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Thought Leadership
White Paper

Mitigating data center harmonics

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Executive summary

Line harmonics can have costly and disruptive effects on electrical distribution systems. However, thanks to innovations like faster switching devices, power factor-corrected power supplies and harmonic-mitigating transformers (HMT), many data center operators no longer consider harmonics a serious issue. In actuality, fluctuating loads, equipment, and operating conditions can still produce harmonics, power factor problems, and load balancing issues even at facilities that use newer technologies.

This white paper discusses the ways harmonics can impact data centers and examines strategies for addressing harmonic problems, with a particular focus on the benefits for some facilities of deploying the latest harmonic-mitigating energy-saver uninterruptible power systems (UPSs).

Table of contents

Understanding harmonics

Most utilities provide power with a reasonably smooth waveform. However, non-linear loads such as servers, variable frequency drives (VFDs), florescent lighting, and other electronic devices can distort current and voltage waveforms. Known as harmonics, those distortions appear as supplemental frequencies higher than the fundamental frequency, which is 60 Hz in the U.S. and 50 Hz in most other countries.

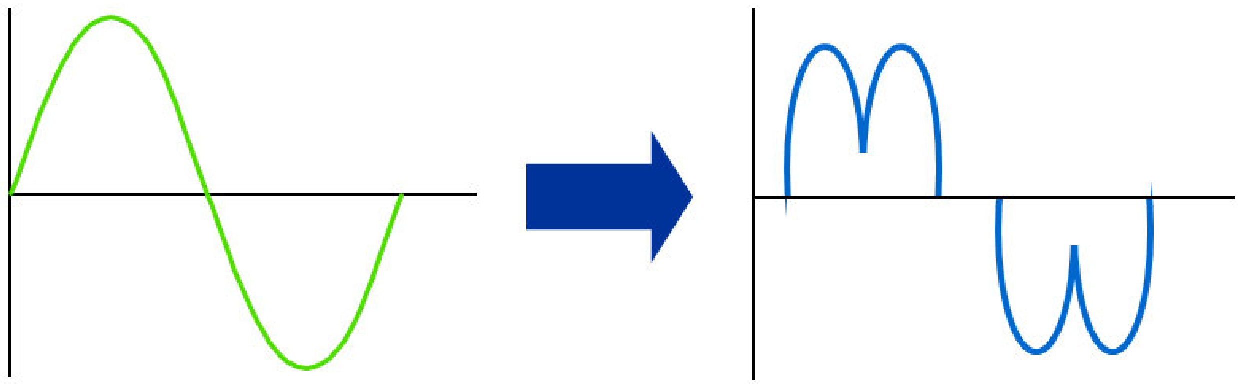

Figure 1. *Harmonics are distorted waveforms caused by supplemental frequencies higher than the fundamental frequency.*

Harmonics come in two basic varieties, current distortion and voltage distortion. Non-linear loads are the most common source of current distortion, while voltage distortion is most commonly produced when an electrical device pulls current distortion through an impedance.

Additionally, poor harmonics at facilities that share a point of common utility coupling can impact neighboring structures as well, so “harmonic pollution” from nearby buildings can cause current distortion, voltage distortion or both.

Why harmonics matter

Minimizing energy costs and maximizing reliability are top priorities for most data center operators today. Harmonics makes both goals harder to achieve by causing these problems:

- *Reduced energy-efficiency:* Harmonic currents increase losses on the power system conductors and transformers, adding heat to the power chain that drives up power and cooling costs.
- *Decreased reliability:* The heat created by harmonics can increase downtime by causing premature equipment failure or malfunctions, overheated wiring, and other hardware issues, including generator transfer switch and control malfunctions.
- *Higher capital expenses:* Harmonics can reduce the lifespan of electrical equipment, forcing companies to purchase replacement devices sooner than would otherwise be necessary. They can also compel data center managers to compensate for increased heating and distortion by investing in oversized generators, neutral conductors, and transformers.
- *Costly utility penalties:* Electrical utilities must compensate for harmonic-related waste by deploying additional generating capacity. For that reason, and to discourage harmonic pollution, many utilities penalize customers that exceed distortion limits defined by the IEEE-519 standard. In addition, many utilities penalize customers with a power factor below 0.9.
- *Inconsistent meter readings:* Phase imbalances and high harmonic voltages and currents can cause electrical meters to report figures that are inaccurate by as much as 20 percent.

Options for mitigating harmonics

Data center operators have a range of options of varying complexity and cost for mitigating harmonics. Companies can employ these singly or in combination, and the ones that make the most sense for a given facility will vary based on the loads it supports, its budget, and the site's specific harmonic-related problems. Some of the most common options are:

- *Oversized generators:* Generators have two to three times the impedance of a typical transformer, so pulling distorted current through a generator distorts the voltage as much as 2 to 3 times more than the same load on the utility service transformer. Using larger generators than electrical loads would otherwise require stabilizes their output and helps compensate for the increased heating distortion can cause, improving data center reliability and lengthening the generator's lifespan. Oversized generators also cost more, however, and therefore drive up capital expenses.
- *Low distortion electronic ballasts:* Like harmonic mitigating transformers (HMTs), low distortion electronic ballasts use passive filtering technology to ease line harmonics. However, they're usually more expensive than the standard magnetic ballasts they typically replace.
- *Active filters:* These provide the most comprehensive cancellation of harmonic distortion available. Active filters inject an additional current into the line that's identical to but 180 degrees opposite of the harmonic current coming from the load. Much as noise-canceling headphones cancel out sonic disturbances, active filters cancel the entire spectrum of harmonics, usually up to the 50th order. Lowering the current distortion served by the utility source or generator consequently reduces voltage distortion and can also correct the power factor of the load by modifying the fundamental current displacement. Although they are generally considered the most effective harmonic solution, active filters are unfortunately also the most expensive.

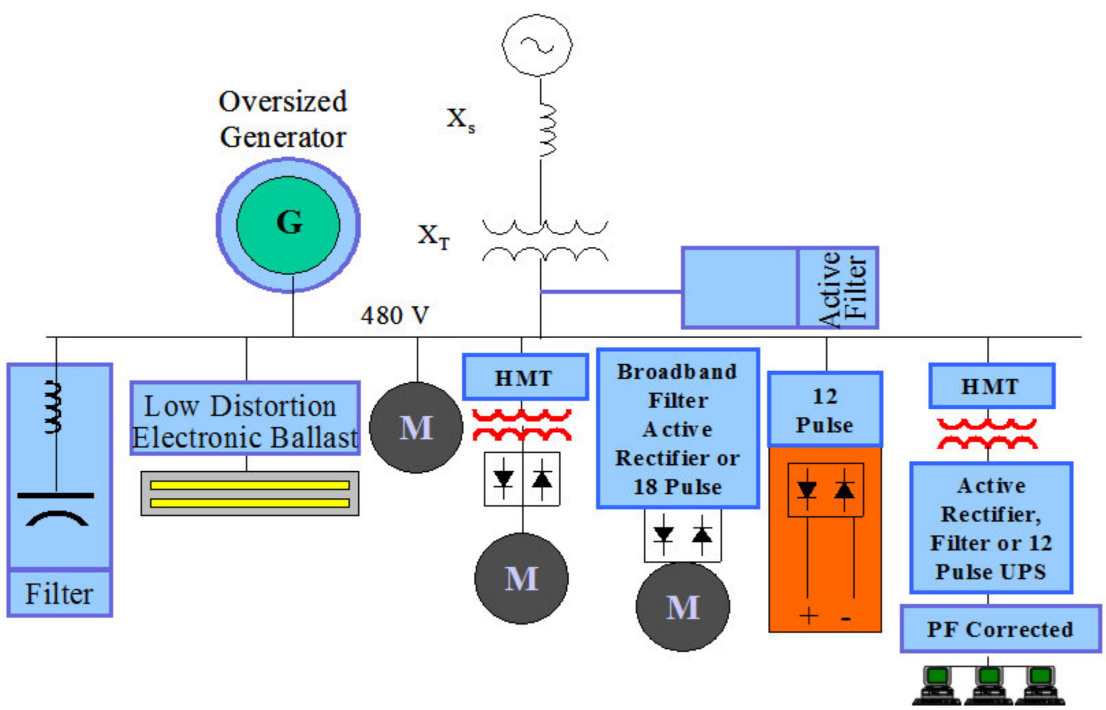

Figure 2. *Data center operators have access to variety of technologies for mitigating harmonics.*

Harmonic mitigation in UPSs

Since UPSs and the loads they serve have historically been considered some of the most significant harmonic loads on a power system, companies can also use harmonic-mitigating UPSs to reduce line harmonics. Much like active filters, harmonic-mitigating UPSs eliminate harmonic distortion by inserting equal and opposite current into the line. They also compensate for reactive power from low power factor loads and balance loads across three phases to avoid stranded capacity, while providing clean and continuous power during utility outages or in response to electrical disturbances.

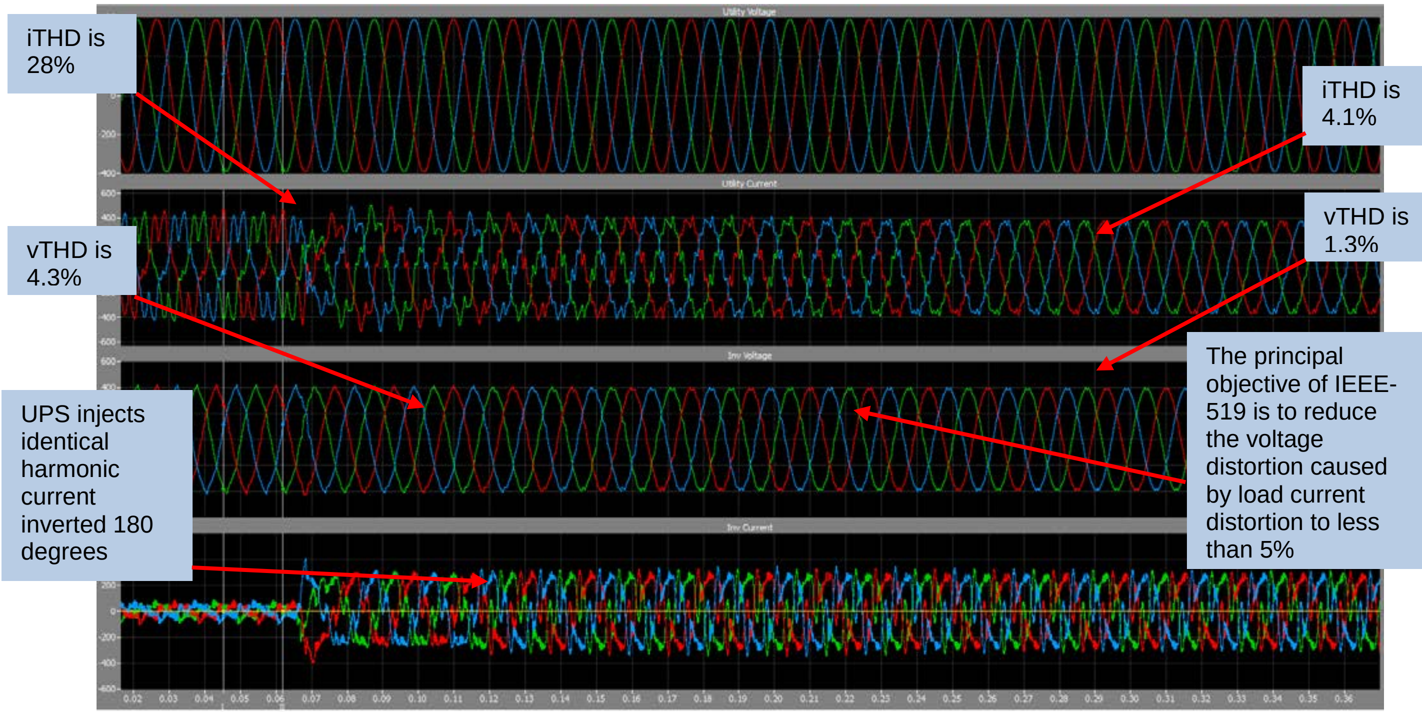

Figure 3. *Sample effects of a harmonic-mitigating UPS on a waveform with harmonic distortion. Note the distortion is corrected within one-fourth of a second.*

Harmonic mitigation in energy-saver UPSs

In their quest to boost efficiency, data centers are increasingly deploying UPSs with energy-saver operating modes. Such products save money and enhance sustainability by reducing data center energy waste up to 10 percent under typical loading conditions. Energy saver UPS are particularly beneficial for loads less than 40%, the point at which traditional UPS efficiency levels sharply decline.

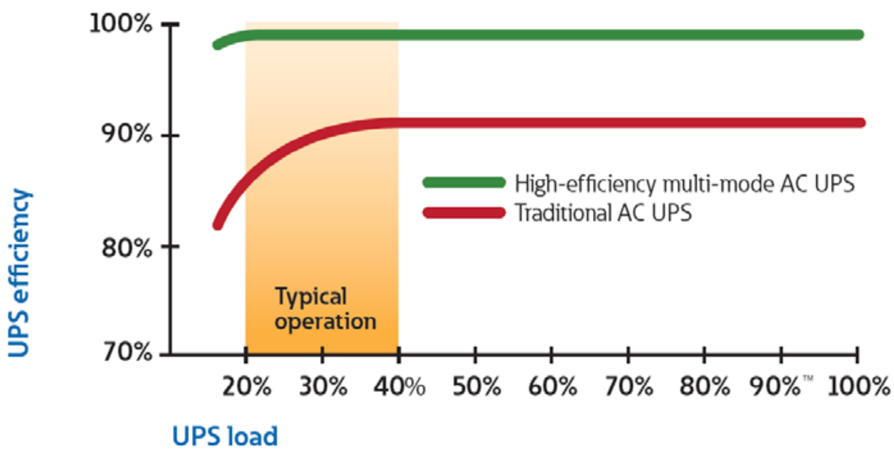

Figure 4. *Energy-saver UPSs deliver significant improvements in power efficiency.*

Those savings aren't automatic, however, since most UPSs equipped for eco mode operation mitigate harmonics, perform power factor correction and balance loads only while in double-conversion mode. As a result, data center operators with harmonics problems who wish to use energy-saver UPSs have traditionally been forced to choose between installing additional mitigation technologies or exposing their facilities to the potentially expensive impact of harmonic distortion.

More recently, harmonic-mitigating UPSs capable of keeping distortion within pre-determined and adjustable limits, correcting power factor, and balancing loads *while in energy-saver mode* have finally begun to reach the market. Moreover, these new systems typically remain within one percent of energy-saver levels while performing these functions, providing a significant improvement over double-conversion efficiency levels.

Furthermore, the harmonic mitigation technology in the latest energy-saver UPSs is a built-in feature that requires no additional footprint, so it doesn't consume valuable data center floor space or inflate installation and maintenance costs. If the source of harmonic current distortion is on the critical bus connected to the UPS, this mitigation technique is convenient and economical.

Sample applications for harmonic-mitigating energy-saver UPSs

Energy saver UPSs with integrated harmonic mitigation can help any organization improve energy-efficiency without exposing electrical systems to the effects of harmonic distortion and low power factor. They can be especially beneficial, however, in these settings:

"Harmonic-rich" environments: Manufacturing systems and medical imaging devices are large, non-linear loads that often add harmonics to electrical distribution systems. As a result, data centers and server rooms located near factories, hospitals and clinics tend to experience high levels of harmonic distortion. Deploying harmonic-mitigating energy-saver UPSs in such facilities reduce harmonics while enabling industry-leading energy-efficiency.

Containerized/modular data centers: Operators of containerized and modular data centers typically pursue every opportunity to increase operating efficiency, but they also utilize identical servers in large quantities, which can magnify the severity of harmonics issues. Harmonic-mitigating energy-saver UPSs allow containerized and modular data centers to overcome those problems while collecting the money-saving rewards of energy saver UPS operation.

Facilities that place non-linear loads on the UPS bus: At one time, most data centers only placed IT loads on the UPS critical bus. Today, however, many facilities put VFDs, computer room air conditioning units and other non-linear loads on the UPS bus as well, creating added potential for harmonic distortion. Harmonic-mitigating energy-saver UPSs enable such data centers to limit distortion, correct power factor and balance loads while also lowering power consumption.

Selecting a harmonic-mitigation strategy

As helpful as energy-saver UPSs with harmonic-mitigation technology can be, there's no single correct strategy for addressing harmonics. Both equipment manufacturers and the IEEE-519 standard define maximum harmonic limits; data centers with distortion below those thresholds may not require mitigation at all, and different combinations of harmonic-mitigating technologies may better serve other facilities. In the design phase, modeling programs can reveal potential harmonic problems, allowing for a comparison of techniques that meet the site requirements and budget. To determine the best harmonic-mitigation strategy for your data center when harmonic issues are suspected, follow these steps:

1. Look for symptoms of high harmonics

These include:

- Generator synchronization failure or generator instability
- Local utility company fines for unacceptable distortion or poor power factor
- Overheated wiring or transformers in your building

2. Perform a facility assessment

Collect precise measurements of the harmonics affecting your data center, and diagnose their origin. If you're experiencing voltage distortion, for example, the source could be current distortion in your load, a source impedance problem or harmonic pollution elsewhere on the grid. Trained and qualified engineers can assist you with this often-complex analysis.

3. Determine if you need harmonic mitigation

Once hard numbers are available, compare your power system's harmonic distortion to the maximum levels specified by your equipment manufacturers and the IEEE-519 standard. Then, calculate your aggregate harmonic-related expenses, including the cost of replacing IT equipment prematurely, suffering added downtime and wasting electricity. Finally, consider the intangible value of being a good corporate citizen by operating your data center in an environmentally sustainable manner and not exposing nearby buildings to the impact of your facility's distortion.

If the total value of deploying harmonic mitigating technologies outweighs what harmonics are currently costing you *and* the harmonics you're experiencing exceed the limits set by equipment manufacturers and the IEEE-519 standard, implementing harmonic-mitigation measures will probably prove cost-effective. If neither condition is met, you may not require harmonic-mitigation technologies.

4. Design and deploy a harmonic-mitigation strategy

If you decide to take action regarding your data center's harmonics, an experienced electrical consultant can help you determine the right mix of mitigation solutions for your specific environment.

5. Analyze the results

After your harmonic reduction solution is in place, repeat the facility assessment you executed in step 2 to see how effectively your mitigation solution has reduced distortion, and how much power and money you're saving as a result.

Conclusion

Line harmonics continue to be a costly issue for data centers, with implications for both reliability and efficiency. Fortunately, IT and facilities managers today have access to a wide array of harmonic-mitigation technologies. In particular, organizations eager to maximize both harmonic reduction and energy-efficiency should investigate the new energy-saver UPSs with built-in harmonic-mitigation capabilities that are now reaching the market. Though not all data centers require them, such systems enable companies to achieve the highest efficiency possible while actively correcting for harmonics as they occur.

About Eaton

Eaton's electrical business is a global leader with expertise in power distribution and circuit protection; backup power protection; control and automation; lighting and security; structural solutions and wiring devices; solutions for harsh and hazardous environments; and engineering services. Eaton is positioned through its global solutions to answer today's most critical electrical power management challenges.

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