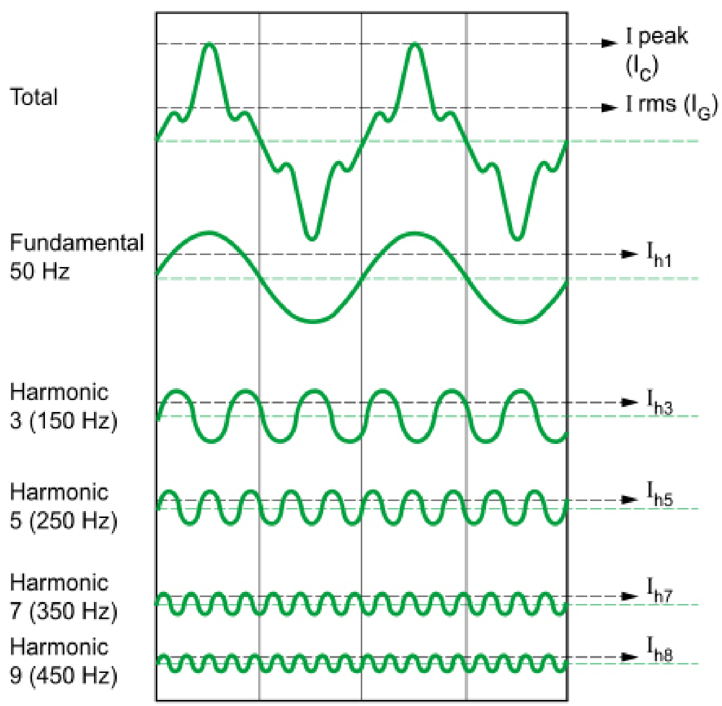
The sum of the harmonics vs Some of the harmonics

Harmonics in power systems are a growing problem that can have serious and costly consequences. A key step to controlling and mitigating this problem is to trace harmonics to their source. **Julian Grant of Chauvin Arnoux** explains how this can be done, after giving a brief overview of what harmonics are, how they are produced, and how they affect electrical installations and equipment.

Much has been written about harmonics in power systems, not least in earlier articles in this series. However, they are such an important issue that it's worth providing a brief refresher, especially as this will lay the foundations for the second part of the article which discusses how to trace the sources of harmonics.

Electricity supplies to consumers are, almost without exception, AC supplies with a nominally sinusoidal waveform of a fixed frequency. If you were to use an oscilloscope to look at the supply waveform, you would probably see that it really is quite close to being a sine wave; if no harmonics were present, it would be a perfect sine wave.

Often the supply waveform is somewhat distorted and it can be shown that any distorted waveform is made up of a large contribution at the supply frequency (50 Hz in the UK), plus smaller contributions at whole-number multiples of this frequency, as is shown in the example. The smaller contributions are the harmonics. For a 50 Hz supply, they occur at 100 Hz (second harmonic as its 2x the supply frequency), 150 Hz (third harmonic), 200 Hz (fourth harmonic), 250 Hz (fifth harmonic) and so on.



A distorted waveform is made up of multiple sine waves added together

There are two things you should note. The first is that, depending on the type of distortion in the supply waveform, not all of the harmonics may be present. It is perfectly possible to have the third and the ninth harmonic but not the second, fourth, fifth, sixth, seventh or eighth. The second thing is that in theory, the harmonics go on indefinitely. There could be a 1,000th harmonic at 50,000 Hz, for example, but in practice the magnitude of the harmonics falls off quickly with increasing frequency and in power systems, it's rarely worth considering harmonics above the 50th (2,500 Hz).

If harmonics are distortions in the supply waveform, what creates these distortions? The answer is non-linear loads. These are loads where the current drawn from the supply is not always proportional to the applied voltage. A good example is a load where the mains supply is rectified and applied to a capacitor. Loads of this type tend to draw a large spike of current for a relatively small part of the positive and negative cycles of the supply and virtually no current for the rest of the time.

Non-linear loads are becoming more and more common. Examples include PCs and other office equipment, power supplies, compact fluorescent and LED lighting systems, televisions and microwave ovens, and most significantly in industrial facilities, variable speed drives for motors. With so many of these loads connected to a typical electrical installation, it's little wonder that significant levels of harmonics are introduced. But why does that matter?

Harmonic currents have a range of negative effects. They cause sensitive electronic devices to malfunction, they increase heating – sometimes dramatically – and they produce mechanical stresses. They are common causes of computer crashes, flickering lights, IT equipment freezing up, electronic component failure and overheating in neutral conductors, transformers, motors and generators. This overheating can lead to failures that are not only costly to repair but also result in downtime that costs even more than the repairs. Also, high levels of harmonics in an installation can affect metering accuracy, so it's perfectly possible that they'll result in inflated energy bills.

Harmonics are bad news, but what can you do about them? The first step is to confirm the level of harmonics in your installation and this is most easily done either with a power quality analyser or with one of the more capable portable energy loggers (PELs) that are available. We've discussed these in detail in previous articles but they're basically all-in-one instruments that will measure, and crucially record, key electrical parameters for an installation. A good PEL should be compact and easy to install, as you'll probably want to use it in multiple locations, and if you're going to get the best value from it, it should also be versatile.

***Power** and **Energy Logger** with harmonic measurement capability*

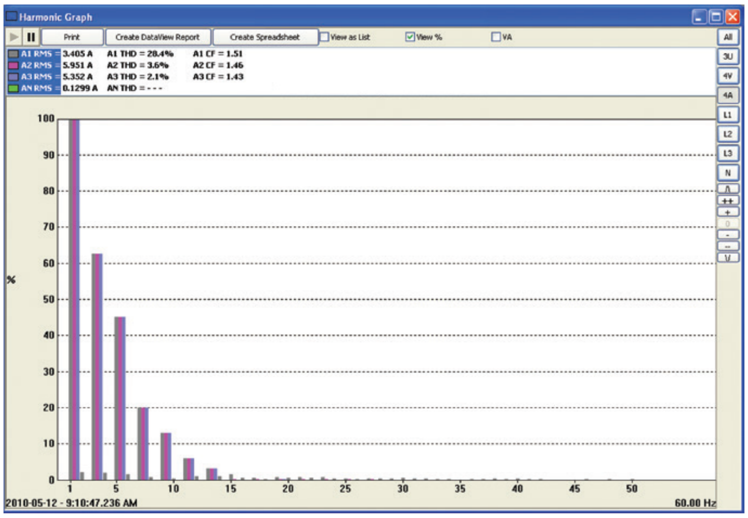
Crucially the PEL should measure and record harmonics. The recording function is important because harmonic problems may not be continuous – for example, they could be associated with a piece of equipment that only operates at certain times of day or even on certain days of the week. Recording over a period of time will quickly reveal this, whereas spot measurements may not.

Almost all PELs will let you measure total harmonic current distortion, which is calculated from the sum of the squares of the harmonic currents, using this formula:

$$THD = \frac{\sqrt{\left(I_2^{\ 2} + I_3^{\ 2} + \ldots + I_n^{\ 2}\right)}}{I_1}$$

In this formula, I1 is the current at the supply frequency, I2 is the current at twice the supply frequency, I3 is the current at three times the supply frequency, and so on. In practice you don't need to worry about the formula as the PEL will do the calculations for you. It is important to note, however, that the THD figure tells you the total level of current harmonics in your installation, which is useful and important to know, but it tells you nothing about the levels of the individual harmonics.

That's a serious shortcoming because knowing about the levels of individual harmonics can help you to find out which item of equipment is producing them. This is because different types of equipment produce different "mixes" of harmonics, as the table shows. For example, if the third and ninth harmonics predominate, with slightly less fifth and seventh, this indicates that the source is likely to be LED lighting, whereas if the 11th and 13th harmonics are dominant, the source is more likely to be a 12-pulse variable speed drive.



Harmonic data captured with PEL 103 Power and Energy Logger

Of course, things will not usually be as clear cut as this, because your supply system will be affected by current harmonics from multiple sources. In these cases, valuable clues can be obtained by looking at the recordings from the PEL and noting how the harmonic levels change over time. If there's a lot of third and ninth harmonic until the administrative section closes for the day, this is a good indication that the source is computers and office equipment. This can be verified by deliberately turning the suspect equipment on and off while monitoring how the harmonic levels change.

Load	Phases	3rd	5th	7th	9th	11th	15th
PC / Office Equipment	Single						
LED Lighting	Single						
Later CFL lamps	Single						
Mainframe Computer	Three						
3-Phase UPS	Three						
6 Pulse VFD	Three						
12 Pulse VFD	Three						

Some typical harmonic currents associated with modern equipment

Further valuable insights can be gained by moving the PEL around, installing it in different distribution boards and noting how this affects the levels of the individual harmonics recorded. The levels, particularly of the higher order harmonics, will usually be greater nearer their source.

With all of this in mind, it's clear that to get to grips with harmonics it's important to have a PEL that not only records the sum total of the harmonics, but also the levels of individual harmonics. But how far should you go? What is the highest order of harmonics you need to look at? Based on practical experience and some of the standards that are out there, the answer is that a PEL which records harmonics up to the 50th will ensure you cover all existing requirements.

Having located your harmonic sources, numerous measures are available to mitigate their effects. In most cases, these measures are relatively inexpensive to implement yet they can save you an awful lot of trouble – and money! Don't forget to use your PEL to confirm the effectiveness of the measures after you've put them in place, and periodically thereafter to make sure nothing has changed, especially if your business invests in new systems and equipment.

Harmonics can be a real nuisance, causing all sorts of problems for businesses of every kind. Fortunately, a good PEL, capable of measuring individual harmonics as well as total harmonic distortion, can help to locate harmonic sources. And, once you've found the source, you're in a position to put in place the measures needed to consign the problem to history!

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