Third harmonic filters

Tuning in to better power quality

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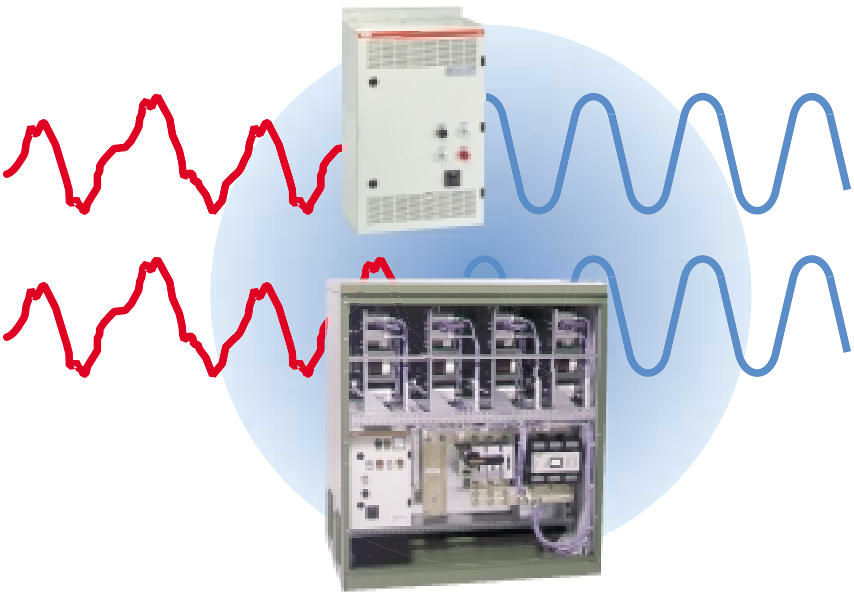
Your PC screen flickers, stops flickering, starts again... Irritating to be sure, and perhaps the first visible sign of a problem – higher-order harmonics – that is growing more common as industry and commerce add more power electronics equipment and computers, not to mention fluorescent lighting, to their electrical load inventory. At the same time, the proliferation of electronic equipment in the workplace puts a question mark against something commerce and industry have come to expect and demand – high power quality.

Single-phase power electronic devices, such as computers, printers, photocopiers, televisions, fax machines, uninterruptible power supplies and lighting, are the main sources of harmonic currents in neutral conductors. The harmonic currents load building wiring, add to the line losses, reduce circuit capacity and overstress the power factor correction capacitors. This is especially a problem in the neutral conductor, where the third harmonic currents – usually those with the highest magnitudes in the phases – cumulate. It is even possible that the third harmonic currents carried by the neutral conductor will exceed the current in the phase conductors.



Problems associated with the harmonic currents from single-phase electronic devices are most prominent in commerce and in the electronics industry, where there are high concentrations of such equipment. An additional problem is that the electrical systems in many older buildings were not designed to support today's all-electronics office.

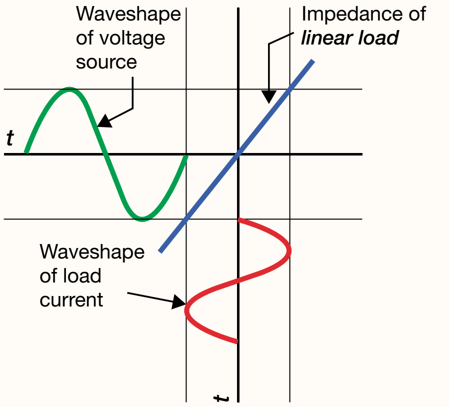
A particular problem for most electronic devices are the non-linear loads caused by the switch-mode power supplies of computers and other office equipment and by supplies with a bridge rectifier and smoothing capacitor.

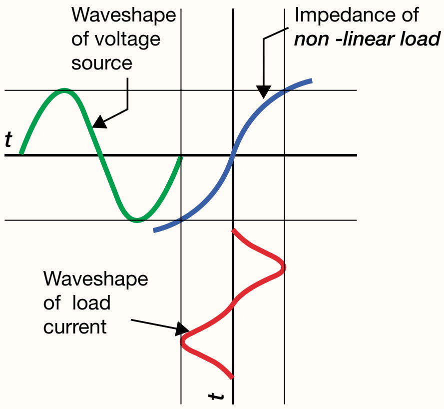
Is your network haunted?

The growing number of non-linear electrical loads being installed – fluorescent lighting, computers, uninterruptible power supplies, welding equipment, etc – are making their presence felt in more ways than one. This is because they generate harmonics, which can cause very significant, and often hard-to-trace, problems for other users hooked up to the same grid. But what are harmonics, where exactly do they come from, and how are they a problem?

What harmonics are is quickly explained: multiples of the sine waveform produced by the generator which appear in the electrical system. For example, in a network where the fundamental waveform is 50 Hz, the third harmonic is 150 Hz, the fifth harmonic 250 Hz, the seventh 350 Hz, and so on. Only odd-numbered harmonics are really important, although all harmonics affect current waveform.

The third harmonic (150 Hz) and the fifth harmonic (250 Hz) are the two that most often occur. Generally, single-phase loads generate the third harmonic, while three-phase loads are responsible for the fifth. (The fifth and seventh harmonics can be filtered out by so-called 'tuned circuits'; however, until now there has been no economic way to filter the third harmonic.)





The electrical load determines the current drawn from the system because the supply voltage is essentially constant. A linear load like a resistor has a constant impedance, and therefore the load current that it draws has the same waveshape as the voltage source and is nicely sinusoidal, providing the supply voltage is sinusoidal.

A non-linear load, on the other hand, changes its impedance, for example, when the amplitude of the voltage changes, and therefore draws a non-sinusoidal current and returns a distorted current waveform to the system. Typical non-linear loads are transformers operated near the saturation knee-point, and rectifiers.

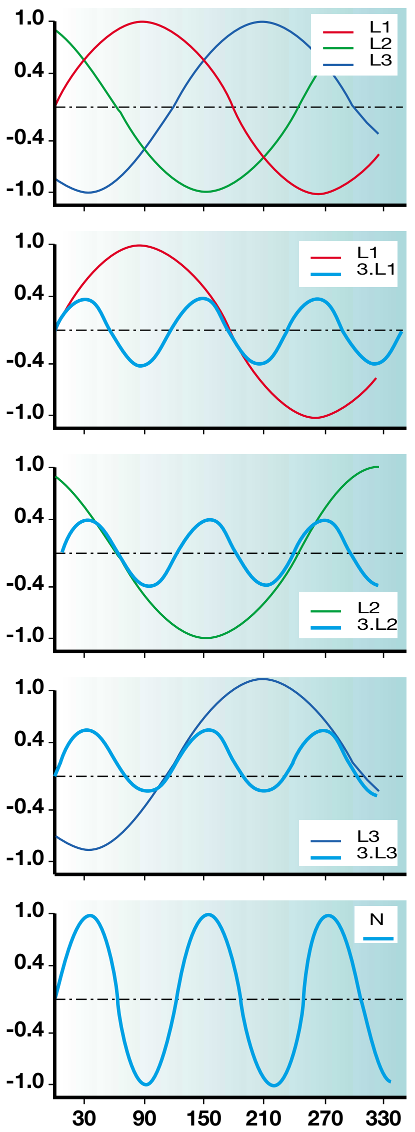
And the problem? Historically, three-phase four-wire distribution systems serving well-balanced, single-phase loads have had a common neutral conductor and this conductor would carry only a minimal current imbalance from the loads. However, in the presence of unbalanced single-phase, non-linear loads the common neutral may carry excessive current due to the third harmonic 'accumulating' in it.

Neutral conductor overload can, of course, be avoided by providing each individual phase with a separate, full-sized neutral conductor back to the panelboard, but this is an expensive solution.

In one real-life example, three 120-V PCs were connected to a three-phase 208/120-V system – one PC to each phase. Each PC consumed 1.2 A, but the neutral carried 2 A! Obviously, there is a risk of fire when very high currents are run through an inadequately rated neutral conductor as there is no fuse to protect it.

Third harmonic problems can be eliminated by installing a special filter, as discussed in this article. One ABB customer in Scandinavia who has recently installed such a filter now reports an annual saving of some $US 100,000 thanks to a reduction in power consumption and improved equipment performance. And the 'electrosmog' generated by the equipment has been radically reduced!

1 The third harmonic currents accumulate arithmetically in the neutral conductor. For example, a 20% third harmonic current in each phase (L1, L2, L3) adds up to 60% in the neutral (N).



During the mains cycle the switch-mode power supplies conduct for only part of the half-wave, so the smoothing capacitor receives a pulsed, non-sinusoidal AC current. Other producers of third harmonic current are discharge lamps, eg fluorescent lights and the new energy-saving lamps.

Third harmonic current dominates

In balanced three-phase systems the fundamental current and the 5th, 7th, etc, harmonics cancel each other out, whereas the single-phase third harmonic currents have the same phase angle and therefore cumulate in the neutral conductor.

Since single-phase electronic equipment draws high harmonic currents, it is possible for a system to be subjected to significant harmonics-related problems even when the load, in terms of real power, is relatively low.

The dominant third harmonic current can add as much as 1 A per kW for lighting appliances and 4 A per kW for computer loads, depending on the network loop impedance and the concentration of the load 1. The harmonics, which, ironically, are generated by the same sources that suffer most from their consequences, cause overheating, damage and power losses in apparatus. In addition, they generate electromagnetic fields and reduce the quality of the current, causing apparatus to malfunction.

The neutral currents that are generated are high enough to start fires. A recent case study revealed neutral currents as high as 1250 A, while the balanced phase currents were only 1000 A.

Heating due to harmonic currents may cause circuit-breakers and fuses to trip. Residual-current-operated circuit-breakers being electromechanical devices, the higher-frequency components might be summated incorrectly, causing the breakers to trip erroneously. When harmonic currents are present, a higher current will flow in the circuit than would otherwise be expected. If the electronic devices and equipment have only simple metering systems, this could also lead to wrong summation of the higher-frequency components.

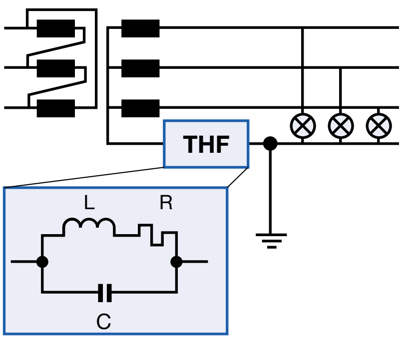
Third harmonic filters – the cost-effective way to remove 3rd harmonic currents

The third harmonic filter (THF) is a parallel resonant filter with a high impedance for the third harmonic current and a very low impedance for the fundamental frequency – so low that inserting the THF in the neutral conductor only slightly increases the operating time of the short-circuit protective devices and the loop impedance of the network. The series-connection of the THF in the neutral conductor has been patented by ABB Control in Finland.

The neutral conductor is the logical and most effective place to install the THF as it is here that the third harmonic phase currents add up arithmetically. Being a passive element, its noise level is very low and, as a blocking-type rather than zero-impedance-type filter, it has no adverse effect on digital signals and causes no instability or resonance in the network. A built-in damping coil ensures that the filter elements can withstand voltage peaks 2.

The filter is installed in the neutral conductor or at the transformer star point adjacent to the switchpanel in the TN-S

2 The neutral conductor is an ideal place to install the third harmonic filter (THF). Being a passive element, the noise level is very low, and it does not cause any resonance in the network. Thanks to a built-in damping coil, the filter components can withstand voltage peaks.



system 3. The THF is equipped with protection that guards it against the 50-Hz fundamental unbalance current and 150-Hz overcurrent.

Neutral and emission currents are effectively reduced

In addition to typically removing about 95% of the third harmonics in the neutral conductor, the THF also removes the 150-Hz current in the phase conductors. A major challenge in the future will be to keep emission levels low at the point of common coupling (PCC); standards such as G5/3 in the UK and the Contrad Emeraude in France have already set the limit for emission current at 34 A and 4%, respectively, while IEEE 519 recommends 5% for major users in the network. The THF can reduce emission levels from consumers' PCCs to the public network whilst reducing voltage distortion on the supply side 4.

Increased network capacity and reduced line losses

The third harmonic current in the LV network forms a loop that extends from the single-phase devices through the line conductors and distribution panels to the transformer star point and neutral conductor, where it is induced into the MV delta winding. In the balanced state, the third harmonic current does not propagate to the MV network but circulates in the delta winding, where it increases the resistive losses and operating temperature whilst reducing the effective load capacity. Harmonic currents, being of higher frequency, also lead to increased magnetic losses in the core and increased eddy current and skin effect losses in the windings.

Problems caused by third harmonics

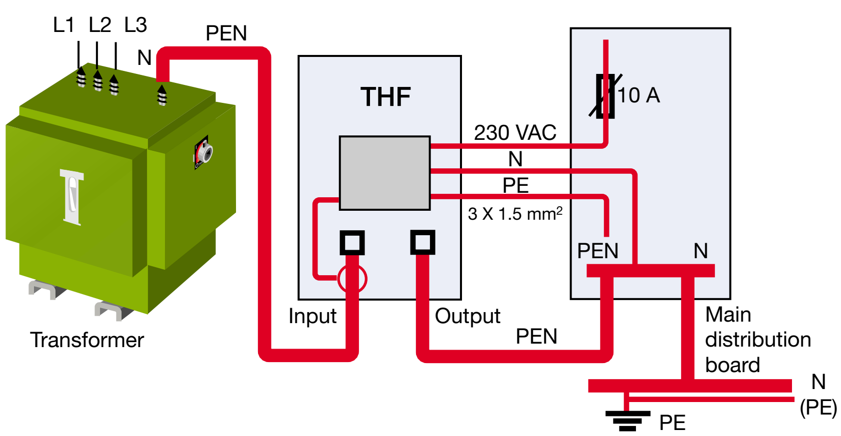
- Currents within the installation
- Overloading of neutrals
- Overheating of transformers
- Spurious tripping of circuit-breakers
- Overstressing of power factor correction capacitors
- Skin effect
- Overheating of induction motors
- Currents in the point of common coupling
- Magnetic fields
- Flickering screens

Energy-saving

Reducing the third harmonic component not only increases the lifetime of the network components but also lowers the power losses by reducing the power component. The THF itself consumes only little power (the power loss per unit is 40 W).

In addition to the lower risk of fire due to conductor overload, users save by reducing the significant building wiring losses attributable to high harmonic currents. In known cases of

3 Connection of the third harmonic filter (with protection unit) to the transformer star point



4 ABB's third harmonic filter family, rated from 25 A to 3000 A, for indoor and outdoor use

concentrations of third harmonic loads, power savings of between 4 and 5% have been measured, allowing the cost of the THF to be repaid within 3 to 10 years, depending on the electrical characteristics and the actual loading of the networks.

Magnetic fields

Unlike the 5th and 7th harmonics, which cancel each other out, the current caused by the third harmonics produces a magnetic field around the single-phase and neutral conductors. The THF mitigates the single-phase currents in the phase, neutral and TN-C system earth wiring. By reducing the third harmonic component, the overall magnetic field in a typical office or hospital building is reduced by about 50% 5.

Specifying the filter

The THF is dimensioned according to the supply-side power transformer or fuse, the principle being that it has to withstand, under all circumstances, the dynamic and thermal stresses at the transformer star point or in the neutral conductor regardless of the actual magnitude of the apparent, reactive or distortion load. This will ensure that the system remains stable when the load varies.

Third harmonics and the law

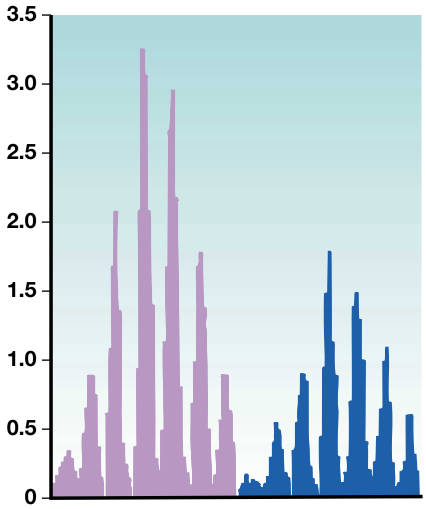
By now, everyone is familiar with the 'CE' stickers on electronic products. This symbol means the device has passed a test: it has been exposed to incoming electromagnetic radiation sweeping through a wide frequency range and has been 'listened to' to see what frequencies it emits during operation.

This is an Electromagnetic Compatibility (EMC) test and there are various standards which tell the testers within which limits the device should operate. Only when it complies may it display the "CE" badge.

'IEC 1000 part 3, paragraph 2' (IEC 1000-3-2) is the standard setting the limits on the harmonics a device may generate. Since January 2001, all devices using less than 16 A must comply – or they may not be sold in the EU! Standards for devices consuming higher currents are in preparation. The 'IEEE 519 Harmonic Guidelines' are similar and are observed by many countries outside the EU.

In spite of these standards, there are many millions of harmonics-generating devices which will remain in use for decades to come. As the electrical 'cleanliness' of the power grid becomes ever more an issue and good power quality becomes a selling point, the filters described in this article will become increasingly important as a means of combating these noisier devices.

5 Plot of magnetic field measurements in various locations in a large hospital. A reduction of 50% was achieved with the third harmonic filter (blue plot).



6 ABB third harmonic filters are installed in one of the world's most prestigious new hotel buildings: the Burj Al Arab-Hotel in Dubai. The THF units contributed to a reduction in conductor temperature, which allowed busbar risers with smaller dimensions to be used.

Reference installations around the world

Since 1994, THFs installed around the world – in office buildings, computer rooms, broadcasting companies, process industries, hotels 6, or for large lighting and greenhouse objects - have shown that they effectively reduce the neutral current by 95% for a typical power saving of 4%. By improving the network conditions, their first-time costs are typically paid back in 3 to 10 years.

For more information visit http://www.abb.com/lvswitches. A CD-ROM is also available to help with selection for various applications.

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