Harmonics: A Brief Introduction

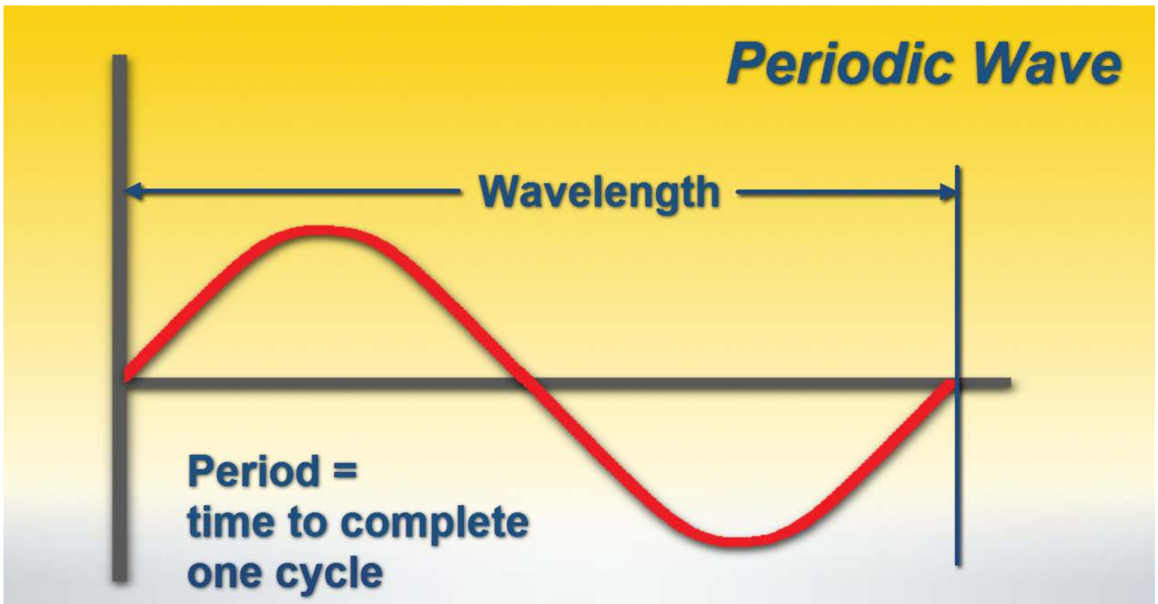
Harmonics is a critically important concept in electronics. Harmonics affect the quality of AC electricity delivered to industrial, commercial, and residential facilities, and the performance of equipment that uses the electricity in these facilities. Harmonics can increase energy costs and reduce the lifespan of hardware. In some cases, harmonics can overheat electrical conductors, creating a fire risk.

In this Application Note, we briefly explain what harmonics are, and why you should care about them.

Periodic Waves, Clean and Distorted

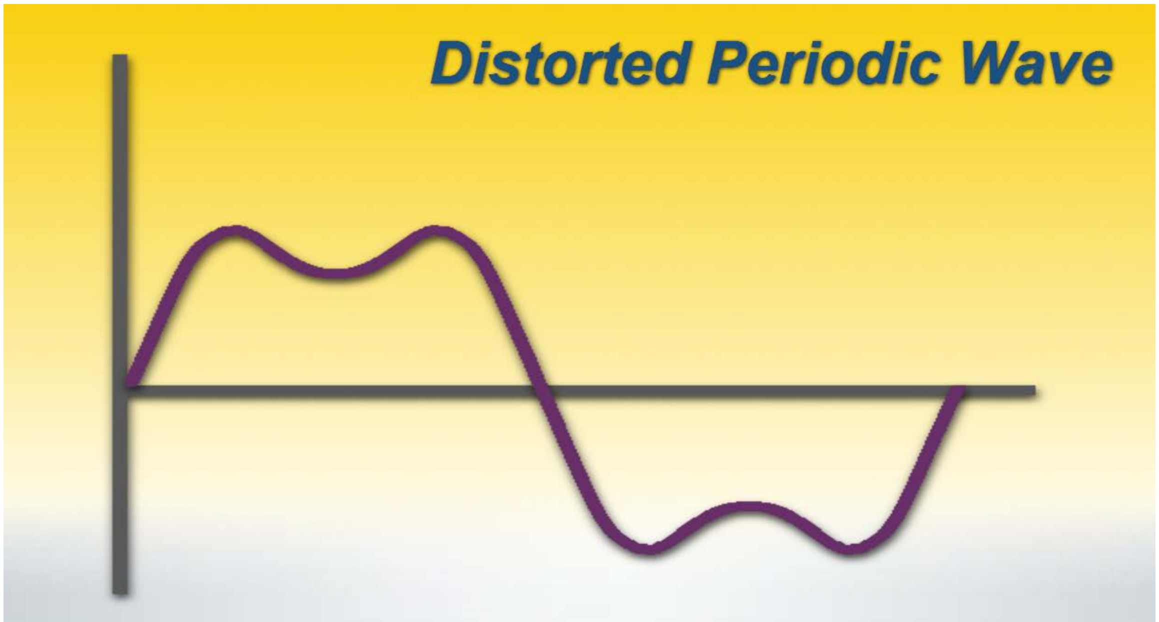
To begin, let's consider a mathematical concept called the periodic wave. This is a graphical representation of a constantly changing variable whose values follow a repeated sequence.

A familiar example is the sine wave shown below.

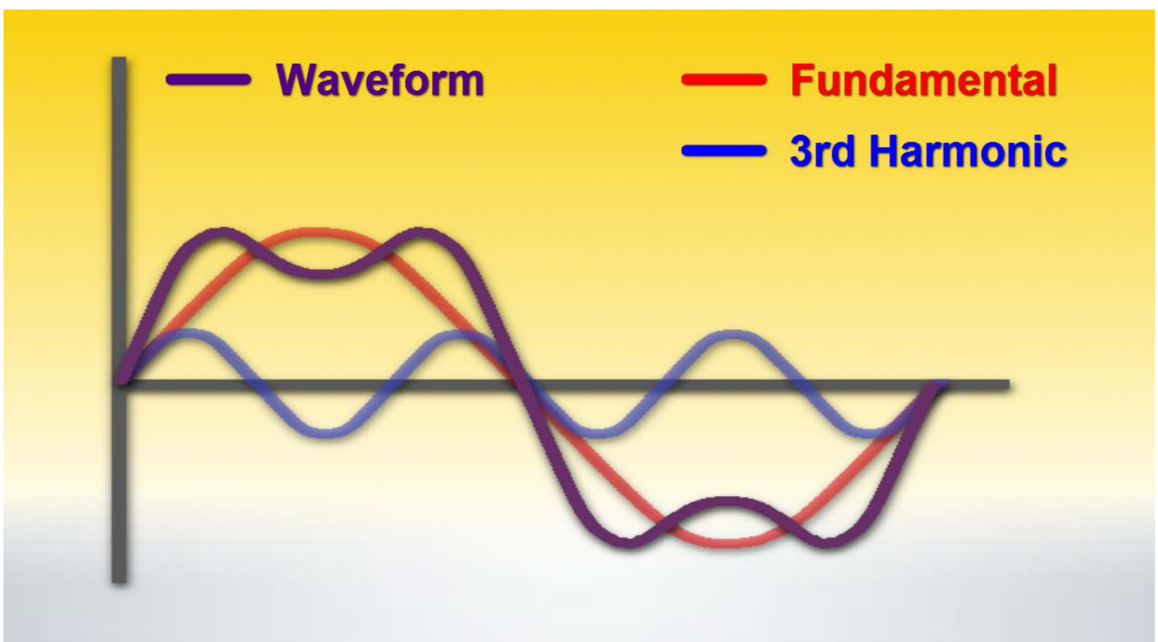


When we examine a sine wave, one of the first things we notice is that it follows a very symmetrical and repeated pattern. Each full wave has a certain length, called its wavelength. The time required for one wavelength to complete its cycle is called its period, from which we derive the term "periodic wave." Periodic waves are found in a wide variety of natural phenomena, including ocean waves, sound, and light. Electricity transmitted over the public power grid can also be graphed as periodic waves.

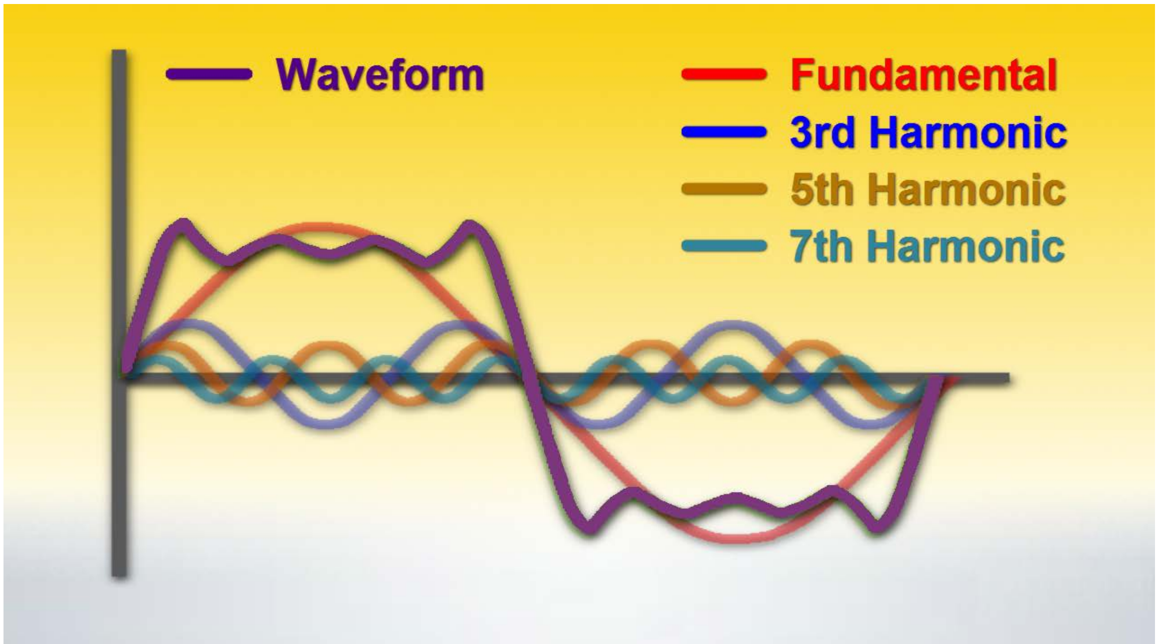
A perfectly regular and symmetrical sine wave represents a very simple and "clean" example of a periodic wave. In the real world, however, periodic waves are subject to numerous influences that affect their shapes. These can produce waves that display distortions and asymmetries, as shown below.



Deconstructing Distorted Waves
To understand how this happens, it might be useful to work backwards and deconstruct this wave into its constituent components. A periodic wave, no matter how distorted, can be defined as the composite of a single primary or fundamental wave, and one or more so-called harmonic waves of varying wavelengths. For example, our illustration can be deconstructed into two waves, the fundamental wave and a harmonic wave whose wavelength is one-third the fundamental. This second wave is therefore called the third harmonic.



The combination of these two waves – the fundamental and the third harmonic – produces the distorted wave shown in our example. Adding additional harmonics results in further distortion in the waveform.



The presence of all these individual harmonics can be expressed as total harmonic distortion, or THD. The mathematical formulas for calculating THD are shown below.

$$THD_F = \frac{\sqrt{\sum_{n=2}^{n=\infty} V_n^2}}{V_1}$$

$$THD_R = \frac{THD_F}{\sqrt{1 + THD_F^2}}$$

Fortunately, modern test instruments designed for measuring harmonics can perform these calculations automatically and display the results, greatly simplifying the process for monitoring THD in a facility.

Harmonics in Electrical Power Lines
In an electrical power line, a number of factors can create harmonic distortion. These include currents introduced into the line by users of non-linear loads, environmental causes such as lightning, electromagnetic interference, and others. As a result, the AC electricity delivered to a facility can include a significant percentage of THD in addition to the fundamental sinusoidal electricity produced by the power generation plant. The higher the THD, the more distorted the electricity's waveform.

This can be a problem for electrical equipment designed to operate optimally when provided with clean, undistorted AC power. A high percentage of THD can stress electrical infrastructure and equipment, resulting in a significant amount of electricity dissipated as excess heat. Left unaddressed, harmonic distortion can produce numerous issues such as system underperformance, shortened hardware life, wasted energy, and increased electrical costs. In extreme cases, THD can increase the risk of personal injury to operators and damage to facilities.

THD can also raise regulatory considerations. A number of guidelines exist, such as IEEE 519-2014, that define how much harmonic distortion is allowed for certain types of facilities (see the excerpt below). Strict adherence to these specifications can be an essential business requirement for many organizations.

Table 1 – Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq$ 69 kV	3.0	5.0
69 kV < $V \leq$ 161 kV	1.5	2.5
161 kV < V	1.0	1.5*

*High-voltage systems can have up to 2.0% THD where the cause is an HDVC terminal whose effects will have attenuated at points in the network where future users may be connected.

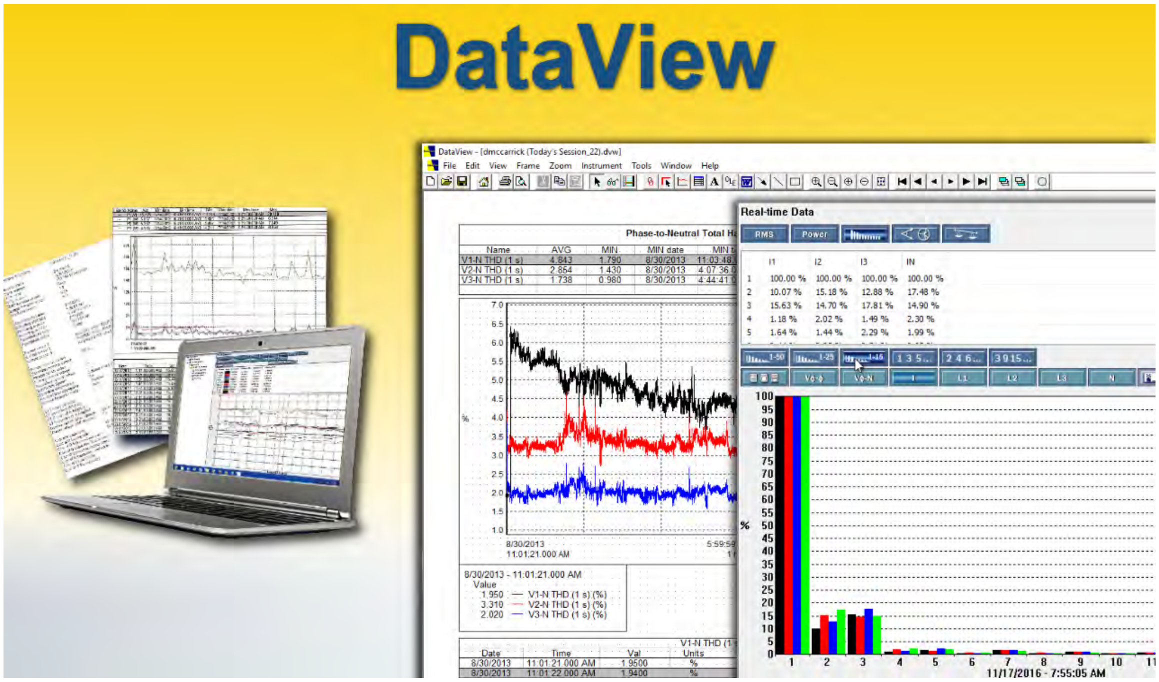
Harmonics Mitigation and AEMC Power Quality Instruments

Fortunately, there are several mitigation techniques that can minimize and even eliminate the impact of harmonic distortion. A first step in this process is to analyze the quality of the power in your facility. This will help you assess how significant a problem THD is at your location, and which measures will likely be the most effective for addressing it.

AEMC offers a full line of power quality analyzers, loggers, and meters that incorporate the most up-to-date measurement technology and communication options.

These include the Power Quality Analyzers Models 8333, 8336, and 8435, as well as the Power and Energy Loggers Models PEL 102, 103, and 105. These and other AEMC instruments (including the Clamp-on Meters 407 and 607) can help you quickly and accurately perform harmonic analysis, with some models capable of automatically measuring and displaying up to the 50th harmonic.

Many of these instruments are supported by DataView, AEMC's data analysis software. You can connect the instrument to a computer running DataView and view its measurement data in real-time. You can also download recorded data from the instrument, and format it into reports that can be analyzed and shared.



This data can then form the basis for a comprehensive harmonics mitigation strategy. And once this strategy is implemented, AEMC power quality instruments can help determine how effective these measures are, and whether they require fine-tuning. In addition, these instruments can also measure numerous other factors that can degrade power quality.

Conclusion

Let's review some of the points we've covered in this Application Note:

- AC electricity produced by power plants is generated as clean, sinusoidal periodic waves.
- A number of causes, both natural and man-made, can result in harmonics being added to electricity as it is transmitted over power lines. These harmonics distort the electricity's original waveform.
- Total harmonic distortion, or THD, can have a significant impact on the operation of electrical equipment, affecting its efficiency, reliability, safety, and cost.
- And finally, AEMC offers a wide range of instruments for measuring and analyzing harmonic distortion in your facility, helping to provide the data on which an effective THD mitigation strategy can be based.