Muswellbrook Solar Farm Harmonic Emissions Assessment and Filter Design Report

For: ESCO Pacific Holdings Pty Ltd.

Attention: Mervin Kall
Lead Engineer - Grid Connections

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Prepared by	Upuli Jayatunga (Power Systems Engineer)
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2	25/01/2023	Concept harmonic filter design included

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Executive Summary

ESCO Pacific Holdings Pty Ltd. (ESCO) engaged Power Systems Consultants Australia Pty Ltd (PSC) to conduct a harmonic assessment for Muswellbrook 135MW Solar Farm (MUSSF) as part of the GPS clause S5.2.5.2 for the connection application.

MUSSF consists of 41 SMA inverters (SMA SC 4200 UP) to be connected to the Ausgrid's 132kV network via the feeder 95M at Singleton STS.

As per the NER requirement clause S5.2.5.2 and the specified automatic and minimum access limits by Ausgrid, PSC has undertaken an assessment to identify the generating system's contribution to voltage and current harmonic distortion.

The results indicate that:

- Without harmonic filters in service,
    - The maximum voltage harmonic distortion of MUSSF at PoC at 8th and 10th harmonic orders exceeds the specified Automatic Access Standard (AAS) and Minimum Access Standard (MAS) allocated limits. The maximum harmonic voltage distortion for 8th and 10th harmonic orders are 0.42% and 0.69% compared to the AAS limit of 0.1% and MAS limit of 0.24%.
    - Connection of MUSSF leads to high amplification of existing background harmonic distortion for 7th to 10th harmonic orders. The maximum harmonic amplification factor was 4.0, which was observed for 10th harmonic order.
    - The maximum current harmonic distortion of MUSSF exceeds the AAS allocated limits for 7th, 8th, 10th, 11th, 13th and 14th order harmonics. Further, the maximum current harmonic distortion of MUSSF exceeds the MAS allocated limits at 10th harmonic order.

Considering the voltage and current harmonic distortion violations, PSC has been engaged to identify a harmonic filter concept solution. Two harmonic filters were proposed to mitigate the excessive harmonic current/voltage levels and to comply with the AAS limits as follows:

- 1 X 6 MVAr C-type filter, Tuned frequency – 370 Hz, Quality factor – 2.5
- 1 X 6 MVAr High Pass (HP) filter, Tuned frequency – 600 Hz, Quality factor – 1

The harmonic assessment was conducted with the abovementioned harmonic filters in service. The results indicate that:

- When the harmonic filters are in service, the maximum voltage and current harmonic distortions at the PoC are in compliance with the AAS allocation limits.

- Connection of the two harmonic filters has improved the harmonic amplification factor at the PoC bringing down it close to unity for complete frequency range. So, there is no significant amplification of the existing background harmonic distortion due to the connection of MUSSF when the harmonic filters are in service.

Contents

Executive Summary 3
1. Introduction 7
2. Overview of NER S5.2.5.2: Quality of Electricity Generated 8
3. Input Data 9
4. Harmonic Distortion Modelling 9
4.1. Network Overview 9
5. Harmonic distortion compliance requirement 13
6. Methodology 15
7. Results 17
7.1. Voltage harmonic distortion 17
7.2. Current harmonic distortion 21
8. Concept Harmonic filter design 25
8.1.1. Voltage harmonic distortion – harmonic filters in service 26
8.1.2. Current harmonic distortion– harmonic filters in service 30
9. Conclusions and Recommendations 34
10. References 35

Appendices and Attachments

Attachments 36

Figures

Figure 1: MUSSF PowerFactory model 9
Figure 2 A simplified Norton equivalent of a generating system connecting to the network. 13
Figure 3. Harmonic impedance polygons (harmonics 2 to 10) at 132kV side main transformer 15
Figure 4. Maximum voltage harmonic distortion at PoC – Direct Injection vs. AAS allocated limits [%] 19
Figure 5. Harmonic Amplification Factors at PoC 20
Figure 6. Harmonic current distortion at PoC Vs AAS current harmonic allocation limits 23
Figure 7. Harmonic current distortion at PoC Vs MAS current harmonic allocation limits 23
Figure 8. Ctype filter parameters 25
Figure 9. HP filter parameters 26
Figure 10. Maximum voltage harmonic distortion at PoC – Direct Injection vs. AAS allocated limits [%]- with harmonic filters in service 28
Figure 11. Harmonic Amplification Factors at PoC- with harmonic filters in service 30
Figure 12. Harmonic current distortion at PoC Vs AAS current harmonic allocation limits- with harmonic filters in service 32

Tables

Table 4-1: Cable type parameters 11
Table 4-2: Transformers parameters 11
Table 4-3: SMA inverter – steady state parameters 12
Table 4-4: 132 kV overhead line parameters 12
Table 7-1: Allocated limits vs. maximum voltage distortion at the PoC [%] 17
Table 7-2: Worst-case network harmonic impedance resulted from voltage harmonic distortion 19
Table 7-3: Allocated limits vs. maximum current distortion at the PoC [%] 21
Table 7-4: Worst-case network harmonic impedance resulted from current harmonic distortion 24
Table 8-1: Allocated limits vs. maximum voltage distortion at the PoC [%] – with harmonic filters in service........ 26
Table 8-2: Worst-case network harmonic impedance resulted from voltage harmonic distortion- with harmonic filters in service 29
Table 8-3: Allocated limits vs. maximum current distortion at the PoC [%]- with harmonic filters in service........ 30
Table 8-4: Worst-case network harmonic impedance resulted from current harmonic distortion- with harmonic filters in service 32

Glossary of Terms

Term	Definition
AAS	Automatic Access Standard
ESCO	ESCO Pacific Holdings (Australia) Pty. Ltd.
GPS	Generator Performance Standard
kV	Kilo-Volt
MAS	Minimum Access Standard
MUSSF	Muswellbrook Solar Farm
MVA	Mega volt ampere
MVAr	Mega volt ampere reactive
MW	Mega watt
NER	National Electricity Rule
NSP	Network Service Provider
OEM	Original Equipment Manufacturer
p.u.	Per-unit
PoC	Point of Connection
PSC	Power System Consultants Australia Pty. Ltd
THD	Total Harmonic Distortion

1. Introduction

Muswellbrook 135MW Solar Farm (MUSSF) consists of 41 x 4.2 MVA SMA inverters (SC 4200 UP) and will be connected to the Ausgrid network via feeder 95M at Singleton STS. The proposed power delivered at the connection point will be 135 MW.

ESCO Pacific Holdings (Australia) Pty Ltd. (ESCO) has engaged PSC to conduct a harmonic assessment and filter design for MUSSF as part of the GPS clause S5.2.5.2 for the connection application. As per the NER requirement clause S5.2.5.2 in meeting the specified automatic and minimum access limits by Ausgrid, PSC has undertaken an assessment of the generating systems contribution to voltage and current harmonic distortion and compared them against the allocated levels.

The harmonic emissions have been calculated in accordance with AS/NZS 61000.3.6 and based on the provided harmonic impedances and Original Equipment Manufacturer (OEM) documentation. The results were then compared with the harmonic allocation limits advised by Ausgrid (Distribution Network Service Provider) with and without the proposed harmonic filter. The harmonic study was undertaken in DIgSILENT PowerFactory 2021 SP 4.

2. Overview of NER S5.2.5.2: Quality of Electricity Generated

Clause S5.2.5.2 of the NER is shown below [1]:

Automatic access standard

(b) The *automatic access standard* is a *generating system* when generating and when not generating must not produce at any of its *connection points* for *generation:*

(1) *voltage* fluctuation greater than the limits allocated by the *Network Service Provider* under clause S5.1.5(a);

(2) harmonic *voltage* distortion greater than the emission limits specified by a *plant standard* under paragraph (a) or allocated by the *Network Service Provider* under clause S5.1.6(a); and

(3) *voltage* unbalance greater than the limits allocated by the *Network Service Provider* in accordance with clause S5.1.7(c).

Minimum access standard

(c) The *minimum access standard* is a *generating system* when generating and when not generating must not produce at any of its *connection points* for *generation:*

(1) *voltage* fluctuations greater than limits determined under clause S5.1.5(b);

(2) harmonic *voltage* distortion more than the lesser of the emission limits determined by the relevant *Network Service Provider* under clause S5.1.6(b) and specified by a *plant standard* under paragraph (a); and

(3) *voltage* unbalance more than limits determined under clause S5.1.7(c).

Negotiated access standard

(d) A *negotiated access standard* negotiated under this clause S5.2.5.2 must not prevent the *Network Service Provider* meeting the *system standards* or contractual obligations to existing *Network Users.*

The focus of this report is to assess the solar farm compliance against S5.2.5.2 (b)(2) clause of the NER.

PO Box 2102, Fortitude Valley BC, QLD 4006
P: +61 7 3613 0100 W: https://www.pscconsulting.com

3. Input Data

The following input data has been provided to PSC for the purpose of this study:

- Harmonic impedance polygons at the 132kV side of main transformer, from Ausgrid [2].
- Harmonic allocation limits at PoC, from Ausgrid [3].
- Harmonic emission and impedance characteristic of SMA SC 4200 UP inverters, from SMA [4].
- MUSSF layout details and details of the 33 kV cable system, from ESCO [5].

4. Harmonic Distortion Modelling

To analyse the harmonic emissions from the new MUSSF at the PoC, PSC has built a detailed model in PowerFactory. The overview of the developed model is provided in the following section.

4.1. Network Overview

Based on the MUSSF layout details provided by ESCO, PSC has built the PowerFactory model, which consists of 41 inverter units connected to the 132 kV connection point via a 170 MVA, 132/33 kV transformer and a 132kV overhead line segment. The station is made up of 6 collector groups (33kV feeders) connected to a 33 kV sub-busbar. There are 2 × 6 MVAr capacitors connected to the 33 kV sub -busbar as well. Figure 1 shows the model developed for this harmonic study.

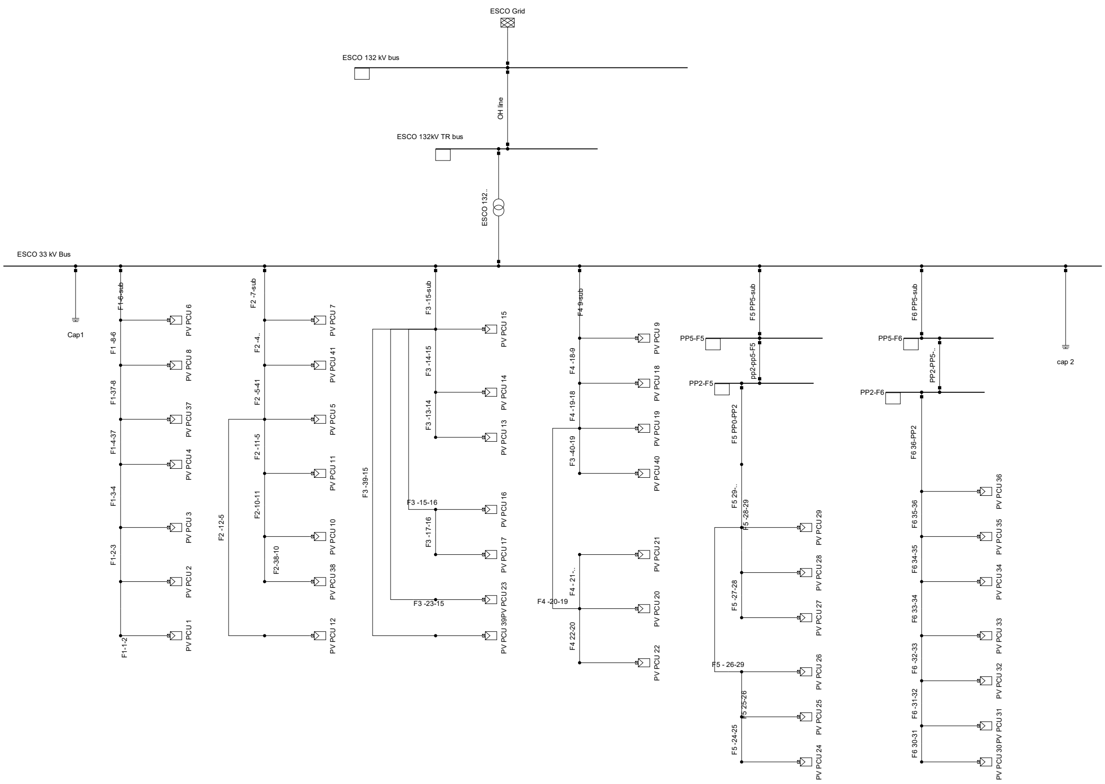

Figure 1: MUSSF PowerFactory model

The details of the 33 kV feeder layout and cable system as provided by ESCO are given in Attachment A. Electrical parameters of cable types used in the model are given in Table 4-1. The 132/33 kV transformer parameters are provided in Table 4-2. The SMA Power Conversion Unit (PCU) SC4200-UP was modelled as a PV system directly connected to 33kV feeders as the PCU Norton equivalent are given inclusive of the 33kV transformer impedance. The parameters used for the PV inverter models (element *.ElmPvsys in PowerFactory) are shown in Table 4-3. Details of the 132 kV overhead line segment which connects the PoC and 132kV side of the transformer is given in Table 4-4: . Further, the 33kV overhead line segments in feeder no. 5 and 6 were modelled using line geometry information given in Attachment B.

PSC has modelled the network harmonic impedance [2], inverter harmonic current injection and equivalent frequency-dependant impedances of the inverters. The harmonic impedance scan data (the polygons) at the 132 kV connection point provided by Ausgrid are included in Attachment C. The harmonic current profile and Norton equivalent frequency-dependent impedances of the SMA inverters are given in Attachment D [4].

Table 4-1: Cable type parameters

Cable	Rtd. Voltage [kV]	rat.Current [kA]	rat.Current (air) [kA]	Frequency [Hz]	R'(AC,20°C) [Ω/km]	X' [Ω/km]	R0'(AC) [Ω/km]	X0' [Ω/km]	C' – C0' [uF/km]
Single Core 185mm^2 Al	33	0.33	0.383	50	0.164	0.145	0.428	0.0703	0.202
Single Core 300mm^2 Al	33	0.421	0.508	50	0.1	0.136	0.364	0.0622	0.242
Single Core 400mm^2 Al	33	0.475	0.584	50	0.0778	0.131	0.342	0.0573	0.267
Single Core 630mm^2 Al	33	0.593	0.764	50	0.0469	0.123	0.312	0.0504	0.329
Single Core 800mm^2 Al	33	0.654	0.862	50	0.0367	0.119	0.301	0.047	0.366

Table 4-2: Transformers parameters

Basic Data	S [MVA]	F [Hz]	Rated voltage [kV]	x1 p.u.	r1 p.u.	Vec.Grp	x0 [p.u.]	r0 [p.u.]	Tap Size	Max Tap	Nom Tap	Min Tap
170 MVA 132/33 kV two winding transformer	170	50	HV - 132 MV - 33	0.125	0.0028	YNd1	0.125	0.0028	1.25% HV	17	9	1

Power Quality / Harmonics	No Load Current [%]	No Load Losses [kW]	Distribution of leakage Reactance, pu		Distribution of leakage Resistance, pu		Factor K and ratio FHL
			x, Seq+ HV	x, Seq+ LV	r,Seq+ HV	r,Seq+ LV	
170 MVA 132/33 kV two winding transformer	0.1	100	0.5	0.5	0.5	0.5	0.1

Table 4-3: SMA inverter – steady state parameters

Name	No. Parallel	S [MVA]	pf	P [kW]	Harmonic Currents	Current [A]	r1h(f)	x1h(f)
PV PCU_i[1]	1	4.2	1	4.2	SMA 4200 UP I(h)	73.5 @ 33kV	SMA 4200 UP Inv_R(f)_pu	SMA 4200 UP Inv_X(f)_pu

Table 4-4: 132 kV overhead line parameters

Configuration	R1 [Ω]	X1 [Ω]	B1 [μS]	R0 [Ω]	X0 [Ω]	B0 [μS]
Single circuit line	0.092	0.414	3.72	0.295	0.96	23.13

[1] All 41 PV inverters are modelled as identical models.

5. Harmonic distortion compliance requirement

To describe the compliance requirement, a simplified model of the generating system and the network is presented in Figure 2. As shown, the generating system (MUSSF) can be represented as a Norton equivalent impedance ($Z_{(Gen,h)}$) and an ideal current source ($I_{(Gen,h)}$). Further, the external network is represented by a voltage source ($V_{(Ext,h)}$) and a Thevenin equivalent impedance ($Z_{(Ext,h)}$). Note that $V_{Ext,h}$ and $Z_{Ext,h}$ are generally provided in the form of voltage background distortion and impedance polygons by the NSP.

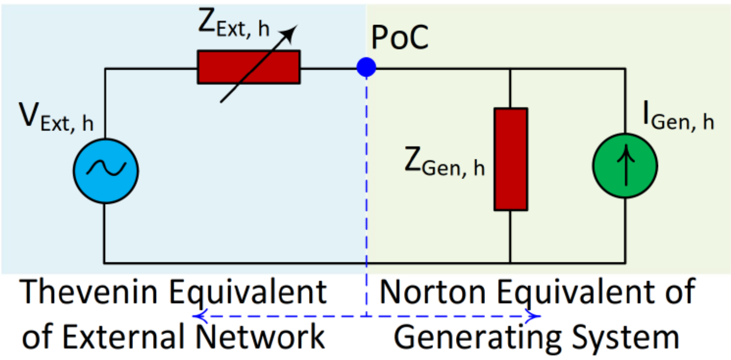

Figure 2 A simplified Norton equivalent of a generating system connecting to the network.

Considering the simplified model shown in Figure 2, the voltage harmonic distortion at PoC consists of two components. The first component represents the direct contribution of the new generating system (i.e. MUSSF) and can be calculated as follows for each harmonic order:

$$V_{1h} = I_{Gen,h} \frac{Z_{Ext,h} Z_{Gen,h}}{Z_{Ext,h} + Z_{Gen,h}}$$

The second component comes from the external sources (the presence of background harmonic voltages) at the PoC and can be calculated as follows:

$$V_{2h} = V_{Ext,h} \frac{Z_{Gen,h}}{Z_{Ext,h} + Z_{Gen,h}}$$

The total harmonic voltage distortion at the PoC ($V_{poc,h}$) is then the summation of all contributions from the internal and external sources which is obtained by accommodating the general summation law [6]. Further, $\propto$, which is the indicative summation exponents proposed in [6] is used to evaluate the total harmonic distortion at the PoC.

$$V_{poc,h} = \sqrt[\propto]{(V_{1h})^{\propto} + (V_{2h})^{\propto}}$$

In addition, the NSP can also separate the new generating system, i.e. MUSSF, from all the other harmonic sources and allocate the value of $V_{allocation,h}$ as the voltage harmonic distortion limit of this new source at harmonic order h (the AAS and MAS limits provided by Ausgrid in [3]). This means that the total contribution of the new generating system should be below $V_{allocation,h}$. Considering that the contribution of the generating system can be calculated by subtracting the harmonic distortion before connection of the generating system from the harmonic distortion after connection of the generating system, the harmonic voltage distortion contribution at the PoC ($V_{POC,h}^{contri}$) can be calculated as follows:

$$V_{POC,h}^{contri} = \sqrt[\propto]{(V_{1h})^{\propto} + (V_{2h})^{\propto} - \left(V_{Ext,h}\right)^{\propto}}$$

As per the NER and Ausgrid requirement, the generating system contribution should not exceed the allocated level as follows:

$$V_{POC,h}^{contri} \leq V_{allocation,h}$$

The background voltage harmonic distortion is not available at PoC of MUSSF. Therefore, the direct contribution from the generating system (MUSSF) is assessed not to exceed the allocated level as follows:

$$V_{1h} \leq V_{allocation,h}$$

Nevertheless, the amplification factor is used as index to assess the impact of the background voltage harmonic distortion on the estimated voltage distortion at PoC. The amplification factor is defined as the harmonic voltage at the connection point after connection of the passive components of proponent's plant (i.e. the generating system model when all harmonic current sources are set at zero), divided by the harmonic voltage at the connection point prior to connection of the proponent's plant. Considering this definition, the amplification factor can be calculated by dividing V_{2h} by $V_{Ext,h}$ when $I_{Gen,h}$ is set at zero. Thus, the amplification factor can be calculated as follows in the simplified model;

$$AF = \frac{Z_{Gen,h}}{Z_{Ext,h} + Z_{Gen,h}}$$

This indicates that the amplification factor is independent of the background voltage distortion, and is derived from the network and generating system impedance characteristics. In the absence of the background voltage harmonic distortion, the comparision of the amplification factor with unity (as a reference point) is quite useful. This is mainly because an amplification factor below unity indicates that the connection of the generating system would attenuate the existing background voltage harmonic distortion.

In addition, individual current harmonic distortion at the connection point should not exceed the AAS and MAS current harmonic limits as specified by Ausgrid. The harmonic allocation limits at PoC are provided in Attachment E [3].

6. Methodology

PowerFactory's Power Quality and Harmonic Analysis module was used to determine the maximum voltage distortion at the connection point.

The network harmonic impedance polygons at the 132 kV side of the main transformer[2] are provided by Ausgrid and the impedance polygons for the first 10 harmonics are shown in Figure 3 for illustration. The harmonic impedance polygon data is given in Attachment C [2].

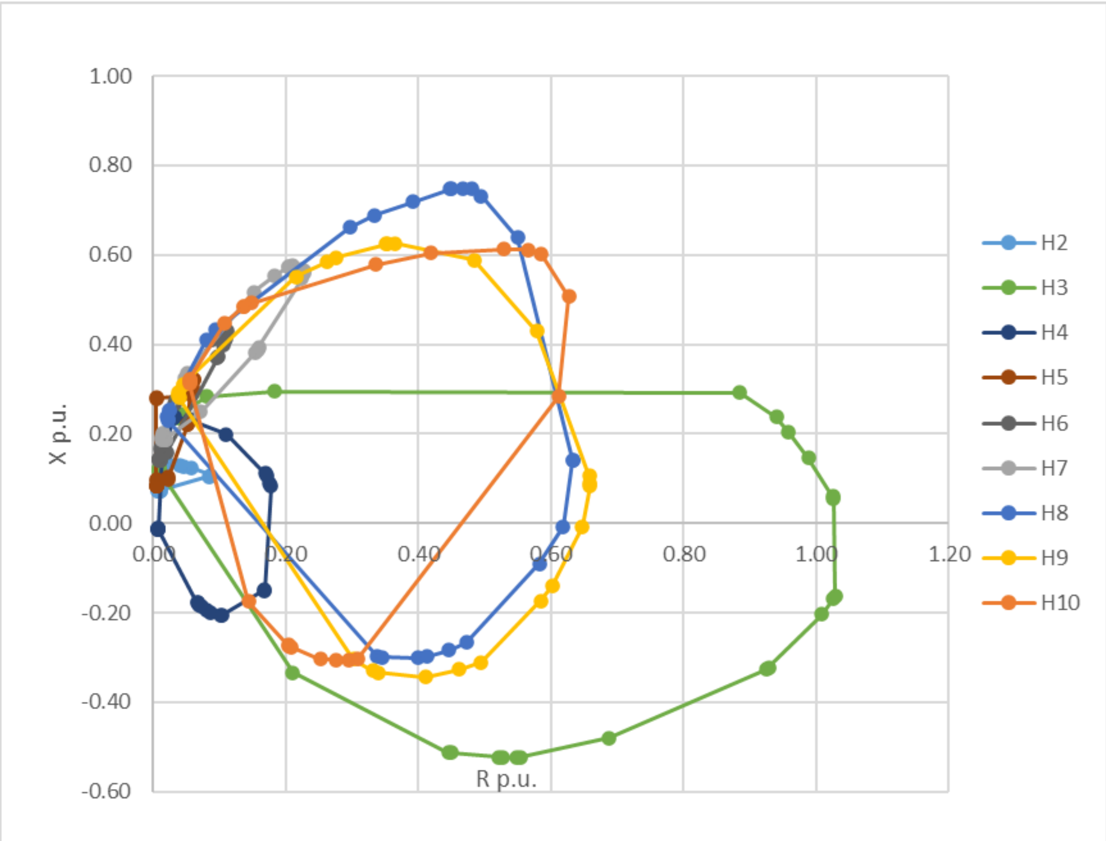

Figure 3. Harmonic impedance polygons (harmonics 2 to 10) at 132kV side main transformer

To determine the maximum voltage distortion at the connection point, an iterative harmonic load flow calculation was performed to scan the border of the user-defined R/X impedance plane (the polygons) for each individual harmonic order and report the highest (worst) voltage distortion.

[2] Network harmonic polygons provided by the Ausgrid are inclusive of the impedance of the 132kV overhead line.

Using the (R, X) points provided for each harmonic order, the voltage harmonic distortion was calculated for several points[3] between each two polygon edge points.

In order to evaluate the maximum harmonic voltage distortion at the connection point, 63 scenarios were studied considering the following variables:

1) Three Balance of Plant (BoP) scenarios including the normal BoP and ±10% variation of cable lengths and transformer impedance.
2) Three dispatch conditions of (Pmax, Q0), (Pmax, Qmax) and (Pmax, Qmin).
3) Each study scenario was further assessed with six N-1 contingency conditions (one of the 33kV feeder is out of service at a time).

In carrying out the harmonic analysis, the following assumptions were made:

- A balanced network harmonic analysis has been undertaken.
- Frequency dependency of the equivalent Norton impedances of the inverters has been included in the study, based on the information provided in Attachment D.Frequency dependency of transformer and line impedances has not been modelled as detailed manufacturer information was not available at this project stage. By default, PowerFactory assumes resistance to be independent of frequency and the reactance data entered for fundamental frequency to be scaled proportional to the harmonic order.
- HD and THD have been calculated based on the total (aggregate) inverter rated current/voltage.
- An alpha exponent value of 1 has been used for all the harmonic orders, for summation of all the internal harmonic sources in the network during harmonic load flow. This results in a more conservative outcome, as harmonics from different sources are summed scalarly, rather than vectorially.
- Harmonic amplification factor for each harmonic order at the connection point was calculated based on the ratio of the harmonic impedance at the PoC after the MUSSF was connected to the same harmonic impedance before the plant was connected.
- The fundamental voltage at the MUSSF connection point was assumed to be 1.05 p.u., based on the historical data.

[3] The number of iterations from one (R, X) point to the next (R, X) point on each polygon was set to 10 in this study

7. Results

7.1. Voltage harmonic distortion

The expected maximum voltage distortion and THD were calculated at the connection point for all scenario mentioned in Section 6. Table 7-1 provides the extracted maximum voltage distortion (direct contribution from MUSSF - V_{1h}) for each harmonic order compared with the AAS and MAS harmonic allocation limits ($V_{allocation,h}$).

Table 7-1: Allocated limits vs. maximum voltage distortion at the PoC [%]

Harmonic order	Maximum voltage harmonic distortion at PoC(%) V_{1h}	AAS voltage harmonic allocation limit (%) $V_{allocation,h}$	MAS voltage harmonic allocation limit (%) $V_{allocation,h}$	Scenario corresponds to maximum voltage HD
THD[4]	0.99	1.38	2.25	
2	0.0121	0.14	0.86	BoP-10%_PmaxQmin
3	0.0697	0.25	1.50	BoP -10%_PmaxQmin
4	0.0292	0.1	0.45	BoP -10%_PmaxQmin
5	0.1016	0.46	1.63	BoP _PmaxQmin
6	0.0252	0.1	0.24	BoP +10%_PmaxQmin
7	0.4007	0.46	1.63	BoP +10%_PmaxQmin
8	0.4149	0.1	0.24	BoP +10%_PmaxQmin
9	0.1150	0.18	0.66	BoP +10%_PmaxQmin
10	0.6912	0.1	0.24	BoP -10%_PmaxQ0
11	0.3150	0.53	1.30	BoP -10%_PmaxQmax
12	0.0325	0.1	0.23	BoP -10%_PmaxQmax
13	0.1772	0.53	1.30	BoP -10%_PmaxQmax
14	0.0701	0.1	0.22	BoP -10%_PmaxQmax
15	0.0281	0.1	0.18	BoP -10%_PmaxQmax
16	0.0314	0.1	0.20	BoP -10%_PmaxQ0
17	0.0109	0.39	0.96	BoP -10%_PmaxQmin
18	0.0050	0.1	0.19	BoP -10%_PmaxQmin
19	0.0099	0.35	0.85	BoP -10%_PmaxQmin
20	0.0108	0.1	0.19	BoP -10%_PmaxQmin
21	0.0034	0.1	0.13	BoP -10%_PmaxQmin
22	0.0070	0.1	0.18	BoP -10%_PmaxQmin
23	0.0069	0.28	0.68	BoP -10%_PmaxQmin

[4] THD is calculated considering the complete spectrum (up to 50th order) of harmonic voltage distortion at the Connection Point.

Harmonic order	Maximum voltage harmonic distortion at PoC(%) V_{1h}	AAS voltage harmonic allocation limit (%) $V_{allocation,h}$	MAS voltage harmonic allocation limit (%) $V_{allocation,h}$	Scenario corresponds to maximum voltage HD
24	0.0038	0.1	0.17	BoP -10%_PmaxQmin
25	0.0152	0.25	0.61	BoP -10%_PmaxQmin
26	0.0137	0.1	0.17	BoP -10%_PmaxQmin
27	0.0069	0.1	0.10	BoP -10%_PmaxQmin
28	0.0129	0.1	0.16	BoP -10%_PmaxQmin
29	0.0169	0.21	0.51	BoP -10%_PmaxQmin
30	0.0058	0.1	0.16	BoP -10%_PmaxQmin
31	0.0115	0.2	0.48	BoP -10%_PmaxQmin
32	0.0147	0.1	0.16	BoP -10%_PmaxQmin
33	0.0030	0.1	0.10	BoP -10%_PmaxQmin
34	0.0071	0.1	0.16	BoP -10%_PmaxQmin
35	0.0126	0.17	0.41	BoP -10%_PmaxQmin
36	0.0020	0.1	0.16	BoP -10%_PmaxQmin
37	0.0075	0.15	0.37	BoP -10%_PmaxQmax
38	0.0156	0.1	0.16	BoP -10%_PmaxQ0
39	0.0026	0.1	0.10	BoP -10%_PmaxQmin
40	0.0070	0.1	0.16	BoP -10%_PmaxQmin
41	0.0049	-	-	BoP -10%_PmaxQmin
42	0.0012	-	-	BoP -10%_PmaxQmin
43	0.0016	-	-	BoP -10%_PmaxQmin
44	0.0032	-	-	BoP -10%_PmaxQmin
45	0.0013	-	-	BoP -10%_PmaxQmin
46	0.0038	-	-	BoP -10%_PmaxQmin
47	0.0036	-	-	BoP -10%_PmaxQmin
48	0.0010	-	-	BoP -10%_PmaxQmin
49	0.0031	-	-	BoP -10%_PmaxQmin
50	0.0049	-	-	BoP -10%_PmaxQmin

The resultant voltage harmonic distortion (direct contribution (V_{1h})) is also plotted against the AAS allocation levels as shown in Figure 4. As can be seen, the maximum voltage harmonic distortion exceeds the allocation limits for 8th and 10th harmonic orders (in comparison to both AAS and MAS limits). The maximum harmonic voltage distortion for 8th and 10th harmonic orders are 0.42% and 0.69% compared to the AAS allocation limits of 0.1% and MAS allocation limits of 0.24%. Therefore, a harmonic filter is required to mitigate the higher distortion caused by 8th and 10th harmonic orders.

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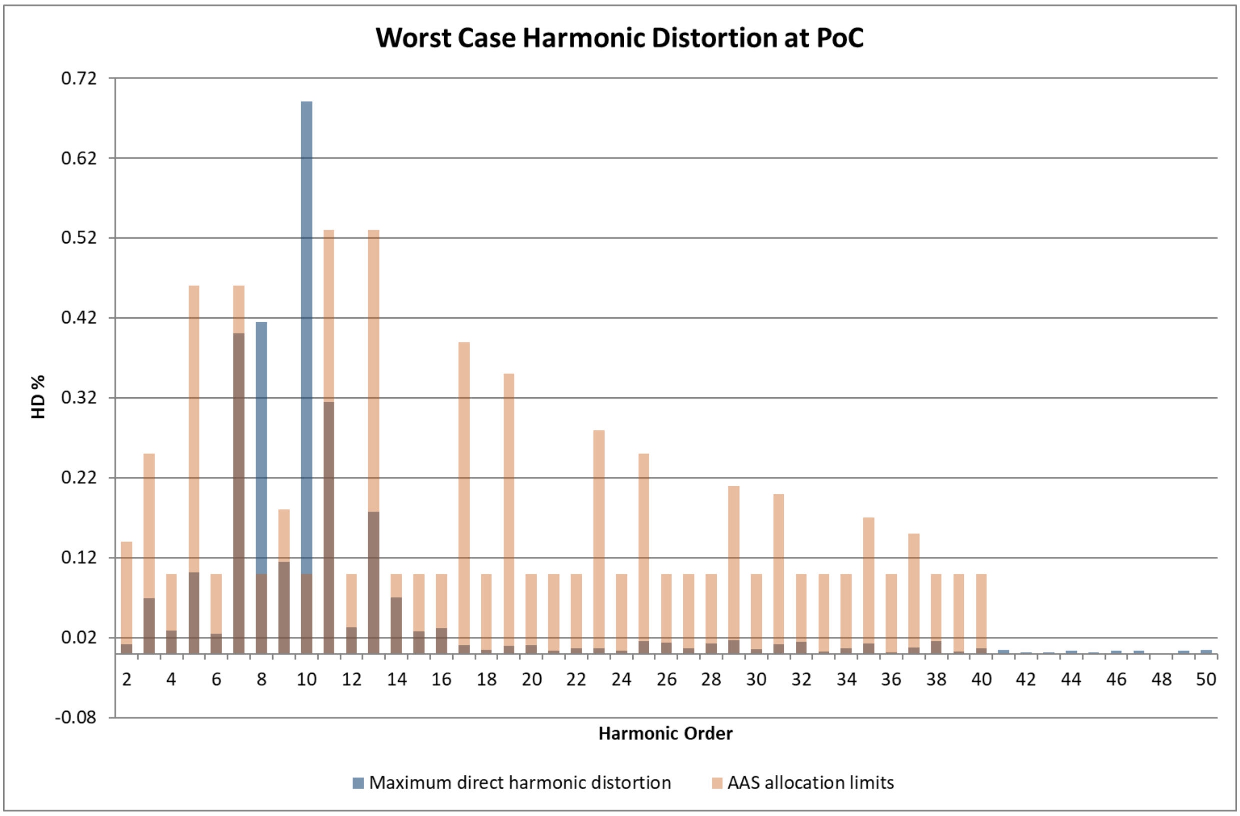

Figure 4. Maximum voltage harmonic distortion at PoC – Direct Injection vs. AAS allocated limits [%]

The network harmonic impedances which gave rise to the maximum voltage harmonic distortion at the point of connection are shown in Table 7-2.

Table 7-2: Worst-case network harmonic impedance resulted from voltage harmonic distortion

F [Hz]	R [Ω]	X [Ω]	F [Hz]	R [Ω]	X [Ω]
100	15.12	18.63	1350	84.4	134.12
150	96.55	-91.2	1400	124.15	101.78
200	18.21	-35.62	1450	103.5	78.78
250	10.12	56.08	1500	58.43	116
300	18.29	75.35	1550	50.96	134.8
350	36.44	100.28	1600	85.75	136.12
400	60.3	121.12	1650	86.2	166.2
450	19.8	70.87	1700	145.27	214.51
500	9.55	56.11	1750	217.52	138.54
550	13.93	32.12	1800	275.6	67.92
600	55.16	-55.74	1850	437.38	104.48
650	40.02	-45.08	1900	404.62	-154.38

F [Hz]	R [Ω]	X [Ω]	F [Hz]	R [Ω]	X [Ω]
700	129.22	-43.65	1950	286.01	-140
750	140.75	14.28	2000	194.36	-160.39
800	109.26	-26.77	2050	157.77	-46.77
850	41.81	-17.82	2100	201.94	63.11
900	56.13	52.7	2150	90.33	113.98
950	76.84	38.97	2200	188.53	67.9
1000	68.43	66.21	2250	251.15	74.57
1050	38.17	76.47	2300	245.52	174.57
1100	51.49	88.72	2350	253.07	111.84
1150	72.16	94.38	2400	90.14	243.5
1200	105.5	91.22	2450	104.2	272.49
1250	130.54	60.96	2500	237.26	280.32
1300	128.48	42.92			

The harmonic amplification factors are shown in Figure 5 and indicates that the amplification of the existing background harmonic emissions could occur around 7th to 10th harmonic orders due to the connection of MUSSF. The highest amplification factor can be observed for 10th harmonic order as 4.0.

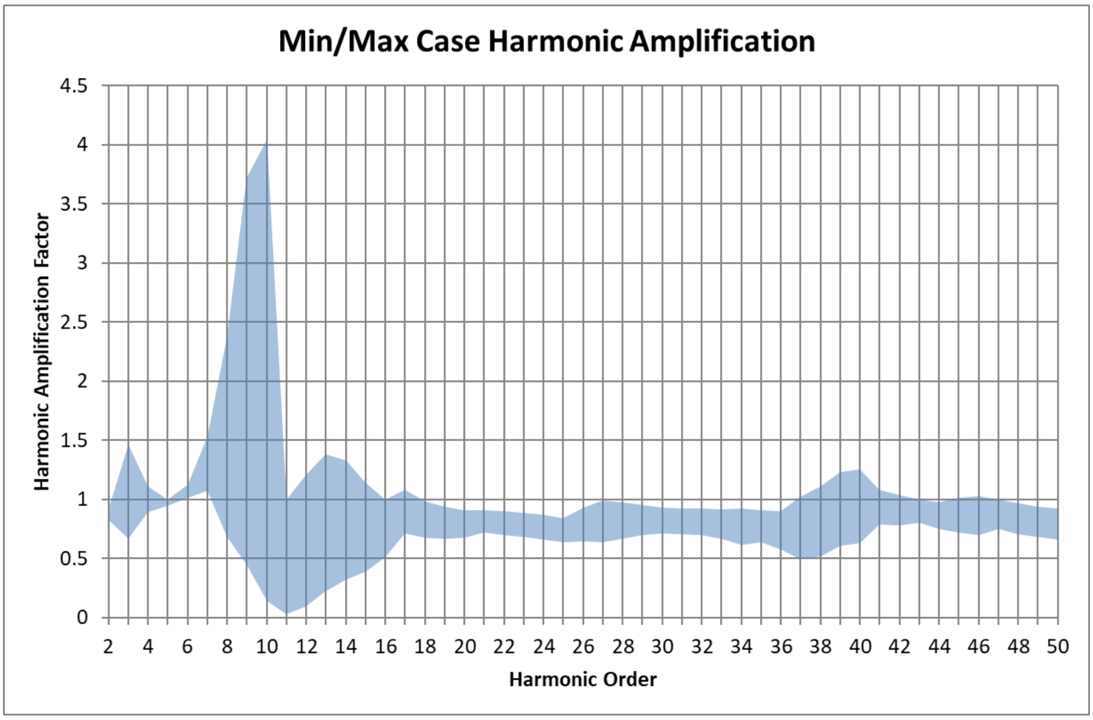

Figure 5. Harmonic Amplification Factors at PoC

7.2. Current harmonic distortion

The expected maximum current harmonic distortion evaluated for all scenarios mentioned in Section 6 is provided in Table 7-3 compared with the AAS and MAS harmonic current allocation limits ($I_{allocation,h}$).

Table 7-3: Allocated limits vs. maximum current distortion at the PoC [%]

Harmonic order	Maximum current harmonic distortion at PoC(A) I_{1h}	AAS current harmonic allocation limit (A) $I_{allocation,h}$	MAS current harmonic allocation limit (A) $I_{allocation,h}$	Scenario corresponds to maximum current HD
2	0.407	4.4	77.3	BoP -10%_PmaxQmin
3	0.433	5.2	90.5	BoP -10%_PmaxQmin
4	0.556	1.5	20.4	BoP -10%_PmaxQmin
5	1.416	2.8	58.9	BoP _PmaxQmin
6	0.248	1.0	7.4	BoP +10%_PmaxQmin
7	2.862	2.0	42.1	BoP +10%_PmaxQmin
8	2.439	0.8	5.5	BoP+10%_PmaxQmin
9	1.309	1.3	13.3	BoP +10%_PmaxQmin_F5OOS
10	9.255	0.6	4.3	BoP -10%_PmaxQ0
11	8.543	1.5	21.4	BoP -10%_PmaxQmax
12	0.524	0.5	3.5	BoP -10%_PmaxQmax
13	2.477	1.3	18.1	BoP -10%_PmaxQmin
14	0.984	0.4	2.8	BoP -10%_PmaxQmin
15	0.334	0.4	2.2	BoP -10%_PmaxQmin
16	0.267	0.4	2.3	BoP -10%_PmaxQmin
17	0.186	1.4	10.2	BoP -10%_PmaxQmin
18	0.068	0.3	1.9	BoP -10%_PmaxQmin
19	0.106	1.1	8.1	BoP -10%_PmaxQmin
20	0.106	0.3	1.7	BoP -10%_PmaxQmin
21	0.037	0.3	1.1	BoP -10%_PmaxQmin
22	0.064	0.3	1.5	BoP -10%_PmaxQmin
23	0.054	0.4	5.3	BoP -10%_PmaxQmin
24	0.026	0.3	1.3	BoP -10%_PmaxQmin
25	0.093	0.3	4.4	BoP -10%_PmaxQmin
26	0.090	0.2	1.2	BoP -10%_PmaxQmin
27	0.050	0.2	0.7	BoP -10%_PmaxQmin
28	0.086	0.2	1.1	BoP -10%_PmaxQmin
29	0.122	0.4	3.2	BoP -10%_PmaxQmin
30	0.043	0.2	1.0	BoP -10%_PmaxQmin
31	0.077	0.4	2.8	BoP -10%_PmaxQmin
32	0.088	0.2	0.9	BoP -10%_PmaxQmin

Harmonic order	Maximum current harmonic distortion at PoC(A) I_{1h}	AAS current harmonic allocation limit (A) $I_{allocation,h}$	MAS current harmonic allocation limit (A) $I_{allocation,h}$	Scenario corresponds to maximum current HD
33	0.016	0.2	0.6	BoP -10%_PmaxQmin
34	0.030	0.2	0.9	BoP -10%_PmaxQmin
35	0.048	0.3	2.1	BoP -10%_PmaxQmin
36	0.006	0.2	0.8	BoP -10%_PmaxQmin
37	0.021	0.3	1.8	BoP -10%_PmaxQmin
38	0.037	0.2	0.7	BoP -10%_PmaxQmin
39	0.008	0.2	0.5	BoP -10%_PmaxQmin
40	0.022	0.2	0.7	BoP -10%_PmaxQmin
41	0.024	-	-	BoP -10%_PmaxQmin
42	0.006	-	-	BoP -10%_PmaxQmin
43	0.010	-	-	BoP -10%_PmaxQmin
44	0.014	-	-	BoP -10%_PmaxQmin
45	0.005	-	-	BoP -10%_PmaxQmin
46	0.014	-	-	BoP -10%_PmaxQmin
47	0.013	-	-	BoP -10%_PmaxQmin
48	0.004	-	-	BoP -10%_PmaxQmin
49	0.011	-	-	BoP -10%_PmaxQmin
50	0.014	-	-	BoP -10%_PmaxQmin

The resultant current harmonic distortion is also plotted against the AAS and MAS allocation limits as shown in Figure 6 and Figure 7.

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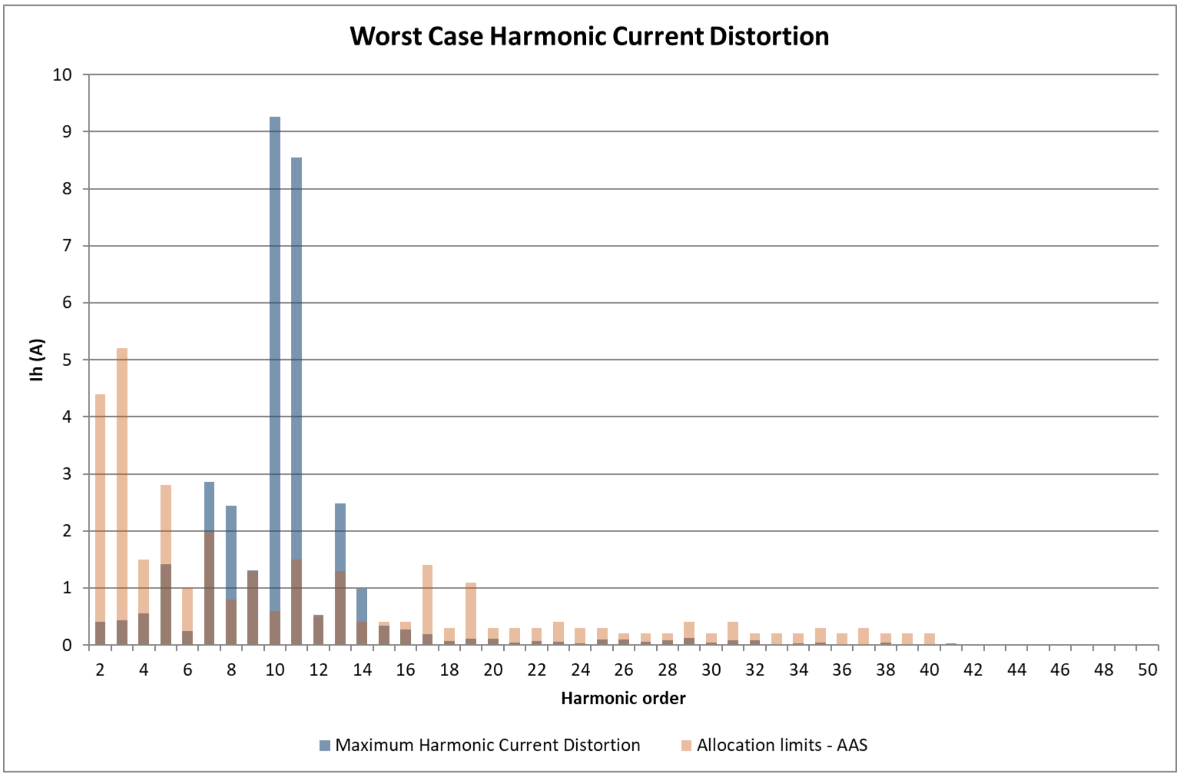

Figure 6. Harmonic current distortion at PoC Vs AAS current harmonic allocation limits

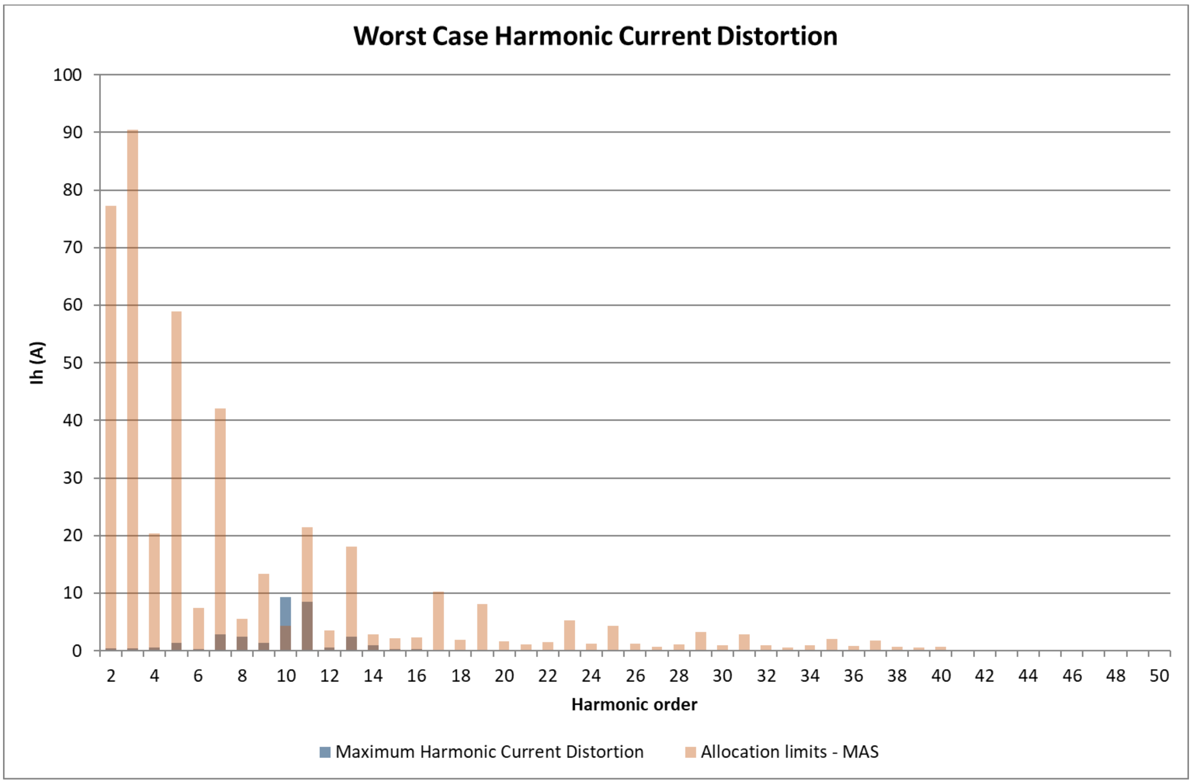

Figure 7. Harmonic current distortion at PoC Vs MAS current harmonic allocation limits

The above results show that the current harmonic distortion for 7th , 8th, 11th , 13th and 14th orders have violated the AAS limit whereas the 10th order has violated both AAS and MAS limits.

The network harmonic impedances which gave rise to the maximum current harmonic distortion at the point of connection are shown in Table 7-2.

Table 7-4: Worst-case network harmonic impedance resulted from current harmonic distortion

F [Hz]	R [Ω]	X [Ω]	F [Hz]	R [Ω]	X [Ω]
100	1.84	12.71	1350	67.9	-7.88
150	77.62	-89.25	1400	44.21	3.84
200	17.86	-35.68	1450	40.32	16.97
250	0.91	14.34	1500	43.65	28.23
300	18.29	75.35	1550	41.21	35.46
350	36.44	100.28	1600	41.37	38.64
400	51.64	115.26	1650	34.57	43.13
450	10.93	58.31	1700	81.73	31.28
500	9.55	56.11	1750	28.28	55.13
550	14.76	16.2	1800	24.11	62.51
600	30.56	-9.89	1850	103.84	-30.38
650	31.35	-31.02	1900	183.82	-111.35
700	28.19	-30.02	1950	157.63	-144.1
750	33.73	-22.23	2000	146.12	-146.51
800	29.01	-2.71	2050	77.45	-52.88
850	34.68	-17.71	2100	96.48	-38.8
900	22.8	1.17	2150	51.58	-8.55
950	23.24	13.45	2200	120.27	-1.17
1000	43.5	22.01	2250	70.88	-20.46
1050	34.5	25.5	2300	129.08	-47.04
1100	25.15	32.17	2350	65.95	-12.87
1150	21.56	41.32	2400	47.33	22.06
1200	13.66	53.28	2450	30.56	53.91
1250	12.65	62.97	2500	22.56	75.47
1300	105.82	1.95			

8. Concept Harmonic filter design

As the simulation result indicated, both voltage and current harmonic distortion contribution of the generating system are above the allocated levels at some harmonic orders. In order to mitigate excessive harmonic voltage/current levels, following filter configuration was proposed to replace the two 6 MVAr capacitors.

- 1 X 6 MVAr C-type filter, Tuned frequency – 370 Hz, Quality factor – 2.5
- 1 X 6 MVAr High Pass (HP) filter, Tuned frequency – 600 Hz, Quality factor – 1

The details of two filters are provided in Figure 8 and Figure 9.

The harmonic study presented in Section 7 was repeated with the two harmonic filters in service and the worst case harmonic distortion results are presented in following sections.
It should be noted that this is a high-level indicative concept design, and it does not include the component rating calculation, which should be conducted at the detailed design stage by a harmonic filter supplier.

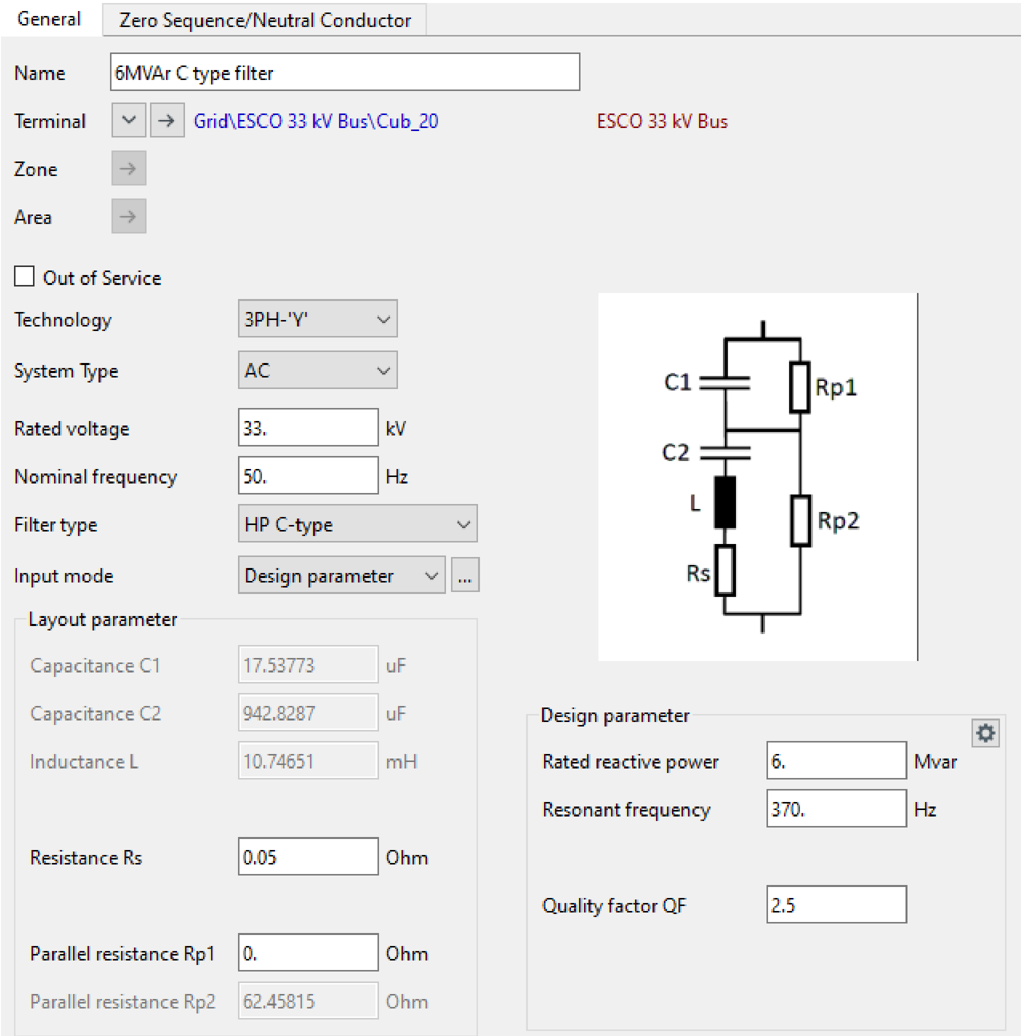

Figure 8. Ctype filter parameters

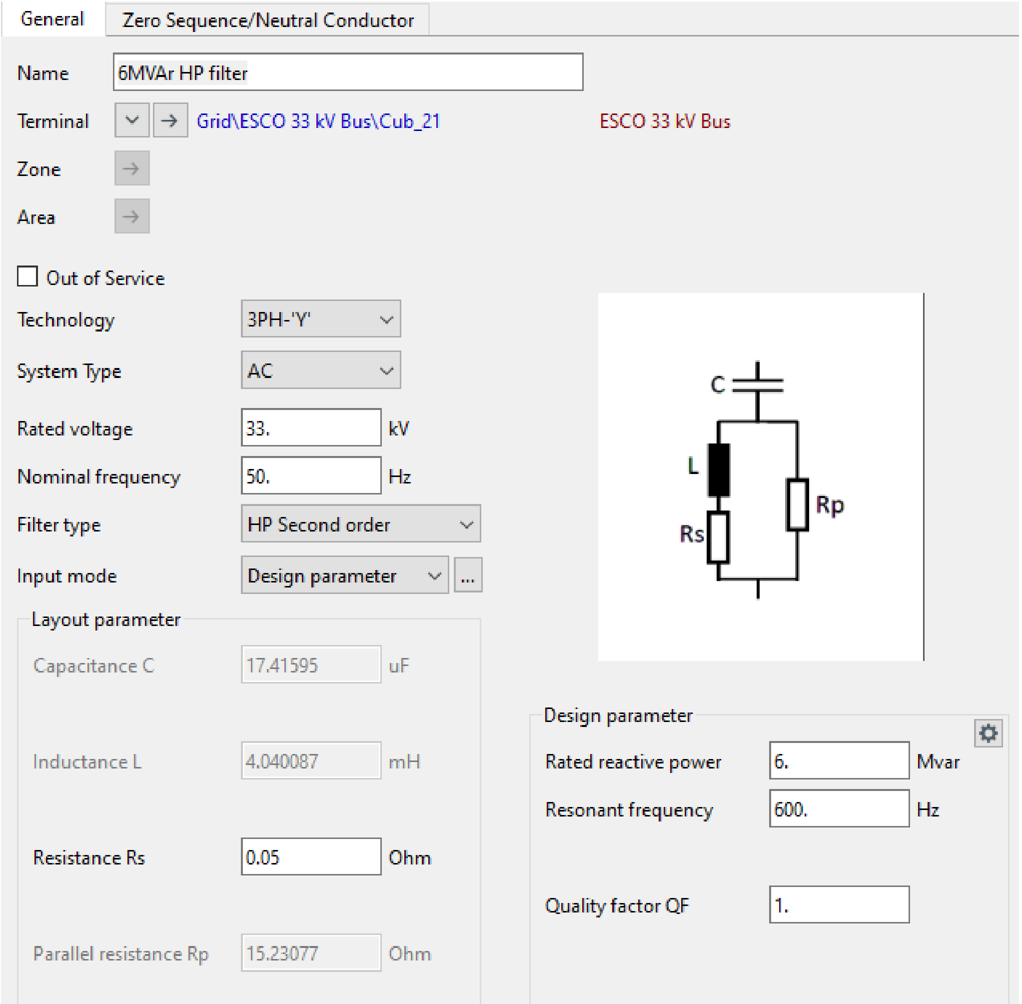

Figure 9. HP filter parameters

8.1.1. Voltage harmonic distortion – harmonic filters in service

The expected maximum voltage distortion and THD at the connection point when harmonic filters are in service (direct contribution from MUSSF - V_{1h}) for each harmonic order are given in Table 8-1 compared with the AAS and MAS harmonic allocation limits ($V_{allocation,h}$).

Table 8-1: Allocated limits vs. maximum voltage distortion at the PoC [%] – with harmonic filters in service

Harmonic order	**Maximum voltage harmonic distortion at PoC(%)** V_{1h}	**AAS voltage harmonic allocation limit (%)** $V_{allocation,h}$	**MAS voltage harmonic allocation limit (%)** $V_{allocation,h}$	**Scenario corresponds to maximum voltage HD**
THD[5]	0.99	1.38	2.25	

[5] THD is calculated considering the complete spectrum (up to 50th order) of harmonic voltage distortion at the Connection Point.

Harmonic order	Maximum voltage harmonic distortion at PoC(%) V_{1h}	AAS voltage harmonic allocation limit (%) $V_{allocation,h}$	MAS voltage harmonic allocation limit (%) $V_{allocation,h}$	Scenario corresponds to maximum voltage HD
2	0.0121	0.14	0.86	BoP-10%_PmaxQmin
3	0.0698	0.25	1.50	BoP-10%_PmaxQmin
4	0.0293	0.1	0.45	BoP-10%_PmaxQmin
5	0.1190	0.46	1.63	BoP-10%_PmaxQmin
6	0.0332	0.1	0.24	BoP-10%_PmaxQmin
7	0.1683	0.46	1.63	BoP-10%_PmaxQmin
8	0.0594	0.1	0.24	BoP -10%_PmaxQmax
9	0.0128	0.18	0.66	BoP-10%_PmaxQmin
10	0.0713	0.1	0.24	BoP-10%_PmaxQmin
11	0.1144	0.53	1.30	BoP-10%_PmaxQmin
12	0.0151	0.1	0.23	BoP-10%_PmaxQmin
13	0.0852	0.53	1.30	BoP-10%_PmaxQmin
14	0.0490	0.1	0.22	BoP-10%_PmaxQmin
15	0.0256	0.1	0.18	BoP-10%_PmaxQmin
16	0.0301	0.1	0.20	BoP-10%_PmaxQmin
17	0.0119	0.39	0.96	BoP-10%_PmaxQmin
18	0.0072	0.1	0.19	BoP-10%_PmaxQmin
19	0.0155	0.35	0.85	BoP-10%_PmaxQmin
20	0.0182	0.1	0.19	BoP-10%_PmaxQmin
21	0.0053	0.1	0.13	BoP-10%_PmaxQmin
22	0.0085	0.1	0.18	BoP-10%_PmaxQmin
23	0.0071	0.28	0.68	BoP-10%_PmaxQmin
24	0.0026	0.1	0.17	BoP-10%_PmaxQmin
25	0.0093	0.25	0.61	BoP-10%_PmaxQmin
26	0.0115	0.1	0.17	BoP-10%_PmaxQmin
27	0.0084	0.1	0.10	BoP-10%_PmaxQmin
28	0.0193	0.1	0.16	BoP-10%_PmaxQmin
29	0.0300	0.21	0.51	BoP-10%_PmaxQmin
30	0.0121	0.1	0.16	BoP-10%_PmaxQmin
31	0.0271	0.2	0.48	BoP-10%_PmaxQmin
32	0.0380	0.1	0.16	BoP-10%_PmaxQmin
33	0.0087	0.1	0.10	BoP-10%_PmaxQmin
34	0.0221	0.1	0.16	BoP-10%_PmaxQmin
35	0.0407	0.17	0.41	BoP-10%_PmaxQmin
36	0.0067	0.1	0.16	BoP-10%_PmaxQmin
37	0.0264	0.15	0.37	BoP-10%_PmaxQmin
38	0.0536	0.1	0.16	BoP-10%_PmaxQmin
39	0.0095	0.1	0.10	BoP-10%_PmaxQmin
40	0.0248	0.1	0.16	BoP-10%_PmaxQmin
41	0.0198	-	-	BoP-10%_PmaxQmin

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Harmonic order	Maximum voltage harmonic distortion at PoC(%) V_{1h}	AAS voltage harmonic allocation limit (%) $V_{allocation,h}$	MAS voltage harmonic allocation limit (%) $V_{allocation,h}$	Scenario corresponds to maximum voltage HD
42	0.0054	-	-	BoP-10%_PmaxQmin
43	0.0076	-	-	BoP-10%_PmaxQmin
44	0.0154	-	-	BoP-10%_PmaxQmin
45	0.0063	-	-	BoP-10%_PmaxQmin
46	0.0200	-	-	BoP-10%_PmaxQmin
47	0.0193	-	-	BoP-10%_PmaxQmin
48	0.0058	-	-	BoP-10%_PmaxQmin
49	0.0189	-	-	BoP-10%_PmaxQmin
50	0.0295	-	-	BoP-10%_PmaxQmin

The resultant voltage harmonic distortion (direct contribution (V_{1h})) is also plotted against the AAS allocation levels as shown in Table 8-4. As can be seen, the maximum voltage harmonic distortion for all harmonic orders is in compliance with the AAS limits.

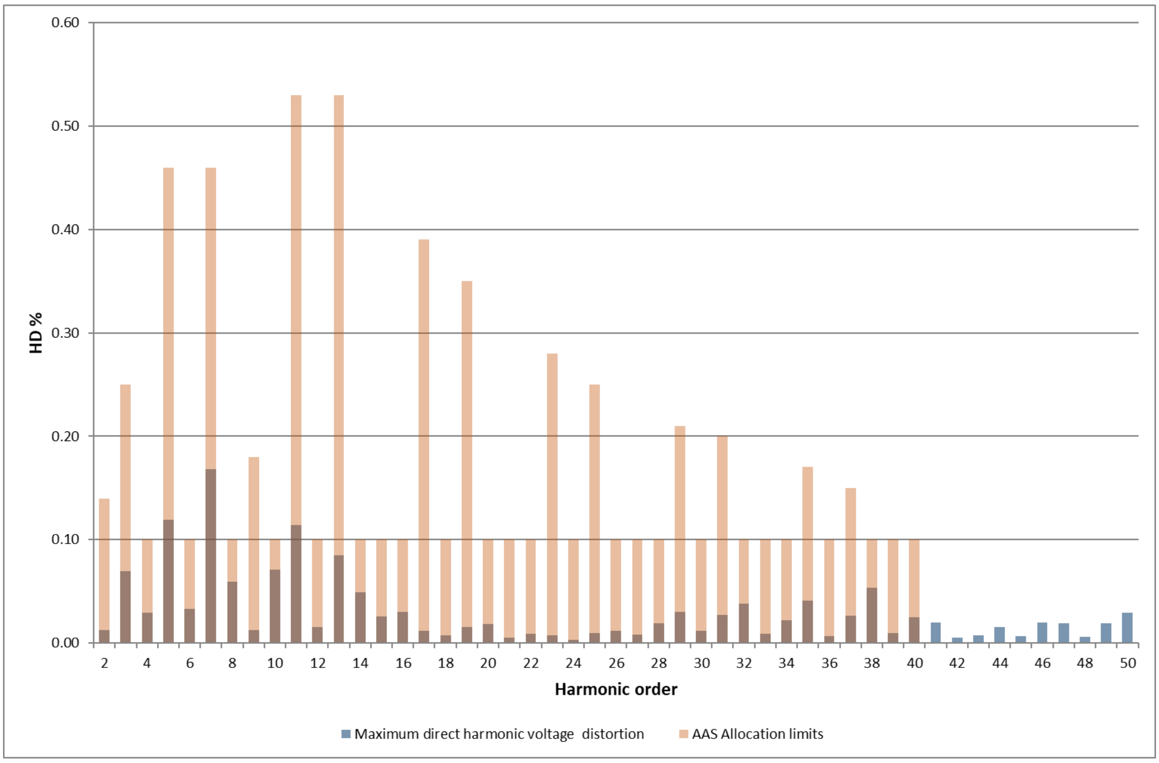

Figure 10. Maximum voltage harmonic distortion at PoC – Direct Injection vs. AAS allocated limits [%]- with harmonic filters in service

The network harmonic impedances which resulted in the maximum voltage harmonic distortion at the point of connection are shown in Table 8-2.

Table 8-2: Worst-case network harmonic impedance resulted from voltage harmonic distortion- with harmonic filters in service

F [Hz]	R [Ω]	X [Ω]	F [Hz]	R [Ω]	X [Ω]
100	15.12	18.63	1350	84.4	134.12
150	96.55	-91.2	1400	124.15	101.78
200	18.21	-35.62	1450	70.29	118.81
250	10.12	56.08	1500	58.43	116
300	18.29	75.35	1550	50.96	134.8
350	36.44	100.28	1600	85.75	136.12
400	83.74	130.19	1650	70.02	174.18
450	84.36	102.64	1700	145.27	214.51
500	102.07	104.87	1750	213.44	153.67
550	155.61	77.56	1800	269.41	169.01
600	162.24	-23.28	1850	437.38	104.48
650	168.14	12.18	1900	496.62	-92.44
700	174.88	14.75	1950	482.75	83.86
750	155.91	55.9	2000	194.36	-160.39
800	144.41	29.59	2050	157.77	-46.77
850	32.27	48.36	2100	201.94	63.11
900	51.39	58.6	2150	90.33	113.98
950	63.35	65.7	2200	188.53	67.9
1000	68.43	66.21	2250	251.15	74.57
1050	38.17	76.47	2300	241.36	184.5
1100	51.49	88.72	2350	253.07	111.84
1150	72.16	94.38	2400	90.14	243.5
1200	105.5	91.22	2450	104.2	272.49
1250	130.54	60.96	2500	237.26	280.32
1300	128.48	42.92			

The new harmonic amplification factors at the PoC when the harmonic filters are in Service are shown in Figure 11 and indicates that there is no significant amplification of the existing background harmonic emissions due to the connection of MUSSF.

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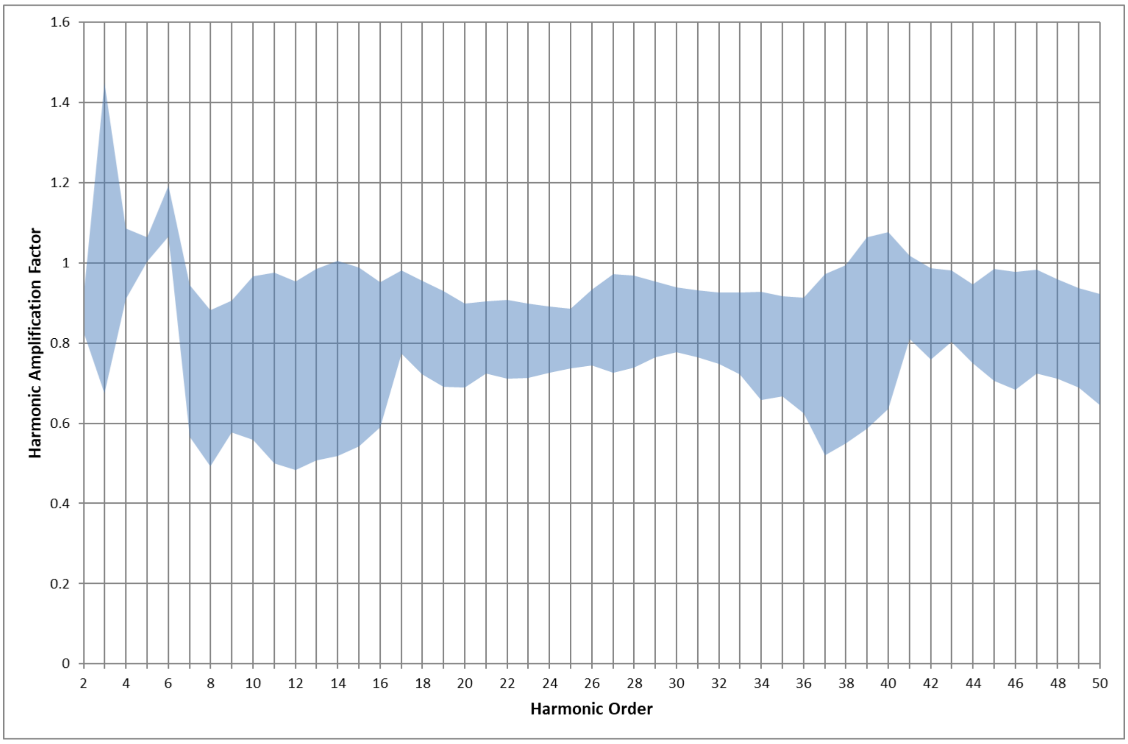

Figure 11. Harmonic Amplification Factors at PoC- with harmonic filters in service

8.1.2. Current harmonic distortion– harmonic filters in service

The expected maximum current harmonic distortion evaluated for all scenarios when the harmonic filters are in service is provided in Table 8-3 compared with the AAS and MAS harmonic current allocation limits ($I_{allocation,h}$).

Table 8-3: Allocated limits vs. maximum current distortion at the PoC [%]- with harmonic filters in service

Harmonic order	Maximum current harmonic distortion at PoC(A) I_{1h}	AAS current harmonic allocation limit (A) $I_{allocation,h}$	MAS current harmonic allocation limit (A) $I_{allocation,h}$	Scenario corresponds to maximum current HD
2	0.408	4.4	77.3	BoP -10%_PmaxQmin
3	0.431	5.2	90.5	BoP -10%_PmaxQmin
4	0.559	1.5	20.4	BoP -10%_PmaxQmin
5	1.592	2.8	58.9	BoP -10%_PmaxQmin
6	0.331	1.0	7.4	BoP -10%_PmaxQmin
7	1.810	2.0	42.1	BoP -10%_PmaxQmin
8	0.502	0.8	5.5	BoP -10%_PmaxQmin
9	0.110	1.3	13.3	BoP -10%_PmaxQmin
10	0.61	0.6	4.3	BoP -10%_PmaxQmin

Harmonic order	Maximum current harmonic distortion at PoC(A) I_{1h}	AAS current harmonic allocation limit (A) $I_{allocation,h}$	MAS current harmonic allocation limit (A) $I_{allocation,h}$	Scenario corresponds to maximum current HD
11	0.951	1.5	21.4	BoP -10%_PmaxQmin
12	0.117	0.5	3.5	BoP -10%_PmaxQmin
13	0.681	1.3	18.1	BoP -10%_PmaxQmin
14	0.388	0.4	2.8	BoP -10%_PmaxQmin
15	0.209	0.4	2.2	BoP -10%_PmaxQmin
16	0.242	0.4	2.3	BoP -10%_PmaxQmin
17	0.194	1.4	10.2	BoP -10%_PmaxQmin
18	0.092	0.3	1.9	BoP -10%_PmaxQmin
19	0.169	1.1	8.1	BoP -10%_PmaxQmin
20	0.180	0.3	1.7	BoP -10%_PmaxQmin
21	0.056	0.3	1.1	BoP -10%_PmaxQmin
22	0.077	0.3	1.5	BoP -10%_PmaxQmin
23	0.055	0.4	5.3	BoP -10%_PmaxQmin
24	0.017	0.3	1.3	BoP -10%_PmaxQmin
25	0.054	0.3	4.4	BoP -10%_PmaxQmin
26	0.072	0.2	1.2	BoP -10%_PmaxQmin
27	0.053	0.2	0.7	BoP -10%_PmaxQmin
28	0.116	0.2	1.1	BoP -10%_PmaxQmin
29	0.203	0.4	3.2	BoP -10%_PmaxQmin
30	0.083	0.2	1.0	BoP -10%_PmaxQmin
31	0.170	0.4	2.8	BoP -10%_PmaxQmin
32	0.21	0.2	0.9	BoP -10%_PmaxQmin
33	0.044	0.2	0.6	BoP -10%_PmaxQmin
34	0.089	0.2	0.9	BoP -10%_PmaxQmin
35	0.155	0.3	2.1	BoP -10%_PmaxQmin
36	0.022	0.2	0.8	BoP -10%_PmaxQmin
37	0.072	0.3	1.8	BoP -10%_PmaxQmin
38	0.122	0.2	0.7	BoP -10%_PmaxQmin
39	0.027	0.2	0.5	BoP -10%_PmaxQmin
40	0.081	0.2	0.7	BoP -10%_PmaxQmin
41	0.101	-	-	BoP -10%_PmaxQmin
42	0.024	-	-	BoP -10%_PmaxQmin
43	0.048	-	-	BoP -10%_PmaxQmin
44	0.069	-	-	BoP -10%_PmaxQmin
45	0.024	-	-	BoP -10%_PmaxQmin
46	0.070	-	-	BoP -10%_PmaxQmin
47	0.071	-	-	BoP -10%_PmaxQmin
48	0.023	-	-	BoP -10%_PmaxQmin
49	0.066	-	-	BoP -10%_PmaxQmin
50	0.085	-	-	BoP -10%_PmaxQmin

The resultant current harmonic distortion is also plotted against the AAS allocation limits as shown in Figure 12.

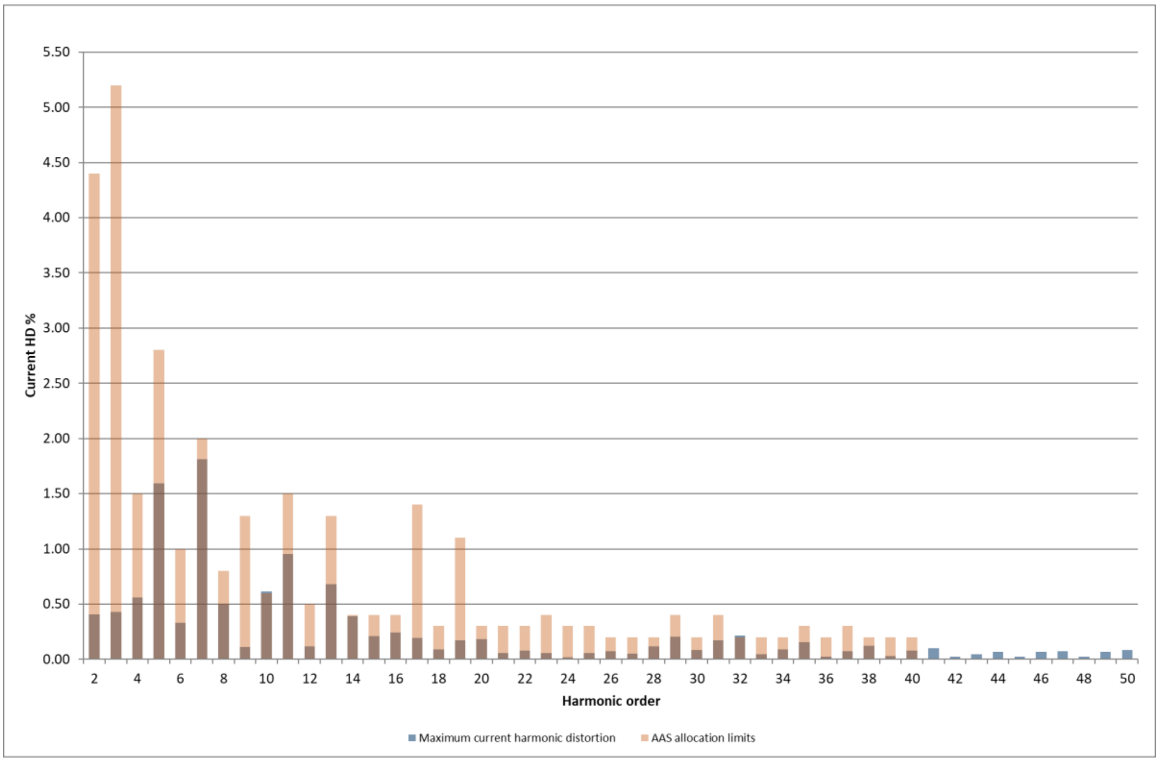

Figure 12. Harmonic current distortion at PoC Vs AAS current harmonic allocation limits- with harmonic filters in service

The above results show that the maximum current harmonic distortion for all harmonic orders does not exceed the AAS limits.

The network harmonic impedances which gave rise to the maximum current harmonic distortion at the point of connection when filters are in service are shown in Table 8-4.

Table 8-4: Worst-case network harmonic impedance resulted from current harmonic distortion- with harmonic filters in service

F [Hz]	R [Ω]	X [Ω]	F [Hz]	R [Ω]	X [Ω]
100	1.84	12.71	1350	67.9	-7.88
150	77.62	-89.25	1400	43.77	4.02
200	17.86	-35.68	1450	27.84	21.01
250	9.03	54.38	1500	27.23	32.73
300	9.8	57.31	1550	30.88	37.9
350	2.5	32.51	1600	28.71	43.29
400	14.9	21.79	1650	33.82	43.26
450	29.79	-2.01	1700	25.12	46.89
500	25.04	-30.56	1750	28.28	55.13
550	16.4	-15.65	1800	24.11	62.51
600	33.81	-30.95	1850	90.8	-25.61

F [Hz]	R [Ω]	X [Ω]	F [Hz]	R [Ω]	X [Ω]
650	33.23	-35.7	1900	98.65	-45.42
700	25.29	-27.04	1950	63.64	-75.71
750	16.77	-9.56	2000	74.49	-92.21
800	13	6.95	2050	48.77	-36.55
850	23.66	-10.34	2100	61.83	-16.23
900	16.65	5.43	2150	51.58	-8.55
950	16.79	15.21	2200	31.99	35.71
1000	13.85	30.63	2250	51.03	-9.45
1050	32.62	26.22	2300	82.04	-15.21
1100	20.92	33.14	2350	54.7	-8.6
1150	18.96	41.95	2400	35.42	25.87
1200	13.66	53.28	2450	28.36	54.27
1250	12.65	62.97	2500	22.52	75.48
1300	105.82	1.95			

9. Conclusions and Recommendations

As per the NER requirement clause S5.2.5.2 and harmonic limits specified by Ausgrid, PSC has undertaken a harmonic assessment for MUSSF. The results indicate that:

- Without harmonic filters in service,
  - The maximum voltage harmonic distortion of MUSSF at PoC at 8th and 10th harmonic orders exceeds the specified AAS and MAS allocated limits. The maximum harmonic voltage distortion for 8th and 10th harmonic orders are 0.42% and 0.69% compared to the AAS limit of 0.1% and MAS limit of 0.24%.

  - Connection of MUSSF leads to high amplification of existing background harmonic distortion for 7th to 10th harmonic orders. The maximum harmonic amplification factor was 4.0, which was observed for 10th harmonic order.

  - The maximum current harmonic distortion of MUSSF exceeds the AAS allocated limits for 7th, 8th, 10th, 11th, 13th and 14th order harmonics. Further, the maximum current harmonic distortion of MUSSF exceeds the MAS allocated limits at 10th harmonic order.

Considering the voltage and current harmonic distortion violations, two harmonic filters were proposed to mitigate the excessive harmonic current/voltage levels and to comply with the AAS limits as follows:

- 1 X 6 MVAr C-type filter, Tuned frequency – 370 Hz, Quality factor – 2.5
- 1 X 6 MVAr HP filter, Tuned frequency – 600 Hz, Quality factor – 1

The harmonic assessment was conducted with the abovementioned harmonic filters in service. The results indicate that:

- The maximum voltage and current harmonic distortions at the PoC are in compliance with the AAS allocation limits.
- The filter aleviated the amplification factor at the PoC for complete frequency range. So, there is no significant amplification of the existing background harmonic distortion due to the connection of MUSSF when the harmonic filters are in service.

It should be noted that this is a concept design, and the report does not include the component rating calculation, which should be conducted at the detailed design stage by a harmonic filter supplier.

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10. References

[1] AEMC, "National Electricity Rules, Version 174," 2021.

[2] Ausgrid, "Network Harmonic impedance at ESCO 135 MW Solar Array POC," 26th September 2022.

[3] Ausgrid, “Power Quality emissions report - 135MW Solar farm connection near Muswellbrook Coal Mine Site AN22654,” 18 February 2022.

[4] SMA Solar Technology AG, "Norton and Thevenin Harmonic Models for SC 4200 UP," 04-08-2020.

[5] ESCO, "20220927_MUSSF_Details.xlsx".

[6] "IEC/TR 61000.3.6:2008 Electromagnetic compatibility (EMC) Part 3.6: Limits - Assessment of emission limits for the connection of distorting installations in MV and HV power systems".

Attachments

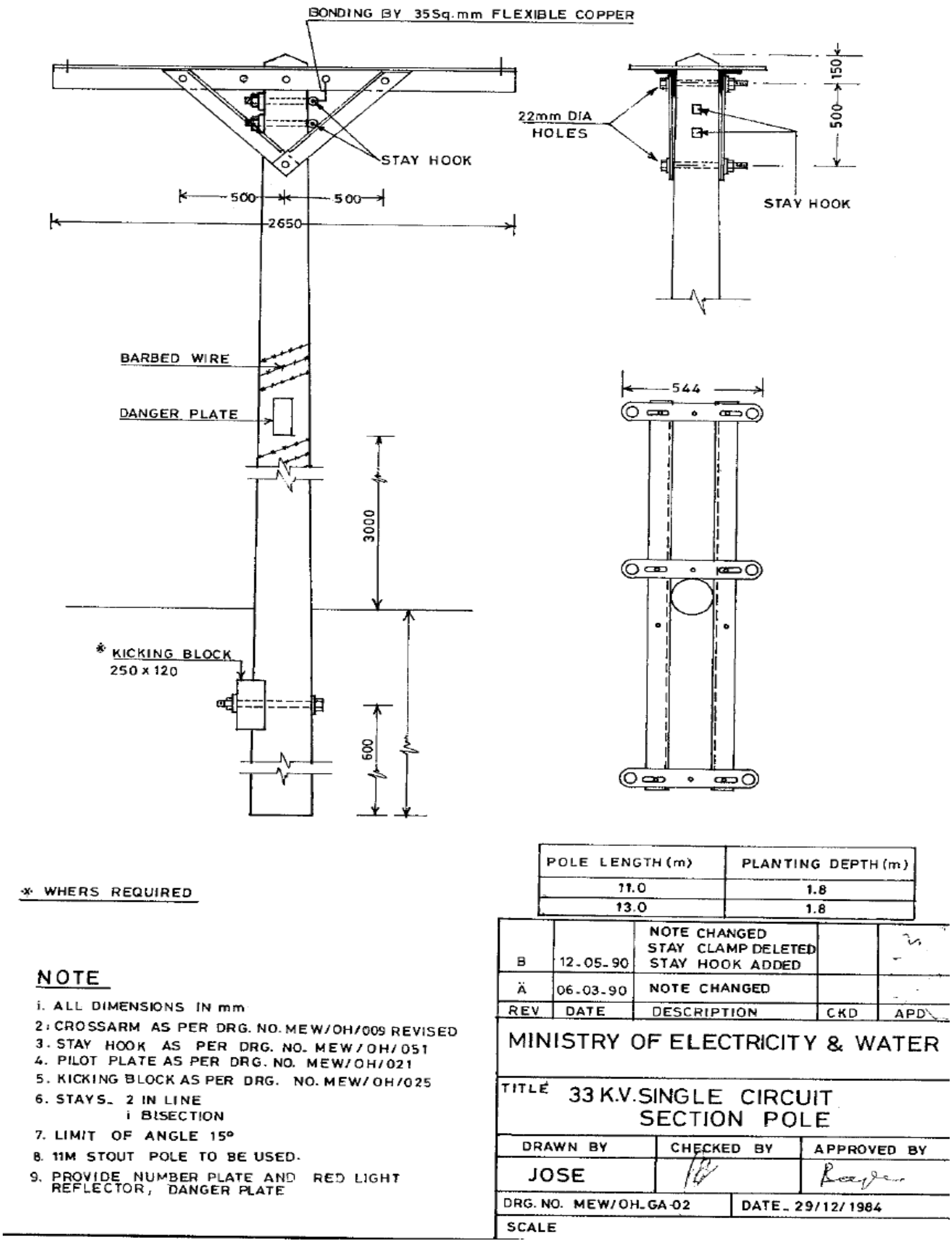
A.1 Attachment A

Details of MUSSF 33 kV cable system [5]

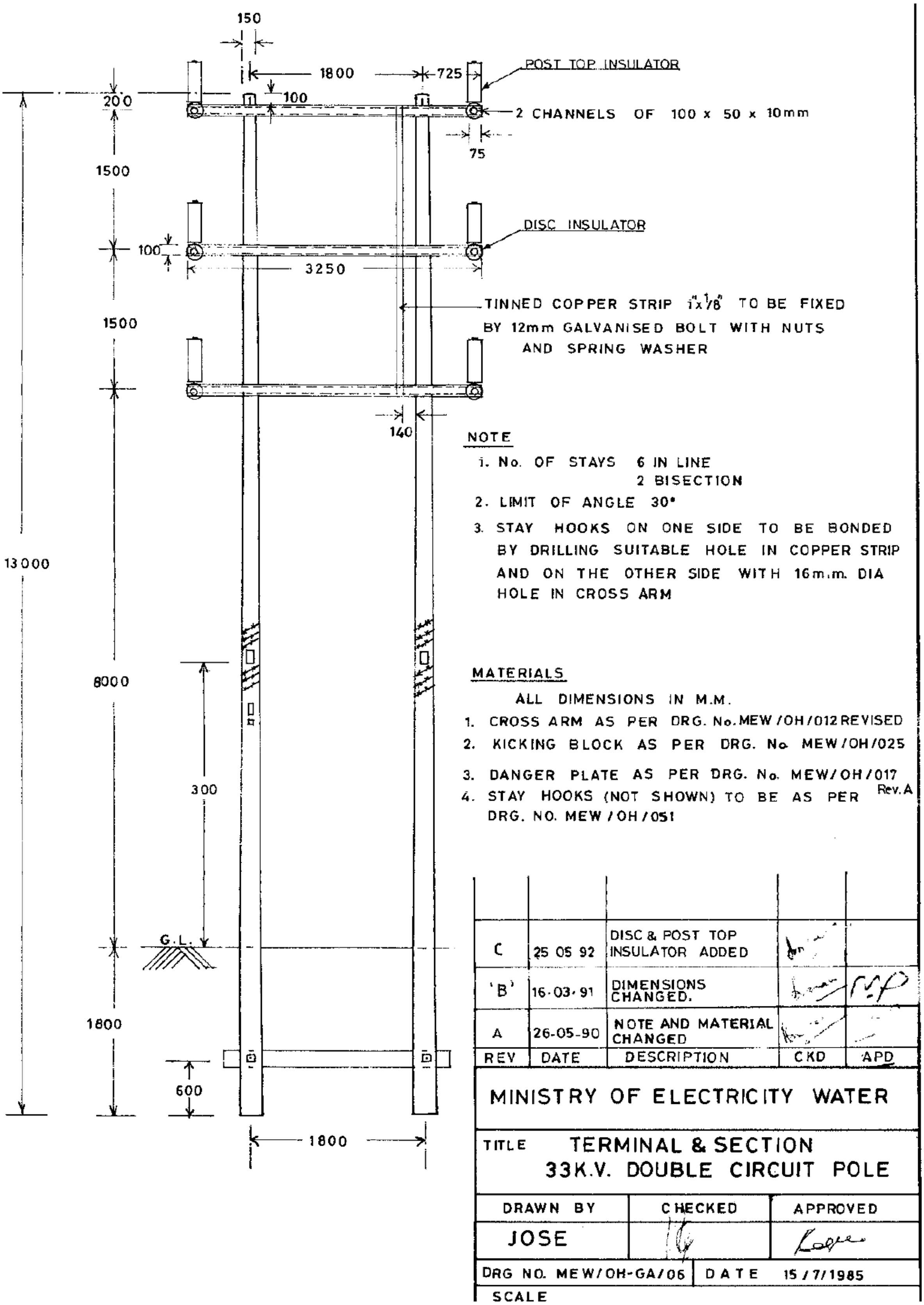
Feeder	From Inv	To Inv	Number of inverters	P(MW)	Length (m)	Conductor	Cable size mm2	Type
Fdr1	1	2	1	4.2	380	3X1C	185	AL
Fdr1	2	3	2	8.4	510	3X1C	185	AL
Fdr1	3	4	3	12.6	470	3X1C	185	AL
Fdr1	4	37	4	16.8	740	3X1C	300	AL
Fdr1	37	8	5	21	130	3X1C	400	AL
Fdr1	8	6	6	25.2	252	3X1C	630	AL
Fdr1	6	sub	7	29.4	10	3X1C	800	AL
Fdr2	38	10	1	4.2	235	3X1C	185	AL
Fdr2	10	11	2	8.4	300	3X1C	185	AL
Fdr2	11	5	3	12.6	390	3X1C	185	AL
Fdr2	12	5	1	4.2	575	3X1C	185	AL
Fdr2	5	41	5	21	520	3X1C	400	AL
Fdr2	41	7	6	25.2	576	3X1C	630	AL
Fdr2	7	Sub	7	29.4	10	3X1C	800	AL
Fdr3	13	14	1	4.2	520	3X1C	185	AL
Fdr3	14	15	2	8.4	270	3X1C	185	AL
Fdr3	17	16	1	4.2	220	3X1C	185	AL
Fdr3	16	15	2	8.4	295	3X1C	185	AL
Fdr3	23	15	1	4.2	655	3X1C	185	AL
Fdr3	39	15	1	4.2	546	3X1C	185	AL
Fdr3	15	sub	7	29.4	1170	3X1C	800	AL
Fdr4	21	20	1	4.2	125	3X1C	185	AL
Fdr4	22	20	1	4.2	400	3X1C	185	AL
Fdr4	20	19	3	12.6	125	3X1C	185	AL
Fdr4	40	19	1	4.2	582	3X1C	185	AL
Fdr4	19	18	5	21	376	3X1C	400	AL
Fdr4	18	9	6	25.2	905	3X1C	630	AL
Fdr4	9	sub	7	29.4	362	3X1C	800	AL
Fdr5	24	25	1	4.2	133	3X1C	185	AL
Fdr5	25	26	2	8.4	130	3X1C	185	AL
Fdr5	26	29	3	12.6	233	3X1C	185	AL
Fdr5	27	28	1	4.2	113	3X1C	185	AL
Fdr5	28	29	2	8.4	233	3X1C	185	AL
Fdr5	29	PP0	6	25.2	82	3X1C	630	AL
Fdr5	PP0	PP2	6	25.2	1136	33/3.00 AAAC/112		Nitrogen
Fdr5	PP2	PP5	6	25.2	4566	33/3.00 AAAC/112		Nitrogen
Fdr5	PP5	sub	6	25.2	188	3X1C	630	AL
Fdr6	30	31	1	4.2	188	3X1C	185	AL
Fdr6	31	32	2	8.4	250	3X1C	185	AL
Fdr6	32	33	3	12.6	282	3X1C	185	AL
Fdr6	33	34	4	16.8	266	3X1C	300	AL
Fdr6	34	35	5	21	902	3X1C	400	AL
Fdr6	35	36	6	25.2	191	3X1C	630	AL
Fdr6	36	PP2	7	29.4	16	3X1C	800	AL
Fdr6	PP2	PP5	7	29.4	4566	33/3.00 AAAC/112		Nitrogen
Fdr6	PP5	sub	7	29.4	188	3X1C	800	AL

A.2 Attachment B

Details of 33kV Single circuit Pole



Details of 33kV Double circuit Pole



A.3 Attachment C

Network harmonic impedance Polygons at MUSSF 132kV connection point: values are given in p.u[6].

R2	X2	R3	X3	R4	X4	R5	X5	R6	X6	R7	X7	R8	X8	R9	X9	R10	X10
0.0068	0.0817	0.0099	0.1228	0.0079	-0.0113	0.0050	0.0830	0.0085	0.1452	0.0155	0.2018	0.0246	0.2517	0.0458	0.3107	0.0548	0.3220
0.0068	0.0803	0.0098	0.1224	0.0081	-0.0134	0.0050	0.0828	0.0084	0.1436	0.0135	0.1929	0.0209	0.2390	0.0382	0.2918	0.0547	0.3168
0.0068	0.0793	0.0096	0.1205	0.0081	-0.0135	0.0050	0.0826	0.0084	0.1426	0.0136	0.1903	0.0218	0.2334	0.0386	0.2876	0.0547	0.3124
0.0068	0.0790	0.0096	0.1185	0.0082	-0.0138	0.0051	0.0825	0.0087	0.1416	0.0140	0.1882	0.0223	0.2307	0.0391	0.2842	0.1437	-0.1754
0.0072	0.0735	0.0097	0.1169	0.0663	-0.1774	0.0052	0.0823	0.0089	0.1407	0.0144	0.1866	0.3385	-0.2974	0.0397	0.2808	0.2035	-0.2723
0.0073	0.0734	0.0098	0.1162	0.0666	-0.1779	0.0053	0.0824	0.0103	0.1410	0.0186	0.1870	0.3456	-0.3001	0.3022	-0.3039	0.2042	-0.2731
0.0106	0.0729	0.2109	-0.3333	0.0695	-0.1821	0.0053	0.0824	0.0104	0.1412	0.0188	0.1871	0.3994	-0.3002	0.3316	-0.3294	0.2079	-0.2772
0.0106	0.0730	0.4455	-0.5122	0.0728	-0.1864	0.0570	0.2782	0.0206	0.1578	0.0716	0.2495	0.4121	-0.2973	0.3394	-0.3337	0.2518	-0.3030
0.0838	0.1050	0.4503	-0.5132	0.0801	-0.1937	0.0577	0.2813	0.0962	0.3689	0.1536	0.3812	0.4461	-0.2834	0.4104	-0.3437	0.2753	-0.3054
0.0868	0.1069	0.5217	-0.5225	0.0867	-0.1990	0.0587	0.2859	0.0980	0.3739	0.1570	0.3872	0.4723	-0.2669	0.4620	-0.3267	0.2952	-0.3051
0.0568	0.1241	0.5265	-0.5228	0.1025	-0.2048	0.0606	0.2962	0.1055	0.3990	0.1595	0.3932	0.5829	-0.0903	0.4945	-0.3106	0.3086	-0.3035
0.0468	0.1276	0.5481	-0.5235	0.1045	-0.2044	0.0620	0.3049	0.1071	0.4062	0.2241	0.5466	0.6184	-0.0077	0.5847	-0.1736	0.6115	0.2842
0.0407	0.1295	0.5541	-0.5234	0.1668	-0.1511	0.0584	0.3216	0.1088	0.4138	0.2282	0.5588	0.6327	0.1407	0.6017	-0.1408	0.6264	0.5075
0.0201	0.1344	0.6878	-0.4805	0.1681	-0.1486	0.0580	0.3219	0.1114	0.4298	0.2270	0.5648	0.6328	0.1422	0.6473	-0.0074	0.5858	0.6019
0.0166	0.1337	0.9245	-0.3267	0.1773	0.0826	0.0570	0.3218	0.1050	0.4325	0.2234	0.5678	0.5494	0.6381	0.6583	0.0843	0.5653	0.6113
0.0163	0.1328	0.9287	-0.3218	0.1760	0.0891	0.0561	0.3211	0.1037	0.4321	0.2091	0.5755	0.4945	0.7315	0.6586	0.0891	0.5291	0.6134
0.0113	0.1144	1.0086	-0.2040	0.1720	0.1061	0.0560	0.3210	0.1006	0.4309	0.2049	0.5742	0.4806	0.7472	0.6582	0.1053	0.4191	0.6043
0.0110	0.1125	1.0262	-0.1681	0.1694	0.1118	0.0519	0.3122	0.1004	0.4307	0.2045	0.5740	0.4663	0.7478	0.5789	0.4301	0.3360	0.5791
0.0068	0.0817	1.0286	-0.1612	0.1098	0.1996	0.0518	0.3121	0.0886	0.4109	0.1821	0.5533	0.4492	0.7475	0.4842	0.5891	0.1492	0.4925
		1.0257	0.0537	0.0550	0.2319	0.0230	0.2218	0.0346	0.2743	0.1512	0.5167	0.4484	0.7474	0.3643	0.6257	0.1374	0.4859
		1.0252	0.0605	0.0324	0.2378	0.0230	0.2218	0.0323	0.2682	0.0518	0.3360	0.3918	0.7194	0.3521	0.6250	0.1372	0.4858
		0.9878	0.1454	0.0309	0.2342	0.0063	0.1041	0.0125	0.1760	0.0470	0.3251	0.3347	0.6891	0.3517	0.6249	0.1081	0.4479
		0.9583	0.2033	0.0309	0.2341	0.0056	0.0990	0.0109	0.1669	0.0155	0.2018	0.2964	0.6615	0.2762	0.5946	0.0548	0.3220
		0.9394	0.2372	0.0150	0.1674	0.0054	0.0967	0.0085	0.1452			0.0936	0.4325	0.2618	0.5843		
		0.8845	0.2923	0.0150	0.1674	0.0053	0.0949					0.0805	0.4096	0.2154	0.5509		
		0.1825	0.2956	0.0148	0.1658	0.0050	0.0830					0.0246	0.2517	0.0458	0.3107		
		0.0799	0.2841	0.0079	-0.0113												
		0.0404	0.2432														
		0.0384	0.2384														
		0.0384	0.2383														
		0.0378	0.2364														
		0.0099	0.1228														

[6] 100MVA base is considered in converted to ohmic values

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R11	X11	R12	X12	R13	X13	R14	X14	R15	X15	R16	X16	R17	X17	R18	X18	R19	X19	R20	X20
0.0969	0.4213	0.1587	0.5078	0.3005	0.5513	0.4746	0.6014	0.0893	0.0505	0.0643	0.1236	0.0695	0.1730	0.0946	0.0346	0.0710	0.1218	0.4224	0.2313
0.0719	0.3822	0.1407	0.4898	0.2683	0.5500	0.4193	0.6134	0.0947	-0.0508	0.0608	0.1118	0.1311	-0.0529	0.0948	0.0323	0.0711	0.1209	0.4168	0.3216
0.0711	0.3738	0.1380	0.4869	0.2342	0.5329	0.2845	0.5803	0.0948	-0.0520	0.0608	0.1116	0.1323	-0.0553	0.0955	0.0312	0.0722	0.1061	0.3927	0.3800
0.0705	0.3671	0.1071	0.4501	0.1797	0.4974	0.2412	0.5424	0.0963	-0.0548	0.0619	0.0942	0.1358	-0.0594	0.1308	0.0067	0.0731	0.1049	0.2851	0.4589
0.0941	-0.0898	0.1036	0.4369	0.1694	0.4883	0.2223	0.5259	0.1170	-0.0768	0.0621	0.0934	0.1990	-0.1016	0.1434	0.0042	0.0963	0.0873	0.2598	0.4708
0.0944	-0.0902	0.1009	0.4265	0.1589	0.4720	0.0969	-0.0200	0.1563	-0.1054	0.0745	0.0401	0.2028	-0.1029	0.1511	0.0047	0.0974	0.0867	0.2396	0.4799
0.0954	-0.0913	0.1940	-0.1776	0.1512	0.4595	0.1452	-0.1552	0.2030	-0.1332	0.0747	0.0399	0.2192	-0.1041	0.1546	0.0072	0.1334	0.0772	0.1799	0.4828
0.1294	-0.1283	0.1951	-0.1789	0.1370	-0.0707	0.1492	-0.1615	0.2279	-0.1470	0.0850	0.0307	0.2337	-0.1050	0.2742	0.1141	0.3413	0.1325	0.1706	0.4784
0.1312	-0.1300	0.3138	-0.3175	0.1907	-0.2049	0.1912	-0.1976	0.3118	-0.1698	0.0978	0.0206	0.2400	-0.1023	0.2822	0.1305	0.3544	0.1381	0.0910	0.3262
0.1497	-0.1424	0.3154	-0.3191	0.1913	-0.2060	0.3389	-0.2284	0.4309	-0.1489	0.1222	0.0029	0.2392	-0.0813	0.3333	0.2693	0.4259	0.2063	0.0622	0.2586
0.3757	-0.1919	0.3274	-0.3272	0.2220	-0.2506	0.4261	-0.2332	0.5781	-0.0685	0.1231	0.0023	0.1977	0.2680	0.3222	0.3025	0.4410	0.2237	0.0647	0.1946
0.3767	-0.1920	0.4335	-0.3544	0.2297	-0.2587	0.7407	-0.2505	0.8060	0.0806	0.1652	-0.0150	0.1976	0.2685	0.2949	0.3363	0.4138	0.3060	0.0665	0.1894
0.3861	-0.1920	0.4787	-0.3384	0.3047	-0.3000	0.7420	-0.2505	0.8078	0.0819	0.1668	-0.0157	0.1852	0.2776	0.2568	0.3583	0.3804	0.3546	0.0706	0.1847
0.4514	-0.1696	0.8926	-0.1651	0.3372	-0.2980	0.7981	-0.2338	0.8612	0.1771	0.5241	-0.1486	0.1702	0.2811	0.2229	0.3751	0.3636	0.3770	0.0789	0.1761
0.8077	0.2036	0.8942	-0.1641	0.3666	-0.2936	0.8026	-0.2324	0.8905	0.2932	0.5653	-0.1554	0.1594	0.2835	0.1772	0.3737	0.2770	0.4424	0.0805	0.1754
0.8807	0.3341	0.9311	-0.1336	0.6917	-0.1495	1.0037	0.0846	0.8948	0.3209	0.6079	-0.1553	0.1076	0.2703	0.1430	0.3727	0.2498	0.4475	0.0899	0.1716
0.9084	0.4058	0.9378	-0.1133	0.8045	-0.0887	0.9441	0.3430	0.8529	0.4025	0.6271	-0.1537	0.0732	0.2012	0.1233	0.3646	0.2291	0.4508	0.2674	0.1213
0.9080	0.4072	1.0081	0.1576	0.8056	-0.0880	0.8597	0.4136	0.6474	0.6006	0.6833	-0.0647	0.0730	0.2007	0.1137	0.3576	0.1296	0.3988	0.3269	0.1133
0.8931	0.4452	0.9099	0.5160	0.9346	0.0159	0.7892	0.4573	0.5833	0.6189	0.8288	0.1698	0.0703	0.1869	0.1040	0.3299	0.1253	0.3821	0.3472	0.1130
0.8476	0.4842	0.9094	0.5172	0.9355	0.0170	0.4746	0.6014	0.5125	0.6075	0.7918	0.2580	0.0695	0.1730	0.0946	0.0346	0.0710	0.1218	0.4224	0.2313
0.7152	0.5756	0.8801	0.5638	0.9650	0.0699			0.4613	0.5968	0.7532	0.3220								
0.4468	0.6547	0.8585	0.5736	0.9647	0.0840			0.4262	0.5838	0.6888	0.3286								
0.4462	0.6548	0.6433	0.6682	0.9495	0.2556			0.0901	0.0530	0.0720	0.1331								
0.4231	0.6568	0.5966	0.6855	0.9082	0.3947			0.0893	0.0505	0.0646	0.1242								
0.2689	0.6138	0.5601	0.6982	0.7927	0.5167					0.0643	0.1236								
0.1960	0.5565	0.3933	0.6694	0.7076	0.5355														
0.0969	0.4213	0.3674	0.6559	0.6618	0.5454														
		0.1587	0.5078	0.6027	0.5547														
				0.3005	0.5513														

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R21	X21	R22	X22	R23	X23	R24	X24	R25	X25	R26	X26	R27	X27	R28	X28	R29	X29	R30	X30
0.0517	0.3080	0.0511	0.3609	0.0825	0.4675	0.0994	0.5188	0.0548	0.3779	0.0549	0.4306	0.0630	0.4916	0.0846	0.5446	0.1107	0.6046	0.1026	0.5955
0.0492	0.2905	0.0502	0.3576	0.0785	0.4600	0.0942	0.5129	0.0673	0.3648	0.0648	0.4205	0.0780	0.4576	0.0822	0.5066	0.0873	0.5634	0.1085	0.5421
0.0525	0.2633	0.0483	0.3436	0.0542	0.4093	0.0644	0.4583	0.0689	0.3633	0.5946	0.0200	0.3719	-0.0268	0.2372	0.0358	0.0923	0.5319	0.1516	0.1978
0.0635	0.2518	0.0488	0.3367	0.0517	0.3916	0.0610	0.4334	0.0726	0.3614	0.6074	0.0112	0.3897	-0.0452	0.2441	0.0271	0.1566	0.1315	0.1541	0.1907
0.1664	0.1608	0.0506	0.3198	0.0514	0.3889	0.0528	0.3325	0.7258	0.3178	0.6216	0.0107	0.3921	-0.0451	0.2456	0.0259	0.1577	0.1259	0.1560	0.1881
0.1722	0.1572	0.1008	0.2136	0.0519	0.3776	0.0527	0.3300	0.7448	0.3197	0.6380	0.0184	0.4031	-0.0440	0.2467	0.0252	0.1594	0.1209	0.1563	0.1879
0.1937	0.1476	0.1136	0.1943	0.0628	0.2713	0.0556	0.3260	0.7492	0.3499	0.6945	0.1162	0.4053	-0.0437	0.2523	0.0225	0.1598	0.1206	0.2505	0.1620
0.1980	0.1464	0.1193	0.1906	0.1088	0.2408	0.0605	0.3194	0.6968	0.4367	0.7374	0.2464	0.4689	-0.0247	0.2539	0.0220	0.1996	0.1041	0.3074	0.1639
0.2477	0.1748	0.1194	0.1905	0.1237	0.2371	0.0676	0.3108	0.6071	0.5506	0.7145	0.3711	0.4817	-0.0202	0.3042	0.0150	0.2350	0.0967	0.3591	0.1741
0.2805	0.2108	0.1199	0.1903	0.1238	0.2371	0.0774	0.3062	0.5373	0.6032	0.6683	0.4501	0.4838	-0.0195	0.3476	0.0145	0.2660	0.0931	0.3977	0.3826
0.2950	0.2363	0.1202	0.1902	0.1246	0.2372	0.0784	0.3058	0.4530	0.6147	0.6655	0.4524	0.5314	0.0081	0.3496	0.0145	0.2926	0.0962	0.3996	0.4042
0.2902	0.2564	0.1470	0.1840	0.1311	0.2398	0.0786	0.3058	0.1873	0.6259	0.5612	0.5343	0.5449	0.0163	0.4503	0.0723	0.3573	0.1043	0.3970	0.5404
0.2412	0.4188	0.1773	0.1781	0.1318	0.2402	0.0839	0.3052	0.1795	0.6231	0.2951	0.7139	0.5466	0.0175	0.5052	0.1331	0.4142	0.1223	0.3969	0.5418
0.2190	0.4389	0.1940	0.1799	0.1764	0.2699	0.1444	0.3156	0.1319	0.5825	0.2871	0.7168	0.6185	0.1029	0.7155	0.4957	0.5061	0.1876	0.3842	0.5984
0.1034	0.4057	0.2098	0.1830	0.1773	0.2709	0.1448	0.3157	0.1179	0.5694	0.2767	0.7156	0.6201	0.1051	0.7257	0.5445	0.5252	0.2127	0.3606	0.6404
0.0986	0.4006	0.2115	0.1839	0.4132	0.5256	0.5942	0.4796	0.0788	0.5112	0.2073	0.6782	0.6598	0.1883	0.7243	0.5529	0.5368	0.2359	0.3354	0.6658
0.0705	0.3598	0.2118	0.1842	0.4154	0.5344	0.6055	0.5236	0.0537	0.3891	0.1324	0.6108	0.6605	0.1907	0.7225	0.5587	0.5961	0.3670	0.1978	0.7122
0.0517	0.3080	0.2186	0.1902	0.4142	0.5417	0.5538	0.5469	0.0536	0.3864	0.1088	0.5710	0.6278	0.3333	0.7145	0.5795	0.5969	0.3691	0.1944	0.7127
		0.2204	0.1950	0.3921	0.5484	0.3616	0.6224	0.0548	0.3779	0.0620	0.4593	0.5082	0.7290	0.7125	0.5842	0.6001	0.4153	0.1941	0.7126
		0.2243	0.2055	0.3819	0.5503	0.3374	0.6228			0.0549	0.4306	0.4844	0.7697	0.7087	0.5901	0.5940	0.4521	0.1102	0.6404
		0.3201	0.4812	0.2274	0.5752	0.1505	0.5545					0.4613	0.7711	0.6595	0.6458	0.5447	0.5311	0.1026	0.5955
		0.3175	0.4865	0.2088	0.5638	0.0994	0.5188					0.3859	0.7706	0.6549	0.6504	0.4415	0.6539		
		0.2955	0.5092	0.0825	0.4675							0.3830	0.7701	0.6150	0.6765	0.4034	0.6819		
		0.2933	0.5096									0.3639	0.7670	0.5793	0.6906	0.3707	0.6955		
		0.1469	0.4919									0.3616	0.7664	0.4153	0.7029	0.3030	0.6934		
		0.0733	0.4136									0.2112	0.6928	0.3692	0.7033	0.1763	0.6814		
		0.0511	0.3609									0.2101	0.6921	0.2624	0.6966	0.1760	0.6812		
												0.1976	0.6784	0.2606	0.6960	0.1396	0.6387		
												0.0952	0.5540	0.2601	0.6958	0.1107	0.6046		
												0.0786	0.5260	0.1712	0.6407				
												0.0630	0.4916	0.1710	0.6404				
														0.1360	0.6125				
														0.1358	0.6123				
														0.1088	0.5790				
														0.0846	0.5446				

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R31	X31	R32	X32	R33	X33	R34	X34	R35	X35	R36	X36	R37	X37	R38	X38	R39	X39	R40	X40
0.1041	0.6495	0.1056	0.7183	0.1186	0.8051	0.1597	0.9364	0.1992	0.9850	0.2702	1.2170	0.2466	0.8819	0.3876	1.0802	0.0992	0.5367	0.1573	-0.1151
0.1051	0.6042	0.1043	0.6745	0.1181	0.7656	0.1060	0.3101	0.1127	0.3667	0.1024	0.4016	0.1009	0.4531	0.1026	0.5041	0.3149	-0.3961	0.2955	-0.3495
0.1646	0.2359	0.1636	0.2514	0.1491	0.2770	0.1095	0.3019	0.1163	0.3531	0.1068	0.3941	0.1464	0.3875	0.0939	0.4681	0.3652	-0.4345	0.3308	-0.4058
0.1680	0.2279	0.1640	0.2491	0.1499	0.2757	0.1349	0.2771	0.1606	0.3177	0.1244	0.3743	0.5211	-0.1470	0.0939	0.4681	0.9047	-0.8270	0.3638	-0.4513
0.1682	0.2276	0.1648	0.2484	0.1941	0.2483	0.1442	0.2691	0.1623	0.3164	0.1384	0.3588	0.6280	-0.1861	0.1018	0.4514	1.2368	-0.9017	0.4275	-0.5292
0.1704	0.2243	0.1935	0.2362	0.1984	0.2476	0.4690	0.1795	0.6066	0.3484	1.2453	0.2021	0.8766	-0.2622	0.1089	0.4381	1.6415	-0.8035	0.8386	-0.8409
0.1737	0.2202	0.2200	0.2263	0.2068	0.2497	0.5031	0.1830	0.6838	0.3558	1.3955	0.2325	1.1907	-0.2845	0.4771	-0.1610	1.6476	-0.7989	1.1102	-0.9211
0.1772	0.2175	0.2374	0.2218	0.6826	0.5353	0.5301	0.1916	0.7474	0.3786	1.4153	0.2388	1.5432	-0.1363	0.5662	-0.2607	2.7706	0.4813	1.1155	-0.9205
0.1963	0.2114	0.2476	0.2283	0.6831	0.5362	0.6619	0.2396	1.1594	0.6317	1.5817	0.3898	2.5102	0.5996	1.0550	-0.6391	2.7647	0.4958	1.2029	-0.8729
0.2365	0.2035	0.4348	0.5313	0.6997	0.5751	0.6828	0.2475	1.1598	0.6320	1.5859	0.4097	2.1860	1.8796	1.2156	-0.7436	2.5757	0.6396	1.7191	-0.2371
0.2739	0.2000	0.5098	0.6660	0.6935	0.6520	0.8290	0.5400	1.2151	0.6766	1.5462	0.9700	1.8542	1.9907	1.3617	-0.8084	1.0989	1.2973	1.9069	0.1587
0.2889	0.2021	0.5121	0.6747	0.6681	0.7381	0.8649	0.6238	1.2329	0.7041	1.5347	0.9910	1.8410	1.9874	1.5203	-0.8384	1.0989	1.2973	1.7594	0.8627
0.3793	0.4793	0.4925	0.7807	0.6333	0.7942	0.8667	0.6345	1.2484	0.7951	0.9326	1.5116	0.6012	1.6385	2.3222	-0.8860	0.5830	1.1968	1.5942	1.1234
0.3847	0.5079	0.4921	0.7813	0.5292	0.9204	0.8892	0.9424	1.2250	0.8819	0.7043	1.6313	0.5167	1.5607	2.8502	-0.5306	0.1083	0.5542	1.2615	1.2971
0.3763	0.6331	0.4424	0.8020	0.5290	0.9206	0.8892	0.9428	1.1334	1.0084	0.6845	1.6271	0.5148	1.5568	2.8550	-0.5136	0.0992	0.5367	0.1342	0.6198
0.3270	0.7367	0.4286	0.8057	0.4947	0.9539	0.8745	1.1341	0.8285	1.1386	0.2702	1.2170	0.2466	0.8819	2.7562	-0.2657			0.1271	0.6151
0.2953	0.7723	0.3791	0.8173	0.4019	0.9997	0.8744	1.1345	0.5628	1.2231					1.5546	2.0089			0.1573	-0.1151
0.2922	0.7738	0.2664	0.8267	0.2686	0.9433	0.8464	1.2160	0.5003	1.2280					1.5440	2.0047				
0.2601	0.7632	0.2341	0.8289	0.2513	0.9330	0.8337	1.2311	0.4028	1.2047					0.5681	1.2561				
0.1389	0.7152	0.1736	0.8114	0.1277	0.8161	0.2906	1.1267	0.2153	1.0096					0.3876	1.0802				
0.1041	0.6495	0.1056	0.7183	0.1186	0.8051	0.1597	0.9364	0.1992	0.9850										

R41	X41	R42	X42	R43	X43	R44	X44	R45	X45	R46	X46	R47	X47	R48	X48	R49	X49	R50	X50
0.1152	0.1360	0.0967	0.2078	0.0772	0.2884	0.0824	0.4345	0.0726	0.5809	0.1307	0.8524	0.0817	0.7587	0.2059	1.0975	0.3515	1.3303	0.7266	1.5729
0.1104	0.0784	0.1088	0.1466	0.1431	0.0835	0.0861	0.3974	0.0728	0.5648	0.0764	0.7115	0.0809	0.7502	0.1060	0.8658	0.3162	1.2900	0.6131	1.5355
0.1108	0.0526	0.1466	0.0648	0.2960	-0.0491	0.1122	0.2640	0.0733	0.5573	0.0764	0.7115	0.1013	0.2911	0.0940	0.8269	0.1274	0.9446	0.1625	1.0290
0.1796	-0.1169	0.1672	0.0320	0.3023	-0.0468	0.1122	0.2640	0.1054	0.3674	0.0740	0.6800	0.3034	-0.0415	0.0791	0.4032	0.1126	0.9039	0.1625	1.0290
0.2799	-0.2098	0.3328	-0.0788	0.3144	-0.0389	0.1205	0.2518	0.2882	-0.0489	0.0746	0.6683	0.3140	-0.0494	0.1469	0.1853	0.0708	0.5007	0.1390	0.9840
0.3204	-0.2337	0.5537	-0.2227	0.5078	0.4285	0.1836	0.2050	0.2929	-0.0542	0.1451	0.1476	0.3785	-0.0739	0.1652	0.1711	0.0709	0.4943	0.0698	0.5910
0.4445	-0.3035	0.5549	-0.2224	0.5279	0.6173	0.6903	-0.0067	0.2929	-0.0542	0.1460	0.1460	0.4968	-0.0936	0.2033	0.1485	0.1240	0.3369	0.0696	0.5871
0.7909	-0.3185	0.5847	-0.2131	0.5185	0.6542	0.8086	-0.0045	0.4068	-0.1174	0.1690	0.1216	0.8576	-0.0817	0.2444	0.1350	0.1263	0.3334	0.1066	0.4571
0.8483	-0.2945	0.5860	-0.2127	0.5185	0.6542	0.8086	-0.0045	0.4068	-0.1174	0.1690	0.1216	0.9572	-0.0766	0.2716	0.1266	0.1294	0.3302	0.1073	0.4562
0.9055	-0.2684	0.8384	-0.0293	0.2766	0.6498	0.8100	-0.0029	0.4849	-0.1324	0.2009	0.0954	1.1265	0.0310	0.3773	0.1112	0.1628	0.3114	0.1292	0.4332
0.9247	-0.1963	1.1590	0.3622	0.0994	0.5560	0.8609	0.0598	0.4865	-0.1324	0.2009	0.0954	1.4524	0.6419	0.3773	0.1112	0.2258	0.3014	0.1293	0.4332
0.9226	-0.0692	1.0273	0.5927	0.0770	0.2900	1.0820	0.3897	0.5399	-0.1252	0.7408	-0.2700	1.3857	0.7341	0.7227	0.2986	0.2258	0.3013	0.1298	0.4331
0.9036	-0.0196	0.8861	0.6398	0.0772	0.2884	1.0820	0.3897	0.5417	-0.1250	0.7558	-0.2731	1.3857	0.7341	0.8330	0.4577	0.5755	1.4807	0.1306	0.4332
0.8088	0.2112	0.1776	0.6882			1.0713	0.4417	0.6805	-0.0598	1.0455	-0.1828	0.2589	1.1118	0.8271	0.4968	0.5980	1.5639	0.1671	0.4519
0.4672	0.5949	0.1734	0.6745			1.0703	0.4450	0.9002	0.0558	1.1151	-0.1133	0.1855	1.0418	0.5173	1.3975	0.5191	1.5057	1.3461	1.5330
0.2875	0.7053	0.0967	0.2078			1.0521	0.5009	1.4301	0.3872	1.1152	-0.1132	0.0880	0.7882	0.3152	1.2793	0.3515	1.3303	1.3617	1.6088
0.2269	0.6880					1.0317	0.5472	1.4414	0.4280	1.1829	0.0028	0.0817	0.7587	0.2061	1.0979			1.2257	1.6409
0.2142	0.6816					1.0300	0.5501	1.4413	0.4281	1.2256	0.1039			0.2059	1.0975			1.1338	1.6612
0.2028	0.6374					0.7011	0.9111	1.1997	0.9643	1.4091	1.0019							0.7266	1.5729
0.1152	0.1360					0.7010	0.9111	1.1996	0.9643	1.3852	1.0589								
						0.4292	0.9303	1.0657	1.0079	0.6747	1.3252								
						0.4292	0.9303	0.5881	1.1586	0.5495	1.2731								
						0.3109	0.8685	0.5598	1.1612	0.1307	0.8525								
						0.1738	0.7957	0.2769	1.0401	0.1307	0.8524								
						0.1738	0.7957	0.2769	1.0401										
						0.1677	0.7867	0.2445	0.9915										
						0.0860	0.6553	0.2444	0.9915										
						0.0847	0.6523	0.1002	0.7407										
						0.0766	0.5037	0.1002	0.7407										
						0.0795	0.4691	0.0964	0.7298										
						0.0824	0.4345	0.0749	0.6243										
								0.0726	0.5809										

A.4 Attachment D

SMA SC4200 UP Norton equivalent circuit parameters [4].

Harmonic order	Frequency [Hz]	Thevenin circuit			Norton circuit			As entered in the model		
		R [Ω]	X [Ω]	Vh [V]	G [mSiemens]	B [mSiemens]	I_h [mA]	R [pu][7]	X [pu]	I_h/I_n %
2	100	2.00	188.78	11.10	0.0561	-5.2966	58.80	0.008	0.728	0.0800
3	150	2.12	287.17	10.55	0.0257	-3.4820	36.75	0.008	1.108	0.0500
4	200	2.39	390.80	22.98	0.0157	-2.5587	58.80	0.009	1.507	0.0800
5	250	2.97	502.23	77.52	0.0118	-1.9910	154.35	0.011	1.937	0.2101
6	300	4.12	624.96	13.78	0.0105	-1.6000	22.05	0.016	2.410	0.0300
7	350	6.32	764.06	123.55	0.0108	-1.3087	161.70	0.024	2.947	0.2201
8	400	10.53	927.34	61.35	0.0122	-1.0782	66.15	0.041	3.577	0.0900
9	450	18.67	1127.67	16.58	0.0147	-0.8865	14.70	0.072	4.349	0.0200
10	500	35.17	1388.04	102.05	0.0182	-0.7200	73.50	0.136	5.353	0.1000
11	550	71.38	1754.02	193.54	0.0232	-0.5692	110.25	0.275	6.765	0.1500
12	600	162.82	2329.96	34.33	0.0298	-0.4271	14.70	0.628	8.986	0.0200
13	650	461.73	3411.90	303.67	0.0390	-0.2878	88.20	1.781	13.159	0.1200
14	700	2160.39	6104.44	333.16	0.0515	-0.1456	51.45	8.332	23.543	0.0700
15	750	14329.12	-1234.04	422.84	0.0693	0.0060	29.40	55.264	-4.759	0.0400
16	800	2401.60	-4413.20	184.64	0.0951	0.1748	36.75	9.262	-17.021	0.0500
17	850	858.16	-2376.74	74.29	0.1344	0.3722	29.40	3.310	-9.166	0.0400
18	900	472.44	-1473.38	22.74	0.1973	0.6154	14.70	1.822	-5.682	0.0200
19	950	317.20	-967.59	29.94	0.3059	0.9332	29.40	1.223	-3.732	0.0400
20	1000	237.87	-637.88	25.02	0.5132	1.3763	36.75	0.917	-2.460	0.0500
21	1050	191.16	-400.56	6.52	0.9704	2.0334	14.70	0.737	-1.545	0.0200

[7] Pu. Values are calculated based on 33kV and 4.2MVA base values.

Harmonic order	Frequency [Hz]	Thevenin circuit			Norton circuit			As entered in the model		
		R [Ω]	X [Ω]	Vh [V]	G [mSiemens]	B [mSiemens]	I_h [mA]	R [pu][7]	X [pu]	I_h/I_n %
22	1100	160.95	-217.58	7.96	2.1973	2.9705	29.40	0.621	-0.839	0.0400
23	1150	140.09	-69.23	5.74	5.7371	2.8354	36.75	0.540	-0.267	0.0500
24	1200	124.95	55.69	2.01	6.6767	-2.9760	14.70	0.482	0.215	0.0200
25	1250	113.55	164.03	7.33	2.8530	-4.1214	36.75	0.438	0.633	0.0500
26	1300	104.70	260.18	10.31	1.3311	-3.3078	36.75	0.404	1.003	0.0500
27	1350	97.66	347.11	7.95	0.7511	-2.6696	22.05	0.377	1.339	0.0300
28	1400	91.96	426.89	19.26	0.4822	-2.2386	44.10	0.355	1.646	0.0600
29	1450	87.25	501.01	37.38	0.3374	-1.9372	73.50	0.337	1.932	0.1000
30	1500	83.31	570.56	16.95	0.2506	-1.7161	29.40	0.321	2.201	0.0400
31	1550	79.97	636.38	37.71	0.1944	-1.5470	58.80	0.308	2.454	0.0800
32	1600	77.12	699.10	51.70	0.1559	-1.4132	73.50	0.297	2.696	0.1000
33	1650	74.65	759.22	11.21	0.1283	-1.3045	14.70	0.288	2.928	0.0200
34	1700	72.50	817.14	24.12	0.1077	-1.2142	29.40	0.280	3.152	0.0400
35	1750	70.61	873.17	45.07	0.0920	-1.1378	51.45	0.272	3.368	0.0700
36	1800	68.94	927.57	6.84	0.0797	-1.0722	7.35	0.266	3.577	0.0100
37	1850	67.46	980.56	21.67	0.0698	-1.0150	22.05	0.260	3.782	0.0300
38	1900	66.14	1032.31	38.02	0.0618	-0.9647	36.75	0.255	3.981	0.0500
39	1950	64.95	1082.98	7.97	0.0552	-0.9201	7.35	0.250	4.177	0.0100
40	2000	63.88	1132.67	25.02	0.0496	-0.8801	22.05	0.246	4.368	0.0300
41	2050	62.91	1181.51	34.79	0.0449	-0.8440	29.40	0.243	4.557	0.0400
42	2100	62.03	1229.57	9.05	0.0409	-0.8112	7.35	0.239	4.742	0.0100
43	2150	61.22	1276.95	18.79	0.0375	-0.7813	14.70	0.236	4.925	0.0200
44	2200	60.49	1323.70	29.22	0.0345	-0.7539	22.05	0.233	5.105	0.0300
45	2250	59.81	1369.89	10.08	0.0318	-0.7286	7.35	0.231	5.283	0.0100
46	2300	59.19	1415.56	31.24	0.0295	-0.7052	22.05	0.228	5.459	0.0300

Harmonic order	Frequency [Hz]	Thevenin circuit			Norton circuit			As entered in the model		
		R [Ω]	X [Ω]	Vh [V]	G [mSiemens]	B [mSiemens]	I_h [mA]	R [pu][7]	X [pu]	I_h/I_n %
47	2350	58.62	1460.77	32.24	0.0274	-0.6835	22.05	0.226	5.634	0.0300
48	2400	58.09	1505.54	11.07	0.0256	-0.6632	7.35	0.224	5.806	0.0100
49	2450	57.60	1549.93	34.20	0.0239	-0.6443	22.05	0.222	5.978	0.0300
50	2500	57.14	1593.96	46.89	0.0225	-0.6266	29.40	0.220	6.148	0.0400

A.5 Attachment E

Harmonic Allocation limits, provided by Ausgrid – Automatic Access standard limits [3]

Harmonic Order (h)	Harmonic voltage allocation limit E_{uhi} (%)	Harmonic current allocation limit E_{ihi} (A)	Harmonic Order (h)	Harmonic voltage allocation limit E_{uhi} (%)	Harmonic current allocation limit E_{ihi} (A)
2	0.14	4.4	23	0.28	0.4
3	0.25	5.2	24	0.10	0.3
4	0.10	1.5	25	0.25	0.3
5	0.46	2.8	26	0.10	0.2
6	0.10	1.0	27	0.10	0.2
7	0.46	2.0	28	0.10	0.2
8	0.10	0.8	29	0.21	0.4
9	0.18	1.3	30	0.10	0.2
10	0.10	0.6	31	0.20	0.4
11	0.53	1.5	32	0.10	0.2
12	0.10	0.5	33	0.10	0.2
13	0.53	1.3	34	0.10	0.2
14	0.10	0.4	35	0.17	0.3
15	0.10	0.4	36	0.10	0.2
16	0.10	0.4	37	0.15	0.3
17	0.39	1.4	38	0.10	0.2
18	0.10	0.3	39	0.10	0.2
19	0.35	1.1	40	0.10	0.2
20	0.10	0.3	THD	1.38	
21	0.10	0.3			
22	0.10	0.3			

Harmonic Allocation limits, provided by Ausgrid – Minimum Access Standard limits [3]

Harmonic order (h)	Harmonic voltage allocation limit E_{uhi} (%)	Harmonic current allocation limit E_{ihi} (A)	Harmonic order (h)	Harmonic voltage allocation limit E_{uhi} (%)	Harmonic current allocation limit E_{ihi} (A)
2	0.86	77.3	23	0.68	5.3
3	1.50	90.5	24	0.17	1.3
4	0.45	20.4	25	0.61	4.4
5	1.63	58.9	26	0.17	1.2
6	0.24	7.4	27	0.10	0.7
7	1.63	42.1	28	0.16	1.1
8	0.24	5.5	29	0.51	3.2
9	0.66	13.3	30	0.16	1.0
10	0.24	4.3	31	0.48	2.8
11	1.30	21.4	32	0.16	0.9
12	0.23	3.5	33	0.10	0.6
13	1.30	18.1	34	0.16	0.9
14	0.22	2.8	35	0.41	2.1
15	0.18	2.2	36	0.16	0.8
16	0.20	2.3	37	0.37	1.8
17	0.96	10.2	38	0.16	0.7
18	0.19	1.9	39	0.10	0.5
19	0.85	8.1	40	0.16	0.7
20	0.19	1.7	THD	2.25	
21	0.13	1.1			
22	0.18	1.5			

PO Box 2102, Fortitude Valley BC, QLD 4006
P: +61 7 3613 0100 W: https://www.pscconsulting.com