Thought Leadership White Paper

No Harmony in Harmonics

Common causes, implications and resolutions for problematic harmonic distortion in your electrical system

Abstract

Harmonic currents generated by non-linear electronic loads increase power system heat losses and power bills for end users. These harmonic-related losses reduce system efficiency, cause apparatus overheating, and increase power and air conditioning costs. As the number of harmonics-producing loads has increased over the years, it has become increasingly necessary to address their influence when making any additions or changes to an installation.

Harmonic currents can have a significant impact on electrical distribution systems and the facilities they feed. It is important to consider their impact when planning additions or changes to a system. In addition, identifying the size and location of non-linear loads should be an important part of any maintenance, troubleshooting and repair program.

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The trouble with harmonics in modern power systems

Harmonics are a distortion of the normal electrical current waveform, generally transmitted by *nonlinear loads*. Switch-mode power supplies (SMPS), variable speed motors and drives, photocopiers, personal computers, laser printers, fax machines, battery chargers and UPSs are examples of nonlinear loads. Single-phase non-linear loads are prevalent in modern office buildings, while three-phase, non-linear loads are widespread in factories and industrial plants.

A large portion of the non-linear electrical load on most electrical distribution systems comes from SMPS equipment. For example, all computer systems use SMPS that convert utility AC voltage to regulated low-voltage DC for internal electronics. These non-linear power supplies draw current in high-amplitude short pulses that create significant distortion in the electrical current and voltage wave shape—*harmonic distortion*, measured as total harmonic distortion (THD). The distortion travels back into the power source and can affect other equipment connected to the same source.

Most power systems can accommodate a certain level of harmonic currents but will experience problems when harmonics become a significant component of the overall load. As these higher frequency harmonic currents flow through the power system, they can cause communication errors, overheating and hardware damage, such as:

- Overheating of electrical distribution equipment, cables, transformers, standby generators, etc.
- High voltages and circulating currents caused by harmonic resonance
- High neutral currents that generate heat and waste energy
- Equipment malfunctions due to excessive voltage distortion
- Increased internal energy losses in connected equipment, causing component failure and shortened life span
- False tripping of branch circuit breakers
- Metering errors
- Fires in wiring and distribution systems
- Generator failures
- High crest factors and related problems
- Lower system power factor, resulting in less usable power (kW vs. kVA) and penalties on monthly utility bills

A technical view of harmonics

Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency. If the fundamental power frequency is 60 Hz, then the 2^{nd} harmonic is 120 Hz, the 3^{rd} is 180 Hz, etc. (see Figure 1). When harmonic frequencies are prevalent, electrical power panels and transformers become mechanically resonant to the magnetic fields generated by higher frequency harmonics. When this happens, the power panel or transformer vibrates and emits a buzzing sound for the different harmonic frequencies. Harmonic frequencies from the 3^{rd} to the 25^{th} are the most common range of frequencies measured in electrical distribution systems.

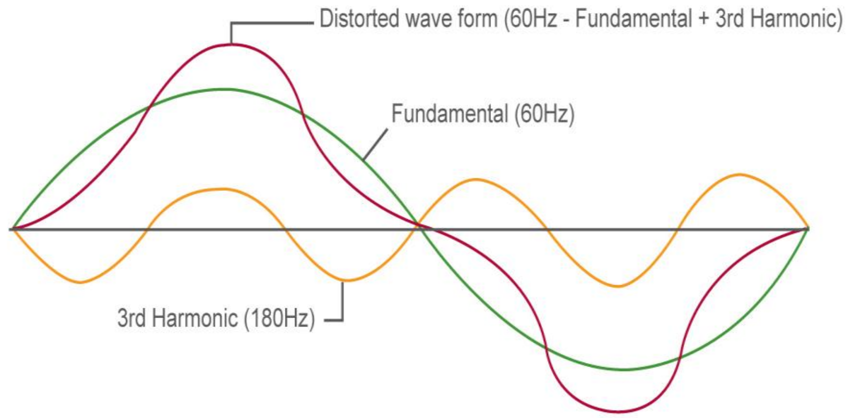
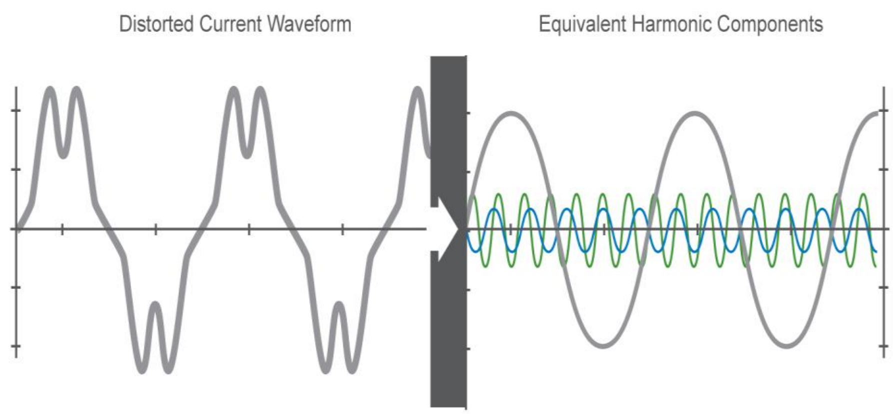


Figure 1. Harmonic distortion of the electrical current waveform

All periodic waves can be generated with sine waves of various frequencies. The Fourier theorem breaks down a periodic wave into its component frequencies.



Harmonic components: Large 1^{st} harmonic (fundamental)
Smaller 5^{th} harmonic
Slightly larger 7^{th} harmonic

Figure 2. Distorted waveform composed of fundamental, 5^{th} and 7^{th} harmonics

The total harmonic distortion (THD) of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental. It provides an indication of the degree to which a voltage or current signal is distorted (see Figure 3).

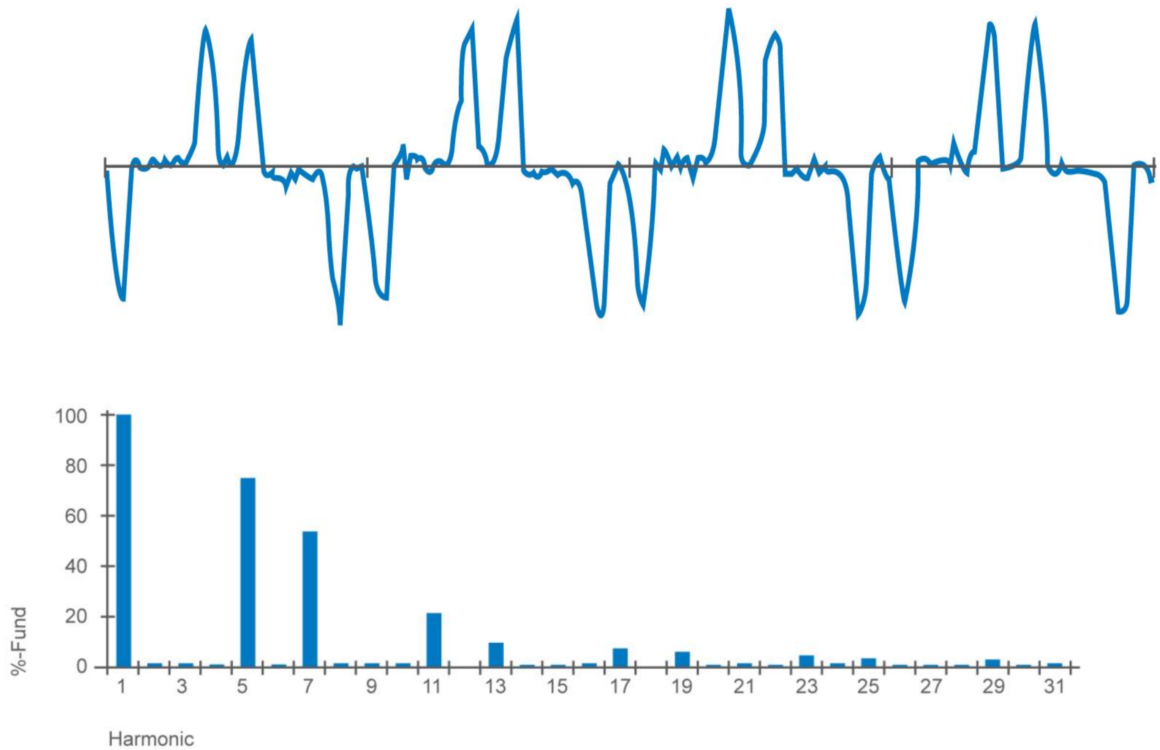


Figure 3. Total harmonic distortion

Solutions to compensate for and reduce harmonics

While standards to limit the generation of harmonic currents are under consideration, harmonic control today relies primarily on remedial techniques. There are several approaches that can be taken to compensate for or reduce harmonics in the power system, with varying degrees of effectiveness and efficiency.

Oversize the neutral wiring.

In modern facilities, the neutral wiring should always be specified to be the same capacity as the power wiring, or larger—even though electrical codes may permit under-sizing the neutral wire. An appropriate design to support a load of many personal computers, such as a call center, would specify the neutral wiring to exceed the phase wire capacity by a factor of 1.73. Particular attention should be paid to wiring in office cubicles. Note that this approach protects the building wiring, but it does not help protect the transformers.

Use separate neutral conductors.

On three-phase branch circuits, instead of installing a multi-wire branch circuit sharing a neutral conductor, run separate neutral conductors for each phase conductor. This increases the capacity and ability of the branch circuits to handle harmonic loads. This approach successfully eliminates the addition of the harmonic currents on the branch circuit neutrals, but the panelboard neutral bus and feeder neutral conductor must still be considered.

Use DC power supplies, which are not affected by harmonics.

In the typical data center, the power distribution system converts 480-volt AC utility power through a transformer that steps it down to 208-volt AC power that feeds racks of servers. One or more power supplies within each server convert this AC input into DC voltage appropriate for the unit's internal components.

These internal power supplies are not energy efficient, and they generate substantial heat, which puts a costly burden on the room's air conditioning system. Heat dissipation also limits the number of servers that can be housed in a data center. It could be worthwhile to eliminate this step by switching to DC power.

According to an article in *Energy and Power Management* magazine, "Computers and servers equipped with DC power supplies instead of AC power supplies produce 20 to 40 percent less heat, reduce power consumption by up to 30 percent, increase server reliability, offer flexibility to installations, and experience decreased maintenance requirements."

That sounds good, but when cost, compatibility, reliability and efficiency are considered together, the move from AC to DC power is not justified for most data centers. AC power—even though it is slightly less efficient—is universally acceptable to existing equipment.

Furthermore, there are no Underwriter's Laboratory (UL) safety standards for high-voltage DC in data centers yet, while standards for AC systems are mature. That means the safety risks could outweigh the potential gain with DC power, for now.

Use K-rated transformers in power distribution components.

A standard transformer is not designed for high harmonic currents produced by non-linear loads. It will overheat and fail prematurely when connected to these loads. When harmonics started being introduced into electrical systems at levels that showed detrimental effects (circa 1980), the industry responded by developing the *K-rated transformer*. K-rated transformers are not used to eliminate harmonics but to handle the heat generated by harmonic currents.

K-factor ratings range between 1 and 50. A standard transformer designed for linear loads is said to have a K-factor of 1. The higher the K-factor, the more heat from harmonic currents the transformer is able to withstand. Making the right selection of K-factor is very important, because it affects cost, efficiency and safety.

Transformers with higher K factors are typically larger than those with lower K factors, so the optimal K factor should be chosen based on the harmonic profile of the data center to optimize the tradeoff between size, efficiency and heat tolerance. The table shows appropriate K-factor ratings to use for different percentages of non-linear current in the electrical system.

Non-linear Load	K-rating
Incidental electronic equipment representing <5 percent	K1
Harmonic-producing equipment representing <35 percent	K4
Harmonic-producing equipment representing <50 percent	K7
Harmonic-producing equipment representing <75 percent	K13
Harmonic-producing equipment representing <100 percent	K20

Power distribution units (PDUs) with a K-13 rated transformer (and oversized neutral) are readily available to efficiently handle harmonic currents. Units with K20 transformers are common but are typically overkill for most modern data centers.

Use a harmonic-mitigating transformer.

The K-rated, dry-type transformer is widely used in electrical environments—either in a PDU or as a standalone unit. But there have been more recent advances in transformer design that offer even better performance in reducing voltage distortion and power losses due to current harmonics.

A *harmonic-mitigating transformer* (HMT) is designed to handle the non-linear loads of today's electrical infrastructures. This transformer uses electromagnetic mitigation to deal specifically with the triplen (3rd, 9th, 15th,...) harmonics. Secondary windings of the transformer are arranged to cancel zero sequence fluxes and eliminate primary winding circulating currents. This transformer also addresses the 5th and 7th harmonics by using phase shifting.

Using these two electromagnetic techniques, an HMT allows loads to operate the way their manufacturers designed them, while minimizing the impact of the harmonics to energy losses and distortion. Most HMTs exceed NEMA TP-1 efficiency standards, even when tested with 100-percent non-linear loads. Wherever a K-rated transformer is specified, an equivalent HMT is a direct substitute.

Key advantages of using HMTs

- Prevents voltage flat-topping caused by non-linear loads
- Reduces upstream harmonic currents
- Eliminates transformer overheating and high operating temperatures
- Eliminates primary winding circulating current
- Saves energy by reducing harmonic losses
- Maintains high energy efficiency even under severe non-loading conditions
- Treats power quality harmonic issues that K-rated transformers do not address
- Suitable for high K-factor loads without increasing in-rush current
- Improves power factor

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Other harmonic-mitigating techniques

An HMT is a great choice for a transformer when initially designing the data center. However, if harmonics are an issue in an existing data center, a zigzag autotransformer can be used to limit the effects due to triplen, 5^{th} and 7^{th} harmonics.

A zigzag autotransformer is a neutral forming transformer that has primary windings but no secondary windings. There are two primary windings for each core, which are wound in opposite directions to provide high impedance to normal phase currents.

When placed close to the load, the zigzag autotransformer can trap triplen harmonics. This autotransformer will need to be sized large enough to only handle the harmonics. The triplen harmonics will then be limited to the autotransformer and the load, thus preventing the upstream distribution equipment from seeing the harmonics. However, the autotransformer cannot be used to modify the voltage to a level different from the source.

The triplen, 5^{th} and 7^{th} harmonics can be eliminated by using the autotransformer described above in parallel with a second feeder. This feeder would normally be supplied by a different source. The autotransformer, along with the second, phase-shifted source, will combine together to capture the triplen, 5^{th}, and 7^{th} harmonics. This application is much trickier, because the two sources need to carry a balanced load to efficiently capture the 5^{th} and 7^{th} harmonics.

Both of these applications are effective in eliminating harmful harmonics. However, installing a single harmonic-mitigating transformer is the most cost-effective means to prevent harmful harmonics from affecting distribution equipment.

Summary

Harmonic currents can have a significant impact on electrical distribution systems and the facilities they feed. It is important to consider the impact of harmonics when contemplating additions or changes to a system. In addition, identifying the size and location of non-linear loads should be an important part of any maintenance, troubleshooting and repair program.

To learn more about Eaton solutions to manage and mitigate harmonics in modern electrical infrastructures, contact Eaton at 800.356.5794 or www.eaton.com/powerquality

Additional references

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About Eaton

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