Harmonic Analysis and Power Factor Correction Evaluation – Plastic Creations Line 13

Prepared by:

Electrotek Concepts, Inc.
Knoxville, TN
www.electrotek.com

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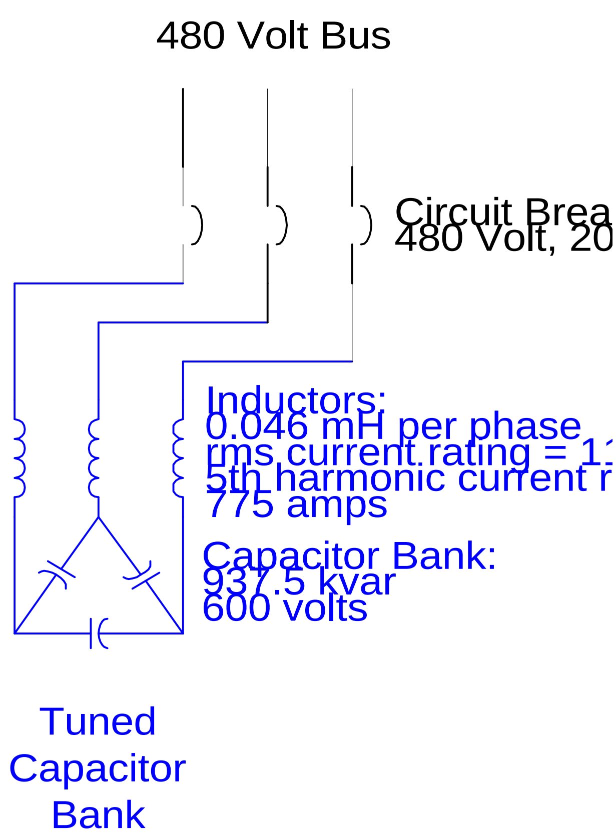
Executive Summary

The Plastic Creations in Newtown has a new Line 13 with ac variable frequency drives for the calender line. The drives have high harmonic current levels but do not require the level of power factor correction that dc drives require.

This evaluation characterizes the loads on Line 13. Power factor correction needs are calculated and the impact of the existing capacitor bank (provides about 600 kvar of compensation) is illustrated. The capacitor increases distortion levels at the 7^{th} and 11^{th} harmonics, resulting in overall voltage distortion levels exceeding 5% on the 480 volt system. Although this should not cause problems for now, the distortion levels are likely to be unacceptable with additional loading from Line 14. Also, the capacitor creates the potential for magnified transient voltages if the utility switches capacitor banks on the transmission system.

The capacitor should be converted into a tuned filter and it should be able to provide power factor correction for the existing Line 13 (correction to a power factor of about unity) and should also be sufficient even after the addition of Line 14 (power factor around 0.97). Specifications for the reactor to tune this bank are provided here.

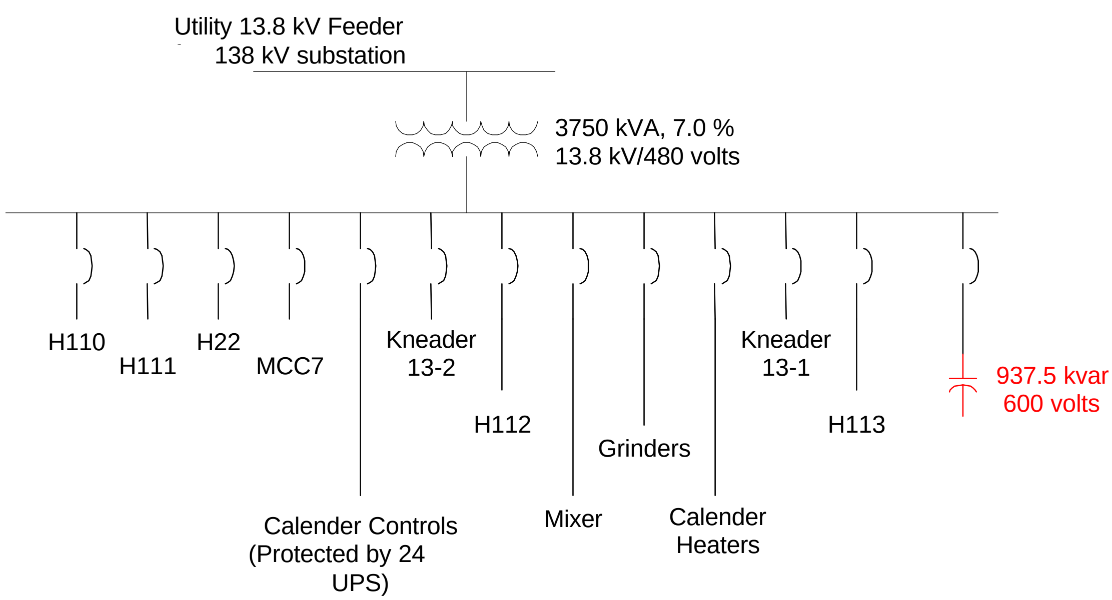


Proposed Filter Configuration for Line 13 and Line 14

1.0 Introduction

The Plastic Creations plant in Newtown has a new Line 13 with a dedicated transformer. Line 13 includes ac variable frequency drives instead of the dc drives that are used on other Plastic Creations lines. This has a dramatic impact on the power factor characteristics of the load. The ac drives have much better displacement power factor (not as much compensation needed) but have significant harmonic distortion levels. The measurements and recommendations presented in this report deal with the power factor correction and filtering requirements for this line, including the impact of a future Line 14 with similar characteristics to Line 13.

One Line Diagram



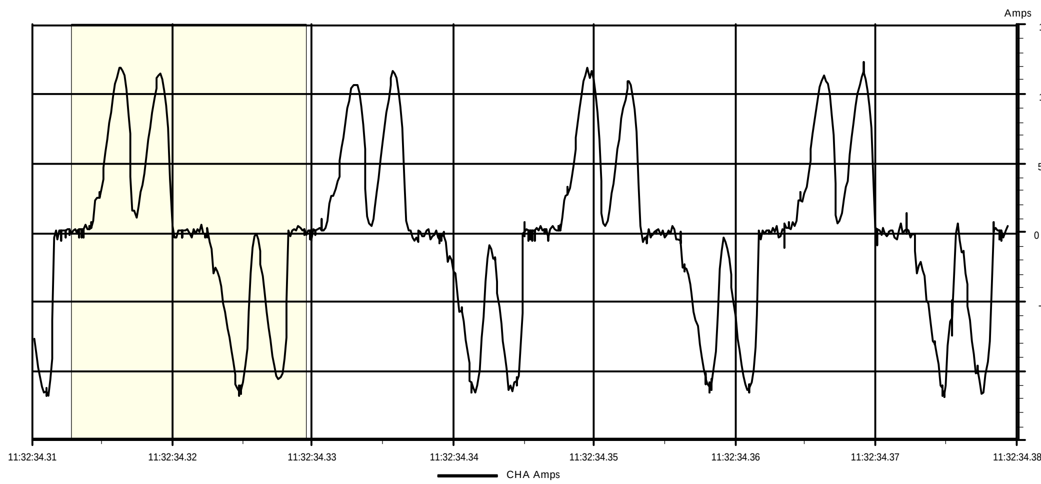
2.0 Field Measurements at Newtown

Measurements were taken to characterize the ac drive loads and the overall load characteristics for Line 13. The measurements also evaluated the impact of the existing capacitor bank on distortion levels on the 480 volt system supplying Line 13.

2.1 AC Drive Characteristics – Roll 1

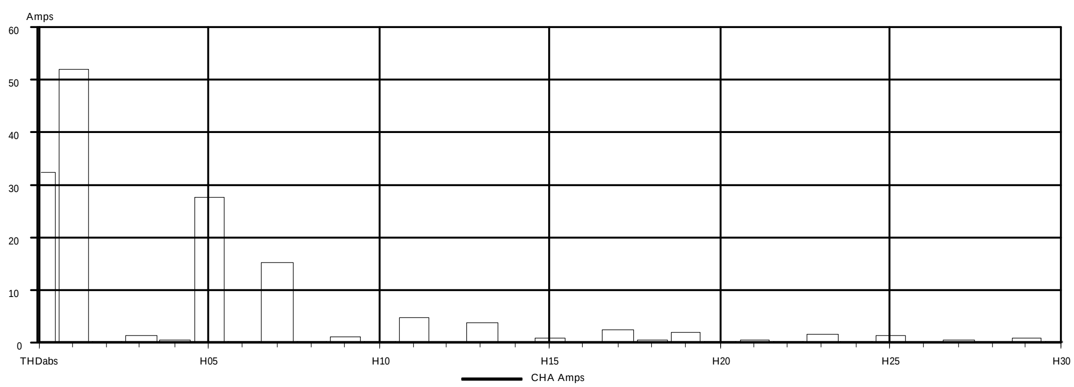
The following waveforms and harmonic spectrums are typical for Roll 1. This is also typical for Roll 3.

Event waveform/detail



Pre/Post-trigger at 02/25/98 11:32:34.312

Event waveform/detail



Total RMS: 61.27 Amps

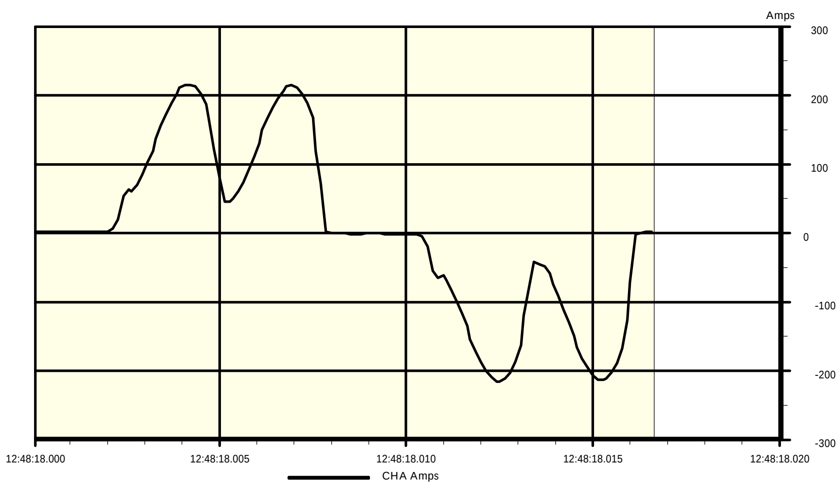
Total harmonic distortion:	**32.52 Amps**
Even contribution (H02-H50):	**1.31 Amps**
Odd contribution (H03-H49):	**32.50 Amps**

Pre/Post-trigger at 02/25/98 11:32:34.362

AC Drive Characteristics – Roll 2

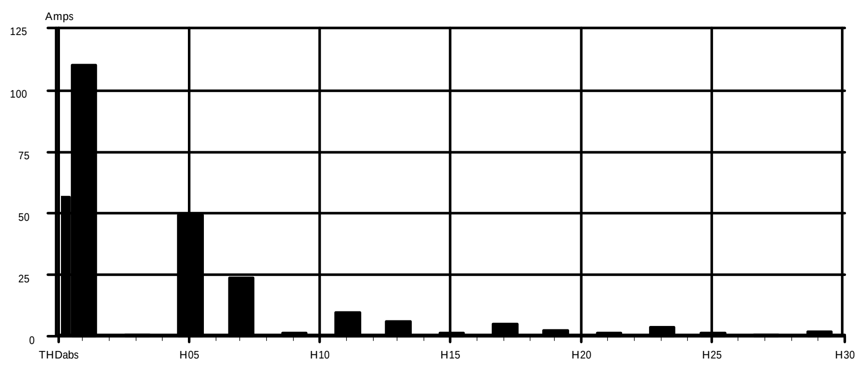
The following waveforms and harmonic spectrums are typical for Roll 2. This is also typical for Roll 4.

Event waveform/detail



Timed event at 02/25/98 12:48:18.000

Event waveform/detail

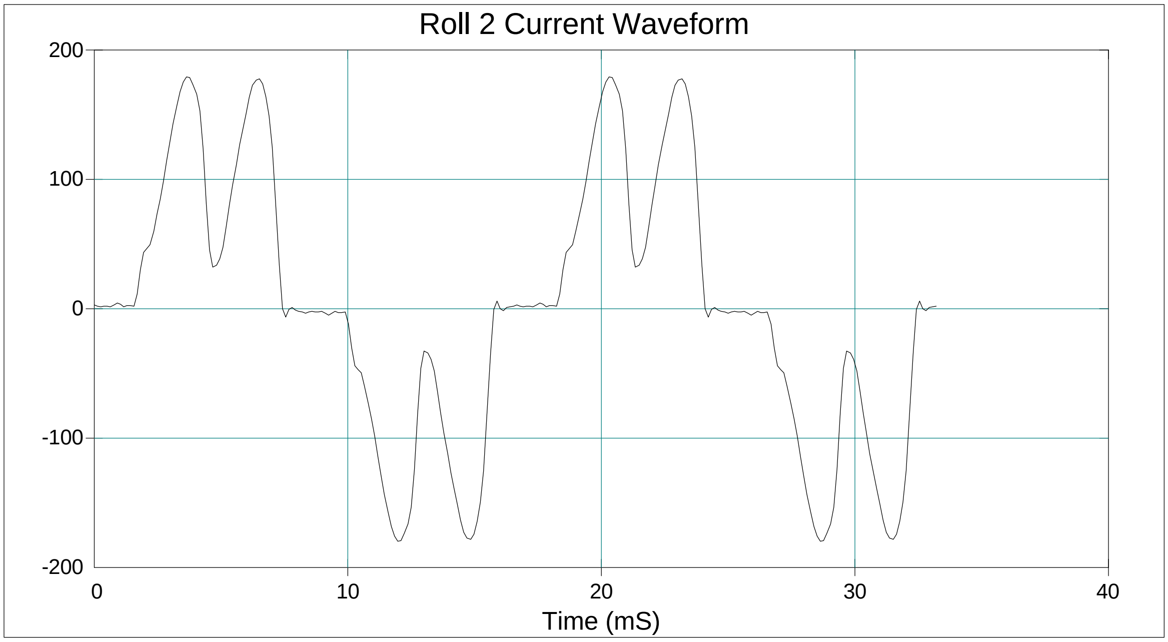


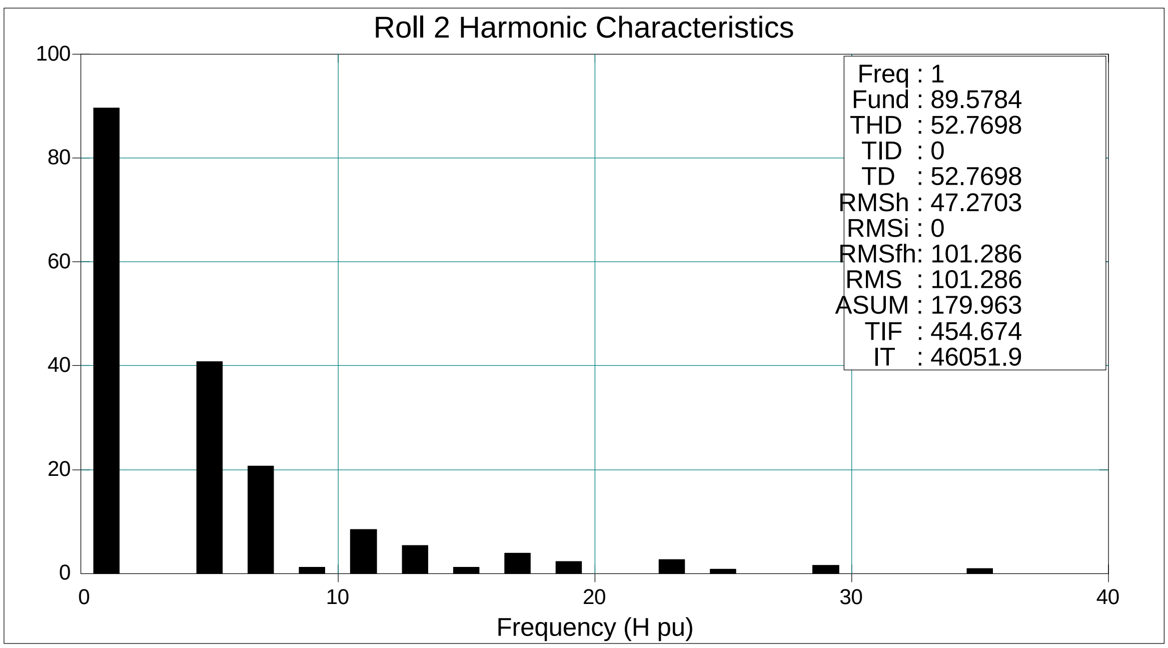
Total RMS: 123.67 Amps

Total harmonic distortion:	**56.36 Amps**
Even contribution (H02-H50):	**0.45 Amps**
Odd contribution (H03-H49):	**56.37 Amps**

Timed event at 02/25/98 12:48:18.000

Example waveform and spectrum from BMI 3030

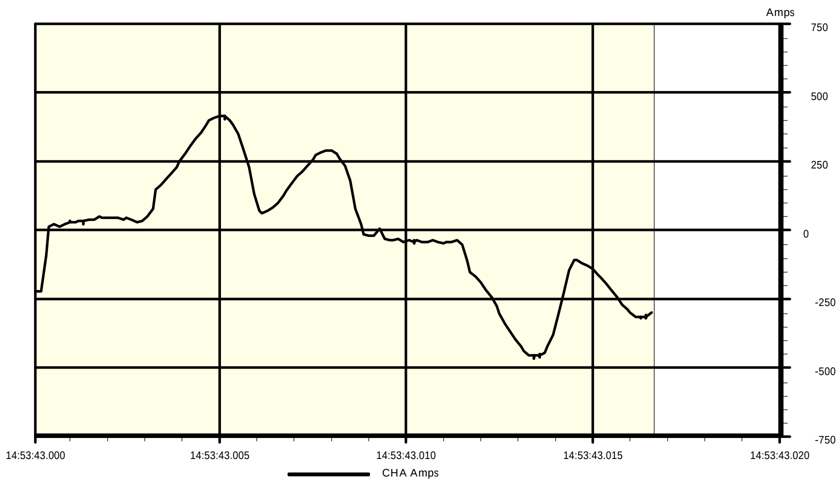




2.2 AC Drive Characteristics – Kneader B

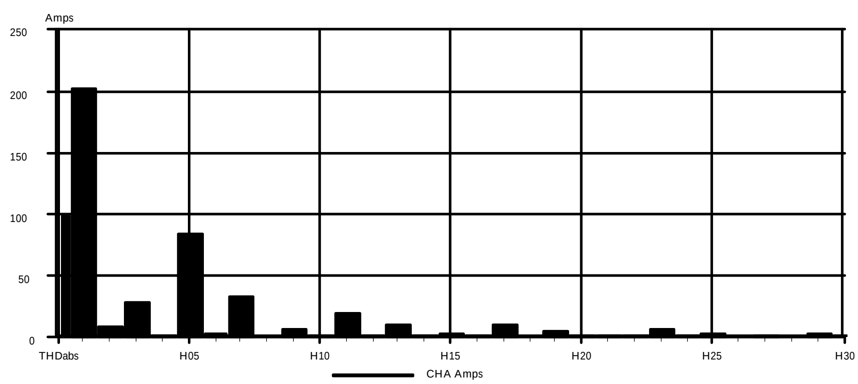
The following waveforms and harmonic spectrums are typical for Kneader B. This is also typical for Kneader A.

Event waveform/detail



Snapshot event at 02/25/98 14:53:43.000

Event waveform/detail



Total RMS: 224.85 Amps

Total harmonic distortion:	**98.85 Amps**
Even contribution (H02-H50):	**9.78 Amps**
Odd contribution (H03-H49):	**98.38 Amps**

Snapshot event at 02/25/98 14:53:43.000

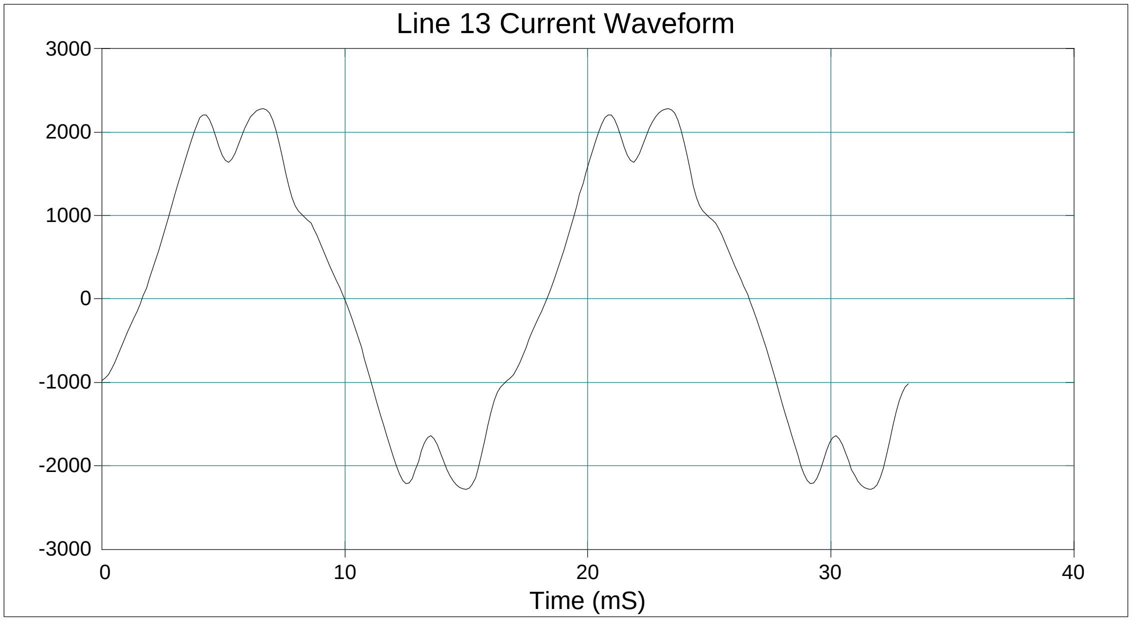
Overall Load Characteristics – Line 13

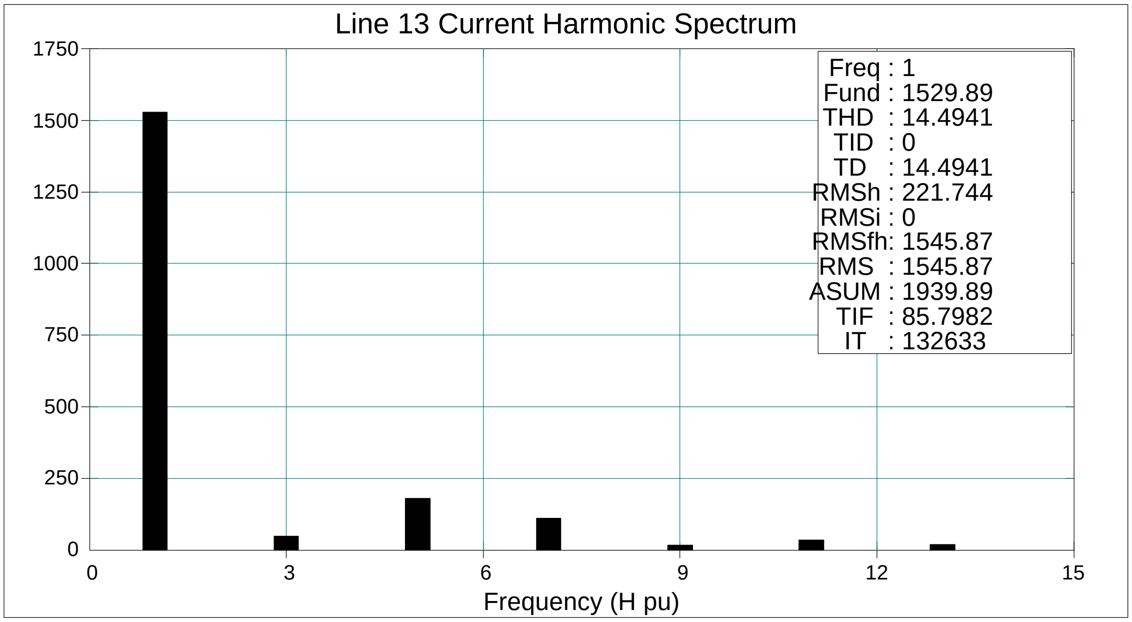
The following summarizes the overall load characteristics for Line 13. This includes the ac drives characterized in the previous sections along with the calender heaters and other loads that are part of the Line. This information can be used for evaluating harmonic filter and power factor correction requirements.

The table also illustrates the effect of the existing capacitor bank on the distortion levels and the power factor. Note that the 7th harmonic is significantly increased when the capacitor bank is in service and the voltage distortion often exceeds 5%. The current distortion increases to more than 30% with 20% at the 7th harmonic. This is an indication of the magnification at the 7th harmonic component.

	No Cap Bank		with Cap Bank	
Current	1300-1800	amps	1300-1600	amps
Power	1.1-1.3	MVA	1.0-1.1	MVA
kvar	480-500	kvar	150-180	kvar lead
PF	.88-.90		0.95	
dPF	.88-.91		0.99	lead
THDv	2.9-3.2	%	4.5-5.9	%
THDi	15-17	%	25-32	%
V5	1.9-2.0	%	2.5	%
I5	12-13	%	19	%
V7	1.8	%	3.2	%
I7	8-9	%	20	%

The following waveform and harmonic spectrum represent typical load characteristics for Line 13 (without the capacitor bank).





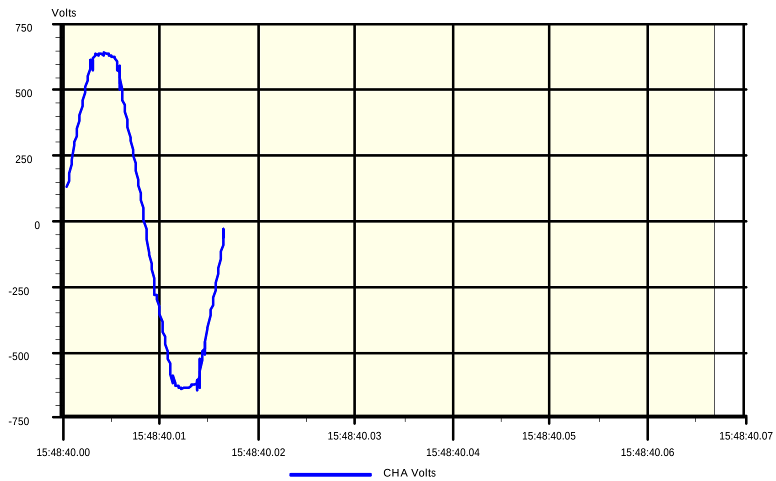
2.3 Voltage Distortion Evaluations

The following measurement results summarize the voltage distortion concerns at the 480 volt bus supplying Line 13.

Voltage Characteristics without Capacitor Bank

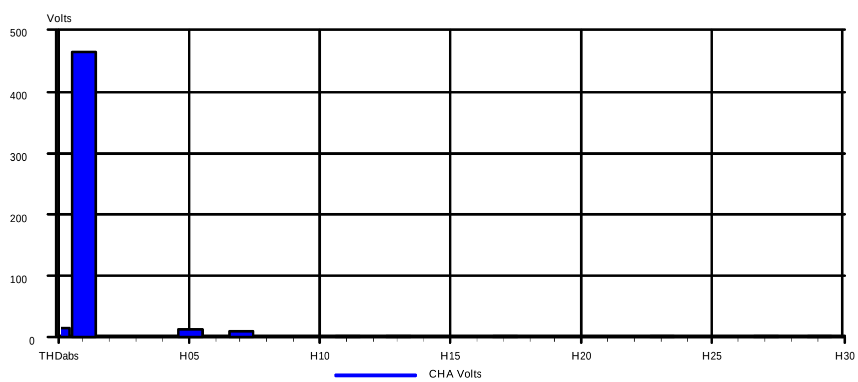
Typical voltage waveforms and spectrums are provided below without the capacitor bank in service. The distortion is dominated by the 5th harmonic component since that is the highest current injection from the drive loads.

Event waveform/detail



Snapshot event at 02/25/98 15:48:40.000

Event waveform/detail



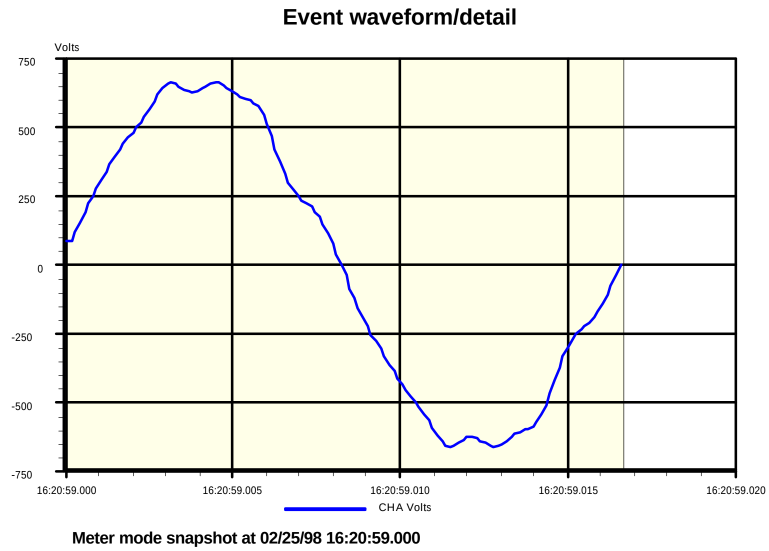
Total RMS: 464.93 Volts

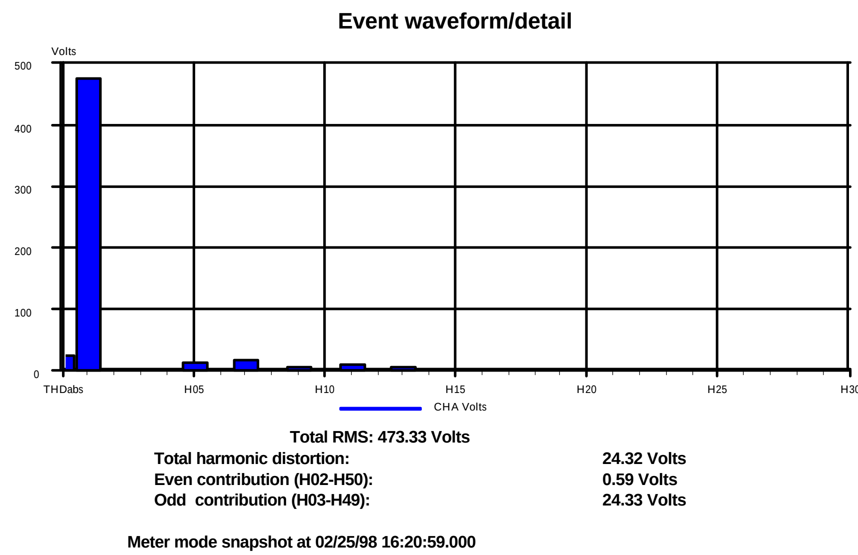
Total harmonic distortion:	**15.76 Volts**
Even contribution (H02-H50):	**2.68 Volts**
Odd contribution (H03-H49):	**15.54 Volts**

Snapshot event at 02/25/98 15:48:40.000

Voltage Characteristics with Capacitor Bank

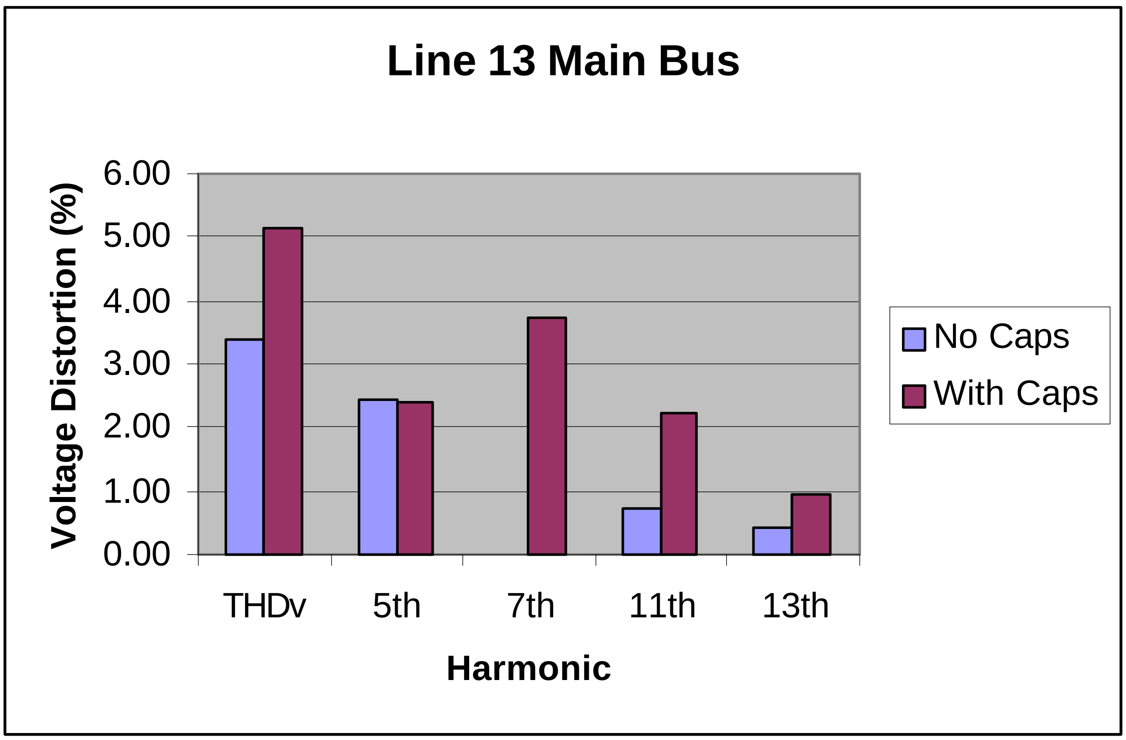
Typical voltage waveforms and spectrums are provided below after the capacitor bank was switched in. The capacitor creates a resonance between the 7th and 11th harmonics, magnifying both of these components. The voltage distortion levels are increased overall and can exceed 5%. The highest distortion is typically at the 7th harmonic with the capacitor bank in due to the magnification.





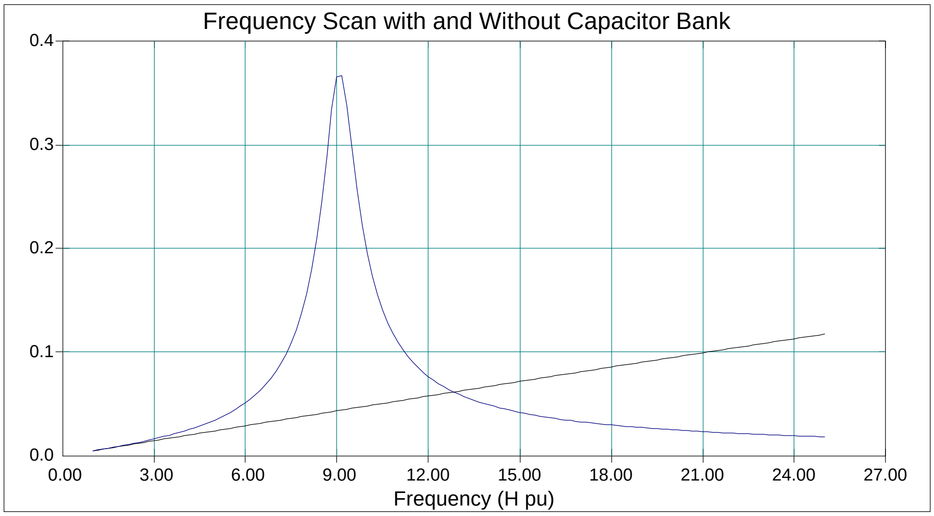
Comparison of Voltage Characteristics

The figure below shows the THD of the voltage on the Line 13 Main Bus and the values of the 5th, 7th, 11th, and 13th harmonic as percentages of the fundamental with the capacitor bank on line and with it off line. The chart makes it easier to see how placing the capacitor bank on line at the Line 13 Main Bus magnifies the 7th and 11th harmonics. The 7th harmonic is virtually non-existent, at 0.02% of the fundamental, with the capacitor bank off line. The 11th harmonic was measured at 0.75% without the capacitor banks. After placing the capacitor banks on line, the 7th increases to 3.73% and the 11th increases to 2.23% of the fundamental.

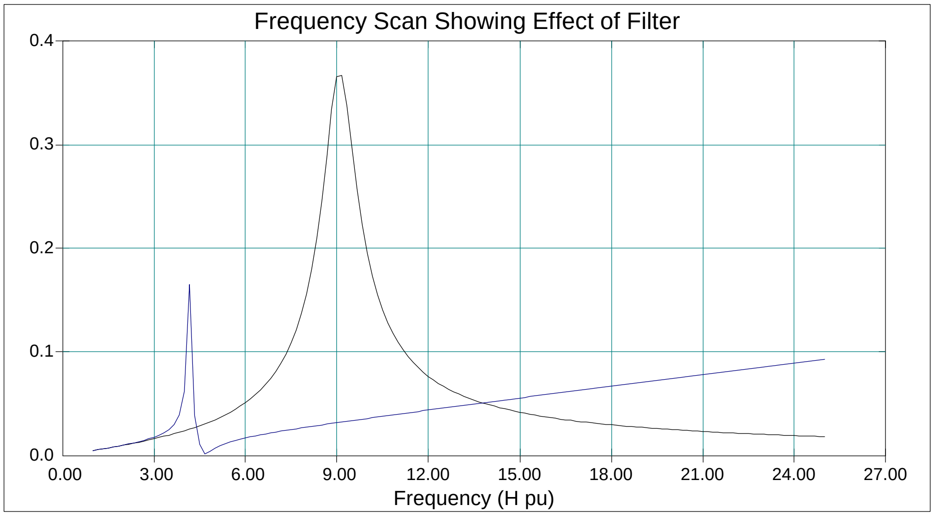


Description of the Resonance Problem

The capacitor bank introduces a resonance between the 7th and 11th harmonics that magnifies both of these components. The frequency scan below illustrates the voltage at the 480 volt bus per amp injected by the drive loads with and without the capacitor bank in service.



This problem can be avoided by converting the capacitor bank into a tuned filter. The frequency scan plots below show the effect of the tuned filter in preventing resonances close to the characteristic harmonics of the drive loads (5th and 7th).



3.0 Recommended Power Factor Correction

This section summarizes the power factor correction needs for the existing configuration with Line 13 and estimates the impacts of a similar line (Line 14) in the future.

3.1 Summary of Reactive Power Requirements

The following table summarizes the load characteristics measured for Line 13 and shows the impact of the 600 kvar of compensation on the power factor of the overall load. The table also shows the effect of this capacitor bank if the load is doubled to include the effect of Line 14 in the future.

The power factor with just Line 13 is corrected to unity with the existing capacitor bank.

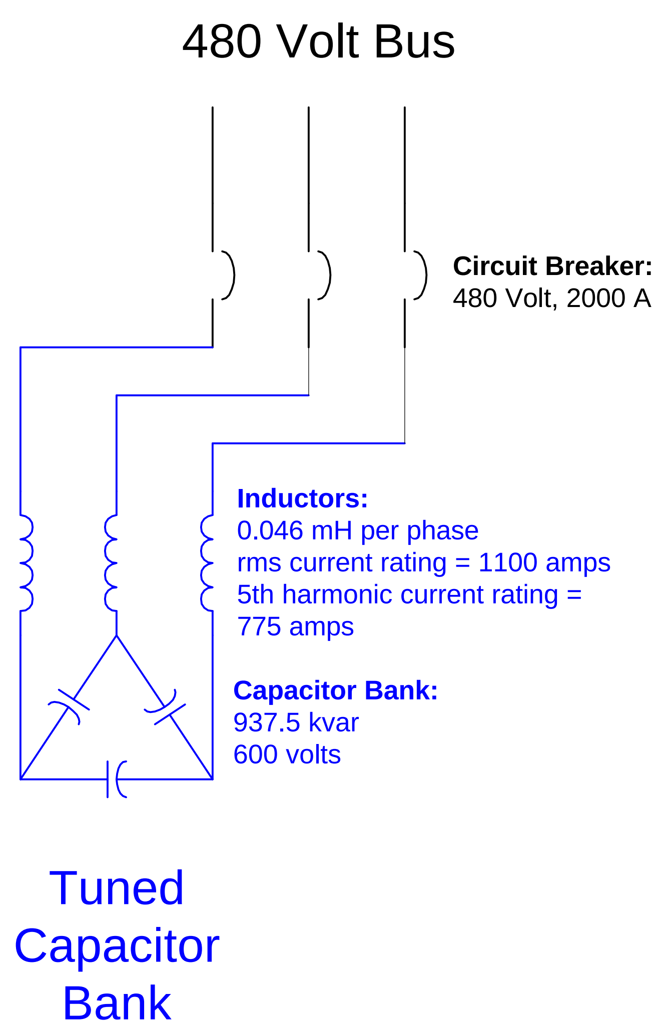
With Line 14, the capacitor bank will correct the power factor to about 0.97 lagging when both lines are running.

	Line 13	Line 13 and Line 14
Transformer Size	3750	3750
Transformer Impedance	7%	7.00%
Peak Load (kVA)	1300	2600
Displacement Power Factor	0.9	0.9
Reactive Power (kvar)	567	1133
Real Power (kW)	1170	2340
Compensation (kvar)	600	600
Total Reactive Power with Compensation (kvar)	-33	533
Power Factor with Compensation	1.00	0.97
Fifth Harmonic Current (%)	15%	15%

The capacitor should be configured as a tuned bank to prevent excessive distortion and problems with magnification of capacitor switching transients. The next section gives parameters for the tuning reactor.

4.0 Proposed Filter Design

Plastic Creations has already purchased a capacitor bank for power factor correction. The capacitor is rated 600 volts so it can easily be used as part of a tuned filter. The proposed filter design is illustrated in the one line diagram below. The following page gives the specifications for the filter reactor that should be purchased.



Proposed Filter Configuration for Lines 13 and 14

Low Voltage Filter Calculations: 600 kvar 480 Volt Filter

SYSTEM INFORMATION:

Filter Specification:	5	th	Power System Frequency:	60	Hz
Capacitor Bank Rating:	937.5	kVAr	Capacitor Rating:	600	Volts
Rated Bank Current:	902	Amps		60	Hz
Nominal Bus Voltage:	480	Volts	Derated Capacitor:	600	kVAr
Capacitor Current (actual):	721.7	Amps	Total Harmonic Load:	2500	kVA
Filter Tuning Harmonic:	4.7	th	Filter Tuning Frequency:	282	Hz
Cap Impedance (wye equivalent):	0.3840	Ω	Cap Value (wye equivalent):	6907.8	uF
Reactor Impedance:	0.0174	Ω	Reactor Rating:	0.0461	mH
Filter Full Load Current (actual):	755.9	Amps	Supplied Compensation:	628	kVAr
Filter Full Load Current (rated):	944.9	Amps			
Transformer Nameplate:	3750	kVA	Utility Side Vh:	2.00	% THD
(Rating and Impedance)	7.00	%	*(Utility Harmonic Voltage Source)*		
Load Harmonic Current:	20.00	% Fund	Load Harmonic Current:	601.4	Amps
Utility Harmonic Current:	175.5	Amps	Max Total Harm. Current:	776.9	Amps

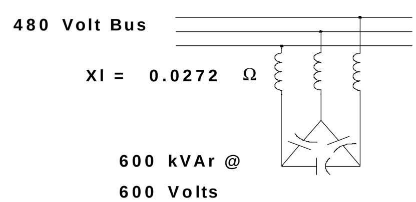
CAPACITOR DUTY CALCULATIONS:

Filter RMS Current:	1084.0	Amps	Fundamental Cap Voltage:	502.8	Volts
Harmonic Cap Voltage:	103.3	Volts	Maximum Peak Voltage:	606.1	Volts
RMS Capacitor Voltage:	513.3	Volts	Maximum Peak Current:	1532.8	Amps

CAPACITOR LIMITS: (IEEE Std 18-1980)

	Limit		Actual
Peak Voltage:	120%	⟷	101%
Current:	180%	⟷	120%
KVAr:	135%	⟷	103%
RMS Voltage:	110%	⟷	86%

FILTER CONFIGURATION:



FILTER REACTOR DESIGN SPECIFICATIONS:

Reactor Impedance:	0.0174	Ω	Reactor Rating:	0.0461	mH
Fundamental Current:	755.9	Amps	Harmonic Current:	776.9	Amps