

POWER

POINTS

A TECHNICAL BRIEFING
FROM PSE&G

The power is in your hands.



PSE&G

60 Hz

HARMONICS

The cause — and cure — of unwanted voltage
and current distortion in power systems



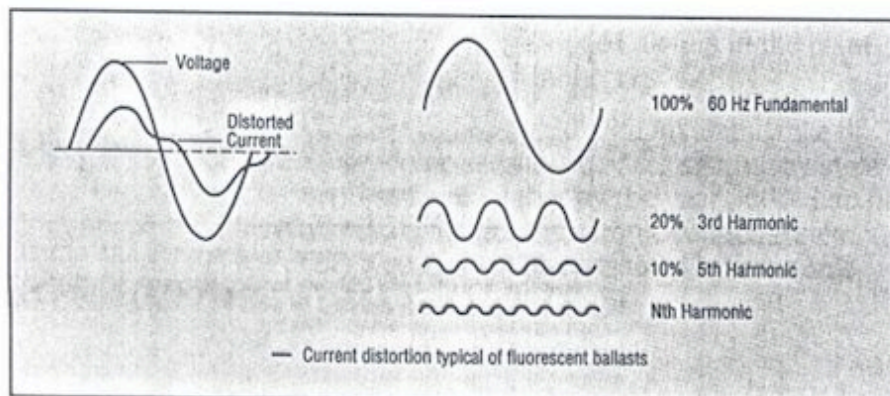
Introduction

In industrial and commercial operations, adjustable-speed motors and power electronics devices can adversely affect power quality, interfering with the operation of other equipment that runs on electricity. One particularly serious phenomenon caused by power switching devices is harmonics, which can result in numerous problems including overloading and overheating of plant equipment.

What are harmonics?

In the United States, utilities provide power to users at a frequency of 60 Hz. Harmonics are voltages or currents that are multiples of this base, or "fundamental," frequency. A harmonic with a frequency of 120 Hz, which is twice that of the fundamental frequency, is called the second harmonic. A harmonic with a frequency of 180 Hz is the third harmonic, and so on.

Harmonics do not provide any usable power to the load and are absorbed as heat in the circuit wiring, line transformers, or capacitors. The greater the magnitude of the harmonic, the greater the adverse effect on power quality.



DISTORTING HARMONICS

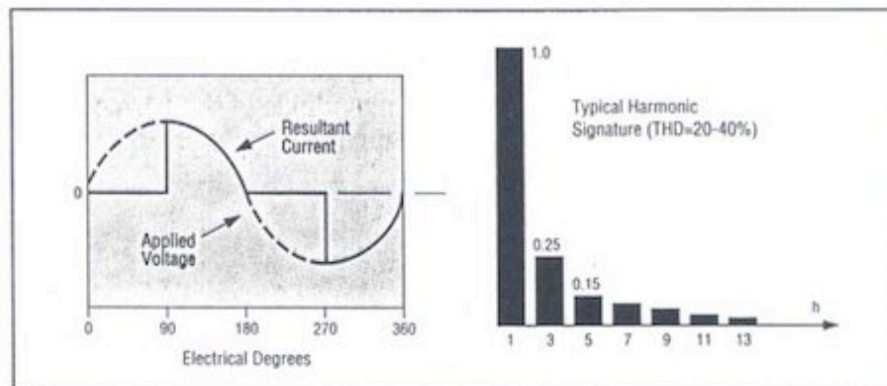
How are harmonics generated?

Harmonics are caused by nonlinear loads. Nonlinear loads use power in a waveform that is not the same shape as the waveform of the "impressed" voltage — a sine wave generated at the utility's power plant.

Instead of using all of the sine wave in a linear fashion, as electrical equipment traditionally has, nonlinear loads "gulp" power at regular intervals along the wave. The resulting nonlinear waveform distorts the waveform of the impressed voltage; the degree of distortion determines the magnitude of the harmonic.

For example, if the harmonic wave is 25 percent of the magnitude of the pure 60-Hz sine wave, the result will be a distorted wave with a peak magnitude 25 percent greater than the fundamental wave.

Odd-numbered harmonics are more common than even-numbered harmonics. Odd-numbered harmonics in general, and the third harmonic in particular, usually have the greatest magnitude and therefore cause the most distortion. The third harmonic and its odd multiples (e.g., 9th, 15th, etc.) are known as triplen harmonics and are the most troublesome.



HOW HARMONICS ARE GENERATED

Wave-chopping effect of a full-wave rectifier. Magnitude of individual harmonics varies with the particular unit, but total harmonic distortion for a full-wave rectifier typically ranges from 20 to 40%.

What equipment generates harmonics?

Most electronic devices — including copiers, fax machines, and computers — consume and distort power to some degree. Harmonics are of greatest concern in manufacturing and commercial operations with a large amount of power-distorting equipment. A single 300 horsepower adjustable-speed motor, for example, can create harmonic distortion equivalent to 4,000 TV sets.

In addition to adjustable speed motors, other equipment generating the nonlinear loads that produce harmonic distortion includes "soft-start" motor controllers, electric arc furnaces, induction heating equipment, electric welding equipment, solid state rectifiers, battery chargers, arc discharge lighting, electronic lighting ballasts, electronic process control equipment, personal computers, and printers. Uninterruptible power systems and transformers operating near capacity also produce harmonics.

How widespread is the problem?

For many years, the degree of harmonics generated in most facilities was so small that harmonics were not a serious problem. That began to change with the proliferation of variable-speed motors in the plant and personal computers in the workplace in the 1980s.

Today most commercial facilities are equipped with an abundance of harmonic-generating and harmonic-sensitive devices sharing a single power supply. Industry sources estimate that by the year 2000, half of all equipment will be electronic or have an electronic control system, and 65 percent of the utility's power will be consumed by harmonic-generating systems.

Negative effects of harmonics

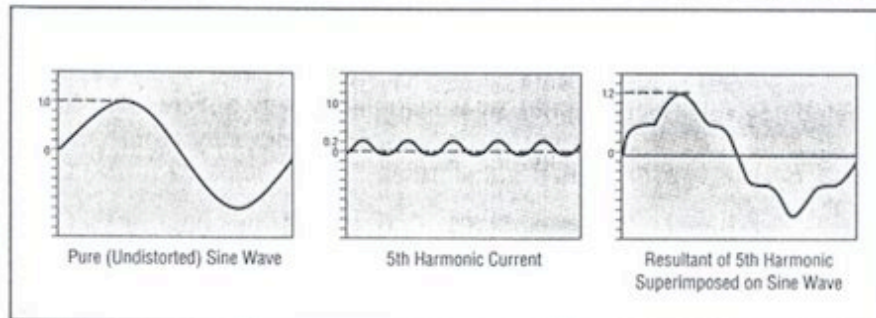
- **Overloading and overheating.** Harmonics can cause overloading of conductors and transformers resulting in damage or even a fire. Overheating of motors, solenoid coils, capacitor banks, and other plant equipment can also occur. Odd-numbered harmonics that are multiples of three (the triplen harmonics) produce overheating of neutral conductors on three-phase systems.
- **Excess voltage.** The resonance of harmonic frequencies can cause excess voltages. High currents flow, causing overheating of the conductor.
- **Equipment failures.** Harmonics can cause failure in numerous types of plant equipment including: transformers, motors, solenoid coils, capacitors, uninterruptible power supplies, electronic components, computers, and fluorescent and HID lighting ballasts.
- **Malfunctions.** Harmonic distortions can interfere with communications systems and cause computers and other electronic systems to operate unreliably. Harmonic frequencies can also blow fuses, trip breakers, and result in unstable operation of adjustable-speed motors. Control systems for lighting, motors, equipment, and HVAC (heating, ventilating, and air conditioning) are also highly sensitive to changes in voltages and harmonics. Degrading power quality can also affect meters and monitors, making readings inaccurate.
- **Higher power costs.** Some utilities set a limit on the harmonics a manufacturing plant can impose on the utility power system. If the limit is exceeded, the electric bill is increased. PSE&G does not penalize its customers for producing harmonics, but instead works with them to minimize harmonics and improve the overall quality of power in their facilities.

Detecting harmonics

The first step in determining whether harmonics are a threat to the safe and reliable operation of facility equipment is to notice whether any of the problems listed in the previous section occur with regularity. If one or more of these symptoms exist, harmonics may be the cause.

Next, initiate an engineering audit to study the problem. The study should include normal and emergency modes of operation, because switching operations can create nonlinear loads that produce harmonics. The goal of the study is to determine the types and magnitudes of harmonics; their source; and whether the system is resonant at or near harmonic frequencies.

An audit should be performed any time significant changes are made to your power system or load. Proposed changes should be analyzed to determine if changes to circuit capacitance or inductance are needed to prevent harmonics from being generated. Keep in mind that harmonics can be amplified by the removal of a load as well as by adding a load.



HOW HARMONICS DISTORT

Pure, undistorted sine wave (left) has a unit magnitude of 1.0. Superimposing a 5th harmonic of 0.2 magnitude on this wave (center) develops the resultant waveform shown at right. The resultant 1.2 unit-magnitude waveform peak can trigger older solid-state overcurrent relays, which interpret average current as a function of the peak value of a resumed sine waveform.

60Hz

Prevention and elimination of harmonics

- **Select the right equipment.** If harmonics are a problem in your plant, then any new equipment you acquire should be designed to generate low harmonic content, so that you do not add more harmonics to the load. When in doubt, contact PSE&G prior to purchasing new equipment for guidance on integrating new systems into your existing electrical environment.

The first generation of high-efficiency electronic ballasts, for instance, produced harmonic distortions two to three times greater than magnetic ballasts. Today, electronic ballasts are available that have harmonics with magnitudes of only 10 percent or less of the fundamental frequency. Total harmonic distortion (THD) is one of the parameters that should be considered when selecting new equipment.

- **Protect critical systems.** Since problems are most likely to occur when harmonic-producing equipment and harmonic-sensitive devices are on the same power supply, trouble can be minimized by separating the two categories of loads, where possible. Machinery and equipment that is being adversely affected by harmonics can be isolated from the resonant frequencies by connecting them to a separate, dedicated transformer.



Critical electronic devices can be protected from the effects of harmonics by using an uninterruptible power system (UPS). Keep in mind that the UPS, while protecting some equipment, can create harmonics that can affect unprotected equipment on the same circuit.



• **Upgrade power systems to handle the harmonic load.** Consider increasing transformer capacity by adding units or replacing existing transformers with larger units. Make sure new transformers are rated with a "K-Factor," which indicates they can withstand harmonics. On three-phase systems, you may want to increase the size of neutral conductors or supplement them with parallel conductors.

• **Change the frequency.** Shift the resonant frequency to a frequency that reduces or eliminates the effects of harmonics. This can be done by using different size capacitors, adding a reactor, or by otherwise altering the circuit inductive and capacitance parameters.



Another method is to alter the circuit inductance or capacitance to create a low-impedance pathway to ground for the harmonic currents. This is known as filtering. Filter components must be of a voltage rating compatible with the voltage rating of the bus to which they are attached. It is strongly recommended that any attempts to filter or change the frequency of your system be preceded by a thorough engineering study.

For more information...

For technical assistance in detecting and eliminating harmonics in your power systems, contact your local PSE&G representative. Or call PSE&G toll-free at:

Cranford	1-800-782-0067
Mt. Laurel	1-800-992-0461
Paramus	1-800-752-0017
Princeton	1-800-832-0076
Secaucus	1-800-722-0256
W. Paterson	1-800-752-0024