Harmonic Currents

Power quality used to be to the ability of the electric utilities to provide electric power without interruption. Today, power quality encompasses any deviation from a perfect sinusoidal waveform.   This includes EMI and RFI noise, transients, surges, sags, brown outs, black outs, and any other distortions to the sinusoidal waveform.   One distortion to the sinusoidal waveform which has dangerous consequences is harmonics.

Harmonics can be present in voltage, current or both.   It is forecast that before the end of the century, half of all electrical devices will operate with nonlinear current draw. These nonlinear loads are the cause of current harmonics.

The term " harmonic currents" is a popular buzz word in the power quality industry and the layman needs some information to understand the term and realize they can be a serious problem if not treated properly.   The treatment and the details of harmonics is better left to the expert with the proper tools and training.

Harmonic currents cause overheating of electrical distribution system wiring, transformer overheating and shortened transformer service life.   Electrical fires resulting from distribution system wiring and transformer overheating were rare occurrences until harmonic currents became a problem.   The frequency of such fires is now becoming more common.   The life safety issues of electrical fires are not part of this discussion, but should be considered.

Imagine the cost to a company such as a stock brokerage firm if a transformer and the distribution wiring failed during a busy trading day.   Power is lost to their trading computer equipment and they cannot carry out their normal business of buying and selling financial instruments.   An electrical system fire could result and destroy part of the electrical distribution system.

These events could take days to correct to put this firm back in business.   The entire distribution system would have to be surveyed for damage.   All damaged or weakened distribution system equipment and wiring would have to be replaced. This list of damages could include damaged conduit, transformers, switch gear, electrical panels, wire, etc.   This list of damaged equipment probably will include equipment connected to the electrical distribution system at the time of system breakdown.   During such a breakdown, other power quality problems will be encountered including shorting of transformers and wiring.   Imagine the effect on sensitive computer equipment not isolated from the electrical distribution system. Transient activity can have a catastrophic effect on computer and telecommunications networks.

In effect, the stock brokerage firm in our example has been put out of business by harmonics until repairs can be completed or operations moved to another location. What could be the bottom line cost?   Millions of dollars would be a conservative

estimate if they were a <u>small</u> firm.   Estimate the cost to your own company if you were out of business for days or a week or longer.   Who would service your customer? Would it be your competition?   Could your company financially survive such a catastrophic event?

Harmonic currents cause false circuit breaker tripping.   Peak sensing circuit breakers often will trip even though the amperage value has not been exceeded. Harmonic current Peak values can be many times higher than sinusoidal waveforms.   In electronic equipment that relies on the zero crossing of the sinusoidal waveform, such as clock timing devices, heavy harmonic content can cause a zero crossing point offset.

In many cases, power factor correction capacitor failure can be directly attributed to harmonic content.   Capacitors appear as extremely low impedance values and are more susceptible to harmonics. High Harmonic currents have been known to overheat correction capacitors, causing premature failure and sometimes resulting in explosion.

Utilities invest millions of dollars annually to ensure the power supplies their customers receive are as close as possible to a sinusoidal waveform. Resistive linear loads such as the incandescent light bulb result in sinusoidal waveforms, but switching loads do not. The power supply in a modern personal computer is a good example of a non-linear load.   The switching action of the computer power supply results in distortion of the current waveform.   There are many other switching loads and a few are listed in the chart below.

LOADS PRODUCING HARMONIC CURRENTS

Electronic Lighting Ballast	**Adjustable Speed Drives**
Electric Arc Furnaces	**Personal Computers**
Electric Welding Equipment	**Solid State Rectifiers**
Industrial Process Controls	**UPS Systems**
Saturated Transformers	**Solid State Elevator Controls**
Medical Equipment	

The above list is not complete and is being expanded every day. The common characteristic shared by most of the equipment on this list is seen more today than before the microprocessor. Most of this equipment relies on an internal DC power supply for operation.

Large commercial buildings have many different sizes and types of loads. The most common power distribution to office systems and equipment is 208/120 transformers in a Wye configuration. This configuration does not include what are known as high voltage loads such as air handlers or high voltage lighting that are

powered by 480 Delta or Wye configuration transformers. Delta and Wye distribution systems are also used in some facilities for specialized equipment. For the purpose of our discussion we will consider the distribution system to be 480 - 208/120 Wye.

The following are definitions that will assist your understanding of this section.

Harmonic: A sinusoidal waveform with a frequency that is an integral multiple of the fundamental 60 Hz frequency.
- 60 Hz fundamental
- 120 Hz 2nd harmonic
- 180 Hz 3rd harmonic
- 240 Hz 4th harmonic, etc.

Triplen Harmonics: Odd multiple of the 3rd harmonic (3rd, 9th, 15th, 21st, etc.)

Harmonic Distortion: Non-linear distortion of a system characterized by the appearance in the output of harmonic currents (voltages) when the input is sinusoidal.

Voltage Harmonic Distortion (VHD): Voltage harmonic distortion is distortion caused by harmonic currents flowing through the system impedance. The utility power system has relatively low system impedance, and the VHD is very low. VHD on the distribution power system can be significant due to its relatively high system impedance. $E + I^2R$ Ohm's Law

Total Harmonic Distortion (THD): The square root of the sum of the square of all harmonic currents present in the load excluding the 60 Hz fundamental. It is usually expressed as a percent of the fundamental.

Harmonic Spectrum "K" Factor: The sum of the product of each harmonic current squared and that harmonic number squared for harmonics from the fundamental (60 Hz) to the highest harmonic of any measurable consequence. When the "K" factor is multiplied by the stray losses of the transformer, the answer represents the loss in the transformer caused by harmonic currents. When these losses are added to the I^2R losses of the transformer, the total load losses are known.

Current waveforms from non-linear loads appear distorted because the non-linear waveform is the result of adding harmonic components to the fundamental current. Non-linear loads generate high levels of harmonic currents and when supplying power to these loads, a special transformer design is necessary.

Of these non-linear loads, the major source of harmonic currents is the switch mode power supply found in most desktop computers, terminals, data processors and other office equipment.

The amount of harmonics produced by a given load is represented by the term "K" factor.   The larger the "K" factor, the more harmonics are present.   The chart below provides a guide of typical "K" factors of different loads. This chart is only a guide and the "K" factor of equipment will vary from one manufacturer to another. The best way to determine "K" factor is by spectrum analysis and should be left to a professional with the proper power quality analysis equipment.

K-Factor By Type of Load

K-1	Resistance Heating	K-13	Telecommunications Equipment
	Incandescent Lighting		Branch Circuits in Classrooms
	Electric Motors		Health Care Facilities
	Control Transformers		
	Distribution Transformers		
K-4	Welders	K-20	Main Frame Computers
	Induction Heaters		AC Variable Speed Drives
	HID Lighting		Circuits With DP Equipment
	Fluorescent Lighting		Personal Computers
	Solid State Controls		Computer Terminals

Harmonics are produced by the diode-capacitor input section of power supplies. The diode-capacitor section rectifies the AC input power into the DC voltage used by the internal circuits.   The personal computer uses DC voltage internally to power the various circuits and boards that make up the computer.   The circuit of the power supply only draws current from the AC line during the peaks of the voltage waveform, thereby charging a capacitor to the Peak of the line voltage. The DC equipment requirements are fed from this capacitor and, as a result, the current waveform becomes distorted.

The harmonics in the electric power distribution system combine with the fundamental (60 Hz) to create distortion.   The level of distortion is directly related to the frequencies and amplitudes of the harmonic current.   All of the harmonic frequency currents combine with the fundamental current to form the total harmonic distortion. (THD)   The THD value is expressed as a percentage of the fundamental current and any THD values over 10% are significant enough for concern.

Modern power quality instruments will read harmonics and do the calculation of the above formula. These are preferably used by trained operators .   If you suspect

you have problems or want to be sure you do not have harmonics present in your electrical distribution system, call upon a professional in the field of power quality.

Wherever there are large numbers of nonlinear loads, there are harmonics in the distribution system. It is not uncommon for THD levels in industrial plants to reach 25%. Normally, THD levels in office settings will be lower than in industrial plants, but office equipment is much more susceptible to variations in power quality.

Odd number harmonics (3rd, 5th, 7th, etc.) are of the greatest concern in the electrical distribution system. Even number harmonics are usually mitigated because the harmonics swing equally in both the positive and negative direction.
The heating effect causes the greatest problem in electrical distribution systems and equipment. Electrical equipment often overheats and fails even when operating well below the design ratings. The increase in temperature is directly related to the increase in RMS current.

Harmonic frequencies are always higher than the 60 Hz fundamental frequency so "skin effect" also becomes a factor. Skin effect is a phenomenon where the higher frequency causes the electrons to flow toward the outer sides of a conductor. This reduces the ability of the conductor to carry current by reducing the cross sectional diameter of the conductor and thereby reduces the ampere capacity rating of the conductor. Skin effect increases as the frequency and the amplitude increase and this is the reason higher harmonic frequencies cause a greater degree of heating in conductors.

Industrial environments can have many three phase, non linear loads drawing high levels of load current. The effect on transformer operation when multiple loads are connected is that each load generates triplen harmonic currents on the neutral conductor. These are sent on to the transformer secondary and reflected into the delta primary and these currents circulate within the delta primary causing overheating, shortened service life, catastrophic failure or worse.

On balanced, three phase systems with no harmonic content, the line currents are 120° out of phase, cancel each other and result in very little neutral current. However, when there is distortion in any one of the phase currents, the harmonic currents increase and the cancellation effect is lessened. The usual result is the neutral current THD is significantly higher than planned. The triplen harmonics (odd multiples of three) are additive in the neutral and can quickly cause dangerous overheating.

In theory, the maximum current that the neutral will carry is 1.73 times the phase current and if not sized correctly, overheating will result. Higher than normal neutral current will cause voltage drops between neutral and ground which are well above normal. Readings above 4 volts indicate high neutral current.

Parallel resonance between the capacitor bank and the source impedance can cause system resonance resulting in higher than normal currents and voltages.   The resulting power factor correction capacitor failure can be directly attributed to harmonics.   Inductive reactance varies directly with frequency ($XL=2x3.14\ fl$).

The majority of problems result when the resonant frequency is close to the 5th or 7th harmonic.   These happen to be the largest harmonic amplitude numbers that most adjustable speed drives create.   When this situation arises, capacitor banks should be re-sized to shift the resonant point to another frequency.

Modern electronics grade distribution panels have lugs for neutrals 2X the phase conductor size in anticipation of neutral currents.   K rated transformers are also built to accommodate high neutral currents.

Another useful parameter is the Distortion Factor, or %DF.   %DF is the Total Harmonic Distortion referenced to the total RMS signal.   The %DF is expressed as a percentage and may not be grater than 100%.   International standard IEC-555 has requirements for equipment that must be met.

The Following are steps to take in alleviating the many problems encountered when harmonics are present in an electric distribution system.   Step #1 can be started by the layman, after that, a professional should be called in.

1. Inventory all equipment that may generate harmonic currents.
2. List the nonlinear loads which are on each branch circuit.
3. Record true RMS current in each phase at the service entrance.
4. Record the neutral current of the transformer secondary.
5. Compare the measured neutral current to the anticipated current due to phase imbalance.   If the phase currents are equal, the vector sum of the neutral currents will add up to zero.   If excessive amounts of triplen harmonics are present in the neutral, neutral current may exceed phase current. Consult the NEC® for the maximum capacity for each of the conductors that have been measured.
6. Measure each feeder for harmonic content. A high degree at this location is often heard as a buzzing sound. A voltage THD reading is also useful at this location.

IEEE standard 519-1992 is a guidance document for utilities and electric power users which specifies both the maximum distortion levels and recommends correction levels.   The harmonic distortion limit of 5% is proven to be the point where harmonics begin to have a detrimental effect on the electrical distribution system.

Harmonic current measurements define the harmonic generation characteristics of the load, so measurements should be taken there when possible.   Voltage

measurements define the system response and are usually taken at the individual busses.

Distribution systems compound the problems that harmonic currents present to the system. The nonlinear harmonic load currents also have an Ohm's Law relationship with the source impedance of the system to produce voltage harmonics. Consider a heavily loaded transformer that is affected by one branch circuit feeding a non linear load; the resulting voltage harmonics can then be passed down to all the remaining circuits fed by that transformer.

Voltage Harmonics

Voltage harmonics may cause havoc within the electrical distribution system. Motors are typically considered to be linear loads; however, when the source voltage supply is rich in harmonics, the motor will draw harmonic current. The result is typically a higher than normal operation temperature and shortened service life.

Different frequency harmonic currents can cause additional rotating fields in the motor. Depending on the frequency, the motor will rotate in the opposite direction (counter-torque). The fifth harmonic, which is very prevalent, is a negative sequence harmonic causing the motor to have a backward rotation, shortening the service life.

Noise can be picked up in computer networks, communications equipment and telephone systems when harmonics are at audio or radio frequencies. With the increase in speed of computer networks, the future will bring these systems into the frequencies where they will be more affected by harmonic generated noise. The noise is inductively or capacitively coupled into the communications and data lines.

When induction-disc watt-hour meters are monitoring non linear loads, depending on the content of the harmonics, the disk may run slower or faster, resulting in erroneous readings.

The majority of generators and transformers base their operating characteristics on non disturbed 60 Hz waveforms. When the waveforms are rich in harmonics, shortened service or complete failure is sure to result.

One option in distribution system if harmonics are present is to de-rate the transformer supplying the system. De-rating K factors can be applied specifically to transformers to ensure dangerous heating will not result when supplying load currents which are rich in harmonic content.

The K factor is determined by measuring the True RMS current of each harmonic, multiplied by the harmonic order and squared. The total sum is then multiplied by the eddy current losses. The K factor of a transformer should be thought of as the

index of the transformer's ability to handle nonlinear load currents without abnormal heating.

The alternate method for de-rating transformers is for buildings which supply single phase, 120 VAC receptacles.   This method is established by The Computer & Business Equipment Manufacturers Associations (CBEMA).

> **CBEMA De-rating Factor = 1.414 divided by Crest Factor**
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> **Crest Factor (CF) = Peak Value divided by RMS Value**

De-rating certain types of electrical equipment is the easiest way to limit the effects increased heating has on equipment.   A 25% de-rating for transformers and generators is commonly employed in industry.

Filtering is currently the most common method used to limit the effects that harmonics present to the rest of the system.   Filters typically consist of tuned series L-C circuits.   Filter impedance is negligible with respect to the rest of the distribution system.   These filter products are commercially available under different trade names.   Most filter products are no more than 50% effective. The best solution is to install transformers, with the appropriate K rating and wiring that is sized to meet the equipment and systems needs.