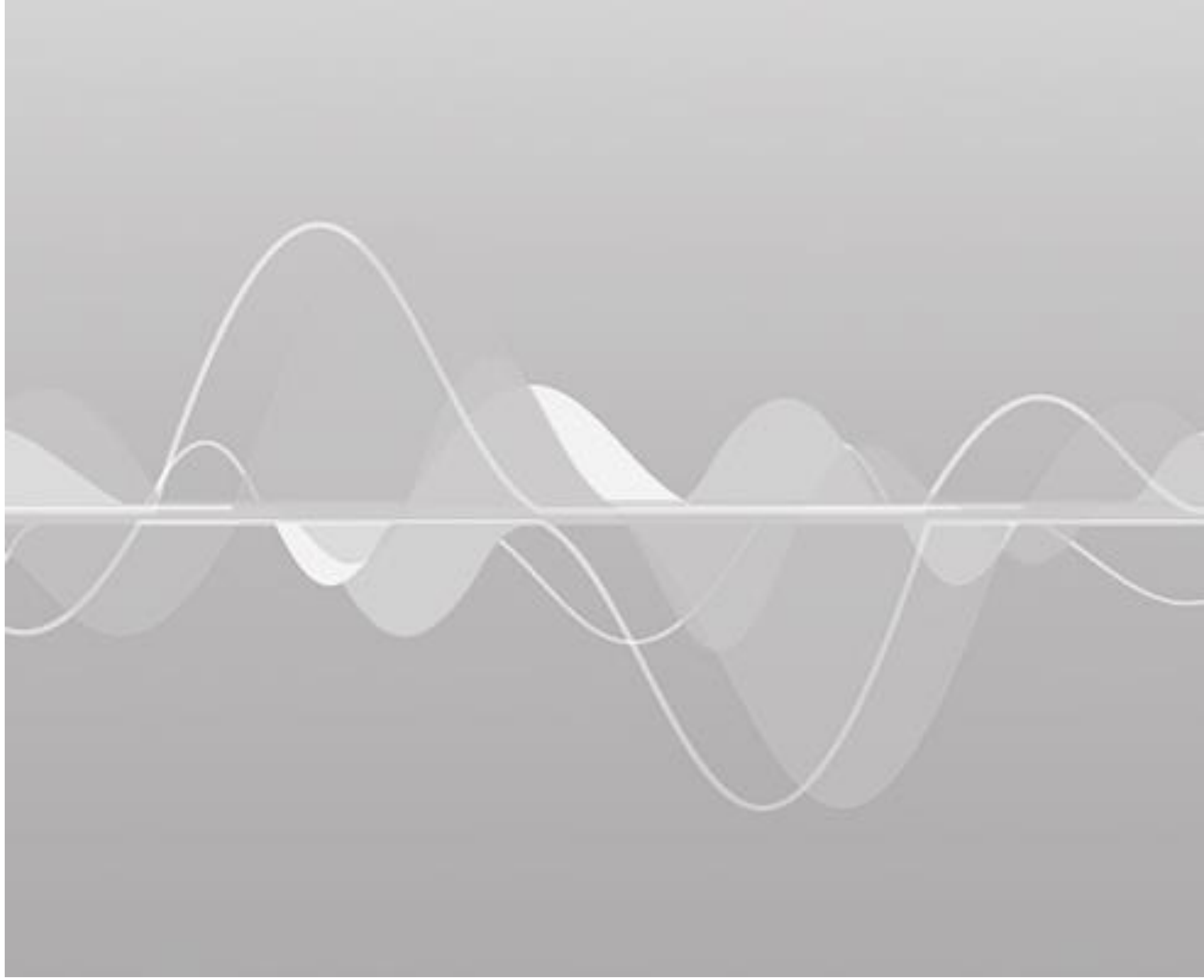
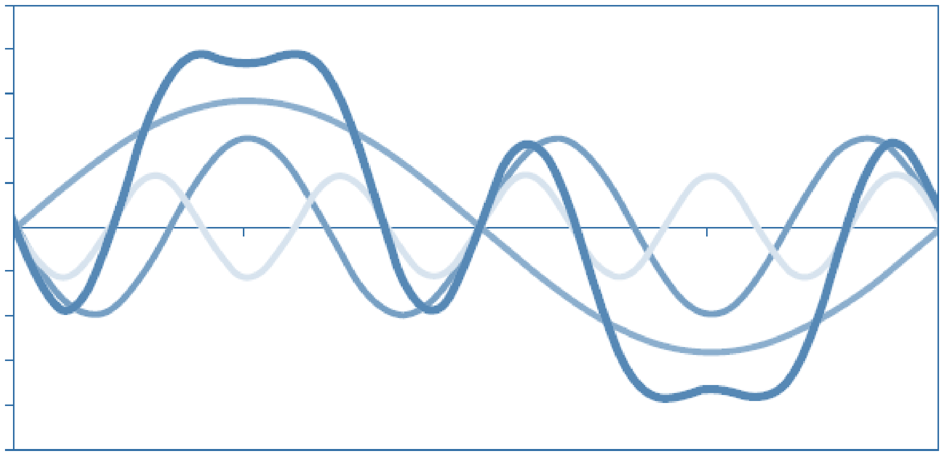
Save Your **Energy.**

Harmonics and Active Filters



Introduction

Electrical systems have a large number of **non-linear loads** that generate, starting from the **sinusoidal waveforms** and with the frequency of the network, other waves of different frequencies, which in turn cause the phenomenon known as **harmonics**.
Harmonics generates problems for both users and the power supplier and cause various harmful effects on network equipment. Let's see in detail what problems and what damage they cause.



Caption:
- nonsinusoidal waveform
- first harmonic (fundamental)
- third harmonic
- fifth harmonic

The **total harmonic distortion** (**THD**) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

Harmonics: what are they?

Harmonics represent a type of disturbance found in electrical systems.

Definition of Harmonic (EN61642):
«One of the components obtained from the composition in the Fourier series of a periodic wave of voltage or current».

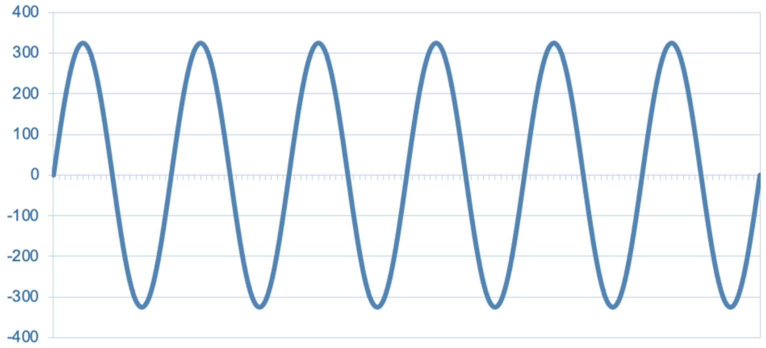
Harmonics are produced by the operation of electrical equipment - both generators and users - and their presence can cause malfunctions and breakages on electrical devices connected to the system.



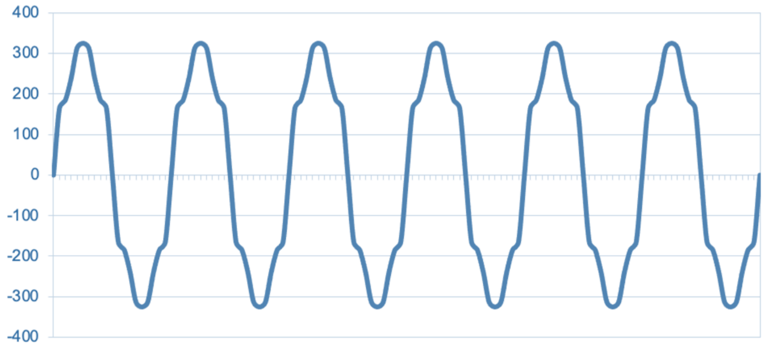

Waveforms of Voltage and Current

Harmonics represent a type of disturbance found in electrical systems.
The ideal voltage has a regular waveform, called a sinusoidal.

If the load is **linear**, the waveform of the absorbed current is also sinusoidal.

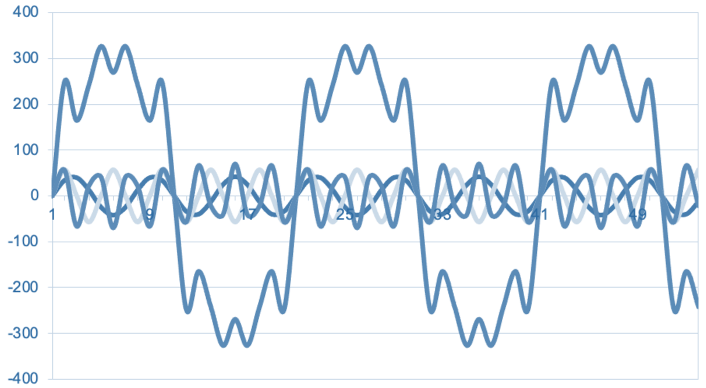


If the load is **non-linear**, the waveform of the absorbed current is also non-sinusoidal.



Fourier series

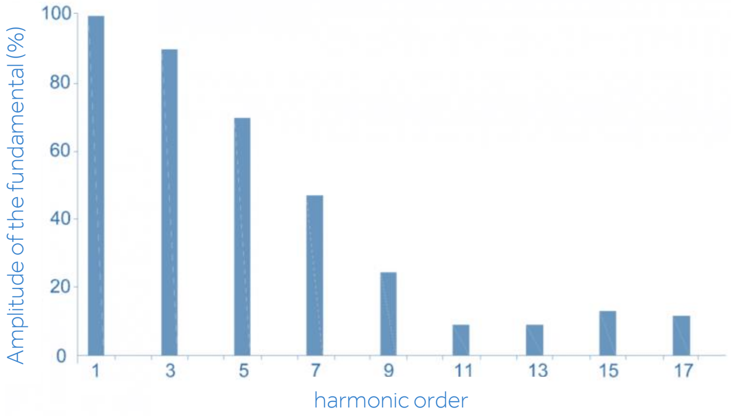
Allows you to consider the non-sine wave as the sum of sine waves. Each sine wave, adding the summation of waves, is called a harmonic.



Each harmonic component is characterized by an amplitude and a natural frequency (order):

- Harmonic order 1 (fundamental frequency f1), amplitude I1
- Harmonic order 5, frequency 5 * f1, amplitude I5
- Harmonic order 7, frequency 7 * f1, amplitude I7
- Harmonic order 11, frequency 11 * f1, amplitude I11

The harmonic content can be represented graphically with a bar diagram, called the «**harmonic spectrum**», which shows the amplitude of each individual harmonic component.



Definitions

Each harmonic contributes to the definition of the overall amplitude (rms value):

$$IRMS = \sqrt{I1^2 + I2^2 + I3^2 + I4^2 + I5^2 + \cdots \ldots ..}$$

The overall presence of harmonics is measured with the THD rate:

$$THDI = \frac{\sqrt{I2^2 + I3^2 + I4^2 + I5^2 + \cdots \ldots ..}}{I1} \times 100$$

And also thorugh the TDD (Total Demand Distorsion) rate:

$$TDD = \frac{\sqrt{I2^2 + I3^2 + I4^2 + I5^2 + \cdots \ldots ..}}{ILmax} \times 100$$

Harmonics: what do they cause?

The following are the main consequences of harmonics:

- Overheating and vibrations with premature aging of all parts, with short and medium term effects on life expectancy
- Faults on power electronics equipment (e.g. VFD)
- Electric motor overloads
- Damage to printed circuit board components
- Premature aging capacitors and damage due to resonance
- Overload of the neutral wire
- Power factor reduction
- Electromagnetic influences
- Measurement errors on energy meters (non-electronic)
- MCCB and contactor interruption faults
- Incorrect tripping of the switch

Harmonics: what generates them?

The most common harmonic generating devices are listed below:

- Switching Power Supplies
- Welders
- UPS
- Old frequency converters with thyristor power converter technology
- Motor drives
- Converters with controlled rectifiers
- DC controller for DC drives
- Induction ovens

Harmonics: where to find them?

The following are the places where it is more frequent to find a high presence of harmonics:

- Hospitals
- Universities, Government centers
- Shopping centers
- Laboratories
- Heavy industries
- Radio, TV, Broadcasting
- Food industry
- Hotel and casino
- Highly automated industry
- Water treatment plants

Regulations and Limits

The main legislative references placed to contain the most frequent disturbances in the power supply network are summarized below:

- The European standards **EN 61000-2-2**, **61000-2-4**, **EN 61000-3-2**, **61000-3-4**, **EN 61000-3-12** establish threshold values for the harmonic oscillations of networks and devices;
- Industry Recommendation **IEEE 519** provides tables for harmonic currents and voltages at the point of common coupling (PCC);
- Energy suppliers in most countries have set power quality standards and are determined to enforce them;
- The **EN 50160** Standard describes the limits within which the voltage characteristics can be expected at the power supply points from European public electricity networks.

EN 50160

The EN 50160 standard defines the following **harmonic voltage** limits:

- the total harmonic distortion (THD) of the supply voltage must not exceed **8%**
- effective values of each single harmonic voltage must be within the limits in the table

ODD HARMONICS				EVEN HARMONICS	
Not multiples of 3		Multiples of 3			
h Order	Relative amplitude u_h	h Order	Relative amplitude u_h	h Order	Relative amplitude u_h
5	6,0 %	3	5,0 %	2	2,0 %
7	5,0 %	9	1,5 %	4	1,0 %
11	3,5 %	15	0,5 %	6 ... 24	0,5 %
13	3,0 %	21	0,5 %		
17	2,0 %				
19	1,5 %				
23	1,5 %				
25	1,5 %				

EN IEEE519

The IEEE519 standard defines the following **harmonic current** limits:

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
< 20[c]	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

- I_{sc} is the system short-circuit current
- I_L is the maximum system current

Harmonic Current Limits: Calculation of I_{sc} e I_L values

Trasformer = 630kva | vcc=6% | Un 400V

Load = maximum power 480kVA | 450kW PF0,937

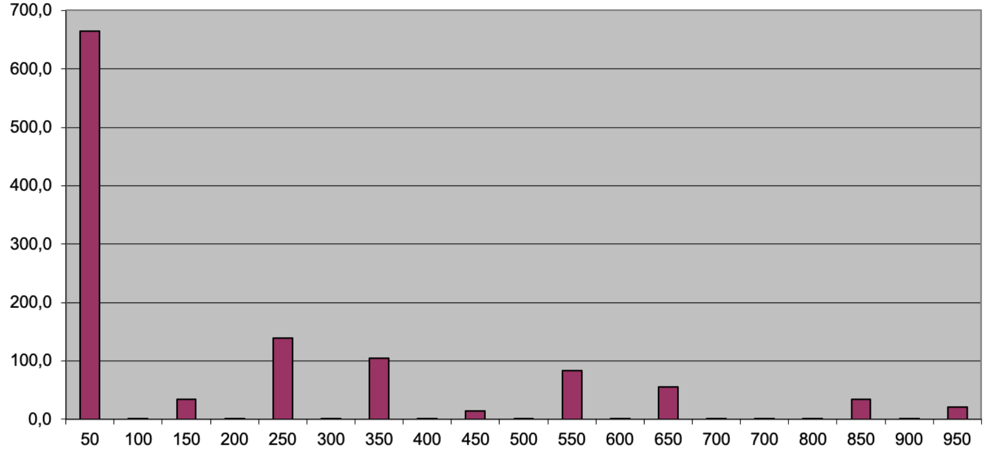
$$I_{sc} = \frac{100}{v_{cc}\%} \times \frac{A_T}{\sqrt{3} \times U_n}$$ -> Isc $$I_{sc} = \frac{100}{6} \times \frac{630000}{\sqrt{3} \times 400} = 15155 \cong 15kA$$

$$I_L = \frac{1000 \times kVA_{MAX}}{\sqrt{3} \times U_n}$$ -> $$I_L = \frac{480000}{\sqrt{3} \times 400} \cong 693A$$

Solutions for Harmonic Reduction

$$I_L = 693A$$
$$I_{SC} = 15000A$$
$$I_{SC}/I_L = 21{,}6$$

Harmonic load analysis: TDD=29,9%



Maximum harmonic current distortion in percent of I_L						
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Maximum allowable TDD = 8% -> <u>the harmonics must be reduced</u>

Solutions for Harmonic Reduction

COMAR's offer includes both passive and active filtering solutions:

Filtering for single harmonics or for single non-linear loads (e.g. for 6-pulse rectifiers).

These systems can only be designed passively and do not actively adapt to the situation.

Active compensation of harmonic currents in the frequency spectrum, up to the 49th order.

Applications: welding machines, induction furnaces, continuous loads, all types of motor drives.

Passive Harmonic Filters

Passive harmonic filters are a cost-effective solution for load harmonic mitigation in three-phase power systems.

All passive harmonic filter configurations have a capacitive character as they are constructed with inductive, capacitive and resistive elements configured and tuned to be used to control harmonics.

The technical approach of such tuned filters is to provide a low impedance path to harmonic currents at certain frequencies.

Passive harmonic filters cannot absorb other harmonics than they are designed for.

Therefore, passive harmonic filters are an **efficient and effective solution if it is necessary to mitigate specific harmonic frequencies** usually produced by specific equipment.

Active Harmonic Filters

Active harmonic filters are energy quality devices that **dynamically supply a controlled current that has the same amplitude as the harmonic current, which is injected in opposition to the harmonics on the network**.

This eliminates the harmonic currents in the electrical system.

As a result, the current supplied by the power source will remain sinusoidal as the harmonics will cancel each other out and harmonic distortion will be reduced to very low values (typically less than 5%).

Active Filters can be installed anywhere on a network and offer many features:

- Eliminate all harmonic currents from non-linear loads *
- Compensate the reactive power and correct the power factor
- Compensate for flicker caused by reactive power

*up to the 50th order

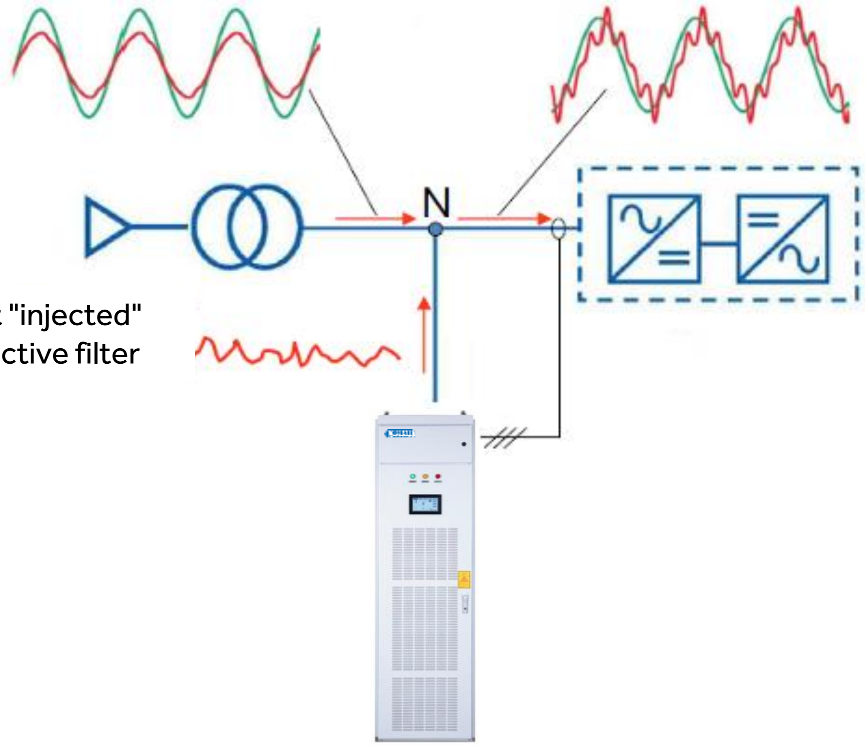
Active Filters: Principle of Operation

Like a power factor correction equipment, the active filter is a system that is connected in shunt to the plant and acts as an "ideal" current generator, capable of simultaneously generating currents with different frequencies (typically 50Hz ÷ 2500Hz) . Through external CTs, mounted in the point of the system where the reduction of the current distortion is to be carried out, the active filter measures the harmonic currents and "injects" (with an angle of 180° and therefore in counter-phase) equal harmonic currents, per module and frequency, to those measured.

Current upstream of the active filter

Load current

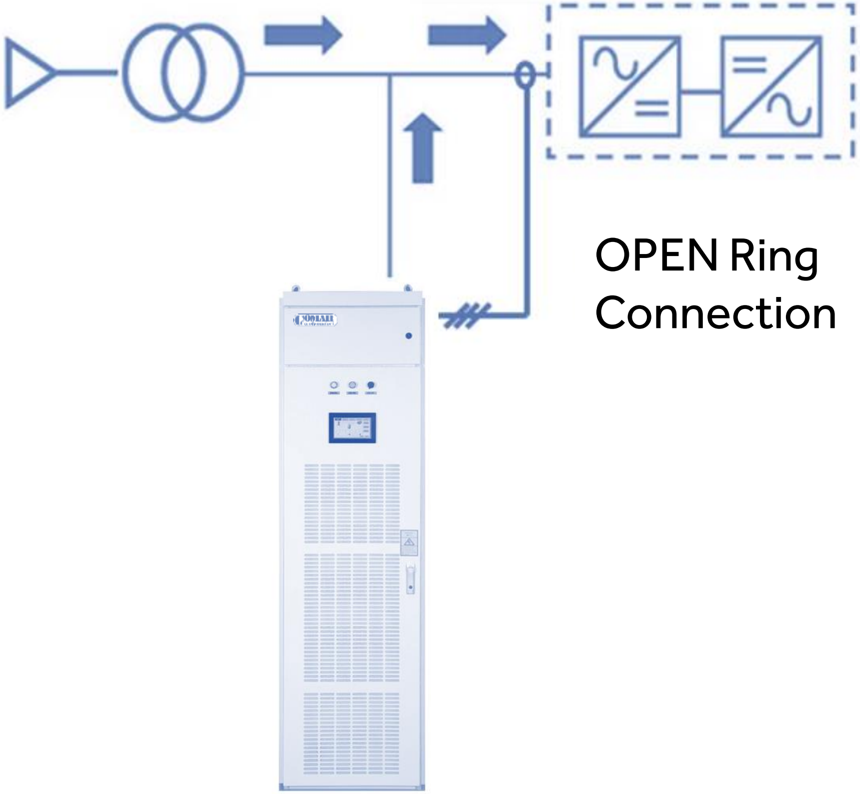
Current "injected" by the active filter



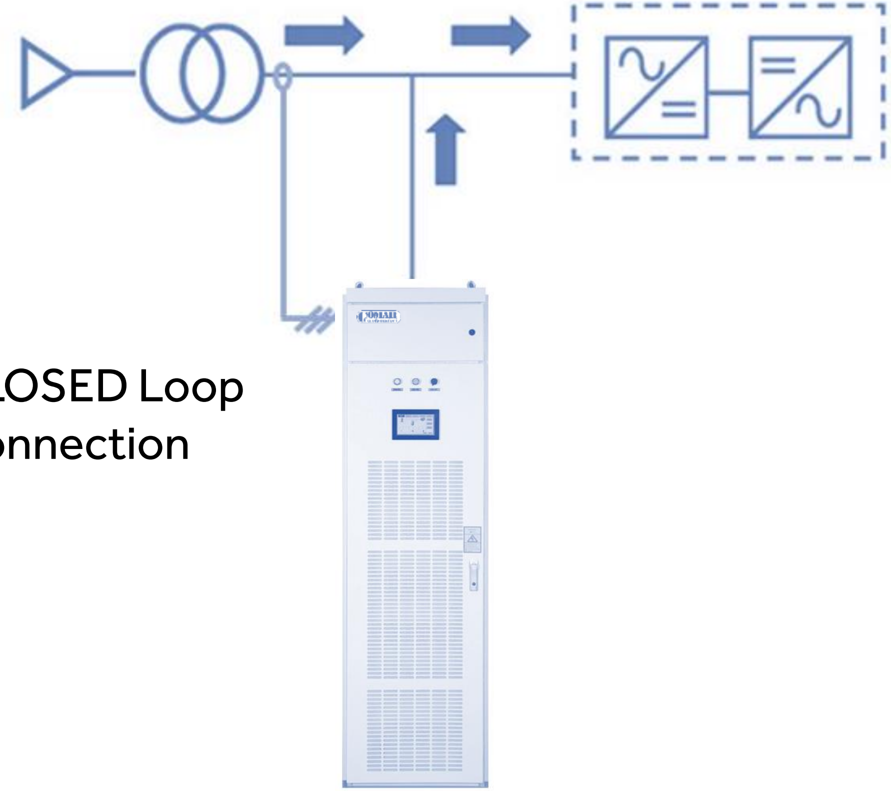
For the Kirchhoff principle, applied to the fictitious node N represented by the power connection point of the active filter, **the harmonic currents coming from the non-linear users located downstream of the node will be canceled**, and therefore only the a component will be present upstream of N network frequency.

Active Filters: Connection Diagram

The current measurement is performed with special CTs, in open loop or close loop:



OPEN Ring
Connection



CLOSED Loop
Connection

Active Filters: Sizing

For the sizing of the active filter it is necessary to know the amount of **harmonic current** to compensate. Normally a network analysis is performed to detect:

- THDI or TDD of the load to be filtered
- I_L Maximum current of the load to be filtered

The harmonic current for dimensioning the active filter is:

$$I_{filter} = I_{harmonic} = TDD \times IL$$

or:

$$I_{filter} = I_{harmonic} = THD \times I1$$

Under maximum load conditions

<u>Example</u>

Load = maximum power 480kVA | 450kW PF0,937 | IL = 693A
Harmonic analysis of the load = TDD = 29,9%

The harmonic current for dimensioning the active filter applies

$$I_{filter} = I_{harmonic} = TDD \times IL = 0{,}299 \text{ x } 693 = 207\text{Amp}$$

Contacts

Contact us for a free consultation:

Telephone
051 733383

E-mail
export@comarcond.com