Gibraltar Strip Steel, Inc.

HARMONIC STUDY

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18 August 2005

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1. GENERAL

1.1 Purpose of this Study

The purpose of this study is to check the influence of harmonic filters, sized for optimum power factor compensation, keeping harmonic distortion at the Point of Common Coupling in compliance with IEEE 519 guidelines. This study is based on the ETAP Power Station simulation software version 5.0.2 and electrical data as indicated in Section 1.2

IEEE 519 Guidelines for Current Distortion

Table 10-3—Current Distortion Limits for General Distribution Systems (120 V Through 69 000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_L	<11	11≤*h*<17	17≤*h*<23	23≤*h*<35	35≤*h*	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harmonics are limited to 25% of the odd harmonic limits above.						
Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.						
* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.						
where I_{sc} = maximum short-circuit current at PCC. I_L = maximum demand load current (fundamental frequency component) at PCC.						

Assuming I_{sc}/I_L = 15.140 / 610 = 24.82, the current distortion limits are:
7% for <10th harmonics
3.5% for 11th to 16th harmonics
2.5% for 17th to 22nd harmonics
1.0% for 23rd to 34th harmonics
0.5% for 35th and higher harmonics
8.0% for THD-I values

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IEEE 519 Guidelines for Voltage Distortion

Table 10-2—Low-Voltage System Classification and Distortion Limits

	Special Applications*	General System	Dedicated System†
Notch Depth	10%	20%	50%
THD (Voltage)	3%	5%	10%
Notch Area (A_N)‡	16 400	22 800	36 500

NOTE — The value A_N for other than 480 V systems should be multiplied by V/480

*Special applications include hospitals and airports.
†A dedicated system is exclusively dedicated to the converter load.
‡In volt-microseconds at rated voltage and current.

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1.2 Data

The following documents were available and used for programming the ETAP simulation model:

- Gibraltar Strip Steel Electrical System Survey One Line Diagram (Thermoelectric Solutions Inc.)
- Gibraltar Strip Steel Capacitor Survey, with Appendixes A to F as follows:
  - Section A: Electrical Power Trend Data, 7 Pages
  - Section B: Harmonic Current and Voltage Data, 50 Pages
  - Section C: First Energy Company Impedance Data, 2 Pages
  - Section D: Electric Bill Summary, 1Page
  - Section E: Electric Rate Schedule, 7 Pages
  - Section F: Sample Electric Bill, 7 Pages

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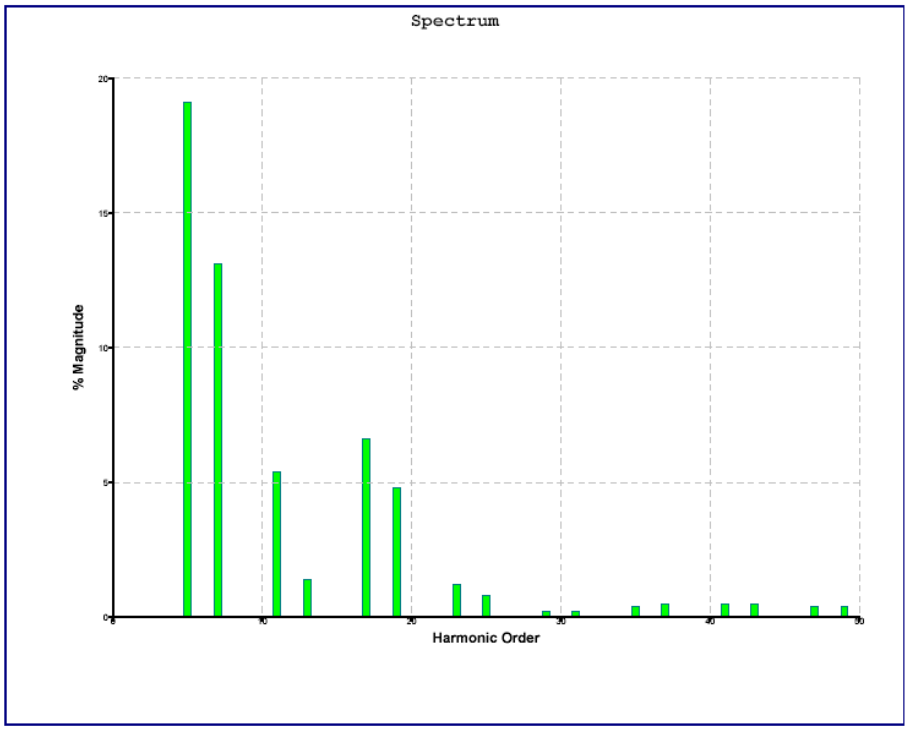
1.3 Assumptions

Following the data specified above and having installed the one line diagram on ETAP, a load flow run was performed assuming a 75% service factor for all loads.

The utility short circuit capacity was set 299 MVA at 11.4 kV
Utility Impedance Values (100 MVA base):
Positive Sequence: R = 4.5452 % X = 33.1345%
0 Sequence: R = 31.0592 % X = 99.3895 %

Drive Harmonic Current Injection for all Drives - Typical IEEE 6-pulse (with some minor adjustments), as follows:



n	%
5	19.10
7	13.10
11	5.40
13	1.40
17	6.60
19	4.80
23	1.20
25	0.80
29	0.20
31	0.20
35	0.40
37	0.50
41	0.50
43	0.50
47	0.40
49	0.40

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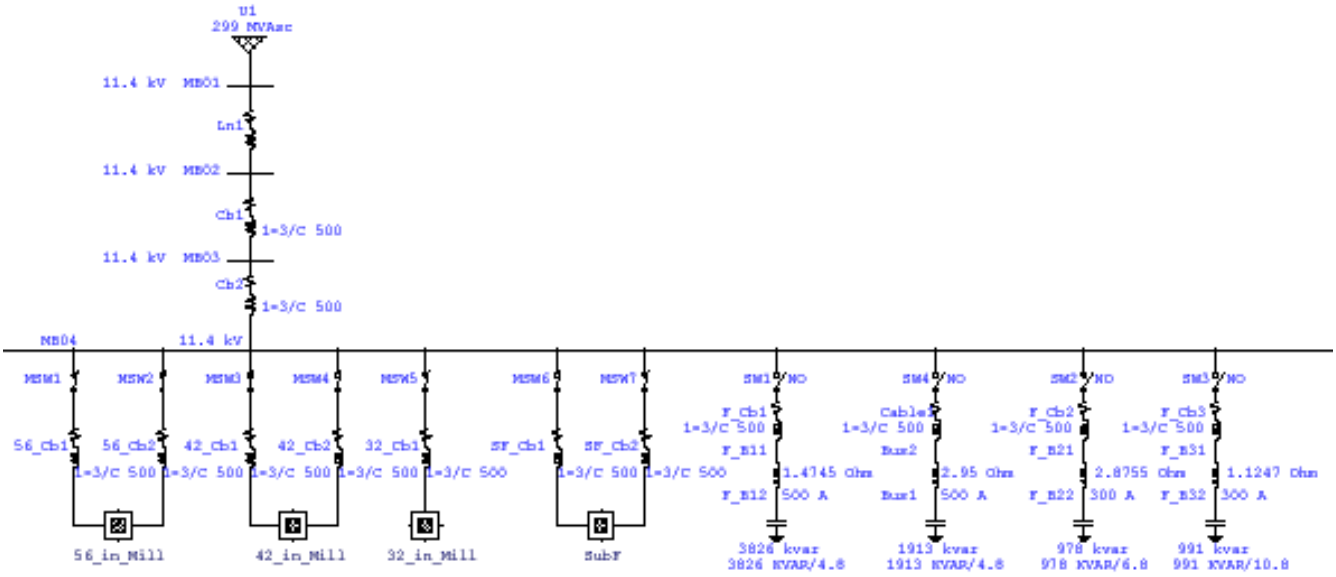
1.4 Simulation One Line Diagram



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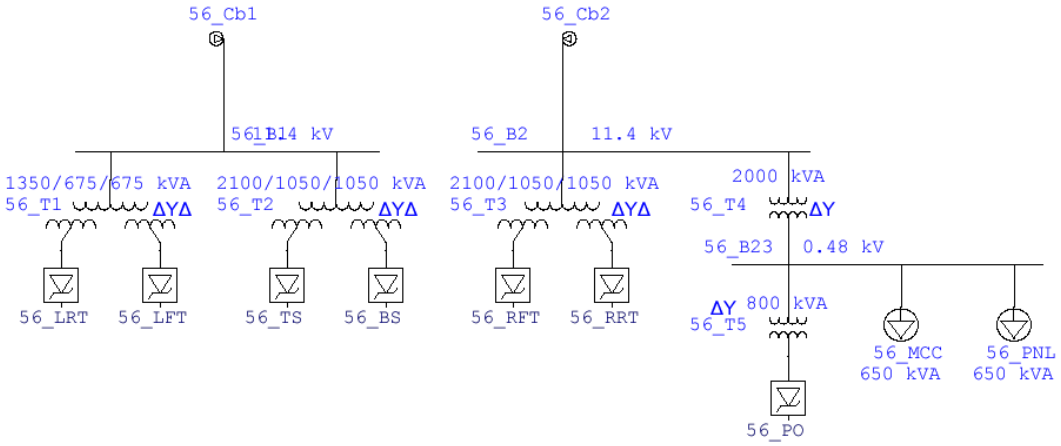
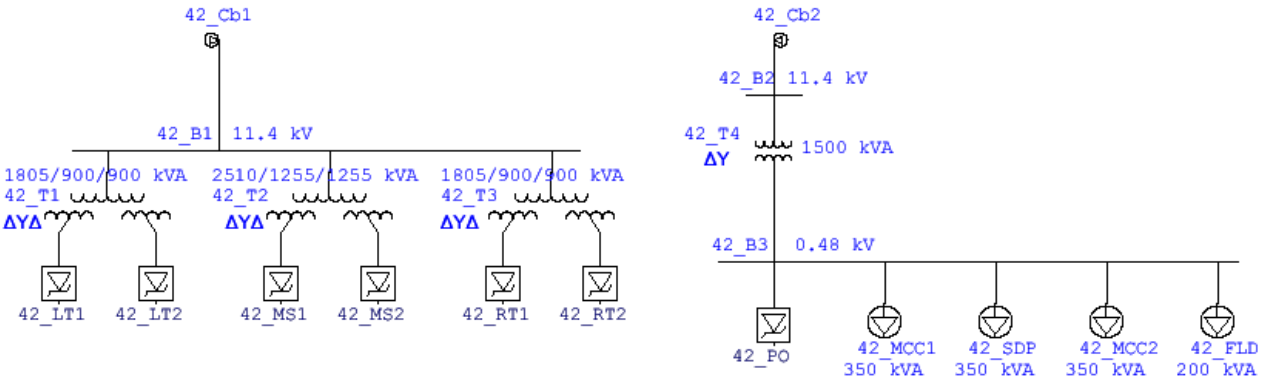
One-Line Diagram - OLV1=>56_in_Mill



One-Line Diagram - OLV1=>42_in_Mill



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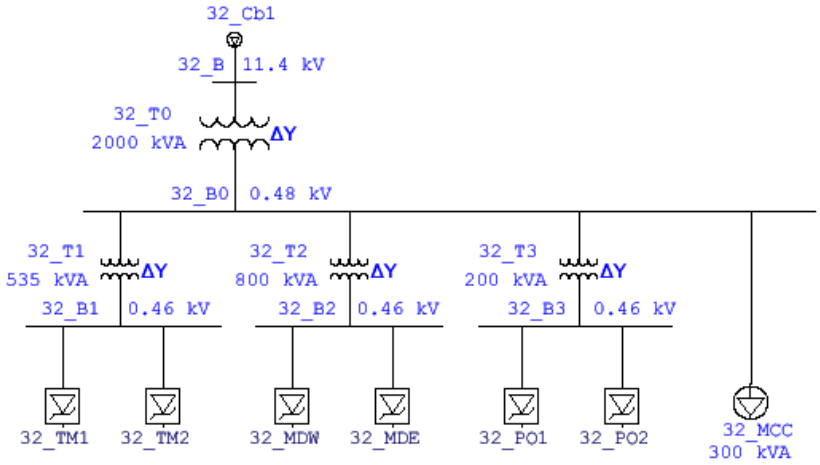
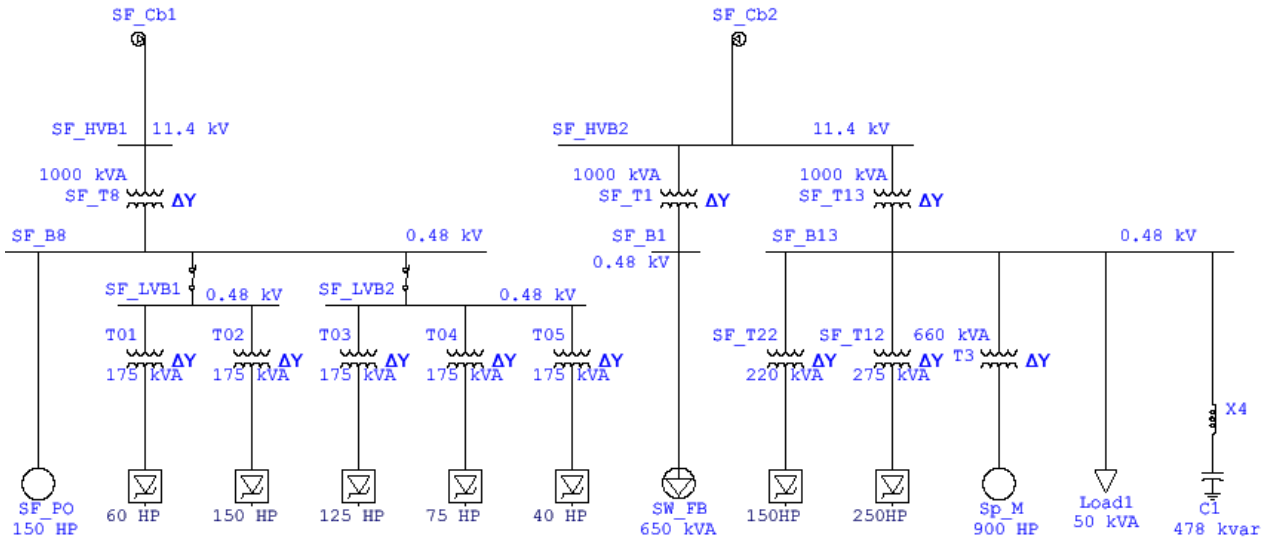
One-Line Diagram - OLV1=>32_in_Mill



One-Line Diagram - OLV1=>SubF



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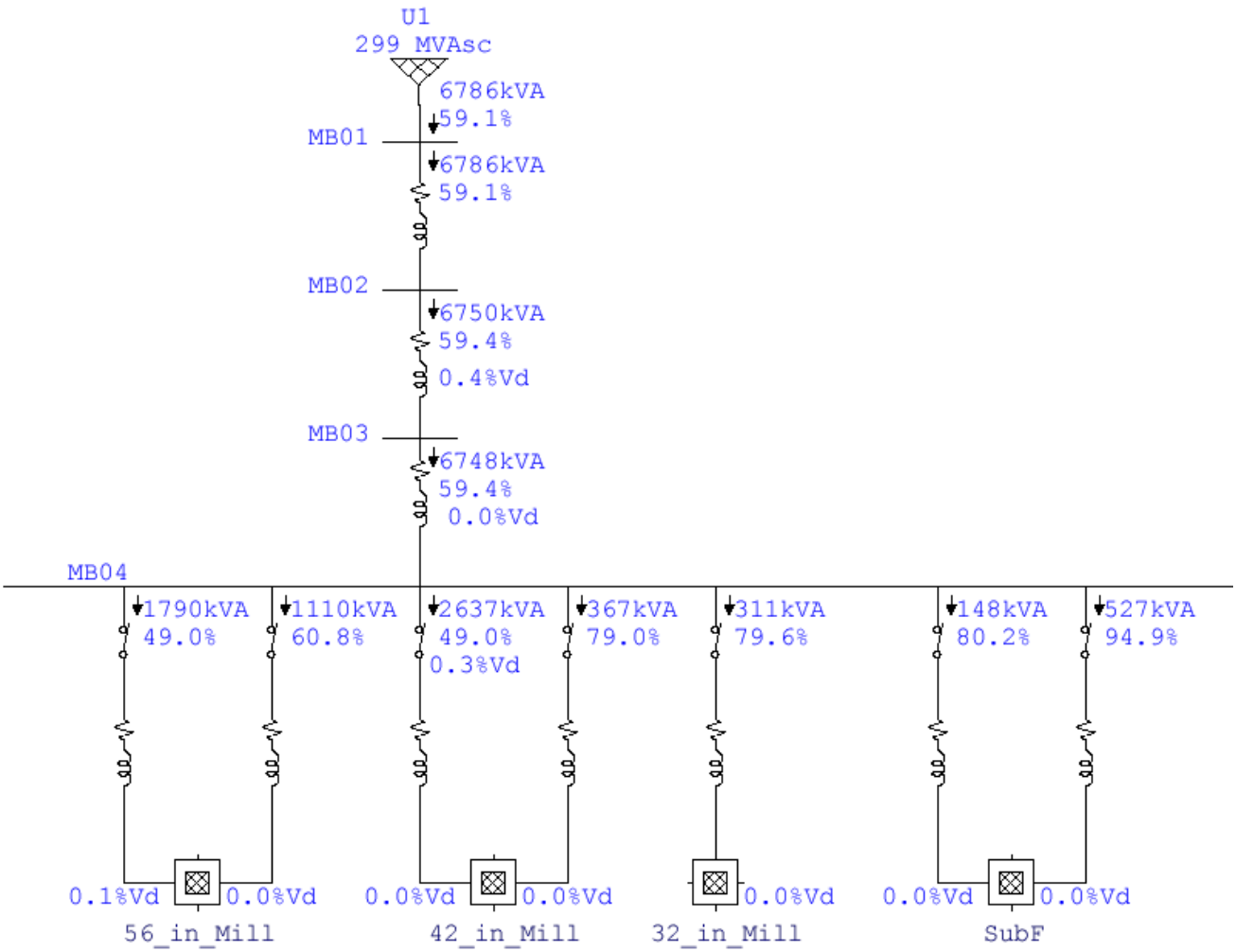
1.5 Load Flow One Line Diagram

Scenario 1: No Filters



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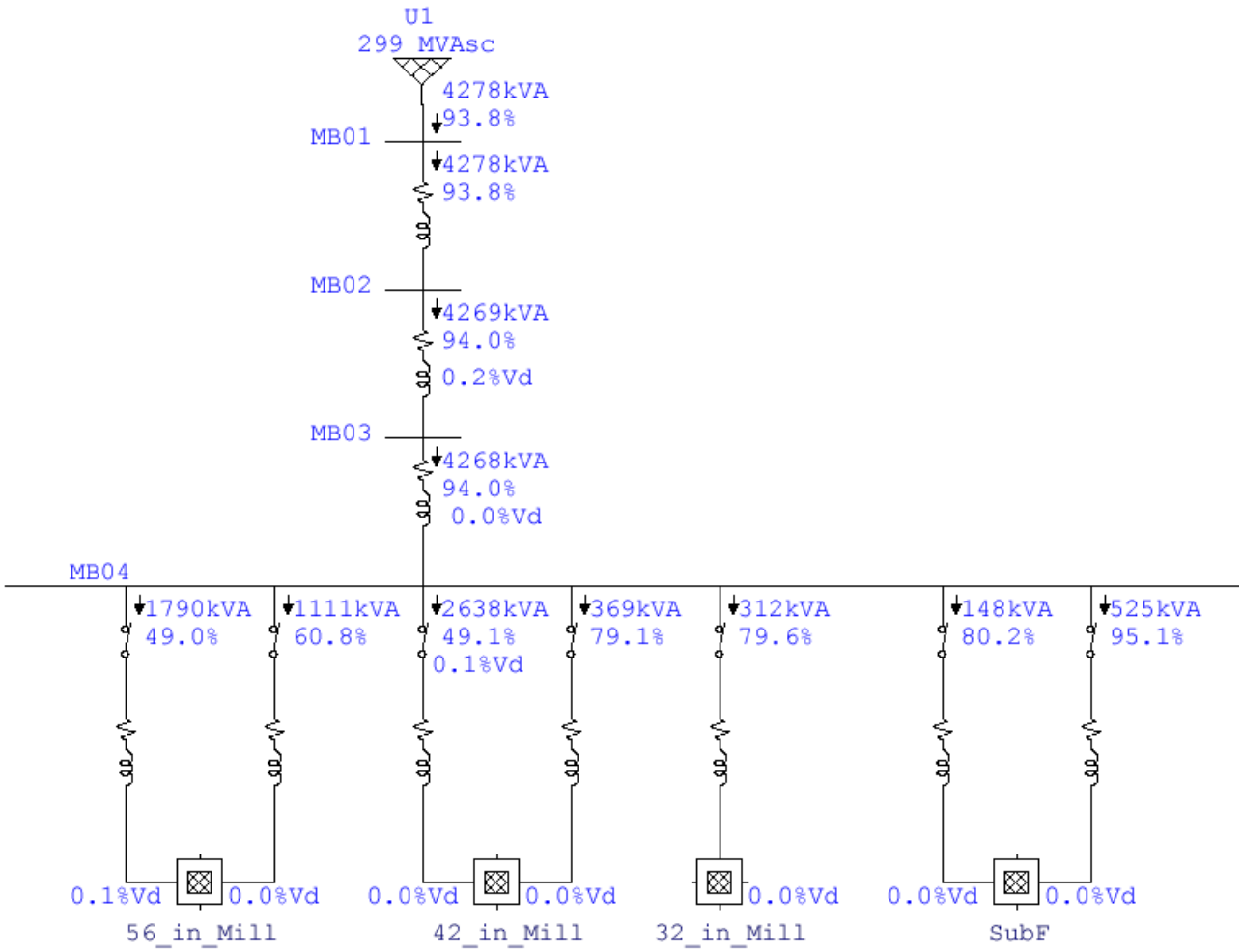
Scenario 3: 4MVAR - 5th, 7th and 11th Harmonic Filter



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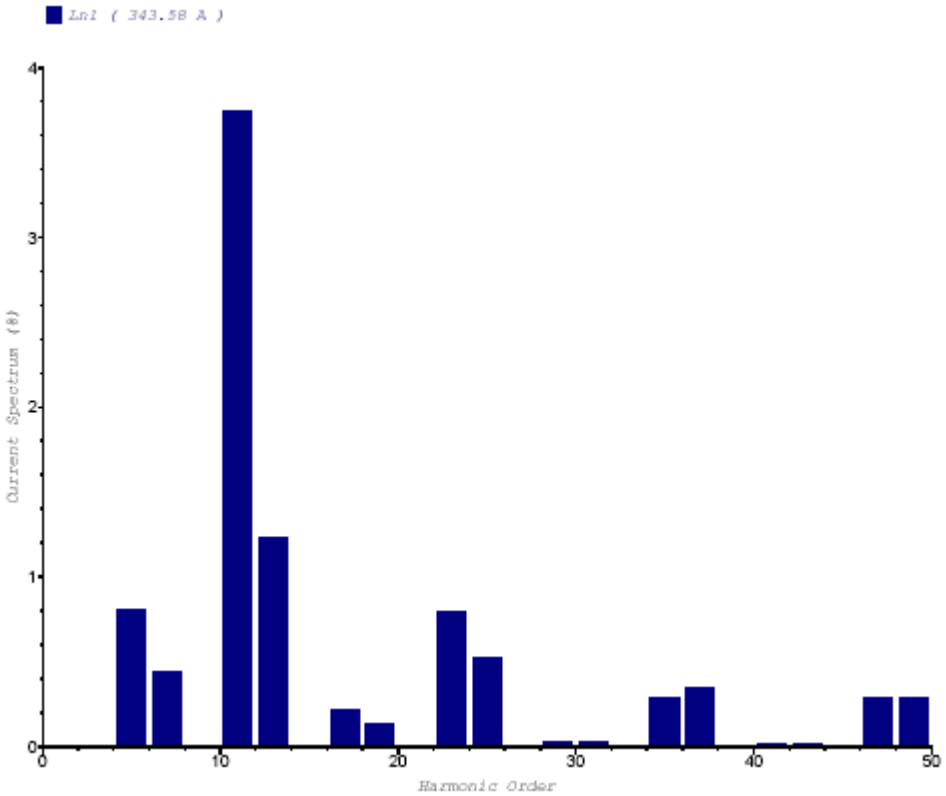
2. RESULTS

2.1 Scenario 1: No Filters

The load flow obtained by the simulation show a total load of 6786 KVA (PF = 59.1%). The harmonic current spectrum at the main supply line Ln1 indicates acceptable current THD (4.21% < 8%). There is infringement of the maximum limit for the 11th harmonic current as indicated in red in the table below. The voltage THD at the main bus MB01 is 1.26%, within the limit (5%) stipulated by IEEE 519.

CURRENT SPECTRUM – MAIN SUPPLY LINE Ln1:



Line	ETAP Model	Measured On Site
1	100%	100%
5	0.8131	4.1800
7	0.4490	2.1550
11	3.7378	3.4850
13	1.2277	1.1850
17	0.2187	0.5130
19	0.1413	0.2150
23	0.8015	0.9900
25	0.5229	0.6200
29	0.0271	0.2900
31	0.0258	0.2550
35	0.2910	0.4450
37	0.3449	0.7200
41	0.0146	-
43	0.0188	-
47	0.2939	-
49	0.2892	-
THD	4.2072	-

Comment

The 5th and 7th harmonic currents cannot be caused by the large 12-pulse drives, not even considering a reasonable voltage unbalance and / or phase shift in the three winding transformers, not even a major drive fault, operating one large drive with only 6-pulses. The higher than predicted 5th and 7th harmonic currents could though be caused by other users - which were not considered in this model - connected at the same 11.4 kV power line. The 5th and 7th harmonic currents do not represent though any problem, as their distortion levels are sufficiently low in % value.

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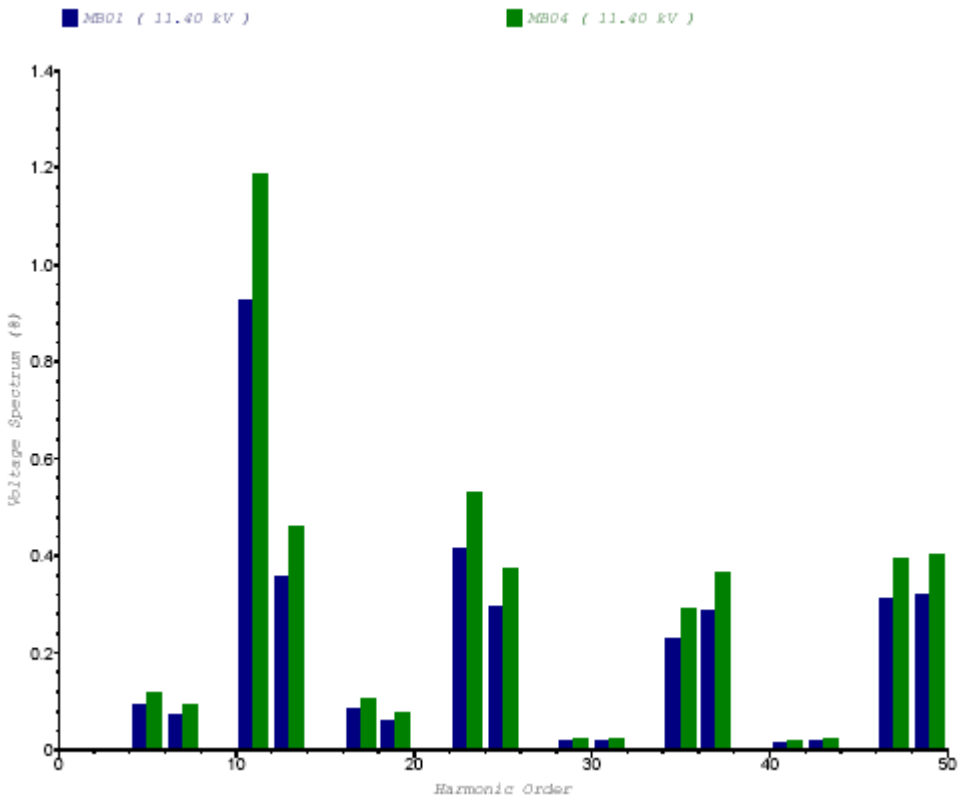
VOLTAGE SPECTRUM - MAIN SUPPLY BUSES MB01 and MB04:



Bus	MB01	MB04
1	100%	100%
5	0.0914	0.1183
7	0.0707	0.0911
11	0.9243	1.1870
13	0.3588	0.4601
17	0.0836	0.1069
19	0.0603	0.0771
23	0.4144	0.5287
25	0.2939	0.3746
29	0.0177	0.0225
31	0.0180	0.0229
35	0.2289	0.2910
37	0.2868	0.3645
41	0.0135	0.0171
43	0.0181	0.0230
47	0.3105	0.3937
49	0.3186	0.4037
THD	1.2645	1.6178

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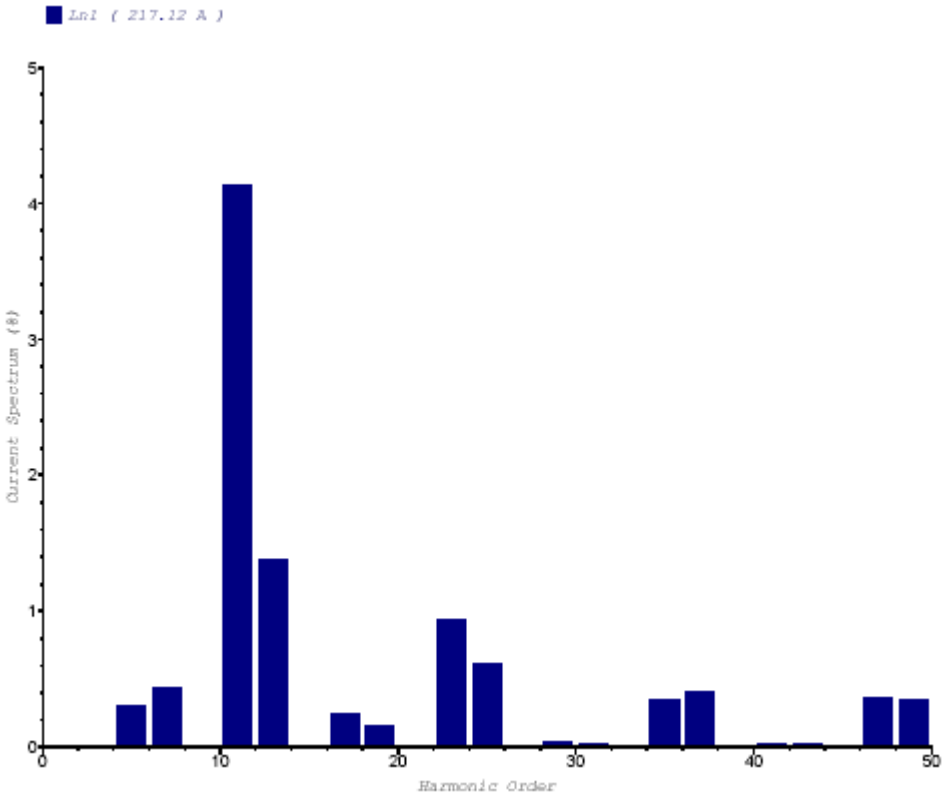
2.2 Scenario 2: 4 MVAR 5th harmonic filter

One 4 MVAR 5th harmonic filter (tuned at 4.8 h) was connected on the simulation. The harmonic current spectrum in the main supply line indicates a better 5th harmonic distortion (only 0.31%) and a still acceptable current THD of 4.59%. But it is apparent that an 11th harmonic filter should be included: the harmonic distortion increased from 3.74% to 4.13%, higher than the IEEE 519 limit of 3.5%. The voltage THD at the main supply bus is 0.91%, falling well below the IEEE 519 limit of 5%.

CURRENT SPECTRUM – MAIN SUPPLY LINE Ln1:



Line	Ln1
1	100%
5	0.3051
7	0.4286
11	4.1259
13	1.3825
17	0.2513
19	0.1634
23	0.9350
25	0.6122
29	0.0319
31	0.0305
35	0.3459
37	0.4112
41	0.0175
43	0.0225
47	0.3554
49	0.3508
THD	4.5925

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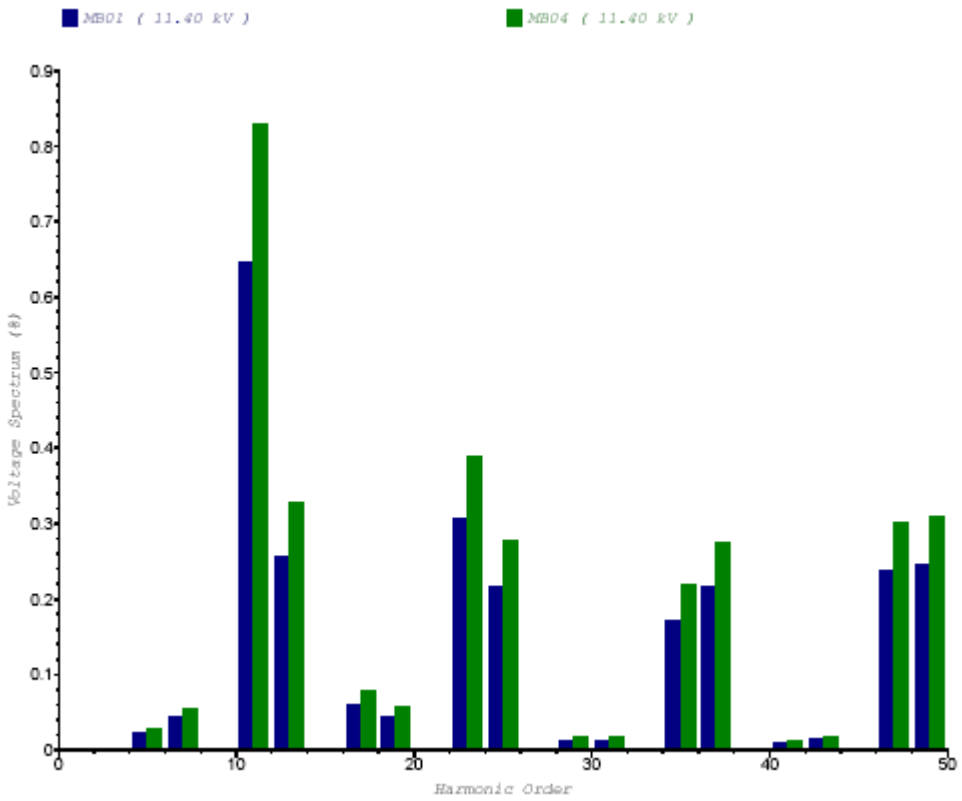
VOLTAGE SPECTRUM - MAIN SUPPLY BUSES MB01 and MB04:



Bus	MB01	MB04
1	100%	100%
5	0.0217	0.0280
7	0.0426	0.0550
11	0.6447	0.8280
13	0.2553	0.3274
17	0.0607	0.0776
19	0.0441	0.0564
23	0.3055	0.3898
25	0.2174	0.2772
29	0.0132	0.0168
31	0.0134	0.0171
35	0.1720	0.2186
37	0.2161	0.2746
41	0.0102	0.0129
43	0.0138	0.0175
47	0.2373	0.3008
49	0.2440	0.3094
THD	0.9067	1.1597

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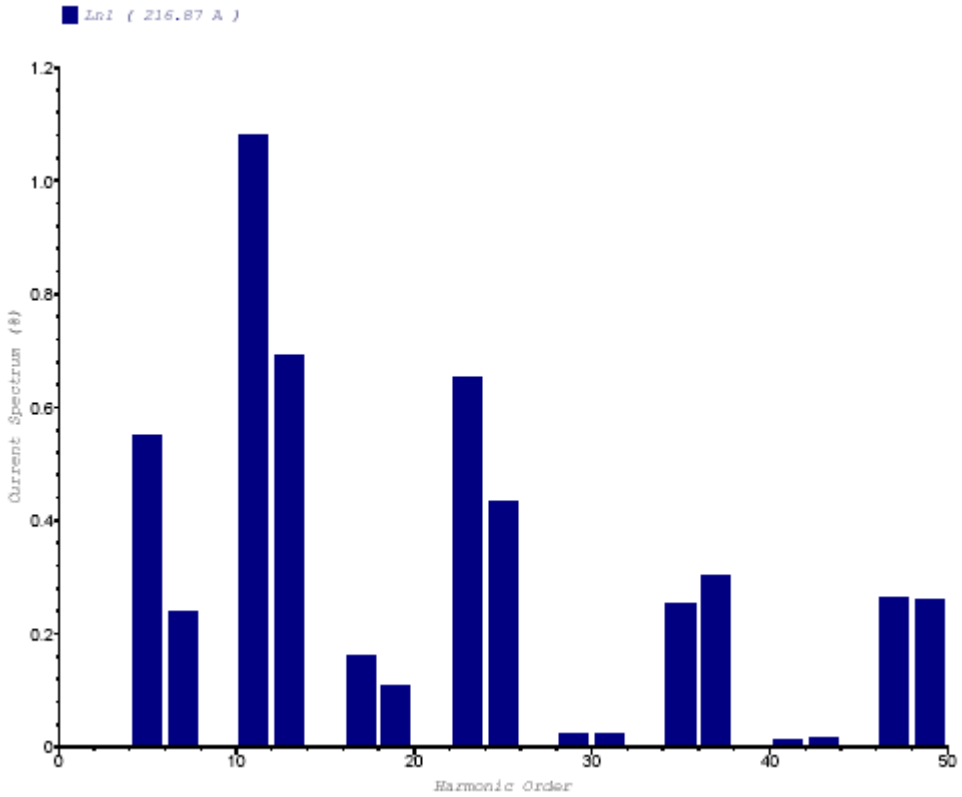
2.3 Scenario 3: 2 MVAR 5th , 1 MVAR 7th and 1 MVAR 11th harmonic filters

A combination of 5th, 7th and 11th harmonic filters (tuned at 4.8 h, 6.8 h and 10.8 h) are connected now. The harmonic current spectrum in the main supply line indicates better harmonic distortions and better current THD (1.72%). The 11th harmonic distortion decreased from 4.13% to 1.08%, falling below the IEEE 519 limit of 3%. Voltage THD at the main supply bus is only 0.474%, well below the IEEE 519 limit of 5%.

CURRENT SPECTRUM – MAIN SUPPLY LINE Ln1:



Line	Ln1
1	100%
5	0.5503
7	0.2398
11	1.0799
13	0.6903
17	0.1610
19	0.1091
23	0.6523
25	0.4326
29	0.0229
31	0.0221
35	0.2523
37	0.3009
41	0.0129
43	0.0166
47	0.2632
49	0.2602
THD	1.7164

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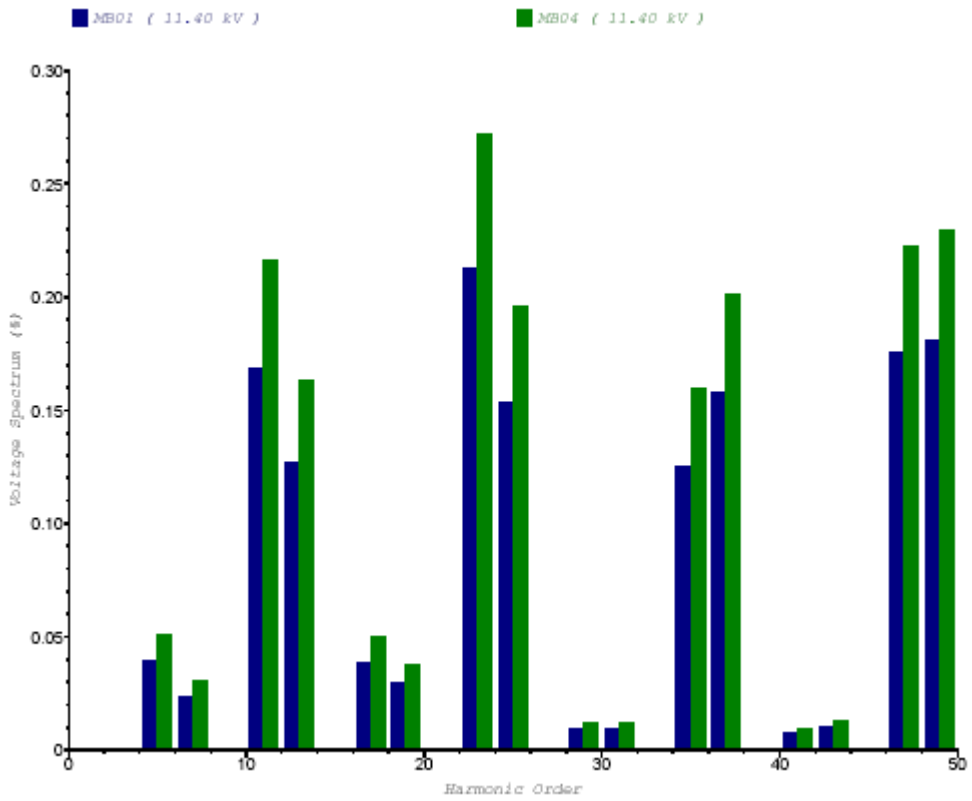
VOLTAGE SPECTRUM - MAIN SUPPLY BUSES MB01 and MB04:



Bus	MB01	MB04
1	100%	100%
5	0.0391	0.0505
7	0.0238	0.0307
11	0.1686	0.2165
13	0.1273	0.1633
17	0.0388	0.0497
19	0.0294	0.0376
23	0.2129	0.2716
25	0.1534	0.1956
29	0.0094	0.0120
31	0.0097	0.0124
35	0.1253	0.1593
37	0.1580	0.2007
41	0.0075	0.0095
43	0.0101	0.0129
47	0.1755	0.2225
49	0.1809	0.2292
THD	0.4717	0.6010

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3. CONCLUSIONS

3.1 Comparing Scenarios

The following table highlights the results for current and voltage harmonics (in % values, unless otherwise stated) at the PCC:

	Current Distortions - Line Ln1			Voltage Distortions - Bus MB01		
Scenario No	1	2	3	1	2	3
1	100%	100%	100%	100%	100%	100%
5	0.8131	0.3051	0.5503	0.0914	0.0217	0.0391
7	0.4490	0.4286	0.2398	0.0707	0.0426	0.0238
11	3.7378	4.1259	1.0799	0.9243	0.6447	0.1686
13	1.2277	1.3825	0.6903	0.3588	0.2553	0.1273
17	0.2187	0.2513	0.1610	0.0836	0.0607	0.0388
19	0.1413	0.1634	0.1091	0.0603	0.0441	0.0294
23	0.8015	0.9350	0.6523	0.4144	0.3055	0.2129
25	0.5229	0.6122	0.4326	0.2939	0.2174	0.1534
29	0.0271	0.0319	0.0229	0.0177	0.0132	0.0094
31	0.0258	0.0305	0.0221	0.0180	0.0134	0.0097
35	0.2910	0.3459	0.2523	0.2289	0.1720	0.1253
37	0.3449	0.4112	0.3009	0.2868	0.2161	0.1580
41	0.0146	0.0175	0.0129	0.0135	0.0102	0.0075
43	0.0188	0.0225	0.0166	0.0181	0.0138	0.0101
47	0.2939	0.3554	0.2632	0.3105	0.2373	0.1755
49	0.2892	0.3508	0.2602	0.3186	0.2440	0.1809
THD	4.207209	4.592489	1.7164	1.264466	0.906725	0.4717

3.2 Recommendation

A combined harmonic filter as indicated in Scenario 3 would compensate the low power factor from 59.1% to 93.8% and would keep the harmonic distortion within IEEE 519 limits.

The budget price for such filter is of US$250,000.00

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4. APPENDIX

4.1 One Line Diagram

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4.2 Thermoelectric Solutions Inc. Survey

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4.3 Illuminating Company Report

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