HarmonicGuard™

Drive-Applied Harmonic Filter
Supplemental Application Notes

Harmonic Currents

AC current is termed linear whenever its values can be expressed by a sinusoidal curve. A system's fundamental frequency is the baseline frequency at which it is designed to operate and, therefore, at which the reactive current is rated. Likewise, at the fundamental frequency, line current is linear. However, power electronic equipment is called nonlinear because it draws nonsinusoidal current. Observe how Figure 1a demonstrates the linear relationship between voltage and current for one phase of a 3-phase induction motor connected to the line, while Figure 1b illustrates the nonlinear current drawn by the same motor when powered by an adjustable drive. This nonsinusoidal current occurs at a frequency whose value is a multiple, or a harmonic, of the fundamental. Any current that is drawn at a harmonic frequency is known as a harmonic current. Power electronic equipment demands that harmonic currents flow. Any nonlinear, 3-phase load will draw current at the same harmonics: 5th, 7th, 11th, 13th, 17th, and 19th. However, the relative magnitude and phase angle of each harmonic will vary with the type of load, with the operating level, and with the electrical characteristics of the distribution system.

Figure 1a -
Linear Current

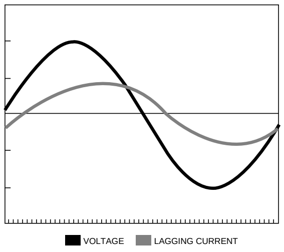
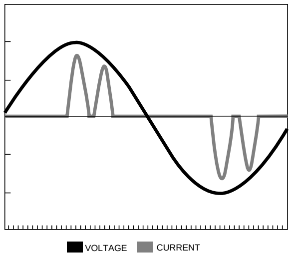


Figure 1b -
Nonlinear Current



Effects of Harmonic Current Distortion

On Operation: The most common problems created by harmonic currents include overheating of transformers, wires, and electrical switchgears; random tripping of circuit breakers; malfunctioning of electrical controls or computers; premature failure of motors or power capacitors; and reduction of power factor. Any transformer, switchgear, or distribution bus that is required to carry harmonic currents, in addition to the fundamental current, can overload, overheat, and fail. Even if the system is large enough to handle the load, the extra capacity consumed by the harmonic currents is no longer available for productive use.

On Equipment: Harmonic distortion can disrupt the performance of sensitive electronic equipment. Some of these disruptive effects include computer-controlled production equipment failure or misoperation, resulting in damaged product; electrical noise, disrupting both communications and computer operations; and interaction among multiple nonlinear loads, causing equipment failure or process downtime.

On Facilities: Wires, transformers, and motors within a plant electrical distribution system are all inductive in nature. The addition of capacitance, in the form of power factor correction capacitors, reduces the natural resonant frequency of a plant's tuned circuit. Harmonic currents will result from the resonant interaction between the power capacitors and the inductive elements in the electrical distribution system. Normally, lowering the resonant frequency of a plant causes no problems. However, if the plant is tuned nearly to one of the characteristic harmonic frequencies drawn by any of the nonlinear loads, extremely high resonant currents will flow throughout the system. Harmonic resonance may disrupt normal plant operation. Resonance is known to cause the failure of switchgears, transformers, capacitors, and wires. In general, if power capacitors are present, nonlinear loads will cause resonance problems. Thus, if nonlinear loads are present, power capacitors can only be safely added when harmonic currents are controlled.

On Power Factor Capacitors: As the frequency increases, power capacitors show a corresponding decrease in impedance. This inverse relationship causes mutiplication of harmonic currents. Consequently, the capacitors can become overloaded. This results in either fuse operation with the loss of power factor correction or in failure of the capacitor cells.

Harmonic Voltage Distortion

The Source: Harmonic currents flowing across circuit reactances and resistances create voltage drops at each existing harmonic frequency. These harmonic voltages add to and, thereby, distort the fundamental source voltage. As indicated by the equation, $X_L = 2\pi f L$, the inductive reactance is directly proportional to the frequency. Consequently, relative to the fundamental frequency, each individual harmonic frequency present will cause any inductance to have its reactance multiplied by a factor corresponding to the numerical harmonic. For example, at the fifth harmonic, any inductance will have five times the reactance relative to that value at the fundamental frequency; at the seventh harmonic, the same inductance will exert seven times the reactance; and so forth.

The Magnitude: The actual magnitude of total harmonic voltage distortion depends on the impedance of the AC lines. Harmonic currents flow through the AC lines, which always contain some impedance, and create some level of voltage distortion. Since a "stiff" AC source contains low AC line inductance, the resulting harmonic current distortion will be high (greater than 100%) but the harmonic voltage distortion will be low (less than 2%). However, a "soft" AC source contains high AC line inductance, which results in low harmonic current distortion (approximately 30% or less) but in high harmonic voltage distortion (greater than 5%). Due to higher inductance, less harmonic currents run through the "soft" AC lines. Nonetheless, the remaining harmonic currents flow across high source inductive reactances and generate high harmonic voltages. These harmonic voltages then add to the fundamental voltage and cause high total harmonic voltage distortion.

Effects of Harmonic Voltage Distortion

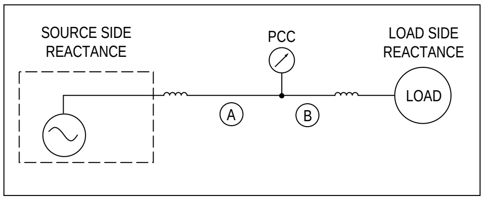


Figure 2

On PCC Measurements: The Point of Common Coupling (PCC) is the electrical interface between the utility distribution system and the facility electrical distribution system. The distortion limits in IEEE 519, 1992, define the quality of the power on the electrical distribution system. Overall, combined voltage distortion can be controlled if individual industrial and commercial systems contribute distortion levels that are lower than those recommended in IEEE 519. For this purpose, the location at which impedance is added to the circuit relative to the PCC is pivotal for regulating the magnitude of the measured voltage distortion. When impedance is added on the source side of the PCC (Point A, Figure 2), harmonic currents in the circuit will be reduced. Still, the remaining harmonic currents will flow through a higher impedance before reaching the PCC. As a result, the voltage distortion registered at the PCC will be higher. However, when impedance is added on the load side of the PCC (Point B, Figure 2), the harmonic currents running through the line side of the PCC will decrease. Furthermore, the voltage distortion associated with the harmonic currents flowing through this impedance registers on the load side. Therefore, this voltage distortion does not add to the voltage at the PCC. Consequently, the voltage distortion measured at the PCC is not increased. Actually, increasing load side impedance reduces the voltage distortion at the PCC since the harmonic currents flowing across the constant source impedance have now been reduced.

Source of Poor Power Factor

For linear loads, power factor is related to a phase angle between voltage and current. However, when nonlinear loads are present, this relationship is no longer that simple. Once the harmonic currents created by these nonlinear loads are present, the familiar expression for determining power factor, kW/kVA, (real power/apparent power), is used. This ratio essentially represents that portion of the power which is available for productive work. Note that the apparent power, kVA, now incorporates both types of currents: the fundamental and the harmonic. It is the presence of a nonlinear load that reduces total power factor since a greater share of the apparent power is now contributed by the counterproductive harmonic currents. This condition could easily translate into a considerable expense due to the potential for power factor penalties.

Estimating Power Factor in the Presence of Harmonic Distortion

It is quite possible to obtain a fairly accurate estimate of power factor, kW/kVA, just by knowing the harmonic distortion that is present in the power distribution system. However, to do this, one must assume that the fundamental current is the only source that is enabling the load to do work and that harmonic currents do not contribute to the work being done. Based on this assumption, set kW in the equation to 1. Now, to account for the harmonic distortion that has been generated by a nonlinear load, the RMS (root-mean-square) summation of all currents present in the electrical distribution system is used to calculate kVA. Note that the harmonic distortion number (THD) is the RMS of the harmonics expressed as a percentage of the fundamental. Therefore, to determine kVA, square the distortion number (written in decimal form), add it to the square of the fundamental (always 1 per the initial assumption), and take the square root of this sum. For example, on a 30% THD of current, an accurate estimate of power factor would be obtained as follows:

$$PF = kW/kVA$$

$$PF = \frac{1}{\sqrt{1^2 + 0.3^2}}$$

$$PF = \frac{1}{\sqrt{1 + 0.09}}$$

$$PF = 1/(1.044)$$

$$PF = 0.958$$

Even though a 30% current distortion represents a very acceptable power factor of approximately 0.958, the resulting voltage distortion could still be quite high. As previously discussed, the magnitude of voltage distortion depends on the impedance of the AC lines. For this reason, many installations will need to add harmonic trap filtering as a means to lower voltage distortion to more acceptable levels.

Comparing Alternatives

Many technologies have been developed for the purpose of harmonic reduction. One such technology is the multipulse drive. The drives utilize a phase-controlling transformer and multiple 6-pulse diode bridges to rotate the phase angle of harmonic currents. In a 12-pulse drive, this rotation cancels 5th and 7th harmonic currents measured at the input of the transformer. Since HarmonicGuard™ filters are designed to relieve the 5th harmonic and a significant portion of the 7th harmonic, the comparative performance of these two techniques is similar. However, the economic impact of a 12-pulse drive is far greater.

The basis for cost comparison is simple. A drive-applied harmonic filter is manufactured from readily available components, such as line reactors and power capacitors. Most multipulse drive installations are application-specific. They require a custom-designed and built phase-shifting transformer and multiple modified diode bridges. In medium horsepower ranges (50-250hp), HarmonicGuard™ filters cost approximately 40% of the cost of a standard 6-pulse drive. Multipulse drives often increase the drive cost by a factor of 2.25 to 2.5.

A Practical, Cost-Effective Solution:

TCI HarmonicGuard™ drive-applied filters represent the industry's most cost-effective method of ensuring clean, protected drive installations. TCI HarmonicGuard™ filters combine the benefits of power factor capacitors with current and voltage harmonic reduction. The standard HarmonicGuard™ filter is tuned just below the 5th harmonic, the lowest harmonic demanded by a variable frequency drive. In addition to attenuating the 5th harmonic, this filter also removes a significant portion of the 7th harmonic. Although standard HarmonicGuard™ filters are available for loads ranging from 7.5 to 1,000 hp, they can be designed and manufactured to accommodate any size drive at any fundamental frequency.

How Drive-Applied Filters Work

The HarmonicGuard™ filter is composed of three elements: the tuned circuit, the line reactor, and the protection monitor. The harmonic filter itself is always connected on the input side of an adjustable drive, as shown in Figures 3a and 3b.

Tuned Circuit: The tuned circuit consists of a tuning reactor in series with a high endurance capacitor. This capacitor provides displacement power factor correction for the fundamental line current in the same manner as a standard power capacitor. Furthermore, it is designed to operate continuously at 225% of nominal fundamental current. The tuning reactor, combined with this capacitor, creates a tuned circuit that absorbs harmonic currents by providing a low impedance path for harmonic currents. This eliminates any possibility of resonant interaction between the capacitor and the electrical distribution system. As a bonus, the additional inductance that is inherent in the structure of the tuning reactor serves to protect the capacitor from high inrush

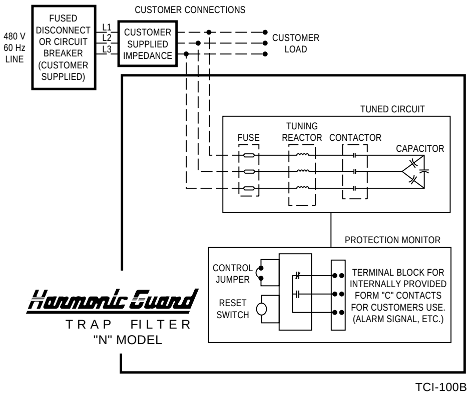


Figure 3a

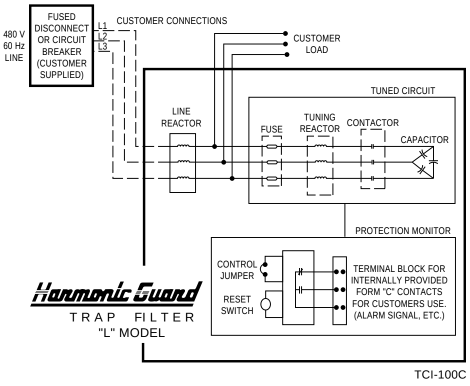


Figure 3b

currents. TCI tuning reactors are custom-designed, “K”-rated, and built to withstand the harmonic loads imposed by the tuned circuit.

Line Reactor: The “K”-rated line reactor provides impedance between the load and the line to protect the load from electrical surges. The extra impedance toward the line increases the effectiveness of the filter in removing harmonic current from the load. It does this by diverting the harmonic current onto a path of least resistance toward the trap filter. Furthermore, this impedance prevents the filter from absorbing harmonics already present in the electrical system, a situation which could overload the filter.

Protection Monitor: TCI builds each HarmonicGuard™ filter that is larger than 20 kVar with a 3-phase monitor circuit designed to protect against the unlikely prospect of a failure within the filter. The protection monitor serves to safeguard the filter from the harshness of the external, natural elements. Should an unexpected event occur, such as a voltage surge, the monitor evaluates the hazard potential of that event and initiates appropriate counteractive measures. The following scenarios demonstrate the multiple self-censoring and auto-correcting capabilities of the protection monitor. For example, if a fuse blows, leading to an unbalanced line condition, this monitor removes the trap from the line, indicates which fuse has blown, and signals the event to a remote location. In case a momentary overload occurs, the monitor checks to see if the condition continues. If the overload is transient, the monitor resets. If the overload persists longer than 20 seconds, the trap is switched off-line, an “overcurrent” indicator is lighted, and a remote signal is activated. If a severe overload occurs, the monitor instantaneously trips the unit off-line. This monitor, whose patent is pending, ensures that your process will not be disturbed in case something goes wrong within the HarmonicGuard™ filter.

Control

HarmonicGuard™ filters include contactors that can be controlled by an auxiliary contact lead from the drive. By switching the HarmonicGuard™ filter on and off with the drive it services, "automatic" power factor and harmonic improvement occurs without the expense of a separate controller.

Construction

TCI’s HarmonicGuard™ filters are manufactured to the highest industrial standards. Standard cabinets are custom-designed to NEMA 1 specifications. Other cabinet NEMA ratings are available. For System Integrators and OEMs, TCI HarmonicGuard™ filters are available in open style configurations that are designed to fit the customer’s preinstalled cabinets. Electrical components are oversized and derated to ensure reliable long-term performance. All TCI HarmonicGuard™ filters are UL-listed (Industrial Control Panels, File E140832). Detailed HarmonicGuard™ sample specifications are available upon request.

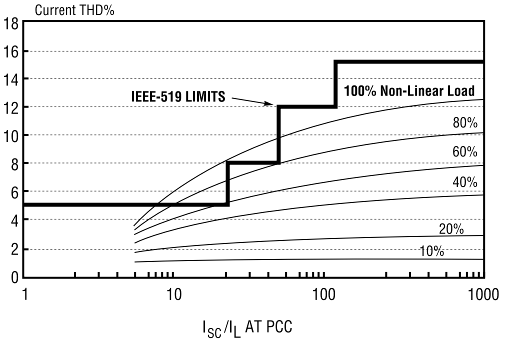
Selecting the Right Filter

Location: The HarmonicGuard™ filter is designed to be located on the input side of each drive that it will filter and is sized for the full load of that drive. This is the most effective application by which to meet harmonic distortion limits. When the required 5% line impedance is already supplied by a line reactor or an isolation transformer that is sized to the load, a filter without series impedance (“N” model) can be used. However, if line impedance is not already present, a filter incorporating a built-in line reactor (“L” model) must be specified.

Size: A simple sizing method is used to select the proper filter for a given load. This method takes into account both the quantity of harmonic distortion to be removed and the capacitance needed to improve the system total power factor. When this method is used, the total power factor is improved to 0.90-0.95. Depending on the bridge input type, use either of the following formulas to calculate kVAR values: kVAR(SCR)= 0.4 X kVA(hp) or kVAR(Diode)= .3 X kVA(hp). Thus, for a 900 kVA rectifier with an SCR input bridge, a 360 kVAR filter would be the appropriate size.

Meeting IEEE 519 Specifications

The most effective and affordable way to reduce total harmonic distortion to levels recommended by IEEE 519 is to install the HarmonicGuard™ drive-applied harmonic filter with each variable frequency or adjustable speed drive. The results that can be expected when AC adjustable drives are properly filtered are illustrated in Figure 4. In this graph, the ISC/IL ratio relates the available short circuit fault current to the maximum demand load current (the fundamental frequency component). It is a measure of the "stiffness" of the utility's electrical distribution system relative to the recipient facility's load. The more capacity the utility has, the higher this ratio. As demonstrated in Figure 4, when HarmonicGuard™ filters are properly sized and installed at a facility whose AC drive load is 60% (40% of the facility load is linear), the harmonic currents will be below the IEEE 519 limits for any sized utility system. Even for a single drive (100% nonlinear load), the IEEE 519 limits will be met in most cases. These filters have proven to be an ideal solution to the problem of meeting harmonic distortion limits.



% CURRENT THD AT PCC FOR
DC DRIVE WITH 5% L.R.,
WITH 5TH HARMONIC TRAP

Figure 4

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