WHITE PAPER:
UNDERSTANDING TOTAL HARMONIC DISTORTION

Contributed by Cowles Andrus September 2012

ABSTRACT

This paper discusses the causes of Total Harmonic Distortion, how it is calculated, measured, and how it can impact a power distribution system.

Total Harmonic Distortion (THD) can be a challenging concept because of the complexity of the power system and its many individual components. THD is better understood when a power system is defined by its simplest parts– the power source and load, as shown in Figure 1.

Because the load affects the current draw on a system, the power quality of the system is often affected as well, depending on the type of load. Loads can be either linear or non-linear. A linear load draws current that is sinusoidal in nature and has smooth current and voltage transitions, so generally this does not distort the waveform as seen in Figure 2.

Many home appliances such as electric hot water heaters, base board heat, irons, and incandescent lighting have mostly resistive loads, which are relatively linear. Harmonic distortion is not usually caused by the power generation or distribution system itself and was not really an issue before 1960. Around this point in time changes in technology began to contribute to changes in customer load. Non-linear components such as diodes and SCR (or thyristors) started to be incorporated into household devices and appliances.

Some devices that have been known to present non-linear loads to the power grid include AC/DC converters, motor speed controls/light dimmers, adjustable frequency drives, copiers, battery chargers, UPS, and also items such as electric welders, electronic ballast, and arc furnace. Higher energy efficiency lighting and government phasing out of incandescent light bulbs is driving consumers to replace old incandescent
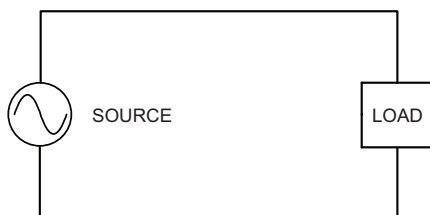

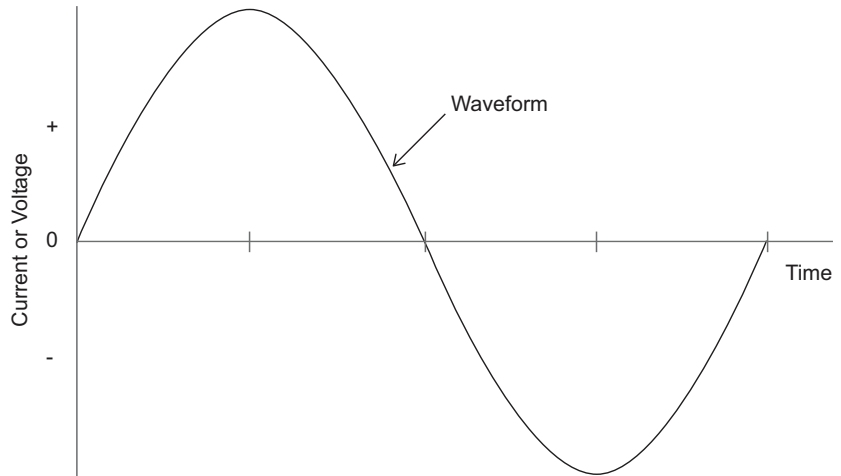Figure 1. Most basic parts of a power system

Figure 2. Ideal sine wave with a linear load provided to the source

light bulbs with compact fluorescent lamps (CFL), light emitting diode (LED) and electron stimulated luminescence (ESL) type lighting. This type of lighting, while very energy efficient, does not provide a linear load such as incandescent light bulbs provide. In fact, the ESL beats out the energy efficiency of the CFL and LED hands down but has a power factor of 0.95 to 0.99 where the CFL and LED are in the 0.5 to 0.8 range. Another new source of harmonic distortion comes from variable motor speed controls currently being introduced in many high-efficiency heat pumps. These non-linear devices present a non-linear load to the power source causing large distortions to the source waveform as shown in Figure 3.
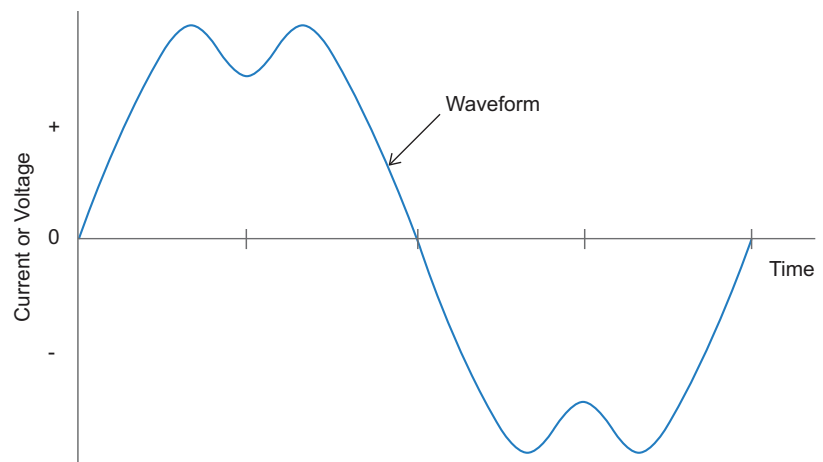

Figure 3. Distorted waveform caused by non-linear loads

Non-linear loads cause waveform distortion, drastically changing the shape of a power source's waveform. All sine waves are composed of harmonics which are multiples of the fundamental waveform. In the United States, the power line frequency is 60 Hz, so multiples of 60 Hz make up the sinusoidal power waveform. Harmonics can be defined as a steady state distortion of the fundamental frequency (e.g. 60 Hz for power lines). It is important to point out that a sine wave is made up of both even and odd harmonics. Non-linear loads usually cause odd-order harmonics to be more pronounced and problematic in a power distribution system. This is because most electrical loads, except for half-wave rectifiers, produce symmetrical current waveforms. This means that the positive half of the waveform is a mirror image of the negative half. This results in only odd harmonic values being present. A half-wave rectifier can produce even harmonics in addition to the odd ones. The illustration shown in Figure 4 demonstrates the relationship between the fundamental and the odd harmonics caused by non-linear loads.

Another factor that can sometimes cause an increase in harmonic problems are capacitor banks that are used to correct the power factor of inductive loads. If the capacitor resonance is at some multiple of the fundamental, it can actually magnify harmonic
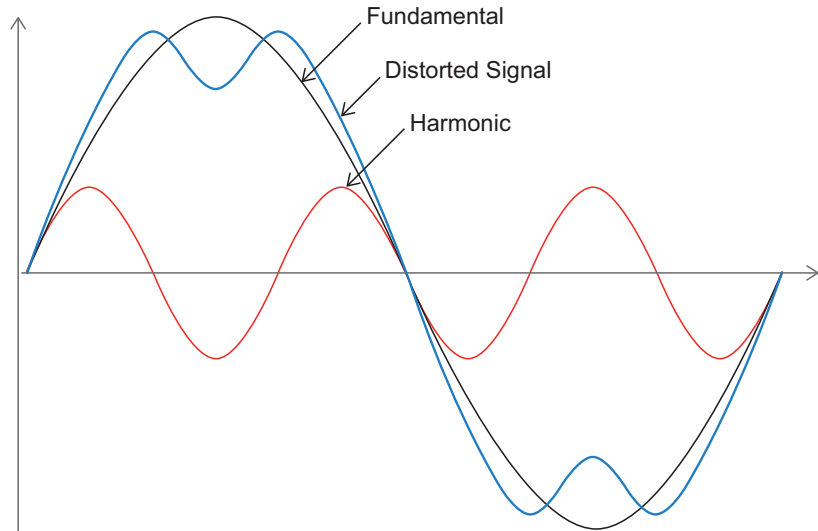
problems. Careful design and consideration is important when installing capacitor banks and it is also important to monitor THD and power factor because the inductive load may change from time to time as a result of new loads presented by customers.

The graph in Figure 5 shows the relationship of the fundamental frequency and some of the lower odd harmonics that add together to form the resultant.
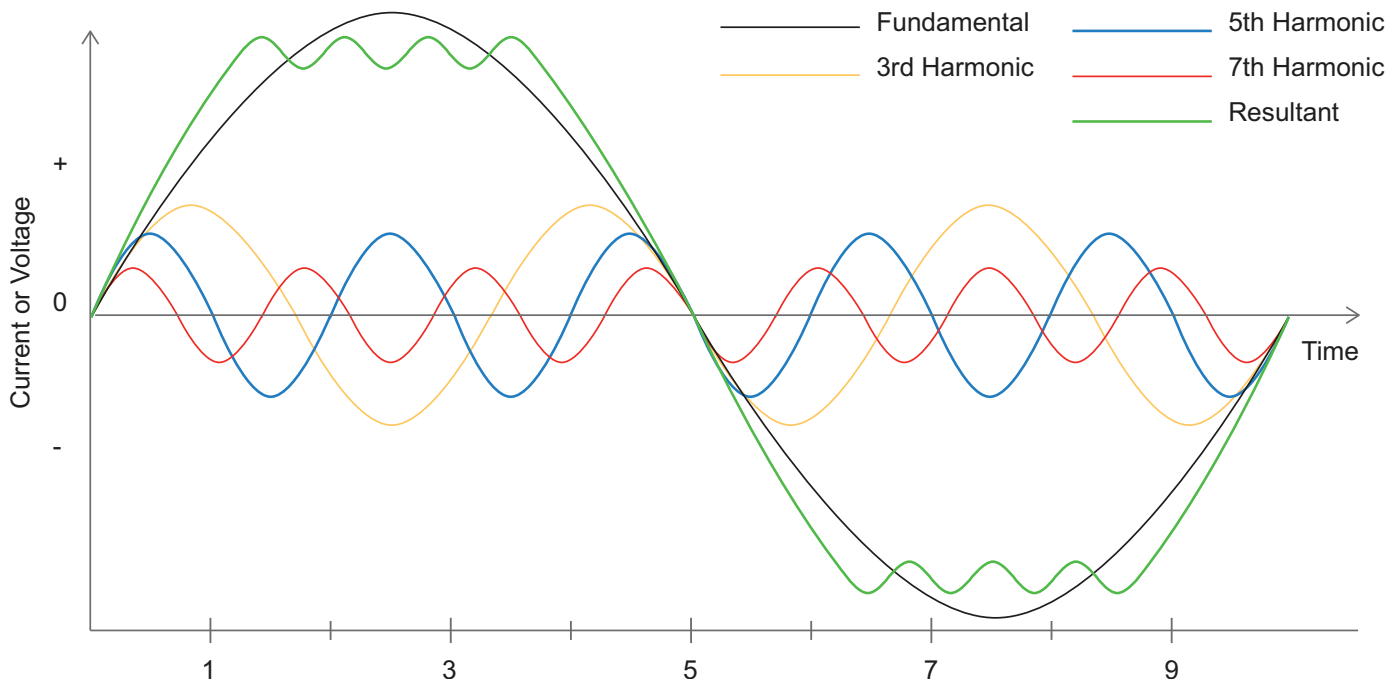
Figure 4. Relationship between the fundamental and odd order harmonics

Figure 5. The relationship of the fundamental frequency and lower odd harmonics that add together to form the resultant

THD

Total harmonic distortion in reference to (F) fundamental represents the ratio, in percent, of the voltage/current harmonic components relative to the voltage/current of the fundamental. When the reference is not indicated (i.e. simply THD), then it is usually assumed the reference is fundamental and not THD-R which is a different measurement. For power systems, THD or THD-F is a better measurement to use. Below is an equation used to calculate THD where V_n is equal to the Magnitude of the nth harmonic.

$$THD = \frac{\sqrt{\left(V_2\right)^2 + \left(V_3\right)^2 + \ldots + \left(V_\infty\right)^2}}{V_1}$$

One of the main reasons to measure THD and accurately assess its value is so the operator can evaluate and monitor the system's distortion level over time. This allows the operator to see what changes need to be made to the power system before the distortion levels elevate to a point where they could damage the system.

Some issues that high THD can cause are overheating transformers, issues with the proper operation of 3-phase motors, increase hysteresis losses, unacceptable neutral-to-ground losses, decreased kVA capacity, inaccurate power measurements, interference to communication systems such as telephone and radio, breaker tripping and fuse blowing, damage to capacitor banks, damage or interference to electronics, and the list goes on.

Technology and growth tend to progressively load the grid with more and more non-linear loads causing total THD to grow. It is very important to monitor the system to head off issues before they shut down the power system and result in damage to critical equipment. The increase in harmonic content may require some systems to be evaluated for proper transformer de-rating or upgrades to power distribution systems with K-rated transformers to reduce overheating or early-life failures.

With ProVision and most PMI recorders, accurate measurement can be taken and displayed on many facets of power quality including Total Harmonic Distortion. The ProVision default for THD is F or fundamental but if desired by the operator, THD-R can easily be displayed by right-clicking on THD-F while in the Harmonic Analysis Magnitude Graph mode. If more detail is needed on the harmonics, press the F key while the cursor is on the graph. This removes the fundamental frequency allowing the graph to scale making the smaller, higher harmonics clearly visible. This could be very useful in areas where THD presents an issue to power quality such as a power related-issue with a 3 phase motor overheating, or communication interference.

Figure 6 shows an example of a harmonic analysis report used to collect data on the LED lamp.

Harmonic Analysis Report

7 W LED 200 lumens bulb

Start: Apr 18, 2012 09:08:56
Stop: Apr 18, 2012 09:37:11
Duration: 0 days, 00:28:15
Firmware Version: 5.62 Unit Type: Revolution
Software Version: 0.00 Serial No.: 61277

Circuit Type:	Wye
Voltage Scale Factor:	x1.00
Current Scale Factor:	x1.00
Current Range:	10 Amps
Interval Time:	1 second

Data computed from Waveform #1, 04/18/12, 09:08:55:33, starting point 1 (0.00 ms)
Harmonic phase refererence: Voltage channel one fundamental

	Vmag		Imag	
	Ch 1	Ch 2	Ch 1	Ch 2
THD, %Fundamental	2.21%	49.90%	144.2%	144.6%
THD, %Fund. Odds	2.21%	44.25%	143.7%	144.1%
THD, %Fund. Evens	0.11%	23.06%	12.73%	12.31%
THD, %Fund. Triplens	1.78%	26.40%	101.9%	102.0%
THD, %RMS	2.21%	44.65%	82.18%	82.25%
THD, %RMS Odds	2.21%	39.60%	81.86%	81.95%
THD, %RMS Evens	0.11%	20.63%	7.25%	7.00%
THD, %RMS Triplens	1.78%	23.62%	58.05%	58.00%
TIF	3.26%	37.44%	28.56%	28.82%
K-Factor	1.04%	228.5%	49.56%	49.55%

Magnitude

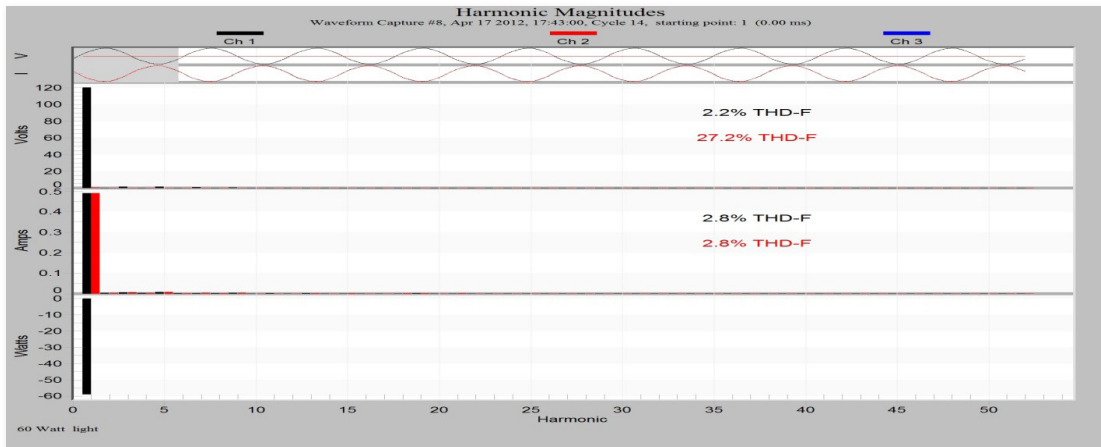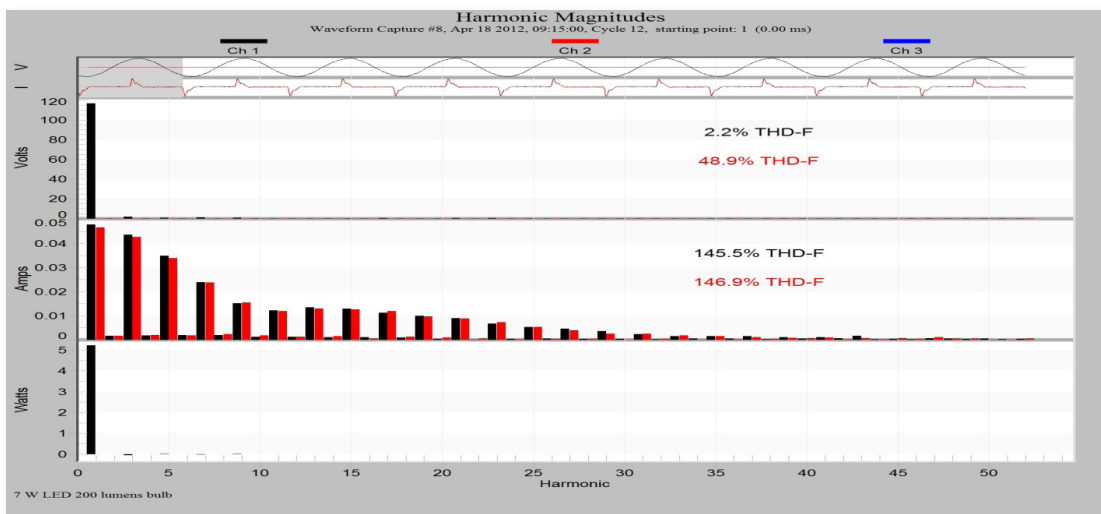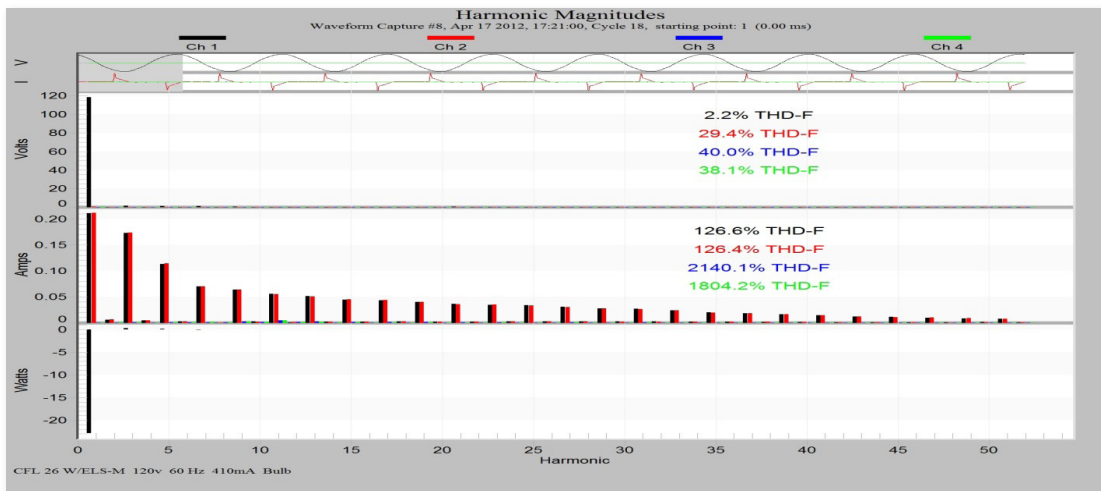*Figure 6. Example harmonic analysis report used to collect data from a Revolution on an LED lamp.*

Figure 7. Data from a Revolution comparing THD of a regular incandescent 60 Watt bulb, a CFL and a LED type light.

Figure 7 shows a comparison of THD of a regular incandescent 60 Watt bulb, a CFL and a LED type light.

All PMI recorders with harmonic capability can record THD stripcharts, which gives a min, max, and average value for each interval period.

Figure 8 shows a mixed stripchart graph with voltage and current THD. The upper plot is channel 1 voltage THD, and the lower plot is channel 1 current THD. Looking at voltage and current THD together can help determine whether a monitored load is contributing to voltage THD, or just being affected by it. Figure 9 shows a Current THD Daily Profile. Like other daily profiles, the THD profile represents the average THD on a 15-minute basis throughout an "average" day, computed by averaging through the entire recording period. Here we see that the THD drops during the day, and rises during the night. This likely indicates more linear loads during the day, and as those turn off at night, the mix skews towards non-linear harmonic-producing loads. Unlike the THD stripcharts, THD Daily Profiles are always enabled in a recorder with harmonic capability, so they can be useful if THD becomes a question after a recording is complete.

CONCLUSION

THD, simply put, is the measurement of the amplitudes of the harmonics that a nonlinear system introduces relative to the amplitude of the fundamental frequency.

As new regulations are put into place to help conserve our natural resources by improving system efficiency, it is essential to have the proper monitoring systems in place to evaluate the power distribution system. Sometimes improvements in one area can cause problems in another area. Harmonics that are caused by nonlinear loads can cause issues such as transformer failures, excessive heating of motors, electronic device failures, and communication issues related to RFI and noise ingression into the communication system. With the right monitoring equipment and integrated software, and an understanding of power quality fundamentals, it is possible to continually and effectively assess overall system health and prevent potential system failure.

Cowles Andrus
Communications Specialist
Power Monitors Inc.
800.296.4120
candrus@powermonitors.com
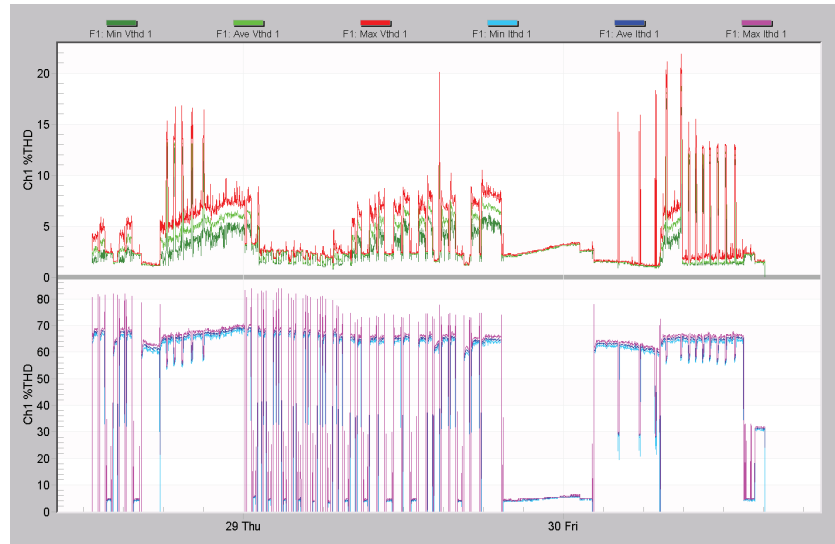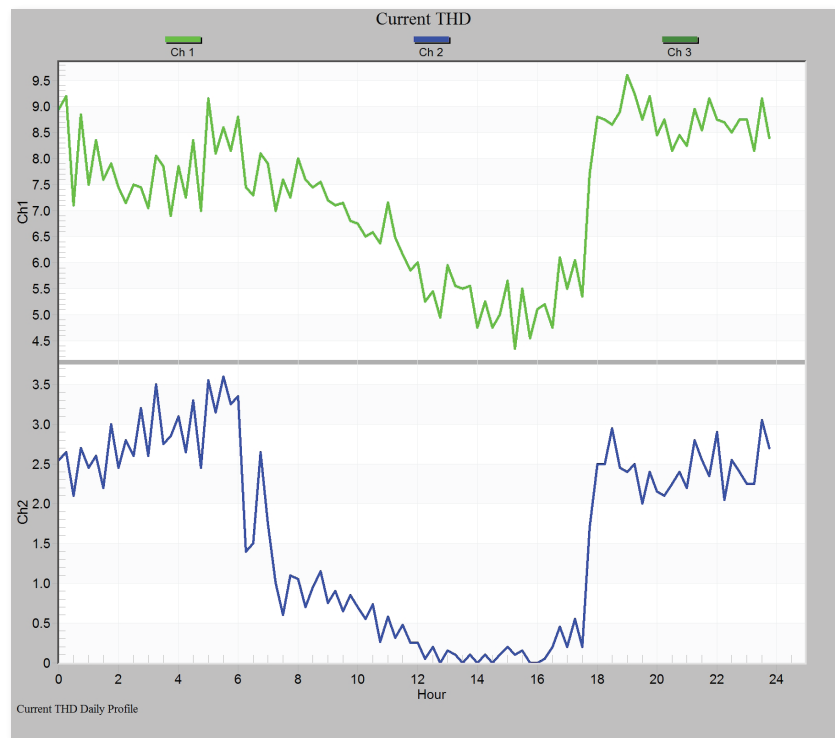http://www.powermonitors.com

Figure 8. Mixed stripchart graph with voltage and current THD

Figure 9. Current THD daily profile