Hazards of Harmonics and Neutral Overloads

White Paper 26

Revision 1

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> Executive summary

This document provides an overview of problems related to harmonic currents, with a specific focus on Information Technology equipment. The way that international regulations solved these problems is described.

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Introduction

Nonlinear loads cause harmonics to flow in the power lines. Harmonics are unwanted currents that are multiples of the fundamental line frequency (50 or 60 Hz). Harmonic currents can overload wiring and transformers, creating heat and, in extreme cases, fire. In information technology power systems it is important to know when and how to address this issue. Recently, the problem has been widely eliminated by international regulations.

Nonlinear loads

Many desktop personal computers present a nonlinear load to the AC supply. This is because they have a power supply design known as a "capacitor input switch mode power supply".

Information technology equipment including servers, routers, hubs, and storage systems almost universally use a different power supply design known as "Power Factor Corrected". These devices present a very linear load to the AC supply and do not generate harmonic currents. In fact they are one of the cleanest loads on the power grid and generate less harmonic current than many other devices such as fluorescent lighting or variable speed motors. Ten years ago, these devices were nonlinear loads like personal computers, but today all of these loads are subject to international regulations which require them to be made with the "Power Factor Corrected" design.

Regulations

There is a significant interest on the part of society to reduce the amount of nonlinear loading on AC power systems. This loading reduces the distribution capacity of the public power system, and it can degrade the quality of the power by distorting the AC power waveform delivered to nearby customers. It can also cause a risk of fire on a customer's premises.

In the 1980s, public utilities and international regulatory authorities including the IEC (International Electrotechnical Commission) took notice of the trend that an increasing percentage of electrical power consumption was caused by electrical equipment, and that an increasing percentage of this equipment used a "capacitor input switch mode power supply". Fluorescent lighting, high performance air conditioning systems, and personal computers were key product categories driving this change. In response the IEC created in 1982 the international standard IEC 555-2 "Harmonic injection into the AC Mains". This standard specifically limited harmonic current injection of "non-professional" equipment. Switzerland, Japan, and other countries adopted the IEC 555 standard soon after release.

Global suppliers of computing products first began to see a restriction on the ability to sell computers into countries that had adopted IEC 555-2 in the mid 1980's. This situation precipitated the development of Power Factor Corrected power supply technology.

In 1995, the IEC introduced an update of the IEC 555-2 standard, called IEC 1000-3-2. In IEC 1000-3-2 the scope of applicability was greatly expanded over IEC 555-2 to cover all equipment drawing up to 16 Amps per phase. The standard added additional limitations on both the absolute and percentage values of harmonics for products with nonlinear switch mode power supplies. Many countries outside of the US and the EC adopted this standard. The EC adopted its own version of this standard later in 1995 as EN61000-3-2 and required equipment manufacturers to comply with the standard under an EC directive called “The EMC Directive". This directive gave manufacturers until 1998 to comply for existing product designs. Later, the EC further extended this deadline to Jan 1, 2001.

The standard limits harmonic current injection as follows:

Table 1

IEC limits on harmonic current injection

Harmonic	Maximum permissible harmonic current per watt (ma/W)
3	3.4
5	1.9
7	1
9	0.5
11	0.35
Other odd harmonics up to 39	3.85/n

By 1995, almost all new computer equipment introduced for networks and communication was in compliance with IEC 1000-3-2. Even though not all countries had adopted the standard immediately, the standard represented a formidable trade barrier for companies that delayed compliance. Computer OEMs were almost universally specifying IEC 1000-3-2 compliance for OEM equipment intended for system integration. This caused virtually 100% of the IT industry to come into compliance well before the Jan 1, 2001 deadline or even the original 1998 deadline.

The USA has proposed an amendment called "amendment 14" to the standard which would weaken the standard and allow more harmonics. It is not clear which countries will adopt this amendment.

Products for sale in the EC and many countries must meet the EN61000-3-2 standard. The US has not formally adopted this standard. Information technology equipment manufactured today is universally designed for worldwide application and therefore requires the CE mark and must meet the IEC standard. Therefore, IT equipment other than small PCs universally complies with the standard (non-compliant PCs are still sold in the USA). Over the past 5 years, due to the natural change-out of equipment with newer models, harmonics have practically been eliminated in the data center environment.

Consequences of the standards on actual systems

A system comprising equipment meeting the IEC 1000-3-2 standard will have the following characteristics:

1. The harmonic current in the neutral circuit will have the currents resulting from the higher harmonics reduced to the point where less than 2% per unit of the current will be due to harmonics greater than the third harmonic, the consequence being that all harmonics other than the third can be neglected for neutral current contribution.
2. The "K" factor of the system has a theoretical maximum value of 9, but only if no loads are above 675 W. If there are larger loads, then the theoretical maximum "K" factor is reduced: For example, with 2 kW loads the maximum "K" factor is 3.
3. The theoretical maximum neutral current will be 1.7 of the rated phase current value, if all circuits are loaded to max rating, no loads are above 675 W, and all loads are generating third harmonic at the compliance limit. If there are larger loads, then the theo-

retical maximum neutral current is reduced: For example, with 2 kW loads the theoretical maximum neutral current is less than the phase current.

In a practical system, the harmonic currents will be lower than the theoretical values for the following reasons:

1. Manufacturers must meet the regulations over wide ranges of voltage, manufacturing tolerances, and load, the result being that actual products are well below the compliance limits at typical operating conditions.
2. Some loads are connected phase-to-phase (particularly in the USA), and therefore do not contribute to the neutral current

Tests were conducted on actual systems to determine the K-factor and neutral current requirements. Two test systems were used. System 1 consisted of an assortment of Dell equipment including 4 different servers, a tape library, and a Network Attached Storage System (similar results are obtained with other brands of equipment). System 2 consisted of all PC loads. Measurements of the harmonic currents were taken with a Fluke Power Line Analyzer. The K-factor was computed using IEEE Std 1100-1992. The neutral current ampacity sizing factor was computed for a 3-phase system loaded to maximum capacity. The results are presented below in **Table 2**.

Table 2

Test results

	System 1: Dell networking equipment	System 2: personal computers	System 3: 50-50 mix of networking equipment and personal computers
K-factor	1.2	11.4	5.2
Neutral sizing (current requirement as % of phase conductor)	8%	102%	42%

Note the tremendous difference between PCs and networking equipment. Note that when PCs and networking equipment are mixed, the K-factor and neutral sizing requirements are reduced from the PC value. This data shows that it is almost impossible to construct an Information Technology data center requiring a "K" rating of over 5, or requiring a neutral current rating in excess of the phase current rating. In the case of a data system constructed purely of PCs, it is possible to drive a K-factor requirement of 11 but neutral oversizing is still unnecessary.

How harmonics overload the neutral wiring in buildings and create a potential fire hazard.

3-phase building wiring consists of 3 hot (or phase) conductors, a ground conductor, and a neutral conductor. Single phase loads are connected between the different hot conductors and the neutral conductor. Therefore, the neutral conductor serves as the "common" return for all of the single phase load currents. It is a property of three phase power systems that if each of the three hot conductors has a nearly equivalent load, that the neutral current will be nearly zero due to the fact that each phase current is "out of phase" with the other. In other words, the load currents "cancel out" in the neutral wire. In North America, sometimes the building wiring design takes advantage of the cancellation and the neutral wire is sized smaller than the hot wires. Unfortunately, the harmonic currents created by computers cause the operation of this system to change. Computers generate a substantial amount of 3rd harmonic current. Due to the mathematical phase properties, third harmonic currents add instead of cancel out on the neutral wire. Therefore, in a building with a large number of Personal Computers installed, the neutral wire can carry much higher currents than it was designed for. In fact, the harmonic current alone in the neutral wire can, in theory, be up to 1.7 times larger than the full rated current of the power wiring. This is the most critical problem relating to harmonics and PCs. Note that the data above shows that while it is unlikely for the neutral current to exceed the phase current, the neutral current can reach the phase current value in a PC environment. For this reason it is essential that neutral undersizing never be used in an office environment.

This problem is not unique to PCs, since there are other loads like fluorescent lighting ballasts that also are nonlinear. However, this problem is no longer significant in data centers due to the regulations requiring Power Factor Corrected equipment. (Note that most buildings do use three phase wiring, even though all of the receptacles may be single phase).

Harmonics overload building power transformers and cause them to wear out.

Power transformers are rated in KVA and are designed to carry currents at the power line frequency (50 or 60 Hz). The factor that limits the power handling capacity of a transformer is how hot it gets. The heat in a transformer is caused by the inherent resistance of the transformer and the current carried by it. When a power transformer carries harmonic currents, an effect known as the proximity effect (sometimes confused with the eddy current effect) causes the effective resistance of the transformer to increase with frequency. The result is that the transformer rating must be decreased if the transformer carries significant harmonic currents, otherwise it will overheat and wear out due to insulation degradation. Transformer failures are often catastrophic and emit noxious fumes or fire; they can result in facility closure for days and a variety of health and safety consequences.

For this to be a problem, three things must happen together: 1) The transformer must be loaded nearly to capacity (unusual); 2) The transformer must have a poor "K" factor rating (bad proximity effect design); and 3) The load in the building must be mainly PCs. This is a real potential problem especially in situations where a large number of PCs have been deployed. Again, the location for concern is typically an office environment with high PC density such as a call center. The problem is no longer of concern in the data center environment as explained previously.

Abatement and mitigation of harmonic problems

There are a number of approaches to avoiding harmonic problems. These include:

1. Specifying equipment that does not create harmonics
2. Correcting harmonics
3. Oversizing neutral wiring
4. K-rated transformers

Specifying equipment that does not create harmonics

In the case of networking equipment, the problem is solved because of the IEC regulations. In the case of PCs, it is more difficult since a large amount of the harmonic contribution comes from the monitor. One approach is to use PCs and monitors with lower power draw overall, such as the use of LCD monitors or laptop PCs. This avoids both building wiring and transformer problems.

Correcting harmonics

If a UPS is used in conjunction with the equipment, then in some cases the UPS can correct or eliminate the harmonics. Some single phase UPS like the Symmetra eliminates neutral current entirely. If a power factor correcting UPS is used to power clusters of PCs, the harmonics problem cannot pass upstream to the building wiring or power transformers. This approach has the advantage that it can be retrofit to an existing building, and used with existing loads. It also corrects both the wiring and the transformer issues. For other types of loads, such as large industrial motor drives which are not covered by the harmonic regulations, specialized products are available that can absorb harmonics near the source.

Oversizing neutral wiring

In modern facilities the neutral wring should always be specified to be the same capacity as the power wiring (or larger). This is in contrast the electrical codes which may permit undersizing the neutral wire. An appropriate design in the case of a large personal computer load like a call center is to specify the neutral wiring to exceed the phase wire capacity by about 50% (2 wire gauges in USA i.e. if the phase wiring is 8-gauge, the neutral wiring should be 6-gauge). Particular attention should be paid to wiring in office cubicles. This protects the building wiring, but does not help protect the transformers.

K-rated transformers

Modern office facilities with high densities of PCs should always be specified to include transformers with a "K" rating of at least 9. These transformers have been specially designed to withstand harmonic currents. For data centers, a "K" rating of 9 would be sufficient to ensure harmonic carrying capability for the fraction of the data center consisting of old legacy loads, PC loads, or lighting loads.

Conclusion

International regulations have dramatically affected the power requirements for computing systems. Networking equipment, once rightly accused of "power pollution" and of causing fires due to overheated transformers and wiring, have transformed into one of the "cleanest" loads to be found in a modern commercial or industrial establishment. Data center design standards specifying double neutrals or transformers with K=20 ratings are driving needless expense and should be updated.

About the author

Neil Rasmussen is a Senior VP of Innovation for Schneider Electric. He establishes the technology direction for the world's largest R&D budget devoted to power, cooling, and rack infrastructure for critical networks.

Neil holds 19 patents related to high-efficiency and high-density data center power and cooling infrastructure, and has published over 50 white papers related to power and cooling systems, many published in more than 10 languages, most recently with a focus on the improvement of energy efficiency. He is an internationally recognized keynote speaker on the subject of high-efficiency data centers. Neil is currently working to advance the science of high-efficiency, high-density, scalable data center infrastructure solutions and is a principal architect of the APC InfraStruXure system.

Prior to founding APC in 1981, Neil received his bachelors and masters degrees from MIT in electrical engineering, where he did his thesis on the analysis of a 200MW power supply for a tokamak fusion reactor. From 1979 to 1981 he worked at MIT Lincoln Laboratories on flywheel energy storage systems and solar electric power systems.

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