A Primer on Power Harmonics in the Entertainment Industry
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Harmonics are caused by or more properly "generated by" non-linear loads. To understand harmonics, you must first understand what is meant by the "out of balance" condition on a three-phase WYE distribution system.

In a three-phase WYE distribution system, there are three phases 120 degrees out of phase with a shared common conductor – the Neutral. As single-phase loads are applied to this three-phase system, i.e. lighting loads, etc. an unequal loading of phases usually occurs. The current on each of the three phases cancels each other, as they are 120 degrees out of phase with each other. When current on each of the three phases is equal, there is no current on the neutral because full cancellation is achieved. As loads change or vary from phase to phase an "out of balance" condition exists. The greater the load difference, the greater/higher the "out of balance" condition. When this happens the cancellation of currents phase to phase cannot be affected at 100%, therefore, there will be a certain amount of current "left over." This "left over" current is the out of balance condition and can be measured on the common or neutral conductor.

With standard resistive loads (sinusoidal loads) the neutral current is consistent with the out of balance condition formula. As non-sinusoidal loads are applied, i.e. gate controlled equipment (SCR and Triac) system dimmers, harmonics are brought into play.

Harmonics – simply put – are a multiplier of the fundamental frequency. There are two types of harmonic distortion – even order and odd order. They are as follows:

Odd		Even	
1	60 Hz	2	120Hz
3	180 Hz	4	240 Hz
5	300 HZ	6	360 Hz
7	420 Hz	8	480 Hz
9	540 Hz	10	600 Hz
. . .	Etc. to infinity	. . .	

Odd order harmonics are the most commonly produced type of harmonics. However, even order harmonics are a natural component of gate controlled loads such as SCR dimmers. As non-sinusoidal loads are increased, the resulting harmonic content is also increased. If a large out of balance condition exists with harmonic non-sinusoidal loads, the standard formula is incomplete because the load is not "traveling" at 60 Hz (60 cycles per second), the load could be "traveling" at 3 to 5 times the prime frequency of 60 Hz (or more.) Since current "travels" at 60 Hz and harmonics act as a multiplier of the fundamental frequency of 60 cycles/second, then as the frequency is increased by the harmonic effect, so is the current, thereby increasing the amperage carried on the neutral or common.

As per Tom Shaughnessy of PowerCET Corporation, in his August 30, 1994 article called Power Factor, Harmonics, & Harmonic Filters, and I quote, "The problem with nonlinear loads is non-sinusoidal current draw. Figure 1 shows the current draw of a single-phase switch mode power supply. The current draw is concentrated into a short

burst about 23 milliseconds in duration each half cycle. In contrast, a sinusoidal load draws current over the full half cycle (8.33 milliseconds) and mirrors the applied voltage waveform. The short current draw of the switch mode power supply causes several problems. First, voltage losses caused by the current draw are concentrated at one point the AC waveform. Second, in three phase distribution systems, load currents for balanced loads share between phases and return current is either zero or equal to the imbalance. However, with switch mode supplies, the short burst of current draw for each phase is unique in time with respect to the other phases. The return current from switch mode loads must return through the neutral because there is no opportunity for the current to share between the phases. For a well-balanced three-phase load, with minimal impedance in the distribution systems, the neutral current becomes 1.73 times larger than the phase currents. *Wiring sized for phase currents is not adequate to carry return current.”* (emphasis added by this author)
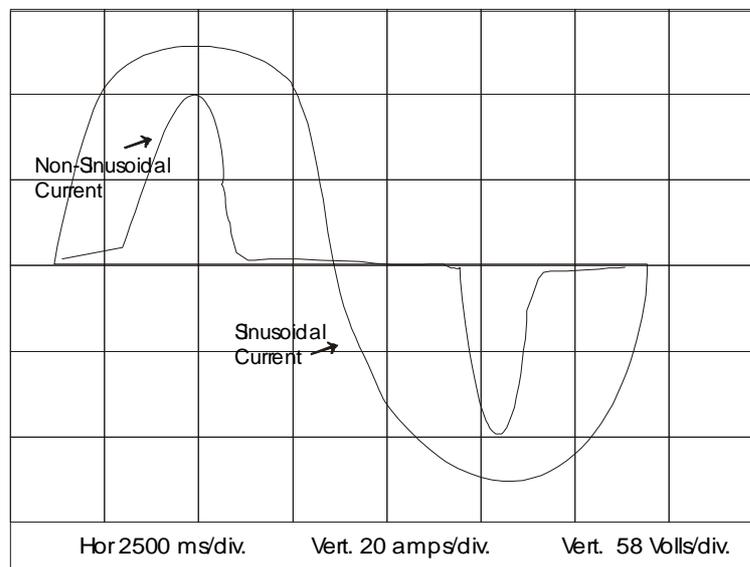

Figure 1 – Single Phase Switch Mode Supply Current

The wire size of the neutral is an important consideration since the out of balance loads can be almost two times the line current from the hot phases. The end results of high harmonic content are:
1. Neutral conductors overheating/failure
2. Transformer neutral overheating
3. Transformer eddy current/hystoresis losses
4. Transformer overheating failure
5. Voltage distortion
6. High levels of neutral to ground voltage
7. DC Flux circulation in primary Delta winding

The ultimate concern is one of safety. As neutrals overheat, the potential for fire hazard increases.

Solutions/Remedies for WDI:

There are many calculations/applications used to determine the condition and solutions to improve power quality of any power distribution system. One guideline currently in use is ANSI/IEEE standard C57, 110-1986. Other practices include K-factor calculations and load balancing and transformer derating. All of these methods must be used conjuntively in order to effectively reduce harmonic currents in any power distribution system. The NEC already requires derating the line circuit overcurrent protection by 20% but this does little to help harmonic current content on neutral conductors.

Harmonic Spectrum "K" Factor definition: The sum of the product of each harmonic current squared and that harmonic number squared for all harmonics from the fundamental (60 Hz) to the highest harmonic of any measurable consequence. When the "K" factor is multiplied by the stray losses of the transformer, the answer represents the losses in the transformer caused by harmonic currents. When these losses are added to the I^2R losses of the transformer, the total load losses are known. The "K" factor for a linear load without harmonics is one (1).

Typical Load K-Factors:

LOAD	K-Factor
Electric discharge lighting	K-4
UPS with optional input filtering	K-4
Welders	K-4
Induction heating equipment	K-4
PLCs and solid state controls (other than variable speed drives)	K-4
Telecommunications equipment (eg. PBX)	K-13
UPS without input filtering	K-13
Multiwire receptacle circuits in general care areas of health care facilities and classrooms of schools, etc.	K-13
Main-frame computer loads	K-20
Solid state motor drives	K-20
Multiwire receptacle circuits in critical care areas and operating/recovery rooms of hospitals	K-20

FOR WDI Applications, the following is recommended:

1. Double the size of all load neutrals from load back to distribution transformer
2. Derate all non K-factor transformers by 50%
3. Test each existing system initially and periodically to determine if derating is providing sufficient protection. If not, investigate the options of using K-rated transformers, "I-trap" neutral current reducing transformers, or use of harmonic filters such as line reactors, passive harmonic filters, regulators or feedback electronic filters.
4. Calculate loads on new distribution systems and use a K-factor rated transformer. Caution is advised in selecting a K-factor transformer. A higher K-factor rating is advised. Better to err on the safe side.

It has become apparent in recent years that the proliferation of non-sinusoidal (harmonic) load devices is rapidly increasing and will become the "rule" instead of the exception. It is very clear that the current mindset of design and application engineers

as well as installers needs to be refocused and informed as to the impact and scope that harmonics will affect power distribution systems now and in the future.

WDI applications will need to be addressed and affirmed on three levels:

1) Existing systems
   a) Test & determine existing system layout and uses
2) Current upgrades/additions
   a) Test and determine current projects and impact on existing systems.
3) Future installations
   a) Carefully determine harmonic content of works in progress and implement design products to handle loads and expansion capabilities.