The Application of Adjustable Frequency Drives to Meet the Requirements of IEEE 519-1992

Application Summary

To facilitate compliance with the voltage and current distortion limits defined in IEEE Std. 519-1992, five possible methods are discussed. A "Clean Power" drive design which draws nearly pure sine waves of current is described which utilizes an integrated 18-pulse method with a Differential-Delta phase-shifting transformer. This method meets the requirements of the IEEE harmonic standard under all operating conditions.

Why be Concerned About Harmonics?

Manufacturers of modern Adjustable Frequency Drives recognize the possibilities of control and power circuit interactions in the presence of harmonic voltages and currents, and suitably configure their own designs to prevent problems. For example, we have conducted tests in which two of our 500 HP AF Drives, that were hard paralleled across a "weak" source, which developed 27% voltage distortion. No unwanted interaction occurred in the drives. However, such high distortions are definitely not recommended. Other more conventional equipment, including telephones and data transmission links, may not be guaranteed to work in such a hostile environment.

One of the major concerns about harmonic voltages is that much equipment is not designed to operate in the presence of harmonics. Harmonic voltage effects are particularly of concern in applications such as Hospitals, Universities, and Waste Water Treatment Plants where stand-by generators are used to maintain services during power outages. Emergency generators have an impedance three or more times larger than the impedance presented by conventional Utility sources. Thus for the same harmonic current, the harmonic voltage is three or more times larger and there is much greater risk for operating problems.

Another major concern, especially for the Utilities, is the additional system and component losses caused by harmonic distortion. These, at the very least, include transformers, motors and cabling losses but more subtle losses are also involved. The increased eddy current losses caused by typical harmonic currents are shown to require current derating factors of 7% to 10% in some transformers [1]. With increased harmonic currents such as those shown in Figure 1 for an AC line reactance of 4%, the transformer derating factors increase to 16.6% and 21.6% respectively.

Specifications

The Static Power Converter Committee of the Industrial Applications Society of the IEEE initiated work several years ago which resulted in the IEEE Std. 519-1981 as a guideline. Subsequently a revised standard was issued in 1992 and became a Recommended Practice – IEEE Std. 519-1992. The IEEE standard is a comprehensive, very readable document which addresses and clearly explains many of the harmonic issues. The essence of the specification is shown in Table 1. International standards concerning harmonics are set by the International Electrotechnical Commission (IEC). The IEC Standards 146 & 555 address issues in a manner similar to the way the IEEE does in the USA.

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Table 1. Highlights of IEEE Std. 519-1992

% Voltage Distortion = 100 x Total Harmonic Voltage/Fundamental Voltage

- Per IEEE Std. 519-1992, <u>If voltage distortion is less than 5%, system problems are unlikely</u>.

- IEEE Voltage Distortion Limits (480V)

APPLICATION CLASS	% DISTORTION	NOTCH DEPTH	NOTCH VOLT-MICROSECONDS
SPECIAL SYSTEM	3	10%	16,400
GENERAL SYSTEM	5	20%	22,800
DEDICATED SYSTEM	10	50%	36500

- IEEE Current Distortion Limits (480V)

Maximum Harmonic Current Distortion in % of the Fundamental

I_{SC}/I_L	Harmonic Order (Odd Harmonics)					TDD
	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	
<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

Where:
TDD = Total demand distortion is the harmonic current distortion in percent of the maximum demand load current (15 or 30 minute demand).
I_{SC} = Maximum short circuit current at the PCC not counting motor contribution
I_L = Maximum demand load current for all of the connected loads (fundamental frequency component) at the PCC

To assist in evaluating current harmonics Figure 1 has been developed, based on a 6-pulse diode bridge rectifier feeding a capacitor filter, which is typical for most AF Drives. The figure shows the effect of line reactance on line harmonic currents. For example, if the total reactance is 4%, then the 5th harmonic current is 37% of the full load fundamental current.

% HARMONIC CURRENT

TOTAL % AC LINE REACTANCE
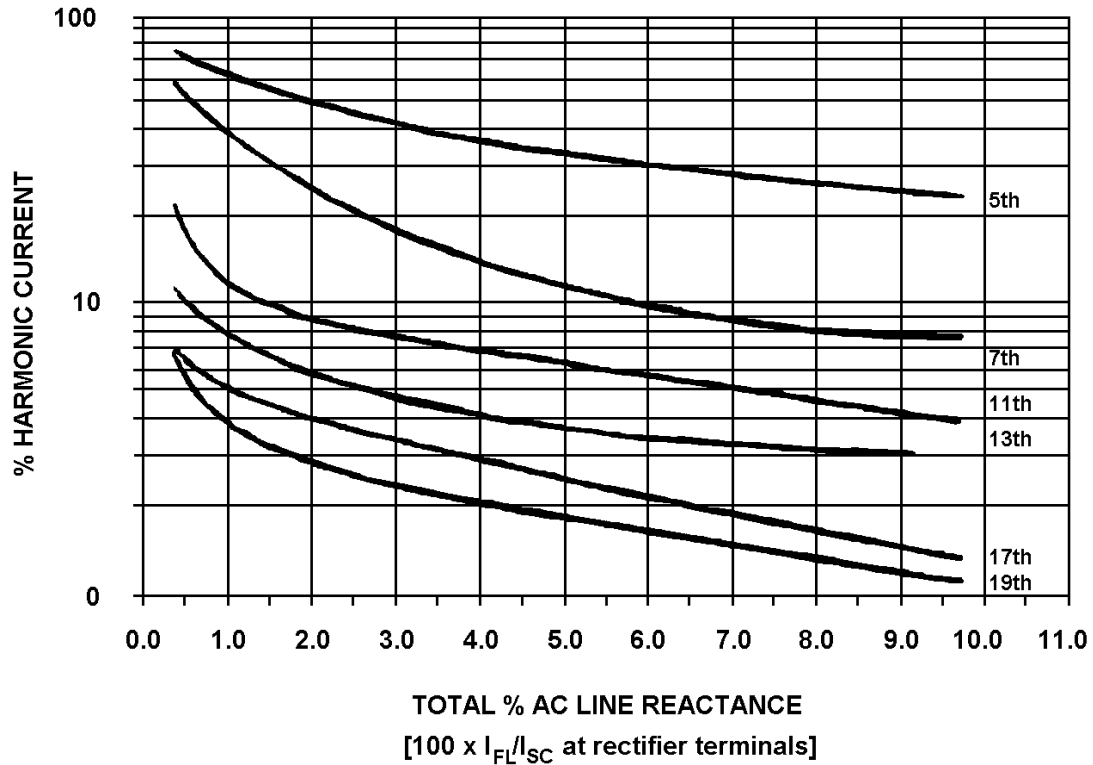
[100 x I_{FL}/I_{SC} at rectifier terminals]

**Figure 1. Typical AC Line Harmonic Currents in a
Three-Phase Rectifier with a large DC Filter Capacitor**

A complication in applying the standard occurs because the levels of harmonics are defined relative to the total load. The total load may include other than power electronics, and to determine whether the recommendations are being met will require knowledge of the total plant load – not only the worst case maximum conditions but also the practical operating levels. One way to avoid the complication is to always meet the toughest restrictions, namely Isc/IL <20 and assume the total load is comprised of power electronics. The challenge with this approach is to keep the cost and size of the installation to a reasonable level – in many cases it will not be practical (for either reason).

WAYS TO MEET IEEE STANDARD 519-1992

1. Passive Filters

Passive filter consist of series tuned LC filters connected across the power line to lower the line imped-ance at the tuned frequency. This reduces the line harmonic voltage and hence the harmonic current flowing into the source. Typically a filter tuned to the fifth harmonic, or slightly below, gives reasonably good results. But before filters are applied, a complete system analysis is recommended to investigate for unwanted resonances. Improperly applied filters can cause resonance problems, which can exceed the distortion that they are intended to cure. In addition, the filters provide a leading power factor load at 60 Hz. This can be a problem if a standby generator is used. Power factor capacitors can react in a similar way. In view of the design costs, technical uncertainty and installation expense of passive filters other methods to eliminate or reduce harmonics have been devised.

2. Phase Shifting of Multiple Equipment

In some installations where multiple power controller or drives using simple 6 pulse rectifiers are de-ployed, it may be helpful to consider feeding different units with differently phased AC supplies. For ex-ample, in a recent evaluation with a total 600 HP load, it was effective to feed 300 HP directly from one source, with the second group of 300 HP fed through a single 30 degree shifted polygon transformer rat-ed at 150 HP. At full load the 5th & 7th harmonics of current drawn from the source were practically elimi-nated. With full load on one group and only 20% on the other the 5th harmonic was still reduced by a fac-tor of 4.

3. Multipulse Methods

The essence of multipulse methods is to use multiple rectifiers feeding one inverter output stage. The rec-tifiers are feed from a transformer which has phase shifted windings to cancel certain harmonics. A differ-ential polygon transformer method, which requires only a fractionally-rated transformer for 12, 18 or 24 pulse application, gives advantages over classical double-wound transformer methods when applied to AF drives. The cost of the transformer and the installation cost of a multipulse system, especially cabling, have to be weighed against the benefits of mitigating some lower order harmonics.

4. Active Filters

In this method a high frequency inverter is used in conjunction with some passive filter elements to inject equal and opposite harmonic currents to those drawn by the AF drive or drives. The method is not re-stricted to particular harmonic frequencies, but rather by the bandwidth of the inverter. Thus it represents a way to clean up a very wide range of harmonics. Modern designs that are emerging also have the ad-vantage over a passive filter in that they can be applied in a retrofit situation without the need to break the existing power line connections and therefore avoid expensive installation costs and excessive downtime to an existing process.

5. Clean Power Drives

In the very worst case, when the total load is comprised of non-linear load such as drives and Isc/Il is less than 20, even lower harmonic currents are required. Under these conditions the currents drawn from the supply need to be sinusoidal and "Clean" such that system interference and additional losses are negligi-ble. To meet such requirements an integrated 18-pulse method was investigated. It uses an appropriate phase-shifting transformer design with a connection which has been named "Differential Delta". This is because the delta connected winding carries only the ampere-turns caused by the difference in load cur-rents. The basic configuration of the transformer is shown in Figure 2. In a practical application, in con-junction with an Adjustable Frequency Drive output, the total KVA rating of the magnetic system was only

48% that of the motor load. This value includes the additional commutating reactance (not shown in Figure 2) which attenuates residual high frequency harmonic currents of frequency (18K + or − 1) times the line frequency. A traditional isolated transformer system, with multipulse windings, would require the full KVA rating to be supported.
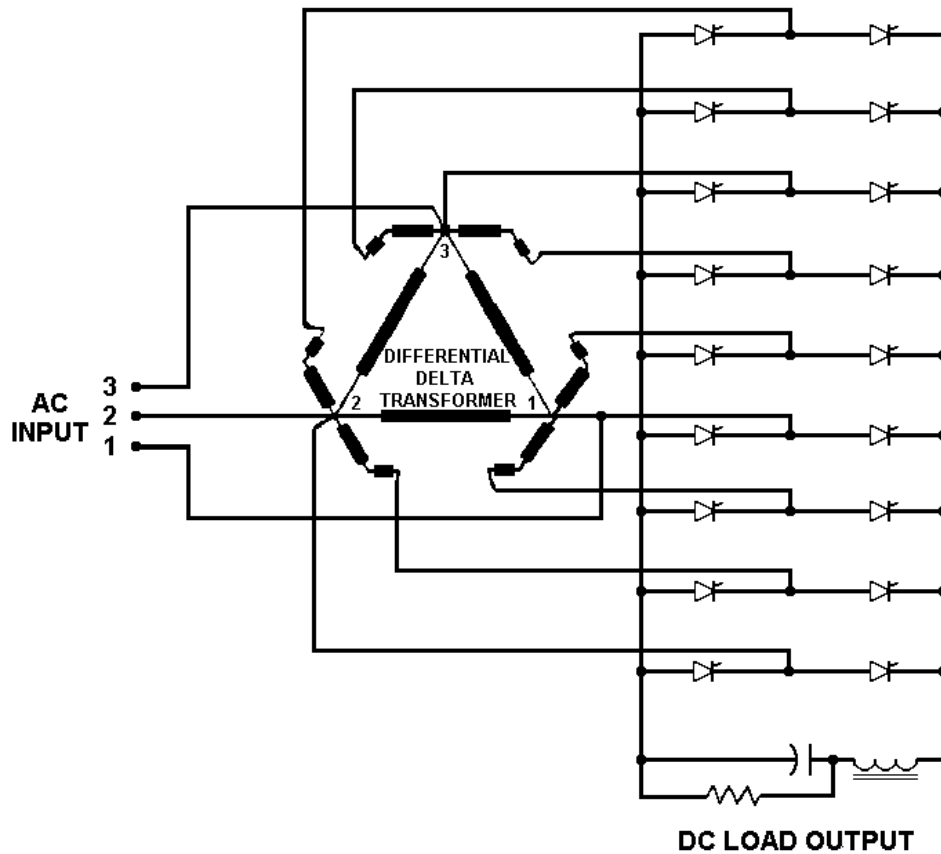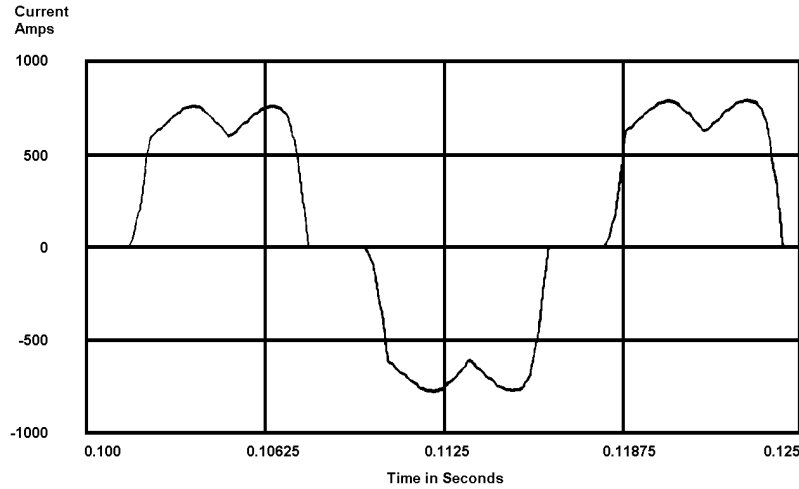

Figure 2. Basic 18-Pulse Rectifier with "Differential Delta" Transformer

The integrated 18-pulse clean power drive, with near sine wave input current and low harmonics will meet the requirements of IEEE 519-1992 under all practical operating conditions. The comparisons with 6-pulse and 12-pulse systems are shown in Figure 3.

6-PULSE CIRCUIT

Current Harmonics

I_1 = 100%

I_5 = 22.5% I_{17} = 2.26%

I_7 = 9.38% I_{19} = 1.77%

I_{11} = 6.10% I_{23} = 1.12%

I_{13} = 4.06% I_{25} = 0.86%

Power = 424 kW

H_C = 167
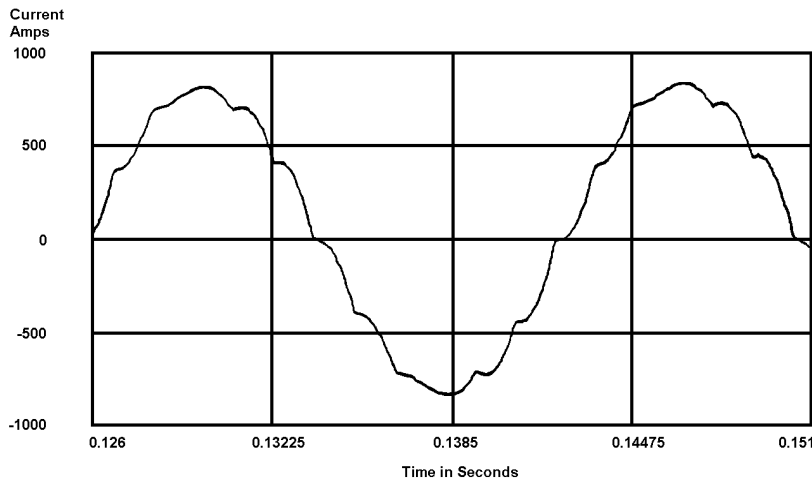
12-PULSE CIRCUIT

Current Harmonics

I_1 = 100%

I_5 = 1.25% I_{17} = 0.21%

I_7 = 0.48% I_{19} = 0.06%

I_{11} = 4.19% I_{23} = 0.87%

I_{13} = 2.95% I_{25} = 0.73%

Power = 419.6 kW

H_C = 66.2
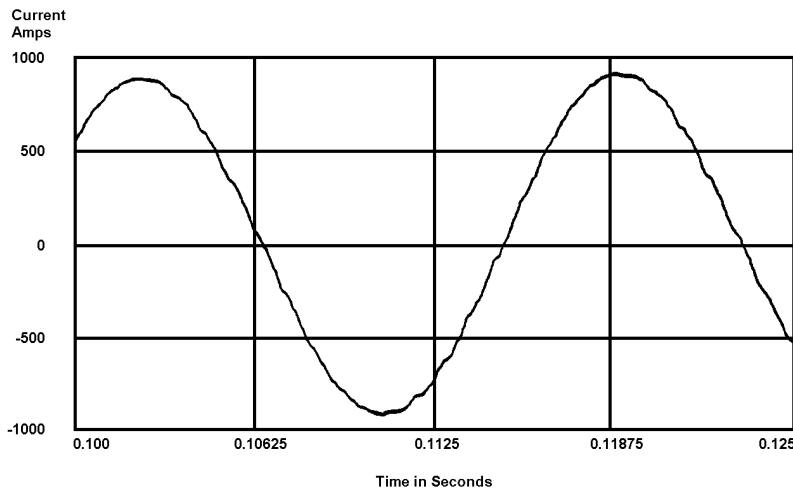
18-PULSE CLEAN POWER Current Harmonics

I_1 = 100%

I_5 = 0.16% I_{17} = 0.86%

I_7 = 0.03% I_{19} = 1.00%

I_{11} = 0.24% I_{23} = 0.01%

I_{13} = 0.10% I_{25} = 0.01%

Power = 428.8 kW

H_C = 24

Figure 3. 500 HP 480V Drive with 6, 12 and 18 Pulse Rectifiers

Summary

The IEEE Standard 519-1992 defines the need to control harmonic currents as well as voltage. This requirement has led to the development of an integrated "Clean Power" Drive with a new 18-pulse converter arrangement which meets (or exceeds) the Recommended Practice. It will be especially useful in weak power systems such as when auxiliary generators are used. It should also be of interest for shipboard and off-shore applications or any situation where the line power supply or control equipment can be adversely affected by harmonic distortion.

References

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3. Paice, D. A. and Spreadbury, R. J., Calculating and Controlling Harmonics Caused by Power Converters. 1989 Conference record of IEEE, IAS Annual Meeting

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7. New Low Harmonic Accutrol Design – Accufacts publication available from Cutler-Hammer, 110 Douglas Road East, Oldsmar, Florida 34677

8. United States Patent #4,876,634

9. United States Patents #4,255,784 and #4,366,532

10. Paice, Derek, Power Electronic Converter Harmonics, IEEE Press Order No. PC5604

Additional Help

In the US or Canada: please contact the Technical Resource Center at 1-877-ETN-CARE or 1-877-326-2273 option 2, option 6.

All other supporting documentation is located on the Eaton web site at www.eaton.com/Drives

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