Q. Reference MHI Report, Review of the Muskrat Falls and Labrador Island HVDC Link and the Isolated Island Option, October 2012, Section 2, section 2.2.2, page 28: In section 2.2.5 MHI recommends that Hydro should consider the synchronous condensers when determining the harmonic impedance of the system. Has Hydro performed new studies following the changes to the synchronous condensers? If so, what was the impact of the new studies? If not, why not?

A. SNC Lavalin (SLI) completed a harmonic impedance study titled, *Harmonic Impedance Studies, document # ILK-SN-CD-8000-EL-SY-0002-01*, prior to award of contract to Alstom Grid for package CD0501. The study assumed that 2x150 MVAR high inertia synchronous condensers (HISC) were connected at the Soldiers Pond 230 kV bus. The dynamic data used for the Soldiers Pond high inertia synchronous condensers was as follows:

Table 1: SLI Harmonic Impedance Study - SOP High Inertia SC Data

Unit MVA	Td_0'	Td_0''	Tq_0'	Tq_0''	H (MWs/MVA)	Xd	Xq	Xd'	Xq'	Xd''	Xl	S1.0	S1.2
						(pu on Machine Base)							
150	11	0.08	-	0.29	7.84	1.24	0.85	**0.27**	-	0.165	0.09	0.04	0.14

Using the ac system network models which included models of the SOP synchronous condensers, SLI provided a table of the harmonic impedance sectors. SLI did not determine a detailed filter design from the results of the study as the selected HVdc vendor would complete their own unique design. The results of the harmonic impedance study are shown in Table 2.

Table 2: SLI Scanned Harmonic Impedances at Soldiers Pond

Converter Station	Soldiers Pond			
Harmonic Order	Zmin	θ min	Zmax	θ max
2	23.1	63.8	45.4	77.8
3	33.9	31	70.7	72.9
4	33.7	22.2	119	71.5
5	30.8	14.4	120	69.4
6	37.8	1.6	172	69.8
7	53.2	-41.7	177	69.2
8	31.3	-45.7	177	68.5
9	17.8	-45.7	188	65.2
10	17.8	-45.3	188	61.3
11	17.9	-45.3	181	76.3
12	22.2	-41.1	167	76.8
13	22.2	-25.9	149	77.5
14	29.9	-4.9	248	79.2
15	48.5	-4.9	564	79.7
16	61	-61.6	937	79.7
17	30	-74.1	1034	79.7
18	17.8	-76.2	1034	79.7
19	15.1	-76.2	1034	75.5
20	14.8	-76.2	1034	71.6
21	14.8	-76.2	872	71.6
22	14.8	-74.5	872	71.6
23	14.8	-74	1056	72.2
24	15.5	-80.7	1056	72.2
25	31.6	-81.4	1294	72.2
26	28.5	-81.4	1294	72.2
27	28.5	-81.4	1294	72.2
28	28.5	-83.2	1294	71.1
29	28.5	-84.3	1294	64.9
30	28.5	-86.3	1294	57.4
31	39.7	-86.5	982	57.4
32	41.2	-86.5	982	51.9
33	23.5	-86.5	982	51.9
34	23.5	-86.7	692	19.3
35	22.9	-87.4	294	27.4
36	22.9	-87.4	259	27.4
37	9.8	-87.4	309	57.9
38	9.8	-87.4	351	57.9
39	5.6	-87.4	373	57.9
40	5.1	-87.4	409	64.2
41	5.1	-87.4	461	76
42	5.1	-87.4	477	76
43	5.1	-87	564	76
44	5.1	-87.7	564	76
45	5.1	-88.4	564	76
46	5.1	-88.4	564	76
47	5.1	-88.4	564	76
48	5.1	-88.4	564	76
49	8.7	-88.4	564	76
50	4.8	-88.4	564	73.8

Following a change of the SOP HISC size from 150 MVAR to 175 MVAR, the Xd'' was adjusted from 0.165 (150 MVA base) to 0.198 (175 MVA base). GE Grid requested ac network models from Nalcor Energy in Siemens PTI PSS®E format to complete their own harmonic impedance study titled *Common-Harmonic Impedance Sectors Study Report document #ILK-AS-SD-8000-EL-H99-0016-01.* The results of the harmonic impedance study are shown in Table 3.

As a result of the harmonic impedance studies, GE Grid have designed a series of filter banks to be installed at the Muskrat Falls Converter Station (MFACS) and the Soldiers Pond Converter Station (SOPCS) to absorb harmonics produced from the switching dynamics of the converter stations.

GE Grid has determined that the ac harmonic filter design at SOP shall involve the switching of five 230 kV, 75 MVAR shunt filter banks to absorb harmonics generated by the converter station switching dynamics and provide reactive power support for the converter and connected ac system. A spare filter bank will be installed at the SOPCS, for a total of six filters to allow operation of the LIL with one filter bank out of service.

GE Grid has determined that the ac harmonic filter design at MFA shall involve the switching of four 315 kV, 72 MVAR shunt filter banks to absorb harmful harmonics and provide reactive power support for the converter and connected ac system. A spare filter bank will be installed at the MFACS, for a total of five filters to allow operation of the LIL with one filter bank out of service.

The SOPCS will have a total of three 75 MVAR 3/12/23 triple tuned filters considered as "Type A" and three 75 MVAR 11/24/36 triple tuned filters considered as "Type B".

The MFACS will have a total of three 72 MVAR 3/12/23 triple tuned filters considered as "Type A" and two 72 MVAR HP11 single tuned filters considered as "Type B".

Table 3: GE Grid Scanned Harmonic Impedances at Soldiers Pond

Converter Station	Soldiers Pond			
Harmonic Order	Minimum		Maximum	
	Zmin	Φmin	Zmax	Φmax
2	27.2	86.5	68.8	66.0
3	41.9	62.4	120.3	37.8
4	24.7	39.9	193.4	49.2
5	43.5	28.0	187.9	54.7
6	14.1	-20.4	348.2	17.5
7	11.6	8.8	256.1	15.5
8	19.8	52.4	224.8	-12.6
9	22.1	66.3	240.6	43.2
10	14.4	-35.5	737.5	10.6
11	10.3	8.6	655.1	-20.9
12	19.3	57.2	351.1	18.0
13	38.6	69.8	517.4	-10.4
14	58.0	75.1	486.5	-29.3
15	44.4	-36.5	173.7	35.3
16	32.7	-25.0	369.7	-6.4
17	24.9	-5.2	369.0	-13.0
18	24.5	20.1	316.1	25.6
19	40.1	-25.2	204.4	-16.1
20	85.2	-65.1	208.2	38.0
21	57.6	-63.5	280.2	29.3
22	53.5	-55.6	247.4	26.7
23	40.0	-73.2	580.4	26.6
24	22.6	-70.0	667.9	15.8
25	9.9	-38.2	343.8	-62.1
26	8.3	-10.8	237.2	-60.4
27	15.6	46.2	218.8	-29.3
28	22.4	54.6	281.1	-21.0
29	44.0	67.6	279.7	-33.2
30	83.6	64.0	199.4	-46.0
31	68.8	-70.4	190.5	19.9
32	62.6	-62.1	148.7	10.4
33	57.0	-77.0	170.2	-7.8
34	32.6	-53.1	184.4	-15.3
35	28.4	-61.1	91.9	-54.3
36	27.2	-53.7	113.0	-27.5
37	19.3	-39.2	83.0	-26.8
38	21.8	-12.1	85.2	-35.4
39	24.0	-51.9	54.7	-56.3
40	17.2	-59.6	63.8	-26.4
41	9.4	-23.3	41.3	-51.9
42	9.7	-14.4	32.6	-34.5
43	8.6	-0.3	20.3	-40.0
44	10.0	24.8	21.6	39.9
45	16.4	43.3	24.9	36.7
46	20.4	45.7	24.9	24.9
47	22.3	58.2	28.3	64.6
48	26.9	64.8	40.1	69.0
49	37.1	68.2	57.3	63.1
50	52.6	63.5	58.1	59.0