Meeting IEEE 519-1992 Harmonic Limits

Using HarmonicGuard® Passive Filters

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Abstract

With the advent of IEEE 519-92, the increasing demand by utilities for power factor improvement, and the proliferation of non-linear loads in industrial power distribution systems, specification of harmonic mitigation has become common. Questions arise regarding the performance of passive harmonic trap filters in removing harmonic distortion.

Data from a number of TCI HarmonicGuard® trap filter installations have been collected which illustrate how closely IEEE 519-92 limits can be met. HarmonicGuard® filters have been installed, both for power factor improvement and to meet harmonic distortion limits based on IEEE 519-92.

A computer model has been developed to help predict the harmonic reduction that can be expected for specific load-filter combinations and the model has been verified with field data. This paper outlines and explains the computer model and details the application of harmonic trap filters. Computer-generated design curves are provided which can be used by a system designer to predict success in meeting harmonic specifications using HarmonicGuard® trap filters.

IEEE 519, 1981

IEEE 519, "Recommended Practices and Requirements for Harmonic Control in Electric Power Systems," was published in 1981. The document established levels of voltage distortion acceptable to the distribution system. This document has been widely applied in establishing needed harmonic correction throughout the electrical power industry. However with the increase in industrial usage of adjustable speed drives, rectifiers, and other non-linear loads, it became apparent that a rewrite of IEEE 519, treating the relationship of harmonic voltages to the harmonic currents flowing within industrial plants, was necessary to support control of harmonic voltages. The new IEEE 519, published in 1992, sets forth limits for both harmonic voltages on the utility transmission and distribution system and harmonic currents within the industrial distribution systems. Since harmonic voltages are generated by the passage of harmonic currents through distribution system impedances, by controlling the currents or system impedances within the industrial facility, one can control harmonic voltages on the utility distribution.

Unfortunately, there is some user confusion regarding the application and intent of the information included in IEEE 519, 1992. Section 10, "Recommended Practices for Individual Consumers" describes the current distortion limits that apply within the industrial plant. Consulting engineers and applications engineers may not be clear as to the proper use of Table 10.3, which outlines the limits of harmonic distortion as a function of the nature of the electrical distribution system.

This paper will explain, with examples, the proper use and interpretation of this table. Using a computer model, we have outlined the level of distortion one might expect to encounter for various types of loads and distribution systems and the level of correction obtainable through the use of line reactors and passive harmonic trap filters has been detailed. It is hoped that the readers of this paper will come away with a better understanding of the meaning and application of IEEE 519, 1992.

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Generation of Harmonic Currents

Power electronic equipment is called non-linear because it draws non-sinusoidal current. Fig. 1a shows the linear relationship between voltage and current for one phase of a 3-phase induction motor connected to the line, while Fig. 1b shows the non-linear current drawn by the same motor powered by an adjustable drive.

IEEE 519, 1992 defines a harmonic as, “A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.”

Linear Current

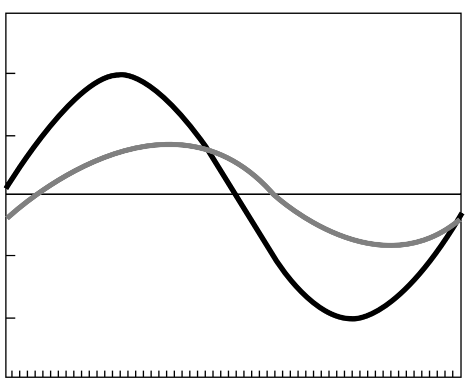


Figure 1a

Non-Linear Current

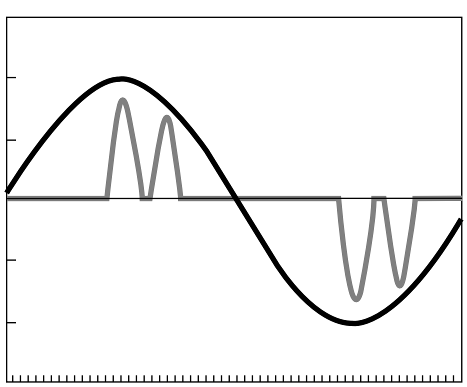
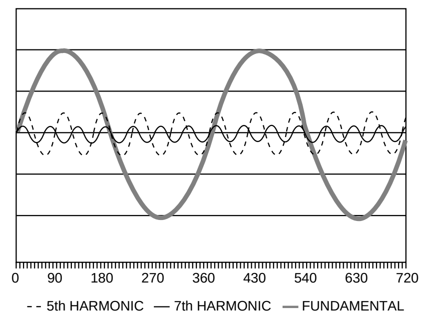


Figure 1b

Harmonics



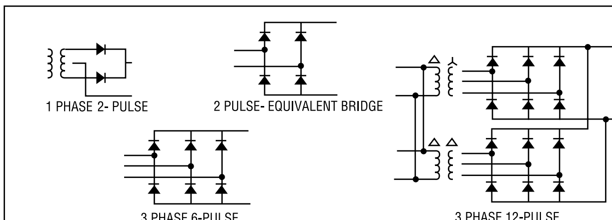
HARMONIC	FREQUENCY
1st	60
2nd	120
3rd	180
4th	240
5th	300
7th	420
9th	540
49th	2940

Figure 2a

Fig. 2a illustrates the frequency relationship of a number of harmonics. As the graph clearly shows, the 5th harmonic has five complete waves for each complete fundamental wave. It is important to remember that harmonic phenomena are “periodic” which indicates their continuous nature. While impulses or spikes in the power system may contain multiples of the fundamental frequency, it is the continuous phenomena which are addressed in the IEEE document and in this paper.

Currents drawn by non-linear loads are rich in harmonics. The harmonics present are a function of the distribution system and the circuit configuration of the distorting load. Typical industrial power systems are:

- 3-phase delta with loads connected phase-to-phase
- 3-phase 4-wire wye with loads connected phase-to-phase
- single phase loads connected phase-to-neutral



PULSE#	CHARACTERISTIC HARMONICS
2	3rd, 5th, 7th, 9th, 11th, 13th, 15th, 17th, 19th, ...
6	5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, ...
12	11th, 13th, 23rd, 25th, 35th, 37th, ...
18	17th, 19th, 35th, 37th, 53rd, 55th, ...

$h = kq \pm 1$

Figure 2b

Fig. 2b illustrates the most commonly utilized rectifier circuits. The harmonic frequencies produced by each of the circuits are characteristic of the number of rectifiers (or pulse number) in the circuit, and are called "Characteristic Harmonics." They can be determined using the equation, $h = kq \pm 1$, where h equals the harmonic number, k equals an integer, and q equals the pulse number. The table in Fig 2b contains characteristic harmonics of various rectifier circuits. Lower harmonics are eliminated when more rectifiers are used, but increasing complexity and cost of the circuit often offset the advantages of reduced harmonics. Note that for illustration purposes, diodes have been used in the circuits. The same circuits could contain SCR's instead of diodes with no change in the characteristic harmonics. Also observe that only odd harmonics are produced. Half-wave converters, which result in the production of even harmonics, are not approved for new installations, and it is recommended that they be phased out of older systems as quickly as possible.

While the characteristic harmonics are a function of the number of rectifiers in the circuit, the relative magnitudes of each harmonic depend on the parameters of the load(s) and the distribution system. As one might expect the number of possible load/distribution configurations is almost limitless. By concentrating on 3-phase loads connected to a typical 3-phase distribution system, we will be analyzing those systems that dominate the industry and are the highest consumers of power. The principles discussed are applicable to any load or system.

IEEE 519, 1992

Current Distortion Limits

Maximum Harmonic Current Distortion in % of I_L

Individual Harmonic Order (Odd Harmonics)

I_{sc} / I_L	< 11	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h$	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. TDD refers to Total Demand Distortion and is based on the average maximum demand current at the fundamental frequency, taken at the PCC.

* All power generation equipment is limited to these values of current distortion regardless of I_{sc} I_L.

I_{sc} = Maximum short circuit current at the PCC
I_L = Maximum demand load current (fundamental) at the PCC
h = Harmonic number

Figure 3

Fig. 3 is a representation of Table 10.3 from IEEE 519, 1992. In order to appreciate the impact of this IEEE document, it is important to understand the meaning of the terms used in Table 10.3.

1) PCC

PCC is the Point of Common Coupling and is probably the most important and most controversial term in the entire document. It is defined as the electrical connecting point or interface between the utility distribution system and the customer's or user's electrical distribution system. While simple in concept, identification of this point is sometimes misunderstood, which leads to confusion and mis-application of the specifications in the table.

Fig. 4 represents a typical small distribution system. The utility distributes power at 69 kV. The utility feeds a distribution line with 13,800 volt 3-phase 60 Hz power through an 8.5% impedance distribution 20 mVA transformer. The factory uses a 1000 kVA 6.7% impedance service transformer to step the 13,800 volts down to 480 volts, which is bused throughout the plant.

The columns of Table 10.3 which should be used to determine harmonic limits will depend on the location of the point of common coupling. PCC-1 is the primary of the service transformer. Often when the customer owns the service transformer, the utility will meter the medium voltage (in this case, 13,800 volts) at this point. If the utility meters the 480 volt bus, PCC-2 is the interface. As we shall see shortly, the allowable harmonic distortion depends on the defined PCC.

There is often a tendency to apply the limits of Table 10.3 to an individual load, as represented by point "A" in Fig. 4. One must remember that any distortion at this point is produced by the drive when it is operating, and will not affect the drive's functions. Furthermore, high distortion at point A does not necessarily result in out-of-limit distortion on the distribution system. If an attempt is made to meet limits for each individual load, one discovers either that currently available technology is incapable of doing the job, or high-cost equipment is needed. If one remembers that IEEE 519, 1992 is meant to apply to system harmonic distortion, rather than to individual load distortion, unnecessary expense can be avoided. (As we will discover later, the most effective way to meet harmonic distortion limits is to filter the harmonics at each individual load and measure them at the PCC.)

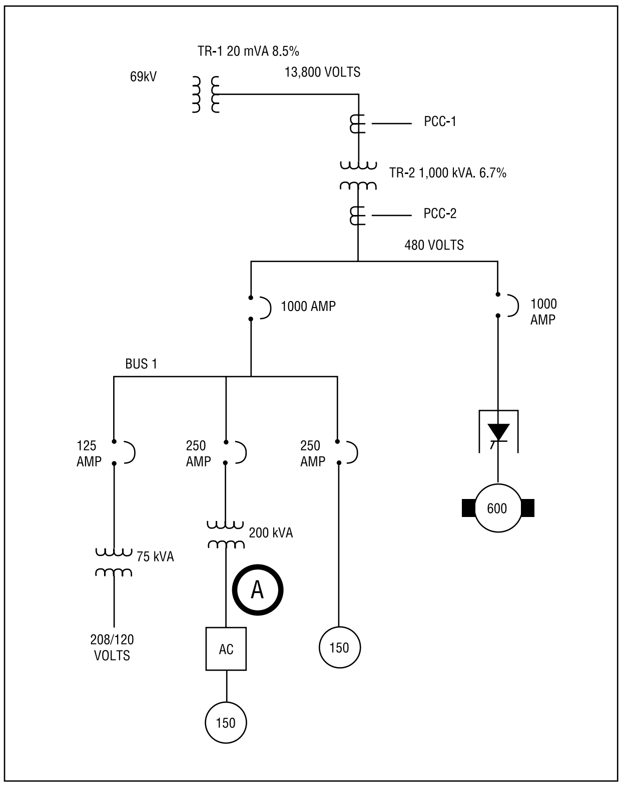


Figure 4

The selection of the PCC within the system is often done by the utility. However, plant engineers and specifying engineers should be aware of the effect the location of the PCC has on harmonic limits, and should work with the utility to ensure that the spirit of IEEE 519, 1992 is met without excessive expense to industry.

2) I_{SC}

I_{SC} is the available short circuit current at the point of common coupling. The I_{SC} is determined by the size, impedance, and voltage of the service feeding the PCC.

3) I_L

I_L is the maximum demand load current (fundamental frequency component) measured at the PCC. It is suggested that existing facilities measure this over a period of time and average it. Those creating new designs should calculate the I_L using anticipated peak operation of the facility.

Examples:

The proper use of the data in Table 10.3 can be illustrated with several sample calculations based on the system outlined in Fig 4

Sample Calculations:

Data

TR-1: 20 mVA, (20,000kVA) 8.5% impedance,69kV to 13,800 V
TR-2: 1,000 kVA, 6.7% impedance, 13,800 V to 480 V
Measured I_L: 1,000 amps
Measured Distortion: 90 amps 5th, 44 amps 7th

I_{sc} PCC-1

$$I_{sc} = \frac{\text{Full Load Current, TR-1}}{\text{Impedance, TR-1}}$$

Full Load Current

$$= \frac{20{,}000 \text{ kVA}}{13{,}800\text{V} \times \sqrt{3}} \times 1{,}000$$

$$= 838 \text{ amps}$$

$$I_{sc} = \frac{838 \text{ amps}}{0.085}$$

$$I_{sc} \text{ (PCC-1)} = \underline{\underline{9{,}858 \text{ amps}}}$$

I_{sc} PCC-2

$$I_{sc} = \frac{\text{Full Load Current, TR-2}}{\text{Impedance, TR-2}}$$

Full Load Current

$$= \frac{1{,}000 \text{ kVA}}{480\text{V} \times \sqrt{3}} \times 1{,}000$$

$$= 1{,}204 \text{ amps}$$

$$I_{sc} = \frac{1{,}204 \text{ amps}}{0.067}$$

$$I_{sc} \text{ (PCC-2)} = \underline{\underline{17{,}970 \text{ amps}}}$$

I_{RMS} of The Load

I_{RMS} of the load is the load current carried by TR-2 and the wiring. The higher the harmonic currents, the more the system capacity is used up carrying non-productive currents.

$$I_{RMS} = \sqrt{\sum_{n=1}^{\infty} I_n^2}$$

$$= \sqrt{I^2_{\text{Fundamental}} + I_3^2 + I_5^2}$$

$$= \sqrt{1000^2 + 90^2 + 44^2}$$

$$= 1{,}005 \text{ amps}$$

$$I_{RMS} = \underline{\underline{1{,}005 \text{ amps}}}$$

TDD And % Distortion of Each Harmonic

$$\text{TDD} = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2} \times 100}{I_{\text{Fundamental, Maximum Demand}}}$$

$$= \frac{\sqrt{90^2 + 44^2}}{1{,}000} \times 100 = 10\%$$

$$\text{5th Harmonic} = \frac{90 \text{ amps}}{1{,}000 \text{ amps}} \times 100$$

$$\text{5th} = 9\%$$

$$\text{7th Harmonic} = \frac{44 \text{ amps}}{1{,}000 \text{ amps}} \times 100$$

$$\text{7th} = 4.4\%$$

I_{sc} / I_L at PCC-1

$$I_L \text{ (13,800V)} = I_L \text{ (480V)} \left(\frac{480}{13{,}800}\right)$$

$$= (1{,}000 \text{ amps}) \left(\frac{480}{13{,}800}\right)$$

$$= 34.8 \text{ amps}$$

$$\frac{I_{sc}}{I_L} = \frac{9{,}858 \text{ amps}}{34.8 \text{ amps}} = \underline{\underline{283}}$$

I_{sc} / I_L at PCC-2

$$\frac{I_{sc}}{I_L} = \frac{17{,}970 \text{ amps}}{1{,}000 \text{ amps}} = \underline{\underline{17.5}}$$

4) I_{SC}/I_L

I_{SC}/I_L is a measure of the ratio of the available short circuit fault current at the PCC to the maximum demand load current (fundamental frequency component) at the same point. It is a measure of the "stiffness" of the electrical system relative to the load. For example, if Niagara Falls is available to feed a small load, the ratio is larger (>1000). If a small transformer with just enough capacity for the load is the only available power source, the ratio is small (<20).

5) TDD

TDD stands for Total Demand Distortion, based on the maximum demand load current (fundamental frequency component). It is a measure of the Total Harmonic current distortion at the PCC for the total connected load. TDD is not intended to be the limits for any individual load within the distribution system.

6) Harmonic Order (h<11, 11≤h<17, etc.)

These columns indicate the limits for any individual harmonic current at the PCC, expressed as a percentage of the fundamental frequency portion of the maximum demand load current.

PCC-1 As The Measuring Point

If PCC-1 is the measuring point, the data from Table 10.3 show that TDD permitted for an I_{SC}/I_L ratio of 283 is 15%. The 5th and 7th harmonics are each permitted to be 12%. The values measured (10% TDD, 9% 5th, and 4.4% 7th) are within the permitted limits and no further action is warranted. This should be expected, since a relatively small 1000 amp (830 kVA) load is being fed by a relatively stiff (20 mVA) system transformer.

PCC-2 As the Measuring Point

If PCC-2 is the measuring point, the data from Table 10.3 show that TDD permitted for an I_{SC}/I_L ratio of 18 is 5%. The 5th and 7th harmonics are each permitted to be 4%. The values measured are all greater than the permitted limits and this system would need harmonic mitigation to meet the requirements of IEEE 519, 1992. This is an example of a small load on a system which is only adequate for that load.

Increasing The Ratio To Meet Harmonic Limits

One way to meet harmonic limits is to increase the "stiffness" of the system, thereby moving into a new row on Table 10.3 and increasing the permitted harmonic levels. This can be done by installing a larger service transformer (in effect "de-rating" the transformer) or by installing a special "K" rated transformer which has a lower impedance. Suppose, in the previous example, TR-2 is replaced with a 2500 kVA “K” rated transformer of 3.7% impedance. I_{SC}/I_L is now 81.

With the new transformer, and PCC-2 as the measuring point, the data from Table 10.3 show that TDD permitted for an I_{SC}/I_L ratio of 81 is 12%. The 5th and 7th harmonics are each permitted to be 10%. The values measured are all within the permitted limit and no further action is warranted.

Replacing the transformer, however, is not usually an economically viable solution to this type of problem. Replacement is expensive, and the transformer is now oversized for the load. The larger transformer has a high magnetizing current and, because it is lightly loaded, a lower (worse) power factor exists. Additional valuable real estate either inside or outside the facility is used. More practical solutions include the use of line reactors and passive harmonic filters.

Distortion Level Predictions

Predicting distortion levels in practical application is far more complicated than it appears at first glance. Although it is convenient to think of non-linear loads as harmonic “current generators,” in reality the inductive impedance is what affects the levels of harmonic currents drawn by these loads. Therefore, we cannot treat loads as ideal generators. It is only partially correct to assume a “typical” harmonic current spectrum for a particular load and then attempt to determine the resulting distortion levels.

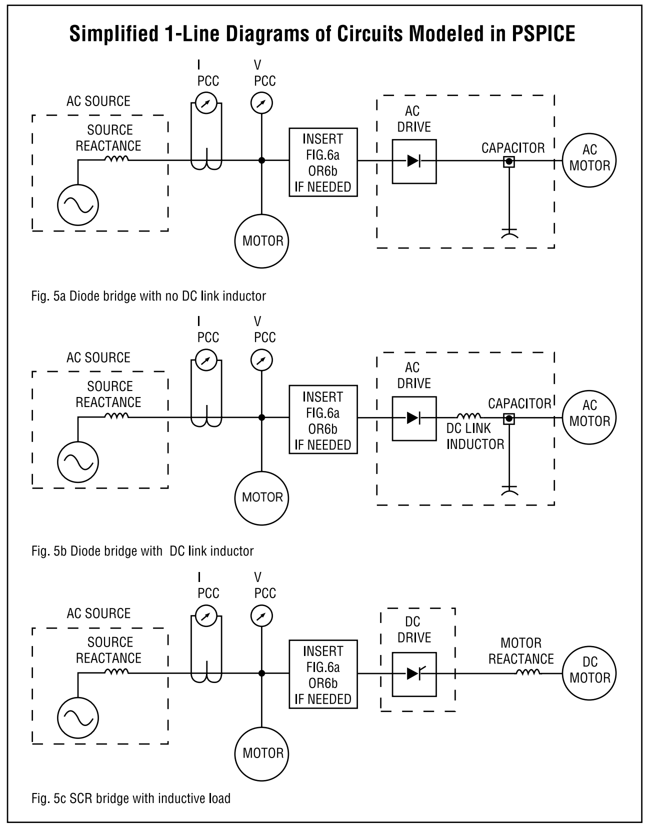
One can model a wide range of distribution system/linear loads/non-linear loads using PSPICE, an electronic circuit simulator software package available from MicroSim Corporation of Irvine, California. PSPICE is based on the SPICE2 circuit simulation program developed at Berkeley in early 1970's. This program has become the *de facto* standard for analog circuit simulation.

Available components such as voltage sources, capacitors, inductors, resistors, diodes, SCR's, etc., may be used to construct circuits. Real world parasitic characteristics can be included. PSPICE simulates the behavior of the circuit over a user-defined window of time, and an output file is created which allows the programmer to probe circuit voltages and currents and to perform a Fourier analysis of any voltage or current.

As stated earlier, the investigation of harmonic distortion undertaken in this paper is limited to 3-phase loads operating on a 3-phase distribution system.

Since IEEE 519, 1992 is intended to be a guideline for an entire plant, and since virtually all plants contain a mix of both linear and non-linear loads, the simplified one-line diagrams depicted in Figs. 5a - 5c were chosen as the basis of investigation. The advantages of using these circuits are:

1) The horsepower of the linear load may be changed relative to the non-linear load so that the percentage of the total load which is non-linear may be varied.



Simplified 1-Line Diagrams of Circuits Modeled in PSPICE

Fig. 5a Diode bridge with no DC link inductor

Fig. 5b Diode bridge with DC link inductor

Fig. 5c SCR bridge with inductive load

Figure 5

2) The impedance of the source may be varied to simulate any I_{SC}/I_L that is likely to appear in actual application.

3) A 3-phase line reactor (Fig. 6a) and 3-phase harmonic trap filter with line reactor (Fig. 6b) may be added ahead of the non-linear load for investigative purposes.

The values of the major circuit elements used in all of the simulations are:

1) All simulations are based on a 100 hp non-linear load. In the case of the AC PWM drive with no DC link inductor, the DC capacitor is set at 7,500 uF. For the

AC PWM drive with a DC link inductor, the DC inductor is set at 0.5 mH, and the DC capacitor is set at 7,500 uF. For the DC drive, the DC inductance is set at 2.5 mH.

Not all 100hp non-linear loads have exactly these values of capacitance and/or inductance, but these represent values used in the vast majority of non-linear loads produced today.

2) The linear motor is set to accommodate 900 to 0 hp, so the 100 hp no-linear load represents 10% to 100% of the total connected load.

3) The inductive impedance of the 3-phase voltage source is varied to represent an I_{SC}/I_L ration of 5 to 1000 (corresponds to 20% impedance to 0.1% impedance respectively).

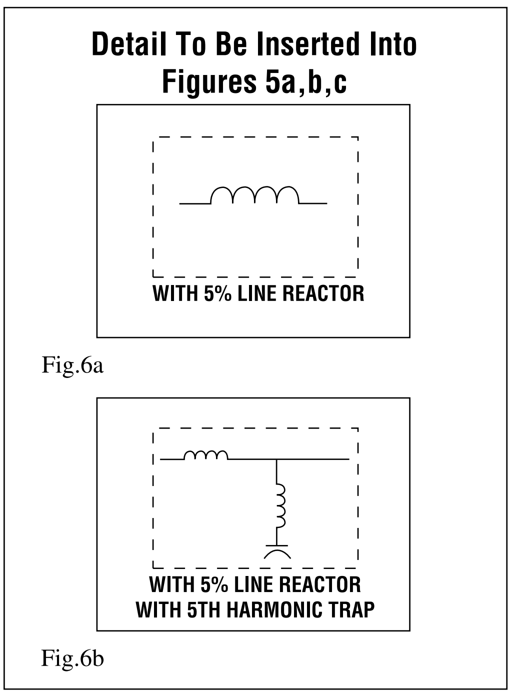


Figure 6

4) The impedance of the 3-phase line reactor (when used) is set at 5%. The harmonic trap filter (when used) is set at 30 kVAR for the AC PWM drive simulations and 40 kVAR for the DC drive simulation.

5) All simulations were done on a full 3-phase system.

6) All parasitic circuit elements that would affect the low-order harmonic response of the system including wire resistance, inductor winding resistance, inductor core losses, capacitor ESR, solid-state device snubbers, etc., are present.

Circuit Review

Most Common 3-Phase Loads

The most common 3-phase non-linear loads found today are the full-wave rectification units which utilize SCR's or diodes as the main rectifying element. Most DC adjustable speed drives, AC PWM drives, large uninterruptable power supplies, 3-phase electronic welders, 3-phase DC power supplies, etc., consist of a 6-pulse power rectifying bridge. The bridge either supplies DC directly to the load or to another section of electronics which converts the DC to another form of electrical energy such as variable voltage, variable frequency AC.

The rectifier section is usually followed by a power filter consisting of inductors and/or capacitors which filter the DC as required by the load or inverter section. It is the presence of these filtering elements (inductance and capacitance) which controls the shape of the AC line current and therefore the magnitude of the harmonic currents. The difference in the general shape of the line current waveform when comparing a “DC” drive with an “AC” drive is dependent upon whether the DC filtering circuit is inductive or capacitive in nature.

Loads With Capacitive DC Circuits (Fig. 5a)

If the DC circuit is capacitive in nature with very little or no DC circuit inductance, the line current waveform will be rounded in shape with a very poor form factor (peak to RMS current ratio). Wave shape will be largely controlled by the amount of reactance on the AC side of the rectifier. This is true for some AC PWM drives which utilize a large DC capacitor as a voltage ripple filter.

The quantity of harmonics in these loads is almost entirely controlled by the amount of AC line reactance. If the AC line reactance is relatively low (high I_{SC}/I_L), the current will have a poor form factor and be rich in harmonics. If, on the other hand, the AC line reactance is relatively high (low I_{SC}/I_L), the form factor will be improved and the harmonic content will be lower.

Loads With Inductive/Capacitive DC Circuits (Fig. 5b)

If the DC circuit contains both inductance and capacitance, the nature of the line current waveform will be similar to that of loads with inductive DC circuits. Most AC PWM drives fall into this category as they contain a large DC inductor in addition to the DC capacitor. The addition of the inductor is generally intended to reduce the amount of ripple current in the capacitor, so the DC presented to the inverter is improved.

Loads With Inductive DC Circuits (Fig. 5c)

If the DC filter is inductive in nature with very little or no capacitance, the line current waveform will be generally square in shape with fast rising edges and a relatively flat top (assuming the converter is operating in "continuous" conduction). This is true because the DC inductance opposes a change in the magnitude of current flowing through it causing a relatively quick commutation of current from one AC line to the other and a somewhat constant level of current during the conduction period. This is generally the case for DC drives supplying a motor armature and for current source inverter AC drives.

The line currents found in these loads can have harmonic contents that closely approach the theoretical square-wave values of 20% 5th, 14% 7th, 9% 11th, 8% 13th, etc. The amount of AC side reactance found in distribution systems is small compared to the DC side inductance. The addition of line reactors or transformers will have only limited effect on the line current distortion. Inductance in the AC lines does affect how rapidly current commutates from one AC line to the next and controls the voltage waveform "line notching." As the total AC inductance increases, the width of the line notches increases.

Modeling Results

Current Distortion vs. I_{SC}/I_L

A normal plant distribution system will contain both linear and non-linear loads. In the following illustrations, the curves labelled 100% non-linear, 80%, 60%, etc. indicate the portion of the total connected load that is non-linear. For example, assume that a plant has two 150 hp adjustable speed DC drives plus seven 100 hp motors that run "across-the-line." Since the total connected load is 1000 hp, 300 hp of which is non-linear in nature, the curve labeled 30% would apply.

No Line Reactors (Figs. 5a,b,c)

Fig. 7a shows the total harmonic current distortion for an AC PWM drive *with no* DC link inductor. Notice that even a "stiff" source (high I_{SC}/I_L, 100% non-linear) creates a current distortion exceeding 120%. With a "softer" source (low I_{SC}/I_L) current distortion is reduced to approximately 18%. The level of distortion is largely controlled by the inductive impedance of the AC lines. Even when only 10% of the load is non-linear, the IEEE 519, 1992 limits are exceeded.

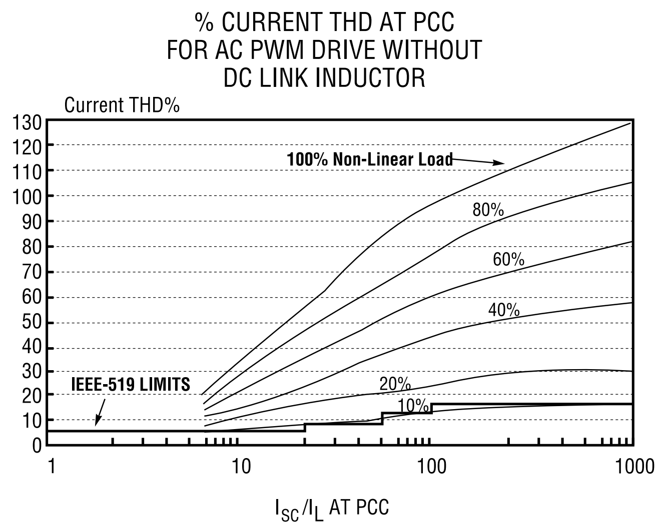


Figure 7a

Fig. 7b shows the total harmonic current distortion for an AC PWM drive *with* a DC link inductor. Notice that with a "stiff" source (100% non-linear load) current distortion is above 30%. If the source is "soft," the distortion remains in the 18% range. The addition of the DC link inductor greatly reduces the level of distortion when the drive is connected to a "stiff" distribution system, but does little when the load is connected to a "soft" distribution system. When non-linear loads are under 20% of the total system load, the harmonic current distortion is within IEEE 519, 1992 limits for moderate to stiff sources (I_{SC}/I_L>~20).

Fig. 7c shows the total harmonic current distortion for a DC drive. The levels of distortion closely resemble the levels shown in Fig. 7b.

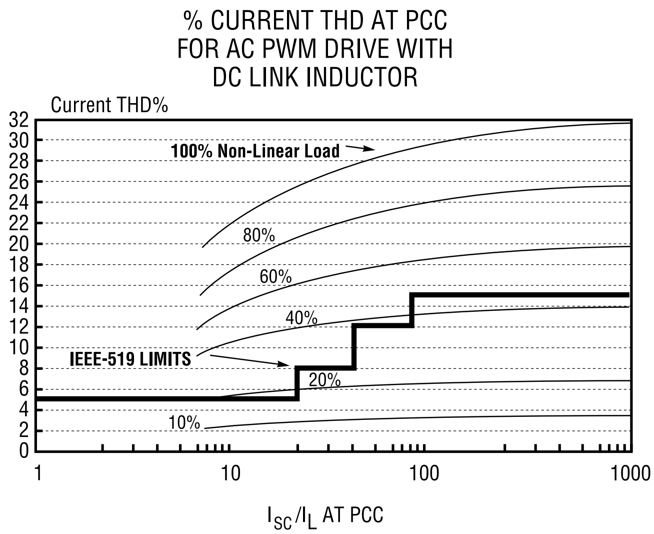


Figure 7b

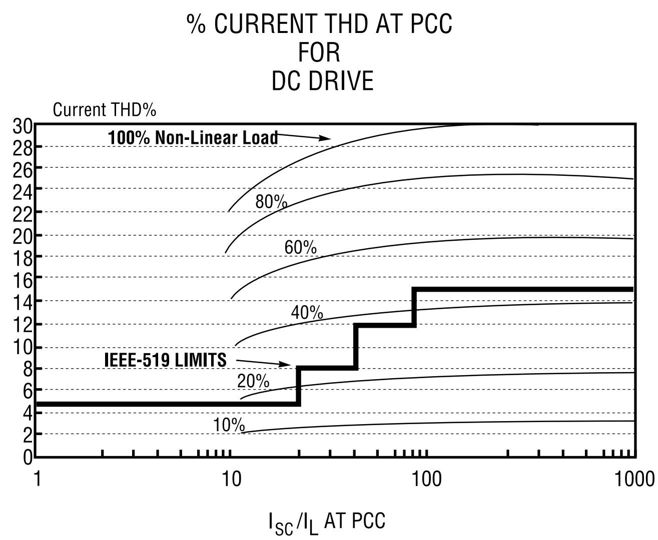


Figure 7c

Adding Line Reactors (Figs. 5a,b,c and 6a)

Figs. 8a, 8b, and 8c show what happens to the current distortion when a 5% line reactor is added ahead of the non-linear load. Form factor and power factor are improved and harmonic distortion is reduced.

Fig. 8a shows the total harmonic current distortion for an AC PWM drive *with no* DC link inductor. The maximum distortion expected when the drive is connected to an extremely “stiff” source is slightly below 32%. The level of distortion present when the drive is connected to a rather “soft” source improves to about 16%. When non-linear loads are under 20% of the total system load, the harmonic current distortion is within IEEE 519, 1992 limits in most cases.

Fig. 8b shows what happens to the total harmonic current distortion of an AC PWM drive *with* a DC line inductor when a 5% line reactor is added. The current distortion level drops 2 - 3% when compared to the drive using no line reactor. IEEE 519, 1992 limits are satisfied when less than 20% of the load is non-linear.

Finally, Fig. 8c shows the total harmonic current distortion for a DC drive. Once again, the level of distortion for a drive with a purely inductive DC circuit very closely resembles that of the AC PWM drive with a DC link inductor.

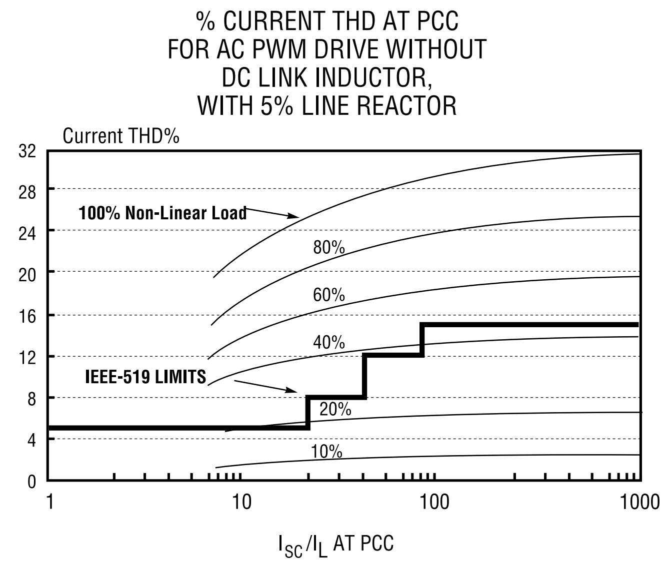


Figure 8a

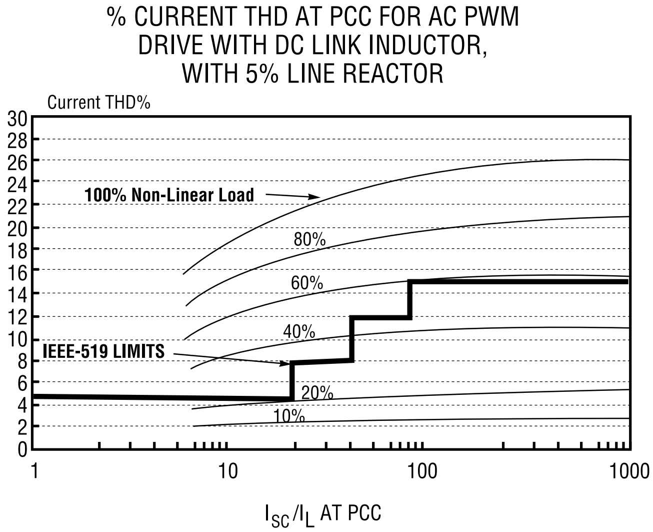


Figure 8b

While series line reactors can be extremely beneficial in eliminating bus over-voltage tripping, reducing high crest factor, and improving power factor somewhat, they cannot reduce the current harmonic distortion to IEEE 519, 1992 levels for cases in which more than 20% of the load is non-linear no matter what type of input circuit is used. Although some may claim that line reactors can “meet IEEE 519 regulations,” this is clearly not the case.

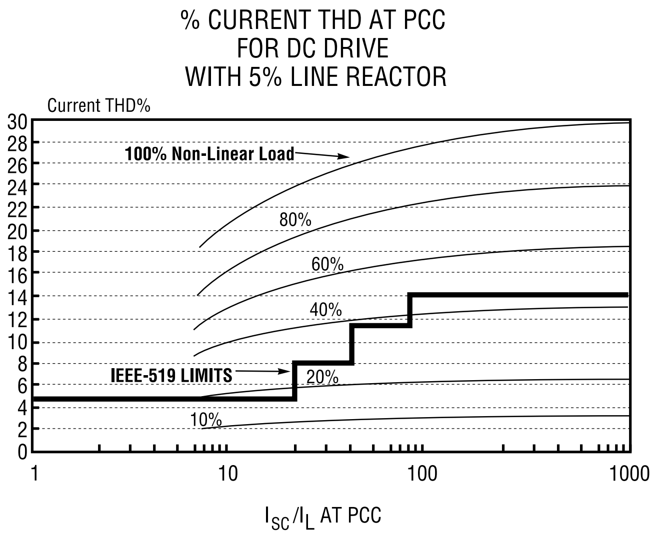


Figure 8c

Harmonic Trap Filters

When non-linear loads make up more than 20% of the electrical load on a distribution system, some type of harmonic filtering is required to maintain harmonic current distortion within the limits recommended by IEEE 519, 1992. The least complicated filter is a series tuned L-C shunt filter, often called “harmonic trap filer.”

Such filters are constructed from specially designed tuning reactors (L) and 3-phase power capacitors (C).

One of the characteristics of a series L-C filter is that its impedance is extremely low at the tuning, or resonant, frequency. If we select the tuning frequency to be major harmonic drawn by a non-linear load, the load will draw only its fundamental frequency current from the distribution system. Most of the selected harmonic current will be drawn from the trap filter. Since much of the harmonic current demanded by the non-linear load now comes from the trap filter and less harmonic current is drawn through the distribution system, the harmonic current distortion at the Point of Common Coupling will be reduced.

An isolation transformer or a series line reactor placed ahead of the trap filter increases the impedance toward the system to harmonic frequencies. The result is diversion of a greater portion of harmonic current to the trap. Harmonic currents in the system are further reduced, and the added impedance prevents other harmonic producing loads from overloading the trap filter. Figs. 9a an 9b show simplified diagrams of trap filters and demonstrate how they are connected to provide harmonic reduction for a solid state non-linear load. (While filters can be located on a bus or at the service transformer to reduce harmonics for the entire load, the most effective filtering occurs when a filter is placed at each individual non-linear load.)

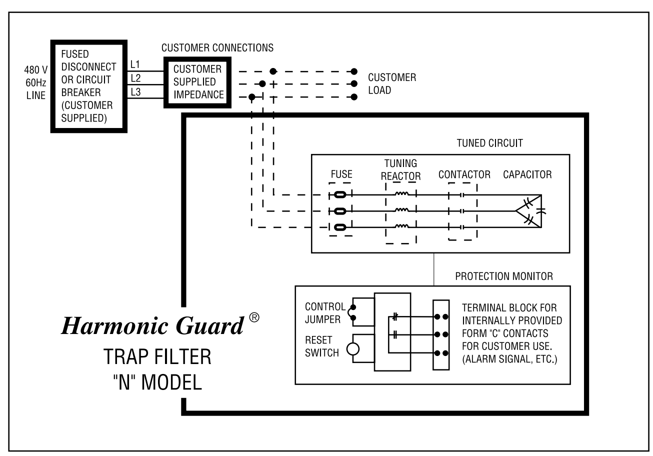


Figure 9a