Harmonics - Don't let them ambush your energy efficiency

Harmonics only create problems in big industrial installations, right? Wrong, says **Julian Grant** of **Chauvin Arnoux**, who explains how nowadays harmonics can, and are, causing problems and reducing electrical efficiency in most buildings and facilities.

High levels of harmonics in an electrical system can be responsible for flickering lights, IT equipment crashing unexpectedly, the nuisance tripping of circuit protective devices, motors to run noisily, and cables and transformers to run hotter than they should. Apart from the inconvenience, and potential costly early failure of equipment that these issues may cause, in almost every case they are also accompanied by a reduction in energy efficiency.

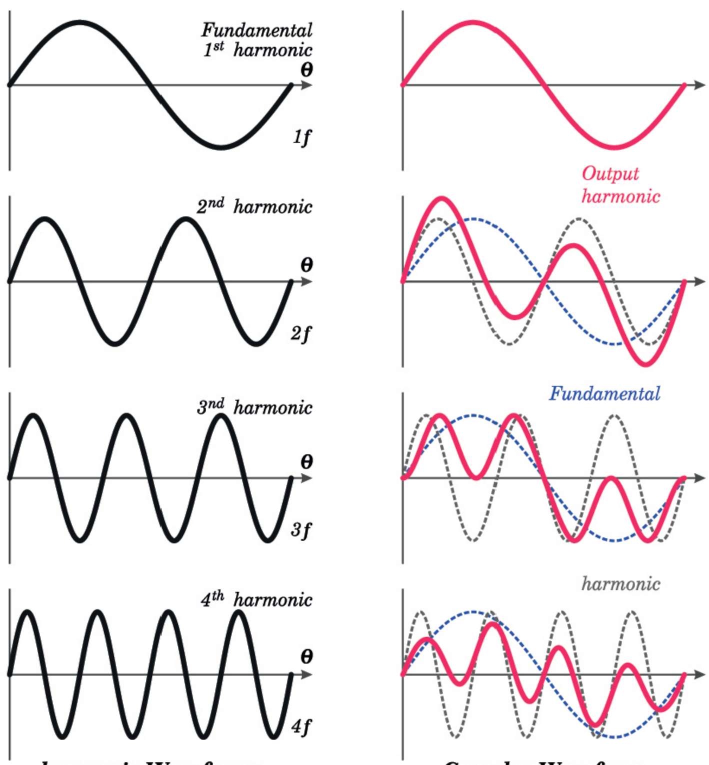
In the past, harmonics were usually an issue only for electrical installations in large factories, but now they're everywhere, and no business owner or facility manager can afford to ignore them.

But what are harmonics, where do they come from, why have they become such a problem, and what can be done about them?

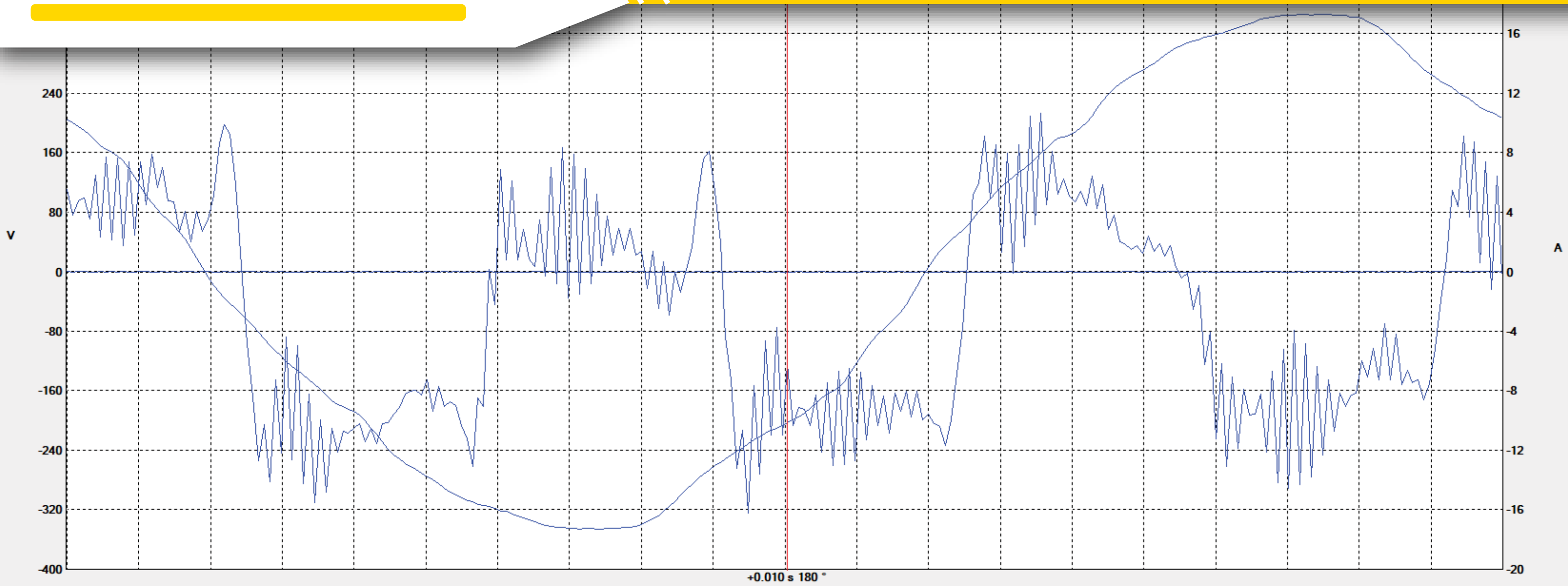
Ideally, the voltage and current waveforms in an installation would be perfectly sinusoidal, and this would not be too difficult to achieve if all the loads connected to the power system were linear – that is, the loads where the current drawn from the supply is always proportional to the applied voltage. Simple heaters and incandescent lamps are examples of linear loads, and until the last few decades of the 20th century, loads were predominantly of this type.

Within the last 30 years, however, there has been a big increase in the number of non-linear loads connected to the electrical network. These include computers and associated IT equipment, uninterruptable power supplies, variable speed motor drives, HVAC systems, electronic lighting ballasts and LED lighting, to name just a few.

Non-linear loads draw currents that are not necessarily sinusoidal. In fact, the current waveform can become quite complex, depending on the type of load and its interaction with other components in the installation. Non-linear loads produce distorted current waveforms in the supply system, and in severe cases this can result in noticeably distorted voltage waveforms.



harmonic Waveforms *Complex Waveform*



Example voltage and current waveforms produced by non-linear load

The distortion of the waveform produced by non-linear loads can be mathematically analysed to show that it is equivalent to adding components at integer multiples of the supply frequency to the 'pure' supply frequency waveform. That is, for a 50 Hz supply, the distortion takes the form of additional components at 100, 150, 200, 250, 300 Hz and so on.

These additional components are the harmonics, and in theory, they can go all the way up to infinity. In practice, however, it is rarely necessary to consider harmonics above say, the 50th, which has a frequency of 50 x 50 Hz = 2.5 kHz and, in most cases, only the lower order harmonics, up to the 25th, will be of importance. Unfortunately, unless they are prevented from doing so, harmonics from a non-linear load will propagate through the supply system causing problems elsewhere.

Knowing that a distorted current waveform can always be represented as a series of superimposed sine waves (using a mathematical procedure known as Fourier analysis) makes it possible to devise a measure of the amount of harmonic distortion present in the current in a supply system. This is known as the total harmonic current distortion or THDi, and is calculated with this formula, where 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.

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

Fortunately, it's unlikely that you will ever have to use this formula in practice, as modern instruments for analysing harmonics carry out all of the necessary calculations automatically and simply present you with the THDi figure.

While some of these effects, such as flickering lights and IT equipment crashes, could be dismissed as no more than irritants, others such as process equipment failures, can lead to costly downtime. Worst of all are failures of power factor capacitors and electrical distribution equipment like cables, transformers, motors and standby generators. Here the replacement equipment is likely to be expensive and may only be available on a long lead time. In these cases, both the repair costs and the consequential costs can be enormous.

Aside of these issues, a matter of increasing urgency based on both the need to achieve Net Zero, and the recent significant increase in wholesale gas and electricity prices, is that the presence of harmonics will also cause reduced electrical efficiency within the installation. This leads to excessive power consumption, an increase in CO2 emissions, and bigger electricity bills.

Harmonic currents cause heat generation in installation equipment and loads, and that unwanted heat represents wasted energy. Of particular concern are triplen harmonics which are odd integer multiples of the 3rd, i.e., the 9th, 15th, and so on. The triplen harmonics on each of the 3 supply phases are in phase with each other, so they add rather than cancel in the neutral conductor of a three -phase four-wire system.

This can overload the neutral conductor if it has not been sized to allow for the potential presence of harmonics, which is almost certainly the case in older installations. And even if it is properly sized – which means a larger and more costly conductor – that unwanted heat still represents wasted energy. Additionally, Eddy current heating in motors and transformers is proportional to the square of the harmonic frequency, so it follows that as the presence of higher order harmonics in the supply system increases, the heating effect will increase even more dramatically.

Apart from the losses that result from heating effects, harmonics in motors can give rise to the problematic phenomenon of torsional oscillation of the motor shaft. Torque in AC motors is produced by the interaction between the air gap magnetic field and induced currents in the rotor. When a motor is supplied non-sinusoidal voltages and currents, the air gap magnetic fields and the rotor currents will unavoidably contain harmonic frequency components. These are grouped into positive, negative and zero sequence components. Positive sequence harmonics (1, 4, 7, 10, 13, etc.) produce magnetic fields, and hence torque, rotating in the same direction as the field and torque produced by the fundamental frequency of the supply. Negative sequence harmonics (2, 5, 8, 11, 14, etc.) produce magnetic fields and torque that rotate in the opposite direction. Zero sequence harmonics (3, 9, 15, 21, etc.) do not develop torque, but produce additional losses in the machine.

+VE	1, 4, 7, 10, 13
- VE	2, 5, 8, 11, 14
Zero	3, 9, 15, 21

If you're still not totally convinced about the importance of harmonics, consider this: the current edition of the IET Wiring Regs mentions the word "harmonic" no fewer than 81 times. Regulation 132.2, for example, covers the number and type of circuits required and states that this shall be determined taking into account factors that include "any special conditions, such as harmonics". So even at the most basic stage of deciding on how many circuits are needed in an installation, harmonics must be considered.

Pertaining to Energy Efficiency, at the moment, the coverage of energy efficiency in the Regs is tucked away in Appendix 17, and this appendix is designated as 'informative' which means that observance of its contents is not compulsory. There are plans for a future amendment to the Regs which will include an expanded section on energy efficiency that could well involve compulsory requirements.

While Appendix 17 clearly makes a wide range of recommendations, there is one common theme that runs throughout and that is the importance of measuring and monitoring. In addition to recommending an accurate initial determination of the load profile, the appendix states that 'provision must be made to allow the measurement and recording of energy consumption throughout major parts of the installation...' and 'to achieve a design capable of delivering a high level of energy efficiency, all available energy consumption data must be taken into account.'

Overall, there's no doubt that Appendix 17 puts a lot of the responsibility for optimising energy efficiency in electrical installations in the hands of facility managers, contractors and electricians. There is also no doubt that this level of responsibility will further increase when the next amendment to the Wiring Regulations is issued.

Now is a great opportunity to prepare or this and get ahead of the game! Of course, getting to grips with new requirements may present a few challenges but, if it does, it's worth remembering that the experienced support team at Chauvin Arnoux is there for you, and is always ready to provide expert advice and guidance, much of which can be found on our website.

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