of the analysis might need to be repeated to ensure that the IESO-controlled grid is not adversely affected.

## System Impact Assessment Report

# 1. Project Description

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Canadian Niagara Power Inc. (CNP) is the Local Distribution Company operating transmission and distribution (T&D) assets in the Cornwall area. CNP is a subsidiary of Fortis Ontario. Cornwall Electric (CE), the CNP distribution system at Cornwall, is presently supplied by and connected to the Cedars system, a subsidiary of Hydro Quebec. Cornwall Electric can also be supplied by the New York ISO grid. CNP is planning to expand their transmission system and interconnection to Ontario and New York.

As part of this plan, CNP has obtained a conditional approval from the IESO (CAA ID 2004-161) to transfer up to 100 MW of load to St. Lawrence TS via a radial connection provided by the 115 kV circuit L5C and a new circuit extension built on existing towers along the Rosemount, McConnell, Adolphus and Courtaulds substations. L5C is presently idle; the in-service date of this connection has currently been deferred by CNP until further notice. Although CNP has been approved for only 100 MW of load, historical data indicate that Cornwall Electric could potentially reach up to 140 MVA in the winter.

As phase two of the plan, Canadian Niagara Power Inc. is proposing to establish a parallel operation of the IESO-controlled grid, Cornwall Electric, New York and Cedars systems. Canadian Niagara Power intends to accomplish this with phase shifter(s) between St. Lawrence and Rosemount that will limit the flow to 100 MW.

The connection applicant retained Acres International (Acres) to conduct a preliminary transmission planning studies for Cornwall system. A report was prepared by Acres that contains analysis of the Cornwall tie power flows.

This System Impact Assessment (SIA) study examines the impact of the proposed interconnection on the reliability of the IESO-controlled grid and equipment requirements for the connection. As a starting point, this assessment examines a connection consisting of a single phase shifter in series with the existing L5C circuit. As this connection arrangement may pose thermal limitations, this SIA will also recommend and evaluate several other alternatives.

– End of Section –

## 2. System Description and Connection Arrangement

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### 2.1 Interconnections between Ontario and New York

The IESO controlled grid is synchronously connected with New York system at Niagara and St. Lawrence.

The Ontario – New York Niagara interconnection provides supply to 60 Hz and 25 Hz systems via circuits at various voltage levels. The supply to the 60 Hz system, is provided by two 230/345 kV circuits (PA301 and PA302), two 230 kV circuits (PA27, BP76) and one 115 kV circuit. The 25 Hz system is supplied, via one 115/69 kV circuit and one 69 kV circuit.

The Ontario – New York St. Lawrence interconnection consists of two 230 kV circuits, L33P and L34P. The interconnection is under the control of phase angle regulators. The limit on this interconnection is about 400 MW for flows into or out of Ontario, which is constrained by thermal limitations.

### 2.2 Interconnections between Ontario – Quebec

The Ontario – Quebec North Interconnection consists of two 115 kV circuits. For flows into Ontario from radial generation, the limit is 84 MW under winter conditions and 65 MW under summer conditions. This interconnection is constrained by thermal limitations.

For flows out of Ontario, the limit is 110 MW in the winter and 95 MW in the summer. Ontario and Quebec North are not synchronously connected.

The Ontario – Quebec South Interconnection consists of one 230/345 kV circuit, four 230 kV circuits and two 115 kV circuits. For flows into Ontario, the interconnection is limited to 1,498 MW due to stability limitations and available radial generation. For flows out of Ontario, the limits are 617 MW for the summer and 637 MW for the winter, due to stability and thermal limitations. Ontario and Quebec South are not synchronously connected.

### 2.3 Cornwall Electric System

The Cornwall Electric system consists of six transmission stations: Rosemount, McConnell, Aldolphus, Loyalist, ICI, Courtaulds and Boundary. The ICI substation was recently de-commissioned and the remaining load was transferred to Rosemount.

The 2005 Cornwall Electric peak demand data under summer and winter conditions are shown in **Table 1**.

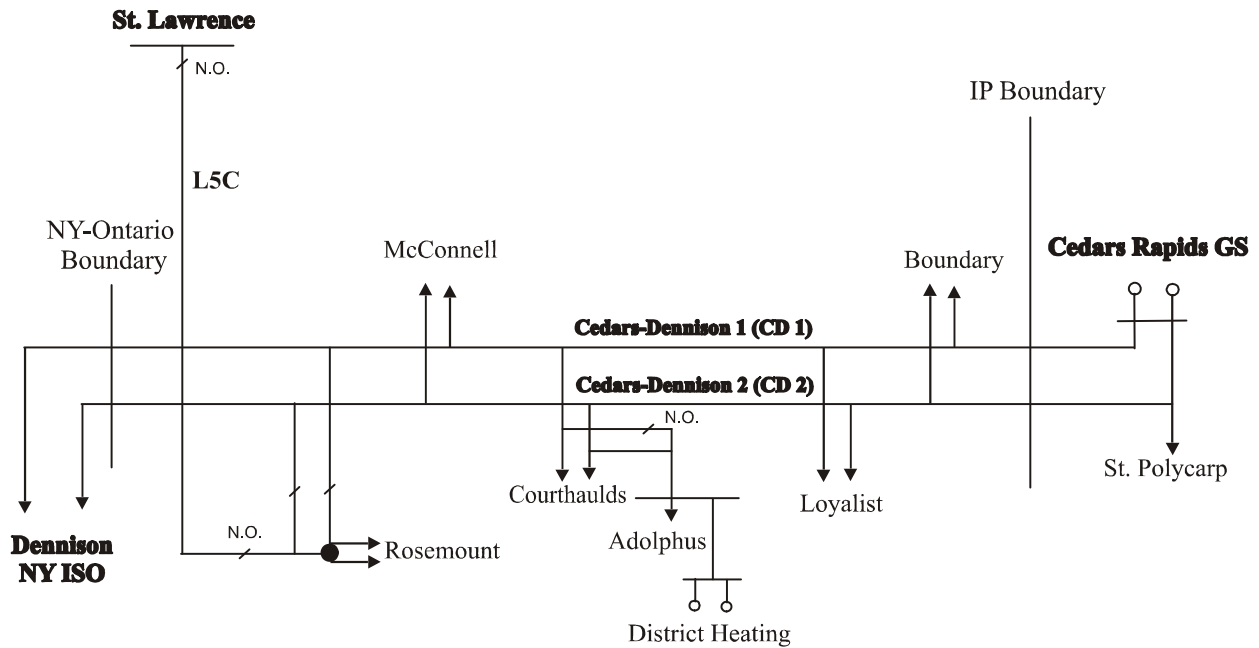
**Table 1. CE System 2005 Peak Loads**

Substation	Summer		Winter	
	MW	Mvar	MW	Mvar
<b>Aldolphus</b>	14.2	4.6	11.9	4.75
<b>Courthaulds</b>	34.2	12.5	36.6	12.9
<b>Loyalist</b>	16.0	4.3	18.1	4.4
<b>McConnell</b>	17.6	3.3	22.5	7.8
<b>Rosemount</b>	31.2	15.5	38.8	12.8
<b>Boundary</b>	2.6	0.4	1.1	0.6
<b>Total</b>	115.8	40.6	129.0	43.25

Cornwall load is currently supplied by the Hydro Quebec’s Des Cedres generating station and the New York system via two normally closed circuits Cedars-Dennison 1 (CD1) and Cedars-Dennison 2 (CD 2). These lines are 230 kV circuits operating at 115 kV.

Under a conditional approval (CAA ID 2004-161), up to 100 MW of Cornwall load can be supplied by St. Lawrence TS via a radial connection of the 115 kV circuit L5C; Cedars GS and New York would be required to supply the remaining load. In this arrangement, the Cedars GS bus is required to be split with CD 1 radially connected to the Hydro One transmission and CD 2 connected to the New York ISO.

A schematic diagram of the 115 kV transmission systems in the Cornwall area is shown in **Figure 1**.



**Figure 1. Cornwall Electric 115 kV System**

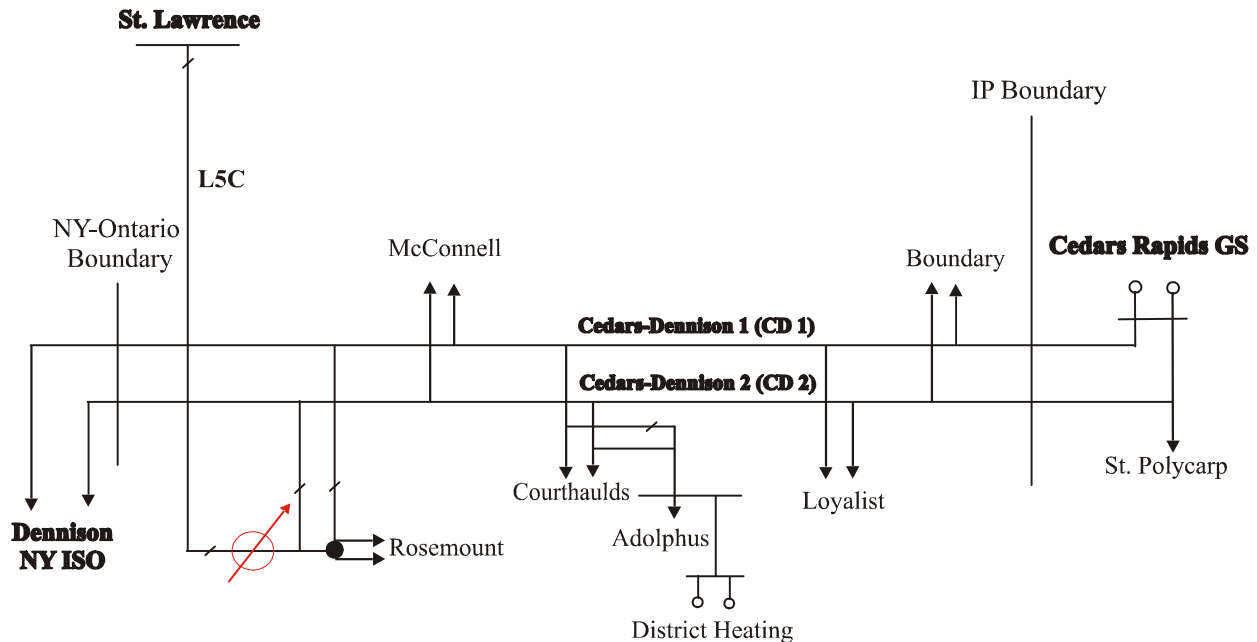
## 2.4 Proposed Interconnection

The proposed interconnection for a single phase shifter in series with L5C is shown in **Figure 2**. With this connection arrangement, Cornwall Electric system will have the ability to be supplied from Hydro One St. Lawrence TS, or Hydro Quebec’s Des Cedres GS, or New York ISO systems. A new interconnection between the IESO-Controlled grid and New York will be established via circuits CD 1 and CD 2.

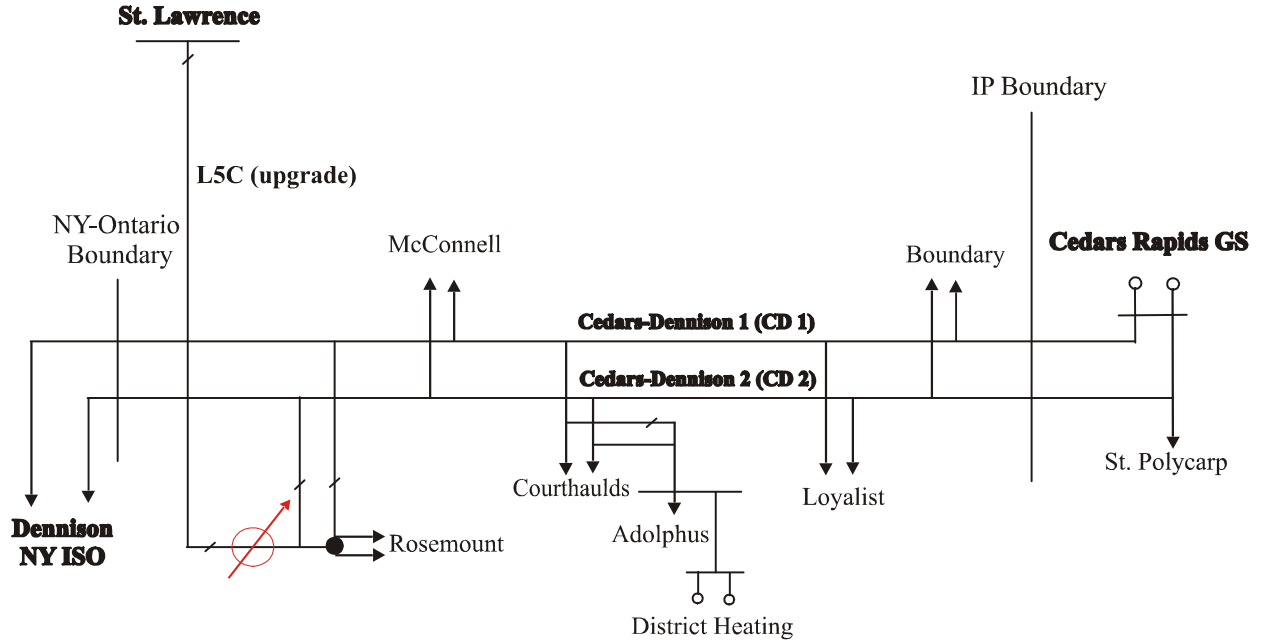
The “single phase shifter in series with L5C” configuration will act as a starting point for the analysis. Although it is the simplest means of interconnecting the IESO and Cornwall Electric systems, a concern is the thermal limitation that L5C presents. The summer continuous rating of L5C is about 108 MVA and its Limited Time Rating (LTR) is 118 MVA; a recognized contingency may result in L5C being overloaded. The proponent is aware of this limitation and has asked the IESO to examine alternatives. They include:

- (1) An upgrade to the existing L5C line, or
- (2) A second line-phase shifter connection parallel to L5C.

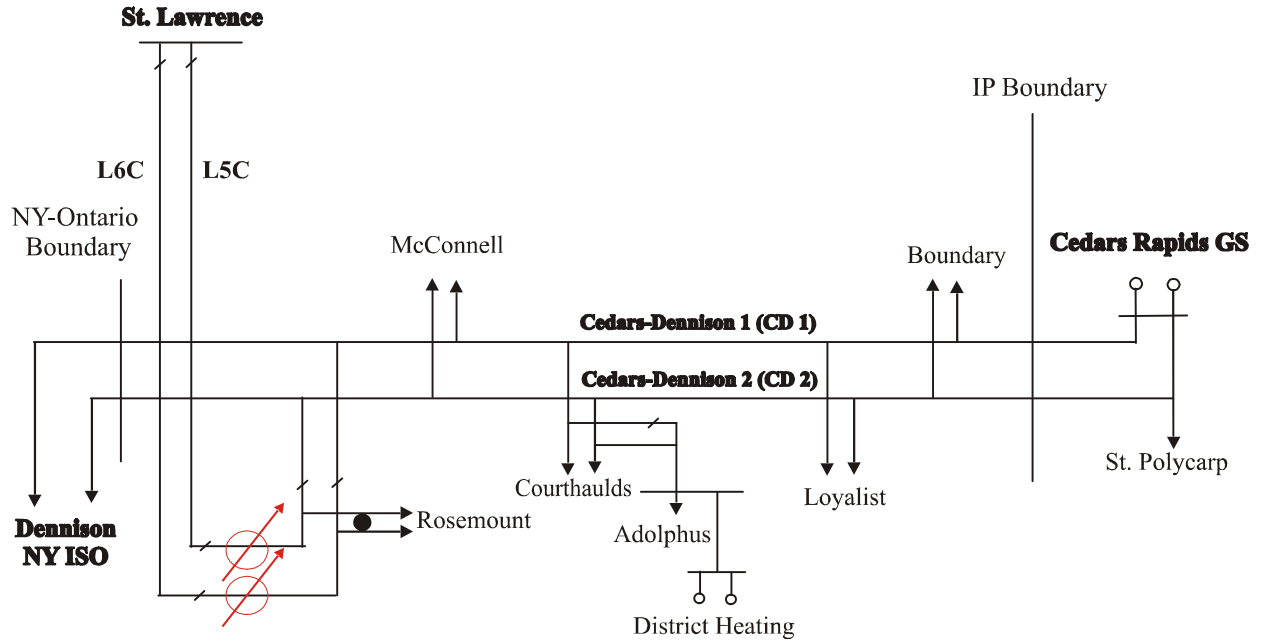
These options, shown in **Figure 3** and **Figure 4**, will be explored at the end of the report as configuration alternatives.



**Figure 2. Proposed Interconnection with Single Phase Shifter**



**Figure 3. Alternative 1: Interconnection with Single Phase Shifter and L5C Upgrade**



**Figure 4. Alternative 2: Interconnection with Two Circuits and Two Phase Shifters**

The continuous rating of circuits CD 1 and CD 2 is 1050 A (209 MVA @ 115 kV). Circuit L5C and the double circuits from CD lines to Rosemount are rated at about 100 MVA. The connection applicant did not provide the LTRs for the CD lines tapping to Rosemount.

## Cornwall Interconnection

Regardless of the configuration, with the new interconnection, the flow on these tap lines could potentially reach 139 MW for a maximum import on L5C into Ontario of 100MW at St. Lawrence and maximum load at Rosemount (39 MW). For the loss of CD 1/CD 2, the companion circuit may be at risk of overloading.

**– End of Section –**

### **3. Short Circuit Assessment**

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Because this project involves the paralleling of two transmission systems and connection of additional generation onto the IESO-controlled grid a short circuit assessment is required. Hydro One will be performing short circuit studies when more detailed technical specifications for the new voltage regulator, the phase shifter and the generation on the New York side will be provided by the proponent.

**– End of Section –**

## 4. Phase Shifter Assessments

This section of the report determines a suitable (i) thermal rating and (ii) angle spread for the “single phase shifter in series with L5C” configuration, shown in **Figure 2**. A phase shifter adequacy analysis was also done whereby the angle spread was validated under various import and export scenarios between Ontario and New York.

### 4.1 Study Assumptions

The load flow used for this assessment was based on a summer 2010 peak system forecast. This study was performed assuming all existing facilities in service, together with any facilities that have obtained connection approvals and are committed to come in service.

Two scenarios were prepared for the studies. They include:

- S1: Maximum export at St. Lawrence on L33P and L34P
- S2: Maximum import at St. Lawrence on L33P and L34P

The maximum import/export capability of L33P and L34P is 400 MW, 200 MW on each tie-line. The S1 and S2 scenarios effectively represent the extreme import and extreme export conditions that the interconnection could face.

The reactance of the phase shifter provided by the connection applicant is  $X = 0.1$  p.u on a 100 MVA base. Where specified, certain simulations were repeated with a limiting phase shifter reactance value of  $X = 0$  pu to understand the effect of varying the transformer impedance. To model the effect of phase shifter angle on impedance, the impedance correction table corresponding to phase shifter L33P was applied to the L5C phase shifter. The correction table is shown in **Table 2**.

**Table 2. L5C Phase Shifter Impedance Correction Table**

Angle in degrees	$\pm 40^\circ$	$\pm 29.5^\circ$	$\pm 25.1^\circ$	$\pm 20.6^\circ$	$0^\circ$
Impedance multiplier	1.660	1.331	1.228	1.144	1.0

The voltage regulator, in series with the L5C phase shifter, used in the studies had an impedance 2.7% on a 100 MVA base and an onload tap range of 0.9370 pu to 1.1022 pu to control reactive power. An impedance correction table corresponding to the L33P voltage regulator was applied to the L5C voltage regulator. The correction table is shown in **Table 3**.

**Table 3. L5C Voltage Regulator Impedance Correction Table**

Turns Ratio	0.9370	1.0000	1.0300	1.1000
Impedance multiplier	1.6410	1.0000	1.0200	1.4270

A complete listing of the load flow data used to model the Cornwall area can be found in Appendix A.

For the “single phase shifter in series with L5C” configuration, CNP has suggested the use of a 100 MVA phase shifter. The rating of the phase shifter was made based on the assumption that the value should not exceed the rating of line it is in series with.

Below in **Table 4** are the ampacity values for L5C for a conductor temperature of 71 °C operating at an ambient temperature of 30° C and wind speed of 4 km/h. It was assumed that the flows are limited to ±100 MW for the studies prepared for this report.

**Table 4. Circuit L5C Ratings**

	Winter Continuous	Winter 15 min	Summer Continuous	Summer 15 min
Amps	700	770	540	590
MVA@115 kV	139	153	108	118

## **4.2 Phase Shifter Specifications**

### **4.2.1 Thermal Rating**

With L5C having a continuous rating of approximately 100 MVA, the phase shifter must have a continuous rating of at least 100 MVA.

### **4.2.2 Angle Spread**

To determine the angle operating range of the phase shifter, the flow at Cornwall via L5C was varied between ±100 MW for the two extreme import and export cases on L33P and L34P. Power flows and phase shifter angles were recorded for an import/export of 400 MW on L33P and L34P against various flows at Cornwall. The results are summarized in **Table 5** and **Table 6**.

Note: At first glance, results below indicate that L33P exceeds its current phase shifter operating range setting. L33P currently operates with a 40° angle range starting from 0°. In real-time operations, changes in local generation would normally accompany imports and exports transfers across phase shifters. This helps to minimize the phase shifter tap movement. For this study, local generation was not re-dispatched with import/export transfers. An alternative method to examine the effect of the new phase shifter on the operating angle ranges of L33P and L34P would be to observe their phase angles displacements with respect to the angles obtained under a 0 MW flow into Cornwall scenario.

A comparison of the L33P and L34P phase angles in **Table 5** indicate that in the worse case, without generation re-dispatch, both L33P and L33P phase shifters change by an additional 7° as a result of the new interconnection. The new L5C interconnection should not have a material effect on the angle operating ranges of L33P and L34P.

**Table 5. Power Flows and Phase Shifter Angles for Export of 400 MW**

	Flow on L5C <sup>1</sup>		
	-100 MW	0 MW	100 MW
Actual Flow @ Cornwall (MW)	-99.7	-0.2	100.4
Actual Flow @ L33P (MW)	198.2	200.3	204.8
Actual Flow @ L34P (MW)	201.1	199.1	202.4
L5C PS angle (°)	-28.6	-9.1	9.3
L33P PS angle (°)	-30.6	-23.9	-17.8
L34P PS angle (°)	-28.3	-22.1	-16

Note:

(1) where positive flow is into the St. Lawrence 115 kV bus

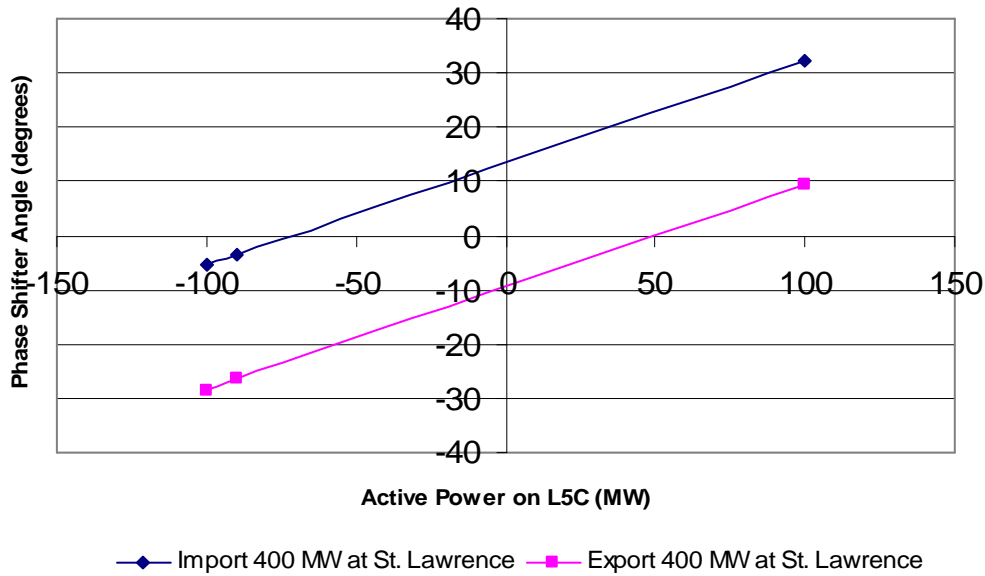
**Table 6. Power Flows and Phase Shifter Angles for Import of 400 MW**

	Flow on L5C <sup>1</sup>		
	-100 MW	0 MW	100 MW
Actual Flow @ Cornwall (MW)	-101.2	-0.3	-98.8
Actual Flow @ L33P (MW)	-200	-200.3	-198.3
Actual Flow @ L34P (MW)	-199	-200.2	-200
L5C PS angle (°)	-5.5	12.5	32.2
L33P PS angle(°)	12.7	18.8	25.3
L34P PS angle (°)	10.9	17.2	23.6

Note:

(1) where positive flow is into the St. Lawrence 115 kV bus

The above results are also illustrated in **Figure 5** as a plot of the phase shifter angle versus active power.



**Figure 5 Phase Shifter Angle versus Active Power on L5C**

As shown, under the assessed conditions, an import/export range of 100 MW can be achieved with a phase shifter operating capability of  $\pm 40^\circ$ . **Figure 5** illustrates that a  $1^\circ$  change in phase angle results in a 5 MW change on this new tie.

### **4.3 Phase Shifter Angle Adequacy Study**

A generation shift factor analysis was performed to determine if a  $\pm 40^\circ$  angle range is sufficient for various import and export scenarios. The shift factors summarized in **Tables 7** and **8** for a phase shifter reactance of (i)  $X=0.1$  and (ii)  $X=0$  at neutral tap positions.

Note: S1 and S2 generation shift factors are slightly different numerically due the differences in the generation and load patterns between the import and export cases.

**Table 7. Generation Shift Factor - 400 MW Export on L33P and L34P**

	Brown's Ferry to Lennox ( $_{BF}G_L$ ) <sup>(3)</sup>		Brown's Ferry to Moses ( $_{BF}G_M$ ) <sup>(4)</sup>		Lennox to Moses ( $_L G_M$ ) <sup>(5)</sup>	
	X = 0.1	X = 0	X = 0.1	X = 0	X = 0.1	X = 0
L33P <sup>(1)</sup>	-0.08530	-0.07839	0.11774	0.11013	0.20304	0.18852
L34P <sup>(1)</sup>	-0.10835	-0.09958	0.14956	0.13989	0.25791	0.23947
L5C <sup>(2)</sup>	-0.03108	-0.05278	0.03426	0.05820	0.06534	0.11098

Notes:

- (1) where positive flow is flow away from the St. Lawrence 230 kV bus
- (2) where positive flow is flow away from the St. Lawrence 115 kV bus
- (3) where  $_{BF}G_L$  represents a generation increase at Brown's Ferry and a generation decrease at Lennox
- (4) where  $_{BF}G_M$  represents a generation increase at Brown's Ferry and a generation decrease at Moses
- (5) where  $_L G_M$  represents a generation increase at Lennox and a generation decrease at Moses and  
 $_L G_M = -_{BF}G_L +_{BF}G_M$

**Table 8. Generation Shift Factor - 400 MW Import on L33P and L34P**

	Brown's Ferry to Lennox ( $_{BF}G_L$ ) <sup>(3)</sup>		Brown's Ferry to Moses ( $_{BF}G_M$ ) <sup>(4)</sup>		Lennox to Moses ( $_L G_M$ ) <sup>(5)</sup>	
	X = 0.1	X = 0	X = 0.1	X = 0	X = 0.1	X = 0
L33P <sup>(1)</sup>	-0.08748	-0.08030	0.12071	0.11282	0.20819	0.19312
L34P <sup>(1)</sup>	-0.10981	-0.10053	0.15151	0.14123	0.26132	0.24176
L5C <sup>(2)</sup>	-0.02980	-0.05173	0.03255	0.05661	0.06235	0.10834

Notes:

- (1) where positive flow is flow away from the St. Lawrence 230 kV bus
- (2) where positive flow is flow away from the St. Lawrence 115 kV bus
- (3) where  $_{BF}G_L$  represents a generation increase at Brown's Ferry and a generation decrease at Lennox
- (4) where  $_{BF}G_M$  represents a generation increase at Brown's Ferry and a generation decrease at Moses
- (5) where  $_L G_M$  represents a generation increase at Lennox and a generation decrease at Moses and  
 $_L G_M = -_{BF}G_L +_{BF}G_M$

Based on the generation shift factors above, **Table 9** summarizes the change in flow on L5C and phase shifter angle due to a generation shift of 1000 MW between Ontario and New York ( $_L G_M$ ). The change in phase shifter angle was calculated assuming a 1° change in phase shifter angle results in a 5 MW change in flow on L5C.

**Table 9. Changes in L5C Flow and Phase Shifter Angle for 1000 MW Generation Shift**

Generation Shift of 1000 MW				
1000 MW shift	L5C Flow $\Delta$		Phase Shifter Angle $\Delta$	
	X=0.1	X=0 <sup>1</sup>	X=0.1	X=0
Export	65.3	111.0	13.1°	22.2°
Import	62.3	108.3	12.5°	21.7°

Note:

(1) In the limiting phase shifter impedance case, a 1000 MW shift between Ontario and New York would result in L5C being overloaded.

Assuming that the phase shifter is controlled to 0° prior to the transfer, both impedance cases show that a phase shifter with a  $\pm 40^\circ$  angle range can handle an additional 1000 MW export/import between Ontario and New York.

A phase shifter with a larger impedance will leave more angle room on the phase shifter after an import or an export transaction.

## 5. System Impact Studies

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This section of the report examines the impact of a “single phase shifter in series with L5C” configuration on the reliability of the IESO-controlled grid.

In particular, this section analyzes

- (i) the effect of the proposed connection on system pre and post contingency voltages and
- (ii) the impact of the Cornwall interconnection on import/export capability between Ontario-New York at St. Lawrence based on thermal loading

### 5.1 Voltage Assessments

- The IESO's Market Rules (Appendix 4.1) indicate the minimum continuous voltage is 113 kV for a 115 kV system.
- The IESO Transmission Assessment Criteria (4.3 Voltage Change Limits) indicates that voltage declines should be less than 10%.

A simulation was performed to determine the effect on local voltages in Cornwall for (i) the loss of L5C, (ii) the loss of L33P, (iii) the loss of L34P, and (iv) the loss of L33P+L34P. The results are summarized in Appendix B.

Results indicate that post contingency voltages (pre-ULTC and post-ULTC) are generally within 2% of pre-contingency values. Post-contingency declines are well within the 10% pre-ULTC and 10% post-ULTC voltage decline criteria set forth by the IESO.

It can be concluded that:

- The addition of the new Cornwall interconnection will not impose any materially adverse Voltage Quality Limits on its surrounding area.

### 5.2 Thermal Loading Assessments

#### 5.2.1 Outage Distribution Analysis

An outage distribution analysis was performed to determine the allowable active power operating range of the phase shifter, while respecting its continuous rating. Factors were calculated for L33P, L34P and L5C under various contingencies at the export and import levels of  $\pm 400$  MW on L33P and L34P. The results are summarized in **Tables 10** and **11**.

The analysis was performed under two sets of phase shifter reactances i)  $X=0.1$  pu and ii)  $X= 0$  pu to examine the effect of impedance.

Note: the S1 and S2 outage distribution factors are slightly different between import and export scenarios due to differences in generation and load patterns between import and export cases.

**Table 10. S1 Outage Distribution Factors -High Exports on L33P and L34P**

	Loss of L33P		Loss of L34 P		Loss of L5C		L33P O/S Loss of L34P		L34P O/S Loss of L33P	
	X=0.1	X=0	X=0.1	X=0	X=0.1	X=0	X=0.1	X=0	X=0.1	X=0
L33P <sup>(1)</sup>	-1	-1	0.468	0.415	0.318	0.318	0	0	-1	-1
L34P <sup>(1)</sup>	0.528	0.474	-1	-1	0.404	0.404	-1	-1	0	0
L5C <sup>(2)</sup>	0.139	0.230	0.157	0.255	-1	-1	0.295	0.436	0.295	0.436

Notes: (1) where positive flow is flow away from the St. Lawrence 230 kV bus  
 (2) where positive flow is flow away from the St. Lawrence 115 kV bus

**Table 11. S2 Outage Distribution Factors - High Imports on L33P and L34P**

	Loss of L33P		Loss of L34 P		Loss of L5C		L33P O/S Loss of L34P		L34P O/S Loss of L33P	
	X=0.1	X=0	X=0.1	X=0	X=0.1	X=0	X=0.1	X=0	X=0.1	X=0
L33P <sup>(1)</sup>	-1	-1	0.484	0.427	0.325	0.324	0	0	-1	-1
L34P <sup>(1)</sup>	0.540	0.483	-1	-1	0.407	0.406	-1	-1	0	0
L5C <sup>(2)</sup>	0.135	0.227	0.151	0.251	-1	-1	0.293	0.438	0.293	0.438

Notes: (1) where positive flow is flow away from the St. Lawrence 230 kV bus  
 (2) where positive flow is flow away from the St. Lawrence 115 kV bus

The post-contingency flow on L5C can be determined by the following equations shown in **Table 12**:

**Table 12. L5C ODF Equations**

Loss of	ODF Equation
L33P	$L5C_{post} = L5C_{pre} + ODF^{L33P} * L33P_{pre}$
L34P	$L5C_{post} = L5C_{pre} + ODF^{L34P} * L34P_{pre}$
L33P+L34P	$L5C_{post} = L5C_{pre} + ODF^{L34P,L33P} * L33P_{pre} + ODF^{L33P,L34P} * L34P_{pre}$

In the event that L33P or L34P is lost, approximately 14% to 26% of its pre-contingency flow will appear on L5C. Assuming a maximum L33P or L34P flow of 200 MW, this is roughly about 28 to 52 MW of added flow on L5C. Therefore, the flow on L5C will have to be limited pre-contingency to ensure that it does not exceed its continuous rating of ±100 MW post-contingency.

Based on the ODF Equations, the loss of L33P+L34P will result in the greatest loading on L5C.

In the event that L33P+L34P is lost, approximately 29% to 44% of the pre-contingency flow on L33P and L34P will appear on to L5C. At high L33P and L34P import/export levels, this would result in L5C exceeding its continuous rating of ±100 MW.

**Table 13** summarizes the allowable pre-contingency operating flow range on L5C under the maximum import and export levels on L33P and L34P. The operating flow range on L5C for all levels of import and

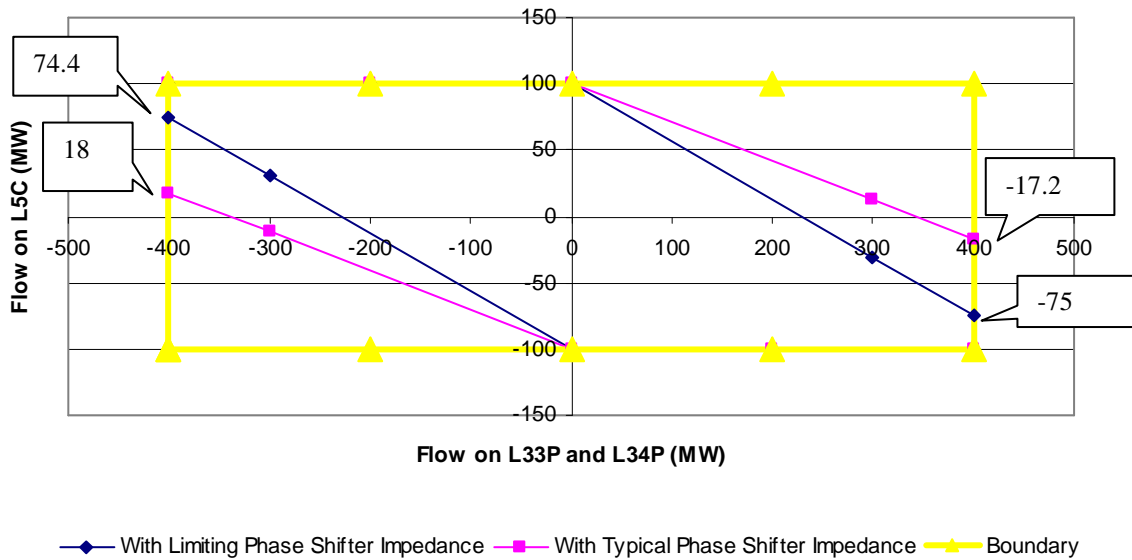
export levels on L33P and L34P is illustrated in **Figure 6**. A typical phase shifter impedance value will result in a larger operating range.

**Table 13. L5C Operating Range to Respect the loss of 400 MW on L33P+L34P**

	L5C Operating Range <sup>1</sup>	
	X=0.1	X=0
Import	-100 MW <L5C< -17.2 MW	-100 MW <L5C< -75 MW
Export	18 MW < L5C < 100 MW	74.4< L5C <100 MW

Note:

(1) where positive flow is into the St. Lawrence 115 kV bus

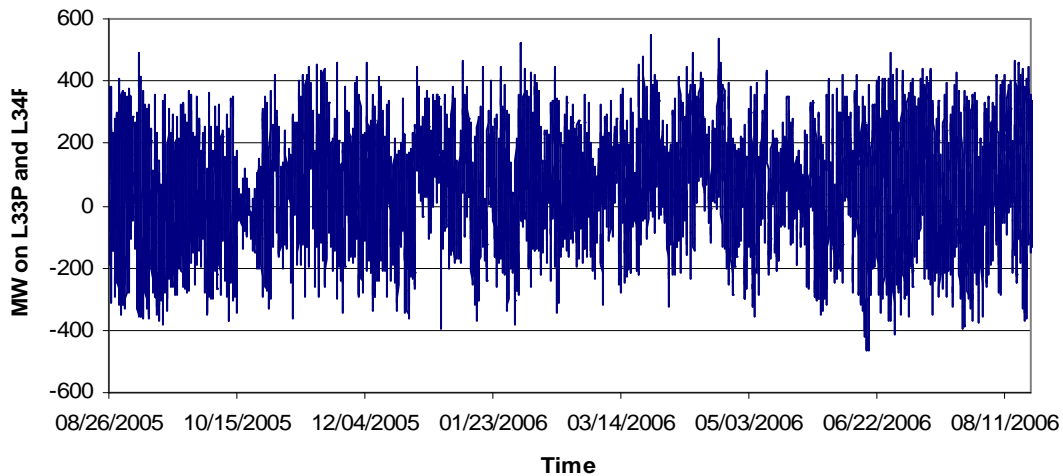


**Figure 6 Permissible Flow on L5C Respecting Loss of L33P and L34P**

It should be noted that these results indicate that under a high L33P and L34P export scenario, Ontario would be required to import from Cornwall. Similarly, under a high L33P and L34P import scenario, Ontario would be required to export to Cornwall. This would result in a reduction in import and export capabilities for the L33P/L34P/L5C interface

High import and export flows are often the flow patterns observed on L33P and L34P. **Figure 7** shows the active power flow on L33P and L34P in 1 Hr average samples during the period from October 2005 to October 2006. The illustration shows a high probability of large import/export power flows on L33P and L34P (over 200 MW). Thus given a “single phase shifter in series with L5C” configuration, the above operating restrictions would likely have to be enforced at all times, thus resulting in a definite decrease in the import and export capability of the IESO-Controlled grid.

## Cornwall Interconnection



**Figure 7 Power Flow on L33P/L34P**

To address the decrease in import/export capability under high Ontario-New York import/conditions, there are three possible solutions in which the proponent can undertake:

- A1. Install a Special Protection System to cross trip for the loss of L33P and L34P
- A2. Upgrade L5C
- A3. Revise configuration to a two phase shifter two line interconnection

The phase shifter requirements outlined in Section 4.1 would still be applicable for Option A1. New phase shifter requirements would be needed for Options A2 and A3.

### **5.2.2 A1: L5C Cross-Tripping Scheme**

One possible solution to address the decrease in import/export capability under high Ontario-New York power transfers would be to provide a scheme that would cross trip for the loss of L33P and L34P.

The sole purpose of this scheme would prevent overloading on L5C in the event that both L33P and L34P are lost.

Voltage declines for the loss of L33P, L34P and L5C are summarized in Appendix C. Voltage declines are within IESO criteria.

In order to comply with the IESO's criteria, this special protection scheme will have to be fully redundant and with separate communication paths. The scheme would need to be capable of meeting the 'Special Protection System Criteria', as detailed in the NPCC Document A-11.

The cross-tripping scheme could be installed at L5C or at Cedars-Dennison 1 and Cedars-Dennison 2 of the New York interconnection, or both. It should be noted that this scheme would require concurrence from New York. Studies by NYISO would be required as well as an agreement from both Ontario and New York.

### 5.2.3 A2: L5C Upgrade

Another solution the proponent could undertake is to upgrade L5C to a conductor with higher thermal ratings. The proposed configuration is shown in **Figure 3**.

A study consisting of an outage distribution factor analysis and phase shifter angle spread analysis was performed to determine the minimum upgrades the line and phase shifter would require. The study was conducted under high import and export scenarios on L33P and L34P and assumed a limiting phase shifter transformer reactance of  $X = 0$  pu. Although L5C would be increased to a higher rating, the analysis assumed the maximum flow remains at 100 MW.

The analysis and results are summarized in Appendix D.

From the analysis, it was determined that:

- For L5C to operate within  $\pm 100$  MW pre-contingency and be within the limits for the loss of L33P and L34P, the 4.2 km of line length can be upgraded to a 1192.5 ACSR 54/19 conductor with a continuous rating of 275 MVA.
- The L5C phase shifter requires a continuous rating of at least 275 MVA
- The L5C phase shifter requires an angle range of at least  $\pm 40^\circ$ .

### 5.2.4 A3: Two Phase Shifter Two Line Interconnection

The third solution the proponent could undertake is to connect a new 115 kV line, L6C, and phase shifter in parallel with the existing L5C line. With this configuration, the impact of a L33P and L34P contingency would be reduced as pre and post contingency flows are shared between the two lines. The proposed configuration is shown in **Figure 4**.

A study consisting of an outage distribution factor analysis and phase shifter angle spread analysis was performed to determine the minimum requirements the line and two phase shifters. Despite the increase in capability of the additional line, the analysis assumes that the maximum flow between the Ontario-Cornwall interconnection remains at 100 MW; the total flows on L5C and L6C cannot exceed 100 MW at any time.

The analysis and results are summarized in Appendix E.

From the analysis it was determined that:

- L6C of conductor type 605 ACSR 54/7 and continuously rated for 200 MVA would allow the Ontario-Cornwall interconnection to operate within  $\pm 100$  MW, pre-contingency.
- Under high imports/exports on L33P and L34P, the flow on L5C will have to be limited within a operating range as shown in **Table 14**. The limitation on L5C would be dependant on phase shifter impedance and is more restrictive with decreasing phase shifter impedance.

**Table 14. L5C Operating Range to Respect the Loss of 400 MW on L33P and L34P**

Condition on L33P and L34P	L5C Operating Range <sup>1</sup>	
	X=0.1	X=0.0
High Import	$-100 < L5C_{flow} < 23.2$	$-100 < L5C_{flow} < 2$
High Export	$-21.2 < L5C_{flow} < 100$	$-4.4 < L5C_{flow} < 100$

Note:

(1) a positive flow value represents flow into St. Lawrence.

- The L5C and L6C phase shifters require continuous ratings of at least 100 MVA and at least 200 MVA respectively
- The L5C and L6C phase shifters both require angle ranges of at least  $\pm 40^\circ$

### 5.2.5 Conclusions

The following conclusions were obtained from thermal studies:

- A “single phase shifter-existing L5C series” configuration would result in a reduction in interconnection transfer capability at St. Lawrence.
- A special protection scheme rejecting L5C for the loss of L33P/L34P would be required to accompany a “single phase shifter-existing L5C series” Ontario-Cornwall Interconnection to prevent this reduction in interconnection transfer capability at St. Lawrence.
- Upgrading L5C to a 1192.5 ACSR 54/19 conductor with a continuous rating of 275 MVA would alleviate the reduction in transfer capability and allow L5C operation within  $\pm 100$  MW. The upgrade in L5C will require a phase shifter with a continuous rating of at least 275 MVA and angle range of at least  $\pm 40^\circ$ .
- A two phase shifter two line interconnection consisting of the existing L5C line and a new L6C line of conductor type 605 ACSR 54/7 and continuously rated for 200 MVA would also alleviate the reduction in transfer capability and allow L5C operation within  $\pm 100$  MW. This configuration would require a L5C and L6C phase shifters with continuous ratings of at least 100 MVA and 200 MVA respectively and angle ranges of at least  $\pm 40^\circ$ . Note, to accommodate for the thermal limitations of the existing L5C line, pre-contingency operating flow limits will be required on L5C.

# Appendix A Cornwall Load Flow Model

rdch

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1
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89380,'ROSTTS1 ', 115.0000,1, 0.000, 0.000, 707, 999,0.99666, -57.1781, 1
89381,'ROSTTS2 ', 115.0000,1, 0.000, 25.000, 707, 999,0.99246, -58.2683, 1
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7,'CEDLT2 ', 11.0000,2, 0.000, 0.000, 704, 840,0.98608, -52.0025, 1
8,'LOYALLT ', 12.5000,1, 0.000, 0.000, 707, 999,0.97579, -60.6738, 1
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Cornwall Interconnection

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Cornwall Interconnection

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1.00000, 0.000
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 1.00000, 0.000

## Appendix B: Voltage Analysis

Contingency	flow into Ontario from L33P+ L34 P @St.Lawrence (MW)	flow into Ontario from Cornwall (MW)	Dennison (Voltage)					Cedars (Voltage)					Rosemount (Voltage)				
			Pre - Conting	Pre - ULTC	% Decline Pre - ULTC	Post - ULTC	% Decline Post - ULTC	Pre - Conting	Pre - ULTC	% Decline Pre - ULTC	Post - ULTC	% Decline Post - ULTC	Pre - Conting	Pre - ULTC	% Decline Pre - ULTC	Post - ULTC	% Decline Post - ULTC
Loss of L5C	400	-100	116.97	116.15	-0.70	116.16	-0.69	124.65	123.70	-0.76	123.72	-0.75	115.07	113.67	-1.22	113.69	-1.20
		100	115.94	116.33	0.34	116.33	0.34	123.63	123.83	0.17	123.84	0.17	113.54	113.85	0.28	113.86	0.28
	-400	-100	118.80	118.64	-0.14	118.63	-0.14	125.93	125.91	-0.02	125.91	-0.02	118.58	118.19	-0.33	118.18	-0.34
		100	118.01	118.54	0.44	118.49	0.40	125.85	125.90	0.04	125.90	0.04	117.18	118.11	0.79	118.07	0.76
Loss of L33P	400	-100	116.97	117.02	0.04	117.02	0.04	124.65	124.62	-0.03	124.62	-0.03	115.07	115.03	-0.04	115.03	-0.03
		100	115.94	116.35	0.36	116.35	0.36	123.63	124.02	0.32	124.03	0.32	113.54	114.12	0.51	114.12	0.51
	-400	-100	118.80	118.85	0.04	118.77	-0.02	125.93	125.93	0.00	125.93	0.00	118.58	118.65	0.05	118.54	-0.04
		100	118.01	117.83	-0.16	117.78	-0.19	125.85	125.82	-0.02	125.82	-0.02	117.18	116.81	-0.31	116.79	-0.33
Loss of L34P	400	-100	116.97	117.01	0.03	117.01	0.03	124.65	124.59	-0.05	124.59	-0.05	115.07	114.99	-0.07	114.99	-0.07
		100	115.94	116.38	0.38	116.38	0.38	123.63	124.05	0.34	124.05	0.34	113.54	114.15	0.54	114.16	0.54
	-400	-100	118.80	118.83	0.03	118.74	-0.05	125.93	125.93	0.00	125.93	0.00	118.58	118.63	0.04	118.52	-0.05
		100	118.01	117.76	-0.22	117.71	-0.26	125.85	125.82	-0.02	125.82	-0.02	117.18	116.73	-0.38	116.71	-0.40
Loss of L33P + L34P	400	-100	116.97	116.89	-0.07	116.89	-0.07	124.65	124.17	-0.38	124.18	-0.38	115.07	114.40	-0.58	114.41	-0.57
		100	115.94	117.37	1.24	117.37	1.23	123.63	124.94	1.06	124.94	1.06	113.54	115.46	1.69	115.46	1.69
	-400	-100	118.80	118.79	-0.01	118.59	-0.18	125.93	125.93	0.00	125.90	-0.02	118.58	118.50	-0.07	118.05	-0.45
		100	118.01	116.85	-0.98	117.10	-0.77	125.85	124.99	-0.68	125.33	-0.41	117.18	115.06	-1.81	115.56	-1.38

## Appendix C: A1- Cross Tripping Voltage Analysis

Contingency	flow into Ontario from L33P+ L34 P @ St.Lawrence (MW)	flow into Ontario from Cornwall (MW)	Dennison (Voltage)					Cedars (Voltage)					Rosemount (Voltage)				
			Pre - Conting	Pre - ULTC	% Decline Pre - ULTC	Post - ULTC	% Decline Post - ULTC	Pre - Conting	Pre - ULTC	% Decline Pre - ULTC	Post - ULTC	% Decline Post - ULTC	Pre - Conting	Pre - ULTC	% Decline Pre - ULTC	Post - ULTC	% Decline Post - ULTC
Loss of L33P+L34P+L5C	400	-100	116.97	116.77	-0.18	116.77	-0.17	124.65	124.12	-0.42	124.13	-0.41	115.07	114.27	-0.70	114.28	-0.69
		100	115.94	116.75	0.70	116.75	0.70	123.63	124.14	0.41	124.14	0.41	113.54	114.28	0.65	114.28	0.65
	-400	-100	118.80	118.67	-0.11	118.67	-0.11	125.93	125.91	-0.02	125.91	-0.02	118.58	118.22	-0.31	118.22	-0.31
		100	118.01	118.65	0.54	118.65	0.54	125.85	125.91	0.05	125.91	0.05	117.18	118.21	0.88	118.20	0.87

# Appendix D: A2 – L5C Upgrade Analysis

The A2 Ontario-Cornwall interconnection configuration calls for an upgraded L5C line in series with a phase shifter. The configuration is shown in **Figure 3** of the main report.

The following analysis was done to determine the necessary upgrade to L5C and phase shifter requirements, such that the Ontario-Cornwall interconnection could handle the loss of L33P and L34P without reducing the Ontario-New York transfer capability.

The analysis was divided into two steps:

- a) Outage distribution factors were obtained with the existing L5C line to determine an appropriate summer continuous rating for the upgrade.
- b) Outage distributions factors were re-calculated with the new line specifications to ensure it can handle a L33P and L34P contingency. A phase shifter angle spread analysis was also done to determine an appropriate angle range for the phase shifter.

## (a) Outage Distribution Factors using existing L5C line

The following table shows the pre-contingency flows , outage distribution factors, and post-contingency flows obtained under high imports and high exports on L33P and L34P and assuming a phase shifter reactance of  $X=0$  pu.

Note: outage distribution factors are slightly different between import and export scenarios due to differences in load and generation patterns.

ODFs and Flows obtained with existing L5C line						
Scenario	L5C <sub>pre</sub> <sup>(2)</sup>	L33P <sub>pre</sub> <sup>(1)</sup>	L34 <sub>pre</sub> <sup>(1)</sup>	ODF <sup>L34P, L33P</sup>	ODF <sup>L33P, L34P</sup>	L5C <sub>post</sub> <sup>(2)</sup>
Import	-100	-200	-200	0.438	0.438	-275.2
Export	100	200	200	0.436	0.436	274.4

Notes: (1) where positive flow is flow away from the St. Lawrence 230 kV bus  
 (2) where positive flow is flow away from the St. Lawrence 115 kV bus

The results above indicate the import scenario is most limiting.

Assuming active power is equal to apparent power ( $MW=MVA$ ), the current corresponding to 275.2 MW is about  $I=1381.62$  A, where  $I=S/\sqrt{3}*V$  and  $V=115$  kV. A new line with a summer continuous rating of about 1380 A would be required for an upgraded L5C line.

## (b) Outage Distribution Factors using upgraded L5C line

According to data from the Hydro One Secure Operations website, a 1192.5 ACSR 54/19 has a summer continuous rating of approximately 1380 A.

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Applied to a length of 4.2 km, an upgraded L5C line with a 1192.5 ACSR 54/19 conductor would have the following properties:

Line Specifications for L5C upgrade				
R	X	B	Winter Continuous (A)	Winter 15 min (A)
0.00173	0.01450	0.00203	1530	1810
Summer Continuous (A)	Summer 15 min (A)	Conduct size	Cond stranding	
1390	1630	1192.5	54/19	

The following table shows the pre-contingency flows , outage distribution factors, and post-contingency obtained under high imports and high exports on L33P and L34P and assuming a phase shifter reactance of X=0 pu with the upgraded L5C line.

The post flow on L5C is expressed in both an active power and current value. Note: outage distribution factors are slightly different between import and export scenarios due to differences load and generation patterns.

ODF's obtained with upgraded L5C line							
Scenario	L5C <sub>pre</sub> <sup>(2)</sup>	L33P <sub>pre</sub> <sup>(1)</sup>	L34 <sub>pre</sub> <sup>(1)</sup>	ODF <sup>L34P, L33P</sup>	ODF <sup>L33P, L34P</sup>	L5C <sub>post</sub> <sup>(2)</sup> (MW)	L5C <sub>post</sub> <sup>(2)</sup> (A)
Import	-100	-200	-200	0.440	0.440	-276	1386
Export	100	200	200	0.439	0.439	275.6	1384

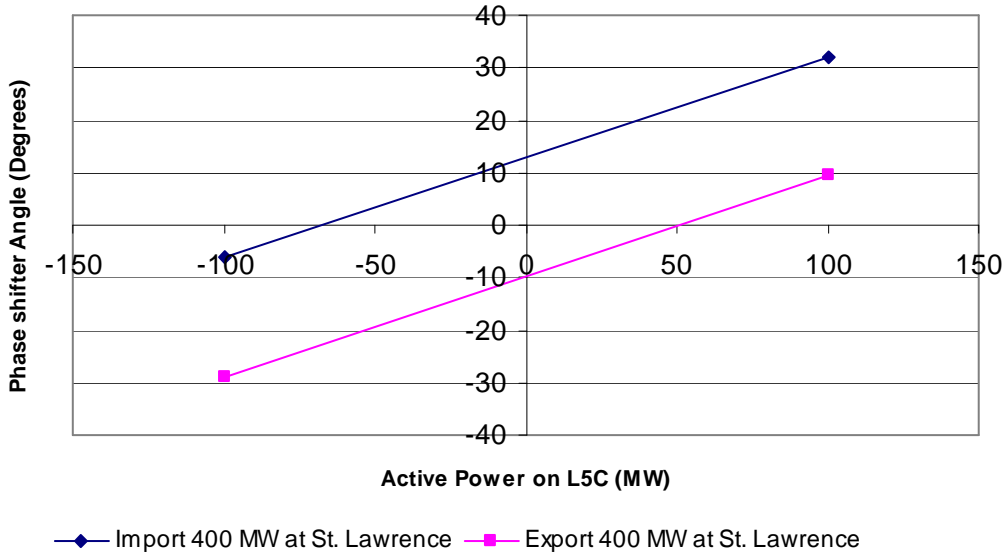
Notes: (1) where positive flow is flow away from the St. Lawrence 230 kV bus  
 (2) where positive flow is flow away from the St. Lawrence 115 kV bus

The following are the results of a flow variation study used to determine an appropriate angle range for the L5C phase shifter. The flow of the phase shifter was varied between ±100 MW given a high import or high export scenario. Results indicate that an angle range of at least ± 40 ° is required.

Scenario	L5C Phase Shifter Conditions	
	Flow on L5C <sup>(1)</sup>	Angle (°)
Import 400	100	32.0
	-100	-6.0
Export 400	100	9.7
	-100	-29.0

Notes:  
 (1) where positive flow is into the St. Lawrence 115 kV bus

The above results are illustrated below as a plot of phase shifter angle versus active power. As shown from the graphs, 1° change in phase angle would result in a 5 MW change on this new tie.



**(c) Conclusions**

- 1) For L5C to operate within  $\pm 100$  MW pre-contingency, the 4.2 km of line length can be upgraded to a 1192.5 ACSR 54/19 conductor with a continuous rating of 275 MVA.
- 2) The L5C phase shifter requires a continuous rating of at least 275 MVA.
- 3) The L5C phase shifter requires an angle range of at least  $\pm 40^\circ$ .

# Appendix E: A3 – Two Phase Shifter Two Line Analysis

The A3 Ontario-Cornwall interconnection configuration calls for two 115 kV lines and two phase shifters. This configuration employs the existing L5C line, along with a new 115 kV line, L6C. The configuration is shown in **Figure 4** of the main report.

The following analysis was done to determine the necessary L6C conductor and L5C/L6C phase shifter requirements, such that the Ontario-Cornwall interconnection could handle the loss of L33P and L34P without reducing the Ontario-New York transfer capability.

The analysis was divided into four steps:

- a) An appropriate conductor was chosen for L6C.
- b) Outage distribution factors were obtained under a high export scenario on L33P and L34P.
- c) Outage distributions factors were obtained under a high import scenario on L33P and L34P.
- d) A phase shifter angle spread analysis was done to determine appropriate angle ranges for the L5C and L6C phase shifters.

## (a) L6C Conductor Requirements

An assumption to use a 200 MVA continuously rated conductor for L6C was made. A preliminary study using a 150 MVA continuously rated conductor for L6C indicated that it would not be possible to operate the Ontario-Cornwall interconnection at the maximum import/export level of 100 MW, while still respecting loss of L33P and L34P.

According to data from the Hydro One Secure Operations website, a 605.0 ACSR 54/7 has a summer continuous rating of approximately 1010 A, approximately 201 MVA.

Applied to a length of 4.2 km, an upgraded L5C line with a 605.0 ACSR 54/7 conductor would have the following properties:

Line Specifications for L6C				
R	X	B	Winter Continuous (A)	Winter 15 min (A)
0.00273	0.01404	0.00210	1100	1210
Summer Continuous (A)	Summer 15 min (A)	Conduct size	Cond stranding	
1010	1120	605.0	54/7	

**(b) Outage Distribution Factor: High Exports on L33P and L34P**

ODFs were calculated with various nominal phase shifter reactances for L5C and L6C: (i)  $X=0.1$ , representing a typical phase shifter reactance and (ii)  $X=0$ , representing a limiting phase shifter reactance value.

The following table summarizes the outage distributions factors (ODFs) obtained for a high export scenario on L33P and L34P at St. Lawrence (+400 MW). Note: outage distribution factors are slightly different between import and export scenarios due to differences load and generation patterns.

ODFs: Export 400 MW on L33P + L34P @ St. Lawrence				
Monitored Line	L33P O/S Loss of L34P		L34P O/S Loss of L33P	
	X=0.1	X=0	X=0.1	X=0
L33P	0	0	-1	-1
L34P	-1	-1	0	0
L6C	0.188	0.247	0.188	0.247
L5C	0.197	0.239	0.197	0.239

Using the data above while respecting conductor ratings, under high exports on L33P and L34P, pre-contingency operating ranges for L5C and L6C would be required to be bounded by the following equations:

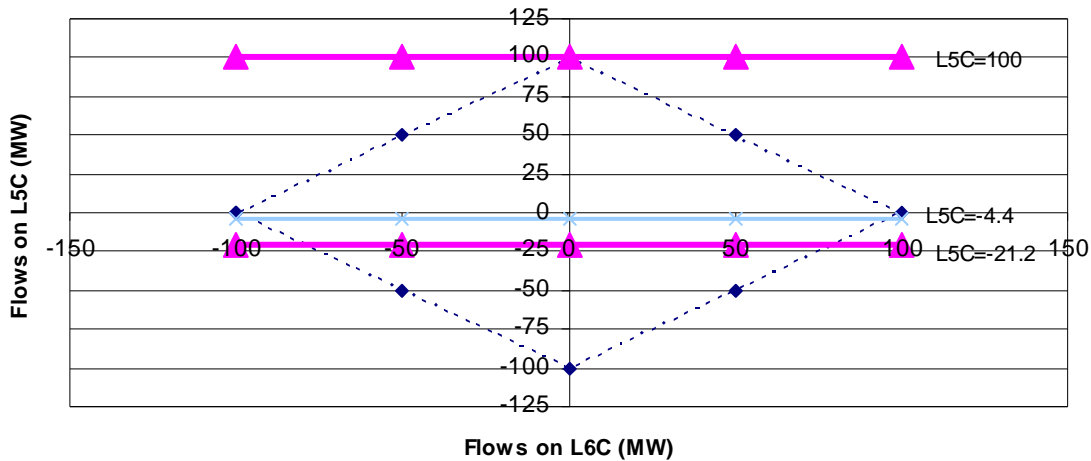
L5C and L6C Operating Range Under High L33P+L34P Exports <sup>1</sup>	
X=0.1	X=0
$-100 < L6C_{flow} < 100$	$-100 < L6C_{flow} < 100$
$-21.2 < L5C_{flow} < 100$	$-4.4 < L5C_{flow} < 100$
$100 < L6C_{flow} + L5C_{flow} < 100$	$-100 < L6C_{flow} + L5C_{flow} < 100$

Notes:

(1) where positive flow is into the St. Lawrence 115 kV bus

The following figure summarizes the operating ranges of L5C and L6C under high exports on L33P and L34P. The ideal operating area, without the above restrictions, is depicted by the dotted line. Note: the area of operation is larger with a higher nominal phase shifter impedance

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---◆--- Boundary    —▲— With Typical Phase Shifter Impedance    —x— With Limiting Phase Shifter Impedance

**(c) Outage Distribution Factor: High Imports on L33P and L34P**

ODFs were calculated with various nominal phase shifter reactances for L5C and L6C: (i)  $X=0.1$ , representing a typical phase shifter reactance and (ii)  $X=0$ , representing a limiting reactance value.

The following table summarizes the outage distributions factors (ODFs) obtained for a high import scenario on L33P and L34P at St. Lawrence (-400 MW). Note: outage distribution factors are slightly different between import and export scenarios due to differences load and generation patterns.

ODFs: Import 400 MW on L33P + L34P @ St. Lawrence				
Monitored Line	L33P O/S Loss of L34P		L34P O/S Loss of L33P	
	X=0.1	X=0	X=0.1	X=0
L33P	0	0	-1	-1
L34P	-1	-1	0	0
L6C	0.192	0.244	0.192	0.244
L5C	0.192	0.245	0.192	0.245

Under high imports on L33P and L34P, pre-contingency operating ranges for L5C and L6C are bounded by the following equations:

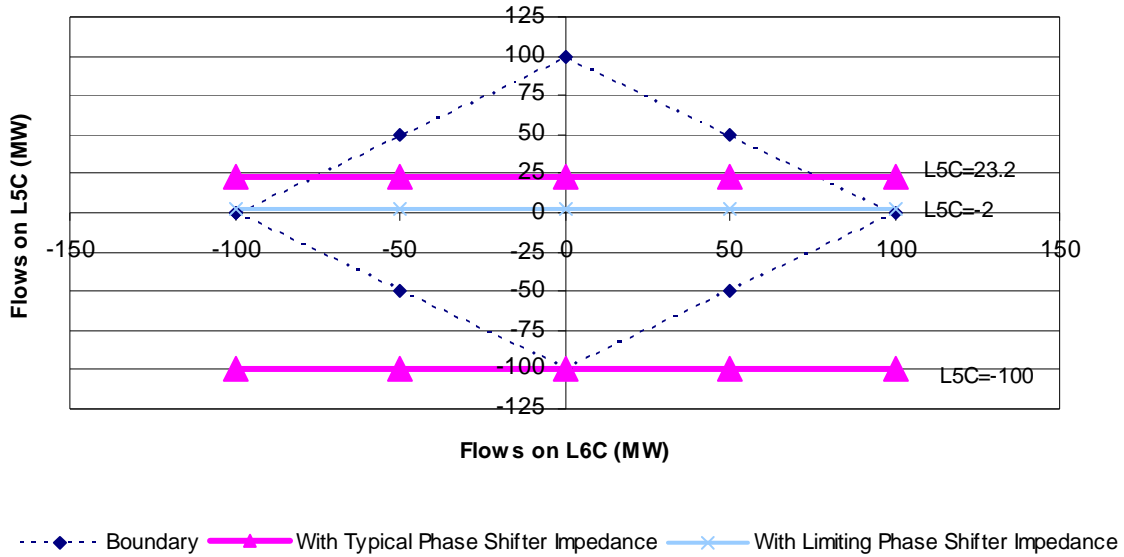
L5C and L6C Operating Range Under High L33P+L34P Imports <sup>1</sup>	
X=0.1	X=0
$-100 < L6C_{flow} < 100$	$-100 < L6C_{flow} < 100$
$-100 < L5C_{flow} < 23.2$	$-100 < L5C_{flow} < 2$
$-100 < L6C_{flow} + L5C_{flow} < 100$	$-100 < L6C_{flow} + L5C_{flow} < 100$

Notes:

(1) where positive flow is into the St. Lawrence 115 kV bus

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The following figure summarizes the operating ranges of L5C and L6C under high imports on L33P and L34P.



**(d) Angle Spread**

The following are the results of an angle spread study used to determine an appropriate angle range for the L5C and L6C phase shifters. The flows of the phase shifters were varied between  $\pm 100$  MW given a high import or high export scenario.

	L5C Phase Shifter Conditions		L6C Phase Shifter Conditions	
	Flow @ Cornwall (MW)	PS Angle(°)	Flow @ Cornwall(MW)	PS Angle(°)
Import 400	0	1.9	-100	-6.0
	-100	-5.3	0	2.2
	0	22.7	+100	32.0
	+100	32.0	0	22.7
Export 400	0	-16.4	-100	-25.0
	-100	-25.0	0	-16.5
	0	4.1	+100	12.2
	+100	12.2	0	4.1

An angle range of at least  $\pm 40^\circ$  is required for both phase shifters.

**(e) Conclusions**

- 1) L6C of conductor type 605 ACSR 54/7 and continuously rated for 200 MVA would allow the proponent to operate the Ontario-Cornwall interconnection within  $\pm 100\text{MW}$ , pre-contingency.
- 2) Under high imports/exports on L33P and L34P, the flow on L5C will have to be limited within a operating range. The limitation on L5C would be dependant on phase shifter impedance and is more restrictive with decreasing phase shifter impedance.

Condition on L33P and L34P	L5C Operating Range <sup>1</sup>	
	X=0.1	X=0.0
High Import	$100 < L5C_{\text{flow}} < 23.2$	$-100 < L5C_{\text{flow}} < 2$
High Export	$-21.2 < L5C_{\text{flow}} < 100$	$-4.4 < L5C_{\text{flow}} < 100$

Note:

(1) a positive flow value represents flow into St. Lawrence.

- 3) The L5C and L6C phase shifters requires a continuous ratings of at least 100 MVA and at least 200 MVA respectively
- 4) The L5C and L6C phase shifters both require angle ranges of at least  $\pm 40^\circ$