APPLICATION GUIDE FOR HARMONIC MITIGATION

From the Engineers at Myron Zucker, Inc.

MZI

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PART 2 - APPLICATION GUIDE FOR HARMONIC MITIGATION

SECTION I - HARMONIC DISTORTION

UNDERSTANDING HARMONIC DISTORTION

In recent decades, commercial, institutional, and industrial facilities have experienced tremendous growth in the use of equipment that generates "harmonic" distortion in power systems. Examples of this equipment include DC drives, AC variable frequency drives, rectifiers, induction furnaces, and uninterruptible power supply (UPS) systems. Harmonic distortion creates a wave form resulting in higher than normal current values (and heat). Nuisance fuse blowing, circuit breaker tripping, over-heated transformers, and premature capacitor failure generally result from this condition.

If a facility utilizes any of the above mentioned equipment, an analysis by MZI can determine the harmonic distortion present in the system. Depending on the facility size and number of harmonic sources, the analysis can range from determining harmonic number and amplitude to a complete audit of the total electrical system.

DEFINITIONS

Harmonics are multiples of the fundamental frequency of an electrical power system. If, for example, the fundamental frequency is 60 Hz, then the 5th harmonic is five times that frequency, or 300 Hz. Likewise, the 7th harmonic is seven times the fundamental, or 420 Hz, and so on for the higher-order harmonics.

Harmonics can be discussed in terms of current or voltage. A 5th harmonic current is simply a current flowing at 300 Hz on a 60 Hz system. A 5th harmonic voltage occurs from the 5th harmonic current flowing through the impedances present. Usually harmonic levels are expressed as Total Harmonic Distortion (THD). The formula for calculating THD is as follows:

$$I_{THD} = \sqrt{\frac{\sum_{h=2}^{\infty} I_h^2}{I_1^2}} \times 100\%$$

If:

I_1 = current at 60 Hz = 250 Amps

I_5 = current at 300 Hz = 50 Amps

I_7 = current at 420 Hz = 35 Amps

Then...

$$I_{THD} = \sqrt{\frac{(50^2 + 35^2)}{250^2}} \times 100\% = 24\%$$

SECTION II - HARMONIC SOURCES

If these harmonic currents exist in a power system, they cause what is known as poor "power quality" or "dirty power." There are other causes of poor power quality, including transients such as voltage spikes, surges, sags, and ringing. As shown in **Figure 1**, harmonics are considered a steady-state cause of poor power quality because they repeat every cycle. **Figure 2** shows the resultant wave form from a 5^{th} harmonic present in a 60 Hz system.

Harmonics are caused by devices that draw non-sinusoidal currents when a sinusoidal voltage is applied. These are often devices which convert AC to DC. Some of the devices which cause harmonics are listed below:

- Adjustable Speed Drives (ASDs)
  - DC Drives
  - Variable Frequency Drives (VFDs)
- 6-Pulse Converters
- Power Rectifiers (e.g., plating systems
- Induction Heating Units
- Uninterruptible Power Supplies (UPSs)

The devices listed above use power electronics such as SCRs, diodes, and thyristors and have become a growing percentage of the load in industrial power systems. The majority use of 6-pulse converter similar to that in **Figure 3**.

Figure 1 - Fundamental and 5^{th} Harmonic

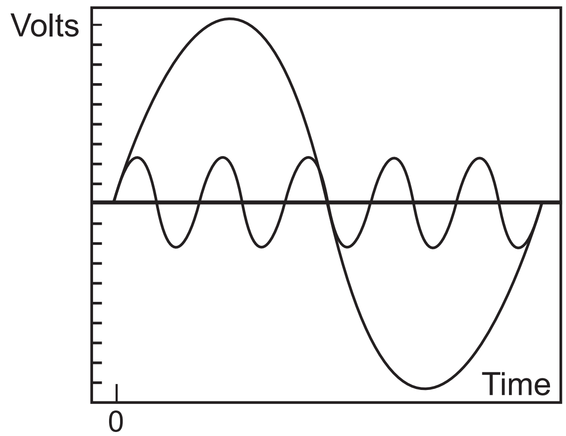


Figure 2 - Fundamental and 5^{th} Harmonic Combined

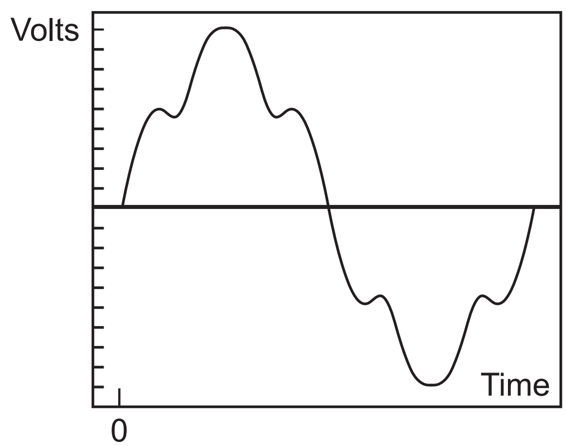
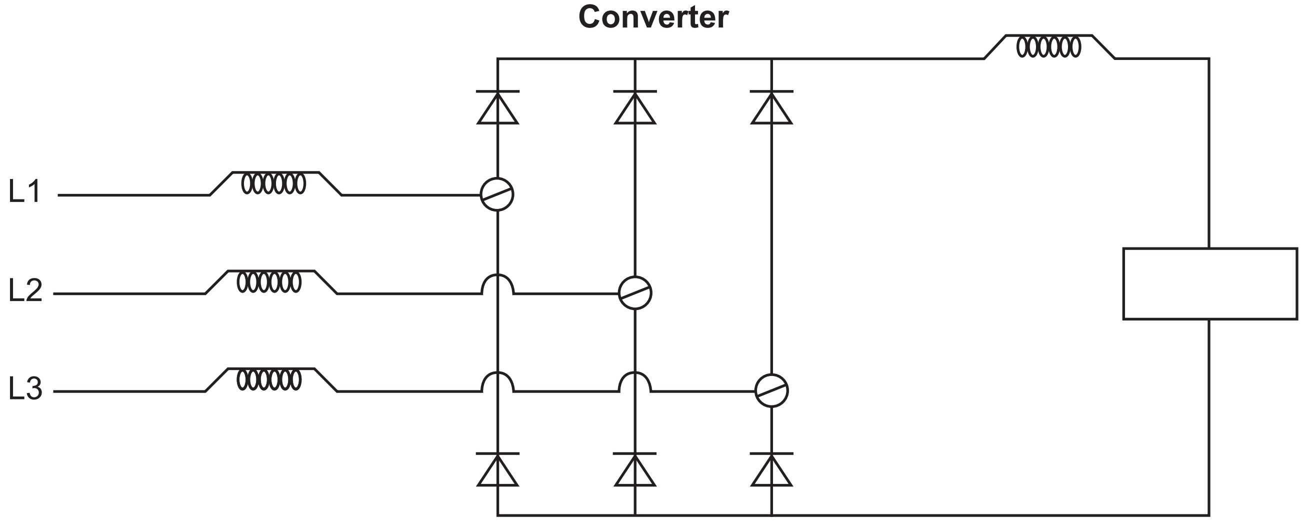


Figure 3 - A Typical 6-pulse Converter



Loads which cause harmonics do so as a steady-state phenomenon. Therefore, if a load is suspected to be non-linear, even an instantaneous reading of the load (while it is operating) can determine if it is harmonic producing.

Each type of load would typically exhibit a specific harmonic spectrum. For example, the most common industrial harmonic source is the 6-pulse converter. It exhibits a spectrum starting with the 5th harmonic and decreasing in amplitude throughout its spectrum. This spectrum is defined in the following formula and corresponding graph (**Figure 4**):

$h = np \pm 1$

where **h = harmonic numbers of the spectrum**
$n = 1, 2, 3, \ldots$
$p = 6$ for a 6-pulse converter

Therefore **$h = 5, 7, 11, 13, 17, 19, 23, 25, \ldots$**

Another common spectrum is that of a switch-mode power supply used for personal computers. This is found in commercial applications and has a spectrum starting with the 3rd harmonic and continuing with the triplens as the most dominant.

$h = 3, 9, 15, 21, 27, \ldots$

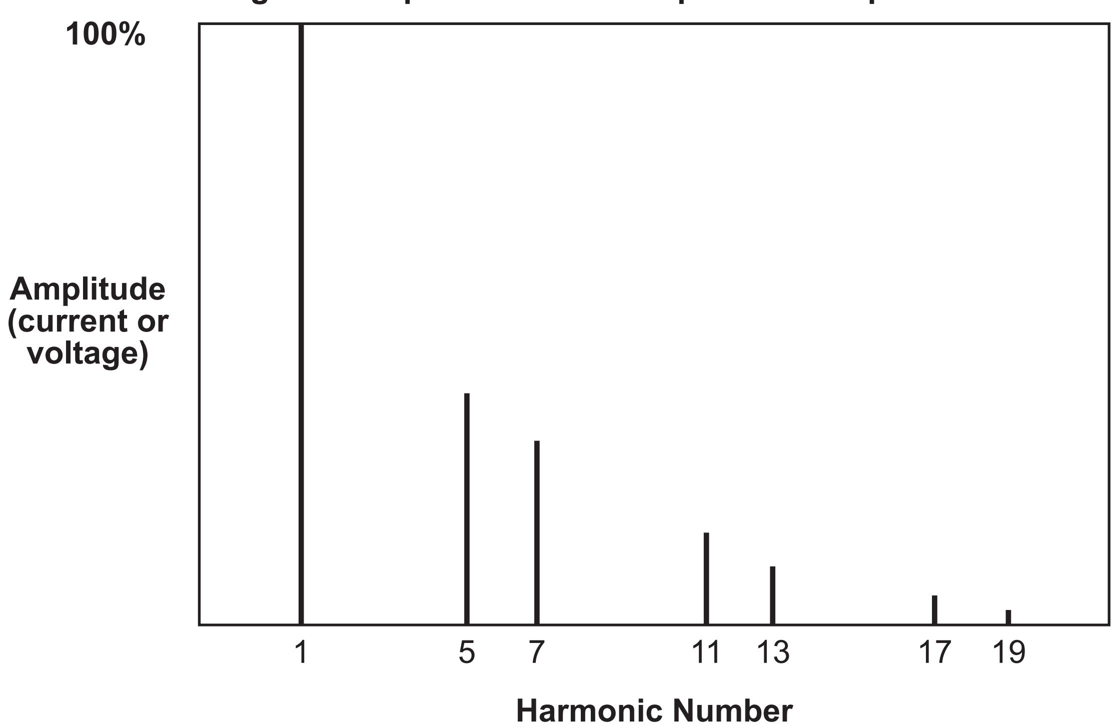
Large UPS systems exhibit yet another typical spectrum. They tend to use a 12-pulse converter and have the following spectrum:

$h = np \pm 1$

where **h = harmonic numbers of the spectrum**
$n = 1, 2, 3, \ldots$
$p = 12$ for a 12-pulse converter

Therefore **$h = 11, 13, 23, 25, 35, 37, \ldots$**

Figure 4 - 6-pulse Converter Spectrum Graph



SECTION III - PROBLEMS RESULTING FROM HARMONICS

There are many problems that can arise from harmonic currents flowing in a power system. Some are easy to detect. Other problems may exist and persist because harmonics are not suspected as the cause. Harmonic currents cause higher RMS current and voltage in the system. This can result in any of the following problems:

- Failed Power Factor Correction Capacitors
- Blown Fuses (no apparent fault)
- Tripped Circuit Breakers
- Overheated Transformers
- Overheated Conductors
- Damaged Insulation on Conductors
- Misfiring of AC and DC Drives

One of the larger problems is overheating transformers. In fact, a 10 °C rise in operating temperature of a transformer can reduce its life expectancy by 50%. Motors, capacitors, and conductors are similarly affected. Also, since harmonic currents are at higher frequencies and tend to travel along the outside (skin effect) of the conductors, insulation breakdown is accelerated.

SECTION IV - THE NEED TO ADDRESS HARMONICS

One of the two most common problems for industrial power users is striving to meet IEEE Std. 519-1992. IEEE 519 is a standard developed for utility companies and their customers in order to limit harmonic content and provide all users with better power quality. In the future, some utility companies may impose a penalty for users producing harmonics. Some key areas of the standard shown in **Table 1** and **Table 2**.

The other most common problem resulting from harmonics is power factor capacitor failures, or a need to correct power factor in a harmonic environment. In a low-voltage systems (600 V or less), capacitors are typically the lowest impedance at harmonic frequencies. Therefore, they experience very high currents and increased heat, which cause them to fail. So even if meeting IEEE 519 is not the goal, dealing with harmonics may still be required.

When correcting power factor, there is the possibility of creating a resonant circuit. A resonant circuit occurs at the frequency when the impedance of the system (mostly the power transformer) and the impedance of the power factor capacitor are equal. This is called the resonant frequency.

The following formula can be used to find the resonant frequency in terms of harmonic number.

$$h = \sqrt{\frac{kVA_{SC}}{kVAr}}$$

h = resonant frequency in terms of harmonic number

kVA_{sc} = short-circuit capacity at the capacitor

kVAr = rated kVAr of the unswitched capacitance

If there are any sources of current at that frequency, they will be amplified. This will cause high distortion levels and could blow fuses or trip circuit breakers.

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TABLE 1

Voltage Distortion Limits

Bus Voltage at PCC*	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

NOTE: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.

*PCC is Point of Common Coupling

TABLE 2

Current Distortion Limits for General Distribution Systems (120 V Through 69 000 V)

Maximum Harmonic Current Distortion in Percent of I_L

Individual Harmonic Order (Odd Harmonics)

I_{SC}/I_L	<11	11<h<17	17<h<23	23<h<35	35<h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits above.
Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed

*All power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L

where

I_{SC} = maximum short-circuit current at PCC**.
I_L = maximum demand load current (fundamental frequency component) at PCC**

**PCC is Point of Common Coupling

SECTION V - LOCATING THE SOURCE OF HARMONICS

When electric power users need to correct power factor, or they desire to meet IEEE 519, they must first locate the source harmonics.

If the electrical power system is in the design phase, gather any and all information regarding the harmonics that may be produced by non-linear loads. A good start to locating harmonics and the resulting problems is to develop a detailed one-line diagram including system voltages, transformer impedances, ADS Hp ratings, power rectifier kVA ratings, UPS kVA ratings and capacitor kVAr ratings. MZI has produced a “Power Factor Correction & Harmonic Filter Questionnaire” which guides the user through a series of questions to obtain the data listed above and requests a one-line diagram.

The same approach should be used for an existing system. A harmonic study can be conducted to verify the system characteristics expected from the questionnaire or it can be done to determine the actual system characteristics. MZI can provide assistance with both methods of locating harmonics.

SECTION VI - SOLVING THE HARMONIC PROBLEM

Harmonics can be “trapped” by the application of a MZI tuned filter trap. The trap is an inductor-capacitor (LC) filter which provides a low-impedance path for the harmonic currents. It “traps” the harmonics between itself and the harmonic source. As in correcting power factor problems at the source with capacitors, MZI also recommends correcting harmonics problems at the source by using traps. For that reason, MZI manufactures ***Caltrap™*** brand harmonic filters from 10 to 100 kVAr, commonly tuned for the 5^{th} harmonic (other points available). MZI can also provide ***Caltrap™*** brand harmonic filters with an integral line reactor to further isolate harmonics and provide other line reactor benefits such as reduced voltage notching from ASDs. Typical installations are shown in **Figure 5** and **Figure 6**.

Figure 5 - *Caltrap™* Harmonic Filter

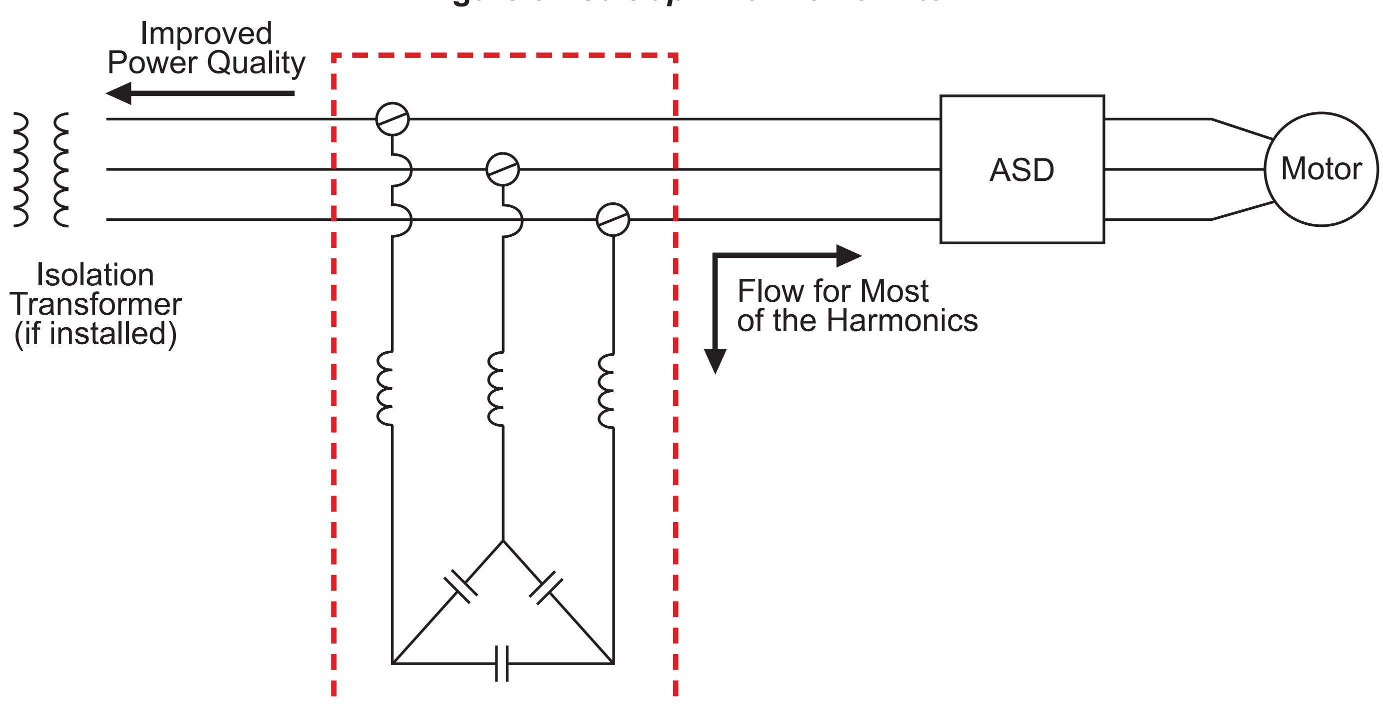
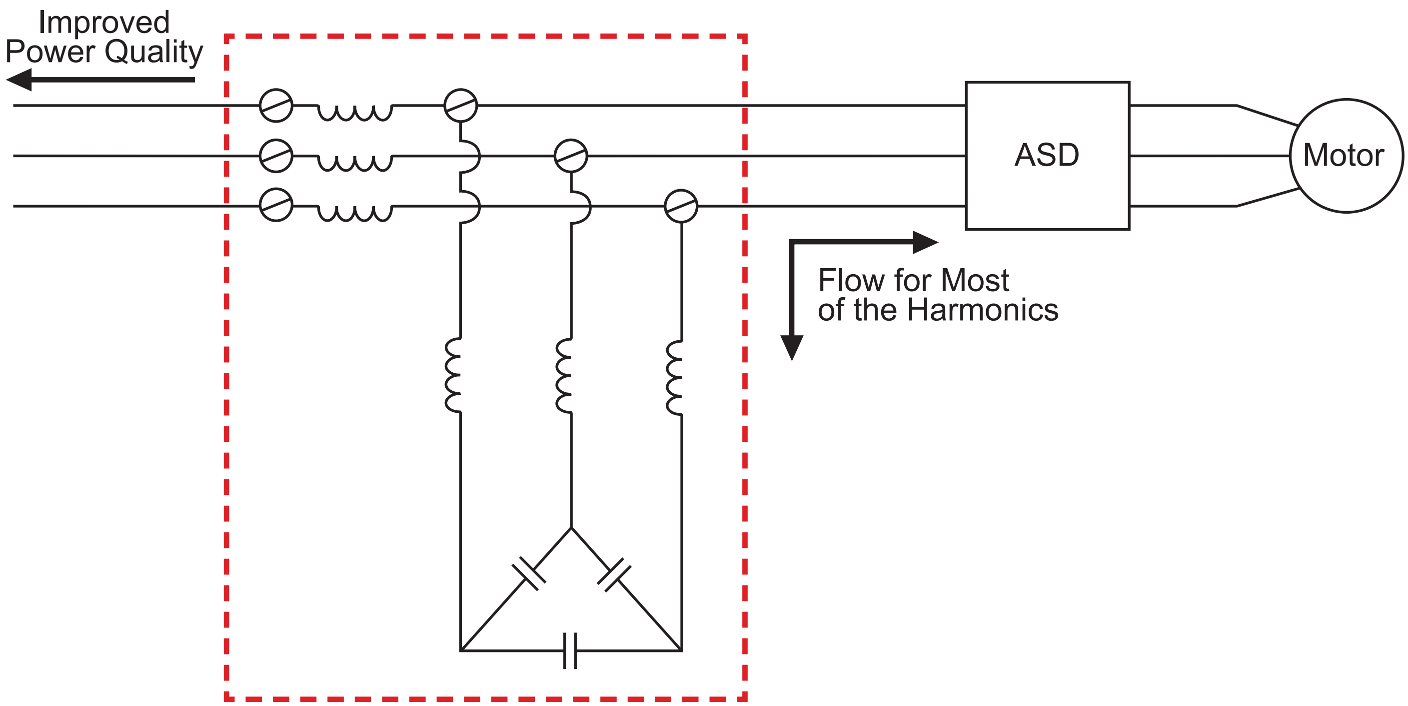


Figure 6 - *Caltrap™ with Line Reactor* Harmonic Filter



Although the best engineering practice is to trap the harmonics at the source, for economic reasons it may be advantageous to use one trap for several harmonic sources. For example, a machine with several ASDs could be corrected with one trap at the machine control panel. In the same way, several small ASDs fed from one bus duct could have a trap at the beginning of the bus duct, giving the rest of the system better power quality.

In some cases, an even larger trap can be provided at the switchgear, feeding an entire low-voltage system. This traps the harmonics before the service transformer and could be used to reduce utility voltage harmonics.

Myron Zucker, Inc. designs and manufactures ***Capacitrap®*** brand harmonic filters and automatically controlled ***Autocapacitrap™*** brand harmonic filters for these applications. A local MZI representative or the MZI Application Engineering Department can help determine what products are best for any application.

MZI has successfully installed ***Caltrap™***, ***Capacitrap®***, and ***Autocapacitrap™*** brand harmonic filters throughout the United States and other countries. Myron Zucker, Inc.'s quality products and over 50 years of experience in the power industry can be beneficial in any application.

NOTES