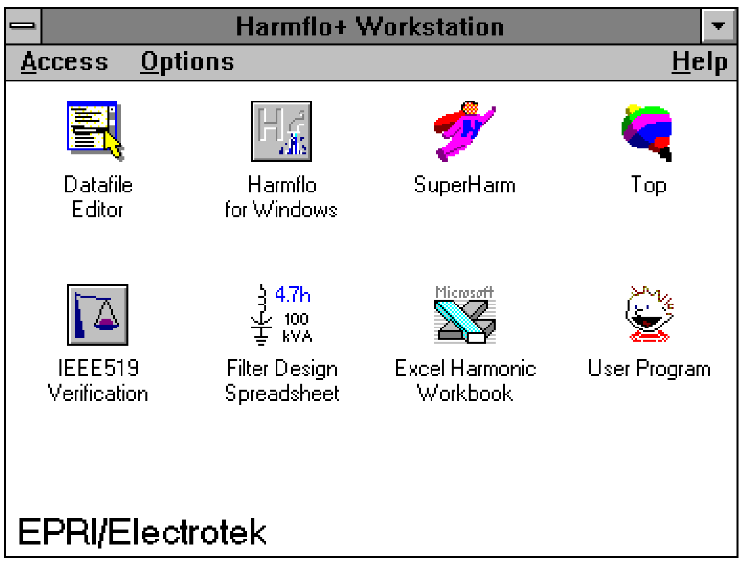
HarmFlo+ Tech Notes



for users of the EPRI/Electrotek HarmFlo+ Workstation

Issue # 93-2 | ***September, 1993*** | ***Editor: Thomas Grebe***

in this issue:

Letter from the Editor:

This is the second issue of *HarmFlo+ Tech Notes*. The technical newsletter provided to members of the HarmFlo User's Group. The initial plan for the newsletter is a quarterly technical publication highlighting contributions from members of the User's Group. This newsletter is published using Microsoft Word for Windows. If you wish to contribute an article, please contact me for appropriate text and figure formats. Contributions in the following areas are welcome:

- Technical articles
- Modifications / enhancements to the code
- Case studies / unique simulations
- Research projects
- SuperHarm / HARMFLO data preparation / model development
- Include / library files developed for distribution on the BBS
- Letters to the editor / User's Group
- Technical paper abstracts
- Questions for members of the User's Group

I believe that the exchange of technical information is one of the most important functions of the HarmFlo User's Group and this newsletter, in conjunction with The Resonant, will help to serve the needs of the members. As always, I'm open for suggestions regarding this publication and the User's Group in general.

Thanks for your support

For more information concerning the newsletter or to submit a contribution please contact:

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Case Study - Plastics Plant

HarmFlo+ Case Study - Plastics Extrusion Facility

Background

When a plastics extrusion facility in Wichita, Kansas, announced a major expansion of equipment and then experienced an outage (resulting from the failure of fuse-links due to overload in the 12.5kV distribution line protective devices serving the facility), memories of past concerns with harmonics in this area resurfaced. Several years ago, responding to complaints from other customers served by the same distribution line, determinations were made that harmonic distortion was present around the extrusion plant. Then, the extrusion plant officials were approached to install harmonic filters within the facility; however, due to plant budget constraints and the lack of standards to support the utility's request, the filters were never installed. Current plant expansion, coupled with the importance of IEEE 519 and quality power, suggested the need for further study. Western Resources, Inc. Field Support Engineering (FSE) personnel and members of the Power Technology Center (PTC) installed equipment to gather harmonic data.

The manufacturing facility is served by the Company's 12.5kV electric distribution line and the facility owns three 12.5kV/480V 3 phase power transformers. Adjustable speed DC drives used by this facility range in size from 50 HP to 500 HP. The three mile section of 12.5kV line also serves many residential and small commercial facilities. Several 3 phase distribution capacitor banks exist along this circuit to reduce inductive losses and support voltage levels. The source of this circuit is a 69/12.5kV, 10.5 MVA FA (7.5 MVA OA) substation transformer which is located 1½ miles from the extrusion facility.

By placing monitoring equipment at both the substation and the extrusion facility, we gained voltage and current information concerning harmonic content. Line personnel also were involved in staging the distribution capacitors on and off to determine the possibility of a resonant condition on the 12.5kV circuit.

Table 1 summarizes the findings of this study.

Table 1 - Study Findings

Capacitive Reactance On-Line, kVAr	Current Arms	Voltage THD avg.	Current THD avg.	True P.F.	Transformer Load kVA	Xfmr Derating*
0	230	3.6%	7.4%	75.0%	5000	98.7%
1200	193	5.3%	16.2%	88.0%	4200	96.6%
2100	167	6.5%	27.0%	96.0%	3600	92.9%
3000	180	10.2%	54.0%	90.0%	4000	80.1%

*Derating found by measuring instrument that uses methodology outlined in ANSI/IEEE C57.100-1986; Assumed Eddy-Current Loss Factor (Pec-r) = 8%.

Clearly, a resonant condition was appearing. Normally, when distribution capacitors are switched on a line, the following conditions are expected:

- RMS Current should decrease
- Voltage and Current distortion levels should not change drastically
- True Power Factor should approach unity
- Substation transformer loading should decrease

In Table 1, for stepped on-line capacitive reactance values from 0 kVAr to 2100 kVAr, voltage and current distortion levels increased gradually with increases in kVAR. Also, RMS current, true power factor, and substation transformer loading reacted as expected. When the total on-line capacitive reactance was increased from 2100 kVAr to 3000 kVAr, we experienced a drastic increase in current and voltage distortion. Also, RMS current, true power factor, and substation transformer loading levels reacted opposite of what normally would be expected. All these indications pointed toward a harmonic resonant condition resulting from the combination of load current harmonics and power factor correction capacitors.

To establish a greater understanding of the measurements being experienced, a SuperHarm computer model of the transformer, circuit, and load was constructed using field and line information. We developed a single phase model for this application for simplicity and because the actual circuit is relatively balanced with respect to load.

By modeling this circuit with SuperHarm, a resonant condition was confirmed at the 5th harmonic. This was also the offending harmonic monitored inside the extrusion facility and generated by the plant's ASDs. The SuperHarm model was verified through comparison with actual information gained from the monitoring equipment in the field. This computer model next was used to determine the effectiveness of tuned filter capacitor banks located on the 480v bus inside the extrusion facility. With all of the 480v filtered capacitors modeled on-line and 3000 kVAr of 12.5kV distribution capacitors modeled on-line (5th harmonic resonance condition), the %V THD was reduced from 10.2% to 1.1% and %I THD was reduced from 54% to 6.3%.

The plastics extrusion facility currently has obtained bids for 4.7th harmonic filtered capacitors to reduce harmonic injection to the distribution system and to increase their power factor. The vendor has specified "auto-stepping" filtered 480V capacitor banks at each of the customer's three transformers (2-1500 kVA, 1-2000 kVA). These proposed units will be 300 kVAr, 550 kVAr, and 800 kVAr. Unit specifications were placed in the SuperHarm model to determine their effect on the 12.5kV distribution system. Increased voltage and current stresses on the 480V capacitors due to harmonic injection also were calculated.

Table 2 summarizes these computations based upon 3000 kVAr of 12.5kV capacitors on-line.

Table 2

Location	%V RMS (480V base)	%I RMS	%V THD	%I THD
300 kVAr 480V unit	110%	120%	9.3%	45.0%
550 kVAr 480V unit	111%	115%	6.5%	29.8%
800 kVAr 480V unit	111%	111%	5.2%	21.5%
12.5kV customer meter			1.7%	12.3%
12.5kV substation bus			1.1%	6.3%

The capacitors specified for this 480V application are rated at 600V. This 600V rating will allow the capacitors to handle the additional voltages and currents produced by harmonic injection without exceeding their ratings.

A frequency scan was obtained using the Super-Harm simulation. With all 480V secondary filters on-line, a new resonant point extremely close to the 3rd harmonic will exist. From measurements found by the monitoring equipment placed at the 69/12.5kV substation, approximately 4A of 3rd harmonic current is presently being injected into our distribution system (without any harmonic filtering). Although this does not seem a vital concern now, future development of 3rd harmonic producing equipment (personal computers & other electronic load) could change the voltage THD profile significantly.

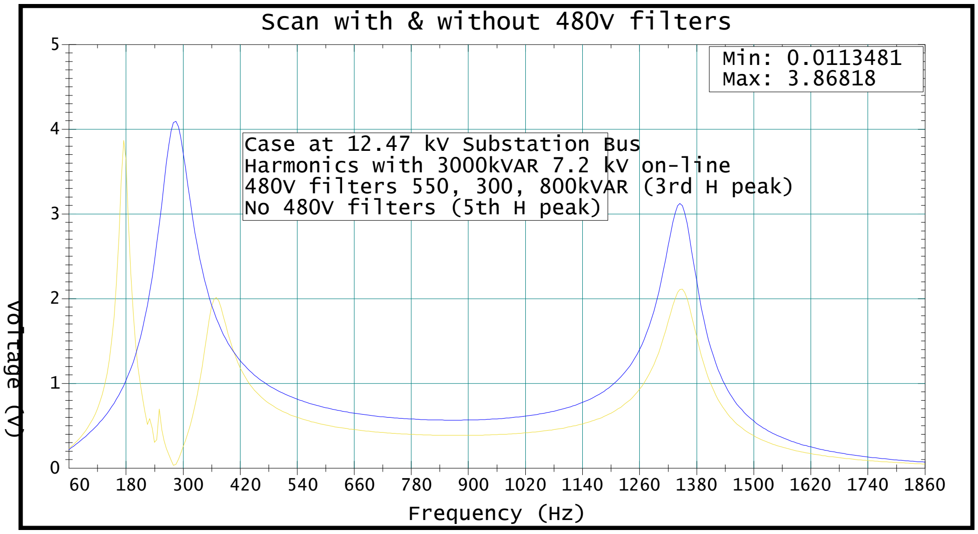


Figure 1 - Impact of 480 Volt Capacitors on Frequency Response

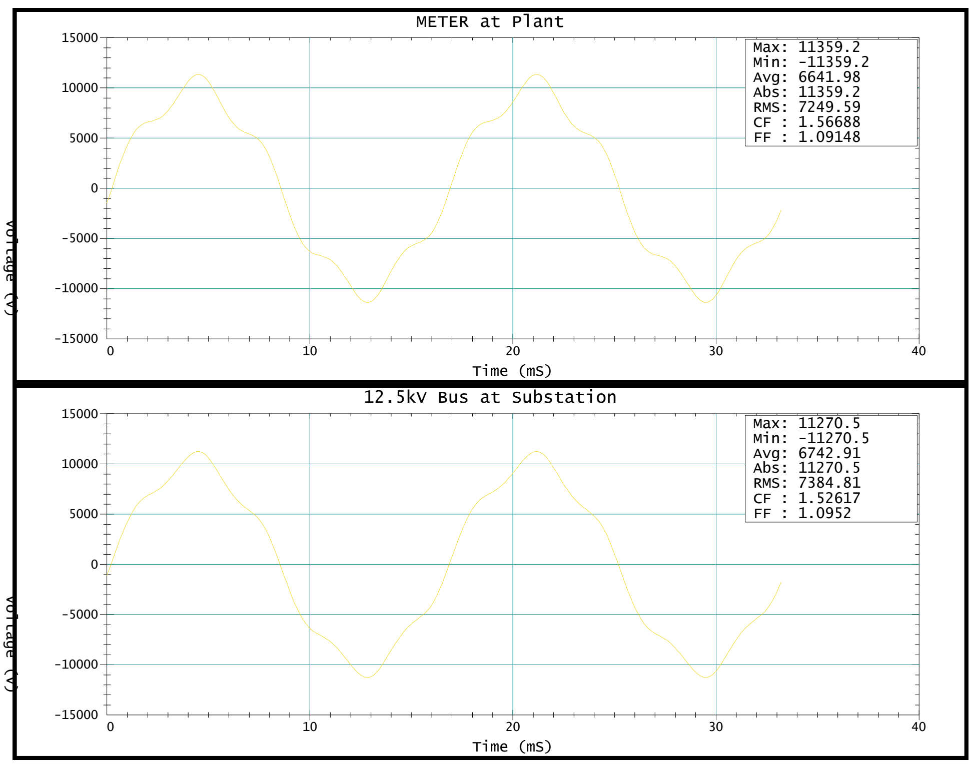


Figure 2(a) - Voltage at Meter and 12.5kV Substation Bus without Filters

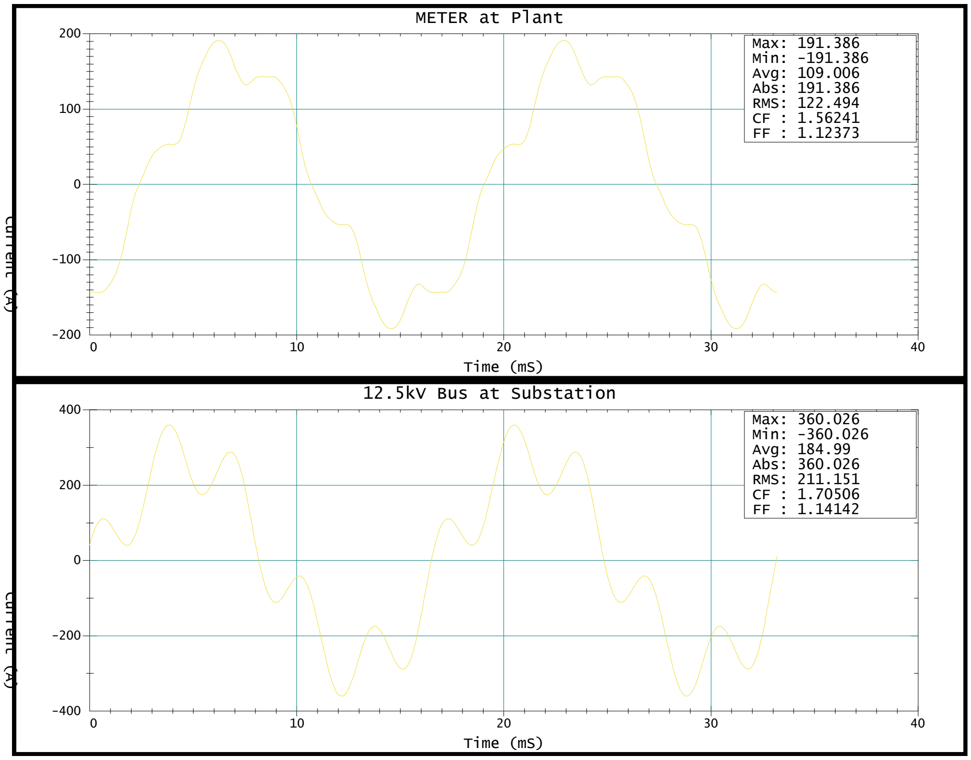


Figure 2(b) - Current at Meter and 12.5kV Substation Bus without Filters

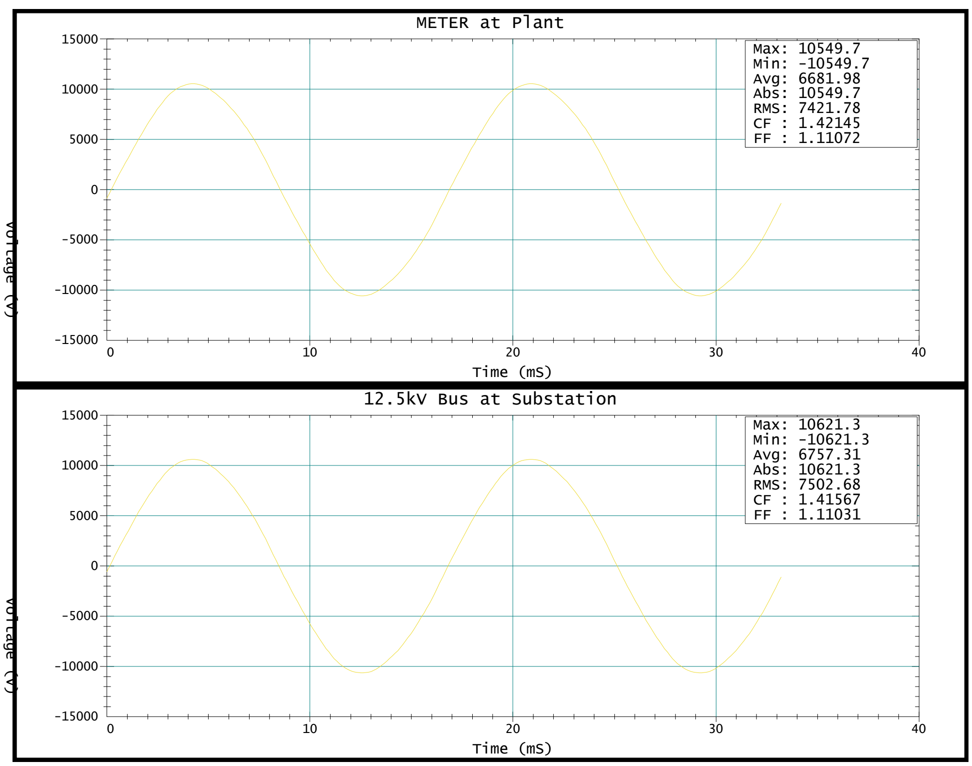


Figure 3(a) - Voltage at Meter and 12.5kV Substation Bus with Filters

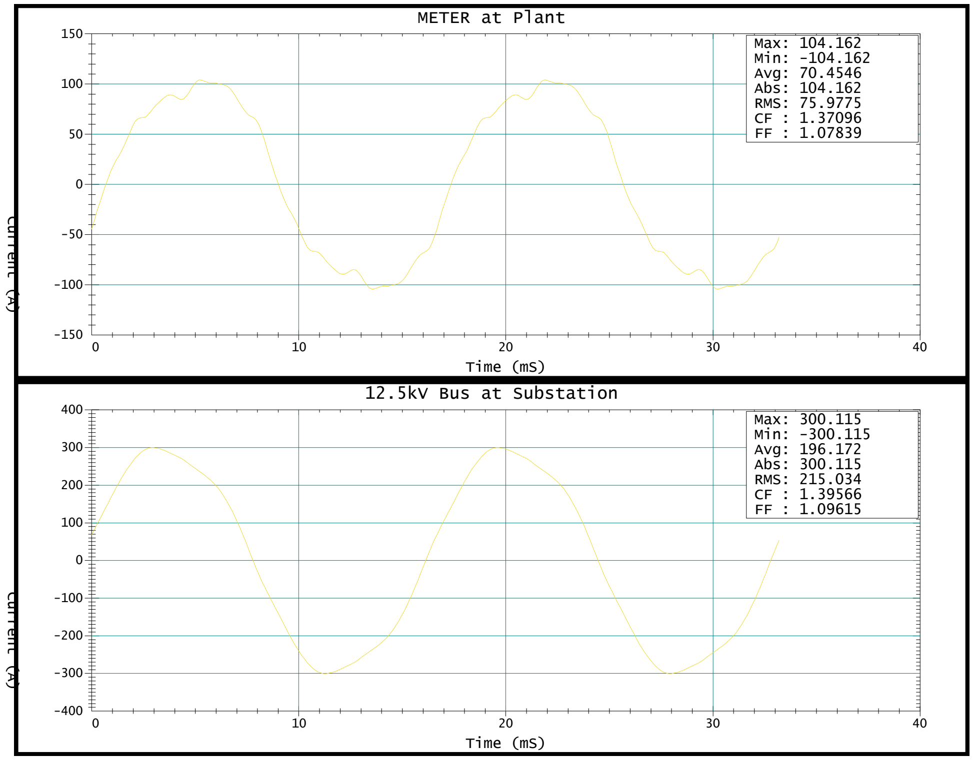


Figure 3(b) - Current at Meter and 12.5kV Substation Bus with Filters

Field measurements will be taken after the 480V filtered capacitor units are installed to verify the accuracy of the SuperHarm model. SuperHarm has been implemented in this study to make use of the actual information gathered in the field. Different scenarios were incorporated into the simulation to obtain anticipated distribution system response. SuperHarm was fast, reliable, and easy to use during input/output of data.

Phill Zimmers, Senior Engineer &
Carl Miller, Power Quality Engineer
Western Resources, Inc.

Case Study - Pumping Station

Application of Harmonic Limits at a Wastewater Treatment Plant Pumping Station

Introduction

Several architectural and engineering firms are starting to add harmonic current injection requirements into their construction specifications. Some companies are requiring contractors to meet IEEE 519 guidelines during normal operation and backup generator operation (a misapplication of the standard), and at the strictest levels ($I_{SC}/I_L < 20$). Firms specializing in the construction of wastewater treatment plant pumping stations are particularly adamant about their future stations meeting IEEE 519 guidelines. Also, since the construction firms are requiring that the stations meet IEEE 519 guidelines before the station is even built, many assumptions have to be made including the average demand load current and harmonic distortion of the ASDs.

One such case occurred in Arizona, where a small community was building a wastewater treatment plant with three pumping stations located in various parts of the city. Each pumping station will use four 125 Hp PWM ASDs to control the pumps. As stated above, each pumping station must meet the new IEEE 519 harmonic current limits during both normal and backup generator operation. Since the pumping stations are identical, the results of the simulations and measurements at only one of the stations will be detailed. The SuperHarm computer program was used to model the pumping stations.

Assumptions

Since the study was to be completed before the plant was even built, many assumptions had to be made. The assumptions were based on previous studies performed and with conversations with the vendors of the equipment that was being installed.

1. Drives run in pairs and at the same speed

2. Drives are fed through isolation transformers and each pair are connected wye-wye and wye-delta

   - Therefore, 5th and 7th harmonic components will cancel
   - For study purposes, it was assumed that 10% of the 5th and 7th harmonic components do not cancel

3. Two operating conditions were analyzed

   - 2 drives running at same speed was the base case
   - 4 drives running at same speed to determine worst case harmonic levels

4. Maximum average demand current based on IEEE 519 is assumed to be 250 kVA (300 Amps at 480 Volts)

5. ASD harmonic levels provided by the manufacturer

Adjustable Speed Drive Characteristics

Pumping stations are normally dominated by pulse-width modulation (PWM) drives. The harmonic currents associated with PWM adjustable speed drives (ASDs) can be very distorted making computer analysis of the stations necessary. In addition, the displacement power factor of PWM drives is near unity, further complicating matters if harmonic filters are needed to meet IEEE 519 limits. Figure 1 is a waveform and harmonic spectrum of the drive current as supplied by the manufacturer that was used in the simulations. The total harmonic distortion specified was 48%.

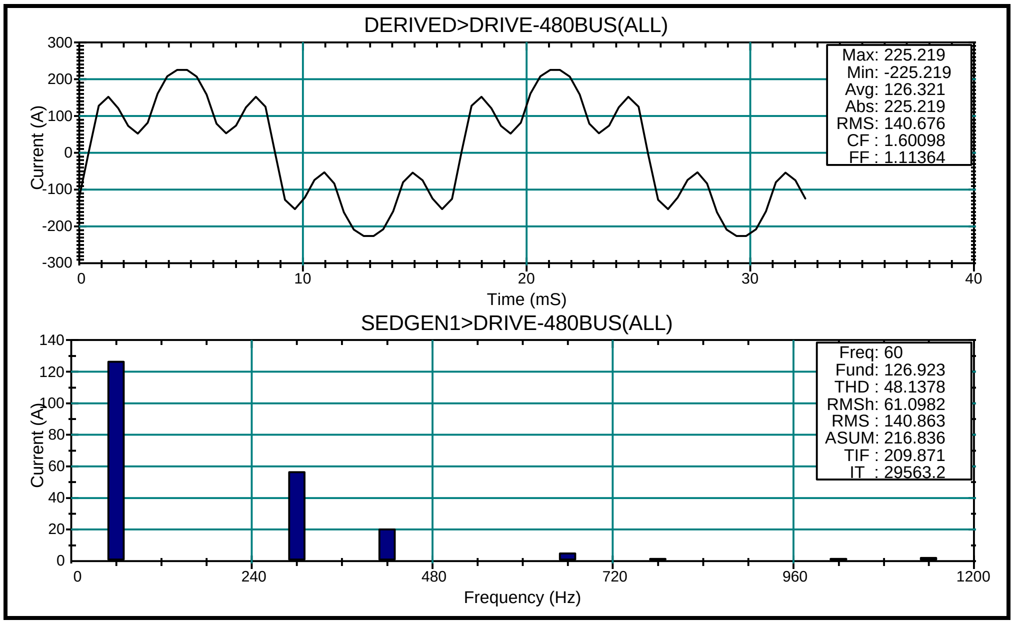


Figure 1 - Adjustable Speed Drive Current and Harmonic Spectrum

Harmonic Limits

The harmonic limits used for this evaluation were based on the latest revision of IEEE 519. The standard gives recommended harmonic current limits for individual customers and recommended voltage distortion limits for the overall power system. The current limits are shown in Table 1.

Table 1 - Maximum Harmonic Current Distortion in % of I_L
1

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

The limits are a function of three parameters:

- the size of the load
- the short circuit strength at the point of common coupling (PCC)
- the harmonic frequencies

The limits are expressed as a percent of the "average maximum demand current" which is calculated as the average of twelve successive monthly maximum demand currents. This current was assumed to be 300 Amps at 480 Volts for this study. The actual limits depend on the ratio between the system short circuit current and this average maximum demand current (I_{SC}/I_L). For larger values of this short circuit ratio (small loads with respect to system strength), higher levels of harmonic current injection on to the power system are allowed.

The limits also decrease as the harmonic frequency increases. This accounts for increased transformer losses and increased communication interference problems at higher frequencies. Note that the individual harmonic component limits and the total demand distortion (TDD) limit must all be met.

The more important case for this study occurs for the case when the backup generator is operating. The specifications for the overall installation state that the tightest limits ($I_{SC}/I_L < 20$) must be met for this operating condition.

IEEE 519 also includes recommended voltage distortion limits (Table 2) for the overall power system. These are meant as guidelines for customer facilities and limits for the utility interface. These limits are evaluated at each pumping station.

Table 2 - IEEE 519 Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0

Backup Generator Operation Simulations

Figure 2 is a one-line diagram of the pumping station in question. This is the worst case harmonic scenario since it is a weaker source than the utility grid. However, no harmonic currents will be injected back on to the utility system. The question becomes, where is the point of common coupling? IEEE 519 defines the point of common coupling (PCC) as "any point as long as both the utility and the consumer can either access the point for direct measurement of the harmonic indices meaningful to both or can estimate the harmonic indices at point of interference through mutually agreeable methods." It was felt that IEEE 519 harmonic current injection limits should not be applied since this is an emergency case and the customer is isolated from the utility system.

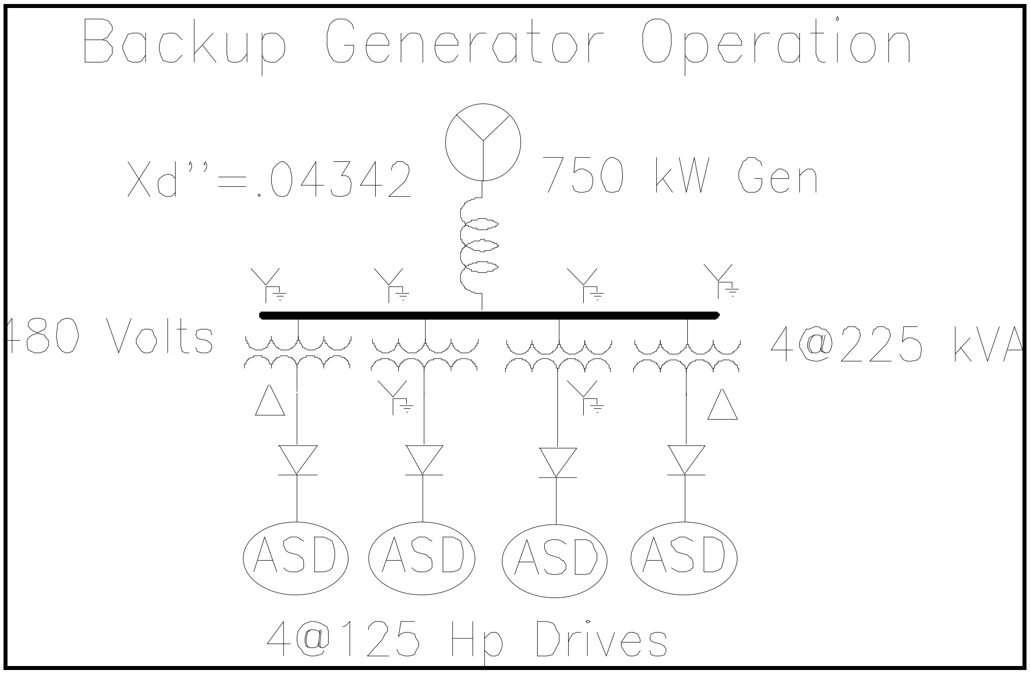


Figure 2 - Backup Generator One-Line

The standard also does not require that the limits be met for absolutely all conditions. It recognizes that higher harmonic levels may exist during contingency conditions. The customer stated that they were requiring IEEE 519 to be met during this condition in order to protect the generator. It was again felt that this was a misapplication of the standard and that limits supplied by the generator manufacturer should be used instead. However, the customer insisted that IEEE 519 limits be used anyway.

The cases were run in SuperHarm, and the calculated harmonic current values were inputted into an EXCEL spreadsheet that determined if IEEE 519 injection limits were violated. Table 3 shows the results of the first case which was 2 drives running at full speed. The IEEE limits shown in the table are for an $I_{SC}/I_L < 20$, as specified by the customer. The 5th harmonic component still exceeds the limit even with cancellation assumed. The 11th, 19th, and TDD exceed also. The case with 4 drives running will clearly be worse.

Table 3 - Two Drives Running, Backup Generator Operation

Harmonic Number	Frequency (Hz)	Load Curr (Amps)	IEEE Limit %	Current (% Demand)	Exceeds Limit
1	60	N/A	N/A	N/A	N/A
5	300	12.05	4.0	4.0	Exceeds
7	420	4.14	4.0	1.4	OK
11	660	10.74	2.0	3.6	Exceeds
13	780	4.02	2.0	1.3	OK
17	1020	3.71	1.5	1.2	OK
19	1140	5.48	1.5	1.8	Exceeds
TDD:	>>>>>>>>>>>>>>>>>>>>>>		5.0	6.1	Exceeds

Harmonic Filter Design

To bring the pumping station within IEEE 519 limits, a harmonic reduction scheme utilizing two harmonic filters was designed. Even with the 5th and 7th harmonic cancellation assumed, the 5th harmonic current distortion level is exceeded. Therefore, a 5th harmonic filter was designed. This filter was designed for the worst possible case harmonic loading. It was sized to handle the emergency condition of one drive running, and in case not all 5th and 7th harmonic currents were canceled. The 5th harmonic filter also reduces the overall system impedance at higher frequencies but the harmonic control is not sufficient to handle the 11th and 13th harmonic components when two drives are running (these two components add). Therefore, an 11th harmonic filter was also designed. The 11th was designed to filter out higher frequency components. A 7th harmonic filter was not designed because it will aggravate leading power factor situation and complicate the overall filter design, making filter tolerances extremely crucial. The limits were evaluated for nominal filter component values and with expected tolerances. The filters must be tuned very close to the desired frequency in order to work effectively. With a capacitor tolerance of 0 to +10% and a reactor tolerance of +/- 5%, the filter performance could be easily unacceptable. Figure 3 is a frequency scan at the pumping station.

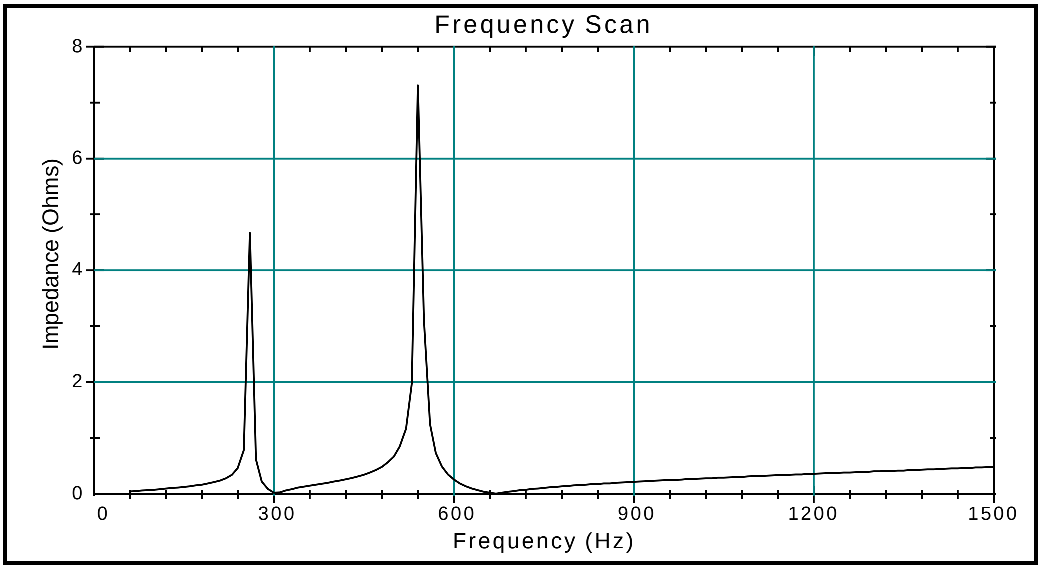
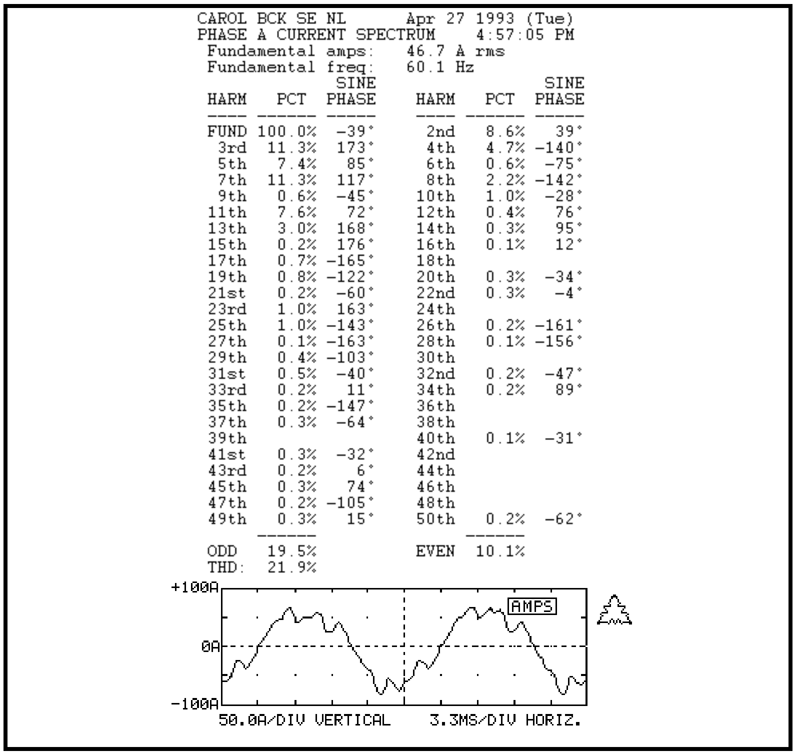


Figure 3 - Frequency Scan

Measurement Results

After the stations were built, harmonic measurements were taken. The measurements showed that the assumptions were a bit on the conservative side. Almost all 5th and 7th harmonic current components canceled resulting in extremely low current distortion. IEEE 519 limits were met during normal and backup generator operation with 2 drives running even without the filters in. However, with 4 drives running the filters were needed.

Figure 4 and Table 4 show the results with 2 drives running at 30 Hz during backup generator operation with no filters in. The table shows that no limits were exceeded. The total harmonic current distortion was about 22%, and the voltage distortion was well below 5%.


CAROL BCK SE NL Apr 27 1993 (Tue)
PHASE A CURRENT SPECTRUM 4:57:05 PM
Fundamental amps: 46.7 A rms
Fundamental freq: 60.1 Hz

HARM	PCT	SINE PHASE	HARM	PCT	SINE PHASE
FUND	100.0%	-39°	2nd	8.6%	39°
3rd	11.3%	173°	4th	4.7%	-140°
5th	7.4%	85°	6th	0.6%	-75°
7th	11.3%	117°	8th	2.2%	-142°
9th	0.6%	-45°	10th	1.0%	-28°
11th	7.6%	72°	12th	0.4%	76°
13th	3.0%	168°	14th	0.3%	95°
15th	0.2%	176°	16th	0.1%	12°
17th	0.7%	-165°	18th		
19th	0.8%	-122°	20th	0.3%	-34°
21st	0.2%	-60°	22nd	0.3%	-4°
23rd	1.0%	163°	24th		
25th	1.0%	-143°	26th	0.2%	-161°
27th	0.1%	-163°	28th	0.1%	-156°
29th	0.4%	-103°	30th		
31st	0.5%	-40°	32nd	0.2%	-47°
33rd	0.2%	11°	34th	0.2%	89°
35th	0.2%	-147°	36th		
37th	0.3%	-64°	38th		
39th			40th	0.1%	-31°
41st	0.3%	-32°	42nd		
43rd	0.2%	6°	44th		
45th	0.3%	74°	46th		
47th	0.2%	-105°	48th		
49th	0.3%	15°	50th	0.2%	-62°
ODD	19.5%		EVEN	10.1%	
THD:	21.9%				

Figure 4 - Two Drives Running at 30 Hz, No Filters

Table 4 - Two Drives Running at 30 Hz, No Filters

Harmonic Number	Frequency (Hz)	Load Curr (Amps)	IEEE Limit %	Current (% Demand)	Exceeds Limit
1	60	N/A	N/A	N/A	N/A
3	180	5.3	4.0	1.8	OK
5	300	3.5	4.0	1.1	OK
7	420	5.3	4.0	1.8	OK
9	540	0.3	4.0	0.1	OK
11	660	3.5	2.0	1.2	OK
13	780	1.4	2.0	0.5	OK
17	1020	0.3	1.5	0.1	OK
19	1140	0.4	1.5	0.1	OK
21	1260	0.1	1.5	0.0	OK
23	1380	0.5	0.6	0.2	OK
25	1500	0.5	0.6	0.2	OK
29	1740	0.2	0.6	0.1	OK
TDD:	>>>>>>>>>>>>>>>>>>>>>>		5.0	3.0	OK

Figure 5 and Table 5 show the results with 4 drives running at 60 Hz during backup generator operation with no filters in. This was the only operating condition when IEEE 519 limits were exceeded. The table shows that the 5th and 7th harmonic cancellation was still sufficient to keep those components well within limits. However, the 11th and 13th harmonic components exceeded IEEE 519 limits.

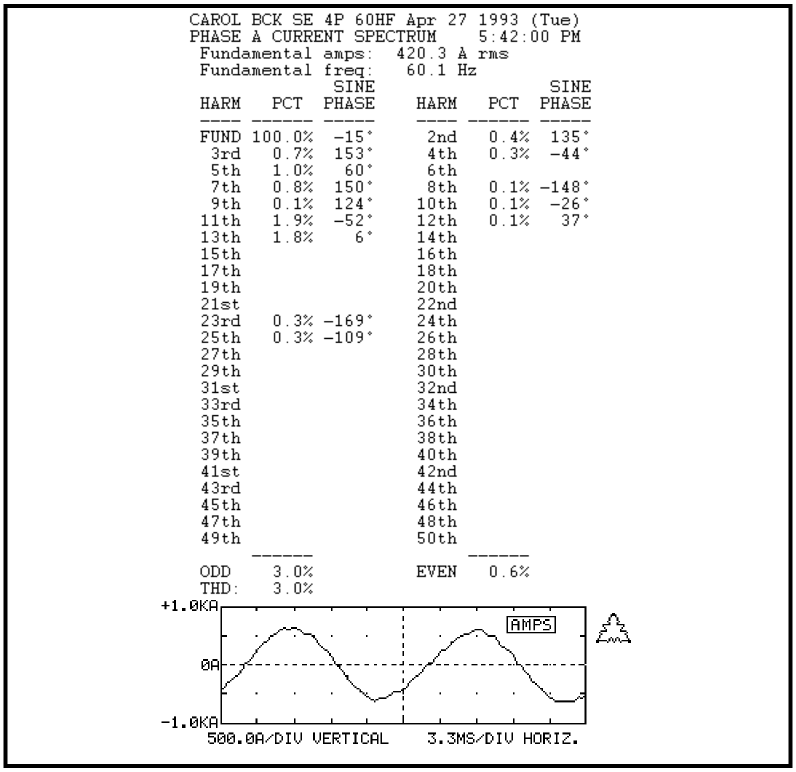


Figure 5 - Four Drives Running at 60 Hz, No Filters

Table 5 - Four Drives Running at 60 Hz, No Filters

Harmonic Number	Frequency (Hz)	Load Curr (Amps)	IEEE Limit %	Current (% Demand)	Exceeds Limit
1	60	N/A	N/A	N/A	N/A
3	180	2.9	4.0	1.0	OK
5	300	4.2	4.0	1.4	OK
7	420	3.4	4.0	1.1	OK
9	540	0.4	4.0	0.1	OK
11	660	8.0	2.0	2.7	Exceeds
13	780	7.6	2.0	2.5	Exceeds
17	1020		1.5		OK
19	1140		1.5		OK
21	1260		1.5		OK
23	1380	1.3	0.6	0.4	OK
25	1500	1.3	0.6	0.4	OK
29	1740		0.6		OK
TDD:	>>>>>>>>>>>>>>>>>>>>>>		5.0	4.2	OK

The filters were then switched in and another snapshot (Figure 6) was taken. Table 6 shows the IEEE 519 evaluation. All limits were easily met during this operating condition.

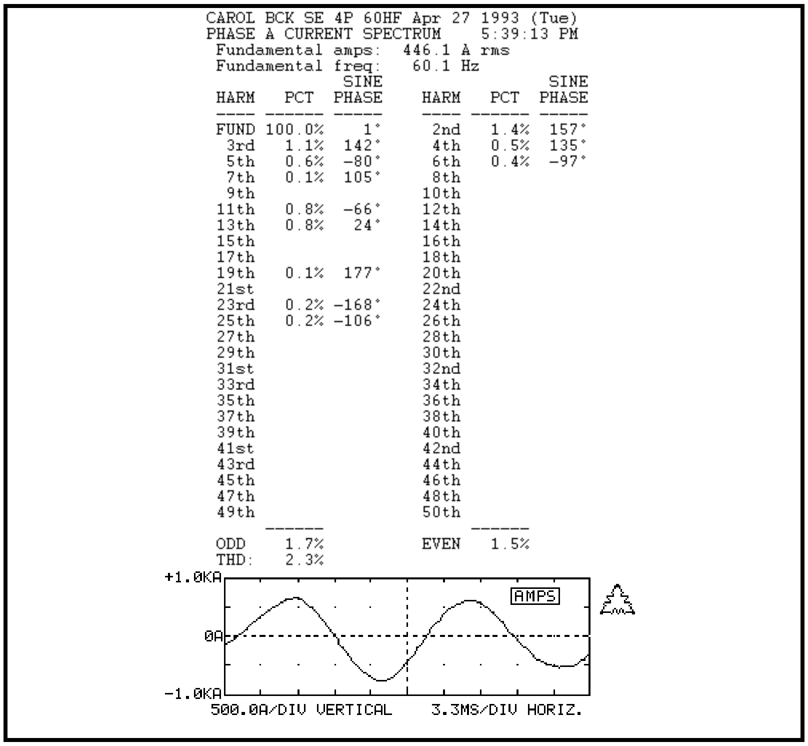


Figure 6 - Four Drives Running at 60 Hz, Filters In

Table 6 - Four Drives Running at 60 Hz, Filters In

Harmonic Number	Frequency (Hz)	Load Curr (Amps)	IEEE Limit %	Current (% Demand)	Exceeds Limit
1	60	N/A	N/A	N/A	N/A
3	180	4.9	4.0	1.6	OK
5	300	2.7	4.0	0.9	OK
7	420	0.4	4.0	0.1	OK
9	540		4.0		OK
11	660	3.6	2.0	1.2	OK
13	780	3.6	2.0	1.2	OK
17	1020		1.5		OK
19	1140	0.4	1.5	0.1	OK
21	1260		1.5		OK
23	1380	0.9	0.6	0.3	OK
25	1500	0.9	0.6	0.3	OK
29	1740		0.6		OK
TDD:	>>>>>>>>>>>>>>>>>>>>>>		5.0	2.5	OK

Summary and Conclusions

It was felt that IEEE 519 was misapplied in the case of backup generator operation. Generator manufacturer limits should have been used instead. Many assumptions are required to perform this type of analysis, especially when the plant had not even been built yet. However, the assumptions turned out to be on the conservative side which should be the case. Harmonic cancellation was greater than assumed, enabling the pumping station to meet IEEE 519 current injection limits for all normal operating conditions even without filtering. Voltage distortion limits were acceptable for all cases. The only case where filters were necessary was during backup generator operation with 4 drives running.

Jeff Lamoree
Supervisor, Power Quality Studies
Electrotek Concepts, Inc.

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HarmFlo+ Worksheet Support

Overview

The HarmFlo+ Worksheet is a collection of EXCEL spreadsheets that assist in the analysis of the impact of power system harmonics. The worksheet is based on an EXCEL Workbook file (HFPLUS.XLW). Figure 1 illustrates the method for using the Workbook file.

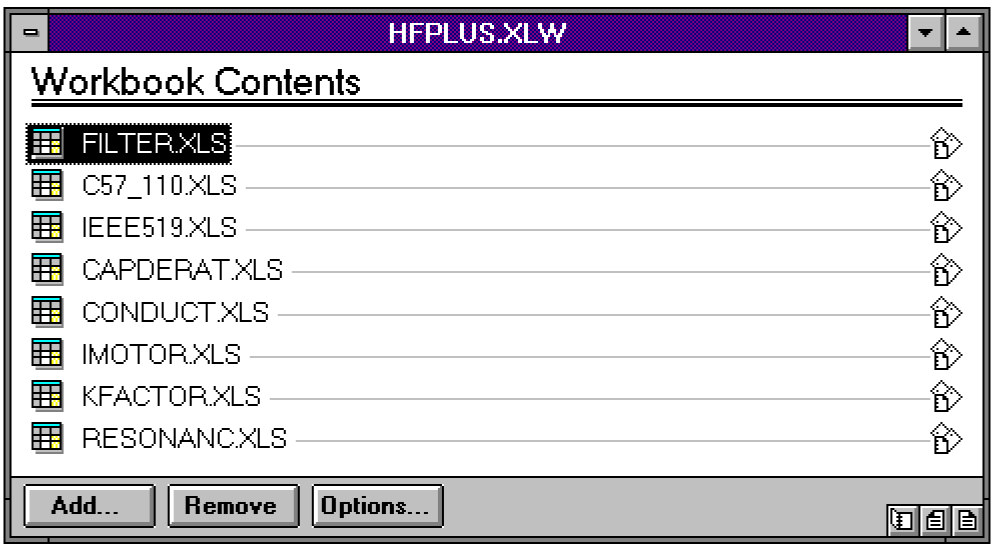


Figure 1 - EXCEL HarmFlo+ Workbook (HFPLUS.XLW)

The user should start EXCEL and then load the HFPLUS.XLW Workbook file. This can also be accomplished by adding the XLW file as an icon in you Simulation Tools group. Each individual spreadsheet is accessed by double-clicking on the appropriate file-name or icon. The Workbook and associated files may be downloaded from the HarmFlo User's Group bulletin board (615-675-1506). User's Group members without access to a modem can contact me for distribution.

Workbook Files:

The following files are included in the workbook:

HFPLUS.XLW	Excel Workbook file
FILTER.XLS	Filter design spreadsheet
C57_110.XLS	IEEE transformer derating spreadsheet
IEEE519.XLS	IEEE 519 application spreadsheet
CAPDERAT.XLS	IEEE Std. 18 capacitor limits
CONDUCT.XLS	Conductor derating
IMOTOR.XLS	Induction motor derating
KFACTOR.XLS	K-Factor calculation and xfmr derating
RESONANC.XLS	Simple harmonic resonance calculation
HF_XLS.ZIP	All of the above files - zipped using PKZIP

Harmonic Filter Design:

FILTER.XLS

Low Voltage Filter Calculations: **Example Filter Design Spreadsheet**

SYSTEM INFORMATION:

Filter Specification:	5	th	Power System Frequency:	60	Hz
Capacitor Bank Rating:	500	kVAr	Capacitor Rating:	600	Volts
Rated Bank Current:	481	Amps		60	Hz
Nominal Bus Voltage:	480	Volts	Derated Capacitor:	320	kVAr
Capacitor Current (actual):	384.9	Amps	Total Harmonic Load:	1000	kVA
Filter Tuning Harmonic:	4.7	th	Filter Tuning Frequency:	282	Hz
Cap Impedance (wye equivalent):	0.7200	W	Cap Value (wye equivalent):	3684.1	uF
Reactor Impedance:	0.0326	W	Reactor Rating:	0.0865	mH
Filter Full Load Current (actual):	403.2	Amps	Supplied Compensation:	335	kVAr
Filter Full Load Current (rated):	503.9	Amps			
Transformer Nameplate:	2000	kVA	Utility Side Vh:	2.00	% THD
(Rating and Impedance)	6.00	%	*(Utility Harmonic Voltage Source)*		
Load Harmonic Current:	35.00	% Fund	Load Harmonic Current:	421.0	Amps
Utility Harmonic Current:	103.7	Amps	Max Total Harm. Current:	524.6	Amps

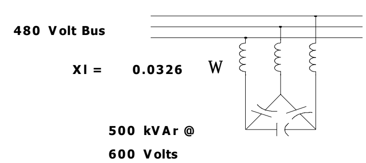
CAPACITOR DUTY CALCULATIONS:

Filter RMS Current:	661.7	Amps	Fundamental Cap Voltage:	502.8	Volts
Harmonic Cap Voltage:	130.9	Volts	Maximum Peak Voltage:	633.6	Volts
RMS Capacitor Voltage:	519.5	Volts	Maximum Peak Current:	927.8	Amps

CAPACITOR LIMITS: (IEEE Std 18-1980)

	Limit		Actual
Peak Voltage:	120%	⟵⟶	106%
Current:	180%	⟵⟶	138%
KVAr:	135%	⟵⟶	119%
RMS Voltage:	110%	⟵⟶	87%

FILTER CONFIGURATION:



FILTER REACTOR DESIGN SPECIFICATIONS:

Reactor Impedance:	0.0326	W	Reactor Rating:	0.0865	mH
Fundamental Current:	403.2	Amps	Harmonic Current:	524.6	Amps

Figure 2 - EXCEL Filter Design Spreadsheet

Transformer Derating:

C57_110.XLS

IEEE Recommended Practice for Establishing Transformer Capability
When Supplying Nonsinusoidal Load Currents

ANSI/IEEE C57.110-1986

Transformer Data:

Number of Phases (1 or 3):	**3**	**Phase(s)**
System Frequency:	**60**	**Hz**
High-Voltage (Outer) Winding:		
Line-to-Line Voltage:	**10,000**	**Volts**
Winding Resistance (see note 2):	**0.848**	**W**
Low-Voltage (Inner) Winding:		
Line-to-Line Voltage:	**480**	**Volts**
Winding Resistance (see note 2):	**0.001**	**W**
Rated Capacity:	**1,000**	**KVA**
Full Load Losses:	**31,232**	**Watts**

HV Current Rating:	**58**	**Amps**
LV Current Rating :	**1,203**	**Amps**
Turns Ratio:	**20.83**	**/ 1**
Rated Eddy-Current Loss (Wndgs):	**25,011**	**Watts**
Inner Winding Eddy-Loss Factor:	**70**	**%**
Max Winding Eddy-Current Loss:	**35.33**	**pu**

note (2) Enter above the dc resistance between two of the terminals.
(Optional):
To calculate the resistance between two terminals from a measurement with three phases connected in series, fill in one box for each winding:

HV Side :		Delta	series resistance:	3.815	Ohms x 2/9=	0.848	W
	or	Wye	series resistance:		Ohms x 2/3=		W
LV Side :		Delta	series resistance:	0.004	Ohms x 2/9=	0.001	W
	or	Wye	series resistance:		Ohms x 2/3=		W

Harmonic Distribution of Transformer Load Current:

Harmonic	Current	Freq (Hz)	Current (pu)	I^2	I^2 * h^2
1	1.000	0	1.000	1.000	1.000
3	0.003	0	0.003	0.000	0.000
5	0.020	0	0.020	0.000	0.010
7	0.009	0	0.009	0.000	0.004
11	0.004	0	0.004	0.000	0.002
13	0.002	0	0.002	0.000	0.000
17	0.002	0	0.002	0.000	0.001
19	0.001	0	0.001	0.000	0.000
21	0.000	0	0.000	0.000	0.000
23	0.001	0	0.001	0.000	0.001
25	0.001	0	0.001	0.000	0.000
			Totals:	1.001	1.019

Transformer Derating Factor:	**0.991**	**pu**
Harmonic Load Current Limit:	**1,192**	**Amps rms**

Figure 3 - EXCEL Transformer Derating Spreadsheet

IEEE 519 Application:

IEEE519.XLS

IEEE 519 Current Distortion Limits: ***Example***

Red Fonts:	Data to be entered by user
Blue Fonts:	Data calculated by spreadsheet
Purple Fonts:	Table 10.2 lookup by spreadsheet

Load Voltage Bus Voltage:	**480**	**Volts**			
High Voltage Bus Voltage:	**13800**	**Volts**			
Short Circuit at Load Voltage Bus:	**25.0**	**MVA**	>>>>>>>	**30070**	**Amps**
Short Circuit at High Voltage Bus:	**200.0**	**MVA**	>>>>>>>	**8367**	**Amps**
Avg. Maximum Demand Load:	**800**	**kVA**	>>>>>>>	**962**	**Amps**
Isc/IL Ratio (load voltage bus):	***31***				
Isc/IL Ratio (high voltage bus):	***250***				

IEEE 519 Current Distortion Limits: ***Example***

PCC: Transformer Low Side

Harmonic Number	Frequency (Hz)	Load Curr (Amps)	IEEE Limit %	Current (% Demand)	Exceeds Limit
1	60	N/A	N/A	N/A	N/A
5	300	25.214	4.0	2.6	OK
7	420	29.901	4.0	3.1	OK
11	660	14.583	2.0	1.5	OK
13	780	8.620	2.0	0.9	OK
17	1020	7.241	1.5	0.8	OK
19	1140	4.409	1.5	0.5	OK
TDD:	>>>>>>>>>>>>>	>>>>>>>>>>>>	5.0	4.5	OK

Isc/IL Ratio (low voltage bus): 31

Figure 4 - EXCEL IEEE 519 Spreadsheet

IEEE Std. 18 Capacitor Derating:

CAPDERAT.XLS

Recommended Practice for Establishing Capacitor Capabilities
When Supplied by Nonsinusoidal Voltages **IEEE Std 18-1980**

Capacitor Bank Data:

Bank Rating:	225	kVAr
Voltage Rating:	400	V (L-L)
Operating Voltage:	400	V (L-L)
Supplied Compensation:	225	kVAr
Fundamental Current Rating:	325	Amps
Fundamental Frequency:	50	Hz
Capacitive Reactance:	0.711	W

Harmonic Distribution of Capacitor Voltage:

Harmonic Number	Frequency (Hertz)	Volt Mag - Vh (% of Fund.)	Volt Mag - Vh (Volts)	Cap. Current (% of Fund.)
1	50	100.00	400.0	57.74
3	150	0.00	0.0	0.00
5	250	3.68	14.7	10.62
7	350	1.79	7.2	7.23
11	550	7.78	31.1	49.41
13	650	1.09	4.4	8.18
17	850	0.68	2.7	6.67
19	950	0.16	0.6	1.76
21	1050	0.00	0.0	0.00
23	1150	0.00	0.0	0.00
25	1250	0.00	0.0	0.00

Voltage Distortion (THD):	8.89	%
RMS Capacitor Voltage:	401.58	Volts
Capacitor Current Distortion:	90.35	%
RMS Capacitor Current:	437.68	Amps

Capacitor Bank Limits:

	Calculated	Limit	Exceeds Limit
Peak Voltage:	115.2%	120%	No
RMS Voltage:	100.4%	110%	No
RMS Current:	134.8%	180%	No
kVAr:	135.3%	135%	Yes

Figure 5 - EXCEL Capacitor Derating Spreadsheet

Conductor Derating:

CONDUCT.XLS

Evaluation of Conductor Rating in Non-Sinusoidal Environments

(methodology by David Rive of GE in paper "Adjustable-Speed Drives and Power Rectifier Harmonics - Their Effect on Power System Components" - IEEE paper # PCIC-84-52)

Conductor data:

Type: Cu

Size: 250 MCM

Ampacity: 325.0 Amps

Fundamental conductor current: 100.0 Amps

Magnetic permeability (mu): 1.00 (equal to one for non-magnetic materials)

DC resistance at operating temp: 0.0308 Ohms/1000Ft

Conductor diameter: 0.60 (any units)

Axial spacing between conductors: 0.95 (same units as diameter)

System Frequency: 60 Hz

K ==> 0.632 (conductor diameter / axial spacing)

Harmonic Currents and Conductor Calculations:

x = 0.027678 * [(f *mu)/Rdc]^1/2 Ycs' = f(x) Ycp = f(x)*k^2*[1.18/f(x)+0.27)+0.312*k^2] Rac/Rdc = 1+Ycs+Ycp

Harmonic Number	Frequency (Hz)	Current (Amps)	I pu	I pu ^2	x	Ycs'	Ycs	Ycp	Rac/Rdc	Rh*(I pu)^2
1	60	100.00	1.000	1.00E+00	1.22	0.012	0.012	0.020	1.031	1.03149
3	180				2.12	0.097	0.097	0.129	1.225	
5	300	33.60	0.336	1.13E-01	2.73	0.237	0.237	0.232	1.469	0.16586
7	420	1.60	0.016	2.56E-04	3.23	0.399	0.399	0.300	1.699	0.00044
9	540	8.70	0.087	7.57E-03	3.66	0.553	0.553	0.344	1.897	0.01436
11	660	1.20	0.012	1.44E-04	4.05	0.697	0.697	0.374	2.071	0.00030
13	780	4.50	0.045	2.03E-03	4.40	0.827	0.827	0.396	2.223	0.00450
17	1020	1.30	0.013	1.69E-04	5.04	1.057	1.057	0.427	2.484	0.00042
19	1140				5.32	1.157	1.157	0.439	2.597	
23	1380	2.80	0.028	7.84E-04	5.86	1.344	1.344	0.459	2.803	0.00220
25	1500	1.20	0.012	1.44E-04	6.11	1.431	1.431	0.467	2.898	0.00042

Total Harmonic Distortion: 35.2118 % **Irms (amps):** 106.02

Harmonic Load Factor: 30.7692 % **Conductor Derating Capacity:** 0.905

Note: **f(x) determined from table of skin effect resistance for solid and concentric round conductors**

Figure 6 - EXCEL Conductor Derating Spreadsheet

Induction Motor Derating:

IMOTOR.XLS

Derating of Induction Motors Due to Harmonics

(methodology by Pankaj K. Sen, and Hector A. Landa in paper "Derating of Induction Motors Due to Waveform Distortion" - IEEE Trans. on Ind. App., Vol. 26, No. 6, Nov./Dec. 1990)

Motor Data:

Motor Rating:	**5**	Hp
Stator Resistance:	**0.055**	pu
Rotor Resistance:	**0.055**	pu
Stator Reactance:	**0.048**	pu
Rotor Reactance:	**0.072**	pu
Magnetizing Reactance:	**1.9**	pu
Slip:	**4.5**	%
Saturation Factor (Mf):	**1.27**	
System Frequency:	**50**	Hz

Harmonic Distribution of Supply Voltage:

Harmonic	Freq (Hz)	Voltage %	Current (pu)	I^2
1	50	**100.00**	1.0057	1.0115
2	100			
3	150			
4	200			
5	250	**3.30**	0.0542	0.0029
6	300			
7	350	**7.63**	0.0902	0.0081
8	400			
9	450			
10	500			
11	550	**0.50**	0.0038	0.0000
12	600			
13	650	**0.23**	0.0015	0.0000
17	850			
19	950			
	Totals:	8.33	1.1553	1.0226

Percent increase in temperature from harmonic	**2.26%**
currents and corresponding derating factor	**0.98**

Figure 7 - EXCEL Induction Motor Derating Spreadsheet

K-Factor and Transformer Derating:

KFACTOR.XLS

Site: **Example Plant**

CF Pump PVS-2 Isolation Xfmr

Harmonic Distribution of Transformer Load Current:

Harmonic	Current (%)	Freq (Hz)	Current (pu)	I^2	I^2 * h^2
1	100.000	60	1.000	1.000	1.000
3	1.600	180	0.016	0.000	0.002
5	26.100	300	0.261	0.068	1.703
7	5.000	420	0.050	0.003	0.123
9	0.300	540	0.003	0.000	0.001
11	8.900	660	0.089	0.008	0.958
13	3.100	780	0.031	0.001	0.162
15	0.200	900	0.002	0.000	0.001
17	4.800	1020	0.048	0.002	0.666
19	2.600	1140	0.026	0.001	0.244
21	0.100	1260	0.001	0.000	0.000
23	3.300	1380	0.033	0.001	0.576
25	2.100	1500	0.021	0.000	0.276
			Totals:	1.084	5.712

K Factor: 5.3

Standard Derating(ANSI/IEEE C57.110-1986): 0.87 pu

Assumed Eddy-Current Loss Factor (Pec-r) 8%

Figure 8 - EXCEL K-Factor and Transformer Derating Spreadsheet

Allowable Compensation:

RESONANC.XLS

Calculation of Allowable Compensation for Power Factor Correction

Transformer Rating:	**2000.00**	**kVA**
Transformer Impedance:	**6.00**	**% at rated kVA**
Bus Voltage:	**480**	**Volts**
Base Impedance:	**0.1152**	W

Harmonic Number	Frequency (Hz)	Xl (Ohms)	Xc (Ohms)	Allowable kVAr
1	60	0.0069	0.0069	N/A
2	120	0.0138	0.0276	8333
3	180	0.0207	0.0622	3704
4	240	0.0276	0.1106	2083
5	**300**	**0.0346**	**0.1728**	**1333**
6	360	0.0415	0.2488	926
7	**420**	**0.0484**	**0.3387**	**680**
8	480	0.0553	0.4424	521
9	540	0.0622	0.5599	412
10	600	0.0691	0.6912	333
11	**660**	**0.0760**	**0.8364**	**275**
12	720	0.0829	0.9953	231
13	**780**	**0.0899**	**1.1681**	**197**
14	840	0.0968	1.3548	170
15	900	0.1037	1.5552	148

Figure 9 - EXCEL Resonance Calculation Spreadsheet

Several of these spreadsheets are based on IEEE standards and several are based on technical publications. If you use another method, or have additional applications that you would like to share with the User's Group, please feel free to give me a call at (615) 675-1500 x33

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