PQSoft Case Study

Concrete Facility Harmonic Evaluation
ASD Drive Trips and Transformer Fires

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Keywords:

Power Quality Category	Harmonics		
Solution	Isolate Loads	Change Capacitor to Filter	Detune Filter
Problem Cause	Improper Application		
Load Type	AC ASD	DC ASD	Capacitors
Customer Type	Industrial	Cement	
Problem Symptoms	Capacitor Failure	ASD Drive Trips	Transformer Fires
Miscellaneous	25 MW facility load		
References			

Abstract:

A Kiln ID fan drive (12 pulse rectifier) powers a 3000 HP medium voltage (4kV) motor. The associated harmonic filter periodically becomes overloaded and trips the corresponding 4kV breaker. The associated isolation transformer caught on fire within the first three months of operation. There have also been problems with the power factor correction capacitor banks.

The case study presents a summary of a harmonic evaluation that was performed before the plant substation was upgraded.

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RELATED STANDARDS

ANSI/IEEE Std. 18-1980: *IEEE Standard for Shunt Power Capacitors*
IEEE Std. 1159 – 1995 *Recommended Practice for Monitoring Electric Power Quality*
IEEE Std. 519-1992: *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*

GLOSSARY AND ACRONYMS

THD	Total Harmonic Distortion

EXECUTIVE SUMMARY

Electrotek Concepts performed a site survey at the concrete facility from October 2 - 3, 2000. Measurements show that the harmonic filters installed at the Kiln ID Fan Drive (also known as the 21 Fan Drive) are not designed for operation with the current system configuration.

The site survey, measurements, and simulations show that there are some things that the customer can do to improve the reliability of the 21 Fan Drive. Electrotek recommends that the Kiln Main Drive be supplied from a new feeder. Supplying the 21 Fan Drive and the Kiln Main Drive from different feeders will lower the current into the 21 Fan harmonic filters and will increase the reliability of the process.

The 11^{th} harmonic filter should be detuned also if it has not been. Calculations show that using the 105% taps on the 0.83mH filter reactors will decrease the current into the 11th harmonic filter.

The customer could improve the uptime of the 21 Fan Drive and the plant process by serving each filter through a dedicated breaker and removing the interlocks between the filter overloads and the main breaker.

Electrotek recommends that the customer operate with one 2400 kVAr capacitor bank step on-line.

Electrotek recommends that the old 1800 kVAr capacitor bank should be converted to a 2000 kVAr 5^{th} harmonic filter - the filter be tuned to 297 Hz. This recommendation does improve on all of the other recommendations, but it may not be necessary after the Kiln Main Drive is supplied from a new feeder. Electrotek suggests that the customer implement the other recommendations and evaluate the operation of the 21 Fan Drive and the harmonic filters. The evaluation should include measurements at the 21 Fan harmonic filters for at least one week. The evaluation may show that the investment in a 5^{th} harmonic filter may not be cost effective.

A harmonic evaluation should be performed before the plant substation is upgraded or before major equipment or system changes are made.

INTRODUCTION

The customer manufactures cement for use in the construction industry. Limestone (chalk) is mined and processed with other raw materials at the plant to create the cement.

The Kiln ID fan drive (Allen-Bradley 12 pulse rectifier) powers a 3000 HP medium voltage (4kV) motor. The associated harmonic filter periodically becomes overloaded and trips the corresponding 4kV breaker. The associated isolation transformer caught on fire within the first three months of operation. There have also been problems with the power factor correction capacitor banks.

Measurements show that the harmonic filters installed at the Kiln ID Fan Drive (5^{th}, 7^{th} and 11^{th}) are not designed for operation with the current system configuration. Recent operating experience has shown that each of the three filters has tripped the above-mentioned 4 kV breaker. The Kiln ID fan drive and the Kiln Main Drive (600 hp DC motor) are currently fed from a common feeder.

The facility also has many other sources of harmonics including about 2000hp of 6 pulse drives. It is possible that the eleventh harmonic filter mentioned above, in combination with other power factor correction capacitors, resulted in a new resonance near the fifth or seventh harmonic that was excited by some of these other loads.

The harmonic problem seems to be less prominent when both finish mill (3700 hp synchronous) motors are running and when the power factor correction capacitors are in service.

An Allen-Bradley representative has reviewed the situation and has concluded that the problems are due to high levels of “pre existing” harmonics on the drive feeder bus. The source of those harmonics is thought to be from various low voltage 6-pulse drives (total amount about 2000 hp).

FIELD MEASUREMENTS

Measurements were performed at most of the 4160 volt feeders. Figure 1 shows a simplified one-line diagram for the plant electrical power system. The feeder current measurements were performed in the main switchgear room at the existing current transformers. The bus voltage for these measurements is the voltage measured at the potential transformer secondaries in the Incoming power cabinet.

The measurement snapshots show the three-phase voltage and current waveforms and the harmonic spectrum for the Phase A current. The Phase A voltage spectrum is shown with the Incoming measurement snapshot.

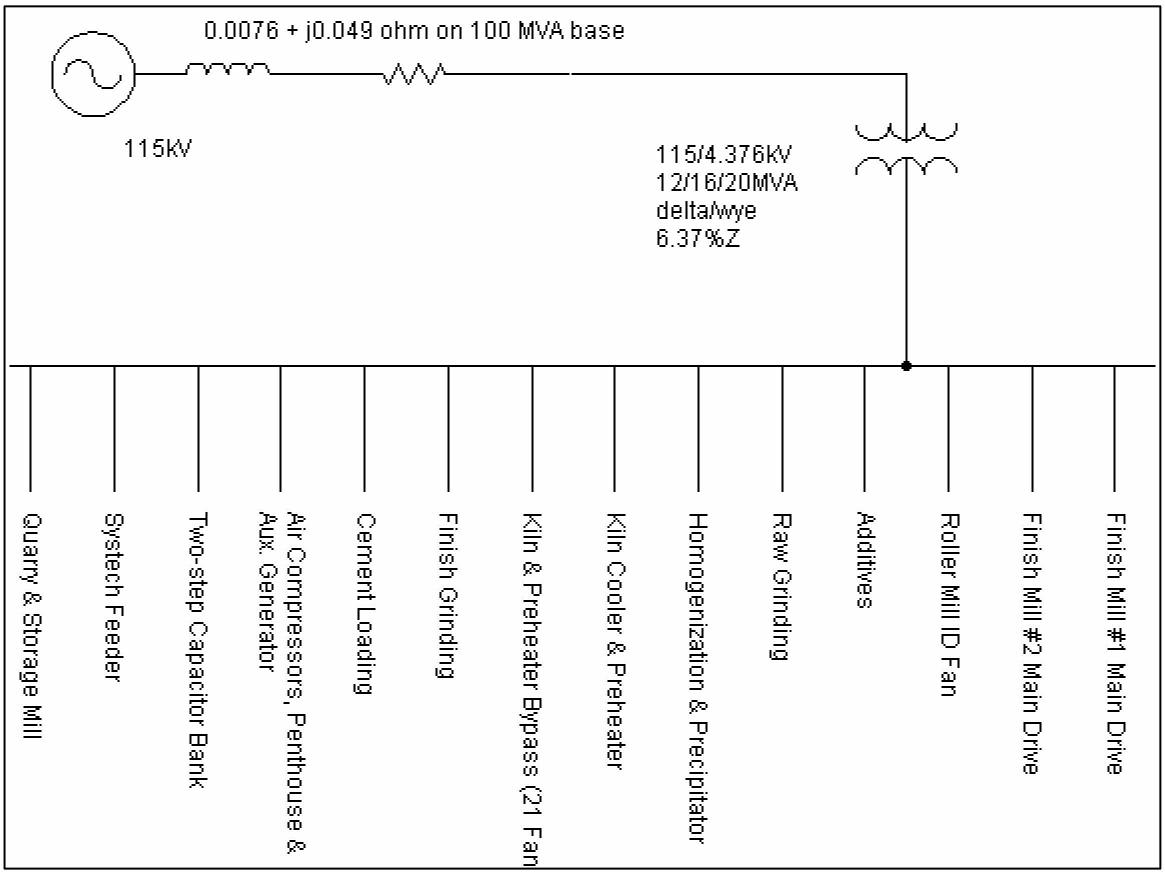
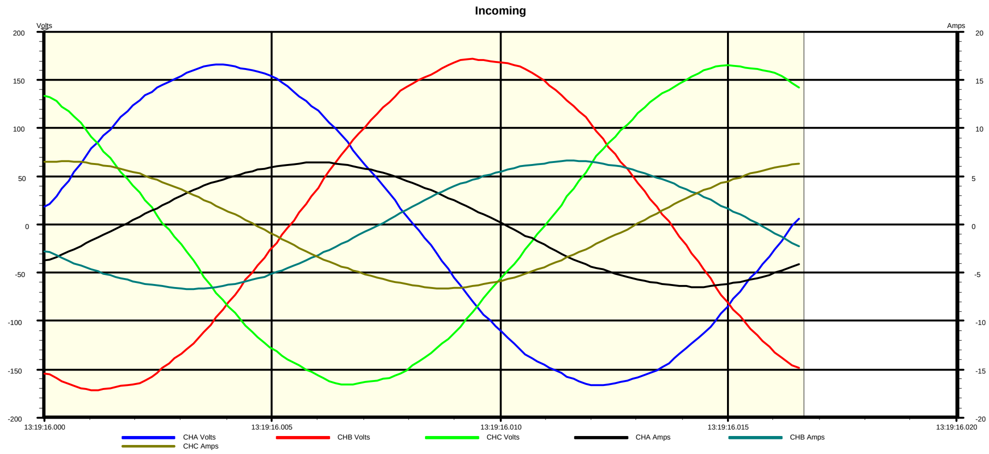
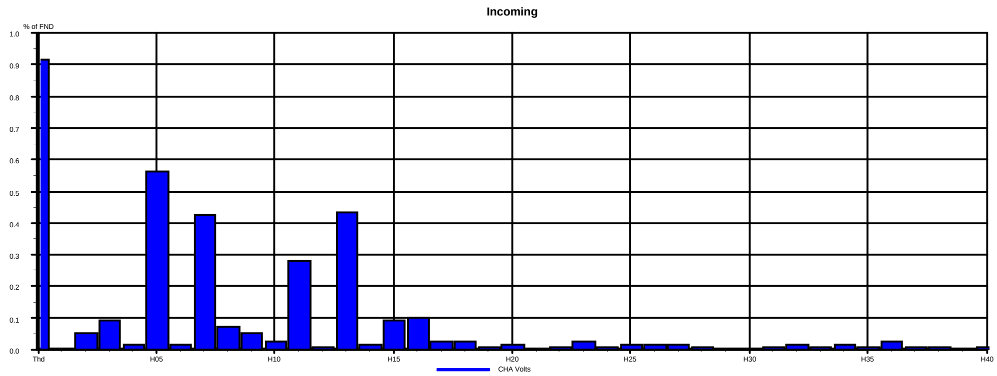


Figure 1 - Electrical Power System One-line

Incoming



Timed event at 10/03/00 13:19:16.000



Total RMS: 117.31 Volts
DC Level : 0.05 Volts
Fundamental(H1) RMS: 117.30 Volts

Total Harmonic Distortion (H02-H50):	**0.92 % of FND**
Even contribution (H02-H50):	**0.17 % of FND**
Odd contribution (H03-H49):	**0.90 % of FND**

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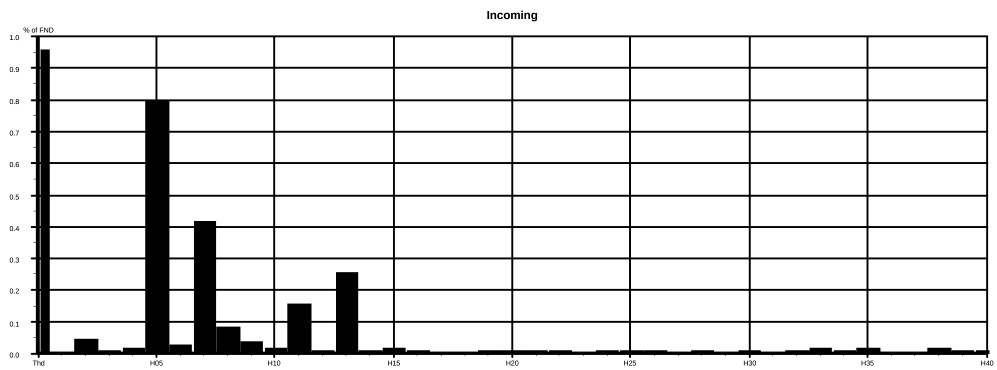


Total RMS: 4.52 Amps
DC Level : 0.01 Amps
Fundamental(H1) RMS: 4.52 Amps

Total Harmonic Distortion (H02-H50):	**0.97 % of FND**
Even contribution (H02-H50):	**0.12 % of FND**
Odd contribution (H03-H49):	**0.96 % of FND**

Timed event at 10/03/00 13:19:16.000

Figure 2 - Incoming Measurement Snapshot

Finish Mill #1 Main Drive

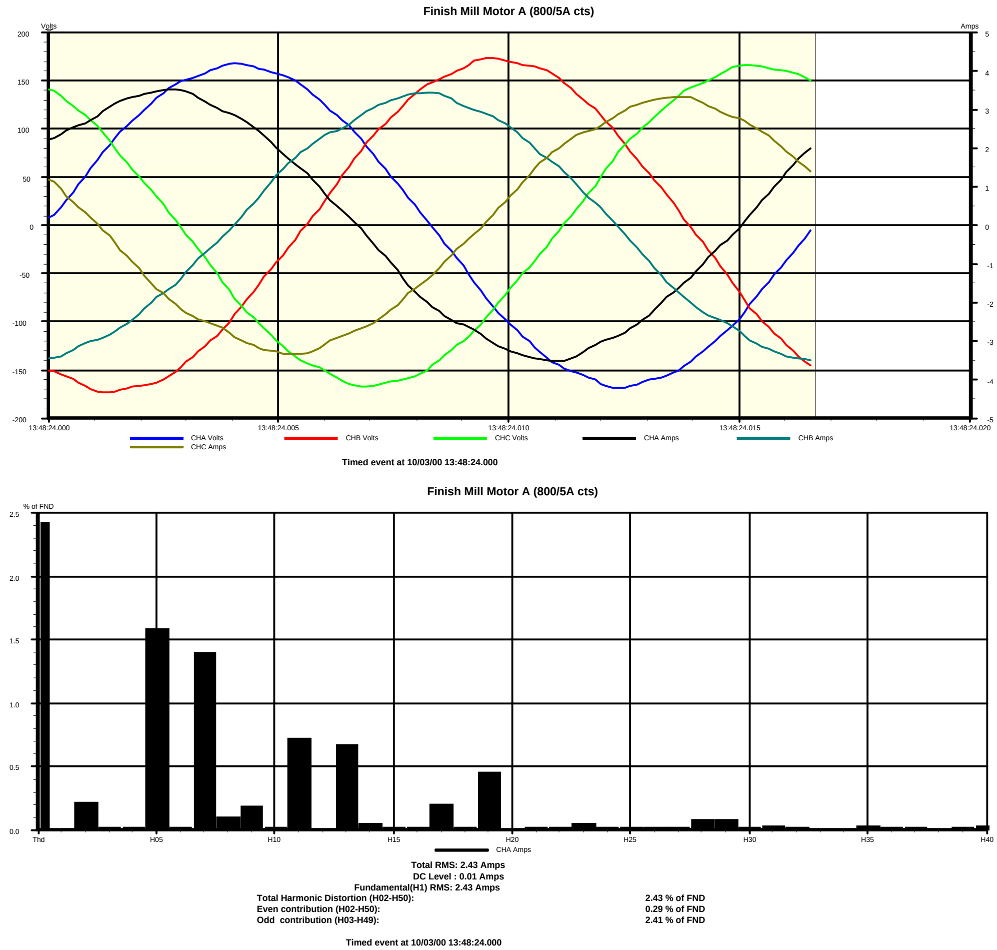
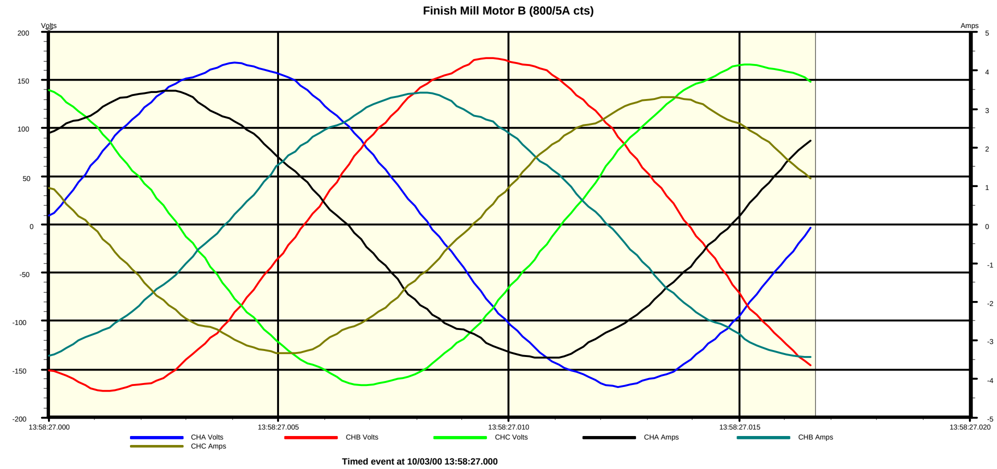


Figure 3 - Finish Mill #1 Main Drive Measurement Snapshot

Finish Mill #2 Main Drive



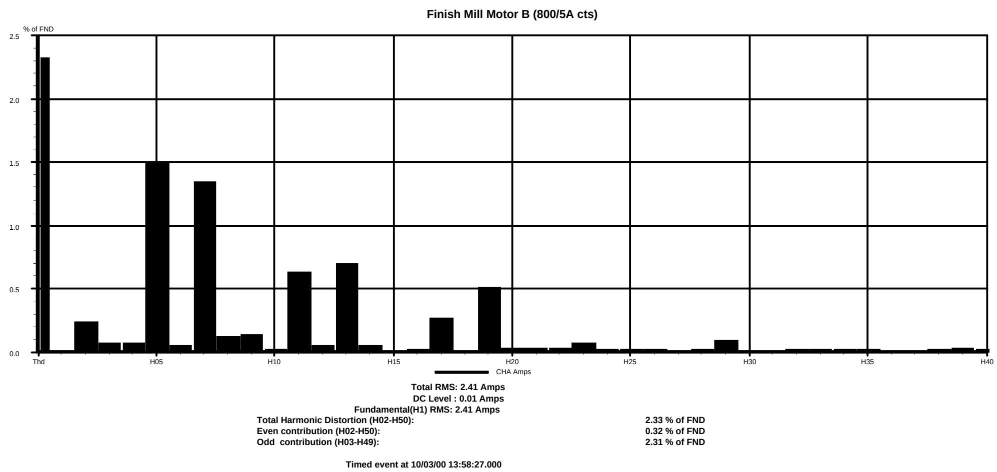
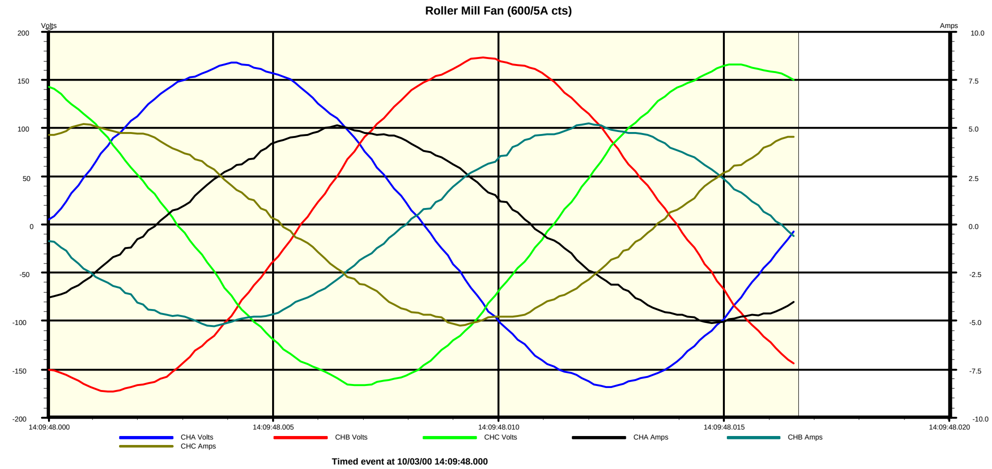


Figure 4 - Finish Mill #2 Main Drive Measurement Snapshot

Roller Mill ID Fan



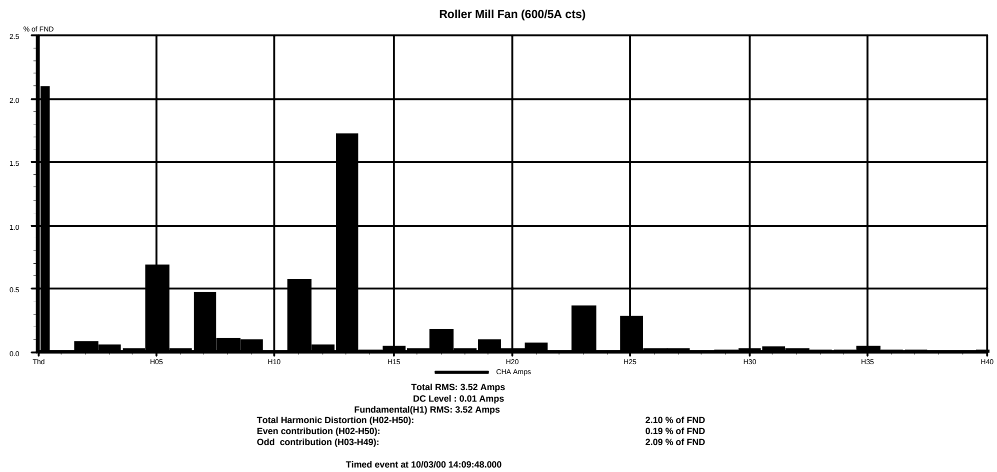
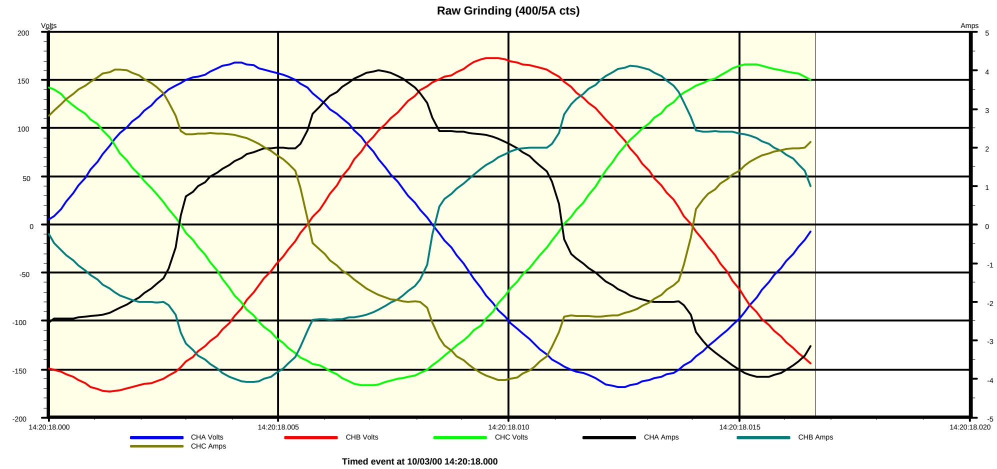


Figure 5 - Roller Mill ID Fan Measurement Snapshot

Raw Grinding



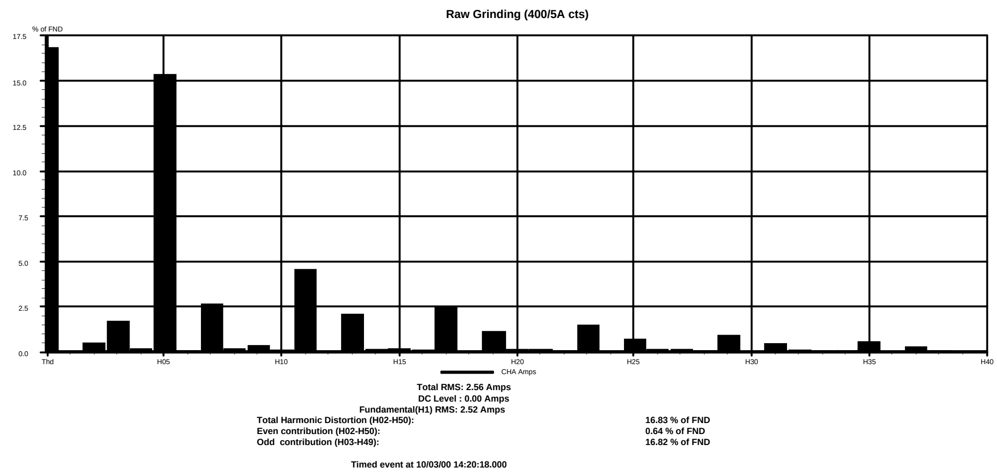
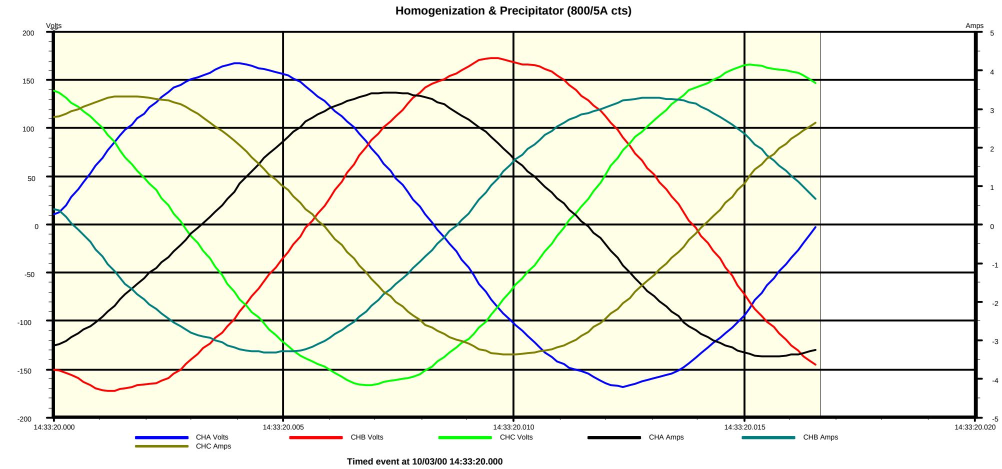


Figure 6 - Raw Grinding Measurement Snapshot

Homogenization & Precipitator



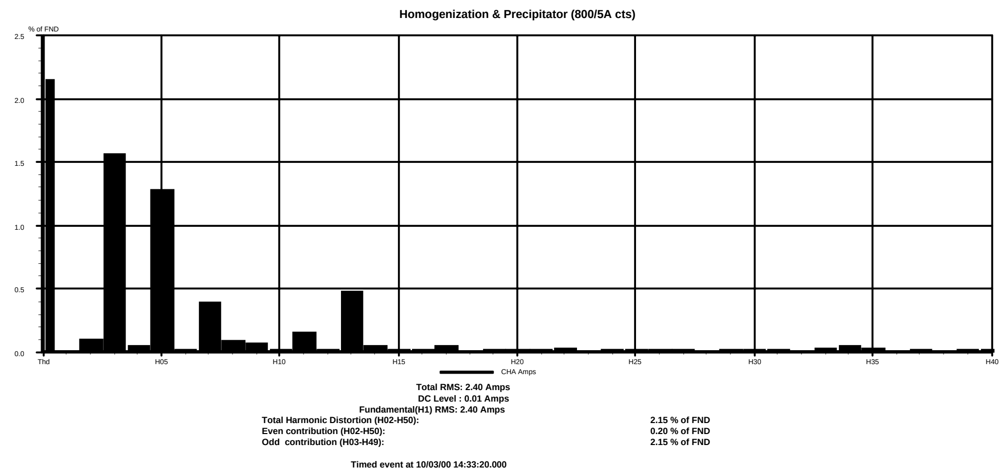


Figure 7 - Homogenization & Precipitator Measurement Snapshot

Kiln Cooler & Preheater

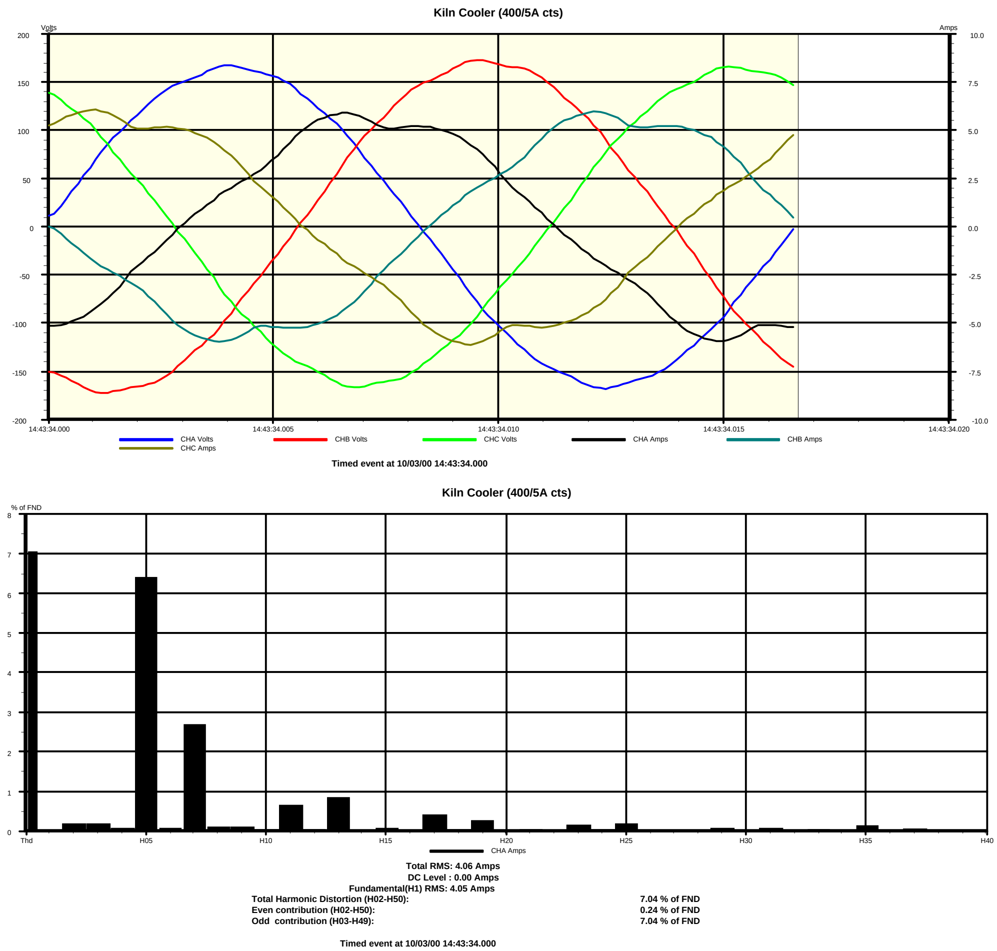


Figure 8 - Kiln Cooler & Preheater Measurement Snapshot

Kiln & Preheater Bypass (21 Fan)

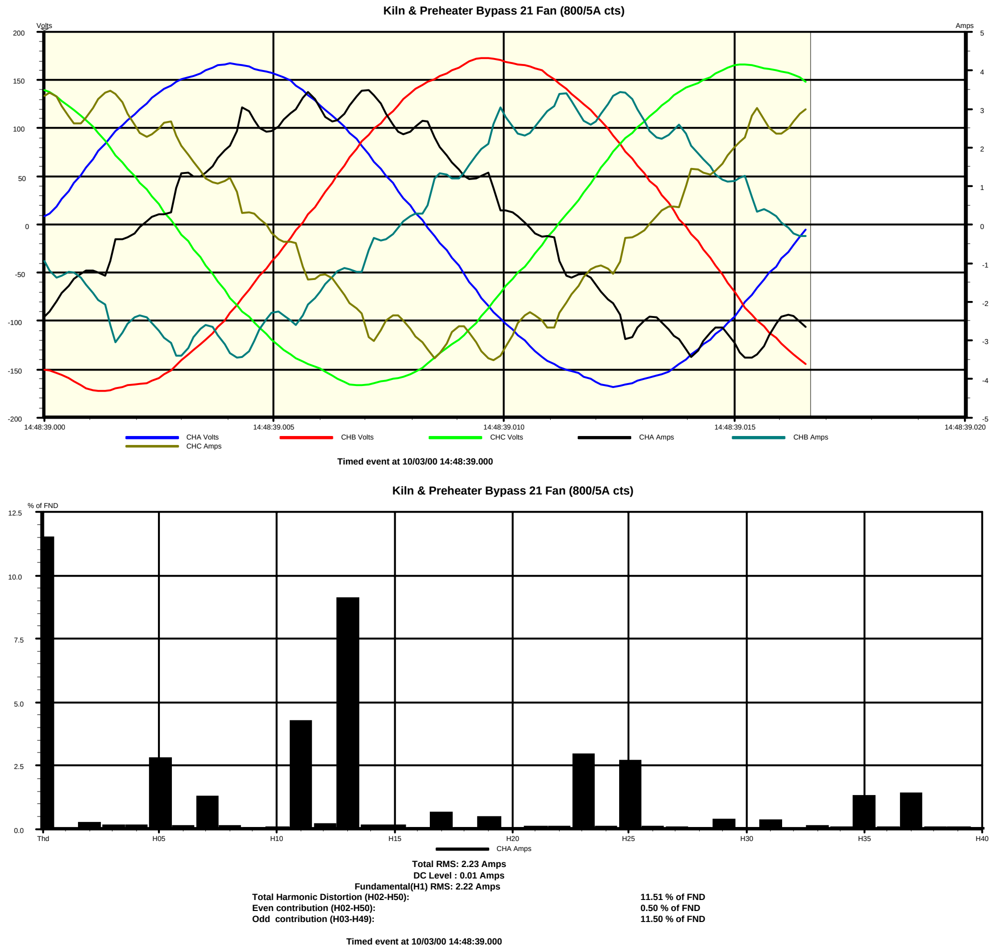


Figure 9 - Kiln & Preheater Bypass (21 Fan)

Finish Grinding

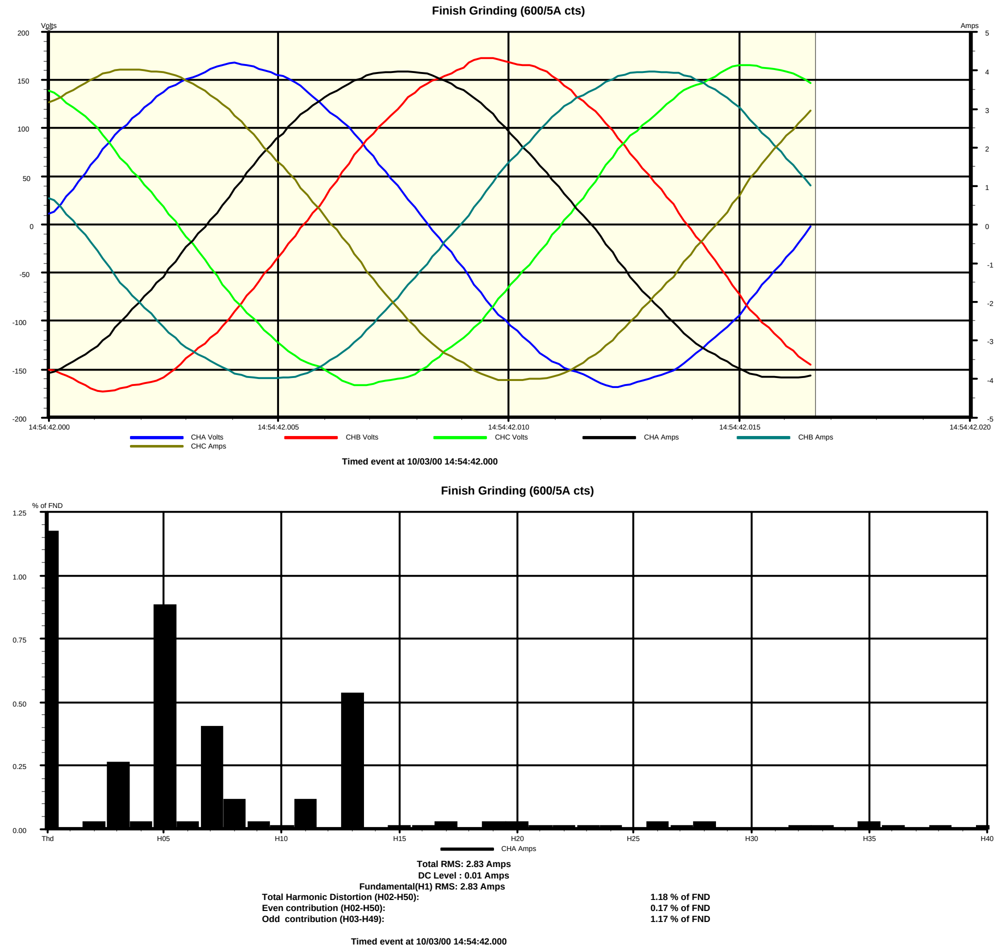
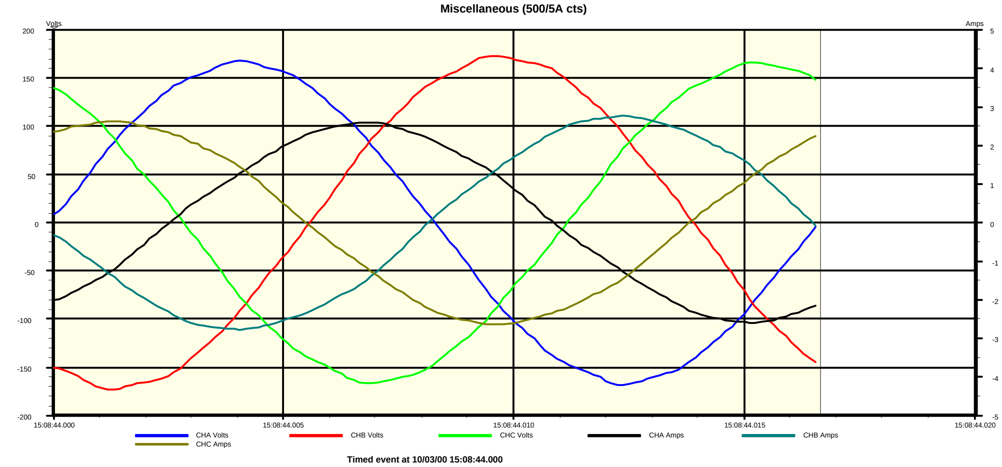


Figure 10 - Finish Grinding Measurement Snapshot

Air Compressors, Penthouse & Auxiliary Generation



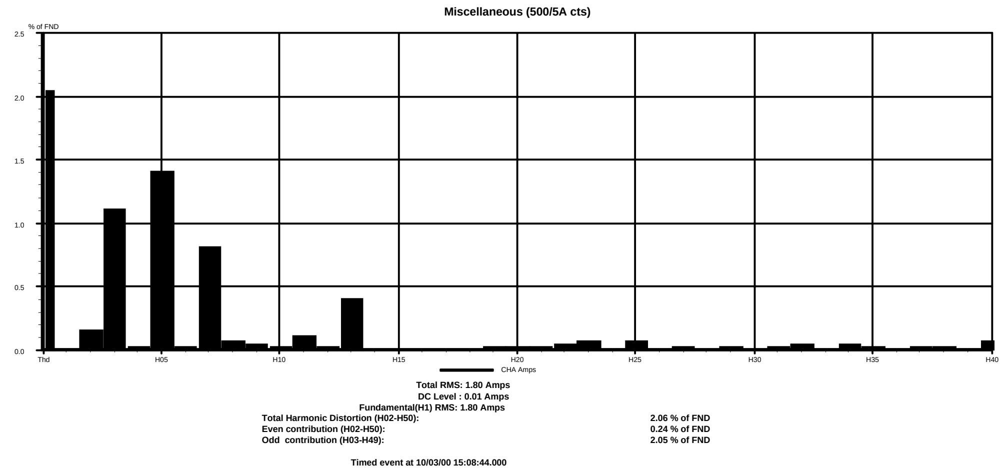
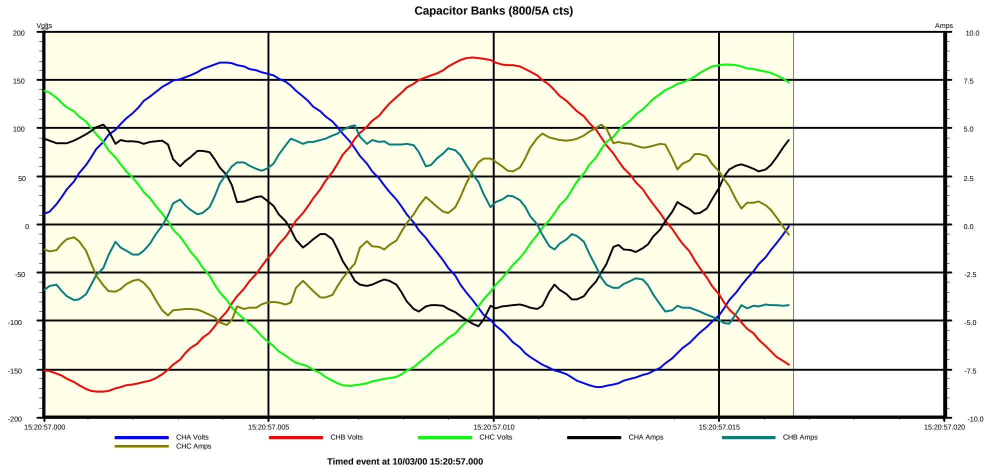


Figure 11 - Miscellaneous Measurement Snapshot

Two-step Capacitor Bank



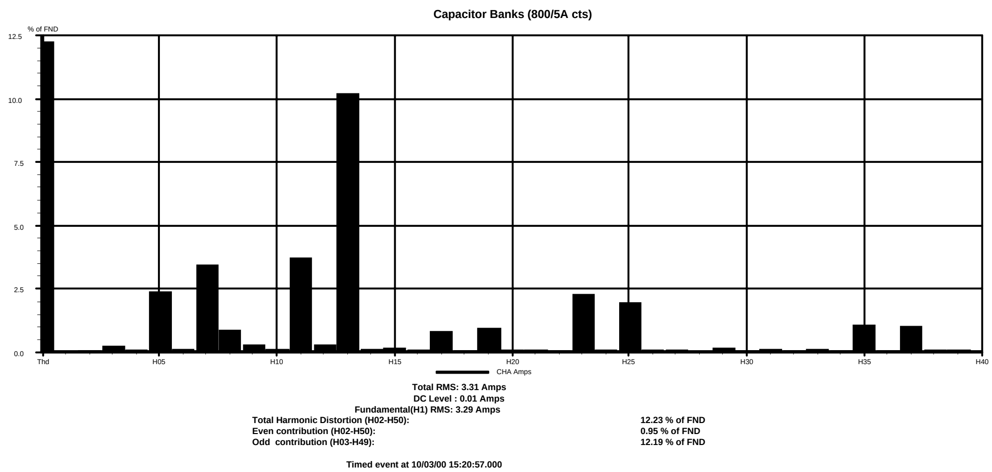
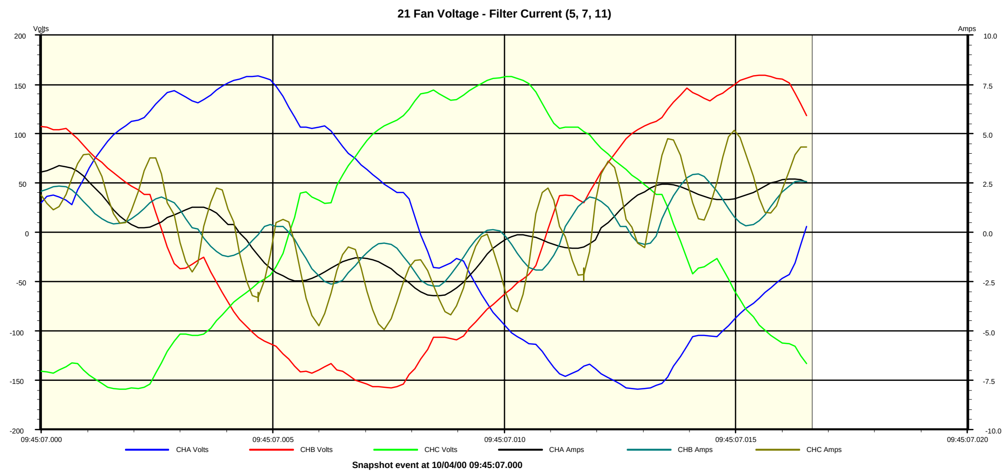


Figure 12 - Capacitor Bank Measurement Snapshot

21 Fan



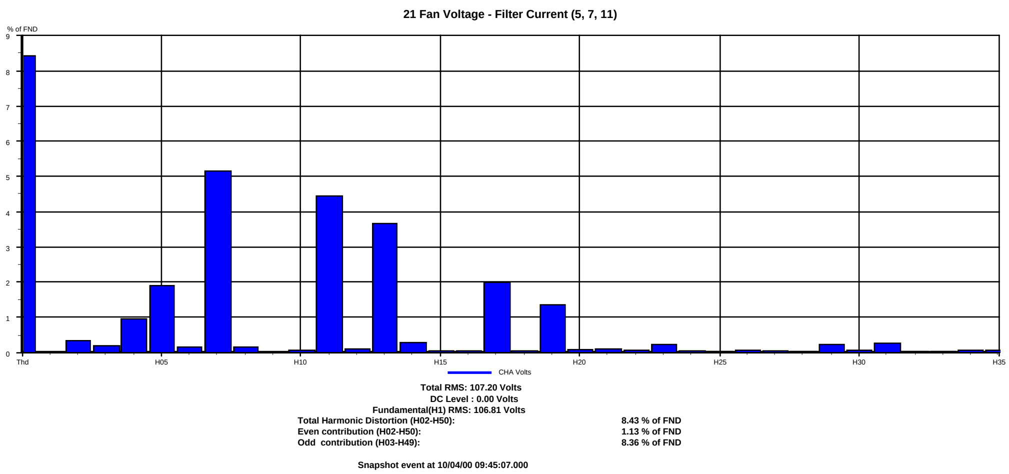


Figure 13 - 21 Fan Measurement Snapshot (5th, 7th, 11th harmonic filter current)

Measurements were performed at the supply to the 21 Fan and each of the harmonic filters. In Figure 13, Phase A current is one phase of the 5th harmonic filter current, Phase B is one phase of the 7th harmonic filter current, and Phase C current is one phase of the 11th harmonic filter current.

Table 1 - Filter Current

	60 Hz	Harmonic	Irms
5th	35	14	37
7th	25	18	31
11th	65	48	80

Table 1 shows a summary of the current measured at each filter. Filter current is characterized by the fundamental component and the harmonic component. The harmonic current in a filter is predominantly at the tuned frequency of the filter. The harmonic current in the 5th harmonic filter is 300 Hz current (5th harmonic), the harmonic current in the 7th harmonic filter is 420 Hz current, and the harmonic current in the 11th harmonic filter is 660 Hz current. The fundamental current into the filters will increase as the bus voltage increases.

Measurements at the capacitor banks show that the capacitors are filters to higher order harmonic current, like the 13th harmonic. Figure 12 shows the measurement snapshot of the capacitor bank current. 10 % of the capacitor bank current is 13th harmonic current. This occurs because low impedance is created by the parallel combination of the capacitor banks and the system inductance. The system inductance is dominated by the substation transformer reactance.

The power factor correction installed at the 400 HP Roller Mill ID Fan creates a similar situation. The current measurements at the Roller Mill ID Fan feeder show 13th harmonic current. Some 13th harmonic motor current is not necessarily harmful to the motor. Bus voltage distortion and operating experience are the best indicators of potential motor problems caused by harmonics. Harmonic voltage distortion begins to seriously impact motor life when it reaches 8% to 12%, or higher. Another reason to not be too concerned about the harmonic current in the Roller Mill ID Fan feeder is that 13th harmonic current is positive sequence current. Positive sequence current creates a field that rotates in the same direction as the field created by fundamental, 60 Hz, current. Negative sequence current (5, 9, 15 harmonic) is the greatest concern to motor operation.

THD_V with Different Capacitor Bank Configurations

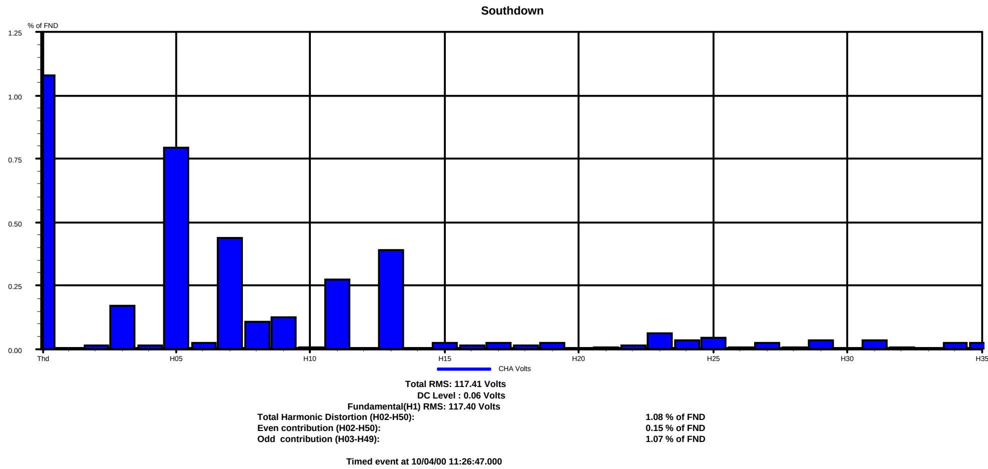


Figure 14: THD_V with Both Capacitor Banks On-line

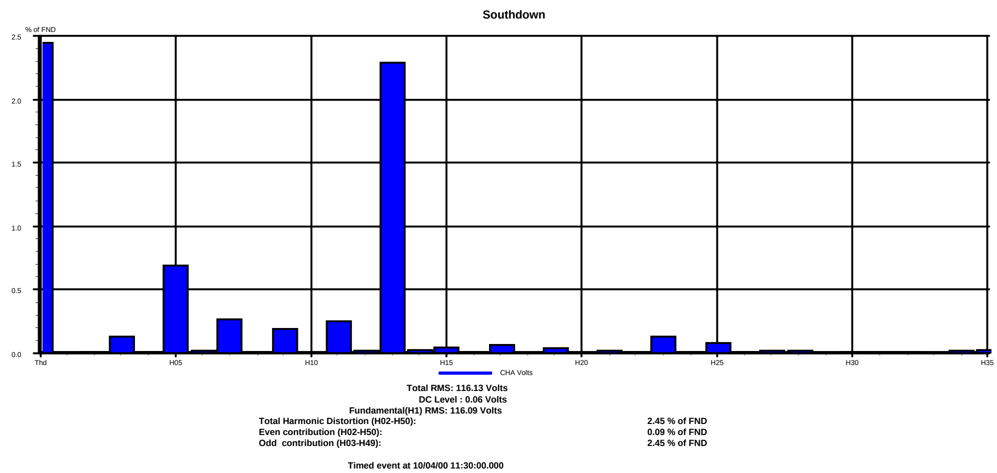


Figure 15 - THD_V with One Capacitor Bank On-line

A comparison of Figure 14 and Figure 15 shows that the high impedance caused by the parallel combination of the capacitor banks and the system inductance moves from near the 7^{th} or 8^{th} harmonic to somewhere closer to the 13^{th} harmonic.

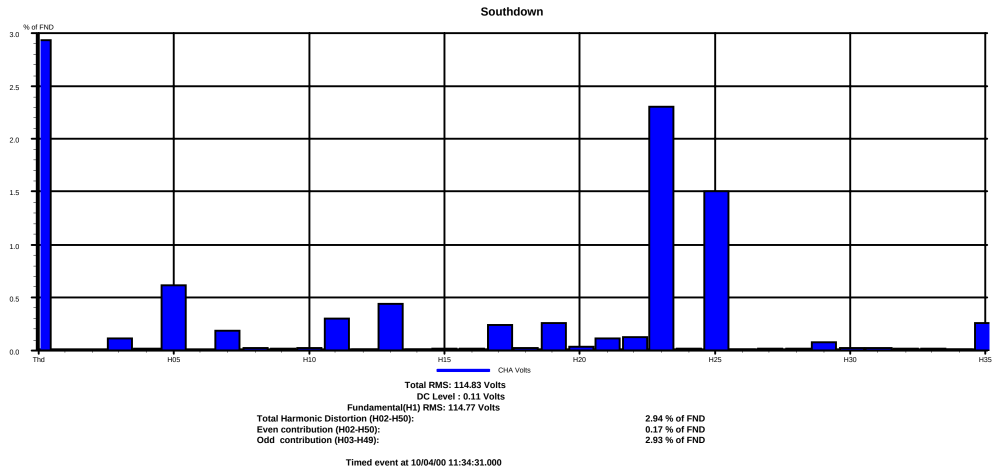


Figure 16 - THD_V with No Capacitor Banks On-line

Figure 16 shows that the system parallel resonance has moved to a higher frequency between the 20th and 25th harmonic.

The measurements show that the normal capacitor bank configuration, both steps on-line, is the best configuration as far as minimizing bus THD_V. It is not clear from the measurements how the capacitor bank configuration affects the 21 Fan harmonic filter current.

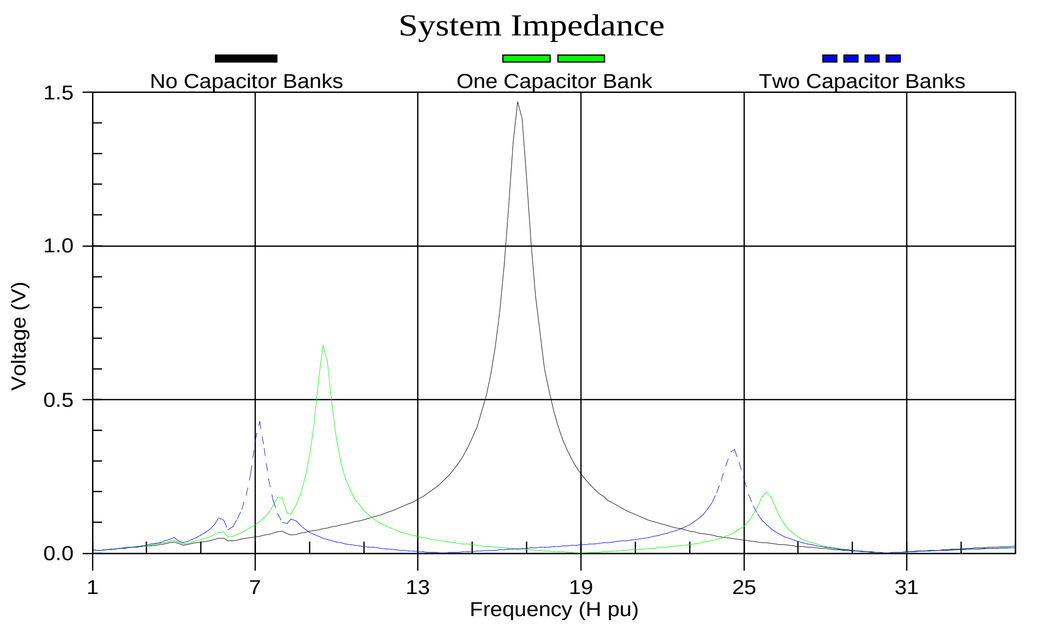


Figure 17 - Simulated System Impedance with different Capacitor Bank Configurations

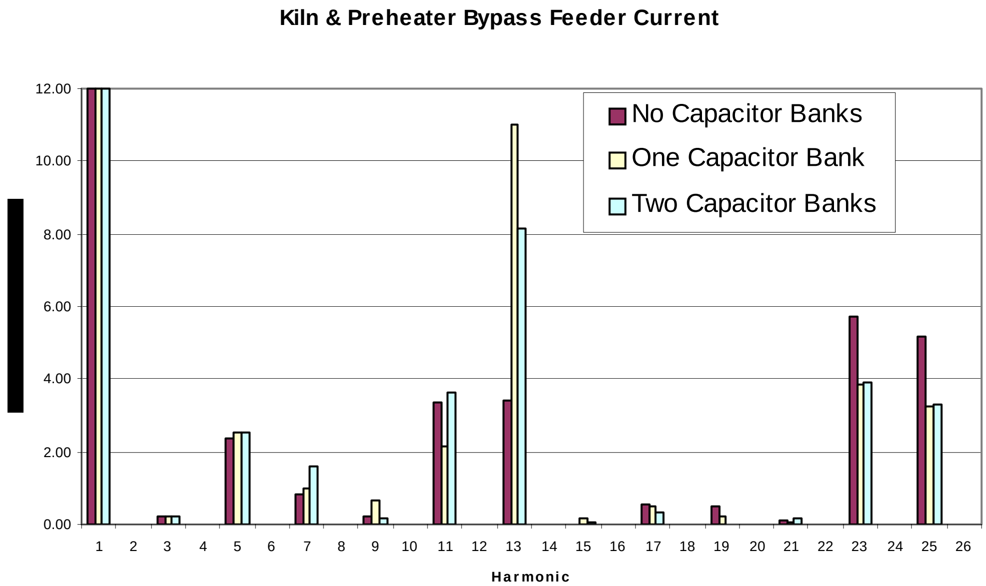


Figure 18 - Kiln & Preheater Bypass Feeder Current

The chart of the Kiln & Preheater Bypass feeder current shows that the 13th harmonic current is highest with one capacitor bank on-line, it is lowest with no capacitor banks on-line. These results coincide with the system impedance evaluations and with the voltage distortion recorded during the different capacitor bank configurations.

13th harmonic current from the 21 Fan and from the Kiln Main Drive normally flows into the capacitor banks. The capacitor banks are filtering 13th harmonic current.

HARMONIC SIMULATIONS

Electrotek developed a power system model for the facility and the associated utility power system. The model is used to simulate harmonic voltage distortion and to evaluate power system impedance with respect to power system configurations and equipment.
Simulations were performed to evaluate solutions that focused on improving the reliability of the process by eliminating the overload of the harmonic filters at the 21 Fan. Simulations are also used to evaluate the impact that specific solutions have on the entire plant power system and if solutions introduce any operational restrictions.

The simulations show that the harmonic filters at the 21 Fan are providing harmonic current control for the 21 Fan Drive and the Kiln Main Drive. Operational experience has proven that the harmonic filters are not designed to control the harmonic current from any loads other than the 21 Fan Drive. Calculations show that the filter design for application at the 21 Fan Drive alone is questionable.

Basecase

The harmonic simulations performed with SuperHarm were verified with the measurements that were taken at the facility. Measurements are used to create the base case for the harmonic simulations. The measurements that represent the worst-case harmonic current injected into the power system are used to develop the base case model. The base case represents "normal" conditions – both capacitor bank steps on-line and the plant operating with both finish mills running. The base case simulations are compared with the measurements to verify the accuracy of the model.

The simulated THD_V at the main 4160 volt bus is 1.22%.

Table 2 - Basecase Harmonic Filter Phase Current (amps)

	Basecase - Present Configuration		
Filter Current	Fundamental	Harmonic	RMS
5 h Filter	30.4	17.6	35.1
7 h Filter	22.3	16.1	27.5
11 h Filter	58.7	82.2	100.9

The table shows the phase current into each filter for the Basecase simulation. The results compare with the measured values.

5th Harmonic Filter at 4160V Main Bus

A common approach to controlling harmonic current is to install a passive harmonic filter (or multiple filters). Passive harmonic filters are normally implemented at a main bus or where the voltage distortion problems are being experienced. The implementation of harmonic mitigation depends on many other considerations, like – initial cost of mitigation equipment, installation costs, operation costs, maintenance, control of equipment, space requirements, impact on the power system impedance, impact on other equipment, voltage rise, and resulting power factor. Distributing harmonic filters throughout a facility is usually more expensive to implement than consolidating the control of harmonic current at a main bus. It is more difficult to evaluate and control the operation of filters distributed throughout a facility.

This case evaluated the system with a 1500 kVAr harmonic filter tuned to the 5^{th} harmonic and a 2400 kVAR fixed capacitor bank. The idea is to utilize the fixed capacitor bank for power factor compensation and it also filters higher order harmonic current like the 13^{th} harmonic. The new 5^{th} harmonic filter would limit the amount of harmonic current into the 21 Fan harmonic filters from other nonlinear loads.

Table 3 - 21 Fan Filter Phase Current – 5^{th} Harmonic Filter at 4160V Main Bus

	5h Filter at Main Bus		
Filter Current	Fundamental	Harmonic	RMS
5th harmonic	30.3	17.7	35.1
7th harmonic	22.2	14.3	26.4
11th harmonic	58.4	78.6	97.9

Table 3 shows the simulated phase current into each 21 Fan harmonic filter. The simulations show that installing a 5^{th} harmonic filter at the main bus does not reduce the filter current during normal operation. The results suggest that the harmonic current into the filters from sources other than the 21 Fan and the Kiln Main Drive is normally very small.

New Feeder to Supply the Kiln Main Drive

Simulations were performed with a new dedicated feeder for the Kiln Main Drive.

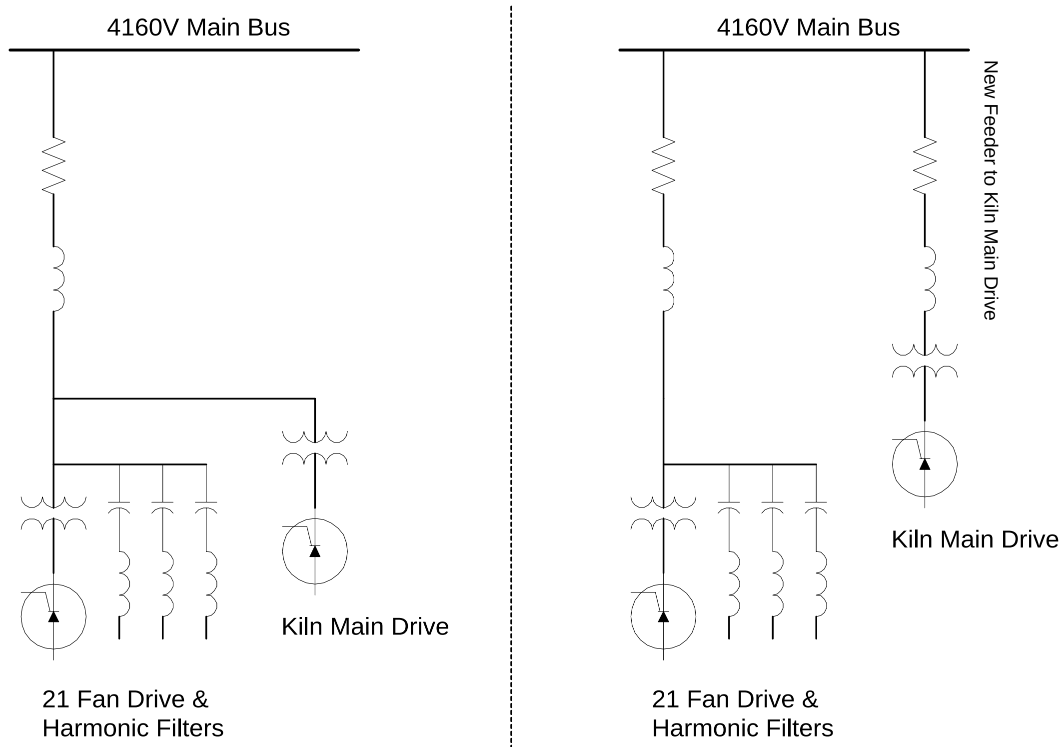


Figure 19 - Kiln Main Drive Power

The figure shows the present configuration for the supply of power to the Kiln Main Drive and a simple one-line diagram showing a new feeder for the supply of power to the Kiln Main Drive. The Precipitator ID Fan and the Quench Fan should also be supplied from the new feeder.

Table 4 - 21 Fan Filter Phase Current – New Feed to the Kiln Main Drive

	New Feed to Kiln Main Drive		
Filter Current	Fundamental	Harmonic	RMS
5 h Filter	30.9	6.1	31.5
7 h Filter	22.7	5.1	23.3
11 h Filter	59.7	80.6	100.3

The table shows that there is a significant decrease in the harmonic current into the 5th and 7th harmonic filters when the Kiln Main Drive is fed from a dedicated feeder and not tapped off of the 21 Fan feeder. The reduction in rms current correlates to the reduction in harmonic current.

New Feeder and 5th Harmonic Filter at the Main Bus

Simulations were performed with a 1500 kVAr 5th harmonic filter installed at the 4160 volt bus and with a new feeder to the Kiln Main Drive.

Table 5 - 21 Fan Filter Phase Current – New Feeder and 5th Harmonic Filter

5h Filter at Main Bus & New Feed to Kiln Main Drive			
Filter Current	Fundamental	Harmonic	RMS
5 h Filter	30.8	2.4	30.9
7 h Filter	22.6	3.0	22.8
11 h Filter	59.5	76.7	97.1

The simulations show that this solution results in the least amount of current in the 21 Fan harmonic filters.

The impedance between the Kiln Main Drive and the 21 Fan harmonic filters is increased when the Kiln Main Drive is supplied from a new dedicated feeder. The added impedance helps to decrease the harmonic current into the filters from the Kiln Main Drive. The 5th harmonic filter at the main bus limits the amount of harmonic current to the 21 Fan filters from other plant drives.

Frequency Scans

Frequency scans are performed to show system impedance as a function of frequency.

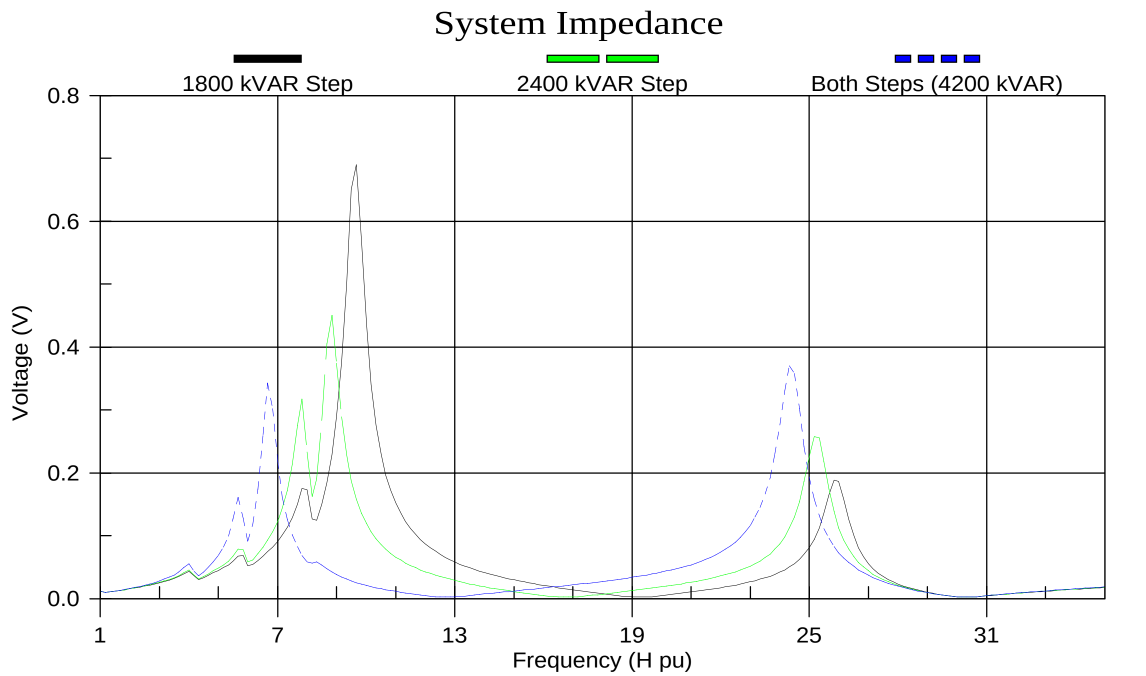


Figure 20 - System Impedance with 1800 kVAr & 2400 kVAr Steps

The figure shows that a parallel resonance exists between the 5th and 7th harmonic with both the 1800 kVAr and the 2400 kVAr steps on-line. Parallel resonances at characteristic harmonic frequencies (5, 7, 11, 13, etc.) should be avoided when applying power factor correction. The frequency scans also shows that a series resonance exists at the 13th harmonic when both banks are on-line.

Capacitor banks will often detune themselves during operation when a parallel resonance at a characteristic harmonic causes voltage to rise high enough to cause individual capacitor cans to fail. Capacitors will fail until the parallel resonance moves away from the characteristic harmonic. As cans fail, the parallel resonance will shift to higher frequencies in the spectrum. High harmonic current in capacitors can also cause them to fail.

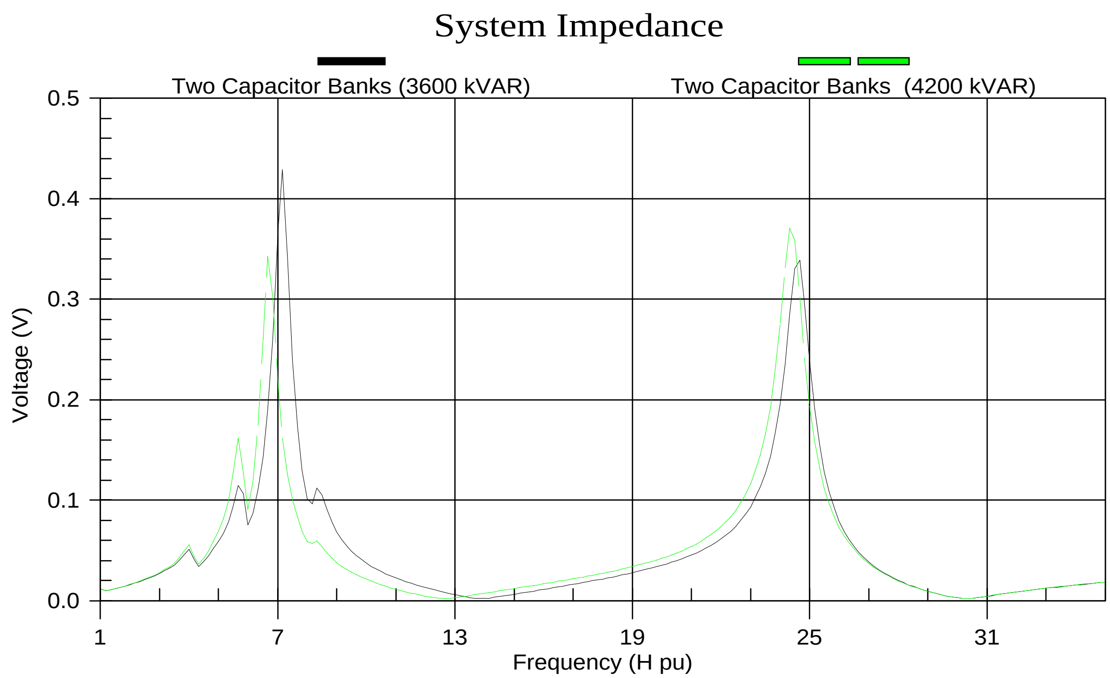


Figure 21 - System Impedance with Original kVAr and Present kVAr

Figure 21 shows how the system impedance has changed from the original compensation of 4200 kVAr to the present. The system impedance does not seem to have changed much, but plant operation and system configuration will affect the outcome of the interaction between plant loads and the system impedance.

An increase in system voltage can be the difference between a capacitor failing or not when a parallel resonance exists at a characteristic frequency. Bus voltage will increase at night, during the weekend, and when large loads are secured, like one of the mills at the plant. It is not certain what scenario caused capacitors to fail.

Figure 22 shows the results of the frequency scan with the 1500 kVAr 5th harmonic filter at the main bus. The recommended filter creates a series resonance is at the 5th harmonic. Compensation is added to the remaining capacitor bank to increase the total compensation of the bank to 2400 kVAr. 2400 kVAr of compensation places the parallel resonance near the 9th harmonic.

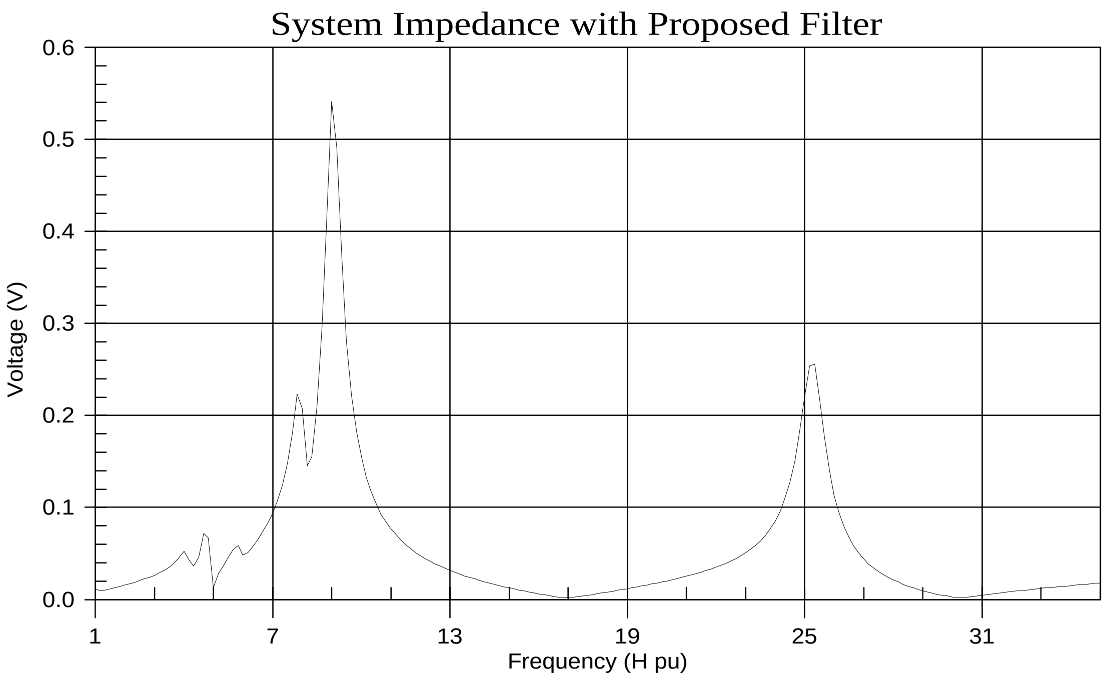


Figure 22 - System Impedance with Recommended 5th Harmonic Filter

Harmonic filters at various harmonic loads

The harmonic filters installed at the 21 Fan were not designed for application at the cement facility. The filters appear to be designed for the control of harmonic current injected by the 12-pulse A-B drive and nothing else. It is difficult to successfully apply harmonic filters at different harmonic loads. It is even more difficult to apply filters at one of several harmonic loads.

Applying harmonic filters at the drive is theoretically appealing because it limits harmonic current to the source. There is no easy, reliable, or relatively inexpensive way to implement this option. In order to avoid overloading, the filters often have to be installed with isolating reactors to prevent the flow of harmonic currents from other loads. This increases the cost of the individual filter installations. It is apparent that the filters are absorbing harmonic current from the 600 HP Kiln Main Drive. The filters are connected very close to where the Kiln Main Drive feeder taps off of the main Kiln & Preheater Bypass feeder.

The impedance of the long feeder from the main 4160 volt bus to the 21 Fan may limit the filter harmonic current from other ac and dc drives in the plant. How much current in the filters is from other drives depends on how many steps of the capacitor bank are on-line and what plant loads are operating.

Harmonic filters are usually applied at the main bus level when there are several harmonic loads. Even if the A-B drive were the only nonlinear load at the facility, the filters should be designed for reliable operation with 1.0% to 2.0% THD_V due to the utility supply.

RECOMMENDATIONS

1. Electrotek recommends that the Kiln Main Drive be supplied from a new feeder. The Precipitator ID Fan and the Quench Fan may be supplied from the new Kiln Main Drive feeder, also. Supplying the 21 Fan Drive and the Kiln Main Drive from different feeders will lower the current into the 21 Fan harmonic filters and will increase the reliability of the process. Performance of this recommendation may allow the client to forego the performance of Recommendation 5, the installation of a 2000 kVAr filter at the main bus. This is explained further with Recommendation 5.

2. The 5th harmonic filter and the 7th harmonic filter at the 21 Fan Drive have been detuned by utilizing the 105% tap of the respective filter reactors. The 11th harmonic filter should be detuned also if it has not been. Calculations show that using the 105% taps on the 0.83mH filter reactors will decrease the current into the 11th harmonic filter. This recommendation may be performed at any time.

3. The A-B 21 Fan Drive trips off-line when a harmonic filter overload trips because the harmonic filters do not have dedicated breakers to open and protect the filters. The same breaker serves as protection for the 21 Fan Drive isolation transformer and each filter. The company could improve the uptime of the 21 Fan Drive and the plant process by serving each filter through a dedicated breaker and removing the interlocks between the filter overloads and the main breaker. It makes sense to control what filters are on-line at the same time and there are filter combinations that should not cause the 21 Fan Drive to trip.

   These filter configurations could be permitted during drive operation:
   1. All three filters off-line.
   2. 5th harmonic filter on-line.
   3. 5th and 7th on-line.
   4. 5th and 11th harmonic filters on-line.
   5. 11th harmonic filter on-line.
   6. All three filters on-line.

   This recommendation may be performed at any time.

4. The amount of compensation that should be installed as a fixed capacitor bank is 2400 kVAr. The one-line drawing shows that one step of the capacitor bank used to be 2400 kVAr. This recommendation is to operate with one 2400 kVAr step on-line. 2400 kVAr is a good amount of compensation because the system parallel resonance is near the 9th harmonic. The 9th harmonic is acceptable because it is in between the characteristic 7th and 11th harmonics.

   This recommendation can be performed at any time. It appears that this could be performed by company personnel and requires no material expense. Capacitors could be removed from the other capacitor bank (the 1800 kVAr bank) to increase the compensation of the 2400 kVAr bank back to its original value.

5. The old 1800 kVAr capacitor bank should be converted to a 2000 kVAr 5th harmonic filter. Electrotek recommends that the filter be tuned to 297 Hz. The recommended filter is designed with 4800 volt capacitors so the effective compensation of the filter will be about 1560 kVAr. The harmonic filter at the main bus will greatly reduce the amount of 5th or 7th harmonic current into the 21 Fan filters from other adjustable speed drives. The filter design specifications are included in the appendix at the end of the report.

   This recommendation does improve on all of the other recommendations, but it may not be necessary after the Kiln Main Drive is supplied from a new feeder. Electrotek suggests that the company implement Recommendation 1 and evaluate the operation of the 21 Fan Drive and the harmonic filters. The evaluation should include measurements at the 21 Fan harmonic filters for at least one week. The evaluation may show that the investment in a 5th harmonic filter may not be cost effective.

6. A harmonic evaluation should be performed before the plant substation is upgraded or before major equipment or system changes are made. Examples of things that will need to be evaluated are: 1. System Impedance. Determine where the parallel resonance is that is created by the parallel combination of the 2400 kVAr fixed capacitor bank and the system inductance. The substation transformer greatly influences the system inductance and the resulting system impedance. 2. Determine the affect that new loads or a new substation transformer will have on the loading of the 5^{th} harmonic filter, the 21 Fan filters, or the harmonic voltage distortion.

   It is very important that this recommendation is applied. Electrotek will be happy to provide the company with advice on whether or not a harmonic evaluation or an engineering study needs to be performed. This advice is free of charge.

Appendix A: Filter Design Spreadsheets

Filter Calculations: **Southdown Main Bus**

Filter Specification:	**5 th**	**Power System Frequency:**	**60 Hz**
Capacitor Bank Rating:	**2000 kVAr**	**Capacitor Rating:**	**4800 Volts**
Rated Bank Current:	**241 Amps**		**60 Hz**
Nominal Bus Voltage:	**4160 Volts**	**Derated Capacitor:**	**1502 kVAr**
Capacitor Current (actual):	**208.5 Amps**	**Total Harmonic Load:**	**3000 kVA**
Filter Tuning Harmonic:	**4.95 th**	**Filter Tuning Frequency:**	**297 Hz**
Cap Impedance (wye equivalent):	**11.5200 Ω**	**Cap Value (wye equivalent):**	**230.3 uF**
Reactor Impedance:	**0.4702 Ω**	**Reactor Rating:**	**1.2471 mH**
Filter Full Load Current (actual):	**217.4 Amps**	**Supplied Compensation:**	**1566 kVAr**
Filter Full Load Current (rated):	**250.8 Amps**		
Transformer Nameplate:	**12000 kVA**	**Utility Side Vh:**	**1.50 % THD**
(Rating and Impedance)	**6.00 %**	*(Utility Harmonic Voltage Source)*	
Load Harmonic Current:	**15.00 % Fund**	**Load Harmonic Current:**	**62.5 Amps**
Utility Harmonic Current:	**75.2 Amps**	**Max Total Harm. Current:**	**137.7 Amps**

CAPACITOR DUTY CALCULATIONS:

Filter RMS Current:	**257.3 Amps**	**Fundamental Cap Voltage:**	**4337.0 Volts**
Harmonic Cap Voltage:	**549.5 Volts**	**Maximum Peak Voltage:**	**4886.5 Volts**
RMS Capacitor Voltage:	**4371.7 Volts**	**Maximum Peak Current:**	**355.0 Amps**

CAPACITOR LIMITS: (IEEE Std 18-1980)

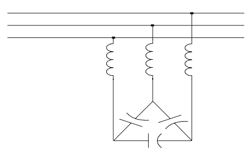
	Limit		Actual
Peak Voltage:	120%	⟵⟶	102%
Current:	180%	⟵⟶	107%
KVAr:	135%	⟵⟶	97%
RMS Voltage:	110%	⟵⟶	91%

FILTER CONFIGURATION:

4160 Volt Bus

Xl = 0.4702 Ω

2000 kVAr @
4800 Volts



FILTER REACTOR DESIGN SPECIFICATIONS:

Reactor Impedance:	**0.4702 Ω**	**Reactor Rating:**	**1.2471 mH**
Fundamental Current:	**217.4 Amps**	**Harmonic Current:**	**137.7 Amps**