Neutral Ratings For Power Distribution Systems in the Data Center

Introduction

Global competition is ballooning, forcing companies to seek value and automate processes where ever possible. Computer technology is increasingly used to accomplish these goals, which means more compute power is required. Companies are designing, consolidating or re-designing data centers to accommodate the need for more capacity while also dealing with shrinking budgets and the limited availability of additional power from utilities, particularly in metropolitan areas. Data center managers, facilities managers, and electrical architects need to work together to design flexible, cost-effective data center power distribution systems that safely comply with codes. One topic that might cause some confusion and contention in the design process is harmonic currents. This is an issue that was extremely relevant in the data center 10 to 20 years ago, but due to regulations and new technology, it is much less of an issue today. To help you design a more cost-effective power distribution system for modern computer systems, this paper defines harmonics, discusses some options that might be recommended to deal with harmonics, and provides a valid argument why these expensive options are generally no longer necessary when providing power to modern IT equipment.

Non-Linear Loads and Harmonics

In AC power distribution systems, harmonics occur when the normal electric current waveform is distorted by non-linear loads. A linear load is one where voltage (a sine wave) is applied across a constant resistance resulting in current (another sine wave), as shown in Figure 1.

![Linear Load](image)

**Figure 1.** Linear load sine wave.

Non-linear loads occur when the resistance is not a constant and changes during each sine wave of the applied voltage waveform, resulting in a series of positive and negative pulses, illustrated in Figure 2.
These pulses can create harmonic currents in addition to the original current. For example, the third harmonic of 60 Hz is 180 Hz. In three-phase power systems, even harmonics cancel out, so only the odd harmonics are of concern. On three-phase systems each phase voltage is 120 degrees out of phase, causing the phase current to be 120 degrees out of phase as well, shown in Figure 3.

In a balanced distribution, where each phase carries an equal amount of current, the currents cancel each other out when they combine at the common neutral conductor to return to the source, causing the neutral current to be zero. This is why one neutral can handle three phases and why most wiring codes permit the neutral to be downsized to a smaller gauge wire. Although a perfectly balanced distribution is next to impossible to implement, circuits carrying linear loads generally do not create much neutral current.

With non-linear loads, the third harmonic on all three phases is exactly in phase and adds, rather than cancels, thus creating current and heat on the neutral conductor. Left un-treated, harmonic loads can reduce the distribution capacity and degrade the quality of the power of public utility power systems, increase power and AC costs, and result in equipment malfunctions such as communication errors and data loss. The effect on the public power system has led regulatory agencies to set lower harmonic levels and power utilities to charge more for wasted energy.

Sources of non-linear loads are computer equipment with switched-mode power supplies, variable speed motors and drives, photocopiers, laser printers, fax machines, battery chargers, UPSs, fluorescent light ballasts, and medical diagnostic equipment. Historically, single-phase non-linear loads were common in
office buildings and three-phase non-linear loads were generally found in factories and industrial plants. However, data centers are increasingly moving to three-phase power distribution.

**Options to Mitigate Harmonics**

Realistically, completely eliminating harmonics in the data center would be too difficult and expensive. When building a new data center or re-modeling an existing data center, electrical engineers or facilities managers might specify options to mitigate harmonics in the power distribution center. It is important to understand these options and their costs in order to balance the real harmonic load against the cost of the solution. A number of options that work to minimize actual harmonic loads are currently available, but should be carefully considered because of the added expense and because they utilize more copper, which is becoming increasingly scarce.

- **200% neutral conductors**: One option is to specify an 200% neutral conductor or to use separate neutral conductors. Triplen harmonics (3, 9, 15, etc.) can produce neutral currents that can be up to the theoretical maximum of 173% of the phase current, which is why a 200% neutral conductor is usually specified.

- **K-factor transformers**: Standard transformers can overheat and fail prematurely due to the high currents produced by non-linear loads. K-rated transformers are designed to handle the heat generated by harmonic currents. Standard transformers have a K-factor rating of one. The higher the K-rating, the more harmonic-generated heat the transformer can accommodate and minimize. K-factor transformers must be properly selected in order to balance cost, efficiency, and safety.

- **Phase shifting transformers**: These transformers can help cancel harmonics when several non-linear loads of equal ratings share a power system.Loads are phased-shifted opposite of each other (e.g., -20° phase shift and +20° phase shift) so that when combined, the harmonics from both phases create a clean sine wave. This option adds another expense to the data center and is not always completely effective as the loads need to be exactly the same on each transformer.

- **Harmonics filters**: Harmonic filters remove harmonics and correct the phase of the fundamental current, thus converting non-linear loads into linear loads.

**A Better Option — Design Better Systems and Devices**

A better way to handle harmonics in the data center is to simply design better systems and devices, which fortunately has already been accomplished for the most part. In 1982, the International Electronic Commission (IEC) created the international standard IEC 555-2 to limit the harmonic injection into AC mains in order to reduce energy waste. Switzerland, Japan, and other countries adopted the standard soon after it was released. In 1995, the IEC updated the IEC 555-2 standard with IEC 1000-3-2 (also known as EN 61000-3-2) to cover all equipment drawing up to 16 Amps per phase. The European Commission and many other countries adopted this standard, which was updated again in 2008 and 2009, so products available for sale in these countries must comply with the standard. In order to offer products in the world-wide market, nearly every computer equipment manufacture is in compliance.
To comply with the regulation, global computer equipment vendors developed Power Factor Corrected (PFC) power supply technology.

Power factor is the ratio of the real power to the load and the apparent power and is a number between zero and one (e.g., 0.5 pf = 50%pf). Real power is the capacity of the circuit. Apparent power is the product of the current and voltage in the circuit. If energy is stored in the load and returned to the source, or if it is distorted by a non-linear load, the apparent power will be greater than the real power. Loads with a high power factor draw less current than loads with low power factors, and these higher currents increase energy loss and require larger equipment.

Switched-mode power supplies have a low power factor. PFC power supplies control the harmonic current using either a filter or an electronic system that controls the amount of power drawn by the load. The purpose of the PFC is to make the power factor as close to one as possible, where the current waveform is proportional to the voltage waveform. When this is the case, the voltage and current are in phase and the reactive power consumption is zero, enabling power companies to efficiently deliver power. In other words, all of the energy supplied by the source is consumed by the load and none is returned to the source.

In the U.S., the utility-funded incentive program 80 PLUS performance specification requires that certified power supplies in computers and servers be at least 80% energy efficient or greater at 20%, 50%, and 100% of the rated load with a power factor of 0.9 or greater. 80 PLUS certifies 115V and 230V internal power supplies. 80 PLUS certified power supplies nearly eliminate harmonics and as a result they also reduce energy consumption, reduce heat output and cooling costs, increase computer reliability, and enable more computers to be run on the same branch circuit. For more information on vendor certifications see: http://www.plugloadsolutions.com/80PlusPowerSupplies.aspx

In the US, the Energy STAR Program Requirements for Computers Version 4.0 incorporates the 80 PLUS specification and calls for a power factor greater than 0.9 at 100% of the rated output in a PCs power supply. Version 5.0 calls for 85% minimum efficiency at 50% or rated output and 82% minimum efficiency at 20% and 100% or rated output with a power factor of greater than or equal to 0.9 at 100% rated output. Version 5.0 applies to desktop computers, notebooks, workstations, thin clients, and small-scale servers. An Energy Star specification for computer servers is currently in draft and under review. For more information on the server specifications see http://www.energystar.gov/index.cfm?c=revisions.computer_servers.

Below is a brief listing of server manufactures that conform to one or all of the specifications (EN 61000-3-2, 80 PLUS, Energy STAR):

- Power supplies for HP ProLiant servers all contain circuitry to correct the power factor. (Power basics for IT Professionals HP technology brief). HP currently has 37 power supplies that are 115V 80 PLUS certified.
- Power factor correction is a standard feature on all Cisco Catalyst 6500 series AC-input power supplies and 7600 series Internet Routers.
- Dell currently has 51 power supplies with 80 PLUS c115V certification.
- FSP Technology, Inc has 246 80 PLUS 115V certifications.
- Lenovo has 23 115V certifications.
Some vendors with 230V 80 PLUS certifications are: Dell, Fujitsu, HP, Hitachi, IBM, and NEC.

A study undertaken by the 1996 NEC Subcommittee on nonlinear loads quantified the effects of these improvements in technology: “The subcommittee reviewed all available data regarding measurements of circuits that contain nonlinear loads. The data was obtained from consultants, equipment manufacturers, and testing laboratories, and included hundreds of feeder and branch circuits involving 3-phase, 4-wire, wye-connected systems with nonlinear loads. The data revealed that many circuits had neutral conductor current greater than the phase conductor current, and approximately 5 percent of all circuits reported had neutral conductor current exceeding 125 percent of the highest phase conductor current. One documented survey with data collected in 1988 from 146 three-phase computer power system sites determined that 3.4 percent of the sites had neutral current in excess of the rated system full-load current.” Technology improvements since the time of this report have undoubtedly further reduced neutral harmonics.

**Conclusion**

Harmonics in the data center was a real concern in the past. Fortunately, it is one of those issues that is close to being solved, at least for computing equipment, by regulatory agencies and computer equipment manufactures. It's not an issue that receives a lot of press or marketing, as companies tend to focus more on the more tangible benefit of energy efficiency and reduced energy costs, which is why the subject of harmonics is still occasionally raised as an issue when designing new power distribution systems. Facilities managers or electrical architects who are unfamiliar with modern computer equipment might specify costly solutions such as K-factor transformers or 200% neutral conductors, to handle non-linear loads and harmonic neutral currents that are relatively rare in today's IT environments. Data center managers who are armed with the knowledge that computer vendors are compliant with harmonic elimination standards can help drive more realistic and cost-effective power distribution designs in the data center and be more proactive in replacing non-conforming, legacy equipment. Simply stated, 100% rated neutral conductors are suitable for the vast majority of applications.

Circumstances might arise where oversize neutral conductors are necessary for the remaining non-linear loads in the data center, such as lighting and cooling equipment, or legacy equipment that must be maintained for a particular application. StarLine Track Busway products offer efficient oversize neutral conductors to help you in those cases. When in doubt, check for EN 61000-3-2, Energy Star 5.0, or 80 PLUS compliance on your equipment, make sure to purchase compliant equipment, and monitor power usage and harmonic levels on the bus, which can provide real evidence of harmonics and enable you to apply more expensive harmonic-mitigating solutions to only those devices that actually need it. In the end, you'll have a more energy efficient data center and cut energy costs as well.

**About StarLine Busway and Universal Electric**

StarLine Track Busway is a revolutionary electrical power distribution system that is ideal for today's dynamic data centers. It is the simple, versatile, fast and economical solution for supplying power to electrical loads and is unique because the busway can be tapped instantly at any location — without losing any uptime!
Today, Universal Electric Corporation remains the industry leader in customizable power distribution. The company’s award-winning StarLine systems are the only fully flexible products available that allow access to power anywhere it is needed. Designed to meet the changing electrical power needs of any business requiring ultimate flexibility, StarLine products continue to revolutionize electrical power distribution in data centers, industrial manufacturing facilities, retail chains and grocery stores worldwide.