

Guide to Harmonics

POWER QUALITY

The Basics of Harmonics

All business types, commercial, industrial, government and energy/utility have a concern with power quality. The reliable and continuous delivery of “expected quality” electricity is critical for proper daily operations. From a manufacturing facility to a brokerage firm, the need for utility grade or better power exists. Further, with more digital technologies installed on the load, “high nines” type power requirements keep increasing. Environments rich in harmonic content can place serious burdens on power distribution systems and the equipment to which it is connected.

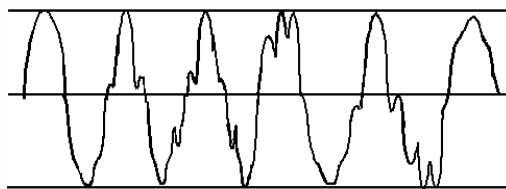
AC electrical loads generally have resistive, inductive and capacitive components. To take a step further, there are three major classes of harmonic producing devices.

1. Ferromagnetic (magnetizing) device—basically a coil wound around an iron core. Examples here include transformers and motors. These devices normally do not present a problem unless resonant conditions exist.
2. Electronic rectifiers and inverters. Examples of this include computers, adjustable speed drives, and UPS systems.
3. Arcing devices. This can include fluorescent and vapor lighting, arc welders and arc furnaces.

Simply put, harmonics are currents and voltages that have multiplied within an electrical system. Commonplace linear loads continue to become more non-linear due to electronic and digital type devices. Because of this, the traditional sine wave shape has changed, reflecting these many current and voltage distortions. Harmonics are

created mainly from silicon-controlled rectifiers (SCR's), and solid state diode converters that are found in a wide range of equipment types. The operating design of SCR's and converters changes AC to DC or DC to AC, in a high speed, rapid pulsing manner, emitting a spectrum of harmonics, which is “captured” in the power system.

A sine waveform has a fundamental frequency of 50Hz or 60Hz (400Hz for some other applications), which is measured in integer multiples of the fundamental frequency and listed as “orders.” Common rating examples in a 60Hz (fundamental) system would include a third order harmonic (3 x 60Hz) 180Hz; fifth order harmonic (5 x 60Hz) 300Hz and so forth. A harmonic spectrum consists of the fundamental frequency (60Hz), with a value of 100%, along with a current harmonic distribution and total harmonic distortion value. For example, the Total Harmonic Distortion (THD) may be 35%. The distribution of harmonics then may be: 5th order of 27%, 7th order of 5%, 11th order of 2%, 13th order of 1% etc. A harmonic spectrum is obtained by on-site data collection and analysis, along with possible computer modeling and simulation.



Harmonic Distortion Waveform Example

Certain orders of harmonics may cause serious equipment and system problems. IEEE 519 Guide for Harmonics references other types of harmonics and the activities that can contribute to system wide problems and methods for mitigation.

STACO
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Your tailored power solutions provider



Industries Where Harmonics May be Present

- Water Treatment Facilities
- Plastics/Coatings
- Glass Making
- Chemical Plant
- Steel Processing
- Paper Processing
- Printing/Publishing
- Automotive
- Packaging
- Data Centers
- UPS Installations
- Petro/Chemical

Solutions


Solutions can range from simply tightening connections in a switchboard to help overheating of conductors, to use of a 200% rated neutral in a panel board. Commodity, or off-the-shelf products such as line reactors and K-rated transformers are also options. Application engineered solutions may include air and iron-core reactors, phase-shift and zig-zag wound transformers, broad band filters, detuned and tuned systems, and hybrid and dedicated power electronic harmonic mitigation equipment. Staco Energy offers detuned, tuned and active harmonic filter solutions along with the ability to meet other user requirements.

A detuned capacitor bank differs from a tuned bank (noted below), in that the filter elements will not trap or eliminate a majority of a specific harmonic orders—just a small percentage. Where harmonic conditions are present within the load and power factor correction is desired, the capacitors and filter reactors will combine to add capacitance, while controlling any adverse system interactions. The reactors provide a “smoothing” effect by not allowing the switching of capacitors to further amplify the harmonic condition, while providing safe operation of the capacitor bank and a more controlled network. This can be represented by a simple L-C circuit. A detuned bank generally requires minimal product engineering, with the 5th or 7th harmonic order consisting of the majority of requirements. Harmonics apparent on the load here usually represent >5%, with minimal concern for the user.

Use of a tuned capacitor bank is a method to remove or absorb a large portion of adverse harmonics. By tuning to a specific harmonic frequencies, where currents will flow into and out of the filter, the predominant harmonic, (say the 5th order), can be essentially eliminated. Other close order harmonics (higher harmonics such as the 7th, and 11th) generally can be reduced somewhat as well. For example, in a tuned 5th order harmonic system, the resulting resonant frequency is shifted to below the 5th harmonic, avoiding parallel resonance (generally there are little harmonics generated below this order). In this example, the power factor is corrected and the power system is mitigated of adverse harmonic currents. This type of equipment can be provided with switched or fixed capacitors, or with no capacitors. A tuned bank will require application engineering, including the most current data/studies and sizing recommendations from the user (or third party source), combined with the supplier of the reactor/filter product. Generally, this type of installation is required where harmonics characterize a significant part of the load.

Active harmonic filters employ the use of power electronic technology, which monitors the non-linear load and dynamically corrects a wide range of harmonics, such as the 3rd to 51st harmonic orders. By the injection of a compensating current into the load, the waveform is restored, which dramatically reduces distortion to <5% THD, meeting IEEE 519 Standards. Power is moved from the AC source to the DC electronic platform, then back to AC. This is achieved at a very rapid rate, allowing for cancellation of the high frequency output current, then followed by determining the precise value of the injected load current. The power electronics platform has been designed to operate at levels that continuously adapt to rapid load conditions and is suitable for various environments, while maintaining a small physical footprint. Passive capacitors can also be included for increased kVAR (minimal kVAR included with an active filter).

Further, to meet other power quality demands, surge protection, metering, relay protection, controls, SCADA and communications can be included, as well as integration with other equipment, to make a full service energy management system.



As an accepted guideline, voltage at a 5% THD limit at the point of common coupling (PCC) is a practical recommendation. This value generally refers to aggregate harmonics, helping to assure efficiency and reliability for industrial applications. Some electrical power distribution systems and connected equipment may function well at higher limits, and may require only minimal mitigation.

There are other devices which do not actually create harmonics, but rather magnify pre-existing harmonic currents. Capacitor systems fall into this category, and it should be noted that capacitors do not create harmonics. When harmonic currents are injected into a system in "parallel resonance," the currents are magnified and significant voltage distortion can then result. Series resonance occurs when capacitors are located near the end of feeder branches in the power system. The capacitor acts as a low impedance to a particular harmonic current, almost like a tuned filter. Nuisance blown fuse conditions and capacitor degradation are possible. Harmonic currents due to non-linear loads generally flow from the load to the utility source. Sizing, designing and locating capacitor and filter products into the power system is critical for optimum performance

Other types of harmonics exist such as third and triplens (3rd, 9th) orders where a neutral connection exists, and even orders (2nd, 4th etc.) which are not a large concern due to low magnitudes and sub-harmonic orders. Staco Energy concentrates primarily on odd order harmonic problems, which are found in a wide range of industrial and commercial applications.

Causes

Equipment widely used in offices and manufacturing not only create harmonic issues, but also are susceptible to harmonic disorders and problems. Commonly found installations:

- Computers (power supplies), PC, laptop, mainframe, servers
- Monitors, video displays
- Copiers, scanners, facsimile machines, printers, plotters
- Lighting controls, dimmers
- Electronic ballast

- Communication systems, telephone, data transmission
- Data centers, co-location facilities
- UPS systems, battery chargers, storage systems
- Standby and emergency generation, distributed generation systems
- Adjustable speed drives, drive systems
- Transformers, generators
- Arc electric furnaces, welding equipment
- Medical and dental equipment

Effects

When these types of apparatus are operating daily, especially in a 24/7 environment, both the equipment and systems may incur difficulty functioning properly from:

- Overheating of neutral conductors, bus bar, lug connections, mercury vapor and florescent lighting (electronic ballast), motor control and switchgear, which may affect current interrupting capabilities
- Circuit breaker nuisance tripping, improper function of on-board breaker electronics, excessive arcing, improper fuse operation or nuisance blown fuse interruption (artificial heating, or "skin effect")
- AC motor torque pulsation, voltage sags, notching; DC adjustable speed drives creating high inrush currents
- Overheating in transformers and cable systems, insulation (dielectric) breakdown
- Power factor capacitors becoming overloaded, blown fuse, case swelling, insulation failure from excessive peak voltages, overheating due to high RMS currents
- Effective use of power factor capacitors minimized, increasing costs, potential for resonance conditions
- Meter, protective relaying, control and other communication and measurement-instrumentation devices (including ground fault detection and digital displays) malfunctioning or providing a faulty reading, mis-operation of electronic components and other equipment
- Communications (telephone, data, video) susceptible to noise, interference in motor controls, control systems, signal distortion
- Lifespan of equipment can be reduced, potential for premature failure, downtime increased, higher maintenance costs, increase for potential loss of specific production line or process, interruption in operations, or catastrophic loss.

Application Requirements

User systems and their respective needs vary considerably. With this in mind, it is necessary to collect specific information to fully assess each application. Initial data should include:

- Previous six to twelve months of electric utility billing data, contract, and tariffs agreements. This should also include rate structure, load usage, kW/kVA, peak demand and power factor penalty
- Single line diagram of the building or facility, with all updates or revisions
- Plans for new capital equipment installations, general equipment upgrades, facility expansion, or improvements
- Most recent data from instrument measurements, site survey, general equipment and system notes, past electrical system studies

To better understand the application requirements and assist with initial system parameters, the following should be completed.

Primary voltage _____ (line-to-line)

Secondary voltage _____ (line-to-line)

System short circuit capability _____

Transformer rating (kVA) _____

Transformer impedance (%) _____

Wire/Cable/Bus Systems _____

Copper or aluminum _____

Ratings and size _____

Length of runs, ways, systems and locations
(provide single line with specific comments)

Installed Equipment

List each device or piece of equipment. Nameplate data and/or instruction manuals should contain pertinent information. Office equipment, computer and communication systems should also be considered. For example:

Drive Type:

Manufacturer, H.P./kW, Amperes, kVA, PF Pulse (AC/DC)

Capacitor Type:

Manufacturer, kVAR, voltage, fixed/switched, phases, how fused, minimum power factor present, maximum power factor, utility limit, and desired power factor, if applicable.

Communications:

Interface, tele/data, satellite

Other Considerations

What equipment, processes and operations are the most vulnerable?

Are there critical loads and a need for high power?

Have there been both long and short term outages?

Does a routine maintenance plan exist?

Have UPS, voltage regulation, generation, power distribution, motors/drives, and other power quality equipment been evaluated to meet existing and future expansion needs?

What are the costs for downtime, maintenance, scrap, lost production, return to uptime (waiting for parts, new equipment)?

Other Types of Installed Equipment

UPS	Battery Chargers	Rectifiers
Motors	Other Storage Systems	Load Banks
Resistor Banks	Furnaces	HVAC
Generators	Lighting Systems	Compressors
Prime Power/DG	Emergency/Standby Power	

Upon collecting this information, an engineering service firm or power quality consultant may be required to perform an analysis and software generated modeling and equipment sizing study. There may be several solutions, which should be reviewed based upon the need to correct an isolated problem, resolve system wide concerns, or development and implementation of a long-term power quality strategy.

Symptom	Cause	Solution
High voltage distortion, no harmonic source near equipment	Capacitor bank in a resonance condition, harmonic currents drawn to bank	Locate source of harmonics, relocate capacitor bank, change capacitor bank size, convert/add filter
High voltage distortion, exceeds limits	Network is in a resonance condition with one or more dominant harmonic frequencies	Locate source of harmonics, move capacitor bank, change controller settings (KVAR steps), add filters
Distortion is intermittent, comes and goes at similar intervals	Harmonics generated from a planned load (operation or process), industrial environment	Locate the source , install filters
Capacitor blown fuses, capacitor failure, high harmonics present	High frequency resonance, with high currents (fuses), peak voltage due to a 3rd or 5th order resonance condition (capacitors)	Detune the network, change capacitor size
Power transformer overheating below rated load, and machinery overheating at no load or below rated load	Excessive harmonic currents (transformer), high voltage distortion (machinery)	Detune or change the capacitor equipment size (transformer), determine the source, install filters if necessary

Applications primarily will be for three phase systems and involve the installation of equipment at or near the harmonic producing load, or at the main incoming location. Most systems will have an acceptable balanced load; however, consideration should be taken for unbalanced/overload protection. Should capacitors in the system fail (blown fuse), the remaining capacitors will need to function and absorb the system harmonic currents.

Consideration should also be given to the voltage rating of capacitors used in harmonic filtering applications. While capacitors are designed to handle current and voltage levels in excess of their nameplate values, reduced life can be expected from normal operation. When applied in a harmonic environment, capacitors will be (voltage) overrated to accommodate the added stresses.

100-800 Amp Rating Load Profile

Typical load profiles found in commercial and industrial facilities encompass the following:

Basic commercial building or plant—lighting load (all types), personal computers, fax machines, copiers, telecommunications, HVAC, elevators, UPS equipment, panelboards and switchboards, hospitals, both single and three phase power systems, existing and new facilities.

800-2500 Amp Rating Load Profile

Light to medium duty industrial facility—lighting loads (all types), personal computers, mainframe, servers, other office equipment, tele-data and video communications, HVAC and energy management systems, UPS equipment, panelboards, switchboards, switchgear with metering, protective relays, electronic circuit breakers, microprocessor based controls, LAN and various data network schemes, motor control centers, programmable logic controllers, machine controls, motors, adjustable speed drives, including critical process and manufacturing areas. New equipment, equipment upgrades and potential for plant expansion.

2500 Amp and Above Rating Load Profile

Same as above, plus the potential for “high duty” or “heavy” manufacturing needs such as arc furnaces, smelting, arc welders, robotic systems, dedicated machinery and factory automation, battery systems, racks and chargers, large power transformers, emergency and standby power, self-generation or distributed generation.

About Staco Energy Products Company

Since 1937, customers worldwide have been relying on Staco Energy Products Company to deliver voltage control and power quality solutions tailored to their needs.

As a leading power quality resource, we offer our customers world-class support; from our thorough applications assessment, to our ability to design and deliver a solution that is tailored to the specific needs of our customers; through delivery and commissioning.

Our professional, factory trained service team is in place to ensure that our customers' revenues are protected, and their investment provides them with many years of trouble free operation.

Staco develops total power solutions for OEM and end user applications.

We offer a wide array of power quality products, including:

- **Uninterruptible Power Supplies**
- **Power Conditioners**
- **Voltage Regulators**
- **Power Factor Correction and Harmonic Mitigation**
- **Active Harmonic Filters**
- **Variable Transformers**
- **Custom Engineered Test Sets**



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