

August 2, 2018

The Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, PO Box 21040
St. John's, NL
A1A 5B2 Canada

Attention: Ms. Cheryl Blundon
Director of Corporate Services and Board Secretary

Dear Ms. Blundon:

**Re: The Board's Investigation and Hearing into Supply Issues and Power Outages on the
Island Interconnected System —Operational Studies —Stage 3 Reports**

Further to Hydro's correspondence of July 12, 2018, please find attached the "AC Filter Operational Limits Study" in support of Hydro's filing of the Operational Study —Stage 3 "LIL Power Transfer with MFA Filter Switching (phased monopole approach)". The referenced study was not previously submitted to the Board.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO



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Legal Counsel & Assistant Corporate Secretary
MSL/sk

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Paul Coxworthy – Stewart McKelvey

ecc: Denis Fleming – Cox & Palmer

Roberta Frampton Benefiel – Grand Riverkeeper® Labrador

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Engineering Support Services for: RFI Studies

Newfoundland and Labrador Hydro

Attention: Mr. Rob Collett

AC Filter Operational Limits Study

Technical Note: TN1205.57.03

Date of issue: June 25, 2018

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Revisions

Project Name:	RFI Studies
Document Title:	AC Filter Operational Limits Study
Document Type:	Technical Note
Document No.:	TN1205.57.03
Last Action Date:	June 25, 2018

Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	IFC	N. Denboer	R. Ostash	March 16, 2018	Preliminary draft Issued for review by Hydro
01	IFA	N. Denboer	R. Ostash	April 9, 2018	Updated report based on comments received from Hydro on April 9, 2018
02	IFA	N. Denboer	R. Ostash	May 28, 2018	Updated report to include bipole operation up to 225MW.
03	ABC	N. Denboer	R. Ostash	June 25, 2018	Approved by Hydro on June 25, 2018

Legend of Document Status:

Approved by Client	ABC
Draft for Comments	DFC
Issued for Comments	IFC
Issued for Approval	IFA
Issued for Information	IFI
Returned for Correction	RFC
Approval not Required	ANR

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1. Summary

This report presents a study that investigated possible filter switching during monopole and bipole operation with loading of the Labrador Island Link (LIL) up to 225MW during the phased monopolar approach, prior to the installation of the Muskrat Falls generators. The study only considered the harmonic performance limits; the ac filter ratings were not considered. The study looked at the following possible ac filter configurations:

- Muskrat Falls
 - 2A type filters
 - 1A type filter
- Soldiers Pond
 - 1B type filter
 - 1B + 1A type filter

The objective of the study was to determine whether the IEC performance limits would be exceeded and to determine the associated operational limits to meet IEC limits if required. The study was performed for various system loading and generation dispatches.

In this study, the harmonic currents generated by the converter as given in the GE AC Filter Performance report were used. For LIL bipole operation, additional harmonic currents were determined by PSCAD simulation for dc loading points between those provided in the GE AC Filter Performance report.

The study concluded that the LIL may be operated up to 225MW with the following filter configurations to meet harmonic limits in accordance with IEC specifications:

1. Monopole operation
 - a. Muskrat Falls: one, or two Type A filters in service
 - b. Soldiers Pond: one Type B filter, or one Type A and one Type B filter in service
2. Bipole operation
 - a. Muskrat Falls:
 - i. two Type A filters in service
 - ii. ***Operational restrictions***
 - **If only one Type A filter is in service, the LIL power transfer in bipolar mode must be limited to 130MW, assuming both 315 kV CHF-MFA lines are in-service.**
 - **If one of the two 315kV lines between CHF and MFA is out of service, two Type A filters are required for all LIL power transfer levels from minimum power up to 225 MW**
 - b. Soldiers Pond: one Type B, or one Type A and one Type B filter in service

2. IEC Performance Limits

The performance limits according to IEC 61000-3-6 are given in the table below.

Table 1: IEC performance limits

Odd harmonic non-multiple of 3		Odd harmonics multiple of 3		Even harmonics	
Harmonic	Dh (%)	Harmonic	Dh (%)	Harmonic	Dh (%)
5	2	3	2	2	1.4
7	2	9	1	4	0.8
11	1.5	15	0.3	6	0.4
13	1.5	21	0.2	8	0.4
$17 \leq h \leq 49$	$1.2 * 17/h$	$21 < h \leq 45$	0.2	$10 \leq h \leq 50$	$0.19 * (10/h) + 0.22$
THD \leq 3%					

3. Muskrat Falls

3.1 AC system harmonic impedance

Because this study was looking at operational limits, impedance sectors were not used to represent the ac system as was the case for the contract design. Rather, the analysis was performed using loadflow cases which were created by Hydro where calculated impedance points at each harmonic order were considered under various operating conditions. The loadflow cases to represent the Labrador system at peak, intermediate and light load scenarios as shown in Table 2.

Table 2: Loadflows considered for MFA

Number	Load Condition	Island Demand (MW)	LIL LAB to NF Flow (MW)	Island Generation
MON1	Peak	1727.8	225	Maximum
MON3	Intermediate	1246.2	225	Maximum
MON5	Light	762.9	225	Minimum generation

The system conditions that were considered for each power flow case were:

- System intact
- 315kV transmission line between CHF and MFA out of service
- One or two 735kV transmission lines between CHF and Montagnais out of service
- Number of online CHF generators reduced to five

3.2 Background harmonics

The measured background harmonics at CHF were increased by a factor of two¹ and applied at the MFA converter bus. Table 3 shows the background harmonics included in the study. The values for harmonics not included in Table 3 were negligible.

¹ Measurements were performed before the construction of Muskrat Falls Terminal Station 2. In addition, it is expected that the ac terminal station and HVdc converters will be in service before Muskrat Falls generators. On this basis, background harmonics were doubled to provide a conservative representation of system conditions.

Table 3: Background harmonics applied at MFA

Harmonic	2x measured background harmonics at CHF
2	0.24
3	0.84
4	0.12
5	0.5
6	0.08
7	0.32
8	0.04
9	0.08
10	0.06
11	0.12
12	0.04
13	0.18
14	0.04
15	0.02
16	0.02
17	0.08
18	0.04
19	0.06
20	0.02
21	0.02
22	0.04
23	0.04
24	0.02
25	0.04
26	0.02
27	0.02
28	0.02
29	0.02
30	0.02
31	0.02
33	0.02
34	0.02
35	0.02
37	0.02
41	0.02
49	0.02

3.3 Results

In order to determine whether the IEC limits were met, the harmonic performance indices were calculated for two filter configurations:

- with 2A type filters in service, and
- with 1A type filter in service.

The Type A filter is a triple tuned filter, tuned to harmonics 3, 12, and 23. The filter component data is shown in Figure 1 and Table 4.

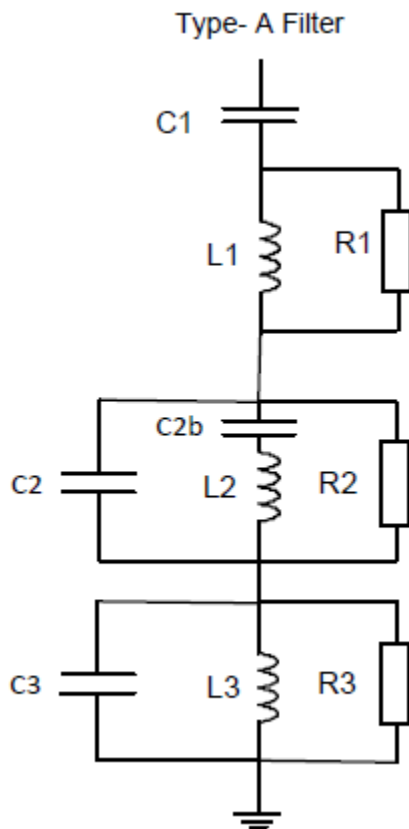


Figure 1: Type A filter circuit

Table 4: Type A filter parameters

Nominal Mvar	72
system voltage (kVrms L-L)	315
C ₁ (µF)	1.91
C ₂ (µF)	13.58
C ₃ (µF)	2.80
L ₁ (mH)	21.03
L ₂ (mH)	55.44
L ₃ (mH)	6.98
R ₁ (Ω)	369
R ₂ (Ω)	443
R ₃ (Ω)	1549
C _{2b} (µF)	126.9

The performance calculations were repeated with and without the 150MVar shunt reactor in service.

The study results showed that the IEC limits were met in all cases for monopole operation. For bipole operation, the IEC limits were met for cases with two Type A filters in service up to 225MW. With one Type A filter in service in bipole operation, the IEC limits were met up to 130MW except for the case when one 315kV line between CHF and MFA was out of service, in this case, the IEC limits were met up to 90MW. The results are shown in Appendix 1 and 3, values above the IEC limits are shown in red. Note that these results are the maximum values for all cases studied, and the values for each harmonic order may not correspond to the same case.

The LIL may therefore be operated up to 225 MW with either one or two Type A filters in service at Muskrat Falls in monopole operation. In bipole operation, the LIL may be operated up to 90MW with one Type A filter in service when one 315kV line between CHF and MFA is out of service and up to 130MW for all other contingencies studied. With two Type A filters in service, the LIL may be operated up to 225MW in bipole operation.

4. Soldiers Pond

4.1 AC system harmonic impedance

Similar to Muskrat Falls, at Soldiers Pond (SOP), the study considered the calculated impedance points at each harmonic order for the loadflows in Table 5 and for the contingencies listed below. The loadflow cases were created by Hydro to represent the Island system at peak, intermediate and light load scenarios, with the ML link operating in both import and export conditions. These cases were based on the year 2018 and were designed to maximize production from hydraulic resources.

Table 5: Loadflows considered for SOP

Number	Load Condition	Island Demand (MW)	ML Import/Export (MW)	LIL LAB to NF Flow (MW)	NF to NS Flow	Island Generation
MON1	Peak	1727.8	146 EX	225	Maximum export reserve	Maximum generation
MON2	Peak	1753.9	207 IM	225	Max import	Economic Dispatch
MON3	Intermediate	1246.2	376 EX	225	Maximum export	Maximum generation
MON4	Intermediate	1221.6	90 IM	225	Maximum import	Economic dispatch
MON5	Light	762.9	294 EX	225	Maximum export reserve	Minimum generation
MON6	Light	759.1	165 IM	52	Maximum import	Minimum generation

The system conditions that were considered for each power flow case were:

- System intact
- 0-3 SOP syncs in service
- 0-3 HRD syncs in service
- 230kV transmission line between SOP and HRD out of service
- 230kV transmission line between SOP and WAV out of service
- 230kV transmission line between SOP and HWD out of service

4.2 Background harmonics

For SOP, background harmonics were set in accordance with the maximum of the measured background harmonics as measured at Hardwoods Terminal Station, Western Avalon Terminal Station, and Holyrood Terminal Station.

Table 6 below shows the background harmonics included in the study. The values for harmonics not included in Table 6 were negligible.

Table 6: Background harmonics applied at SOP

Harmonic	Maximum measured background harmonics at HWD/WAV/HRD
2	0.02
3	1.06
4	0.08
5	1.42
6	0.03
7	0.52
8	0.01
9	0.20
11	0.10
13	0.36
14	0.01
15	0.01
16	0.01
17	0.05
18	0.01
19	0.03
20	0.01
21	0.01
23	0.05
24	0.01
25	0.07
27	0.01
29	0.02
31	0.01
35	0.01
37	0.01
41	0.01

4.3 Results

In order to determine whether the IEC limits were met, the harmonic performance indices were calculated for two filter configurations:

- with 1B type filter in service, and
- with 1B type and 1A type filter in service.

The Type A filter is a triple tuned filter, tuned to harmonics 3, 12, and 23. The Type B filter is a triple tuned filter, tuned to harmonics 11, 24, and 36. The filter component data is shown in Figure 2 and Table 7.

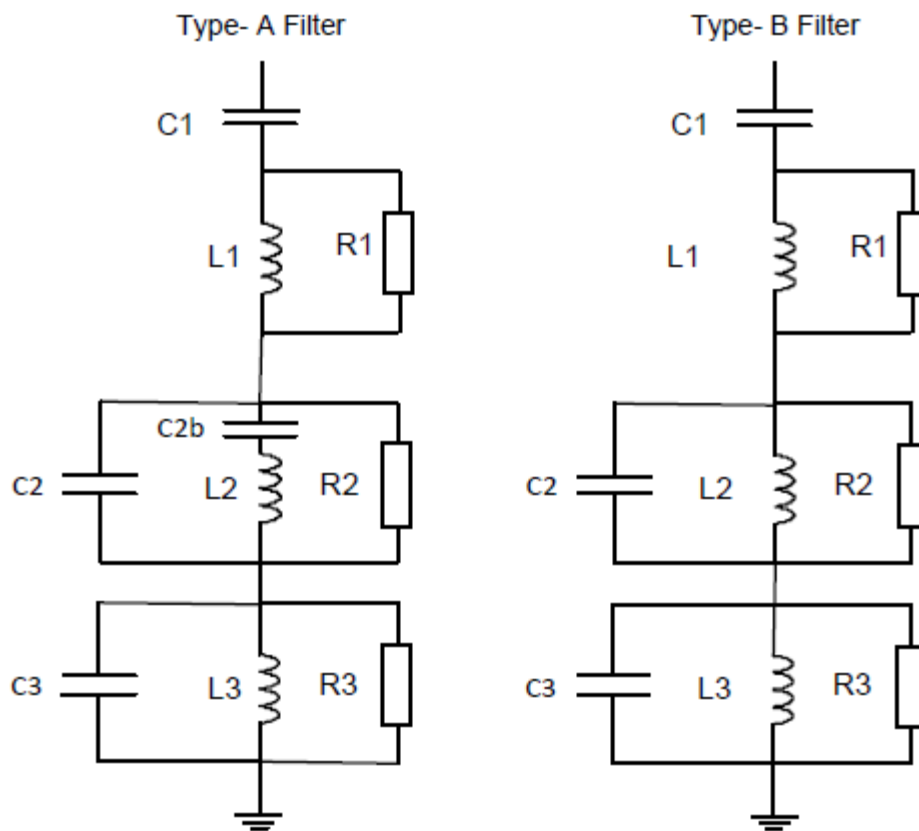


Figure 2: SOP filter circuit

Table 7: SOP filter parameters

Filter type	A	B
Nominal MVar	75	75
system voltage (kVrms L-L)	230	230
C ₁ (µF)	3.73	3.74
C ₂ (µF)	17.34	4.50
C ₃ (µF)	6.99	7.25
L ₁ (mH)	10.72	5.15
L ₂ (mH)	40.21	5.35
L ₃ (mH)	2.88	1.12
R ₁ (Ω)	141	170
R ₂ (Ω)	514	175
R ₃ (Ω)	2028	1491
C _{2b} (µF)	175	-

When the measured background harmonics are applied at Soldiers Pond, the IEC limits were met up to 225MW.

The results are shown in Appendix 2 and 4, values above the IEC limits are shown in red. Note that these results are the maximum values for all cases studied, and the values for each harmonic order may not correspond to the same case.

On the basis of the above, the LIL may be operated up to 225MW with either one Type B filter in service, or with one Type A and one Type B filter in service at SOP in monopole or bipole operation.

5. Conclusion

On the basis of the above, the LIL may be operated up to 225MW with the following filter configurations to meet harmonic limits in accordance with IEC specifications:

- Monopole operation
 - Muskrat Falls: one or two Type A filters in service
 - Soldiers Pond: one Type B filter or one Type A and one Type B filter in service
- Bipole operation
 - Muskrat Falls: two Type A filters in service, operation with one Type A filter in service is possible only up to 130MW for all cases except when one 315kV line between CHF and MFA is out of service, in this case, operation is possible only up to 90MW
 - Soldiers Pond: one Type B filter or one Type A and one Type B filter in service

Appendix 1

MFA Monopole Results



Table 8: MFA Harmonic performance – 2A type, no shunt reactor

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D2	1.4	0.24	0.24	0.24	0.24	0.24
D3	2	0.85	0.85	0.85	0.85	0.85
D4	0.8	0.12	0.12	0.12	0.12	0.12
D5	2	0.50	0.50	0.50	0.50	0.50
D6	0.4	0.08	0.08	0.08	0.08	0.08
D7	2	0.32	0.32	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04	0.04	0.04
D9	1	0.08	0.08	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06	0.06	0.06
D11	1.5	0.17	0.24	0.31	0.38	0.44
D12	0.3	0.04	0.04	0.04	0.04	0.04
D13	1.5	0.19	0.25	0.32	0.41	0.49
D14	0.3	0.04	0.04	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02	0.02	0.02
D17	1.2	0.08	0.09	0.10	0.11	0.12
D18	0.3	-	-	-	-	-
D19	1.1	0.06	0.06	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.02	0.02	0.02
D22	0.2	0.04	0.04	0.04	0.04	0.04
D23	0.9	0.18	0.27	0.33	0.37	0.38
D24	0.2	0.02	0.02	0.02	0.02	0.02
D25	0.8	0.07	0.14	0.20	0.24	0.26
D26	0.2	0.02	0.02	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02	0.02	0.02
D28	0.2	0.02	0.02	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02	0.02	0.02
D30	0.2	0.02	0.02	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02	0.02	0.02
D32	0.2	-	-	-	-	-
D33	0.2	0.02	0.02	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02	0.02	0.02
D35	0.6	0.15	0.21	0.22	0.19	0.13
D36	0.2	-	-	-	-	-
D37	0.6	0.09	0.16	0.20	0.19	0.15
D38	0.2	-	-	-	-	-
D39	0.2	-	-	-	0.00	0.00
D40	0.2	-	-	-	-	-
D41	0.5	0.02	0.02	0.02	0.02	0.02

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D42	0.2	-	-	-	-	-
D43	0.5	-	0.01	0.01	0.01	0.01
D44	0.2	-	-	-	-	-
D45	0.2	-	-	-	-	0.01
D46	0.2	-	-	-	-	-
D47	0.4	0.09	0.11	0.08	0.08	0.10
D48	0.2	-	-	-	-	-
D49	0.4	0.06	0.10	0.09	0.07	0.08
D50	0.2	-	-	-	-	-
THD	3	1.14	1.20	1.25	1.29	1.32

Table 9: MFA Harmonic performance – 2A type, with shunt reactor

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D2	1.4	0.24	0.24	0.24	0.24	0.24
D3	2	0.85	0.85	0.85	0.85	0.85
D4	0.8	0.12	0.12	0.12	0.12	0.12
D5	2	0.50	0.50	0.50	0.50	0.50
D6	0.4	0.08	0.08	0.08	0.08	0.08
D7	2	0.32	0.32	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04	0.04	0.04
D9	1	0.08	0.08	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06	0.06	0.06
D11	1.5	0.17	0.24	0.31	0.38	0.45
D12	0.3	0.04	0.04	0.04	0.04	0.04
D13	1.5	0.19	0.25	0.32	0.41	0.49
D14	0.3	0.04	0.04	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02	0.02	0.02
D17	1.2	0.08	0.09	0.10	0.11	0.12
D18	0.3	-	-	-	-	-
D19	1.1	0.06	0.06	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.02	0.02	0.02
D22	0.2	0.04	0.04	0.04	0.04	0.04
D23	0.9	0.18	0.27	0.33	0.37	0.39
D24	0.2	0.02	0.02	0.02	0.02	0.02
D25	0.8	0.07	0.14	0.20	0.24	0.26
D26	0.2	0.02	0.02	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02	0.02	0.02

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D28	0.2	0.02	0.02	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02	0.02	0.02
D30	0.2	0.02	0.02	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02	0.02	0.02
D32	0.2	-	-	-	-	-
D33	0.2	0.02	0.02	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02	0.02	0.02
D35	0.6	0.15	0.21	0.22	0.19	0.13
D36	0.2	-	-	-	-	-
D37	0.6	0.09	0.16	0.20	0.19	0.15
D38	0.2	-	-	-	-	-
D39	0.2	-	-	-	0.00	0.00
D40	0.2	-	-	-	-	-
D41	0.5	0.02	0.02	0.02	0.02	0.02
D42	0.2	-	-	-	-	-
D43	0.5	-	0.01	0.01	0.01	0.01
D44	0.2	-	-	-	-	-
D45	0.2	-	-	-	-	0.01
D46	0.2	-	-	-	-	-
D47	0.4	0.09	0.11	0.08	0.08	0.10
D48	0.2	-	-	-	-	-
D49	0.4	0.06	0.10	0.09	0.07	0.08
D50	0.2	-	-	-	-	-
THD	3	1.15	1.20	1.25	1.29	1.32

Table 10: MFA Harmonic performance – 1A type, no shunt reactor

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D2	1.4	0.24	0.24	0.24	0.24	0.24
D3	2	0.87	0.87	0.87	0.87	0.87
D4	0.8	0.12	0.12	0.12	0.12	0.12
D5	2	0.50	0.50	0.50	0.50	0.51
D6	0.4	0.08	0.08	0.08	0.08	0.08
D7	2	0.32	0.32	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04	0.04	0.04
D9	1	0.08	0.08	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06	0.06	0.06
D11	1.5	0.30	0.47	0.63	0.79	0.93
D12	0.3	0.04	0.04	0.04	0.04	0.04
D13	1.5	0.23	0.39	0.57	0.77	0.95

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D14	0.3	0.04	0.04	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02	0.02	0.02
D17	1.2	0.09	0.10	0.13	0.15	0.18
D18	0.3	-	-	-	-	-
D19	1.1	0.06	0.06	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.03	0.03	0.03
D22	0.2	0.04	0.04	0.04	0.04	0.04
D23	0.9	0.35	0.53	0.66	0.74	0.76
D24	0.2	0.02	0.02	0.02	0.02	0.02
D25	0.8	0.12	0.26	0.37	0.46	0.50
D26	0.2	0.02	0.02	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02	0.02	0.02
D28	0.2	0.02	0.02	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02	0.02	0.03
D30	0.2	0.02	0.02	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02	0.02	0.03
D32	0.2	-	-	-	-	-
D33	0.2	0.02	0.02	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02	0.02	0.02
D35	0.6	0.27	0.38	0.40	0.34	0.23
D36	0.2	-	-	-	-	-
D37	0.6	0.11	0.22	0.26	0.26	0.20
D38	0.2	-	-	-	-	-
D39	0.2	-	-	-	0.00	0.00
D40	0.2	-	-	-	-	-
D41	0.5	0.02	0.02	0.03	0.03	0.03
D42	0.2	-	-	-	-	-
D43	0.5	-	0.01	0.01	0.02	0.02
D44	0.2	-	-	-	-	-
D45	0.2	-	-	-	-	0.01
D46	0.2	-	-	-	-	-
D47	0.4	0.11	0.13	0.10	0.09	0.11
D48	0.2	-	-	-	-	-
D49	0.4	0.09	0.14	0.13	0.10	0.12
D50	0.2	-	-	-	-	-
THD	3	1.25	1.42	1.58	1.71	1.81

Table 11: MFA Harmonic performance – 1A type, with shunt reactor

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D2	1.4	0.24	0.24	0.24	0.24	0.24
D3	2	0.87	0.87	0.87	0.87	0.87
D4	0.8	0.12	0.12	0.12	0.12	0.12
D5	2	0.50	0.50	0.50	0.50	0.51
D6	0.4	0.08	0.08	0.08	0.08	0.08
D7	2	0.32	0.32	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04	0.04	0.04
D9	1	0.08	0.08	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06	0.06	0.06
D11	1.5	0.30	0.47	0.64	0.79	0.94
D12	0.3	0.04	0.04	0.04	0.04	0.04
D13	1.5	0.23	0.39	0.57	0.76	0.94
D14	0.3	0.04	0.04	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02	0.02	0.02
D17	1.2	0.09	0.10	0.13	0.15	0.18
D18	0.3	-	-	-	-	-
D19	1.1	0.06	0.06	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.03	0.03	0.03
D22	0.2	0.04	0.04	0.04	0.04	0.04
D23	0.9	0.35	0.53	0.66	0.74	0.77
D24	0.2	0.02	0.02	0.02	0.02	0.02
D25	0.8	0.12	0.26	0.37	0.46	0.50
D26	0.2	0.02	0.02	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02	0.02	0.02
D28	0.2	0.02	0.02	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02	0.02	0.02
D30	0.2	0.02	0.02	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02	0.02	0.03
D32	0.2	-	-	-	-	-
D33	0.2	0.02	0.02	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02	0.02	0.02
D35	0.6	0.27	0.38	0.40	0.34	0.23
D36	0.2	-	-	-	-	-
D37	0.6	0.11	0.22	0.27	0.26	0.20
D38	0.2	-	-	-	-	-
D39	0.2	-	-	-	0.00	0.00
D40	0.2	-	-	-	-	-
D41	0.5	0.02	0.02	0.03	0.03	0.03

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D42	0.2	-	-	-	-	-
D43	0.5	-	0.01	0.01	0.02	0.02
D44	0.2	-	-	-	-	-
D45	0.2	-	-	-	-	0.01
D46	0.2	-	-	-	-	-
D47	0.4	0.11	0.13	0.10	0.09	0.11
D48	0.2	-	-	-	-	-
D49	0.4	0.09	0.14	0.13	0.10	0.12
D50	0.2	-	-	-	-	-
THD	3	1.25	1.42	1.58	1.71	1.82

Appendix 2

SOP Monopole Results



Table 12: SOP Harmonic performance – 1B type, measured background harmonics

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D2	1.4	0.02	0.02	0.02	0.02	0.02
D3	2	1.06	1.06	1.06	1.06	1.06
D4	0.8	0.08	0.08	0.08	0.08	0.08
D5	2	1.42	1.42	1.42	1.42	1.42
D6	0.4	0.03	0.03	0.03	0.03	0.03
D7	2	0.52	0.52	0.52	0.52	0.53
D8	0.4	0.01	0.01	0.01	0.01	0.01
D9	1	0.20	0.20	0.20	0.20	0.20
D10	0.4	-	-	-	-	-
D11	1.5	0.24	0.33	0.42	0.50	0.57
D12	0.3	-	-	-	-	-
D13	1.5	0.48	0.53	0.70	0.90	1.11
D14	0.3	0.01	0.01	0.01	0.01	0.01
D15	0.3	0.01	0.01	0.01	0.01	0.02
D16	0.3	0.01	0.01	0.01	0.01	0.01
D17	1.2	0.05	0.05	0.06	0.07	0.09
D18	0.3	0.01	0.01	0.01	0.01	0.01
D19	1.1	0.03	0.03	0.04	0.05	0.06
D20	0.3	0.01	0.01	0.01	0.01	0.01
D21	0.2	0.01	0.01	0.01	0.01	0.01
D22	0.2	-	-	-	-	-
D23	0.9	0.21	0.34	0.44	0.51	0.54
D24	0.2	0.01	0.01	0.01	0.01	0.01
D25	0.8	0.12	0.22	0.32	0.39	0.43
D26	0.2	-	-	-	-	-
D27	0.2	0.01	0.01	0.01	0.01	0.01
D28	0.2	-	-	-	-	-
D29	0.7	0.02	0.03	0.07	0.09	0.11
D30	0.2	-	-	-	-	-
D31	0.7	0.01	0.02	0.02	0.04	0.05
D32	0.2	-	-	-	-	-
D33	0.2	-	-	-	-	-
D34	0.2	-	-	-	-	-
D35	0.6	0.09	0.14	0.16	0.15	0.12
D36	0.2	-	-	-	-	-
D37	0.6	0.04	0.09	0.12	0.13	0.11
D38	0.2	-	-	-	-	-
D39	0.2	-	-	-	-	-
D40	0.2	-	-	-	-	-
D41	0.5	0.01	0.01	0.01	0.01	0.01

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D42	0.2	-	-	-	-	-
D43	0.5	-	-	-	-	-
D44	0.2	-	-	-	-	-
D45	0.2	-	-	-	-	-
D46	0.2	-	-	-	-	-
D47	0.4	0.07	0.09	0.08	0.05	0.03
D48	0.2	-	-	-	-	-
D49	0.4	0.05	0.10	0.10	0.08	0.03
D50	0.2	-	-	-	-	-
THD	3	1.95	1.99	2.08	2.18	2.30

Table 13: SOP Harmonic performance – 1B + 1A type, measured background harmonics

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D2	1.4	0.02	0.02	0.02	0.02	0.02
D3	2	1.06	1.06	1.06	1.06	1.06
D4	0.8	0.08	0.08	0.08	0.08	0.08
D5	2	1.42	1.42	1.42	1.42	1.42
D6	0.4	0.03	0.03	0.03	0.03	0.03
D7	2	0.52	0.52	0.52	0.52	0.53
D8	0.4	0.01	0.01	0.01	0.01	0.01
D9	1	0.20	0.20	0.20	0.20	0.20
D10	0.4	-	-	-	-	-
D11	1.5	0.24	0.33	0.42	0.50	0.57
D12	0.3	-	-	-	-	-
D13	1.5	0.48	0.53	0.70	0.90	1.11
D14	0.3	0.01	0.01	0.01	0.01	0.01
D15	0.3	0.01	0.01	0.01	0.01	0.02
D16	0.3	0.01	0.01	0.01	0.01	0.01
D17	1.2	0.05	0.05	0.06	0.07	0.09
D18	0.3	0.01	0.01	0.01	0.01	0.01
D19	1.1	0.03	0.03	0.04	0.05	0.06
D20	0.3	0.01	0.01	0.01	0.01	0.01
D21	0.2	0.01	0.01	0.01	0.01	0.01
D22	0.2	-	-	-	-	-
D23	0.9	0.21	0.34	0.44	0.51	0.54
D24	0.2	0.01	0.01	0.01	0.01	0.01
D25	0.8	0.12	0.22	0.32	0.39	0.43
D26	0.2	-	-	-	-	-
D27	0.2	0.01	0.01	0.01	0.01	0.01

	IEC Limit	DC Loading (MW)				
		45	90	135	180	225
D28	0.2	-	-	-	-	-
D29	0.7	0.02	0.03	0.07	0.09	0.11
D30	0.2	-	-	-	-	-
D31	0.7	0.01	0.02	0.02	0.04	0.05
D32	0.2	-	-	-	-	-
D33	0.2	-	-	-	-	-
D34	0.2	-	-	-	-	-
D35	0.6	0.09	0.14	0.16	0.15	0.12
D36	0.2	-	-	-	-	-
D37	0.6	0.04	0.09	0.12	0.13	0.11
D38	0.2	-	-	-	-	-
D39	0.2	-	-	-	-	-
D40	0.2	-	-	-	-	-
D41	0.5	0.01	0.01	0.01	0.01	0.01
D42	0.2	-	-	-	-	-
D43	0.5	-	-	-	-	-
D44	0.2	-	-	-	-	-
D45	0.2	-	-	-	-	-
D46	0.2	-	-	-	-	-
D47	0.4	0.07	0.09	0.08	0.05	0.03
D48	0.2	-	-	-	-	-
D49	0.4	0.05	0.10	0.10	0.08	0.03
D50	0.2	-	-	-	-	-
THD	3	1.95	1.99	2.08	2.18	2.30

Appendix 3

MFA Bipole Results



Table 14: MFA Harmonic performance – 2A type, no shunt reactor, all cases

	IEC Limit	DC Loading (MW)		
		90	180	270
D2	1.4	0.24	0.24	0.24
D3	2	0.92	0.92	0.91
D4	0.8	0.12	0.12	0.12
D5	2	0.50	0.50	0.50
D6	0.4	0.08	0.08	0.08
D7	2	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04
D9	1	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06
D11	1.5	0.33	0.49	0.64
D12	0.3	0.04	0.04	0.04
D13	1.5	0.21	0.35	0.51
D14	0.3	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02
D17	1.2	0.08	0.10	0.12
D18	0.3	0.04	0.04	0.04
D19	1.1	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.02
D22	0.2	0.04	0.04	0.04
D23	0.9	0.39	0.57	0.68
D24	0.2	0.02	0.02	0.02
D25	0.8	0.11	0.23	0.36
D26	0.2	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02
D28	0.2	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02
D30	0.2	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02
D32	0.2	-	-	-
D33	0.2	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02
D35	0.6	0.31	0.42	0.42
D36	0.2	-	-	-
D37	0.6	0.15	0.31	0.40
D38	0.2	-	-	-
D39	0.2	-	-	-
D40	0.2	-	-	-
D41	0.5	0.02	0.02	0.02

	IEC Limit	DC Loading (MW)		
		90	180	270
D42	0.2	-	-	-
D43	0.5	0.01	0.01	0.02
D44	0.2	-	-	-
D45	0.2	-	-	0.01
D46	0.2	-	-	-
D47	0.4	0.19	0.22	0.15
D48	0.2	-	-	-
D49	0.4	0.12	0.20	0.18
D50	0.2	-	-	-
THD	3	1.30	1.49	1.63

Table 15: MFA Harmonic performance – 2A type, with shunt reactor, all cases

	IEC Limit	DC Loading (MW)		
		90	180	270
D2	1.4	0.24	0.24	0.24
D3	2	0.92	0.92	0.91
D4	0.8	0.12	0.12	0.12
D5	2	0.50	0.50	0.50
D6	0.4	0.08	0.08	0.08
D7	2	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04
D9	1	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06
D11	1.5	0.33	0.49	0.64
D12	0.3	0.04	0.04	0.04
D13	1.5	0.21	0.35	0.51
D14	0.3	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02
D17	1.2	0.08	0.10	0.12
D18	0.3	0.04	0.04	0.04
D19	1.1	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.02
D22	0.2	0.04	0.04	0.04
D23	0.9	0.40	0.57	0.68
D24	0.2	0.02	0.02	0.02
D25	0.8	0.11	0.23	0.36
D26	0.2	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02

	IEC Limit	DC Loading (MW)		
		90	180	270
D28	0.2	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02
D30	0.2	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02
D32	0.2	-	-	-
D33	0.2	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02
D35	0.6	0.31	0.42	0.42
D36	0.2	-	-	-
D37	0.6	0.15	0.31	0.40
D38	0.2	-	-	-
D39	0.2	-	-	-
D40	0.2	-	-	-
D41	0.5	0.02	0.02	0.02
D42	0.2	-	-	-
D43	0.5	0.01	0.01	0.02
D44	0.2	-	-	-
D45	0.2	-	-	0.01
D46	0.2	-	-	-
D47	0.4	0.19	0.22	0.15
D48	0.2	-	-	-
D49	0.4	0.12	0.20	0.18
D50	0.2	-	-	-
THD	3	1.31	1.49	1.64

Table 16: MFA Harmonic performance – 1A type, no shunt reactor, 315kV CHF line out

	IEC Limit	DC Loading (MW)					
		90	100	130	140	180	270
D2	1.4	0.24	0.24	0.24	0.24	0.24	0.24
D3	2	1.08	0.84	0.84	0.84	1.07	1.06
D4	0.8	0.12	0.12	0.12	0.12	0.12	0.12
D5	2	0.50	0.50	0.50	0.50	0.50	0.50
D6	0.4	0.08	0.08	0.08	0.08	0.08	0.08
D7	2	0.32	0.32	0.32	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04	0.04	0.04	0.04
D9	1	0.08	0.08	0.08	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06	0.06	0.06	0.06
D11	1.5	0.65	0.72	0.88	0.92	1.00	1.32
D12	0.3	0.04	0.04	0.04	0.04	0.04	0.04
D13	1.5	0.26	0.28	0.35	0.34	0.58	0.89

	IEC Limit	DC Loading (MW)					
		90	100	130	140	180	270
D14	0.3	0.04	0.04	0.04	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02	0.02	0.02	0.02
D17	1.2	0.09	0.08	0.08	0.08	0.13	0.18
D18	0.3	0.04	0.04	0.04	0.04	0.04	0.04
D19	1.1	0.06	0.06	0.06	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.02	0.02	0.03	0.03
D22	0.2	0.04	0.04	0.04	0.04	0.04	0.04
D23	0.9	0.78	0.70	0.85	0.91	1.13	1.36
D24	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D25	0.8	0.20	0.26	0.33	0.36	0.45	0.71
D26	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D28	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02	0.02	0.02	0.02
D30	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02	0.02	0.02	0.03
D32	0.2	-	-	-	-	-	-
D33	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D35	0.6	0.58	0.61	0.75	0.79	0.78	0.79
D36	0.2	-	-	0.01	0.01	-	-
D37	0.6	0.21	0.26	0.34	0.37	0.42	0.53
D38	0.2	-	-	-	-	-	-
D39	0.2	-	-	-	-	-	-
D40	0.2	-	-	-	-	-	-
D41	0.5	0.02	0.02	0.02	0.02	0.03	0.03
D42	0.2	-	-	-	-	-	-
D43	0.5	0.01	0.01	0.01	0.01	0.02	0.03
D44	0.2	-	-	-	-	-	-
D45	0.2	-	0.01	0.01	0.01	-	0.01
D46	0.2	-	-	0.01	0.01	-	-
D47	0.4	0.22	0.25	0.29	0.30	0.25	0.17
D48	0.2	-	-	-	-	-	-
D49	0.4	0.12	0.14	0.18	0.20	0.21	0.19
D50	0.2	-	-	-	-	-	-
THD	3	1.75	1.64	1.86	1.94	2.22	2.60

Table 17: MFA Harmonic performance – 1A type, with shunt reactor, 315kV CHF line out

	IEC Limit	DC Loading (MW)					
		90	100	130	140	180	270
D2	1.4	0.24	0.24	0.24	0.24	0.24	0.24
D3	2	1.12	0.84	0.84	0.84	1.11	1.09
D4	0.8	0.12	0.12	0.12	0.12	0.12	0.12
D5	2	0.50	0.50	0.50	0.50	0.50	0.50
D6	0.4	0.08	0.08	0.08	0.08	0.08	0.08
D7	2	0.32	0.32	0.32	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04	0.04	0.04	0.04
D9	1	0.08	0.08	0.08	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06	0.06	0.06	0.06
D11	1.5	0.65	0.72	0.88	0.92	1.00	1.33
D12	0.3	0.04	0.04	0.04	0.04	0.04	0.04
D13	1.5	0.26	0.28	0.35	0.34	0.58	0.89
D14	0.3	0.04	0.04	0.04	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02	0.02	0.02	0.02
D17	1.2	0.09	0.08	0.08	0.08	0.13	0.18
D18	0.3	0.04	0.04	0.04	0.04	0.04	0.04
D19	1.1	0.06	0.06	0.06	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.02	0.02	0.03	0.03
D22	0.2	0.04	0.04	0.04	0.04	0.04	0.04
D23	0.9	0.78	0.70	0.85	0.92	1.14	1.36
D24	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D25	0.8	0.20	0.26	0.33	0.36	0.45	0.71
D26	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D28	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02	0.02	0.02	0.02
D30	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02	0.02	0.02	0.03
D32	0.2	-	-	-	-	-	-
D33	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02	0.02	0.02	0.02
D35	0.6	0.58	0.61	0.75	0.79	0.78	0.79
D36	0.2	-	-	0.01	0.01	-	-
D37	0.6	0.21	0.26	0.34	0.37	0.42	0.54
D38	0.2	-	-	-	-	-	-
D39	0.2	-	-	-	-	-	-
D40	0.2	-	-	-	-	-	-
D41	0.5	0.02	0.02	0.02	0.02	0.03	0.03

	IEC Limit	DC Loading (MW)							
		90	130	140	150	160	170	180	270
D28	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
D30	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
D32	0.2	-	-	-	0.01	-	-	-	-
D33	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D35	0.6	0.45	0.58	0.62	0.64	0.67	0.72	0.61	0.62
D36	0.2	-	-	-	-	-	-	-	-
D37	0.6	0.07	0.11	0.12	0.13	0.14	0.15	0.14	0.17
D38	0.2	-	-	-	0.01	-	-	-	-
D39	0.2	-	-	-	-	-	-	-	-
D40	0.2	-	-	-	0.01	-	-	-	-
D41	0.5	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
D42	0.2	-	0.00	0.00	0.01	0.00	0.01	-	-
D43	0.5	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.04
D44	0.2	-	-	0.01	0.01	-	0.01	-	-
D45	0.2	-	-	0.01	0.01	-	0.01	-	0.01
D46	0.2	-	-	-	-	-	-	-	-
D47	0.4	0.04	0.06	0.06	0.06	0.06	0.07	0.05	0.03
D48	0.2	-	-	-	-	-	-	-	-
D49	0.4	0.17	0.26	0.28	0.30	0.31	0.34	0.29	0.27
D50	0.2	-	-	-	0.01	-	0.01	-	-
THD	3	1.70	1.73	1.79	1.85	1.90	1.98	2.08	2.44

Table 19: MFA Harmonic performance – 1A type, with shunt reactor, all other cases

	IEC Limit	DC Loading (MW)							
		90	130	140	150	160	170	180	270
D2	1.4	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
D3	2	1.14	0.84	0.84	0.84	0.84	0.84	1.12	1.11
D4	0.8	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
D5	2	0.50	0.50	0.51	0.51	0.50	0.51	0.50	0.50
D6	0.4	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
D7	2	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
D8	0.4	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
D9	1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
D10	0.4	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
D11	1.5	0.67	0.91	0.95	0.98	1.02	1.07	1.03	1.37
D12	0.3	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
D13	1.5	0.28	0.37	0.36	0.41	0.46	0.51	0.63	0.97

	IEC Limit	DC Loading (MW)							
		90	130	140	150	160	170	180	270
D14	0.3	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
D15	0.3	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02
D16	0.3	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D17	1.2	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09
D18	0.3	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
D19	1.1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
D20	0.3	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D21	0.2	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.03
D22	0.2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
D23	0.9	0.70	0.76	0.82	0.85	0.90	0.96	1.01	1.21
D24	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D25	0.8	0.17	0.29	0.32	0.35	0.38	0.41	0.39	0.61
D26	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D27	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D28	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D29	0.7	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D30	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D31	0.7	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
D32	0.2	-	-	-	0.01	-	-	-	-
D33	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D34	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D35	0.6	0.45	0.59	0.62	0.64	0.67	0.72	0.61	0.62
D36	0.2	-	-	-	-	-	-	-	-
D37	0.6	0.07	0.11	0.12	0.13	0.14	0.15	0.14	0.17
D38	0.2	-	-	-	0.01	-	-	-	-
D39	0.2	-	-	-	-	-	-	-	-
D40	0.2	-	-	-	0.01	-	-	-	-
D41	0.5	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
D42	0.2	-	-	-	0.01	-	0.01	-	-
D43	0.5	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.04
D44	0.2	-	-	0.01	0.01	-	0.01	-	-
D45	0.2	-	-	0.01	0.01	-	0.01	-	0.01
D46	0.2	-	-	-	-	-	-	-	-
D47	0.4	0.04	0.06	0.06	0.06	0.06	0.07	0.05	0.03
D48	0.2	-	-	-	-	-	-	-	-
D49	0.4	0.17	0.26	0.28	0.29	0.31	0.34	0.29	0.27
D50	0.2	-	-	-	0.01	-	0.01	-	-
THD	3	1.71	1.73	1.80	1.85	1.91	1.99	2.10	2.45

Appendix 4

SOP Bipole Results



Table 20: SOP Harmonic performance – 1B type, measured background harmonics

	IEC Limit	DC Loading (MW)			
		90	180	225	270
D2	1.4	0.02	0.02	0.02	0.02
D3	2	1.10	1.10	1.06	1.09
D4	0.8	0.08	0.08	0.08	0.08
D5	2	1.42	1.42	1.42	1.42
D6	0.4	0.03	0.03	0.03	0.03
D7	2	0.52	0.52	0.52	0.53
D8	0.4	0.01	0.01	0.01	0.01
D9	1	0.20	0.20	0.20	0.20
D10	0.4	-	-	-	-
D11	1.5	0.55	0.74	0.62	0.92
D12	0.3	-	-	-	-
D13	1.5	0.90	0.83	1.16	1.09
D14	0.3	0.01	0.01	0.01	0.01
D15	0.3	0.01	0.01	0.01	0.01
D16	0.3	0.01	0.01	0.01	0.01
D17	1.2	0.05	0.06	0.05	0.09
D18	0.3	0.01	0.01	0.01	0.01
D19	1.1	0.03	0.04	0.03	0.06
D20	0.3	0.01	0.01	0.01	0.01
D21	0.2	0.01	0.01	0.01	0.01
D22	0.2	-	-	-	-
D23	0.9	0.47	0.73	0.90	0.92
D24	0.2	0.01	0.01	0.01	0.01
D25	0.8	0.17	0.39	0.47	0.59
D26	0.2	-	-	-	-
D27	0.2	0.01	0.01	0.01	0.01
D28	0.2	-	-	-	-
D29	0.7	0.03	0.07	0.02	0.13
D30	0.2	-	-	-	-
D31	0.7	0.02	0.02	0.01	0.06
D32	0.2	-	-	-	-
D33	0.2	-	-	-	-
D34	0.2	-	-	-	-
D35	0.6	0.20	0.29	0.35	0.32
D36	0.2	-	-	-	-
D37	0.6	0.07	0.18	0.25	0.24
D38	0.2	-	-	-	-
D39	0.2	-	-	-	-
D40	0.2	-	-	-	-
D41	0.5	0.01	0.01	0.01	0.01

	IEC Limit	DC Loading (MW)			
		90	180	225	270
D42	0.2	-	-	-	-
D43	0.5	-	-	-	0.01
D44	0.2	-	-	-	-
D45	0.2	-	-	-	-
D46	0.2	-	-	-	-
D47	0.4	0.14	0.19	0.23	0.16
D48	0.2	-	-	-	-
D49	0.4	0.09	0.19	0.25	0.22
D50	0.2	-	-	-	-
THD	3	2.19	2.27	2.39	2.49

Table 21: SOP Harmonic performance – 1B + 1A type, measured background harmonics

	IEC Limit	DC Loading (MW)			
		90	180	225	270
D2	1.4	0.02	0.02	0.02	0.02
D3	2	1.09	1.09	1.06	1.08
D4	0.8	0.08	0.08	0.08	0.08
D5	2	1.42	1.42	1.42	1.42
D6	0.4	0.03	0.03	0.03	0.03
D7	2	0.52	0.52	0.52	0.52
D8	0.4	0.01	0.01	0.01	0.01
D9	1	0.20	0.20	0.20	0.20
D10	0.4	-	-	-	-
D11	1.5	0.42	0.57	0.47	0.70
D12	0.3	-	-	-	-
D13	1.5	0.47	0.45	0.54	0.52
D14	0.3	0.01	0.01	0.01	0.01
D15	0.3	0.01	0.01	0.01	0.01
D16	0.3	0.01	0.01	0.01	0.01
D17	1.2	0.05	0.06	0.05	0.07
D18	0.3	0.01	0.01	0.01	0.01
D19	1.1	0.03	0.03	0.03	0.05
D20	0.3	0.01	0.01	0.01	0.01
D21	0.2	0.01	0.01	0.01	0.01
D22	0.2	-	-	-	-
D23	0.9	0.28	0.43	0.53	0.54
D24	0.2	0.01	0.01	0.01	0.01
D25	0.8	0.12	0.25	0.30	0.38
D26	0.2	-	-	-	-
D27	0.2	0.01	0.01	0.01	0.01

	IEC Limit	DC Loading (MW)			
		90	180	225	270
D28	0.2	-	-	-	-
D29	0.7	0.02	0.02	0.02	0.03
D30	0.2	-	-	-	-
D31	0.7	0.01	0.01	0.01	0.02
D32	0.2	-	-	-	-
D33	0.2	-	-	-	-
D34	0.2	-	-	-	-
D35	0.6	0.18	0.25	0.31	0.28
D36	0.2	-	-	-	-
D37	0.6	0.06	0.14	0.20	0.20
D38	0.2	-	-	-	-
D39	0.2	-	-	-	-
D40	0.2	-	-	-	-
D41	0.5	0.01	0.01	0.01	0.01
D42	0.2	-	-	-	-
D43	0.5	-	-	-	0.01
D44	0.2	-	-	-	-
D45	0.2	-	-	-	-
D46	0.2	-	-	-	-
D47	0.4	0.11	0.15	0.18	0.13
D48	0.2	-	-	-	-
D49	0.4	0.07	0.15	0.19	0.17
D50	0.2	-	-	-	-
THD	3	1.99	2.07	2.09	2.16