

May 19, 1999

USCCEMC 99-01

1 Introduction

Loads connected to electricity supply systems may be broadly categorized as either linear or nonlinear. Until quite recently, the vast majority of loads have been linear. Examples include induction motors and incandescent lamps. Linear loads may exhibit high or low power factor, but in either case draw current only at the powerline fundamental frequency. In contrast, nonlinear loads such as rectifiers or switchmode power converters also draw significant current at harmonic frequencies. Harmonic currents flowing through electric power supply systems cause voltage distortion. Voltage distortion caused by growing penetration of nonlinear loads has in many cases been accommodated without serious consequences, but in other cases mitigation steps have been required to avoid compromised power quality.

Control of lower order powerline harmonic emissions from nonlinear loads is a serious issue that requires cooperation between utilities, equipment manufacturers, premises owners, and end users. Utilities desire to prevent problems by restricting emissions from products and/or utility customers connected to the public supply network. Equipment manufacturers desire to keep overall product costs low for the consumer and prefer supply system modifications or local mitigation when required. End users want low cost, high performance, and trouble free operation.

Different approaches are under consideration. One approach, typified by IEEE Standard 519, seeks to control emissions at the interface between facilities and the public distribution system. Another approach, typified by IEC/EN 61000-3-2, focuses primarily on controlling emissions at the product level. Utilities and manufacturers need to agree on the existing level of concern, the potential for future problems, and the most effective methods of controlling harmonic emissions.

This position paper is a direct result of the efforts to reach mutual understanding and consensus between electric utilities and equipment manufacturers. The United States offers the following guiding principles for consideration as a way forward that can be the accepted international approach for managing harmonic emissions. These guiding principles would then be used to develop detailed strategies and requirements for both residential and commercial applications and for specific product sectors.

2 Guiding Principles for Harmonic Limits

2.1 Minimum overall cost to society

All costs associated with harmonic emissions are ultimately born by consumers. Emission control requirements, including guidelines and standards, should strive to minimize the overall cost to society while providing both needed flexibility for product design freedom and the ability for utilities to maintain acceptable electric power quality.

This generally necessitates a sharing of mitigation responsibilities. Minimum cost to society best serves the interest of all parties even when one party bears a larger portion of the cost. Minimum cost to society maximizes the benefit for all provided that neither the power distribution network, installation premises, nor the product designs are constrained for satisfying other important customer requirements (e.g., minimum size, weight, component recycling, electric supply quality, etc.)

2.2 Minimal regulatory interference with free market mechanisms

Regulations should promote free market mechanisms and promote free trade. They should not create trade or market barriers.

2.3 Equal opportunity for all affected parties

All affected parties must have equal opportunity to participate in the establishment of the limits.

May 19, 1999

USCCEMC 99-01

2.4 *Limits based on objective data*

Any decision to limit emissions and selection of limit values must follow from proper use of objective data. Factors that should be considered include power level, actual or expected market volume, usage patterns, efficiency, and emission properties.

Electric utility and building electric power network properties must also be considered. These properties include but are not limited to system impedance, network topologies, attenuation, cancellation, and dilution.

Application of limits is appropriate in two situations:

1. Statistically valid field data documents the existence of voltage distortion problems that may be attributed to harmonic emissions from identifiable product classes.
2. Models that correlate with statistically valid field data predict future problems for electric supply quality if identifiable product classes are deployed in the system.

2.5 *Simple compliance test methods are preferred*

Simple tests are less expensive and promote enhanced reproducibility and repeatability. Simple tests are also easier to verify and provide a lower total cost to society. Simple tests allow more flexibility, innovation, and creativity in product design while satisfying all compatibility objectives

2.6 *Targeted application*

Harmonic limitations on products should consider the power consumption, duty cycle and the quantity of those products that will be connected to the supply system. Low power products and products with only a small quantity of units in service may not need any limits. Requirements should begin for products whose power consumption and expected quantity in service reach levels at which problems are reasonably anticipated via statistically valid field data establishing a definitive trend. More stringent requirements may need to apply to products with greater impact.

The anticipated conversion of higher power loads from linear to electronic control is likely to convert these loads from linear to nonlinear and poses a larger threat to supply systems. Setting appropriate limits today for higher impact products will prevent unacceptable future designs without the burden of redesigning existing products. Further, harmonic control for some of the larger power loads may have an acceptable cost/price premium when compared to very low power, very low cost products.

2.7 *Gradual implementation*

Initial requirements should reflect the fact that present problems on utility grids due to distributed harmonic sources in residential and commercial are minimal. Some products have been present for many years, and they operate without significant negative impact on the electric power supply system. These products should be exempted from initial requirements. Examples might include selected consumer electronics, small appliances, information technology equipment, and some lighting products.

Requirements should also consider the fact that some products become obsolete in a very few years. It is not necessary to redesign existing products with inherently short product life cycles. Requirements for short life cycle products can be adjusted as needed in the future.

3 Rationale and Areas of Mutual Understanding

3.1 *Utility supply voltages are presently within compatibility limits*

Measurements around the world have shown the supply voltage distortion at the point of common coupling is below levels of immediate concern. Some studies show a slow increase in distortion, however the levels are still acceptable. The utility supply system has generally been able to accept the present amount of nonlinear loads without widespread, significant problems. Most problems to date have only been with highly concentrated, high power nonlinear loads and have been mitigated with local solutions.

May 19, 1999

USCCEMC 99-01

3.2 Nonlinear load currents can cause problems

Nonlinear loads of sufficient size and quantity can cause problems in electric supply systems. The severity of problems depends upon the local and regional supply characteristics, the size of the loads, the quantity of these loads, and how the loads interact with each other (factors like harmonic cancellation, attenuation, and dilution).

Utilities are clearly concerned about future problems from increased concentrations of nonlinear loads that will result from the growing proliferation of electronic equipment. Experience shows that higher concentrations of nonlinear loads tend to increase the number and severity of supply problems. Problems from high concentration of nonlinear loads in industrial systems are well documented. In the U.S., information technology manufacturers under the guidance of the Information Technology Industry Council (ITIC) recognized localized potential problems at the installation facility level. Since 1988, information technology manufacturers have held workshops and issued guidelines to inform their customers about proper building facility wiring requirements to accommodate these types of nonlinear loads. The National Electrical Code guidelines address building wiring requirements for nonlinear loads.

3.3 Interaction between loads needs adequate consideration

In general, it is known that that emissions from nonlinear loads do not add directly. Higher order harmonics are much less likely to be additive than lower order harmonics. Cancellation by selection of transformer connections is a common strategy in U. S. industrial loads. Hence, simulation model parameters must adequately account for cancellation and attenuation between loads.

For example, distributed nonlinear loads in residential and some commercial installations account for a small percentage of today's total load. Market research shows that about 80% of the total residential load is linear. Linear loads absorb harmonic currents from localized nonlinear loads in a way that tends to reduce voltage distortion below levels that would be expected if these effects are not considered. This is one reason why supply systems have not experienced widespread problems from distributed nonlinear loads.

3.4 Harmonic limits should reflect product impact on the power distribution system

A survey of U.S. based Edison Electric Institute member utilities shows greater concern for larger loads and support for more stringent THD limits at higher power levels. Some loads are insignificant when compared to the total load, and the same survey shows little concern for low power loads. This fact should influence the development of limits and may affect certain product industries more than others.

3.5 Harmonic control at the customer-utility interface is effective for industrial and large commercial loads

U. S. utilities have good experience with IEEE 519 Recommended Practice for industrial and large commercial loads. These customers understand harmonics and can deal with them internally. IEEE 519 allows these users to implement a variety of local harmonic control strategies. Building owners have demonstrated a willingness to use special wiring techniques for concentrations of information technology equipment. Acceptance of National Electrical Code wiring requirements reflects this willingness. Industrial supply designs often include phase shifting designs for harmonic cancellation.

3.6 Growth of distributed residential and commercial nonlinear loads is a greater concern

Residential and small commercial customers are generally unable to understand harmonics. They are less able and less likely to take responsibility to solve harmonic emission problems. Thus, product harmonic limits for these markets may be more important, especially for high power, high volume products.

3.7 Some product industries with high load concentrations already have effective voluntary limits

The lighting industry in the U.S. voluntarily developed and implemented harmonic limits for commercial electronic ballasts. These limits have been instrumental in the development of electronic ballast technologies that require no more harmonic current than the traditional magnetic ballast technology. In fact, many, modern electronic ballasts have lower emissions than the ANSI C82.11 standard and have lower emissions than

May 19, 1999

USCCEMC 99-01

traditional magnetic ballasts. Lighting accounts for nearly 50% of commercial energy use, and these limits have effectively prevented problems. It may even be possible that conversion to electronic ballasts will slightly reduce harmonic levels on distribution systems.

The electric vehicle battery charging industry is working in cooperation with utilities to establish harmonic limits. Also, other product manufacturers are adopting low harmonic, high power factor designs for non-regulatory business reasons. For example, some manufacturers choose high power factor designs to deliver maximum available power to a load when restricted by power cord ratings, fuse limitations, or circuit breaker size.

3.8 Simplified method for specification of limits and compliance testing

Either of the following two methods should be sufficient to address product emission limits when required.

1. The first method uses combined limits on power factor and Total Harmonic Distortion (THD). This method of specifying limits allows adequate differentiation between true power factor and harmonic emissions.
2. The second method uses combined limits on individual low order harmonics and THD. Individual limits may only be necessary for harmonic orders up to 15 and would be set to prevent unacceptably high emissions at any single frequency. This method allows one or more individual harmonic emissions to exceed expected levels provided the THD limit is met.

Several otherwise adequate power factor correction circuits fail because they slightly exceed one or a few individual limits. For example, some of the high power factor electronic ballast designs may fail on an individual harmonic limit even though field experience has shown they do not cause problems. More flexibility is needed. It should not be necessary to satisfy precise, individual harmonic current limits out to the 39th harmonic.

3.9 Overly complex requirements prohibit acceptable solutions without adequate justification

Some existing and proposed harmonic standards and tests inappropriately constrain equipment designs and impose unnecessary costs. This prevents otherwise satisfactory designs from ever reaching the market.

3.10 Local harmonic current control is preferred

High reactance in medium and high voltage (MV, HV) systems makes it very difficult to supply harmonic currents over long distances and through step-down transformers. Further, maintenance of high power factor in these systems creates a variety of resonance conditions that are difficult to manage. Thus, it is generally more practical to control harmonic currents within local environments such as individual building wiring systems or within products. One method for local harmonic control utilizes passive and/or active harmonic filters. These filters may be placed at the point of common coupling or distributed throughout the low voltage wiring systems. Another method is phase displacement by special transformer winding connections in building wiring systems. It is also possible to control harmonics by using products or product systems with low emissions.

4 Conclusion

By cooperation between standards bodies, equipment manufacturers and electric power suppliers, it should be possible reach a consensus on control of powerline harmonics that makes sense both economically and technically. A stable and clean power system is in everyone's best interest; however, that objective should not be achieved by the application of harmonic limits on products where there is little or no valid field data for supporting them. Unless a consensus is reached based on data and reasonable compromise, an unjustified economic burden on the consumer is likely to be the result.

May 19, 1999

USCCEMC 99-01

5 References

1. IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, IEEE Inc., New York, NY, April 1993.
2. IEC 61000-3-2 (1997-12), Electromagnetic Compatibility (EMC) Part 3: Limits – Section 2: Limits for harmonic current emissions (equipment input current $\leq 16A$ per phase), International Electrotechnical Commission, Geneva, Switzerland, 1997.
3. IEC 725 (1981), Considerations on Reference Impedances for Use in Determining the Disturbance Characteristics of Household Appliances and Similar Electrical Equipment, International Electrotechnical Commission, Geneva, Switzerland, 1981.
4. IEC 1000-2-2 (1990), Electromagnetic Compatibility (EMC) Part 2: Environment – Section 2: Compatibility levels for low-frequency conducted disturbances and signaling in public low-voltage power supply systems, International Electrotechnical Commission, Geneva, Switzerland, May 1990.
5. D. D. Sabin, D. L. Brooks, A. Sundaram, Indices for Assessing Harmonic Voltage Distortion from Power Quality Measurements: Definitions and Benchmark Data, to be published in IEEE Transactions on Power Delivery, Paper No. PE-063-PWRD-0-06-1998.
6. IEC Committee Document 77A/WG1(Conrad)45-98, Results of EEI Harmonic Survey for IEC, Rome WG1 Meeting, November 1998.