Eskom	Report	Network Planning

Title: **Normandie MTS Harmonics & EMT Study – Proposed Capacitor Banks Suite (Pontus, Pongola, Makhathini, Gezisa)**

Compiled by:		**Functional Responsibility**	**Authorised by**
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1. INTRODUCTION

Various substations being fed from Normandie 400kV Substation are experiencing low voltages on the 132kV bus-bars which are below acceptable limits (0.95 p.u). These substations include: Candover, Makhathini, Nondabuya, Ndumo and Mkuze. With the current electrification load growth in the areas around the listed substations and Gezisa Substation establishment, the bus-bar voltages will further drop below minimal acceptable limits.

The Normandie MTS is not completely back-feedable. A loss of either the Normandie Vergenoeg 132 kV line or the Normandie Pongola 132 kV line will result in load being shed.

The harmonics on the Normandie MTS need to be understood in order to execute a number of interim and medium term solutions involving reactive devices that will stabilize the system voltages.

2. KEY ASSUMPTIONS

2.1 SOFTWARE

All studies were performed using Digsilent Powerfactory 2014 Build 15.1.4 (x86)

2.2 CASE FILES

Network Planning utilised the Powerfactory case file “KZOU MasterProject_201703.pfd” for the undertaking of this harmonics study. For the purpose of this study this case file was assumed as accurate and no data verification was done.

The methodology and the case file used by Digsilent Buyisa in the undertaking of the Ndumo Capacitor bank study was used as a reference.

The loads used in the study were compiled by the Geo based load forecasting team and modified to a 24 hour load forecast.

2.3 FUTURE CAPACITOR BANKS

The scope of this study includes the following:

- 1st 8 Mvar Ndumo Capacitor Bank
- 2nd 8 Mvar Ndumo Capacitor Bank
- 2 x 5 Mvar Pongola Capacitor Bank
- 2 x 5 Mvar Gezisa Capacitor Bank
- 2 x 3 Mvar Makhathini Capacitor Bank
- 2 x 3 Mvar Pontus Capacitor Bank

The proposed capacitor banks at Pontus, Makhathini, Gezisa and the upgraded Pongola Capacitor bank are included in this study. The Ndumo 8 Mvar capacitor Banks were modelled with the filters as listed in section 4.4 as stipulated in a study performed by Digsilent Buyisa.

2.4 NDUMO FILTERS

Digsilent Buyisa was requested to perform harmonic and switching studies for the design of new capacitors to be installed at Ndumo Substation. The capacitors are to be 2 x 8 Mvar installed at the 132kV busbar.

The outcomes of their study recommended the installation of filters at Ndumo 132 kV Busbar with the specifications as stipulated in table 1 and 2.

Table 1: Filter 1 specification

De-tuned 3rd Harmonic Damped Filter (YN connection)		
Shunt Type	R-L-C-Rp	
Rated Reactive Power	8.0	MVAr
Harmonic Order (resonance)	2.78	h
Quality Factor (at resonance frequency)	100	Assumed
Nominal Voltage	132	kV
Nominal Frequency	50	Hz
Capacitance C	1.274	µF
Inductance L	1027	mH
Parallel Resistance Rp	4200	Ω

Table 2: Filter 2 specification

De-tuned 3rd Harmonic C-Type (YN connection)		
Shunt Type	R-L-C1-C2,Rp	
Rated Reactive Power	8.0	MVAr
Harmonic Order (resonance)	2.78	h
Quality Factor (at resonance frequency)	100	Assumed
Nominal Voltage	132	kV
Nominal Frequency	50	Hz
Capacitance C1	9.866	µF
Capacitance C2	1.461	µF
Inductance L	1027	mH
Parallel Resistance Rp	1600	Ω

The C-Type filter has a lower 50Hz power consumption in the damping resistor (0.18 kW) and should be used as the first capacitor switched in for voltage support. The damped filter has a 50Hz power consumption of 90.1 kW and should be used as the second filter to be switched in for voltage support.

2.5 GEO BASED LOADFORECAST

A 2018 24 hour load forecast was used for majority of the operation scenarios (excluding Mbazwane) simulated as all of the initiated strengthening projects would be completed by 2018.

The operation scenarios including Mbazwane were simulated using a 2020 24 hour load forecast as this is the expected year of commissioning.

2.6 TRANSMISSION IN-FEED

The substations and switching stations involved in this study include Vergenoeg, Pontus, Pongola, Candover, Makhathini, Nondabuya, Ndumo, Gezisa and Mbazwane (future) which are all supplied from Normandie 400/132 kV transmission substation.

The harmonic network impedance of the Normandie 132 kV supply Busbar was used from previous case file supplied by Digsilent Buyisa and is displayed in figure 1.

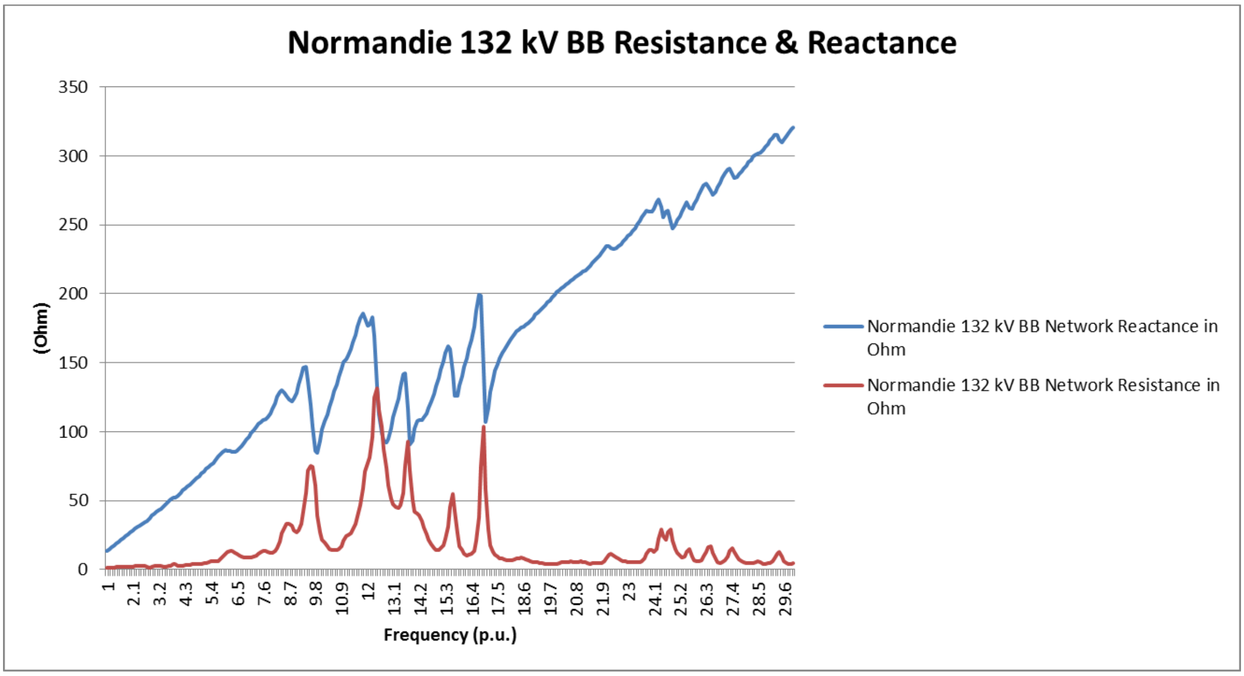

Figure 1: Normandie 132 kV BB Reactance & Impedance

2.7 SCENARIOS

An array of operation scenarios were considered for this study which included the introduction of new equipment and contingency scenarios as listed in table 4 with the scenario codes depicted in table 3.

Table 3: System Scenario Code Descriptions

Scenario Code	Scenario
SN	Normal conditions
NC1-8	Ndumo 8 Mvar Cap bank In service
NC2-8	Ndumo 8 Mvar Cap bank In service
NCF	Ndumo Filter In service
N-1V	Loss of Normandie Vergenoeg
N-1P	Loss of Normandie Pongola
2PC	2^{nd} Pongola Candover Line
M	Mbazwane SS establishment
GZ-10	Gezisa 10 Mvar Cap bank In service
MK-6	Makhathini 6 Mvar Cap bank In service
PT-6	Pontus 6 Mvar Cap bank In service
PG-10	Pongola 10 Mvar Cap bank In service
B2B	Candover Back To Back Transformer Est

Analysed Scenarios

The 371 analysed operational scenarios included in this study can be found via the link to Project Wise provided below.

pw:\\MKDVMSA024.elec.eskom.co.za:Eastern_Region\Documents\NETWORK SERVICES\NETWORK PLANNING\Network Development Plans\Empangeni Zone\SubT01 Impala Normandie Sub Tx NDP Area\2017 Harmonics Study\Operational Scenarios\

3. FREQUENCY SCAN APPROACH

3.1 LINE MODELLING

In the models used for this study all the lines were modelled with a distributed line parameter.

All of the lines were modelled with tower geometry together with the correct conductors in order to ensure that the skin effect is modelled in the conductor definition.

3.2 AMPLIFICATION FACTOR (AF)

Frequency scan results are displayed in this report as the impedance Amplification Factor (AF). Pure inductive network impedance will increase linearly with system frequency from its 50Hz value such that the impedance for harmonic order h will be:

$$Z(h) = h * Z(1) \text{ ; where } Z(1) \text{ is the 50Hz impedance.}$$

The Amplification factor at a particular harmonic is defined as the ratio of the network impedance at that harmonic to the linear impedance value.

$$AF(h) = Z(h) / (h * Z(1))$$

For a purely inductive network, the amplification factor would be approximately 1 across the harmonic range. The amplification factor thus illustrates how the harmonic impedance is amplified by resonances (presence of capacitance) in the network.

3.3 DESIGN OBJECTIVE

The design objective is to try and achieve an impedance profile where the amplification factor does not go above 2 to 2.5 at buses which are affected by the Ndumo and Pongola capacitors, particularly around the characteristic harmonics 3rd, 5th, 7th, 11th and 13th.

4. FREQUENCY SCANS

This section covers the impact that the new capacitors and strengthening equipment have on network impedance by undertaking frequency scans for 22 and 132kV busbars of substations in the network.

4.1 EXISTING NETWORK

This section of the report considers the existing network together with the proposed 22kV capacitor banks at Pongola and Makhathini as well as the 11kV Capacitor bank at Pontus. The Ndumo SS 132 kV capacitor banks and filters are considered in all operational scenarios. The Gezisa SS 10 Mvar capacitor bank was modelled, however this proposition was then discarded due to the low fault levels at Gezisa SS and the physical space constraints. Graphs for all BB's not represented below can be found in the Appendix.

The AF's for the 22 kV and 132 kV BB's are shown in figure 2-7 together with a legend representing the harmonic levels displayed. All other 22kV and 132 kV BB results are included in the appendix.

A Word Document is available on PW where all of the operation scenarios can be identified. The document can be accessed via the following link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/P{d15d4cd3-cc5e-4b83-8d58-7c1204d8e890}/

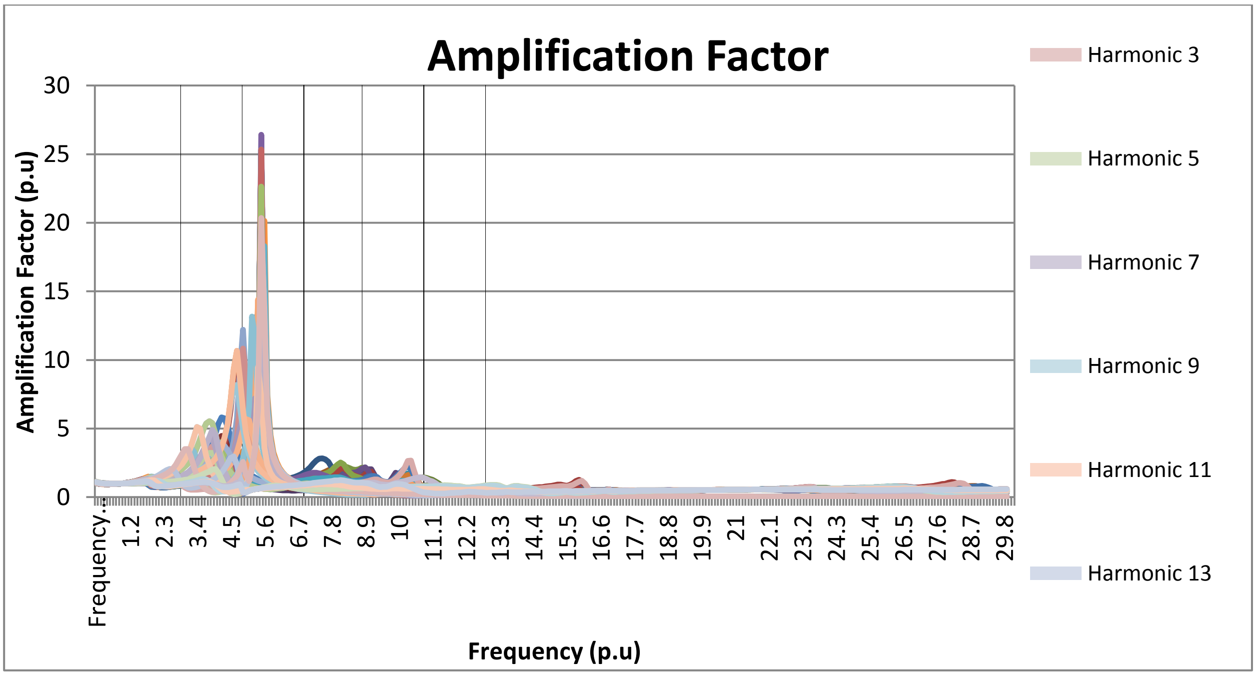

Figure 2: Pongola 22 kV BB AF's

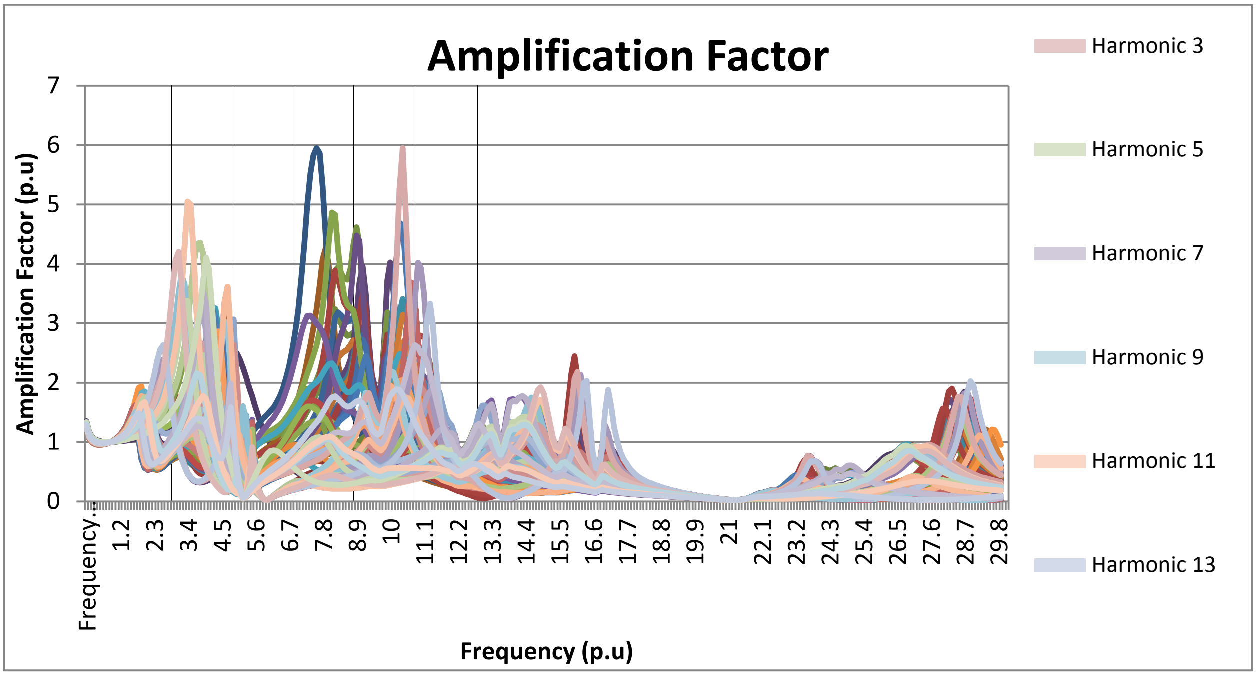

Figure 3: Pongola 132 kV BB AF's

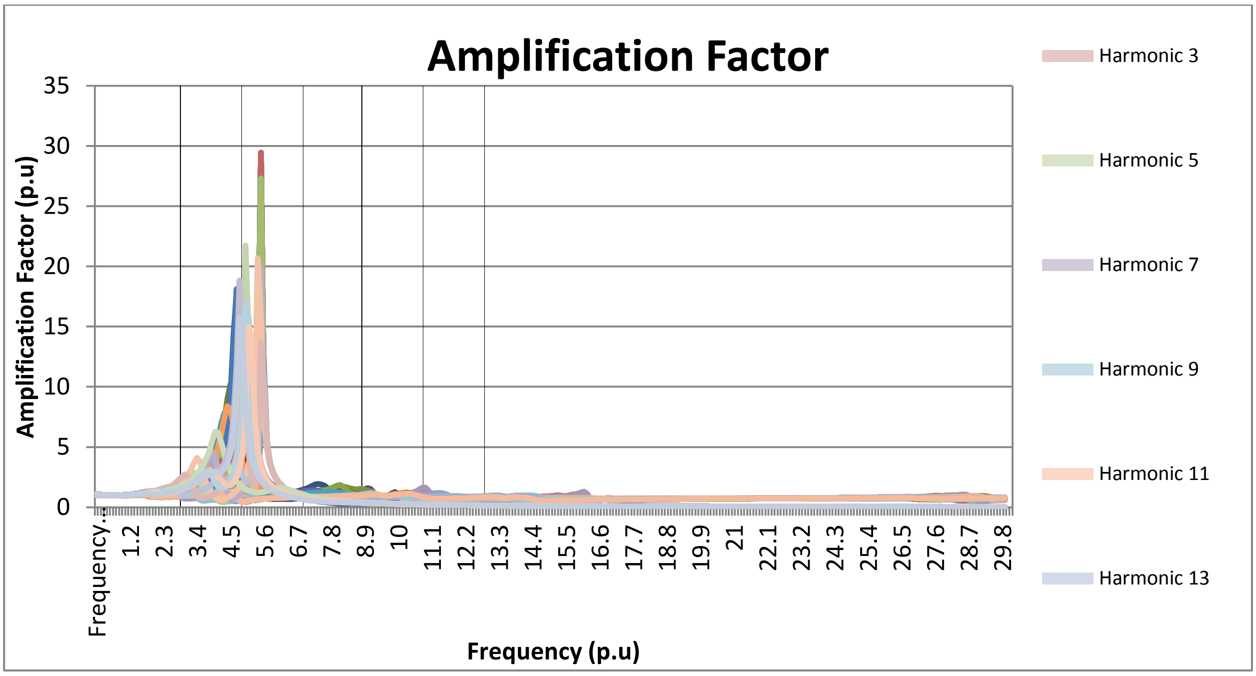

Figure 4: Pontus 11 kV BB AF's

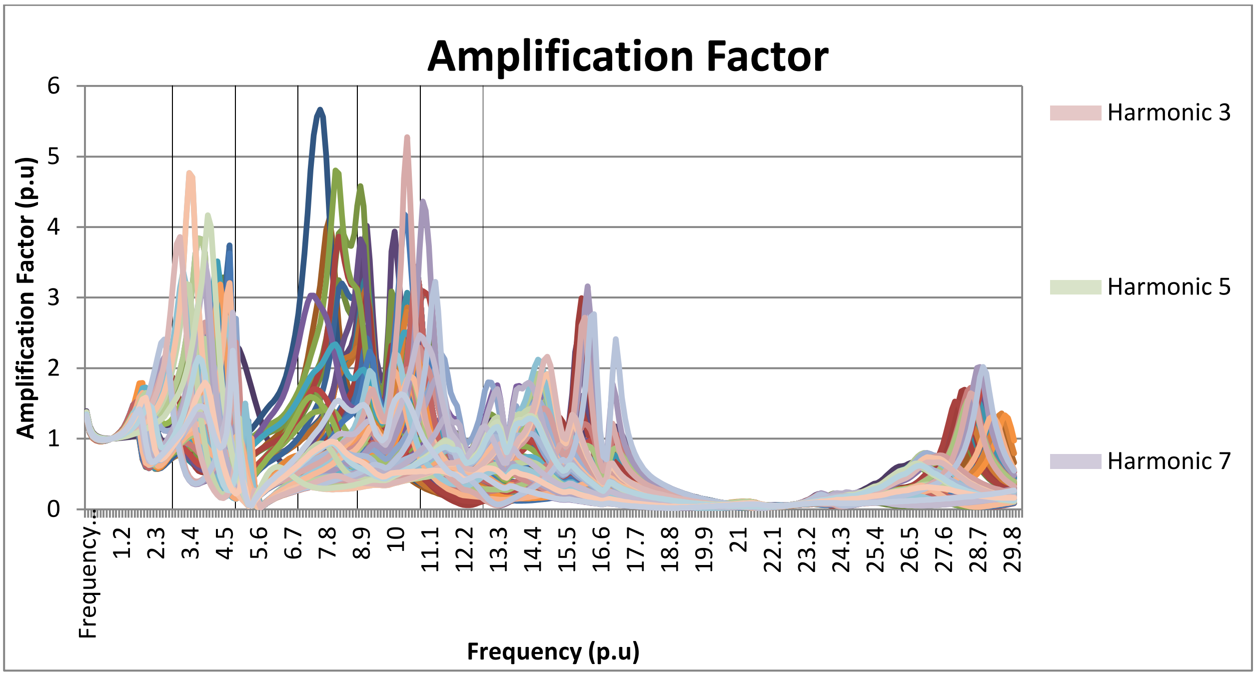

Figure 5: Pontus 132 kV BB AF's

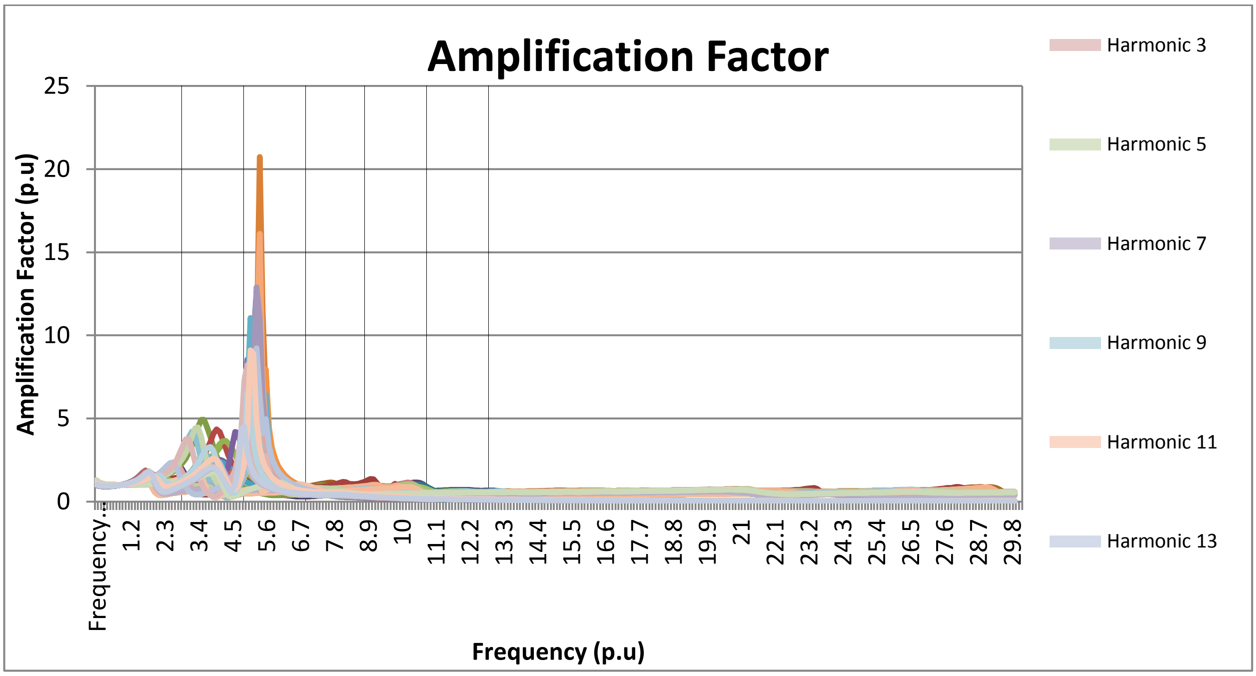

Figure 6: Makhathini 22 kV BB AF's

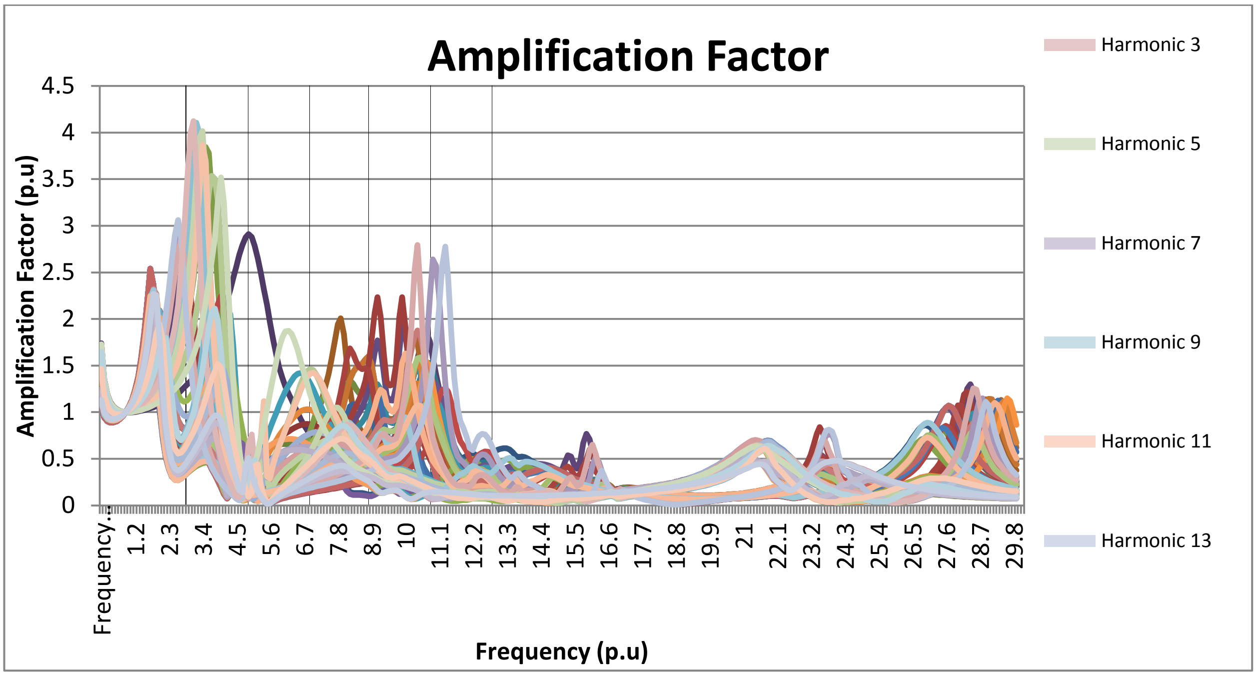

Figure 7: Makhathini 132 kV BB AF's

4.2 C-TYPE 3RD HARMONIC FILTER

Various damping resistors were selected which resulted in an AF between 2.5 and 3 below for Pongola 22kV BB, Pontus 11 kV BB and Makhathini 22 kV BB. All other 22kV and 132 kV BB results are included in the appendix.

The C Type filter reduces the 50 Hz power loss, uses a smaller damping resistor and achieves more damping in comparison to the damped filter. Due to the smaller damping resistor size the effect of the damping can be seen at nearby substations.

The C Type damped filter proved to be more efficient that the damped filter options and was therefore the chosen filter for the proposed capacitor banks.

The results displayed in the figures below show the change in AF after individually activating each of the proposed filters.

4.2.1 Pongola 3rd Harmonic C Type Filter Proposal

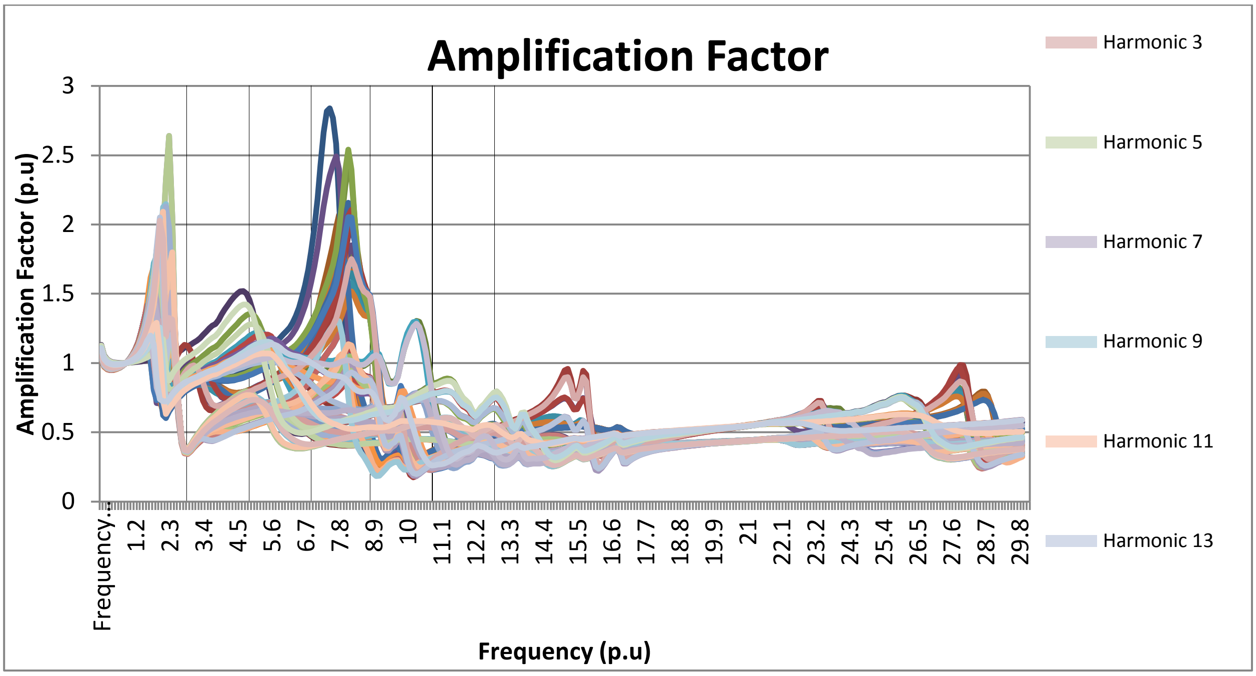

Figure 8: Pongola 22 kV BB AF's for C Type 3rd Harmonic filter.

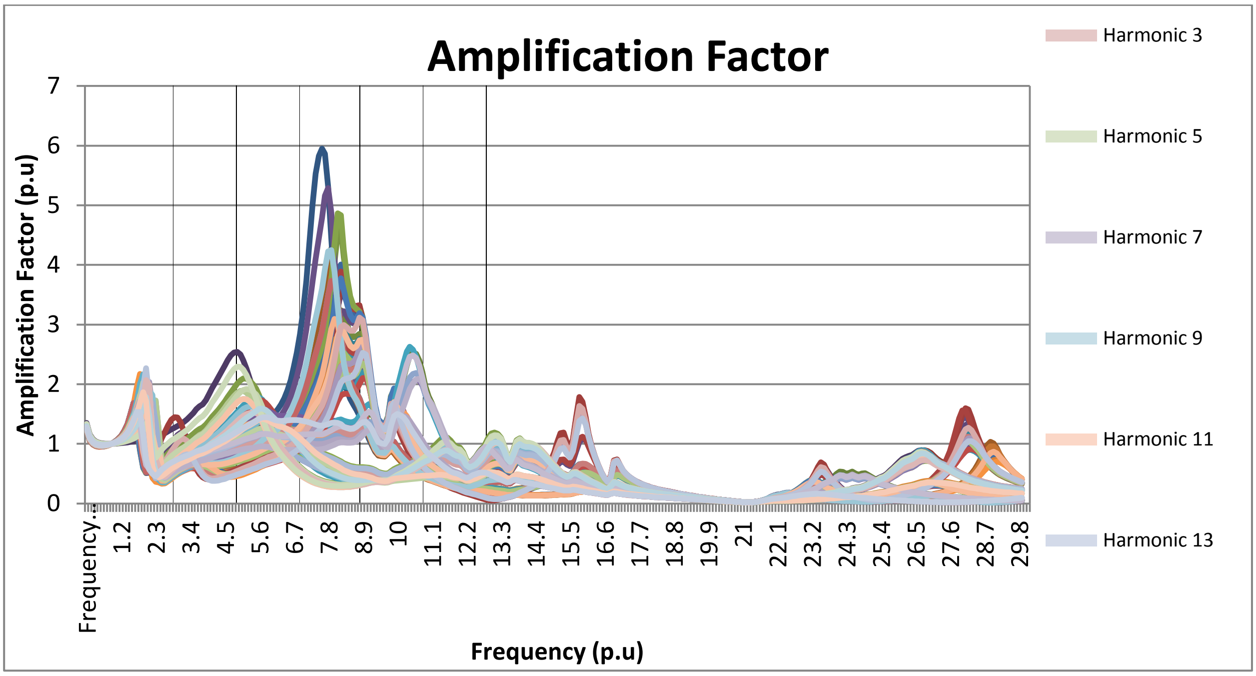

Figure 9: Pongola 132 kV BB AF's for C Type 3rd Harmonic filter.

4.2.2 Pontus 3rd Harmonic C Type Filter Proposal

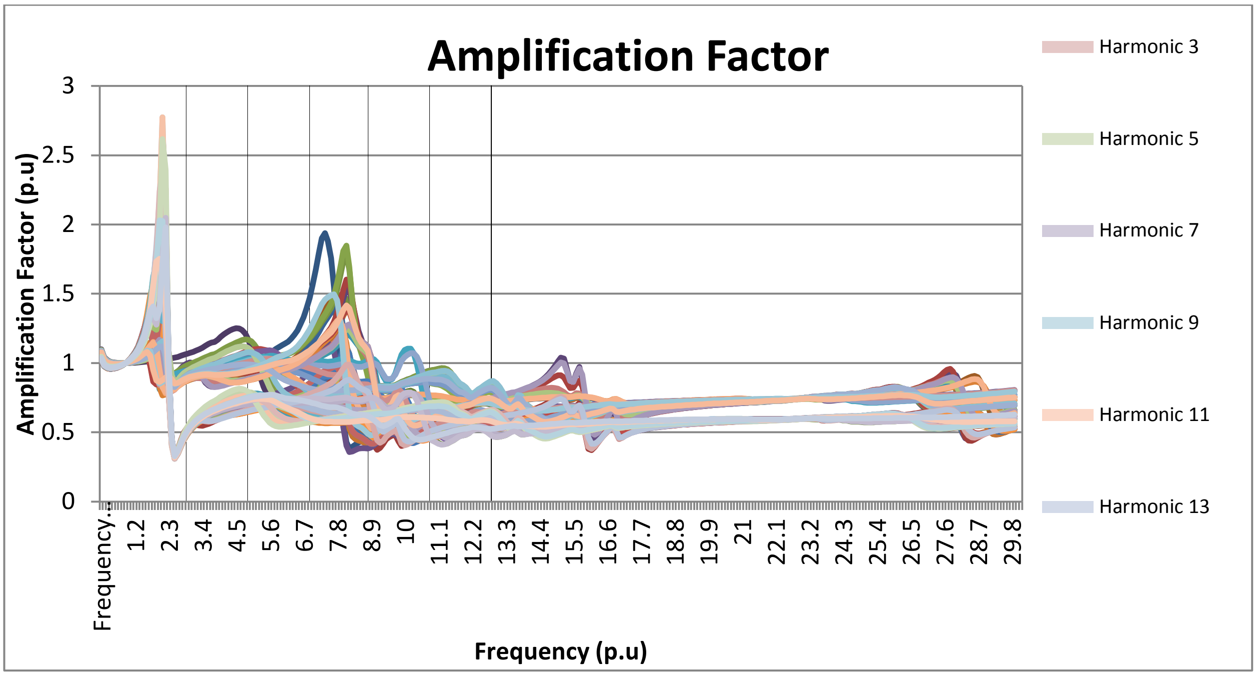

Figure 10: Pontus 11 kV BB AF's for C Type 3rd Harmonic filter.

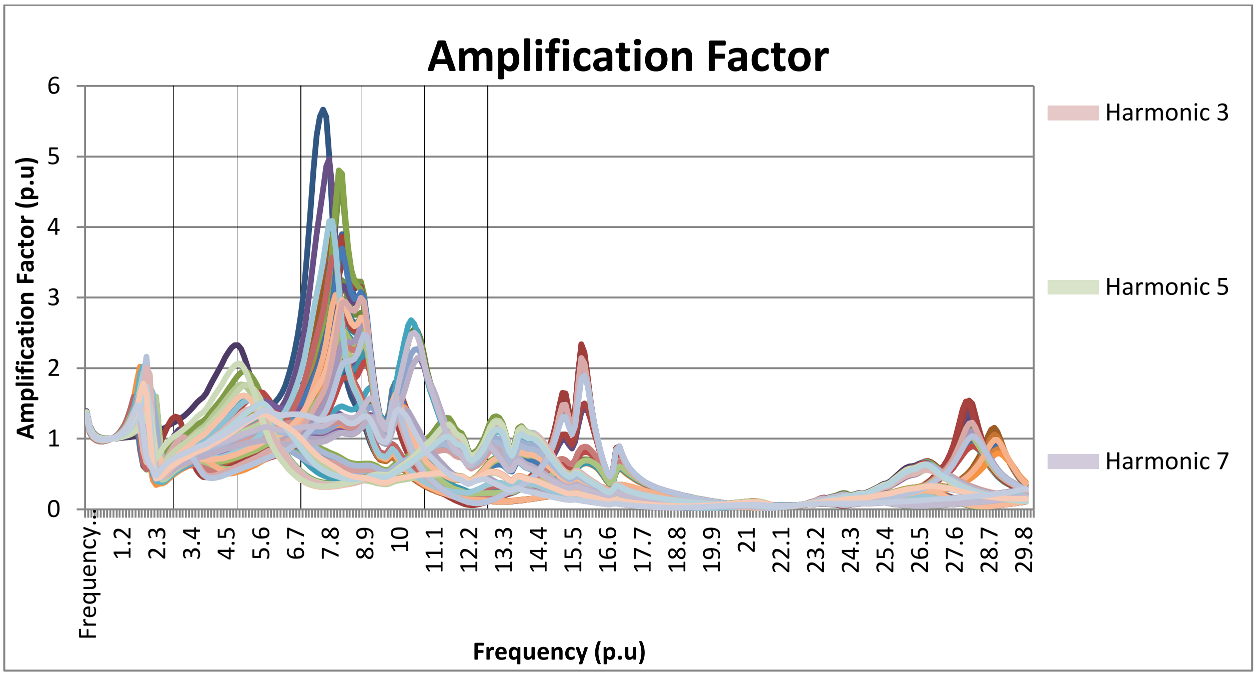

Figure 11: Pontus 132 kV BB AF's for C Type 3rd Harmonic filter.

4.2.3 Makhathini 3rd Harmonic C Type Filter Proposal

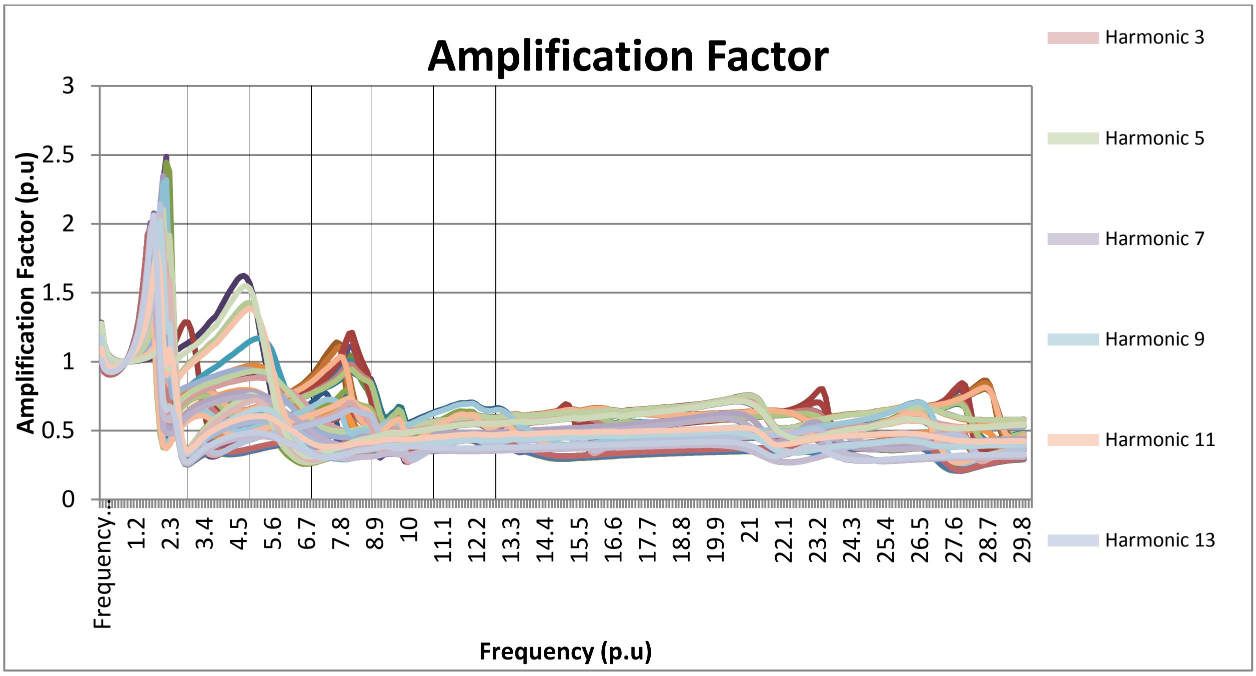

Figure 12: Makhathini 22kV BB AF's for C Type 3rd Harmonic filter.

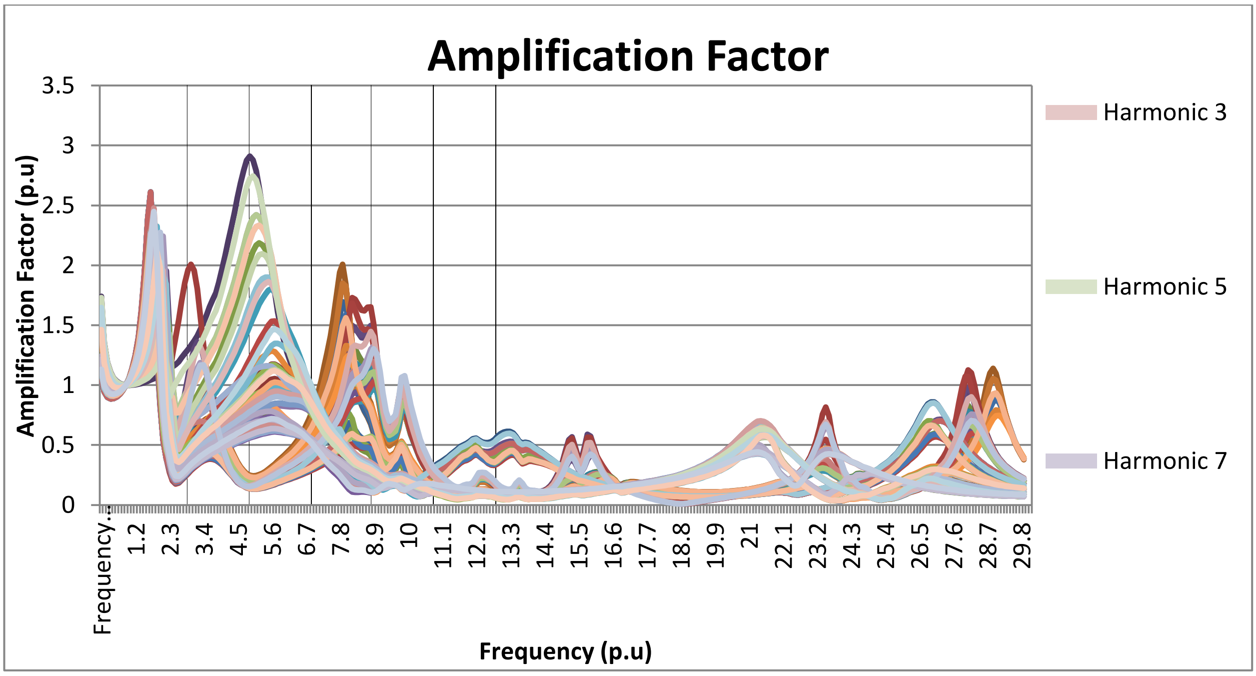

Figure 13: Makhathini 132kV BB AF's for C Type 3rd Harmonic filter.

5. FILTER CONFIGURATION

It is recommended that a C Type filter be installed on Pongola 22 kV BB as per the filter specification listed in Table below.

C Type Filter Configuration		
Shunt Type	R-L-C1-C2,Rp	
Rated Reactive Power	5.0	Mvar
Harmonic Order (resonance)	2.85	h
Quality Factor (at resonance frequency) Assumed	100	Assumed
Nominal Voltage	22	kV
Nominal Frequency	50	Hz
Capacitance C1	234.211	µF
Capacitance C2	32.883	µF
Inductance L	43.261	mH
Parallel Resistance Rp	200	Ω

It is recommended that a C Type filter be installed on Pontus 11 kV BB as per the filter specification listed in Table below.

C Type Filter Configuration		
Shunt Type	R-L-C1-C2,Rp	
Rated Reactive Power	3	Mvar
Harmonic Order (resonance)	2.55	h
Quality Factor (at resonance frequency) Assumed	100	Assumed
Nominal Voltage	11	kV
Nominal Frequency	50	Hz
Capacitance C1	434.256	µF
Capacitance C2	78.920	µF
Inductance L	23.332	mH
Parallel Resistance Rp	150	Ω

It is recommended that a C Type filter be installed on Makhathini 22 kV BB as per the filter specification listed in Table below.

C Type Filter Configuration		
Shunt Type	R-L-C1-C2,Rp	
Rated Reactive Power	3	Mvar
Harmonic Order (resonance)	2.85	h
Quality Factor (at resonance frequency) Assumed	100	Assumed
Nominal Voltage	22	kV
Nominal Frequency	50	Hz
Capacitance C1	140.522	μF
Capacitance C2	19.720	μF
Inductance L	72.101	mH
Parallel Resistance Rp	300	Ω

6. EMT SWITCHING STUDIES

6.1 MODELLING

6.1.1 Circuit Breakers

Circuit breakers are assumed to have infinite resistance (open breaker) or zero resistance (closed breaker). Hence circuit breakers are not modelled in detail. It is assumed that no re-ignition will occur and that the closing of any breaker is re-strike free during the switching operation. Hence these events are not modelled.

6.1.2 Transmission Lines

Transmission lines were modelled with a frequency dependant distributed parameter model with a

frequency for travel-time estimation of 250Hz, a minimum and maximum frequency for parameter fitting of 0.001 Hz and 10 kHz and a tolerance for Bode Approximation of 5%.

6.1.3 Surge Arrestors

Surge arrestors on lines and bus-bars were not considered so the calculated over-voltages represent a worst case condition.

6.2 METHODOLOGY

The switching studies consider the energization transients when a filter is switched on. Two aspects of energization have been analysed: the maximum switching overvoltage and the maximum inrush current. The capacitor is considered completely discharged prior to the switching action and therefore there are no residual voltages across the capacitor terminals.

This study focuses on maximum instantaneous values of current and voltage after the switching has occurred. A statistical analysis is carried out to determine the probability of such voltage occurring during the energization of the filter banks.

The filter bank energization studies consider non-synchronised breakers as a worst case condition for switching. The closing time of non-synchronised breakers cannot be determined. Furthermore the closing on all phases doesn’t always happen simultaneously. Given this statistical nature of breaker closing operation, a stochastic switching analysis has been done. The statistical switching evaluation is done by using the following steps:

6.3 E M T S W I T C H I N G S T U D I E S

1. Generate a random closing (switching) time between -10ms to +10ms for the filter bank to be energized.

2. Generate a random pole scatter time of between 0 and 1ms for each pole closing. These are delay times between closing instructions action and the actual closing time of each phase.

3. Run the simulation for a period of 200ms. (10 full cycles)

4. Record the maximum (absolute instantaneous) voltage and current crest values that occur during the period of simulation in (3) for all monitored variables. Record the randomly generated times in (1) and (2).

5. Repeat 1 to 4 above 100 times (100 simulations).

6. Calculate the highest and lowest maximum out of 100 values recorded in (4)

7. Calculate the probability of every switching voltage magnitude in (6) occurring during a switching operation.

8. Determine the value of current/voltage that has a 2% probability of being exceeded according to a "Weibull probability distribution" as recommended in Annex C of the IEC60071 part 2 (Insulation Co-Ordination).

6.4 ENERGIZATION STUDIES

Energization studies were performed for scenario 21 listed in Section 3.7. Each capacitor energization study was performed with the Ndumo capacitors in service. The peak energization voltages and currents are shown from table 4 to 11.

It must be noted that the Pongola 6 Mvar capacitor bank was modelled as a single 6 Mvar capacitor bank.

Table 4: Pongola 5 Mvar Filter Energization Voltages (peak Values)

	Maximum (p.u.)	Value at 2 % Prob (p.u.)	Value at 2 % Prob (kV)
Pongola bus voltage (phase)	1.13	1.15	20.7
Filter Capacitor C1	0.22	0.24	4.3
Filter Capacitor C2	1.61	1.69	30.4
Filter Reactor	2.77	2.91	52.3

Table 5: Pongola 5 Mvar Filter Energization Currents (peak Values)

	Maximum (A)	Value at 2 % Prob (p.u.)
Filter Capacitor C2	559.9	654.18
Filter Reactor	554.0	643.56
Damping Resistor	82.67	94.07

Table 6: Pongola 6 Mvar Filter Energization Voltages (peak Values)

	Maximum (p.u.)	Value at 2 % Prob (p.u.)	Value at 2 % Prob (kV)
Pongola bus voltage (phase)	1.2	1.2	21.6
Filter Capacitor C1	0.25	0.26	4.7
Filter Capacitor C2	1.78	1.85	33.2
Filter Reactor	2.98	3.15	56.6

Table 7: Pongola 6 Mvar Filter Energization Currents (peak Values)

	Maximum (A)	Value at 2 % Prob (p.u.)
Filter Capacitor C2	751.01	852.90
Filter Reactor	748.96	849.53
Damping Resistor	33.47	37.89

Table 8: Makhathini 3 Mvar Filter Energization Voltages (peak Values)

	Maximum (p.u.)	Value at 2 % Prob (p.u.)	Value at 2 % Prob (kV)
Pongola bus voltage (phase)	1.15	1.14	20.5
Filter Capacitor C1	0.22	0.23	4.1
Filter Capacitor C2	1.6	1.65	29.6
Filter Reactor	2.78	2.86	51.4

Table 9: Makhathini 3 Mvar Filter Energization Currents (peak Values)

	Maximum (A)	Value at 2 % Prob (p.u.)
Filter Capacitor C2	333.51	389.53
Filter Reactor	329.59	383.03
Damping Resistor	53.89	62.46

Table 10: Pontus 3 Mvar Filter Energization Voltages (peak Values)

	Maximum (p.u.)	Value at 2 % Prob (p.u.)	Value at 2 % Prob (kV)
Pongola bus voltage (phase)	1.16	1.16	10.4
Filter Capacitor C1	0.32	0.34	3.1
Filter Capacitor C2	1.79	1.86	16.7
Filter Reactor	2.99	3.18	28.6

Table 11: Pontus 3 Mvar Filter Energization Currents (peak Values)

	Maximum (A)	Value at 2 % Prob (p.u.)
Filter Capacitor C2	685.58	768.47
Filter Reactor	680.86	760.9
Damping Resistor	56.75	64.92

7. CONCLUSIONS AND RECOMMENDATIONS

This report presents the findings of the harmonic study performed on the Sub-transmission network fed from Normandie MTS. The harmonic study indicated that a suitable filter is required for the Pongola 10 Mvar 22 kV capacitor at Pongola 132 kV substation, Pontus 6 Mvar 11 kV capacitor at Pontus132 kV substation and Makhathini 6 Mvar 22 kV capacitor at Makhathini 132 kV substation.

The recommended filter for the Pongola 6 Mvar Capacitor bank is a detuned 3rd harmonic C Type filter.

The C Type filter resulted in lower AF's at all of the selected substations and an average of 15-20 % lower 50 Hz power losses in comparison to the damped filter option.

8. REVISIONS

Date	Rev.	Compiler	Remarks
November 2017	0	L Pather	Harmonic Study Required

9. DEVELOPMENT TEAM

The following people were involved in the development of this document:

- Rianta Bhugwandeen
- Leeshen Pather

APPENDIX A: ESKOM DOCUMENT HIERARCHY

10. AMPLIFICATION FACTORS – DETAILED

10.1 BASELINE (NDUMO CAPACITORS WITH FILTERS AND PONGOLA, PONTUS AND MAKHATHINI CAPACITORS ONLY)

The Normal State (Excluding Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{38a708cd-4cf7-4321-b412-c275727a56f9}

The Normal State (Including Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{d58b758a-e2e9-4700-967e-b48b6143abaa}

The Contingency State (Excluding Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{cb62805a-8239-494b-b20e-657a88e381c8}

The Contingency State (Including Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{d58b758a-e2e9-4700-967e-b48b6143abaa}

10.2 C TYPE 3RD HARMONIC FILTER

The detailed AF's are listed for all simulated substations below.

10.2.1 Pongola Filter Only

The Normal State (Excluding Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{fc0ff94d-5953-447c-8124-cb6a9cd9ba76}

The Normal State (Including Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{d4c8cac8-b212-4145-9ad7-6bc5497c2140}

10.2.2 Pontus Filter Only

The Normal State (Excluding Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{9803abf9-3579-4690-90a1-9760a505fb9d}

The Normal State (Including Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{16487852-8fc3-4c58-9175-ea436ac0253b}

10.2.3 Makhathini Filter Only

The Normal State (Excluding Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{59055d31-e4d3-489f-8236-4452481a647e}

The Normal State (Including Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{2e8ac0f5-0d51-470d-8dbe-6f9a043572aa}

10.2.4 Pongola, Pontus & Makhathini Filters

The Normal State (Excluding Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{28ec6bb1-243c-404e-b0b6-3bd2ced2c783}

The Normal State (Including Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{2d687459-b716-49e5-8727-443eefde419f}

The Contingency State (Excluding Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{e26cd72c-5523-4c8e-850e-bba55b8d3448}

The Contingency State (Including Mbazwane) results can be accessed via the following PW link:

pw://MKDVMSA024.elec.eskom.co.za:Eastern_Region/Documents/D{a7acb468-b726-4cce-b1ee-260b31cbccd8}