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Subject: Primer on Harmonic Currents

Linear and Non-linear Loads.

Electrical loads can be characterized by the way in which they draw current. An induction motor, when connected to a sinusoidal AC voltage source will draw sinusoidal current. The waveform of the current will look almost the same as the voltage waveform, as shown in Figure 1. Likewise, electrical resistance heaters and incandescent lights draw current waveforms that look like the voltage. Such loads are called “linear loads.”

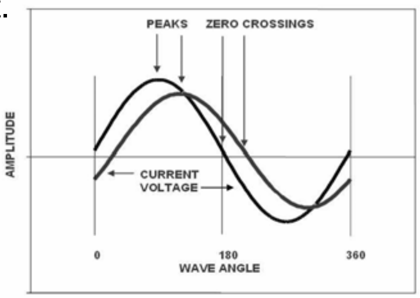

Figure 1. Current-voltage relationship, linear load.

Electronic loads, called “non linear loads,” draw currents with waveforms that do not look like sine waves, as shown in Figure 2. Computer power supplies are non- linear loads.

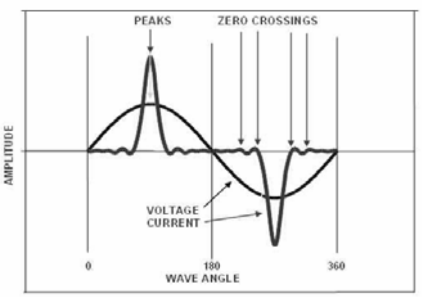

Figure 2. Current-voltage relationship, non-linear load.

The electrical load profile has changed for commercial facilities. Thirty years ago the electrical load in an office building was primarily linear. Electric typewriters were powered by induction motors. Today commercial facilities have a computer on every desk. This changing load has increased the demand on electrical distribution to the point that many older facilities are experiencing severe transformer overloading.

Harmonics

Harmonics are defined as continuous integral multiples of the fundamental frequency. If the fundamental (or 1st harmonic) frequency is 60 Hz, the 3rd harmonic would be 180 Hz (3 x 60), the 5th harmonic would equal 300 Hz, etc. This relationship is shown in Figure 3. Harmonics are introduced into electrical power systems because of the way that non-linear electrical loads draw current from the system. By drawing currents which are not sine waves, non-linear loads cause harmonic currents also to flow in the system. These harmonic currents

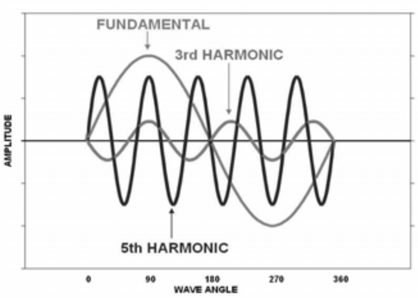

Figure 3. Harmonic relationships.

are in addition to the 60 Hz current that provides power to the load.

The harmonic currents a computer power supply causes to flow are the 3rd, 5th, 7th, 9th, 11th, 13th, and higher harmonic currents. These harmonics are independent of the make or model of computer. All computer power supplies connected to 120 volts AC cause the same harmonic currents to flow. These currents are shown graphically in Figure 4. The amount of harmonic current drawn by a computer can be over 100% of the fundamental 60 Hz current.

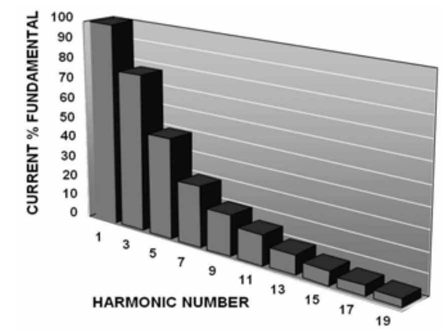

Figure 4. Typical computer harmonic spectrum

Powering Computers

Today's commerce depends on computers. The proliferation of single-phase computer loads has resulted in significant problems with power distribution systems.
Computers are connected phase-to-neutral in a 3-phase 4-wire wye system as shown in Figure 5. This method of power distribution is attractive due to the way that return currents combine on the common neutral. If the 120 volt 60 Hz currents are balanced, that is the loads are equal on all three phases, the return currents in the neutral cancel and the neutral current is zero. If loads on all three phases are not equal, the neutral does carry return currents, but only the current due to phase imbalance. For 60 Hz this current will always be lower than any of the phase currents. Cancellation of currents in the combined neutral also occurs for most harmonics. This not the case for 3rd harmonic currents.

Neutral current cancellation does not occur for harmonics, which are multiples of three (3.) These "triplen" harmonics, instead of canceling in the common neutral, are additive. For example, with 100 amps of 60 Hz current on each of three phases, the 60 Hz neutral current would be zero (0) amps. However, with 100 amps of 3rd harmonic current on each phase, the neutral current would be three hundred (300) amps, all 3rd harmonic. When many computers are connected to a wye distribution system, the neutral current due to 3rd harmonic can easily exceed any of the phase currents, and can, in a worst-case scenario equal 1.73 times the largest

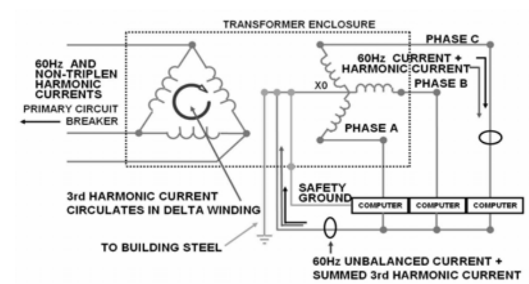

Figure 5. Wye connected transformer powering computer loads.

phase current.

Triplen harmonics return to the transformer where they are coupled into the delta 3-phase primary. Transformer theory shows that triplen harmonic currents cannot pass out of a delta winding, but instead are circulated within the winding and are dissipated as heat.

The primary of the transformer is now carrying not only the phase current needed to supply secondary loads, but also circulating triplen harmonic currents. Thus a transformer which should, according to the loads being served, be lightly loaded, can actually be reaching overload.

The only symptom of this overload, since circulating currents cannot be measured, is the transformer becoming hot. It is common to find a transformer, serving multiple computer loads, operating at or near its upper temperature limit while only 40% loaded. In addition to the transformer, system components such as wires, breakers, distribution panels, etc. are all rms current limited. The presence of harmonic currents in the phase wires and high harmonic currents in the neutral wire not only reduces system capacity, but also overloads the system causing excessive heat. Excessive heat is the major cause of transformer and wiring failures in electrical distribution systems serving single-phase computer loads.

SOLUTIONS TO SINGLE-PHASE HARMONIC PROBLEMS

A number of methods have been developed to enable electrical systems to function while serving multiple computer loads. These include: doubling neutrals and de-rating transformers; using special k-rated transformers; using zig-zag transformers; and connecting harmonic suppression systems.

Doubling Neutrals and De-rating Transformers.

Harmonic currents flowing in an electrical distribution system add to the load that must be carried by wiring, breakers, panels, transformers, etc., resulting system components becoming overheated. Increasing the size of the electrical system will enable it to successfully carry these extra currents. Since triplen harmonics concentrate in the neutral wire, the neutral wire can be doubled, or an individual neutral wire can be run for each phase wire in the system, making it a 3-phase 6-wire system. An oversized transformer can be installed and can be limited to only 40% loading. All of these solutions result in an accommodation of the harmonic currents, but do not actually remove them from the system.

K-rated Transformers:

One possible solution to transformer overheating problems caused by 3rd harmonic currents is the k-rated transformer. A k-rated transformer is specially designed to be able to handle high harmonic loading without burning up and the neutral connection lugs are oversized and are doubled to handle two neutral wires. Special construction using more material results in k-rated transformers being heavier than their standard counterparts, and they usually have a larger footprint – a consideration where space is at a premium.

The transformer will not fail when overheated by high harmonic loading, but harmonic currents are still present in the system. Thus, while a k-rated transformer will enable the system to operate successfully, it will not reduce the levels of harmonic currents circulating within the primary winding or flowing out to the loads.

Zig-zag Transformers.

Another method of handling high 3rd harmonic currents in the distribution transformer is to use a “zig-zag” transformer. The zig-zag transformer, containing multiple windings connected so as to present low impedance to 3rd harmonic currents, is connected in parallel with the distribution transformer between the transformer and the loads. 3rd harmonic currents are intercepted before they can reach the distribution transformer.

Since these harmonic currents no longer reach the distribution transformer, they cannot circulate in its delta primary. Phase wires from the distribution transformer to the point where the zig-zag is connected are also relieved of the 3rd harmonic load. Zig-zag transformers do a good job of protecting the distribution transformer and greatly reduce transformer heating caused by circulating harmonic currents. However, 3rd-harmonic currents are still permitted to flow through system wiring to the computer loads, and neutrals and switchgear can still become overheated.

Harmonic Suppression Systems.

The harmonic suppression system is a device which removes 3rd harmonic currents from the electrical distribution system by preventing them from ever existing. Harmonic suppression systems are connected in the common neutral return path of a wye distribution system as shown in Figure 6 . In this location the device blocks the flow of 3rd harmonic current in the neutral, and therefore also in any of the phases since current in the phases must be carried back to the transformer by the neutral wire. If 3rd harmonic current cannot flow through the phase wires, it cannot flow anywhere in the distribution system served by the transformer. Thus a single device can render an entire facility free of 3rd harmonic currents and the problems they cause. Since the

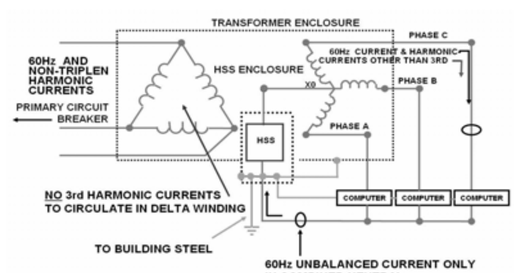

Figure 6. Wye connected transformer powering computer loads with a harmonic suppression system installed in the common neutral return path.

currents never flow, there is no heat associated with their removal. Reduced waste heat leads to energy savings – as much as 8% of the energy used to power the computers.

Conclusions.

For 3-phase wye connected systems, found in most commercial facilities, the presence of harmonic currents caused by computer loads can lead to serious overloading of transformers, breakers, and wiring that can cause equipment failures. Harmonics also cause reduced efficiency of utilization, and extra operating costs. Systems can be designed to accommodate harmonic currents by doubling neutral wires, over sizing branch circuits and transformers, or utilizing k-rated transformers. Zig-zag transformers can be added to protect the distribution transformer. These techniques can prevent system failure. A harmonic suppression system, which eliminates harmonic currents in the system by preventing them from ever forming, can unload the entire distribution system and reduce waste heat, leading to significant energy savings.

For further information contact:

- Harmonics Limited Customer Service, 800-892-3755
  CustomerService@HarmonicsLimited.com
- Your Sales Representative