Harmonics

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Service reliability and quality of power have become growing concerns for many facility managers, especially with the increasing sensitivity of electronic equipment and automated controls. There are several types of voltage fluctuations that can cause problems, including surges and spikes, sags, harmonic distortion, and momentary disruptions. Harmonics can cause sensitive equipment to malfunction and other problems, including overheating of transformers and wiring, nuisance breaker trips, and reduced power factor.

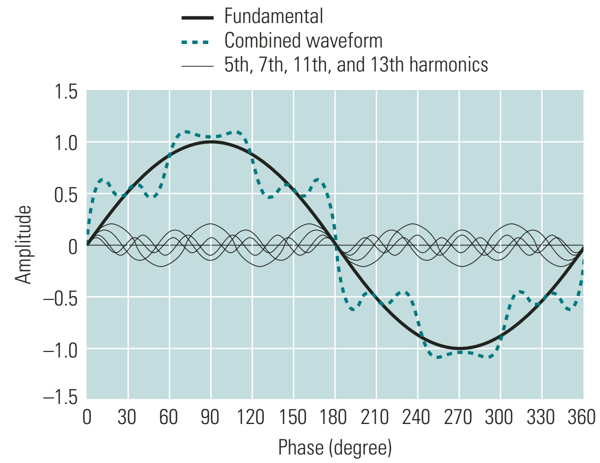
What Are Harmonics?

Harmonics are voltage and current frequencies riding on top of the normal sinusoidal voltage and current waveforms. Usually these harmonic frequencies are in multiples of the fundamental frequency, which is 60 hertz (Hz) in the U.S. and Canada. The most common source of harmonic distortion is electronic equipment using switch-mode power supplies, such as computers, adjustable-speed drives, and high-efficiency electronic light ballasts.

Harmonics are created by these "switching loads" (also called "nonlinear loads," because current does not vary smoothly with voltage as it does with simple resistive and reactive loads): Each time the current is switched on and off, a current pulse is created. The resulting pulsed waveform is made up of a spectrum of harmonic frequencies, including the 60 Hz fundamental and multiples of it. This voltage distortion typically results from distortion in the current reacting with system impedance. (Impedance is a measure of the total opposition—resistance, capacitance, and inductance—to the flow of an alternating current.) The higher-frequency waveforms, collectively referred to as total harmonic distortion (THD), perform no useful work and can be a significant nuisance.

Figure 1: Effect of harmonics on normal voltage or current waveform

The combined waveform shows the result of adding the harmonics onto the fundamental.



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Harmonic waveforms are characterized by their amplitude and harmonic number. In the U.S. and Canada, the third harmonic is 180 Hz—or 3 x 60 Hz—and the fifth harmonic is 300 Hz (5 x 60 Hz). The third harmonic (and multiples of it) is the largest problem in circuits with single-phase loads such as computers and fax machines. **Figure 1** shows how the 60-Hz alternating current (AC) voltage waveform changes when harmonics are added.

The Problem with Harmonics

Any distribution circuit serving modern electronic devices will contain some degree of harmonic frequencies. The harmonics do not always cause problems, but the greater the power drawn by these modern devices or other nonlinear loads, the greater the level of voltage distortion. Potential problems (or symptoms of problems) attributed to harmonics include:

- Malfunction of sensitive equipment
- Random tripping of circuit breakers

- Flickering lights
- Very high neutral currents
- Overheated phase conductors, panels, and transformers
- Premature failure of transformers and uninterruptible power supplies (UPSs)
- Reduced power factor
- Reduced system capacity (because harmonics create additional heat, transformers and other distribution equipment cannot carry full rated load)

Identifying the Problem

Without obvious symptoms such as nuisance breaker trips or overheated transformers, how do you determine whether harmonic current or voltages are a cause for concern? Here are several suggestions for simple, inexpensive measurements that a facility manager or staff electrician could take, starting at the outlet and moving upstream:

- *Measure the peak and root mean square (RMS) voltage at a sample of receptacles.* The "crest factor" is the ratio of peak to RMS voltage. For a perfectly sinusoidal voltage, the crest factor will be 1.4. Low crest factor is a clear indicator of the presence of harmonics. Note that these measurements must be performed with a "true RMS" meter—one that doesn't assume a perfectly sinusoidal waveform.
- *Inspect distribution panels.* Remove panel covers and visually inspect components for signs of overheating, including discolored or receded insulation or discoloration of terminal screws. If you see any of these symptoms, check that connections are tight (since loose connections could also cause overheating), and compare currents in all conductors to their ratings.
- *Measure phase and neutral currents at the transformer secondary with clamp-on current probes.* If no harmonics are being generated, the neutral current of a three-phase distribution system carries only the imbalance of the phase currents. In a well-balanced three-phase distribution system, phase currents will be very similar, and current in the neutral conductor should be much lower than phase current and far below its rated current capacity. If phase currents are similar and neutral current exceeds their imbalance by a wide margin, harmonics are present. If neutral current is above 70 percent of the conductor's rated capacity, you need to mitigate the problem.
- *Compare transformer temperature and loading with nameplate temperature rise and capacity ratings.* Even lightly loaded transformers can overheat if harmonic current is high. A transformer that is near or over its rated temperature rise but is loaded well below its rated capacity is a clear sign that harmonics are at work. (Many transformers have built-in temperature gauges. If yours does not, infrared thermography can be used to detect overheating.)

In addition to these simple measurements, many power-monitoring devices are now commercially available from a variety of manufacturers to measure and record harmonic levels. These instruments provide detailed information on THD, as well as on the intensity of individual harmonic frequencies. After taking the appropriate measurements to determine whether you have high levels of harmonics and, if so, to find the source, you will be well-positioned to choose the best solution.

Solutions to Harmonics Problems

The best way to deal with harmonics problems is through prevention: choosing equipment and installation practices that minimize the level of harmonics in any one circuit or portion of a facility. Many power quality problems, including those resulting from harmonics, occur when new equipment is haphazardly added to older systems. However, even within existing facilities, the problems can often be solved with simple solutions such as fixing poor or nonexistent grounding on individual equipment or the facility as a whole, moving a few loads between branch circuits, or adding additional circuits to help isolate the sensitive equipment from what is causing the harmonic distortion.

If the problems cannot be solved by these simple measures, there are two basic choices: to reinforce the distribution system to withstand the harmonics or to install devices to attenuate or remove the harmonics. Reinforcing the distribution system means installing double-size neutral wires or installing separate neutral wires for each phase, and/or installing oversized or K-rated transformers, which allow for more heat dissipation. There are also harmonic-rated circuit breakers and panels, which are designed to prevent overheating due to harmonics. This option is generally more suited to new facilities, because the costs of retrofitting an existing facility in this way could be significant. Strategies for attenuating harmonics, from cheap to more expensive, include passive harmonic filters, isolation transformers, harmonic mitigating transformers (HMTs), the Harmonic Suppression System (HSS) from Harmonics Ltd., and active filters (**Table 1**).

Passive filters (also called traps) include devices that provide low-impedance paths to divert harmonics to ground and devices that create a higher-impedance path to discourage the flow of harmonics. Both of these devices, by necessity, change the impedance characteristics of the circuits into which they are inserted.

Another weakness of passive harmonic technologies is that, as their name implies, they cannot adapt to changes in the electrical systems in which they operate. This means that changes to the electrical system (for example, the addition or removal of power factor–correction capacitors or the addition of more nonlinear loads) could cause them to be overloaded or to create "resonances" that could actually amplify, rather than diminish, harmonics.

Active harmonic filters, in contrast, continuously adjust their behavior in response to the harmonic current content of the monitored circuit, and they will not cause

Table 1: Solutions to harmonics problems

There are pros and cons to the various solutions for harmonics problems. The solutions listed here are in approximate order from least expensive to highest initial costs. Although they are among the most expensive options, harmonic mitigating transformers and harmonic suppression systems can be very cost-effective in the right applications.

Solution	Best applications	Notes
Reinforce distribution system (add double-sized neutral wires, harmonics-rated circuit breakers, oversized or K-rated transformer, etc.)	New facilities	Simple, relatively low capital costs, but doesn't remove problem
Passive filter	For circuits that include three-phase loads, where there are only minor voltage imbalances between phases	Lower-cost than active filters, but requires analysis and a trial-and-error approach; does not adapt to changes in system
Isolation transformer	Where sources of harmonics are on separate branches from harmonics-sensitive equipment	Isolates but does not remove the problem
Harmonic mitigating transformer	On a moderately to heavily loaded transformer with high harmonic content in system, and/or where critical loads are backed up by an uninterruptible power supply	Reduces energy losses in transformer; cost: about $25 to $30/kVA
Harmonic suppression system	For circuits with only single-phase loads and existing or new facilities with high reliability needs; where problems exist downstream of distribution panel	Removes the source of the problem and reduces energy costs; cost: about $80 to $120/kVA
Active harmonic filter	For circuits that include three-phase loads; voltage imbalances between phases can be present	Adapts to changes in system; self-regulates to avoid overloading; cost: about $500/kVA

Notes: kVA = kilovolt-ampere. All costs listed are in U.S. dollars.

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resonance. Like an automatic transmission in a car, active filters are designed to accommodate a full range of expected operating conditions upon installation, without requiring further adjustments by the operator.

Isolation transformers are filtering devices that segregate harmonics in the circuit in which they are created, protecting upstream equipment from the effects of harmonics. These transformers do not remove the problem in the circuit generating the harmonics, but they can prevent the harmonics from affecting more sensitive equipment elsewhere within the facility.

Harmonic mitigating transformers actually do relieve problematic harmonics. HMTs can be quite cost-effective in the right application, because they can both improve reliability and reduce energy costs. The right application includes transformers that are heavily or moderately loaded and where high levels of harmonic currents are present. In addition, HMTs are very effective in supporting critical loads that are backed up by a UPS. UPSs and backup generators tend to have high impedance, which results in high voltage distortion under nonlinear loading. Because of this, equipment that operates flawlessly when supplied by utility power may malfunction when the backup system engages during a utility outage. Note that some of these power systems have output filters (either passive or active) to control harmonic levels. The presence or absence of such filters should be determined before adding an HMT.

The Harmonics Ltd. Harmonic Suppression System is a unique solution for single-phase loads that is designed to suppress the third harmonic. An HSS is generally more expensive than an HMT, but it is designed to attenuate the harmonics problems throughout the entire distribution system, not just upstream of the transformer. The types of facilities that present the best opportunities for HSS installation are those that place a very high premium on power quality and reliability, such as server farms, radio and television broadcast studios, and hospitals. (See www.harmonicslimited.com.)

Economic Evaluation

Evaluating the life-cycle costs and effectiveness of harmonics mitigation technologies can be very challenging—beyond the expertise of most industrial facility managers. After performing the proper measurement and analysis of the harmonics problem, this type of evaluation requires an analysis of the costs of the harmonics problem (downtime of sensitive equipment, reduced power factor, energy losses or potential energy savings) and the costs of the solutions. A good place to start in performing this type of analysis is to ask your local utility or electricity provider for assistance. Many utilities offer their own power quality mitigation services or can refer you to outside power quality service providers.

Additional Resources

Institute of Electrical and Electronics Engineers (IEEE), Standard 519-1992, “IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems” (1992), available at www.ieee.org.