



**ATCO Electric  
Hangingstone Substation**

**HARMONIC STUDY**

Prepared By  
Pierre Archambault, PEng  
Power Survey International Inc.  
8025 Trans Canada Hwy.  
St-Laurent, QC  
H4S 1S4  
CANADA

Rev.: 6 March 2007

## TABLE OF CONTENTS

<b>1.</b>	<b>GENERAL</b>
1.1	Purpose of this Study
1.2	Data
1.3	Assumptions
1.4	ETAP One-Line Diagram
1.5	Load Flow Report
<b>2.</b>	<b>RESULTS</b>
2.1	Scenario 1: no filters, no capacitors
2.2	Scenario 2: 5 MVAR - 5 <sup>th</sup> harmonic filter
2.3	Scenario 3: 5 MVAR - 5 <sup>th</sup> harmonic filter and 5 MVAR capacitor bank
2.4	Faulting Utilities
<b>3.</b>	<b>CONCLUSIONS</b>
3.1	Comparing Scenarios
3.2	Recommendations

## 1. GENERAL

### 1.1 Purpose of this Study

The purpose of this study is to check the influence of harmonic filters keeping harmonic distortion at Hangingstone Substation in compliance with IEEE 519 guidelines. This study is based on the ETAP Power Station simulation software version 5.5.0 and electrical data as indicated in Section 1.2

### IEEE 519 Guidelines for Current Distortion

IEEE Std 519-1992

IEEE RECOMMENDED PRACTICES AND REQUIREMENTS

**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	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	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.

Values for  $I_{sc}/I_L < 20$  do apply here.

## IEEE 519 Guidelines for Voltage Distortion

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

	Special Applications <sup>*</sup>	General System	Dedicated System <sup>†</sup>
Notch Depth	10%	20%	50%
THD (Voltage)	3%	5%	10%
Notch Area ( $A_N$ ) <sup>‡</sup>	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.

## 1.2 Data

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

ATCO Electric Harmonic Filter Specification Hangingstone Substation, March 2006  
Excel.Hangingstone ION 701T.xls  
HangingstoneSystemDataR0.doc: Hangingstone Substation System Data, September 19, 2006  
HangingstoneSystemDataR1.doc: Hangingstone Substation System Data, Rev1  
Word.vfd information.doc: VFD Details  
Operating Single Line Diagram, 820S Hangingstone  
Operating Single Line Diagram, 718S Parsons Creek, sheet 1  
Operating Single Line Diagram, 718S Parsons Creek, sheet 2  
Operating Single Line Diagram, 875S Algar Substation  
Operating Single Line Diagram, 848S Ruth Lake, sheet 1  
Operating Single Line Diagram, 848S Ruth Lake, sheet 2  
Operating Single Line Diagram, 848S Ruth Lake, sheet 3  
Operating Single Line Diagram, 848S Ruth Lake, sheet 4  
Operating Single Line Diagram, 860S Crow Substation  
Operating Single Line Diagram, 883S Gregoire Substation  
Operating Single Line Diagram, 833S Mariana Substation  
Operating Single Line Diagram, 885S McMillan Substation

All above documents have been summed and included in AtcoData.pdf file on the report disk.

### 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 100% service factor for all loads.

#### Utility Impedance Values (100 MVA base):

##### Ruth Lake

Positive Sequence: R = 2.764 % X = 13.073 %

0 Sequence: R = 1.285 % X = 12.237 %

##### Mc Millan

Positive Sequence: R = 1.710 % X = 10.127 %

0 Sequence: R = 0.377 % X = 5.665 %

#### AC Drives - Harmonic Current Injection

The following table summarizes the harmonic injection for all drives:

n	GREGOIRE AND CROW		HANGINGSTONE		ALGAR		MARIANA	
	Amplitude	Angle	Amplitude	Angle	Amplitude	Angle	Amplitude	Angle
2	0.16	58.00						
3	0.59	121.00						
4	0.12	44.00						
5	23.52	111.00	43.71	0.00	42.00	0.00		
6	0.10	102.00						
7	6.08	109.00	7.87	0.00	14.30	0.00		
8	0.03	75.00						
9	0.09	-169.00						
10	0.00	0.00						
11	4.57	-158.00	11.05	0.00	7.90	0.00		
12	0.03	-108.00						
13	4.20	-178.00	5.12	0.00	3.20	0.00		
14	0.03	78.00						
17	1.80	37.00	3.70	0.00	3.70	0.00		
19	1.37	-94.00	2.30	0.00	2.30	0.00		
23	0.75	-92.00	2.30	0.00	2.30	0.00	1.00	0.00
25	0.56	-70.00	1.40	0.00	1.40	0.00	0.50	0.00
29	0.49	-20.00						
31	0.54	7.00						

### **Algar Drive**

This drive had to be slightly adjusted to meet as close as possible the 5<sup>th</sup> and 7<sup>th</sup> current distortions mentioned in *Hangingstone Substation Data Revision 1*, Figures 4.0, 10.0, 14.0 and 18.0. These drives included the drive filters as mentioned in the same reference, page 5.

### **Gregoire and Crow Drives**

All 12-pulse AC drives were simulated with each two 6-pulse AC drives and filters. The drive filters were included following *Hangingstone Substation Data Revision 1*, pages 10 and 13. All 6-pulse drives are fed from a 10 MVA 3-winding drive transformers Y / YD.

### **Mariana Drive**

One 24-pulse AC drive simulated with two 24-pulse AC drives and filters (filters as per *Hangingstone Substation Data Revision 1*, page 5) fed from a 10 MVA 3-winding drive transformer Y / YY.

### **Hangingstone (additional) Drive**

An additional non-linear load of 1,850 KVA (2000 HP or 7.43% of the total load at Hangingstone Substation) had to be included here, following various preliminary test runs which indicated without any doubt that there is no other possibility of reaching considerable 5<sup>th</sup> and 7<sup>th</sup> harmonic current and corresponding voltage distortions at the substation resulting only from the main drives at the pumping stations. These preliminary results were listed in Section 2.1: Scenario 1 – No Filters

HARMONIC STUDY  
 ATCO Electric Hangingstone Substation

The drive harmonic current amplitudes above indicated were adjusted slightly to meet as close as possible the data for steady-state FFT of 25KV bus currents included in *Hangingstone Substation System Data* (Figures: 4.0; 10.0; 14.0 and 18.0) Only 5<sup>th</sup> and 7<sup>th</sup> harmonic currents could be aligned to some extent: it is almost impossible to get better results considering the strong drive to drive harmonic interaction.

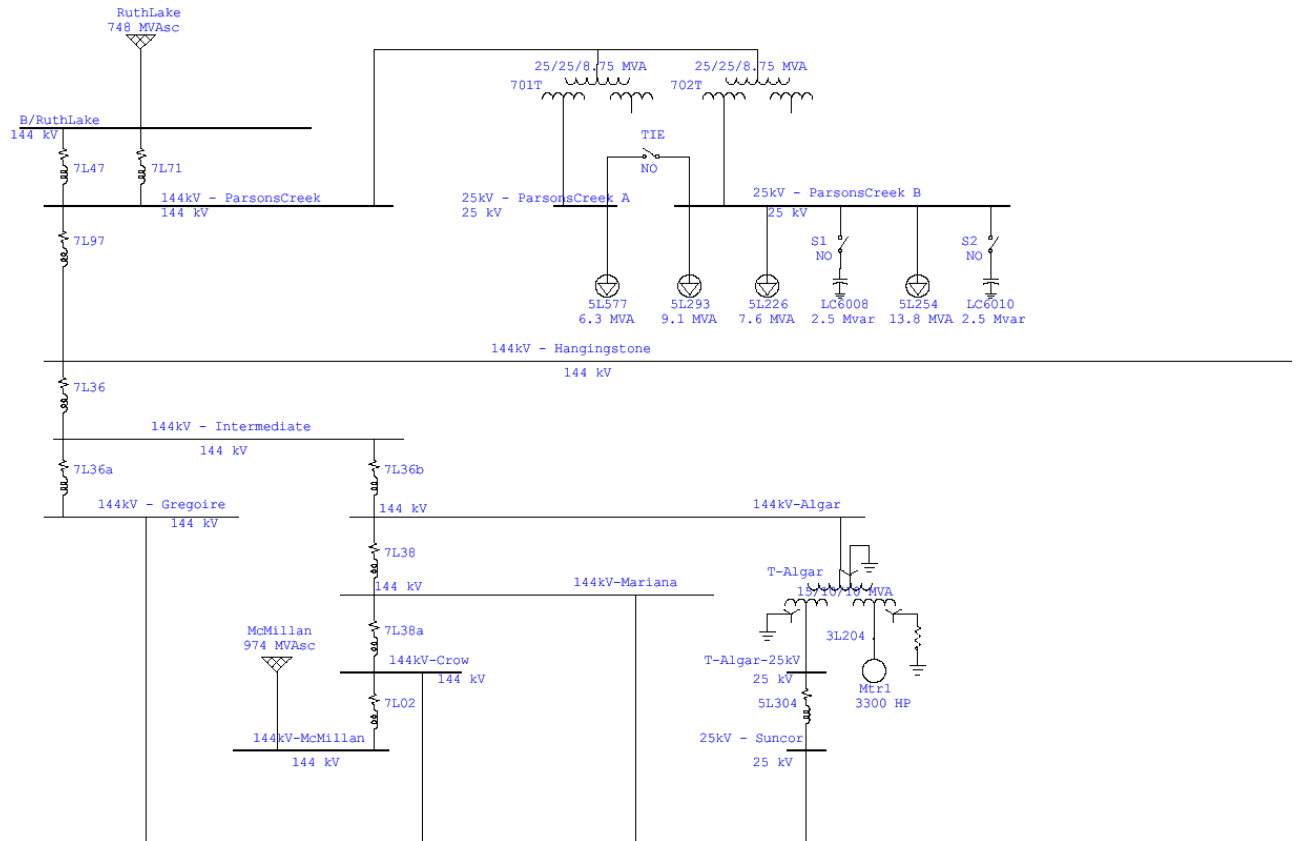
**RESULTING HARMONIC CURRENTS - % OF FUNDAMENTAL**

n	Algar		Crow		Gregoire		Mariana	
	DATA	ETAP	DATA	ETAP	DATA	ETAP	DATA	ETAP
2	0.0000	0.0571	0.0000	0.2142	0.0000	0.1861	0.0000	0.0748
3	0.2730	0.0000	0.2460	0.0000	0.2480	0.0000	0.8920	0.0000
4	0.0000	0.0252	0.0000	0.1078	0.0000	0.2313	0.0000	0.1730
<b>5</b>	<b>3.2800</b>	<b>3.1881</b>	<b>0.9340</b>	<b>0.8833</b>	<b>1.7400</b>	<b>0.9385</b>	<b>1.3400</b>	<b>0.9442</b>
6	0.2730	0.0000	0.4920	0.0000	0.6200	0.0000	0.0000	0.0000
<b>7</b>	<b>0.6560</b>	<b>1.1353</b>	<b>0.9830</b>	<b>0.3584</b>	<b>2.1100</b>	<b>1.0964</b>	<b>0.4460</b>	<b>0.9146</b>
8	0.1370	0.0021	0.0980	0.0082	0.3100	0.0060	0.0000	0.0099
9	0.0660	0.0000	0.2460	0.0000	0.3100	0.0000	0.2230	0.0000
10	-	0.0000	-	0.0000	-	0.0000	-	0.0000
11	-	0.0077	-	0.0125	-	0.0125	-	0.0075
13	-	0.0011	-	0.0044	-	0.0043	-	0.0014
14	-	0.0001	-	0.0009	-	0.0009	-	0.0002
17	-	0.0662	-	0.0873	-	0.0814	-	0.0206
19	-	0.0460	-	0.0739	-	0.0694	-	0.0118
23	-	0.0904	-	0.0723	-	0.0683	-	0.0433
25	-	0.0553	-	0.0589	-	0.0502	-	0.0188
29	-	0.0009	-	0.0308	-	0.0305	-	0.0157
31	-	0.0009	-	0.0334	-	0.0335	-	0.0292

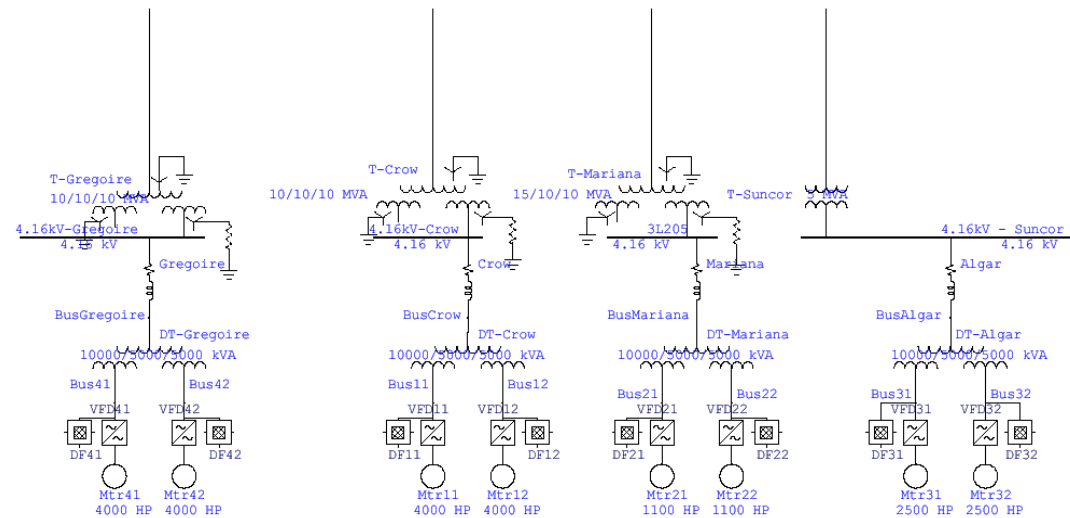


# HARMONIC STUDY ATCO Electric Hangingstone Substation

## 1.4 ETAP One-Line Diagram

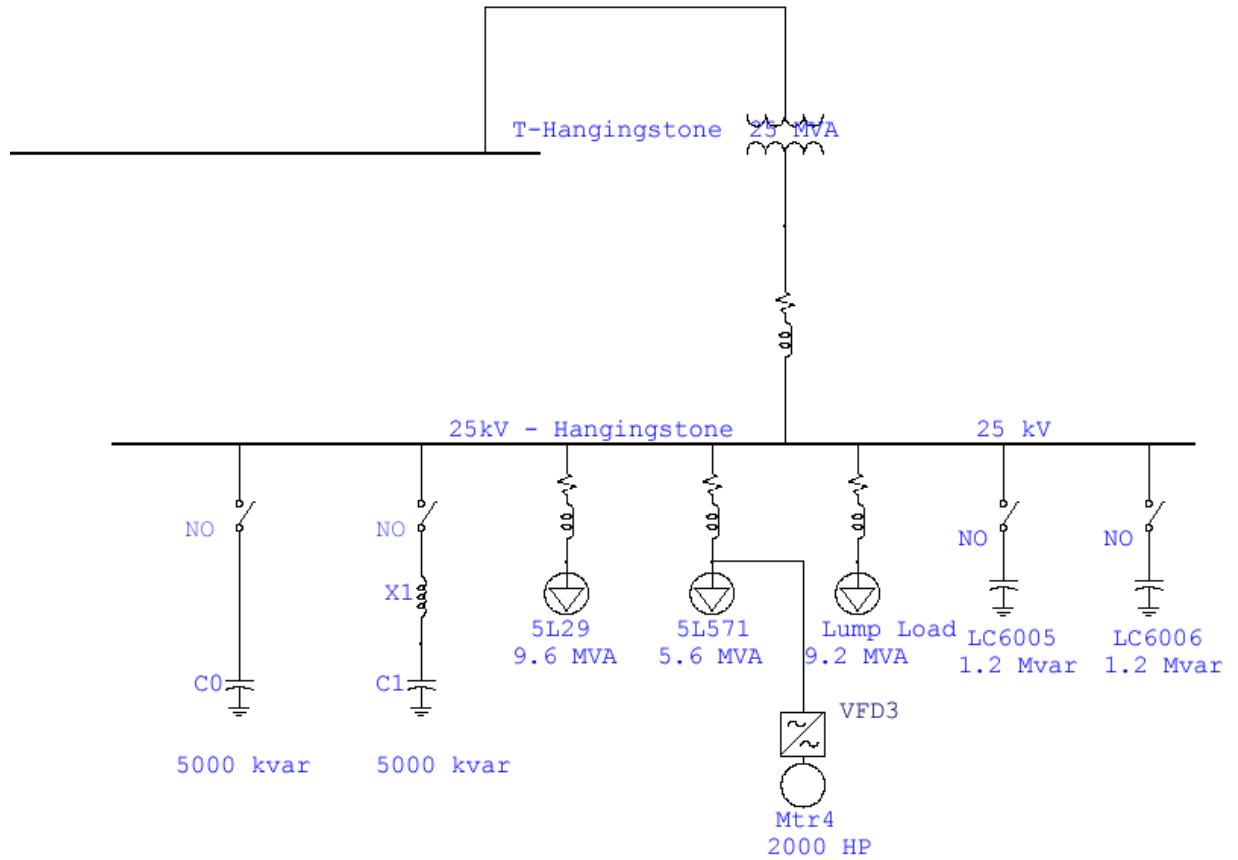


page 1 12:37:04 Jan 24, 2007 Project File: ATCO



HARMONIC STUDY  
 ATCO Electric Hangingstone Substation

CONTINUATION (144kV Hangingstone Bus)



## **1.5 Load Flow Report**

# HARMONIC STUDY

## ATCO Electric Hangingstone Substation

Project:	<b>ETAP</b>	Page:	1
Location:	5.5.0C	Date:	01-24-2007
Contract:		SN:	PWERSURVEY
Engineer:		Revision:	Base
Filename: ATCO	Study Case: LF	Config.:	BASE

### LOAD FLOW REPORT

Bus ID	Voltage			Generation		Load		ID	Load Flow			XFMR	
	kV	% Mag	Ang	MW	Mvar	MW	Mvar		MW	Mvar	Amp	% PF	% Tap
3L204	4.160	97.934	-2.0	0	0	2.612	1.044	144kV-Algar	-2.612	-1.044	398.7	92.9	
								& T-Algar-25kV					
3L205	4.160	100.583	-1.4	0	0	0	0	BusMariana	1.897	-3.727	577.1	-45.4	
								144kV-Mariana	-1.897	3.727	577.1	-45.4	
								& T-Mariana-2					
4.16kV-Crow	4.160	100.451	-2.3	0	0	0	0	BusCrow	6.833	-1.398	963.7	-98.0	
								144kV-Crow	-6.833	1.398	963.7	-98.0	
								& T-Crow-2					
4.16kV-Gregoire	4.160	97.674	-4.2	0	0	0	0	BusGregoire	6.833	-0.486	973.4	-99.7	
								144kV - Gregoire	-6.833	0.486	973.4	-99.7	
								& T-Gregoire-2					
4.16kV - Suncor	4.160	97.781	-9.2	0	0	0	0	BusAlgar	4.276	-1.141	628.1	-96.6	
								25kV - Suncor	-4.276	1.141	628.1	-96.6	
25kV - Hangingstone	25.000	94.595	-6.0	0	0	0	0	Bus2	9.059	2.819	231.6	95.5	
								Bus3	5.284	1.641	135.1	95.5	
								Bus4	8.681	2.700	222.0	95.5	
								Bus1	-23.024	-7.160	588.7	95.5	
25kV - ParsonsCreek A	25.000	97.837	-2.0	0	0	6.027	1.638	701T-3	-6.027	-1.638	147.4	96.5	
								& 144kV - ParsonsCreek					
25kV - ParsonsCreek B	25.000	94.957	-6.3	0	0	28.854	7.841	702T-3	-28.854	-7.841	727.2	96.5	
								& 144kV - ParsonsCreek					
25kV - Suncor	25.000	96.856	-5.5	0	0	0	0	T-Algar-25kV	-4.299	0.855	104.5	-98.1	
								4.16kV - Suncor	4.299	-0.855	104.5	-98.1	
144kV-Algar	144.000	98.348	-1.7	0	0	0	0	144kV - Intermediate	6.634	3.262	30.1	89.7	
								144kV-Mariana	-13.665	-3.724	57.7	96.5	
								T-Algar-25kV	7.031	0.463	28.7	99.8	
								& 3L204					
144kV-Crow	144.000	99.947	-0.1	0	0	0	0	144kV-McMillan	-22.673	6.053	94.1	-96.6	
								144kV-Mariana	15.827	-4.919	66.5	-95.5	
								T-Crow-2	6.847	-1.134	27.8	-98.7	
								& 4.16kV-Crow					
144kV - Gregoire	144.000	97.669	-2.0	0	0	0	0	144kV - Intermediate	-6.847	0.217	28.1	-99.9	
								T-Gregoire-2	6.847	-0.217	28.1	-99.9	
								& 4.16kV-Gregoire					
144kV - Hangingstone	144.000	97.486	-1.7	0	0	0	0	144kV - Intermediate	0.264	-7.577	31.2	-3.5	
								144kV - ParsonsCreek	-23.373	-1.557	96.3	99.8	

# HARMONIC STUDY

## ATCO Electric Hangingstone Substation

Project:  
Location:  
Contract:  
Engineer:  
Filename: ATCO

**ETAP**  
5.5.0C  
  
Study Case: LF

Page: 2  
Date: 01-24-2007  
SN: PWERSURVEY  
Revision: Base  
Config.: BASE

Bus		Voltage		Generation		Load		Load Flow				XFMR	
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
								Bus1	23.109	9.134	102.2	93.0	
144kV - Intermediate	144.000	97.797	-1.8	0	0	0	0	144kV - Hangingstone	-0.250	6.307	25.9	-4.0	
								144kV - Gregoire	6.858	-1.205	28.5	-98.5	
								144kV-Algar	-6.608	-5.102	34.2	79.2	
144kV-Mariana	144.000	99.419	-1.0	0	0	0	0	144kV-Algar	13.785	1.083	55.8	99.7	
								144kV-Crow	-15.685	2.588	64.1	-98.7	
								T-Mariana-2	1.900	-3.671	16.7	-46.0	
								& 3L205					
* 144kV-McMillan	144.000	100.000	0.0	22.696	-6.214	0	0	144kV-Crow	22.696	-6.214	94.3	-96.4	
144kV - ParsonsCreek	144.000	98.478	-0.8	0	0	0	0	B/RuthLake	-27.032	-7.344	114.0	96.5	
								B/RuthLake	-31.609	-5.487	130.6	98.5	
								144kV - Hangingstone	23.598	0.110	96.1	100.0	
								25kV - ParsonsCreek A	6.034	1.766	25.6	96.0	
								& 701T-3					
								25kV - ParsonsCreek B	29.009	10.955	126.2	93.6	
								& 702T-3					
* B/RuthLake	144.000	100.000	0.0	59.380	9.640	0	0	144kV - ParsonsCreek	27.351	5.957	112.2	97.7	
								144kV - ParsonsCreek	32.029	3.683	129.3	99.3	
Bus1	25.000	94.609	-6.0	0	0	0	0	25kV - Hangingstone	23.026	7.166	588.7	95.5	
								144kV - Hangingstone	-23.026	-7.166	588.7	95.5	
Bus2	25.000	93.203	-7.0	0	0	8.974	2.617	25kV - Hangingstone	-8.974	-2.617	231.6	96.0	
Bus3	25.000	93.243	-7.0	0	0	5.236	1.527	25kV - Hangingstone	-5.236	-1.527	135.1	96.0	
Bus4	25.000	93.217	-7.0	0	0	8.600	2.508	25kV - Hangingstone	-8.600	-2.508	222.0	96.0	
Bus11	4.160	101.458	-5.5	0	0	3.401	1.256	Bus73	0.002	-2.190	299.6	-0.1	
								Bus12	-3.403	0.934	482.7	-96.4	
								& BusCrow					
Bus12	4.160	101.981	-6.9	0	0	3.401	1.256	Bus68	0.002	-2.213	301.2	-0.1	
								BusCrow	-3.403	0.957	481.0	-96.3	
								& Bus11					
Bus21	4.160	103.636	-2.4	0	0	0.942	0.362	Bus69	0.002	-2.285	306.0	-0.1	
								Bus22	-0.944	1.923	286.9	-44.1	
								& BusMariana					
Bus22	4.160	104.945	-2.7	0	0	0.942	0.362	Bus70	0.002	-2.343	309.9	-0.1	
								BusMariana	-0.944	1.981	290.2	-43.0	
								& Bus21					
Bus31	4.160	98.622	-11.3	0	0	2.131	0.799	Bus71	0.001	-1.468	206.6	0.0	
								Bus32	-2.132	0.669	314.4	-95.4	
								& BusAlgar					
Bus32	4.160	99.024	-12.2	0	0	2.131	0.799	Bus72	0.001	-1.480	207.4	0.0	

# HARMONIC STUDY

## ATCO Electric Hangingstone Substation

Project:	<b>ETAP</b>	Page:	3
Location:	5.5.0C	Date:	01-24-2007
Contract:		SN:	PWERSURVEY
Engineer:		Revision:	Base
Filename: ATCO	Study Case: LF	Config.:	BASE

Bus ID	Voltage			Generation		Load		ID	Load Flow				XFMR	
	kV	% Mag	Ang	MW	Mvar	MW	Mvar		MW	Mvar	Amp	% PF	% Tap	
								BusAlgar & Bus31	-2.132	0.681	313.7	-95.3		
Bus41	4.160	97.928	-7.7	0	0	3.401	1.256	Bus63	0.001	-1.747	247.6	-0.1		
								Bus42 & BusGregoire	-3.402	0.491	487.2	-99.0		
Bus42	4.160	98.139	-9.2	0	0	3.401	1.256	Bus66 BusGregoire	0.001	-1.755	248.1	-0.1		
								Bus41	-3.402	0.498	486.3	-98.9		
Bus63	4.160	97.928	-7.7	0	0	0.001	-1.747	Bus41	-0.001	1.747	247.6	-0.1		
Bus66	4.160	98.139	-9.2	0	0	0.001	-1.755	Bus42	-0.001	1.755	248.1	-0.1		
Bus68	4.160	101.981	-6.9	0	0	0.002	-2.213	Bus12	-0.002	2.213	301.2	-0.1		
Bus69	4.160	103.636	-2.4	0	0	0.002	-2.285	Bus21	-0.002	2.285	306.0	-0.1		
Bus70	4.160	104.945	-2.7	0	0	0.002	-2.343	Bus22	-0.002	2.343	309.9	-0.1		
Bus71	4.160	98.622	-11.3	0	0	0.001	-1.468	Bus31	-0.001	1.468	206.6	0.0		
Bus72	4.160	99.024	-12.2	0	0	0.001	-1.480	Bus32	-0.001	1.480	207.4	0.0		
Bus73	4.160	101.458	-5.5	0	0	0.002	-2.190	Bus11	-0.002	2.190	299.6	-0.1		
BusAlgar	4.160	97.785	-9.3	0	0	0	0	4.16kV - Suncor Bus31	-4.274	1.148	628.1	-96.6		
								Bus32	4.274	-1.148	628.1	-96.6		
BusCrow	4.160	100.442	-2.4	0	0	0	0	4.16kV-Crow Bus11	-6.829	1.416	963.7	-97.9		
								Bus12	6.829	-1.416	963.7	-97.9		
BusGregoire	4.160	97.631	-4.4	0	0	0	0	4.16kV-Gregoire Bus41	-6.829	0.504	973.4	-99.7		
								Bus42	6.829	-0.504	973.4	-99.7		
BusMariana	4.160	100.701	-1.4	0	0	0	0	3L205 Bus21	-1.896	3.733	577.1	-45.3		
								Bus22	1.896	-3.733	577.1	-45.3		
T-Algar-25kV	25.000	98.636	-2.9	0	0	0	0	25kV - Suncor 3L204	4.413	-0.698	104.6	-98.8		
								& 144kV-Algar	-4.413	0.698	104.6	-98.8		
701T-3	4.160	97.799	-2.0	0	0	0	0	144kV - ParsonsCreek & 25kV - ParsonsCreek A	0.000	0.000	0.0	0.0		
702T-3	4.160	94.775	-6.7	0	0	0	0	144kV - ParsonsCreek & 25kV - ParsonsCreek B	0.000	0.000	0.0	0.0		
T-Crow-2	25.000	99.877	0.3	0	0	0	0	4.16kV-Crow & 144kV-Crow	0.000	0.000	0.0	0.0		
T-Gregoire-2	25.000	97.681	-1.6	0	0	0	0	4.16kV-Gregoire	0.000	0.000	0.0	0.0		

# HARMONIC STUDY

## ATCO Electric Hangingstone Substation

---

Project:	<b>ETAP</b>	Page:	4
Location:	5.5.0C	Date:	01-24-2007
Contract:		SN:	PWERSURVEY
Engineer:		Revision:	Base
Filename: ATCO	Study Case: LF	Config.:	BASE

---

Bus		Voltage		Generation		Load		Load Flow				XFMR	
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
								& 144kV - Gregoire					
T-Mariana-2	25.000	99.206	-0.9	0	0	0	0	3L205	0.000	0.000	0.0	0.0	
								& 144kV-Mariana					

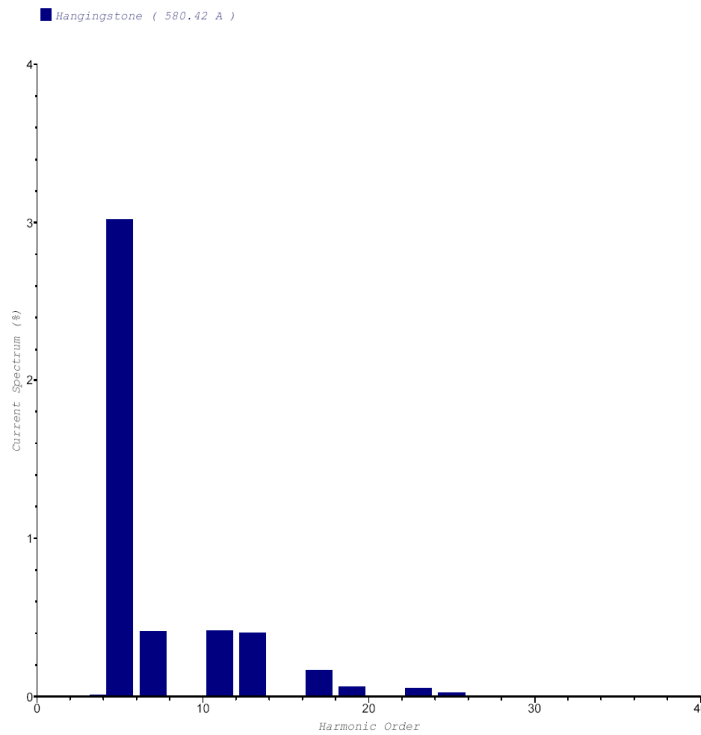
\* Indicates a voltage regulated bus ( voltage controlled or swing type machine connected to it)

# Indicates a bus with a load mismatch of more than 0.1 MVA

## 2. RESULTS

### 2.1 Scenario 1: No Filters

#### CURRENT SPECTRUM – HANGINGSTONE 25 KV SUPPLY:



n	Measured	Preliminary	Final Model
1	100	100	100
2	0.1600	0.0036	0.0036
3	2.5000	0.0000	0.0000
4	0.0000	0.0067	0.0078
5	3.0300	0.0753	3.0204
6	-	0.0000	0.0000
7	0.4160	0.1049	0.4130
8	0.0000	0.0007	0.0009
9	0.4000	0.0000	0.0000
10	-	0.0000	0.0000
11	0.4160	0.0020	0.4154
13	0.4000	0.0004	0.4002
14	-	0.0001	0.0002
17	-	0.0028	0.1658
19	-	0.0033	0.0645
23	-	0.0005	0.0545
25	-	0.0010	0.0247
29	-	0.0010	0.0017
31	-	0.0005	0.0008
THD	4.2462	-	3.1083

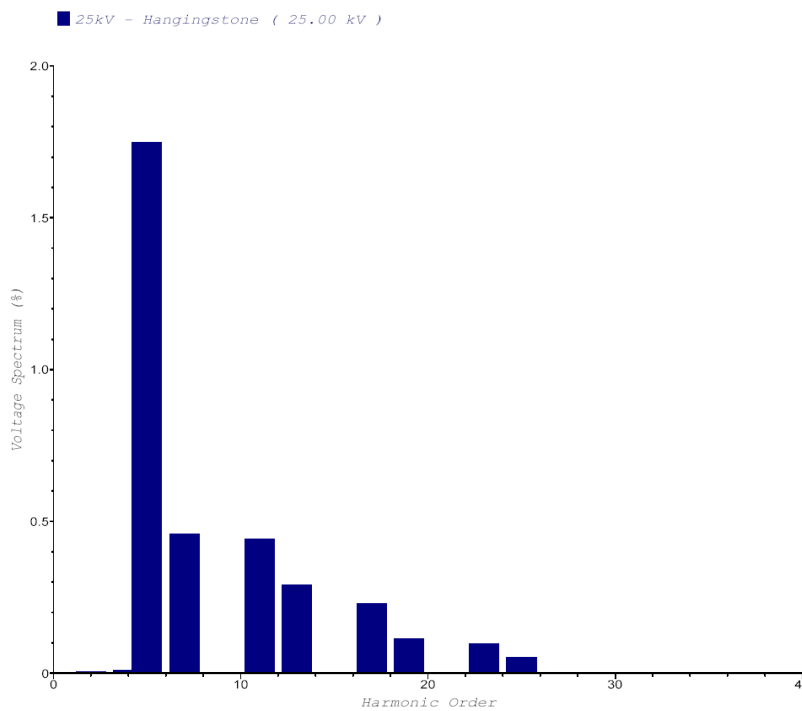
#### Comments

The 5<sup>th</sup> and 7<sup>th</sup> harmonic currents predicted by the preliminary model were much lower than the measured values as per *ATCO Electric Harmonic Filter Specification, Page 4*. The measured current harmonic values of about 3.03% for the 5<sup>th</sup> harmonic current are most probably not caused by the large 12-pulse drives, not even if considering severe voltage unbalance and / or severe phase shifting of the drive transformers. The much higher than predicted 5<sup>th</sup> and 7<sup>th</sup> harmonic currents could though be caused by other non-linear loads connected from the Hangingstone Substation. This fact obliged us to include an additional non-linear load at Hangingstone. The herewith obtained results are listed under the last two columns named *Preliminary* and *Final Model*. The *Final Model* was used for simulating Scenarios 2 (one 5 MVAR 5<sup>th</sup> harmonic filter at Hangingstone) and 3 (one 5 MVAR 5<sup>th</sup> harmonic filter plus one 5 MVAR capacitor bank at Hangingstone). The 3<sup>rd</sup> harmonic distortion (due to load unbalance) cannot be simulated properly with ETAP.



HARMONIC STUDY  
 ATCO Electric Hangingstone Substation

**VOLTAGE SPECTRUM – HANGINGSTONE 25 KV BUS:**



n	Measured	Preliminary	Final Model
1	100	100	100
2	0.0000	0.0039	0.0041
3	0.8000	0.0000	0.0000
4	0.0000	0.0074	0.0087
5	2.6000	0.0767	1.7489
6	-	0.0000	0.0000
7	0.2400	0.1183	0.4592
8	0.0000	0.0008	0.0008
9	0.2300	0.0000	0.0000
10	-	0.0000	0.0000
11	0.3200	0.0022	0.4412
13	0.1000	0.0004	0.2917
14	-	0.0001	0.0001
17	-	0.0028	0.2287
19	-	0.0035	0.1145
23	-	0.0006	0.0971
25	-	0.0012	0.0523
29	-	0.0011	0.0006
31	-	0.0006	0.0003
THD	2.7610	-	1.9045

**Comments**

The harmonic voltages predicted by the ETAP *Preliminary* model are much lower than the measured values as per *ATCO Electric Harmonic Filter Specification, Page 4*. Same comments as for current harmonics apply. The *Final Model* predicts much closer results.

## 2.2 Scenario 2: 5 MVAR 5<sup>th</sup> harmonic filter

One 5 MVAR 5<sup>th</sup> harmonic filter (tuned at 4.8 h) was connected on the simulation. The harmonic current spectrum in the main supply line indicates an increased 5<sup>th</sup> harmonic distortion of 0.4236 %. The THD value is well below the IEEE 519 TDD limit of 5%. The results for different sub-scenarios are listed below under columns *NO 6000* (no other capacitor banks 6005, 6006, 6008 and 6010 connected); *6008,10* for capacitor banks 6008 and 6010 connected only; *6005,08,10* for capacitor banks 6005, 6008 and 6010 connected and *ALL 6000* for 6005, 6006, 6008 and 6010 connected.

### CURRENT SPECTRUM – HANGINGSTONE 25 KV SUPPLY:

n	NO 6000	6008,10	6005,08,10	ALL 6000
1	100	100	100	100
2	0.0041	0.0042	0.0045	0.0048
3	0.0000	0.0000	0.0000	0.0000
4	0.0485	0.0481	0.0504	0.0514
5	0.4236	0.4409	0.4502	0.4588
6	0.0000	0.0000	0.0000	0.0000
7	0.2018	0.2321	0.2490	0.2706
8	0.0008	0.0006	0.0005	0.0005
9	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000
11	0.4918	0.3760	0.4252	0.4469
13	0.2214	0.2249	0.2889	0.3696
14	0.0001	0.0001	0.0001	0.0001
17	0.1229	0.1231	0.1886	0.1944
19	0.0667	0.0621	0.0909	0.0751
23	0.0669	0.0676	0.1025	0.0630
25	0.0370	0.0374	0.0529	0.0283
29	0.0010	0.0010	0.0018	0.0019
31	0.0005	0.0005	0.0009	0.0009
THD	0.7341	0.6837	0.7672	0.8191

### Comments

The herewith obtained results are all below IEEE 519 limits. Adding capacitor banks 6008 and 6010 increased slightly the 5<sup>th</sup> and 7<sup>th</sup> harmonic current distortions, but reduced higher order harmonic currents resulting altogether in lower THD values. Adding 6005 and 6006 capacitor banks result higher distortions in general, but with exception of the 11<sup>th</sup> harmonic. The overall impact of adding all of the 6000 capacitor banks is minor.

HARMONIC STUDY  
 ATCO Electric Hangingstone Substation

**VOLTAGE SPECTRUM – HANGINGSTONE 25 KV BUS:**

n	NO 6000	6008,10	6005,08,10	ALL 6000
1	100	100	100	100
2	0.0044	0.0044	0.0045	0.0048
3	0.0000	0.0000	0.0000	0.0000
4	0.0179	0.0177	0.0173	0.0514
5	0.2310	0.2300	0.2340	0.4588
6	0.0000	0.0000	0.0000	0.0000
7	0.2323	0.2130	0.2383	0.2706
8	0.0005	0.0004	0.0005	0.0005
9	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000
11	0.2848	0.3922	0.4391	0.4469
13	0.1661	0.1602	0.2041	0.3696
14	0.0001	0.0001	0.0001	0.0001
17	0.1693	0.1695	0.2551	0.1944
19	0.1088	0.1136	0.1612	0.0751
23	0.1160	0.1155	0.1751	0.0630
25	0.0736	0.0735	0.1058	0.0283
29	0.0011	0.0011	0.0015	0.0019
31	0.0006	0.0006	0.0007	0.0009
THD	0.5251	0.5818	0.6923	0.8191

**Comments**

The 5<sup>th</sup> harmonic voltages are, as expected, much lower now when compared with Scenario 1 running without filters. This is the case for all harmonic voltages but the 4<sup>th</sup> harmonic voltage, which increased slightly due to the parallel resonance introduced by the shunt filter. This increase is without implications though. All harmonic voltage distortions are well below IEE 519 limits.

### 2.3 Scenario 3: 5 MVAR 5<sup>th</sup> harmonic filter and 5 MVAR Capacitor Bank

A combination of 5<sup>th</sup> harmonic filter (tuned at 4.8 h) and a 5 MVAR capacitor bank are connected now. The harmonic current spectrum in the main supply line indicates slightly higher harmonic distortions.

#### CURRENT SPECTRUM – HANGINGSTONE 25 KV SUPPLY:

n	NO 6000	6008,10	6005,08,10	ALL 6000
1	100	100	100	100
2	0.0056	0.0057	0.0061	0.0066
3	0.0000	0.0000	0.0000	0.0000
4	0.0503	0.0501	0.0486	0.0468
5	0.4568	0.4741	0.4796	0.4839
6	0.0000	0.0000	0.0000	0.0000
7	0.3176	0.3414	0.3869	0.4353
8	0.0011	0.0009	0.0011	0.0014
9	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000
11	0.5651	0.3738	0.3216	0.2754
13	0.3604	0.3704	0.2904	0.2268
14	0.0002	0.0002	0.0002	0.0002
17	0.0862	0.0865	0.0657	0.0528
19	0.0364	0.0350	0.0278	0.0232
23	0.0243	0.0250	0.0191	0.0153
25	0.0106	0.0109	0.0082	0.0065
29	0.0016	0.0017	0.0017	0.0017
31	0.0008	0.0008	0.0008	0.0008
THD	0.8779	0.7939	0.7586	0.7462

#### Comments

The herewith obtained results are also below IEEE 519 limits. Adding capacitor banks 6008 and 6010 increased slightly harmonics 2<sup>nd</sup> to 7<sup>th</sup>, but reduced some higher order harmonic currents resulting thus in lower THD values. Adding 6005 and 6006 capacitor banks result in even higher harmonic distortions for the 5<sup>th</sup> and 7<sup>th</sup>, but lowering further the THD value. The overall impact of adding all 6000 capacitor banks is minor.

HARMONIC STUDY  
 ATCO Electric Hangingstone Substation

---

**VOLTAGE SPECTRUM – HANGINGSTONE 25 KV BUS:**

n	NO 6000	6008,10	6005,08,10	ALL 6000
1	100	100	100	100
2	0.0048	0.0048	0.0050	0.0051
3	0.0000	0.0000	0.0000	0.0000
4	0.0142	0.0141	0.0131	0.0120
5	0.2488	0.2477	0.2523	0.2571
6	0.0000	0.0000	0.0000	0.0000
7	0.4088	0.3630	0.4186	0.4748
8	0.0010	0.0008	0.0009	0.0008
9	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000
11	0.3197	0.3804	0.3276	0.2816
13	0.2655	0.2591	0.2037	0.1599
14	0.0001	0.0001	0.0001	0.0000
17	0.1124	0.1125	0.0849	0.0678
19	0.0567	0.0565	0.0436	0.0354
23	0.0434	0.0434	0.0336	0.0273
25	0.0233	0.0233	0.0182	0.0148
29	0.0003	0.0003	0.0002	0.0002
31	0.0001	0.0001	0.0001	0.0001
THD	0.6482	0.6507	0.6313	0.6351

**Comments**

The 5<sup>th</sup> harmonic voltages are still much lower compared with Scenario 1. This is the case for all harmonic voltages but the 4<sup>th</sup> harmonic voltage, which increased very slightly due to the parallel resonance introduced by the shunt filter. All harmonic voltage distortions are well below IEE 519 limits.

## 2.4 Faulting Utilities

The following tables show currents and voltage harmonics at Hangingstone when faulting Ruth Lake and McMillan utility supplies. Up direction variations are marked in red.

### CURRENT HARMONICS, SCENARIO 1

n	Measured	ETAP Model		
	RL+MM ON	RL OFF	MM OFF	
1	100	100	100	100
2	0.1600	0.0036	0.0073	0.0130
3	2.5000	0.0000	0.0000	0.0000
4	0.0000	0.0078	0.0104	0.0102
5	3.3300	3.0204	1.8978	2.7088
7	0.4160	0.4130	0.2604	0.2091
8	0.0000	0.0009	0.0003	0.0025
9	0.4000	0.0000	0.0000	0.0000
11	0.4160	0.4154	0.6276	0.8913
13	0.4000	0.4002	0.3208	0.3322
14	-	0.0002	0.0000	0.0001
17	-	0.1658	0.1246	0.1241
19	-	0.0645	0.0667	0.1018
23	-	0.0545	0.0395	0.0538
25	-	0.0247	0.0183	0.0237
29	-	0.0017	0.0013	0.0010
31	-	0.0008	0.0012	0.0009
THD	4.2462	3.1083	2.0466	2.8837

### VOLTAGE HARMONICS, SCENARIO 1

n	Measured	ETAP Model		
	RL+MM ON	RL OFF	MM OFF	
1	100	100	100	100
2	0.0000	0.0041	0.0106	0.0152
3	0.8000	0.0000	0.0000	0.0000
4	0.0000	0.0087	0.0146	0.0115
5	2.6000	1.7489	1.5389	1.7824
7	0.2400	0.4592	0.3081	0.3764
8	0.0000	0.0008	0.0004	0.0024
9	0.2300	0.0000	0.0000	0.0000
11	0.3200	0.4412	0.4830	0.7224
13	0.1000	0.2917	0.3435	0.3729
14	-	0.0001	0.0000	0.0001
17	-	0.2287	0.2179	0.1597
19	-	0.1145	0.1237	0.1248
23	-	0.0971	0.0959	0.0972
25	-	0.0523	0.0521	0.0520
29	-	0.0006	0.0007	0.0004
31	-	0.0003	0.0005	0.0003
THD	2.7610	1.9045	1.6998	2.0083

HARMONIC STUDY  
ATCO Electric Hangingstone Substation

**CURRENT HARMONICS, SCENARIO 2**

	RL+MM ON	RL OFF	MM OFF	RL+MM ON	RL OFF	MM OFF
n	ALL 6000	ALL 6000	ALL 6000	NO 6000	NO 6000	NO 6000
1	100	100	100	100	100	100
2	0.0048	0.0056	0.0179	0.0041	0.0083	0.0150
4	0.0514	0.0503	0.0642	0.0485	0.0453	0.0610
5	0.4588	0.4568	0.5797	0.4236	0.3623	0.5250
7	0.2706	0.3176	0.3399	0.2018	0.3637	0.3714
8	0.0005	0.0011	0.0019	0.0008	0.0004	0.0032
11	0.4469	0.5651	0.7465	0.4918	0.3883	0.4565
13	0.3696	0.3604	0.3369	0.2214	0.1654	0.1864
14	0.0001	0.0002	0.0001	0.0001	0.0000	0.0001
17	0.1944	0.0862	0.1417	0.1229	0.1017	0.1303
19	0.0751	0.0364	0.1179	0.0667	0.0589	0.0787
23	0.0630	0.0243	0.0627	0.0669	0.0504	0.0662
25	0.0283	0.0108	0.0272	0.0370	0.0266	0.0368
29	0.0019	0.0017	0.0010	0.0010	0.0008	0.0006
31	0.0009	0.0009	0.0010	0.0005	0.0008	0.0006
THD	0.8191	0.8779	1.0796	0.7341	0.6788	0.8304

**VOLTAGE HARMONICS, SCENARIO 2**

	RL+MM ON	RL OFF	MM OFF	RL+MM ON	RL OFF	MM OFF
n	ALL 6000	ALL 6000	ALL 6000	NO 6000	NO 6000	NO 6000
1	100	100	100	100	100	100
2	0.0048	0.0048	0.0172	0.0044	0.0111	0.0161
4	0.0514	0.0142	0.0207	0.0179	0.0213	0.0227
5	0.4588	0.2488	0.2326	0.2310	0.2452	0.2272
7	0.2706	0.4088	0.2520	0.2323	0.2219	0.2619
8	0.0005	0.0010	0.0020	0.0005	0.0003	0.0024
11	0.4469	0.3197	0.5788	0.2848	0.3159	0.3613
13	0.3696	0.2655	0.3617	0.1661	0.1817	0.2047
14	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001
17	0.1944	0.1124	0.1739	0.1693	0.1615	0.1447
19	0.0751	0.0567	0.1388	0.1088	0.1077	0.1016
23	0.0630	0.0433	0.1081	0.1160	0.1196	0.1159
25	0.0283	0.0233	0.0569	0.0736	0.0770	0.0726
29	0.0019	0.0003	0.0004	0.0011	0.0012	0.0007
31	0.0009	0.0001	0.0004	0.0006	0.0011	0.0007
THD	0.8191	0.6482	0.8054	0.5251	0.5483	0.5860

HARMONIC STUDY  
ATCO Electric Hangingstone Substation

**CURRENT HARMONICS, SCENARIO 3**

	RL+MM ON	RL OFF	MM OFF		RL+MM ON	RL OFF	MM OFF
n	ALL 6000	ALL 6000	ALL 6000		NO 6000	NO 6000	NO 6000
1	100	100	100		100	100	100
2	0.0066	0.0147	0.0247		0.0056	0.0119	0.0208
4	0.0468	0.0466	0.0582		0.0503	0.0473	0.0624
5	0.4839	0.5122	0.5944		0.4568	0.3908	0.5516
6	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000
7	0.4353	0.2745	0.1783		0.3176	0.2831	0.2149
8	0.0014	0.0005	0.0036		0.0011	0.0004	0.0031
11	0.2754	0.6125	0.5971		0.5651	0.8218	0.9410
13	0.2268	0.1622	0.1319		0.3604	0.2575	0.2276
14	0.0002	0.0000	0.0001		0.0002	0.0000	0.0001
17	0.0528	0.0362	0.0481		0.0862	0.0650	0.0941
19	0.0232	0.0208	0.0327		0.0364	0.0320	0.0489
23	0.0153	0.0124	0.0151		0.0243	0.0187	0.0241
25	0.0065	0.0061	0.0059		0.0106	0.0089	0.0096
29	0.0017	0.0013	0.0009		0.0016	0.0013	0.0010
31	0.0008	0.0011	0.0009		0.0008	0.0011	0.0009
THD	0.7462	0.8623	0.8756		0.8779	0.9913	1.1419

**VOLTAGE HARMONICS, SCENARIO 3**

	RL+MM ON	RL OFF	MM OFF		RL+MM ON	RL OFF	MM OFF
n	ALL 6000	ALL 6000	ALL 6000		NO 6000	NO 6000	NO 6000
1	100	100	100		100	100	100
2	0.0051	0.0131	0.0192		0.0048	0.0123	0.0179
4	0.0120	0.0139	0.0151		0.0142	0.0163	0.0178
5	0.2571	0.2616	0.2515		0.2488	0.2647	0.2450
6	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000
7	0.4748	0.3157	0.3779		0.4088	0.3022	0.4282
8	0.0008	0.0004	0.0022		0.0010	0.0004	0.0029
11	0.2816	0.4220	0.4671		0.3197	0.6310	0.7312
13	0.1599	0.1555	0.1433		0.2655	0.2670	0.2463
14	0.0000	0.0000	0.0000		0.0001	0.0000	0.0000
17	0.0678	0.0651	0.0603		0.1124	0.1089	0.1025
19	0.0354	0.0354	0.0366		0.0567	0.0575	0.0593
23	0.0273	0.0272	0.0273		0.0434	0.0431	0.0434
25	0.0148	0.0149	0.0148		0.0233	0.0234	0.0231
29	0.0002	0.0002	0.0001		0.0003	0.0003	0.0002
31	0.0001	0.0001	0.0001		0.0001	0.0002	0.0002
THD	0.6351	0.6142	0.6718		0.6482	0.8055	0.9251

**Comments**

Only the 7<sup>th</sup> and 11<sup>th</sup> harmonics show some upwards trend depending on the configuration of the capacitor banks. All harmonic distortions are well below IEEE 519 limits. Switching off one of the utility feeders is not critical.

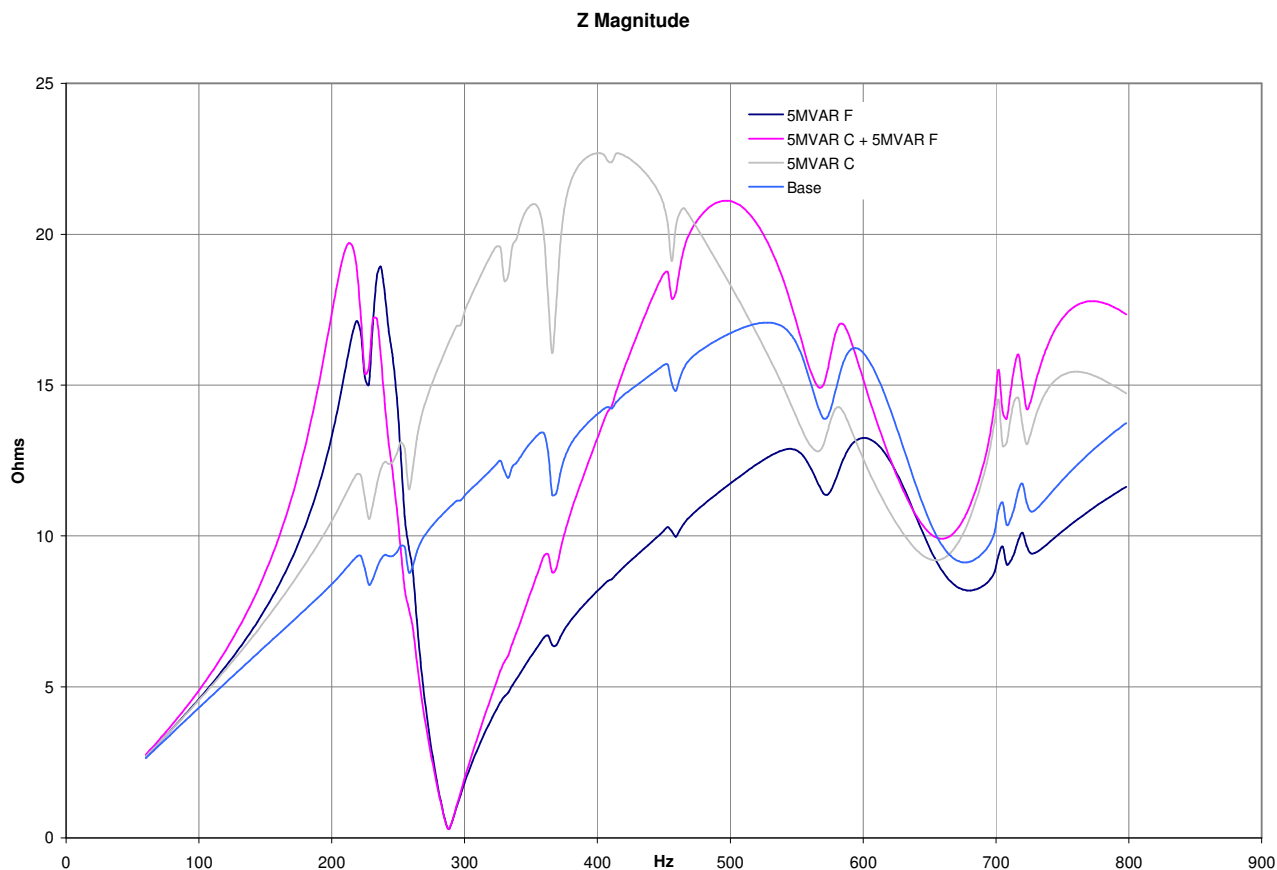


### 3. CONCLUSIONS

#### 3.1 Comparing Scenarios

The following graph highlights the bus impedance scans for all three scenarios, resulting in almost similar shape, but lower values compared with the scans presented in *ATCO Electric Harmonic Filter Specification*, sheet 26. This divergence could be caused by the different assumptions taken for elaborating the models and possibly related to different calculation methods. Similar impacts are detected though on both models, when connecting the 5 MVAR filter and 5 MVAR capacitor bank in parallel and this is important.

The following graph for the Hangingstone Substation 25 kV bus was recorded from the ETAP simulation. Additional poles and zeros are apparent from this graph: they do result from the drive filters, which perhaps were not considered in ATCO simulations.



HARMONIC STUDY  
ATCO Electric Hangingstone Substation

Comments

Connecting a 5 MVAR filter or a combination of filter and capacitor bank will introduce an increase of harmonic current import down from the 144 kV level as well as absorbing any 5<sup>th</sup> harmonic current coming directly from the Hangingstone Substation. Connecting in parallel a capacitor bank of 5 MVAR will not introduce any major additional impact when compared with the 5 MVAR 5<sup>th</sup> harmonic filter of Scenario 2, considering the very slight ringing effect between 7<sup>th</sup> and 10<sup>th</sup> harmonic.

The following harmonic current table summarizes the results for all three scenarios, including all possible sub-scenarios:

**CURRENT HARMONICS- HANGINGSTONE 25KV SUPPLY**

n	SCENARIO 1		SCENARIO 2				SCENARIO 3			
	Measured	Final Model	NO 6000	6008,10	6005,08,10	ALL 6000	NO 6000	6008,10	6005,08,10	ALL 6000
1	100	100	100	100	100	100	100	100	100	100
2	0.1600	0.0036	0.0041	0.0042	0.0045	0.0048	0.0056	0.0057	0.0061	0.0066
3	2.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0078	0.0485	0.0481	0.0504	0.0514	0.0503	0.0501	0.0486	0.0468
5	3.3300	3.0204	0.4236	0.4409	0.4502	0.4588	0.4568	0.4741	0.4796	0.4839
6	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.4160	0.4130	0.2018	0.2321	0.2490	0.2706	0.3176	0.3414	0.3869	0.4353
8	0.0000	0.0009	0.0008	0.0006	0.0005	0.0005	0.0011	0.0009	0.0011	0.0014
9	0.4000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.4160	0.4154	0.4918	0.3760	0.4252	0.4469	0.5651	0.3738	0.3216	0.2754
13	0.4000	0.4002	0.2214	0.2249	0.2889	0.3696	0.3604	0.3704	0.2904	0.2268
14	-	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002
17	-	0.1658	0.1229	0.1231	0.1886	0.1944	0.0862	0.0865	0.0657	0.0528
19	-	0.0645	0.0667	0.0621	0.0909	0.0751	0.0364	0.0350	0.0278	0.0232
23	-	0.0545	0.0669	0.0676	0.1025	0.0630	0.0243	0.0250	0.0191	0.0153
25	-	0.0247	0.0370	0.0374	0.0529	0.0283	0.0106	0.0109	0.0082	0.0065
29	-	0.0017	0.0010	0.0010	0.0018	0.0019	0.0016	0.0017	0.0017	0.0017
31	-	0.0008	0.0005	0.0005	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008
THD	4.2462	3.108292	0.7341	0.6837	0.7672	0.8191	0.8779	0.7939	0.7586	0.7462

Scenario 3 (including all its variations of the capacitor banks 6005 to 6010) delivers acceptable results well below IEEE 519 limits, without introducing any major resonances. All THD values are acceptable.

HARMONIC STUDY  
ATCO Electric Hangingstone Substation

The following harmonic voltage table summarizes the results for all three scenarios, including all possible sub-scenarios:

**VOLTAGE HARMONICS – HANGINGSTONE 25 KV BUS**

n	SCENARIO 1		SCENARIO 2				SCENARIO 3			
	Measured	Final Model	NO 6000	6008,10	6005,08,10	ALL 6000	NO 6000	6008,10	6005,08,10	ALL 6000
1	100	100	100	100	100	100	100	100	100	100
2	0.0000	0.0041	0.0044	0.0044	0.0045	0.0048	0.0048	0.0048	0.0050	0.0051
3	0.8000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0087	0.0179	0.0177	0.0173	0.0514	0.0142	0.0141	0.0131	0.0120
5	2.6000	1.7489	0.2310	0.2300	0.2340	0.4588	0.2488	0.2477	0.2523	0.2571
6	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.2400	0.4592	0.2323	0.2130	0.2383	0.2706	0.4088	0.3630	0.4186	0.4748
8	0.0000	0.0008	0.0005	0.0004	0.0005	0.0005	0.0010	0.0008	0.0009	0.0008
9	0.2300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.3200	0.4412	0.2848	0.3922	0.4391	0.4469	0.3197	0.3804	0.3276	0.2816
13	0.1000	0.2917	0.1661	0.1602	0.2041	0.3696	0.2655	0.2591	0.2037	0.1599
14	-	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000
17	-	0.2287	0.1693	0.1695	0.2551	0.1944	0.1124	0.1125	0.0849	0.0678
19	-	0.1145	0.1088	0.1136	0.1612	0.0751	0.0567	0.0565	0.0436	0.0354
23	-	0.0971	0.1160	0.1155	0.1751	0.0630	0.0434	0.0434	0.0336	0.0273
25	-	0.0523	0.0736	0.0735	0.1058	0.0283	0.0233	0.0233	0.0182	0.0148
29	-	0.0006	0.0011	0.0011	0.0015	0.0019	0.0003	0.0003	0.0002	0.0002
31	-	0.0003	0.0006	0.0006	0.0007	0.0009	0.0001	0.0001	0.0001	0.0001
THD	2.7610	1.9045	0.5251	0.5818	0.6923	0.8191	0.6482	0.6507	0.6313	0.6351

Scenario 3 (including all its variations of the capacitor banks 6005 to 6010) delivers acceptable results well below IEEE 519 limits, without introducing any major resonances. All THD values are acceptable.

### 3.2 Recommendations

A combined harmonic filter and capacitor bank as per Scenario 3 would present a minor ringing effect at about 500 Hz ( $h = 8.33$ ) while keeping harmonic distortions within reasonable distance from IEEE 519 limits. The filter combination will attenuate the 5<sup>th</sup> harmonic distortion, it will also keep the 7<sup>th</sup> harmonic distortion almost unchanged, but it will probably double any existing 3<sup>rd</sup> harmonic voltage distortion.

The following tables illustrate the 5 MVAR Filter currents and voltages for sizing its reactors and capacitors appropriately.

#### REACTOR CURRENTS, Amps

n	5 MVAR FILTER				5 MVAR FILTER + 5MVAR CAP BANK			
	NO 6000	6008,10	6005,08,10	ALL 6000	NO 6000	6008,10	6005,08,10	ALL 6000
1	116.34	116.48	117.03	117.58	118.66	118.80	119.36	119.94
2	0.0122	0.0123	0.0126	0.0129	0.0134	0.0135	0.0138	0.0142
4	0.2701	0.2676	0.2608	0.2486	0.2146	0.2138	0.1973	0.1820
5	15.5321	15.4623	15.7323	16.0112	16.7290	16.6514	16.9625	17.2872
7	1.6660	1.5274	1.7093	1.9323	2.9319	2.6035	3.0025	3.4055
8	0.0028	0.0022	0.0025	0.0030	0.0054	0.0042	0.0045	0.0043
11	0.8505	1.1714	1.3115	1.3683	0.9548	1.1360	0.9785	0.8410
13	0.3933	0.3794	0.4834	0.6148	0.6290	0.6138	0.4825	0.3788
14	0.0001	0.0001	0.0002	0.0003	0.0002	0.0002	0.0001	0.0001
17	0.2877	0.2880	0.4335	0.4401	0.1910	0.1911	0.1443	0.1153
19	0.1626	0.1698	0.2410	0.1932	0.0848	0.0845	0.0652	0.0529
23	0.1400	0.1395	0.2115	0.1303	0.0523	0.0525	0.0406	0.0330
25	0.0814	0.0813	0.1169	0.0634	0.0258	0.0258	0.0201	0.0164
29	0.0011	0.0011	0.0015	0.0007	0.0003	0.0003	0.0002	0.0002
31	0.0005	0.0005	0.0006	0.0003	0.0001	0.0001	0.0001	0.0001
47	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RMS	117.39	117.52	118.10	118.69	119.88	120.00	120.60	121.23
1.35xRMS	158.47	158.65	159.44	160.23	161.83	162.00	162.81	163.66

HARMONIC STUDY  
 ATCO Electric Hangingstone Substation

**CAPACITOR VOLTAGES, % of 25 kV**

n	5 MVAR FILTER				5 MVAR FILTER + 5MVAR CAP BANK			
	NO 6000	6008,10	6005,08,10	ALL 6000	NO 6000	6008,10	6005,08,10	ALL 6000
1	100	100	100	100	100	100	100	100
2	0.0053	0.0053	0.0055	0.0056	0.0058	0.0059	0.0060	0.0061
4	0.0585	0.0579	0.0565	0.0538	0.0465	0.0463	0.0427	0.0394
5	2.6903	2.6781	2.7248	2.7732	2.8975	2.8840	2.9381	2.9942
7	0.2061	0.1890	0.2115	0.2391	0.3627	0.3221	0.3715	0.4213
8	0.0003	0.0002	0.0003	0.0003	0.0006	0.0004	0.0005	0.0005
11	0.0670	0.0922	0.1033	0.1077	0.0752	0.0894	0.0770	0.0662
13	0.0262	0.0253	0.0322	0.0410	0.0419	0.0409	0.0321	0.0252
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0147	0.0147	0.0221	0.0224	0.0097	0.0097	0.0074	0.0059
19	0.0074	0.0077	0.0110	0.0088	0.0039	0.0039	0.0030	0.0024
23	0.0053	0.0053	0.0080	0.0049	0.0020	0.0020	0.0015	0.0012
25	0.0028	0.0028	0.0040	0.0022	0.0009	0.0009	0.0007	0.0006
29	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SUM	103.08	103.08	103.18	103.26	103.45	103.41	103.48	103.56