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Technical article

AFQevo

Multifunction Active Filter

Harmonics: Today's problems and its solution



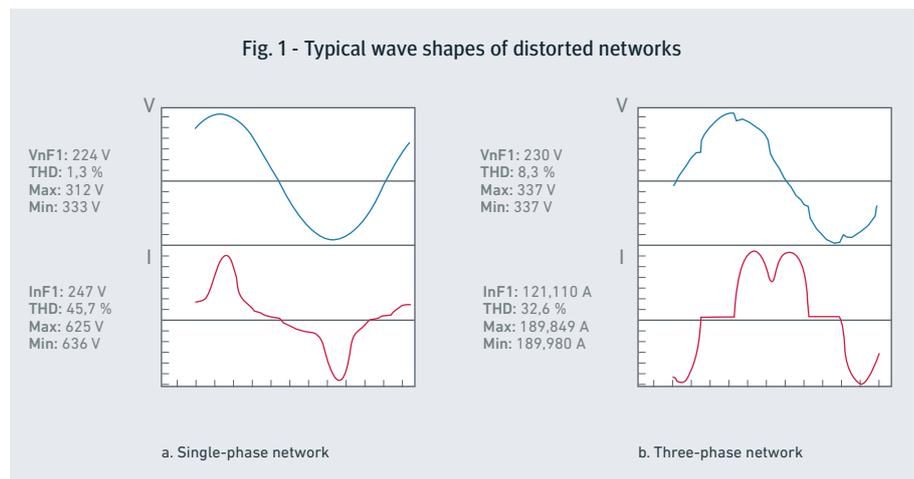
Introduction

Domestic and industrial loads contain increasing numbers of electronic circuits that are supplied with currents that are not purely sinusoidal. For example, engines increasingly use frequency regulation, which requires converting alternating current (AC) to direct current (DC) and then DC back to AC. Given that the supply is normally in AC, this requires increasing use of electronic power converters (rectifiers, inverters, etc.) for these DC-AC and AC-DC transformations. The same thing happens with common loads like computers, LED and discharge lighting, lifts, etc.

This means that the electrical network must supply a large number of charges that rectify the current, distorting the wave shape of the current being consumed so that it is not a purely sinusoidal wave but rather a superposition of sinusoidal waves with frequencies that are multiples of the network frequency (harmonics). Figures 1 and 2 show the typical consumptions of one network with single-phase rectifiers and one with three-phase rectifiers. This type of current is most abundant

in installations like offices, shopping centres, hospitals, etc., and it is formed by a 50 or 60 Hz component (network fundamental frequency) and a set of different percentages of components with multiple frequencies. These percentages may be measured using a harmonics analyzer, which can also measure the total distortion rate, or THD, which gives the ratio between the effective value of the ripple and the effective value of the fundamental component.

Fig. 1 - Typical wave shapes of distorted networks



The result of non-sinusoidal consumption is that the voltage also suffers some distortion due to the voltage drops in the impedances of lines and transformers. In the logs we can note a slight voltage distortion in the single-phase network (low THD) and a stronger distortion in the three-phase example. In both cases the current shape differs greatly from the sinusoidal current, and the THD values are higher.



To regulate this issue and limit the voltage distortion levels at connection points to public networks, there are international standards that establish harmonic emission limits for units and systems connected to the network (Table 1). The most significant are those associated with compatibility levels:

Table 1 - International standards on harmonic emission limits

| Standard | Description |
|----------------|---|
| IEC-61000-2-2 | Electromagnetic compatibility (CEM). Section 2-2: Environment. Compatibility levels for low-frequency conducted disturbances and signalling in low voltage public supply networks. |
| IEC-61000-2-4 | Electromagnetic compatibility (CEM). Section 2-4: Environment. Compatibility levels for low-frequency conducted disturbances in industrial installations. |
| IEC-61000-3-2 | Electromagnetic compatibility (CEM). Part 3-2: Limits. Limits for harmonic current emissions (units with input current ≤ 16 A per phase) |
| IEC-61000-3-4 | Electromagnetic compatibility (CEM). Part 3-4: Limits. Limits of harmonic current emissions in low voltage networks for units with rated currents exceeding 16 A. |
| IEC-61000-3-12 | Electromagnetic compatibility (CEM). Part 3-12: Limits of harmonic currents produced by units connected to public low voltage networks with input current > 16 A and ≤ 75 A per phase. |
| IEEE-519-2014 | IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems |

Some key concepts regarding harmonics

We can better understand harmonics problems by looking at some basic concepts which have been published in several articles and books, and which are summarised below:

- › The origin of harmonics problems are receivers that consume distorted currents (called "non-linear" receivers).
- › The problem spreading to other users connected to the same network depends on the impedance of the network, which depends on the distribution company. This impedance is not usually direct, but can be calculated from the short-circuit power available (the more short-circuit power, the less impedance).
- › Users have a section of the distribution lines before they reach the final load. Thus, the problems that may arise at the mains connection of their installation may be attributed to a lack of short-circuit power, but in many cases, the problems that may arise at points farther down the line from the mains connection are often due to impedances in the installation itself.
- › Furthermore, in terms of distortions farther down the line from the mains connection, we must remember that line impedance has a very significant inductive component. Therefore, many times it is not a question of using distribution cables with larger cross-sections, but of limiting inductance per metre of cables. This is achieved by braiding and twisting the distribution cables (often rejected by installations due to aesthetics).
- › The problem of voltage distortion at the PCC point can be aggravated due to resonances between the power factor compensation capacitors and the inductance of the distribution lines (transformers and lines).
- › Corrective measures (filters) must be installed as close as possible to the loads that are generating harmonics.

In short, the solution to the harmonics problem is two-pronged: On the one hand, users must limit the number of harmonic currents generated by their receivers and must try to distribute electricity in their plants with low impedance per metre of cable. On the other hand, the distribution company must ensure minimal short-circuit power and must ensure that users do not exceed certain distortion limits, so as not to cause harm to their neighbours sharing the network.

When the harmonic levels generated by receivers are not permitted for the distribution system supplying them, corrective filters must be installed. In this article we are going to focus on explaining the concept of filtering.

Compatibility limits due to harmonics

The presence of harmonics in a network has several consequences. The most significant are described below.

- › Deterioration of the voltage wave quality, affecting sensitive receivers.
- › Overloading and possible parallel resonance between the line inductance and the power factor (PF) compensation capacitors.
- › Worsening of the power factor. The network power supply capacity is therefore diminished, due to being oversized.
- › Overloading of cables and especially transformers (very sharp increases in iron losses).
- › Problems of unwanted tripping of protection devices.

To avoid these issues, there are standards that establish a minimum power quality which limits the maximum distortion levels for the voltage wave supplied at the connection point to the public network (PCC). These limits are called compatibility limits. Table 1 presents a summary of these limits for harmonics in industrial LV networks. The different classes mentioned in this table correspond to:

- › Class 1: Industrial environment intended for power supply to sensitive electronic units
- › Class 2: Normal industrial environment. Usual limits for public networks
- › Class 3: Deteriorated industrial environment (generally due to the presence of transducers). Not suitable for power supply to sensitive units.

Table 2 - Compatibility limits: Voltage harmonics (U_n %) in industrial LV networks (IEC-61000-2-4)

| Harmonic order h | Class 1 U_n % | Class 2 U_n % | Class 3 U_n % |
|-------------------------|-----------------|-----------------|-------------------|
| 2 | 2 | 2 | 3 |
| 3 | 3 | 5 | 6 |
| 4 | 1 | 1 | 1,5 |
| 5 | 3 | 6 | 8 |
| 6 | 0,5 | 0,5 | 1 |
| 7 | 3 | 5 | 7 |
| 8 | 0,5 | 0,5 | 1 |
| 9 | 1,5 | 1,5 | 2,5 |
| 10 | 0,5 | 0,5 | 1 |
| >10 mult. of 2 | 0,2 | 0,2 | 1 |
| 11 | 3 | 3,5 | 5 |
| 13 | 3 | 3 | 4,5 |
| 15 | 0,3 | 0,3 | 2 |
| 17 | 2 | 2 | 4 |
| 19 | 1,5 | 1,5 | 4 |
| 21 | 0,2 | 0,2 | 1,75 |
| >21 mult. of 3 | 0,2 | 0,2 | 1 |
| 23 | 1,5 | 1,5 | 3,5 |
| 25 | 1,5 | 1,5 | 3,5 |
| >25 not mult. of 2 or 3 | 0,2+12,5/h | 0,2+12,5/h | 5 x $\sqrt{11/h}$ |
| THD (V) | 5% | 8% | 10% |



Voltage harmonics are due to the voltage drop produced by current harmonics on distribution line impedances. This is illustrated in Fig. 2. So, reaching these limits depends on two factors:

1. Emission level of the receivers: The more emissions, the more distortion caused by the voltage drop produced by harmonic currents in the network
2. Network impedance: The more impedance, the larger voltage drop for the same emission value of the receivers

Table 3 gives the emission limits for low voltage networks established by the **EN-IEC-61000-3-4** standard for mains connection at which the installed power in the disturbing elements does not exceed $(33 \times S_{cc})$, where S_{cc} is the short-circuit power corresponding to the mains connection (Proportional share of the total short-circuit power of the contracted power).

Table 3 - Emission limits for $S_{unit} < 33 \times S_{cc}$ (**EN-IEC-61000-3-4**)

| Harmonic h | Withstand current $I_n / I_{1\%}$ | Harmonic h | Withstand current $I_n / I_{1\%}$ |
|------------|-----------------------------------|------------|-----------------------------------|
| 3 | 21,6 | 21 | $\leq 0,6$ |
| 5 | 10,7 | 23 | 0,9 |
| 7 | 7,2 | 25 | 0,8 |
| 9 | 3,8 | 27 | $\leq 0,6$ |
| 11 | 3,1 | 29 | 0,7 |
| 13 | 2 | 31 | 0,7 |
| 15 | 0,7 | ≥ 33 | $\leq 0,6$ |
| 17 | 1,2 | | |
| 19 | 1,1 | Evens | $\leq 8/n$ or 0,6 |

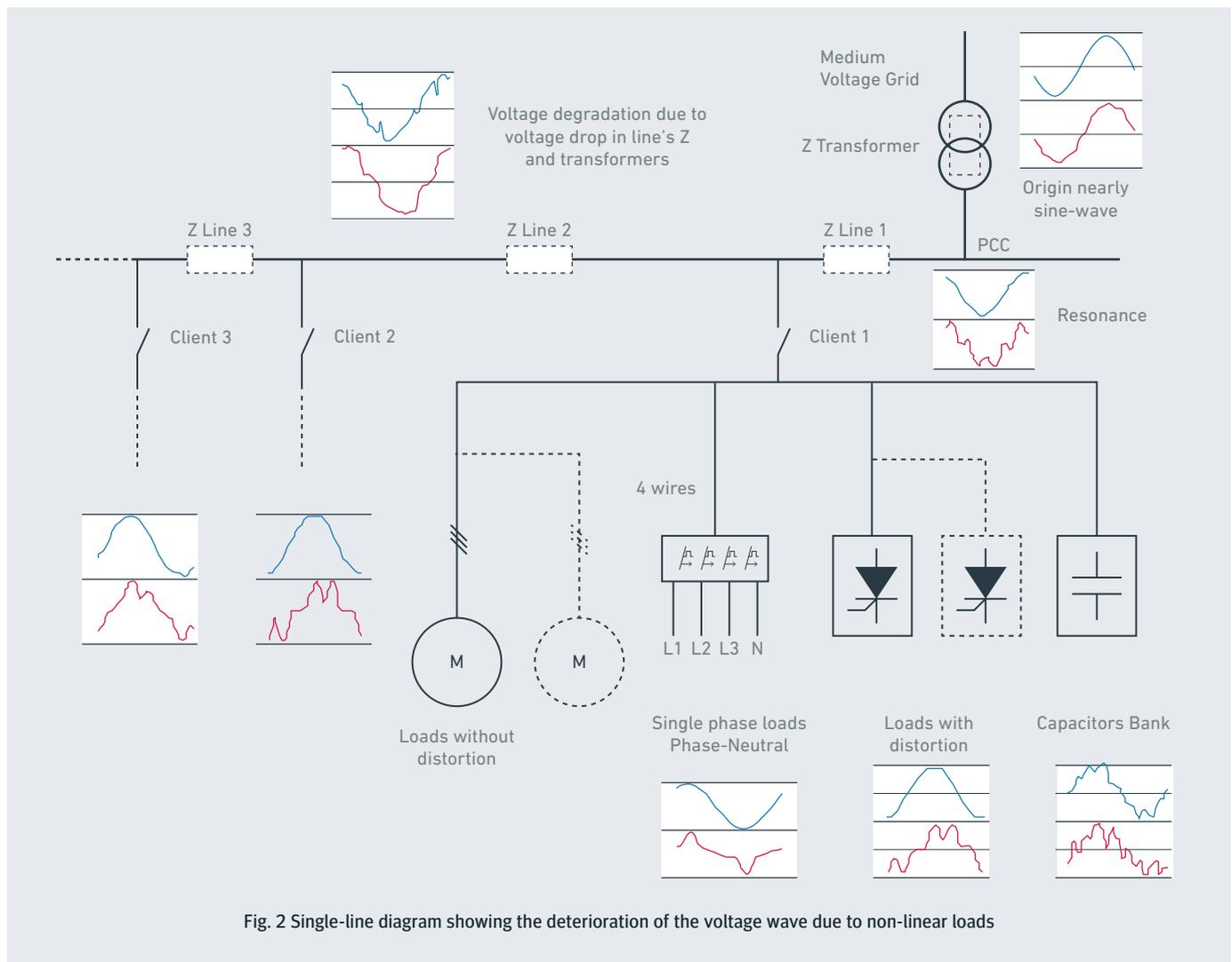


Fig. 2 Single-line diagram showing the deterioration of the voltage wave due to non-linear loads

Which installations need active filters?

Some of the disturbances mentioned above can be mitigated and corrected through filters. Active filters are the perfect solution for installations with a large number of single-phase and three-phase loads that generate harmonics and that have different consumption regimens.

Active filters are units based on transducers that modulate the PWM pulse width. There are two kinds: Serial filters and parallel filters. Parallel filters are often used to comply with the **IEC-61000-3.4** and **IEEE-519** standards, as they are based on using an inverter to inject the harmonics consumed by the load into the network in anti-phase. Fig. 3 illustrates this operating principle, showing the load, filter and network currents. We can see that the sum of $I_{LOAD} + I_{FILTER}$ gives us a sinusoidal $I_{NETWORK}$ current. Fig. 4 shows a parallel active filter and its schematic diagram.

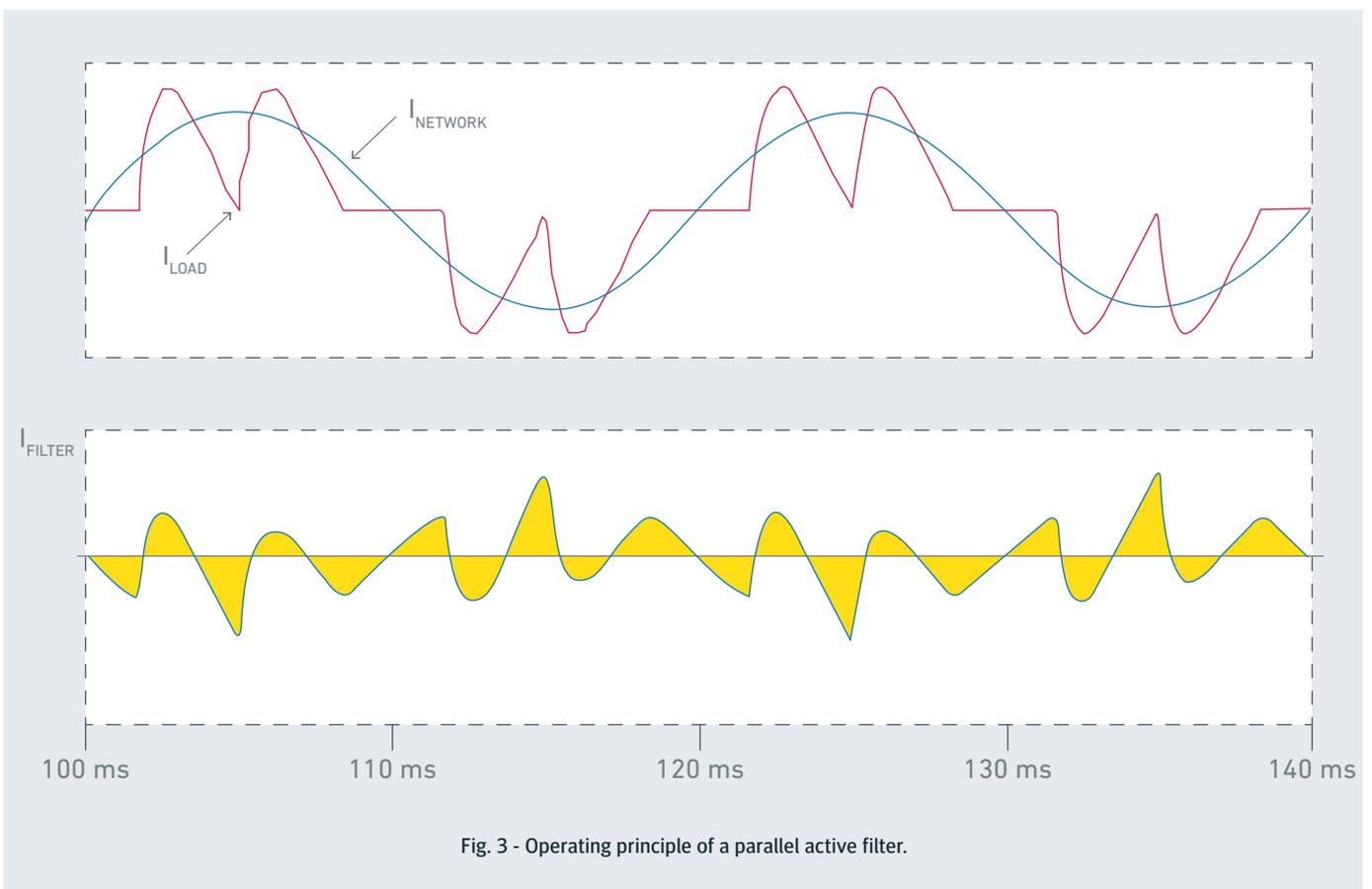
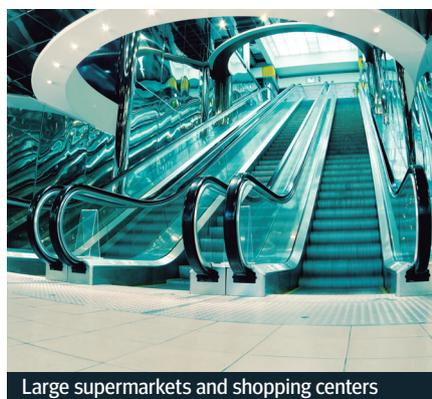


Fig. 3 - Operating principle of a parallel active filter.

The solution

Filtering units have been adding complementary functions to adapt to changes in installations, whether they be expansions or changes to the machinery. This may require more filtering of specific harmonics or phase balancing. It can also be useful to have power factor correction in these units.

As a solution to the mentioned problems, circutor has developed the new afqevo active filter. Its new design offers advantages such as:

- › Filtering capacity for 30 A currents per phase and 90 A of neutral.
- › If more filtering capabilities are required, the system can be extended with up to 100 AFQevo active filters connected in parallel.
- › Reduced metallic enclosure for wall assembly. Its compact dimensions make it easy to install.

- › Communications for better electric energy management of the installation.
- › Voltage and frequency multi-range (50/60 Hz).
- › Reduction of harmonic currents up to the 50th harmonic (2500 Hz).
- › Selectable filtering of harmonic frequencies to achieve higher filtering efficacy.
- › Power factor correction (inductive/capacitive).
- › Phase current balancing. In the 4W model, it helps to reduce consumption in neutral.

Easy interaction With touch screen

They help a better Energy management

The importance of a good installation

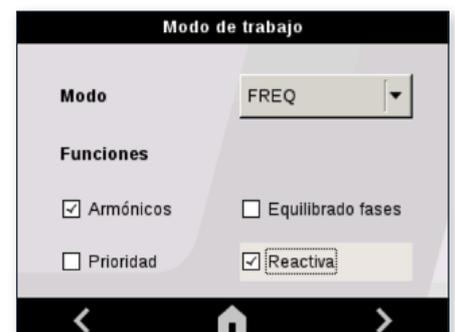
To get the best results, it is useful to have filters like **AFQevo** that are easy to install and manage. Start-up is made easier with the following functions:

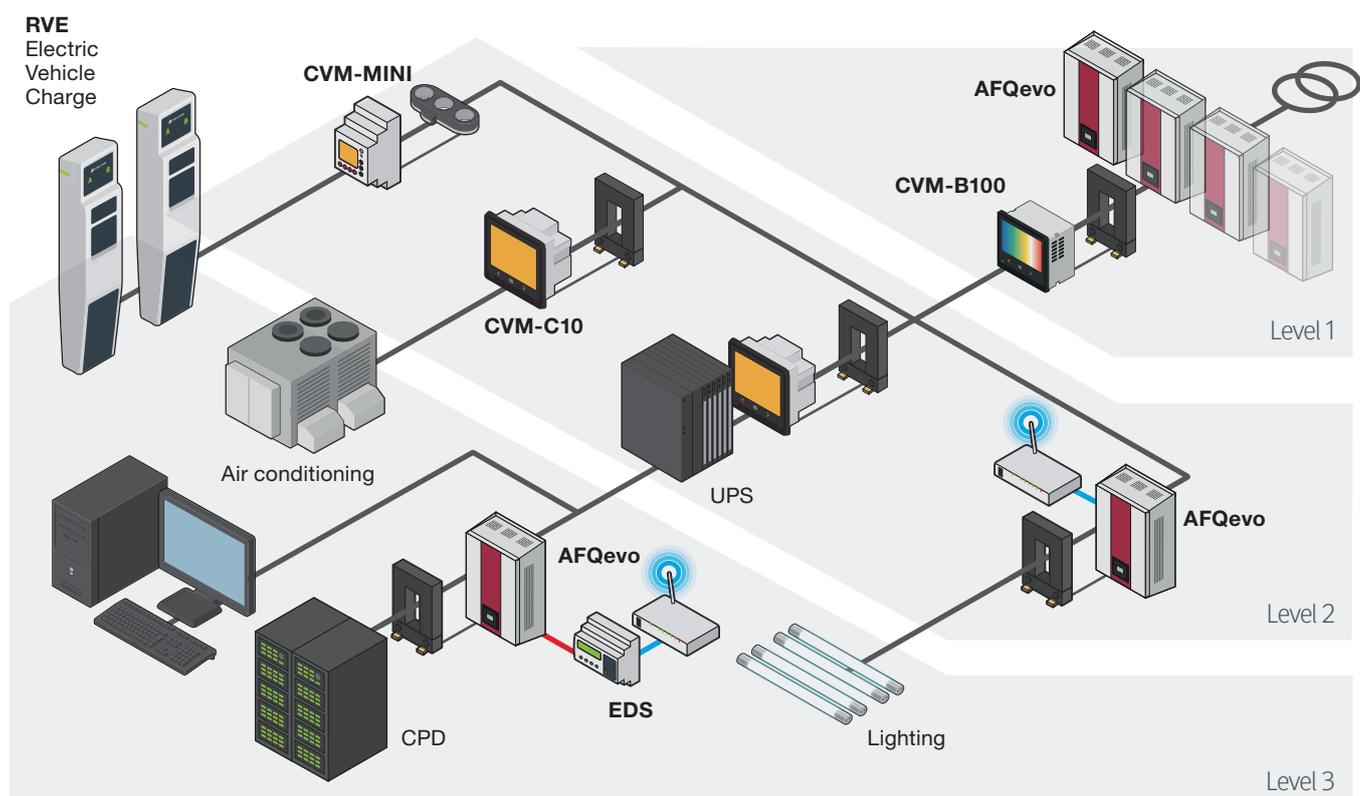
- › 3-step start-up: Connect, Set up and Start
- › Touch screen display for quick management
- › Alarms such as configuration error, polarity, temperatures, resonance, voltages, overload, contactors, DC bus, etc.



Multipurpose: Various configurations and priorities

AFQevo active filters are Very versatile because they allow Different configurations and modes Of operation. Everything for To use them in installations Of different types and in the most Different situations.





Application type with Active Filters Multifunction AFQevo in header and next to the load.

Conclusions.

The presence of harmonics in distribution lines is increasing, causing a set of problems related to deteriorating voltage wave quality. This forces oversized installations, causing significant additional losses. Despite existing standards that limit the consumption of these harmonics, it is useful to filter them as it lets you optimise cable sections and powers to MV substations, reduce losses in installations and avoid production losses.

The solution to the problem is a rational and comprehensive design of harmonic filters (see related article about sizing the right active filter), like active filters, which helps solve the problem with affordable costs easily offset by savings in losses, improves the life of some of the components in installations and optimises their distribution infrastructure (cable conduits, transformers, etc.).

