Product Data

File 8800

Subject: IEEE Standard 519 Applicability to Adjustable Frequency Controllers (AC Line Disturbances)

I. INTRODUCTION

With the growing concern of power line pollution and the adverse effects of this phenomenon, line disturbances will become increasingly important in designing, selling, specifying and applying adjustable frequency drives in the future.

Limits on ac line voltage distortion and harmonic currents resulting from AF drives are frequently specified to meet IEEE Standard 519. In this product data, these recommended limits will be summarized, along with associated causes and effects from AF drives, as described in IEEE Standard 519.

Subjects covered by IEEE Standard 519 include line voltage notching, total power factor, voltage distortion, harmonic current distortion, telephone interference, and flicker. Electromagnetic interference (EMI) disturbances are not addressed in IEEE Standard 519.

II. BACKGROUND

When an IEEE working committee initiated work on IEEE Standard 519-1981 Guide for Harmonic Control and Reactive Compensation of Static Power Converters, industry and utilities were generally not interested in the problem of harmonic currents on their systems. Up until the early 1970's, the electro-chemical and electro-metallurgical industries, and large metal rolling mills, were the largest users of static power converters and had developed techniques to minimize harmonic currents into the power system.

With continued advances in power semi-conductor technology, economical, small and medium sized adjustable speed drives became available from many manufacturers. Each drive, by itself, did not present a problem with harmonic currents. However, with the proliferation of many drives, all operating independently, the problem became more complicated.

During the five years after the standard was issued, electric utilities became concerned about the number of static power converter loads on their systems. When IEEE Standard 519-1981 was scheduled for review, it became apparent that there should be a joint effort between IEEE working groups of the Power Engineering Society and the Industrial Applications Society. From these groups a new task force started work in 1986 to revise the standard.

The need for changes in the standard was obvious. The original document focused attention on problems associated with individual drives. It did not address the concern of electric utilities, with one user consuming all the capacity of a system to absorb harmonic currents. This problem is addressed in the revised edition IEEE Standard 519 which will have a new title, "Recommended Practice and Requirements for Harmonic Control in Electric Power Systems." (Title suggested in October 1988)

III. LINE DISTURBANCES

A brief review of this subject is given below. Additional details are given in IEEE Standard 519.

A. Source of Disturbances

In this product data, line disturbances in a power system are considered line voltage notching and line harmonic currents. The net effect of these two phenomena will be line voltage distortion. These conditions can occur any time current flows in a static power converter. The magnitude and nature of these line disturbances, and any adverse effects they may have on a power system, will be greatly influenced by the type of circuits on the load end of the converter, and the inductance, capacitance, and resistance in the power system ahead of the converter.

Other types of line disturbances include transient voltage surges from lightning, capacitor switching, and jogging motors, which are reviewed in Product Data C-882. Also, disturbances as a result of EMI/RFI are reviewed in Product Data C-884.

In this product data, we are concerned primarily with a static power converter used as the front end of an adjustable frequency drive, as a source of line disturbances. This typically may be a three-phase full wave bridge rectifier using either diode or SCR rectifiers. Simplified circuits are illustrated in Figure 1.

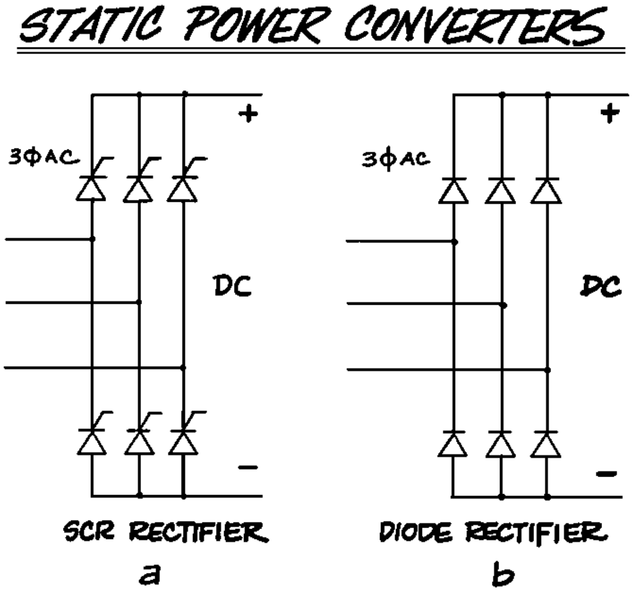


FIGURE 1

Keep in mind that line disturbances, their causes and effects described in this product data, are not unique to AF drives utilizing static power converters. Many types of commonly applied equipment such as transformers and motors, to a lesser degree, are non-linear loads and produce similar harmonics and voltage distortion described in succeeding paragraphs.

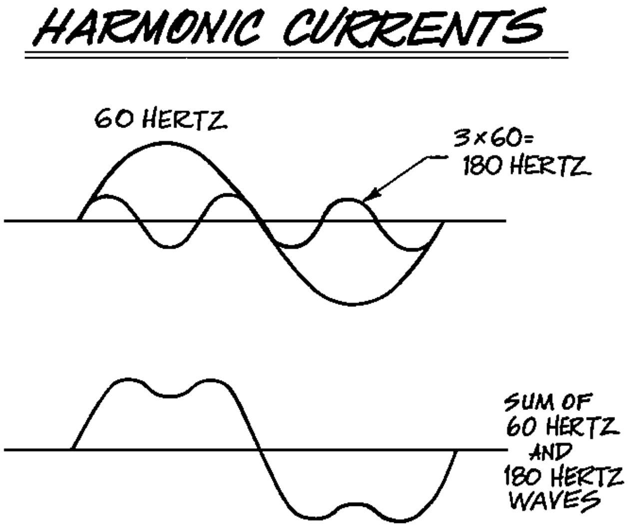


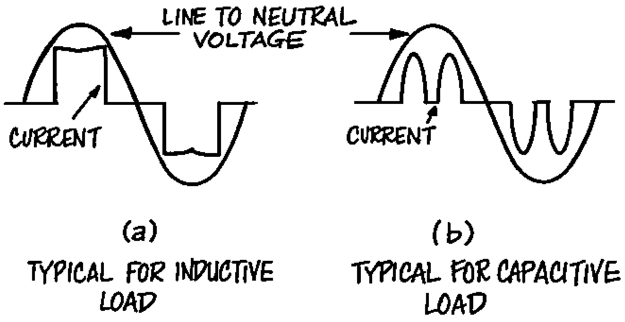
FIGURE 2

B. Harmonic Currents

To understand the phenomenon of harmonics, a brief review is as follows. Any distorted periodic sinusoidal wave can be subdivided into a fundamental frequency and other frequencies (called harmonics) which bear an integral relationship to the fundamental frequency. A simplified example in Figure 2 illustrates this. A 60 Hertz wave with a third harmonic at 180 cycles is illustrated. The sum of the fundamental wave and the harmonic wave will produce the distorted wave.

As mentioned above, line disturbances, and in effect the shape of the distorted line current wave from an AF Drive, will be determined by the type of converter load, and the impedance of the power source. Two examples of extreme conditions are shown in Figure 3.

STATIC POWER CONVERTER AC LINE CURRENTS



(a)
TYPICAL FOR INDUCTIVE LOAD

(b)
TYPICAL FOR CAPACITIVE LOAD

FIGURE 3

The current wave in Figure 3a will be continuous and similar to a square wave for an inductive load. This is typical for AF drives with an SCR converter, illustrated in Figure 1a. Six-step and current source drives without dc choppers fall in this category.

The current wave in Figure 3b will be noncontinuous and similar to twin half sine waves for a capacitive load. This is typical for AF drives with a diode converter, illustrated in Figure 1b. PWM drives and six-step drives with a dc chopper fall in this category.

Harmonic orders and typical magnitudes for these two examples of distorted current waves are illustrated in Table 1. Also, the harmonic effects of a 12-pulse converter versus a 6-pulse converter are illustrated.

TABLE 1

Harmonic Current Per Unit Of Fundamental Current (Typical Values)

Converter Pulses	Converter Loads	Harmonic Order 5	7	9	11	13	15
6	Capacitive	.6	.35	—	.05	.06	—
6	Inductive	.18	.11	—	.04	.03	—
12	Inductive	—	—	—	.04	.03	—

The final magnitude of the various line harmonic currents will be determined by the inductance in the power system (commonly referred to as commutating reactance), the load on the AF drive, and the firing angle delay when SCR's are used. For diode converters the actual circuit inductance at the installation may have a profound effect in lowering the harmonic magnitudes shown in Table 1.

The total harmonic current distortion (TDF) that an AF drive produces on the ac line is determined by the following relationship.

$$\text{TDF} = \frac{\sqrt{\text{Sum of Square of Individual Harmonic Currents}}}{\text{Fundamental Current}}$$

C. Line Voltage Notching

The line-to-line voltage wave with notches, illustrated in Figure 4, is the result of three-

VOLTAGE NOTCHING

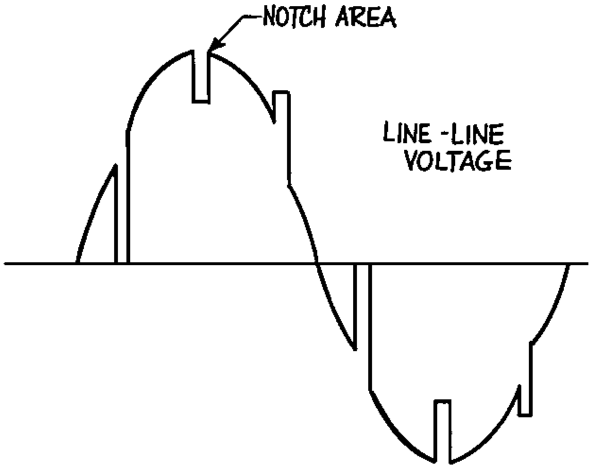


FIGURE 4

phase current flowing into a static power converter using phase controlled SCR's. The circuit in Figure 1a is typical.

The notches occur when continuous line current, illustrated in Figure 3a, commutates (transfers) from one phase to another in a static power converter. During commutation, two phases are connected for a very short duration (short circuited) by the converter through the ac source impedance (which is very low) and thus causes the voltage to drop near zero.

The area of the notch (depth and width) is dependent upon the volt-seconds absorbed in the circuits from the distribution transformer source to the drive input. This notch area and specifically the depth of the notch is an indication of the effect the static power converter may have on other loads in the power system.

Voltage notches can occasionally cause misoperation of the firing circuits of other phase-controlled devices on the system if precautionary measures are not taken. Decreasing the notch depth by increasing the source impedance with line reactors or isolation transformers, may help to improve problems associated with line notching. However, this may not always sufficiently limit the higher harmonic frequencies from voltage notching when sensitive equipment is affected. When using isolation transformers, capacitive coupling in the transformer tends to nullify the reactance above 8 to 10K Hertz. Shunt filters may be required in some cases to solve a notching problem. When practical, strategic design of the power system as described in Paragraph III.F.5 may be the best method to avoid voltage notching problems.

In some cases, when SCR's are used in the converter, voltage spikes of very short duration can be generated immediately following the notch. This is due to reverse recovery of the semiconductor junction and is a phenomenon associated with the operation of solid state devices. Without proper circuit design, this could produce damaging voltage spikes.

Generally RC circuits called snubbers are a part of the controller, and are used to suppress the spikes. However, for proper snubber operation, the source impedance at the controller must be coordinated with the snubber circuit values. As a rule, the spike voltage is generally limited to 1.25 times the peak value of the equipment rated voltage. This prevents power semiconductor damage and insulation system degradation.

When a diode front end is used for an AF drive with non-continuous current, illustrated in Figure 3b, voltage notching does not occur.

D. Voltage Distortion

Voltage distortion occurs in a power system as a result of voltage notching, described above, and harmonic currents flowing in the system.

The distorted voltage wave, due to notching, illustrated in Figure 4, can be subdivided into a fundamental voltage and its harmonics, as explained in Paragraph III.B. The voltage distortion factor (DF_{VN}) related to voltage notching is expressed by the formula below:

$$DF_{VN} = \frac{\sqrt{\text{Sum of Square of all Harmonic Voltages}}}{\text{Fundamental Voltage}}$$

DF_{VN}, however, is commonly related to the area and depth of the voltage notch and the inductance in the circuits. Categories for this phenomenon are illustrated in Tables 2 and 6.

Another contributor to voltage distortion is harmonic currents that are generated as explained in Paragraph III.B. The current at each harmonic frequency will produce a voltage drop, due to the impedance the power system presents at each harmonic frequency. This impedance can vary widely for each harmonic frequency. It includes reactance due to inductance in the transformer and power cables and also any capacitor banks, filters, and stray capacitance in the power system. With the right combination of inductance and capacitance, parallel resonance is possible for a specific harmonic frequency, possibly creating excessive currents at that frequency.

Due to the power system reactance, each installation with a static power converter is unique, resulting in voltage drops in the power system for each harmonic frequency. The net result is a distorted voltage wave in the power system. With improper layout of a power system, this distorted wave may have an adverse effect on other equipment in the system. See Paragraph III.F.5 for examples of layouts.

The voltage distortion factor (DF_{HC}) due to harmonic currents, or percentage voltage distortion, is determined by the same relationship as shown above for voltage notching:

$$DF_{HC} = \frac{\sqrt{\text{Sum of Square of the Harmonic Current Voltage Drops}}}{\text{Fundamental Voltage}}$$

The overall voltage distortion is a net result from voltage notching and line harmonic currents. This produces a spectrum of harmonic voltages illustrated in Figure 5.

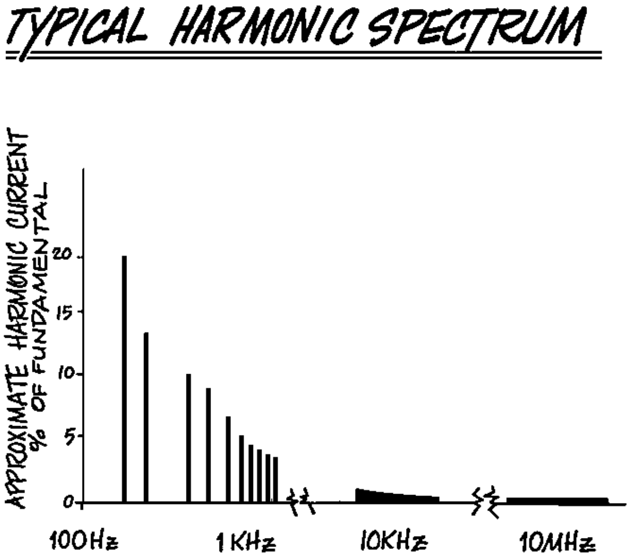


FIGURE 5

The lower order of harmonic voltages (5th harmonic 300 Hertz to 35th harmonic 2.1K Hertz) will contribute mostly to heating and other effects on equipment described in Paragraph III.E.

Generally, harmonics in the 10 to 20K Hertz range will result from voltage notching (when present) and will be more adversive for electronic and communication equipment.

Very high frequencies in the megahertz range will result from the steep wave fronts when power switching devices are very rapidly gated on and off. This occurs with the dc chopper in a six-step drive and inverter devices in a PWM or six-step drive, and can cause malfunctions and interference with electronic equipment and telecommunication. This high order of Radio Frequencies is not addressed by IEEE Standard 519, and presently there are no specific standards for AF drives to address this condition. Fortunately, these problems are rare, and proper installation of the AF drive will usually minimize occurrences of Electromagnetic Interference (EMI) problems. Occasionally, reference is made to limitations described in FCC Rules and Regulations Volume II Part 15 Subpart J for computing equipment. These rules, however, were intended primarily for computing equipment. This subject is reviewed in Product Data C-884 FCC Rules Applicability To Adjustable Frequency Controllers (EMI).

E. Adverse Effects of Line Disturbances

The degree to which harmonic currents and voltage distortion can be tolerated is determined by the susceptibility of the load or power system to them. Several types of loads are reviewed below.

1. **Motors and Generators** — For on-line machinery, the major effect is increased heating due to copper and iron losses at the harmonic frequencies. In some severe cases, pulsating or reduced torques may occur. The sum effect of the harmonics is a reduction in the efficiency and life of the machinery. Neither reduction is pronounced for normally encounted harmonic content, and is usually negligible with harmonic content less than 4%. Still, line current harmonic heating typically can reduce performance to 90% to 95% of that which would be experienced with pure fundamental sine waves applied. This is not to be confused with adjustable frequency drives which require additional motor derating. In some cases, motor insulation degradation may occur when excessive voltage spikes (see Paragraph III.C) are not limited with converters using SCR's. Generator-regulating controls can also be affected by harmonic currents and voltage notching to cause hunting and instability in speed and frequency control, and can make the paralleling of generators difficult or impossible.
2. **Transformers** — Excessive heating may occur should harmonic currents exceed an IEEE C57.1200-1980 standard proposing a limit of 5% current harmonic factor. ANSI/IEEE C57.110-1986 standards may be referenced also.
3. **Power Cables** — Medium voltage cables involved in system resonance, caused by harmonic currents, may be subjected to voltage stress and corona which can lead

to insulation failure. The flow of harmonic currents in a conductor will cause additional heating due to the "skin effect" and "proximity effect," both of which vary as a function of frequency as well as conductor size and spacing. Tables for cable derating percentages are proposed in the revised edition of IEEE Standard 519. However, from available data, it appears that harmonic heating in cables is not normally a matter of great concern, with the exception of a common neutral conductor. In this case, additive harmonic currents can result in a neutral current exceeding the phase currents. This condition is becoming more prevalent and requires careful consideration when sizing a neutral conductor in 4-wire 3-phase systems. Some sources recommend rating up to 150%, and even doubling the phase current rating, for three-phase systems especially when 3rd, 9th, 15th, 21st, etc. harmonic currents are a factor. These harmonics are usually not associated with adjustable frequency drives and are not present in a 3-wire 3-phase system.

4. **Capacitors** — The major concern with capacitors is the possibility of system resonance with harmonic currents. This could impose a higher than normal voltage on the capacitor, and cause excessive currents to blow capacitor fuses and other serious effects in the power system. Increased heating and voltage stress brought about by harmonics will shorten the capacitor life, which can be substantial. Typically, capacitor life is halved for a 10°C or higher temperature, or for a 10% overvoltage. ANSI/IEEE Standard 18-1980 gives limitations on voltage, etc. which can be used to determine maximum allowable harmonic levels. A likely safeguard for capacitor resonance problems is to limit the capacitor KVAR to roughly .3% of the system short circuit KVA at the point of connection, unless control measures are taken to deal with the harmonics.

5. **Switchgear** — As with other types of equipment, excessive harmonic currents can increase heating and losses in switchgear, reducing steady state current-carrying capability for fuses, and shortening the life of some insulating components. There are currently no standards for the level of harmonic currents that switching devices or fuses are required to interrupt or carry.

6. **Protective Relaying**

   Due to the many varieties of protective relays from many manufacturers, and the variation in the nature of line distortions that can occur to affect their operation, it is not possible to completely define relay responses. In some cases, relays may have a tendency to operate slower and/or with higher pick-up values. However, in general, harmonic levels required to cause misoperation of relays are greater than the levels recommended by IEEE Standard 519 revised. Usually, harmonic factors of 10-20% are required to cause problems in relay operation.

7. **Metering and Instrumentation**

   Metering and instrumentation are affected by harmonic components, particularly if resonant conditions exist which result in high harmonic voltages. Induction disk devices such as Watthour meters normally see only fundamental current, but phase unbalances caused by harmonic distortion can cause erroneous operation. Both positive and negative errors are possible, depending on a particular meter and the harmonics involved. Using true RMS sensing meters and relays will help to minimize these problems. In general, the harmonic factor must be greater than 20% before significant errors are detected. 60 Hertz instrument transformers used in metering and relaying are not affected by normally encountered harmonics.

8. **Electronic Equipment**

   Power electronic equipment is susceptible to misoperation caused mostly by voltage notching, especially equipment using phase-controlled devices. The voltage notch can distort the voltage waveform near its zero crossing point, making it difficult to synchronize the firing pulses for phased controlled devices. Computers, electronic instruments and allied equipment may incur erratic operation and sometimes malfunctions when the harmonic factor exceeds 5%, and more than 3% for a single harmonic. The most serious cases are medical instruments. TV and radio equipment are less dramatically affected.

9. **Communications**

   The effects of harmonics in communications are primarily in interference with the transmission of information. In some cases, harmonics can emulate a signal and cause spurious system responses. Generally, communication circuits involving transmission by microwave, satellite, or fiber optics are not greatly affected by power harmonics. However, most wire communications can suffer degradation from proximate power harmonics. Probably the worse case of harmonic interference occurs when a relatively long telephone line is run in close proximity to a power line supplying a load which is mostly power converter. Recommended practice for telephone interference factors is discussed in IEEE Standard 519 revised.

10. **Other**

    Ballasts for fluorescent or mercury lighting occasionally have capacitors which, together with the inductance of the ballast and circuit, have a resonant point. If this corresponds to one of the generated harmonics, excessive heating and failure can result.

    Carrier-current equipment such as clock systems or paging systems can be adversely affected when one of the harmonic frequencies or a resonant frequency falls on or near the carrier frequency. Voltage notching can also cause misoperation of clock systems.

F. **Corrective Measures for Line Disturbances**

Harmonic currents can be controlled by several techniques. These include shunt and series filters, phase multiplication, harmonic injection, power system design, isolation transformers and reactors.

1. **Shunt Filters** — A number of shunt filters, properly designed and applied for the 5th, 7th, 11th and 13th harmonics, can effectively reduce the harmonic currents in a power system. Each filter consists of a series L-C circuit, tuned to resonate at a specific frequency. These filters, located relatively near the harmonic source, will provide a low impedance path and, in effect, shunt most of the source harmonic currents from the power system. However, in some cases, these filters (occasionally called traps) might trap harmonics on a system from other sources, thereby causing overheating of the filter, if not considered initially. Shunt filters can be relatively effective when other methods of correcting disturbance may be impractical. However, filters can be an additional expense in a system and another electrical component to be considered in overall system reliability. In addition, filters introduce leading KVAR's into the power system which can result in a leading power factor. It should be noted that RF filters should not be applied for these lower order harmonics.

2. **Series Filters** — These filters consist of a parallel L-C circuit tuned to resonate at a specific frequency, and can be located at the equipment being affected. This can be advantageous if the affected equipment is relatively small, compared to a much larger size AF drive.

3. **Phase Multiplication** — This involves the use of a phase-shifting transformer to distribute power to converter loads. By properly shifting the phase relationship to various six-pulse converter loads, the net effect in the power system is to create 12

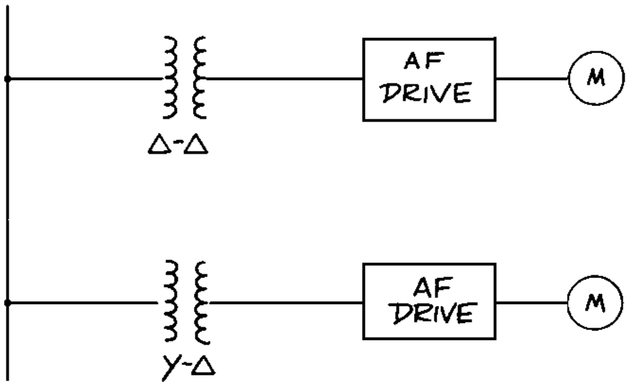


FIGURE 6

pulse circuits. This will generate considerably less harmonics than a six-pulse circuit. See Table 1.

The use of separate transformers, connected as illustrated in Figure 6, will also have a net effect of eliminating the 5th, 7th, etc. harmonics from the line.

However, these methods are most effective to reduce harmonics when the converters are of equal size, and operate with equal loading and equal phase retard when SCR's are used.

4. **Harmonic Injection** — Harmonic currents can be eliminated by inducing harmonic fluxes in the core of a transformer with a 180° phase shift from the harmonic fluxes induced by current flowing in the transformer secondary.

   Adaptive compensators to implement harmonic injection are still in the experimental stage. These devices are designed to constantly monitor the load current, inject a current equal and opposite to the distorted component, and thus cancel it.

5. **Power System Design** — The effects of voltage distortion and harmonic currents can be minimized on other system equipment by properly locating and isolating harmonic-producing equipment as much as possible. This is illustrated in Figure 7.

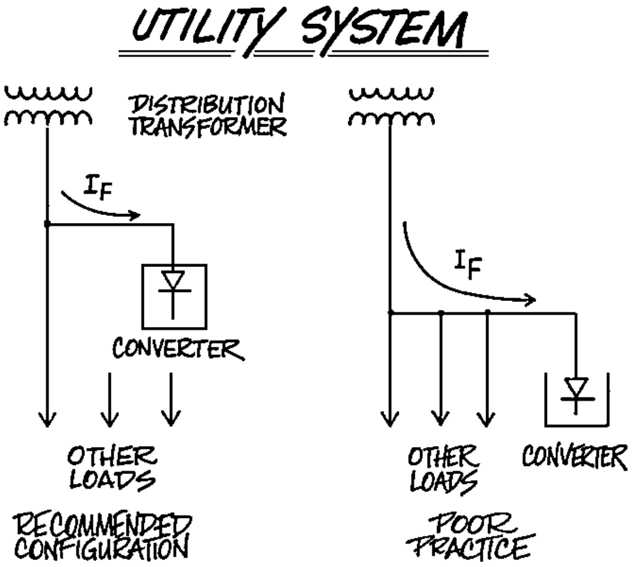


FIGURE 7

The power wiring to a converter can be isolated from control wiring or other load conductors to minimize the inductive and capacitive coupling between the two.

The level of voltage distortion can be improved when the ratio of the distribution transformer short circuit current to actual load current is increased. Also, decreasing the AF drive load as a percentage of total transformer load will improve a harmonic voltage distortion condition.

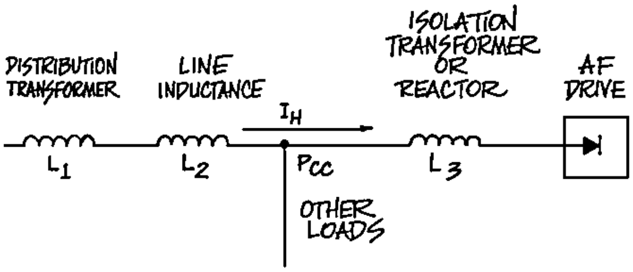
Installing harmonic-producing equipment and sensitive equipment with separate distribution transformers will minimize harmonic problems.

Major resonant conditions can be minimized by locating relatively smaller banks of power factor correction capacitors throughout a power system. These can be switched as needed, versus using a single large bank of capacitors. This will result in lesser possibility of excessive harmonic currents. Techniques in switching capacitors usually result in overvoltage transients which could adversely affect AF drives with nusiance overvoltage tripping. The energy level of these transients will be reduced with distributed capacitors, with less opportunity for nuisance tripping.

6. **Reactors or Isolation Transformers** — Generally, inductive reactance can be added to the system with reactors or isolation transformers. Isolation transformers will require relatively more space and will be more costly, and usually are provided to isolate neutral grounding circuits.

   Applying reactors or isolation transformers will not always prevent or solve harmonic problems. To determine if additional reactance is advisable, the complete power system, including the distribution transformer, and its branch circuits with all connected loads should be analyzed.

   The effect of reactors or isolation transformers is to slightly change the shape of the current wave, illustrated in Figure 3, and thus lower the amplitude but not eliminate the harmonic currents. Generally, this will increase the voltage distortion to the converter load, which is normally not a problem. However, voltage distortion to the power system at the point of common coupling will be reduced. This is illustrated in Figure 8.



HARMONIC VOLTAGE DROP IN L_1 AND L_2 IS LESS WHEN L_3 IS ADDED TO THE CIRCUIT.

FIGURE 8

This method of minimizing voltage distortion is a relatively simple and inexpensive means to deal with harmonic voltages and currents. It is commonly used by many drive manufacturers, but may not always prevent problems.

IV. PRESENT STATUS (OCTOBER 1988)

In IEEE Standard 519-1981, voltage distortion limits resulting from voltage notching were established. Limits on the voltage notch area for defined system impedances were set to determine acceptable voltage distortion levels. Three classes of 460 volt installations were defined. Also, in the 1981 standards, voltage distortion limits resulting from harmonic currents were established for utility medium voltage and high voltage power systems for two classes of installations. These limits are shown in Tables 2 and 3, in Paragraph V.

Limits established in the 1981 edition are frequently specified by consulting engineers and users, but, as mentioned in Paragraph II, they do not address the total problem. The voltage distortion criteria as described in the 1981 edition cannot guarantee the power system will absorb all the harmonic currents, and still be within acceptable limits of voltage distortion and harmonic currents for all users on the system.

Revised IEEE Standard 519, which will deal with this situation, is still in draft form. Data on distortion limits that is likely to be published is shown in Tables 4, 5, and 6 in Paragraph VI. A technical paper on this subject was presented by one of the authors of IEEE Standard 519, at the Petroleum and Chemical Industry Conference September 1988. At this time, it appears these new limitations could become an IEEE-recommended practice — possibly in mid 1989.

The revised edition will establish two criteria to evaluate harmonic distortion. The first is a limitation for harmonic current that a user can transmit into the utility system. The second criterion is the quality of the voltage that the utility must furnish the user. The interrelationship of these criteria shows that the harmonic problem is a systems problem dependent on individual loads that either generate or utilize harmonic currents.

Limits on voltage notching (commutation notches) are also revised to be a function of notch depth, and notch area.

V. IEEE STANDARD 519-1981 EDITION — LINE DISTURBANCE LIMITATIONS

Low voltage system classifications and distortion limits for 460 volt systems resulting from voltage notching are shown in Table 2.

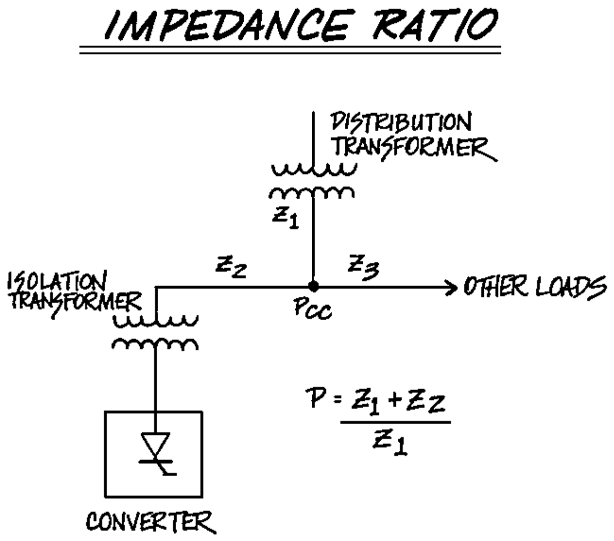


FIGURE 9

TABLE 2

Class	p	A_N	DF
		Volt - Microseconds	%
Special Application*	10	16 - 400	3
General System	5	22 - 800	5
Dedicated System	2	36 - 500	10

* Special applications are those where the rate of change of voltage of the notch might mistrigger an event.
p = the ratio of the total impedance to the common system impedance. This is illustrated in Figure 9.
A_N = the voltage notch area. This is illustrated in Figure 4.
DF = distortion factor as a result of voltage notching. See Paragraph III.D. for an explanation.

Voltage distortion limits for medium and high voltage power systems resulting from harmonic currents are shown in Table 3.

TABLE 3

Power System Voltage Level	Dedicated* System Converter	General Power System
Medium Voltage 2.4 - 69 kV	8%	5%
High Voltage 115 kV and above	1.5%	1.5%

*A dedicated system is one servicing only converters or loads not affected by voltage distortion.

VI. IEEE STANDARD 519 REVISED EDITION — LINE DISTURBANCE LIMITATIONS

NOTE THAT TABLES 4, 5 AND 6 HAVE NOT BEEN OFFICIALLY APPROVED BY IEEE AT THIS TIME, NOVEMBER 1988.

Harmonic current limits for non-linear loads at the point-of-common-coupling (PCC) with other loads, at voltages of 2.4 to 69 kV, are shown in Table 4.

TABLE 4

Maximum Harmonic Current Distortion In Percent of Fundamental						
	Harmonic Order (Odd Harmonics)					
I_{sc}/I_L	<11	11<h<17	17<h<23	23<h<35	35<h	THD
<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.

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

I_{sc} = Maximum short circuit current at PCC. (See Figure 10)

I_L = Maximum load current (fundamental frequency) at PCC.

THD = Total harmonic current distortion. See Paragraph III.B. for explanation of total harmonic current distortion.

For PCC's from 69 to 138 kV, the limits are 50% of the limits above. A case-by-case evaluation is required for PCC's of 138 kV and above.

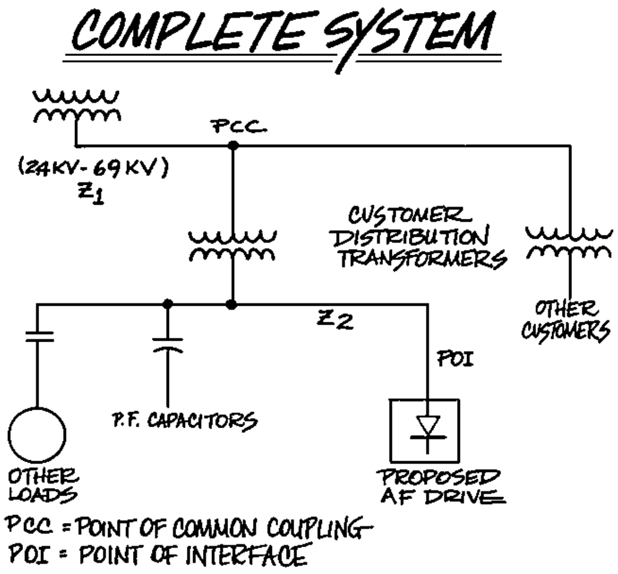


FIGURE 10

Table 4 lists the harmonic current limits based on the size of the user with respect to the size of the power system to which he is connected. The ratio of I_{sc}/I_L is the short circuit current available at the point-of-common-coupling (PCC) to the nominal fundamental total load current. Thus, as the size of the user load decreases with respect to the size of the system, the larger is the percentage of harmonic current the user is allowed to inject into the utility system. This protects other users on the same feeder as well as the utility, which is required to furnish a certain quality of power to its customers.

The second limitation specifies the quality of the voltage that the utility must furnish the user. Table 5 lists the amount of voltage distortion that is acceptable at the primary of a distribution transformer from a utility to a user before his load is connected. To meet the power quality values listed in Table 5, cooperation among all users and the utility is needed to insure that no one user deteriorates the power quality beyond levels in Table 5. The values in Table 5 are low enough to insure that equipment will operate correctly.

TABLE 5

Harmonic Voltage Distortion in Percent At PCC			
	2.3-69kV	69-138kV	>
Maximum for Individual Harmonic	3.0	1.5	1.0
Total Harmonic Voltage Distortion (THD)	5.0	2.5	1.5

Limits on line voltage notching are given in Table 6.

The notch depth and the total Root Sum Square (RSS) distortion factor (DF) of the line-to-line voltage at point-of-common coupling (PCC) and point-of-interface (POI) should be limited as follows: See Figure 10.

TABLE 6

LOW-VOLTAGE SYSTEM CLASSIFICATION AND DISTORTION LIMITS FOR 460V SYSTEMS RESULTING FROM VOLTAGE NOTCHING

Class	Notch Depth	A_N	DF_{VN}
Special Application	10%	—	3%
General System	20%	22,800	5%
Dedicated System	50%	36,500	10%

Special application includes hospitals and airports.

Dedicated system is exclusively dedicated to the converter load.

Notch Depth = $Z_1 / (Z_1 + Z_2)$ where Z_2 is the impedance between the converter and point-of-common-coupling (PCC) and Z_1 is the short circuit impedance at PCC. This is equivalent to 1/p. See Figure 9.

DF_{VN} = Voltage distortion factor from notching. See Paragraph III.D. for explanation of voltage distortion.

A_N = Notch Area (Voltmicroseconds). See Figure 4.

VII. APPLICATION OF IEEE STANDARD 519 AND SQUARE D'S POSITION

Occasionally, a specification will designate a specific percentage limit for voltage distortion with AF drive, or simply will specify to meet IEEE Standard 519. Most AF drive suppliers will question this requirement, simply because it is inconclusive and usually impossible to administer, without further qualification, with the 1981 version.

From an understanding of voltage distortion, explained in Paragraph III.D., it is obvious that no practical qualification for a specified voltage distortion factor can be assured without an analysis of the power system for total harmonic currents and system inductance and capacitance.

Furthermore, quite often when IEEE Standard 519-1981 edition is referenced for voltage distortion, the class of installation is usually not clearly defined by the specifier. In the standard, voltage distortion limits resulting from harmonic currents for various classes of installations are given as a guide for medium voltage systems, shown in Table 3. Separately in IEEE Standard 519-1981, voltage distortion limits for voltage notching for various class installations are given in Table 2.

Square D's position when a percentage voltage distortion is specified is as follows. For Square D OMEGAPAK® drives, which utilize a diode front end, voltage notching will not be a factor; consequently, no voltage distortion will exist for this condition. Overall system voltage distortion resulting from harmonic currents should be determined by a harmonic analysis.

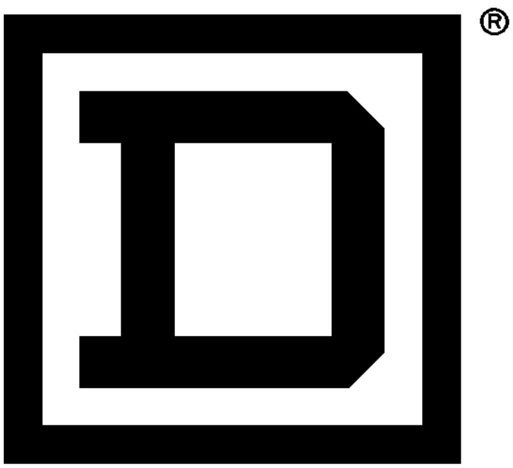
Square D can furnish the spectrum and magnitude of harmonic currents that OMEGAPAK drives will generate in the ac line for a specific installation. To provide this data, it is necessary to know the power system short circuit current availability at the drive, or the source impedance of the line at the point of connection of the AF Drive.

However, it is important to note that harmonic currents may exist in the power system from other sources. Hence, the complete system must be evaluated to determine the total spectrum and magnitude of harmonic currents, and the resulting voltage and current distortion factors at a point-of-common-coupling identified by the specifier. Any system corrective action such as line reactors, transformers, or filters applied to limit the voltage and current distortion factor to a specified percentage, can be greatly influenced by not only the proposed new drive, but by any existing harmonic-producing equipment in the system.

When revised IEEE Standard 519 becomes an official publication, and harmonic distortions are specified as proposed in Tables 4 and 5, a harmonic analysis will be required to determine the total harmonic current and voltage distortion for a system.

The need to limit harmonic currents and voltage distortion is usually a genuine requirement by a user in order to minimize any adverse effects in his power system, as described in Paragraph III.E. However, in future years, this need will most likely be more pressing from utilities, who will be obliged to deliver power with limited harmonic currents and voltage distortion.

J. P. McCauslin/L.M. Liptak



Bulletin C-883 CS 5M 12/88

Printed in USA