

PROCEDURE FOR THE STUDY AND THE ANALYSIS OF HARMONIC DISTURBANCE

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- PFC Division -

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PROCEDURE FOR THE STUDY AND THE ANALYSIS OF HARMONIC DISTURBANCE

1. Harmonic disturbance on our installation

The present substantial growth in electronic devices aimed at equipping our installations has given rise to a significant change in the last few years on the type of loads connected to the electrical distribution system.

Not so long ago the only concern there was when using electricity at home, in establishments and productive centres was simply the voltage, without giving a thought to anything other than whether the equipment and devices were working or not.

These devices, at present, are equipped electronics which in some way or another provide increased performance in the tasks and productive processes we carry out. Everyone uses computers for their personal use, or for the process or control of any production system with variable speed drives, air conditioning units, lifts which adjust slowly on approaching the destination floor, etc. These devices are equipped with rectifiers, modulators, etc. and distort the current waveform for them to work properly.

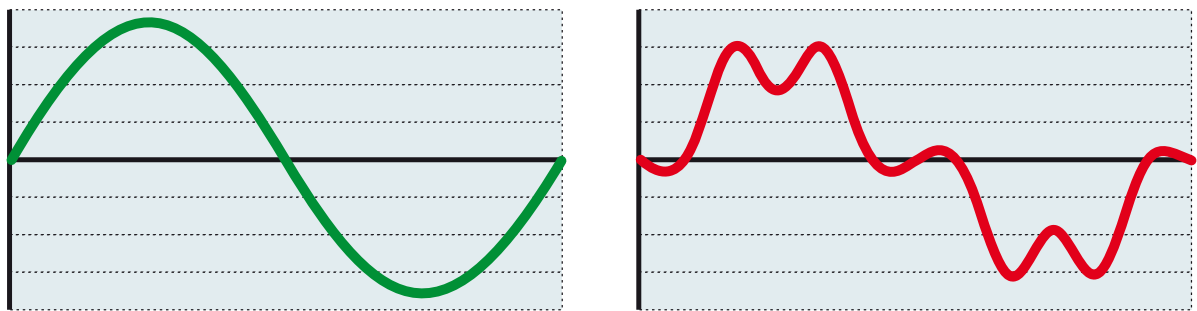
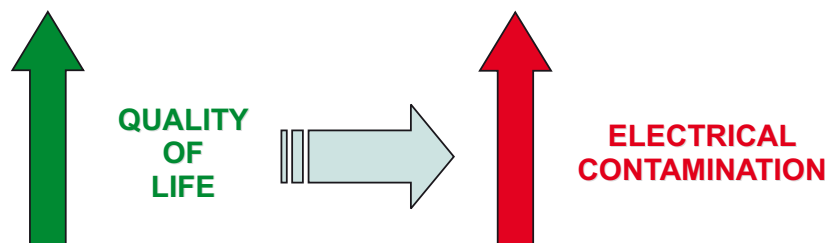
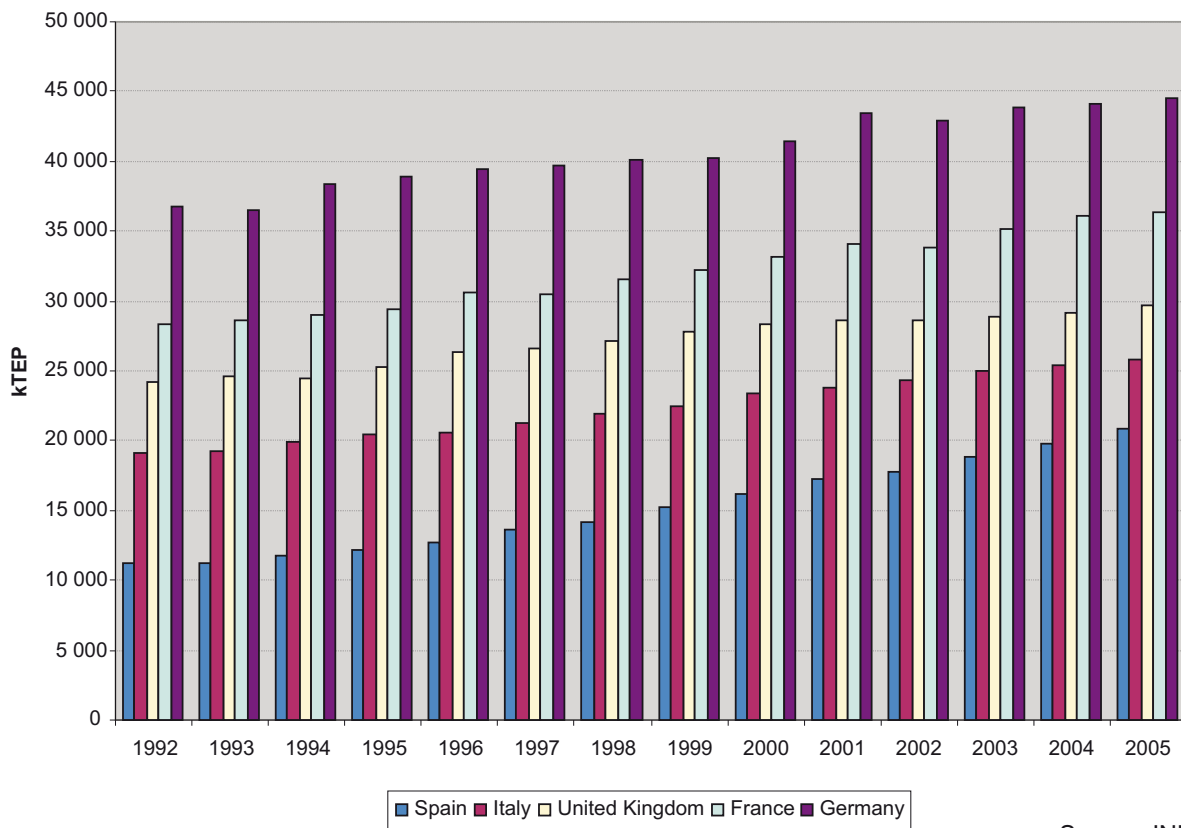


Fig. 1. Ideal waveform and distorted waveform

In short, we can affirm that while all this equipment has improved our **quality of life**, but, on the other hand it has **brought about greater contamination of our electrical system**.





Source: INE, Eurostat

Fig. 2. Electricity end user by countries

This increased electrical pollution is due in general to harmonics. Harmonics can disturb the correct working of machines and equipment.

These disturbances translate into costs which are difficult to appreciate or evaluate. These costs can be differentiated as:

- Technical costs
- Economic costs

1.1. Technical costs

Technical costs are those which bring about a loss of performance on our installation.

That is to say:

- Loss of capacity on energy distribution line
- Transformer overload
- Conductor overload
- Voltage drop
- Derating of transformers
- Losses on lines and machines due to the Joule's effect
- Magnetic losses on electrical machines

Normally, all technical cost turn into economic costs. Here is where the importance of control in our installation.

1.2. Economic costs

Economic costs are those which we can economically quantify, although in some cases it may be difficult. These costs can be divided into **hidden cost** and **visible costs**.

Visible Costs:

- Increased electricity consumption
- Electricity consumption peaks
- Surcharge or payment on reactive energy

Hidden costs:

- Distribution losses
- Power and energy loss (due to the Joule effect and magnetics)
- Enlargement of the installations
- Stoppage of productive process

All these phenomena can be found to a lesser or greater extent depending on the installation itself and the loads connected.

2. Effect of harmonics on the power system

Not all the electrical quality problems that an installation can suffer are attributable to the effects of the harmonics. There are a great variety of phenomena and aspects, not only electric, which may affect the system itself. As we can see in Fig. 3 the harmonics phenomena is only one part of the wave non idealities present on an installation and the grid

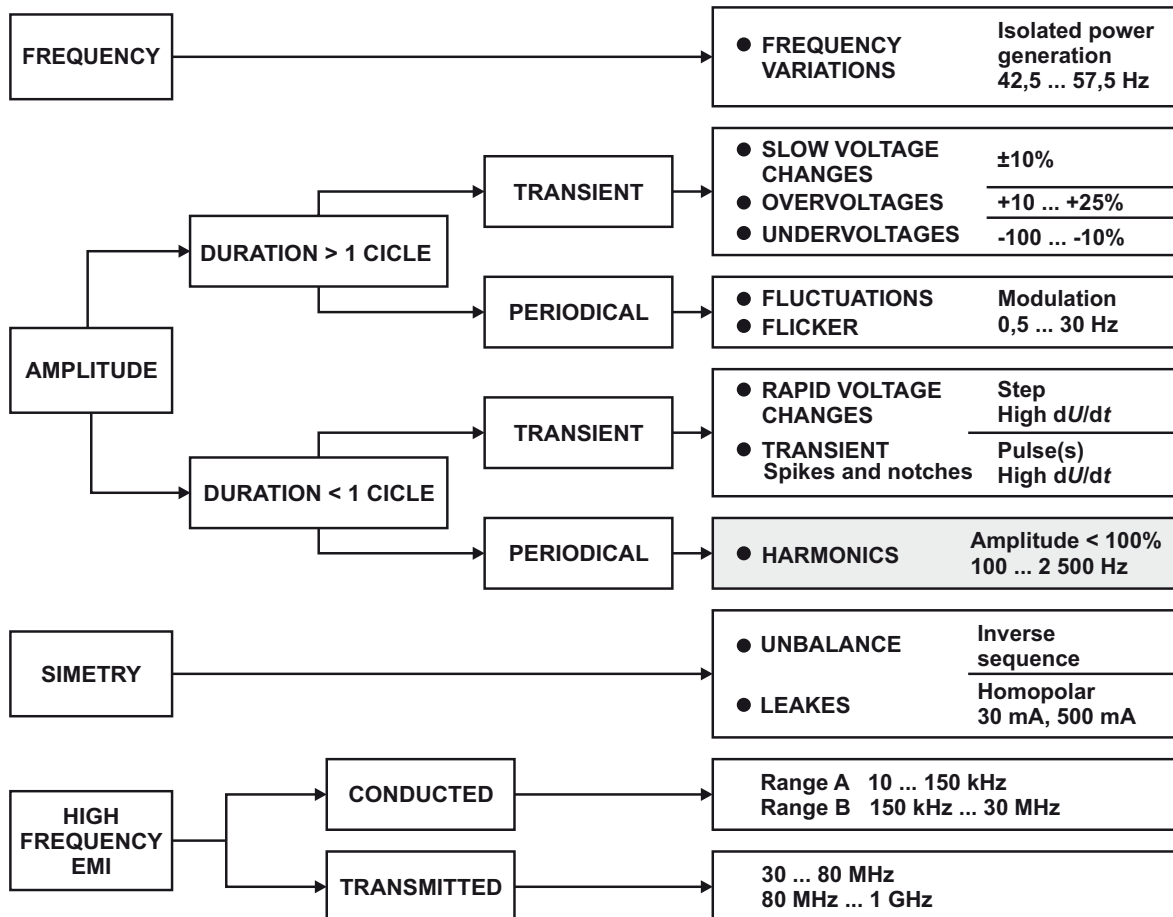


Fig. 3. Classification of the non-idealities principles of an installation and the grid.

The main effects of the voltage and current harmonics in a power system can be cited as:

- The possibility of amplification of some harmonics as a result of serial and parallel resonance.
- Performance reduction in generation, transport and energy usage systems.
- The aging of the grid insulation components and as a consequence, energy reduction.
- Malfunctioning of the system or some of its components.

However to understand these effects better we must know the nature of harmonics.

2.1. What are harmonics?

All periodical non-sinusoidal waveform can be represented as the sum of sine waves whose frequencies are integer multiples of the fundamental frequency, that we call harmonics.

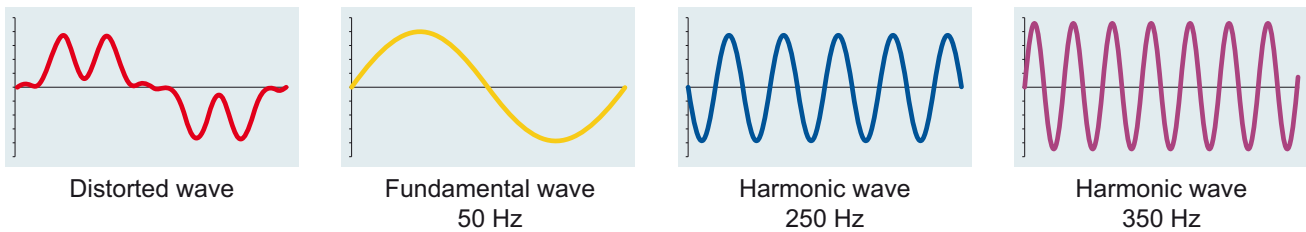


Fig.4 Decomposition of a distorted wave form

Order	Fund.	2	3	4	5	6	7
Frequency	50	100	150	200	250	300	350
Sequence	↻	↻	↑	↻	↻	↑	↻

Fig. 5 Order and behaviour of harmonics

BASIC CONCEPTS

It is useful to define some terms about harmonics which are fundamental to interpret any measurement and study:

- **Fundamental frequency (f_1):** Frequency of the original wave (50/60 Hz)
- **Harmonic order (n):** Integer given by the relation of the harmonic frequency with the fundamental frequency. With which the order the frequency of the harmonic is determined (Example: 5th Harmonic → 5•50 Hz = 250 Hz)
- **Fundamental component (U_1 or I_1):** Sinusoidal component, 1st order in the Fourier frequency series the same as the original periodical wave.
- **Harmonic component (U_n or I_n):** Sinusoidal component higher than one in the Fourier frequency series, integer multiple of the frequency source.
- **Individual distortion rate ($U_n\%$ or $I_n\%$):** Relation in % between the efficient value of the voltage or current harmonic (U_n or I_n) and the effective value of the fundamental component (U_1 or I_1).

$$U_n\% = \frac{U_n}{U_1} \cdot 100 \quad I_n\% = \frac{I_n}{I_1} \cdot 100$$

- **True RMS:** This is the square root of the sum of the squares of all the components which make up the wave.

$$U = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_5^2 + \dots} \quad I = \sqrt{I_1^2 + I_2^2 + I_3^2 + I_5^2 + \dots}$$

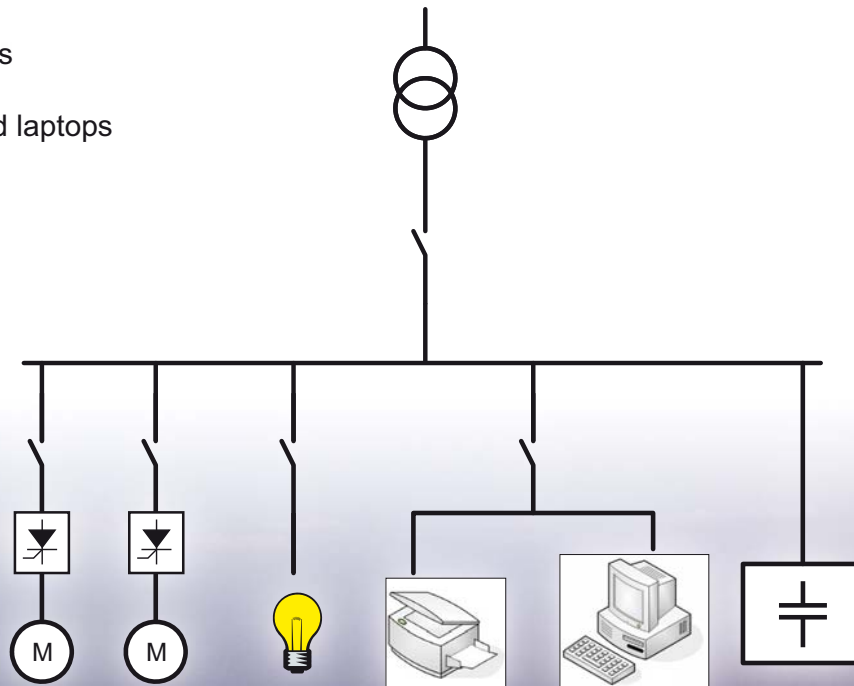
- **Harmonic residue:** Difference between the voltage or total current and the corresponding fundamental value.
- **Total harmonic distortion:** Relation between the efficient value of the voltage harmonic residue of the voltage and/or current and the value of the fundamental component.

$$\text{THD}(U)\% = \frac{\sqrt{U_2^2 + U_3^2 + U_5^2 + \dots}}{U_1} \quad \text{THD}(I)\% = \frac{\sqrt{I_2^2 + I_3^2 + I_5^2 + \dots}}{I_1}$$

2.2. What generates harmonics?

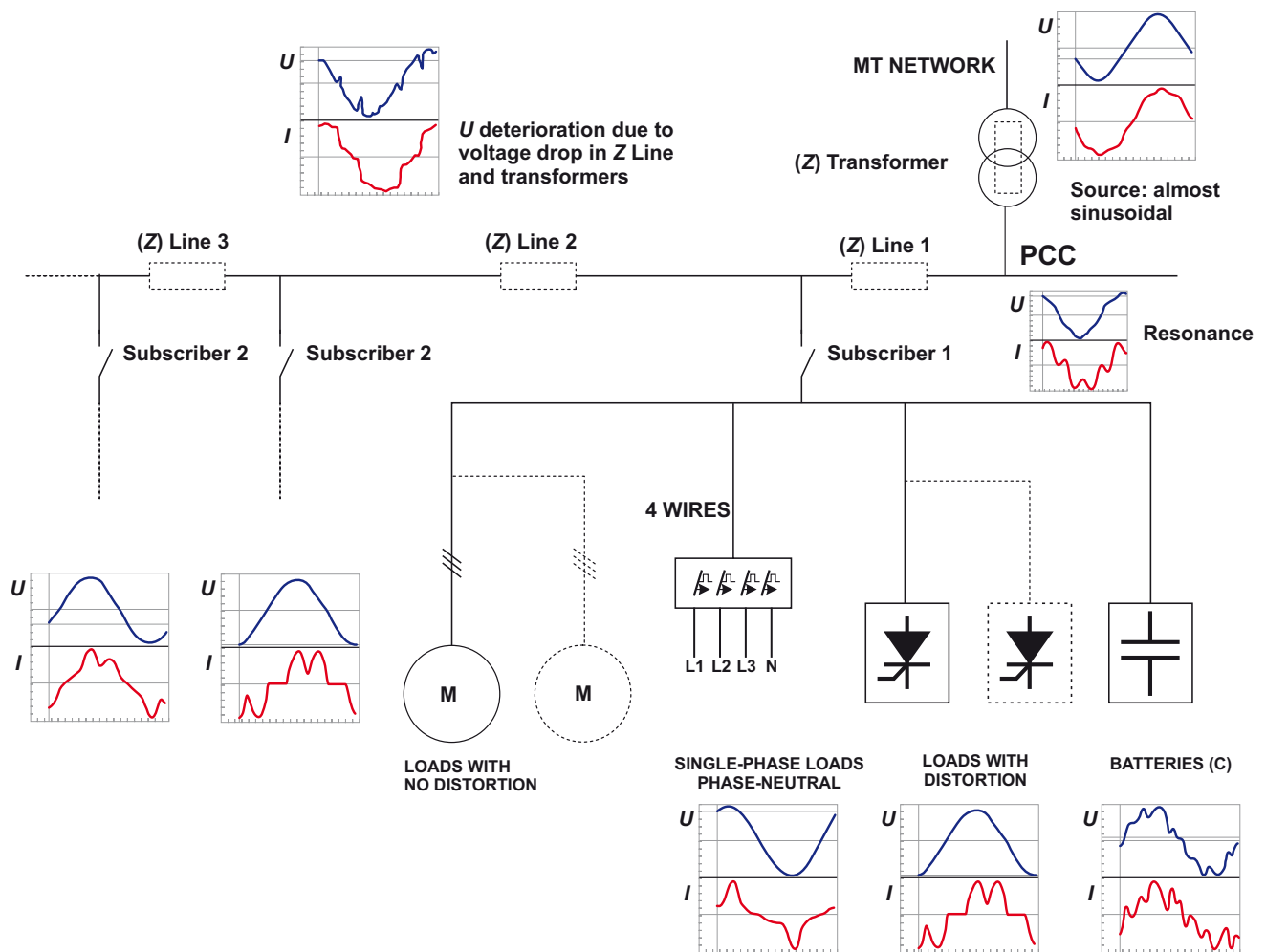
Harmonics are produced by not-linear loads that absorb non-sinusoidal current. The most common loads, both in industrial surroundings and domestic ones, are the following ones:

- Frequency / Variable speed drives
- Discharge lamps (high pressure sodium vapour lamp, mercury vapour lamp, low consumption, fluorescent, etc.)
- Rectifiers
- AC/DC Converters
- Arc welding
- Induction ovens
- UPS
- Computers and laptops
- Etc.



2.3. Intensity-harmonic voltage relationship

The circulation of harmonic currents generated by linear loads via internal impedances in the mains generates a distortion in the voltage wave.



By applying Ohm's law we would get $U_h = Z_h \cdot I_h$, where Z_h y I_h are the harmonic impedance and the harmonic current corresponding to each harmonic range h . Therefore, at a greater circulation of harmonic current generated by the loads, we will get a greater voltage. The further away from the PCC and the closer to the distorting loads, the greater the voltage drop. If we connected sensitive loads away from the PCC and close to these distorting loads, their level of distortion may not be tolerable and this could lead to the malfunctioning of these sensitive loads.

It is important to check the PCC when it is empty and when it is loaded. If the comparison between the levels of voltage distortion when empty and when loaded shows no change in distortion, this indicates that the voltage distortion is from an external source. On the other hand, if the voltage distortion increases in proportion to the current consumed, this indicates that the distortion is from an internal source in our installation.

From here we can deduce the importance of preventing the circulation of harmonic currents in our network.

2.4. What effects do harmonics produce?

Within the wide range of existing disturbances on the grid harmonics produce the following effects on the following components or elements:

Component / Element	Problem	Effect
Conductor	<ul style="list-style-type: none"> - Current increase - Resistance increase - Increase in thermal loss (Joule's effect) - Skin Effect 	<ul style="list-style-type: none"> - Cable heating - Tripping of protection
Neutral Conductor	<ul style="list-style-type: none"> - Circulation of multiple of 3 harmonics - Return through neutral conductor 	<ul style="list-style-type: none"> - Overcurrent flowing in neutral - Heating on neutral - Premature degrading neutral conductor - Neutral –earth voltage - Tripping of protection
Capacitors	<ul style="list-style-type: none"> - Parallel resonance with the system - Harmonic gain 	<ul style="list-style-type: none"> - Heating - Premature aging of capacitors - Capacitor destruction
Transformers	<ul style="list-style-type: none"> - Current harmonics flowing through windings 	<ul style="list-style-type: none"> - Overheating of the windings - Thermal insulation loss due to heating - Copper and Metal loss (Hysteresis and Foucault) - Reduction in performance - Extra-large transformer - Transformer saturation (creates greater distortion)
Motors	<ul style="list-style-type: none"> - Current harmonics flowing through windings 	<ul style="list-style-type: none"> - Overheating of the windings. - Thermal insulation loss due to heating. - Copper and Metal loss (Hysteresis and Foucault) - Decrease in performance - Vibrations on the axis, mechanical wear on bearings and eccentric bearings - Torque reduction
Power generating set	<ul style="list-style-type: none"> - Soft system, with greater impedance than the grid - Distorted voltage 	<ul style="list-style-type: none"> - Difficulty in automatic synchronisation and later switching
Control and measuring equipment	<ul style="list-style-type: none"> - Invalid measurements - Errors in control processes 	<ul style="list-style-type: none"> - Error in equipment taking the zero reference of wave - Saturation of measurement and/or protection measurement. - Incorrect magnitude values

3. How to analyse harmonic problems?

To correctly analyse the harmonics a network analyser is required (portable analyser **AR5L** or **QNA-P**), able to measure all the electrical magnitudes of our installation to be interpreted at a later stage.



AR5L



QNA-P

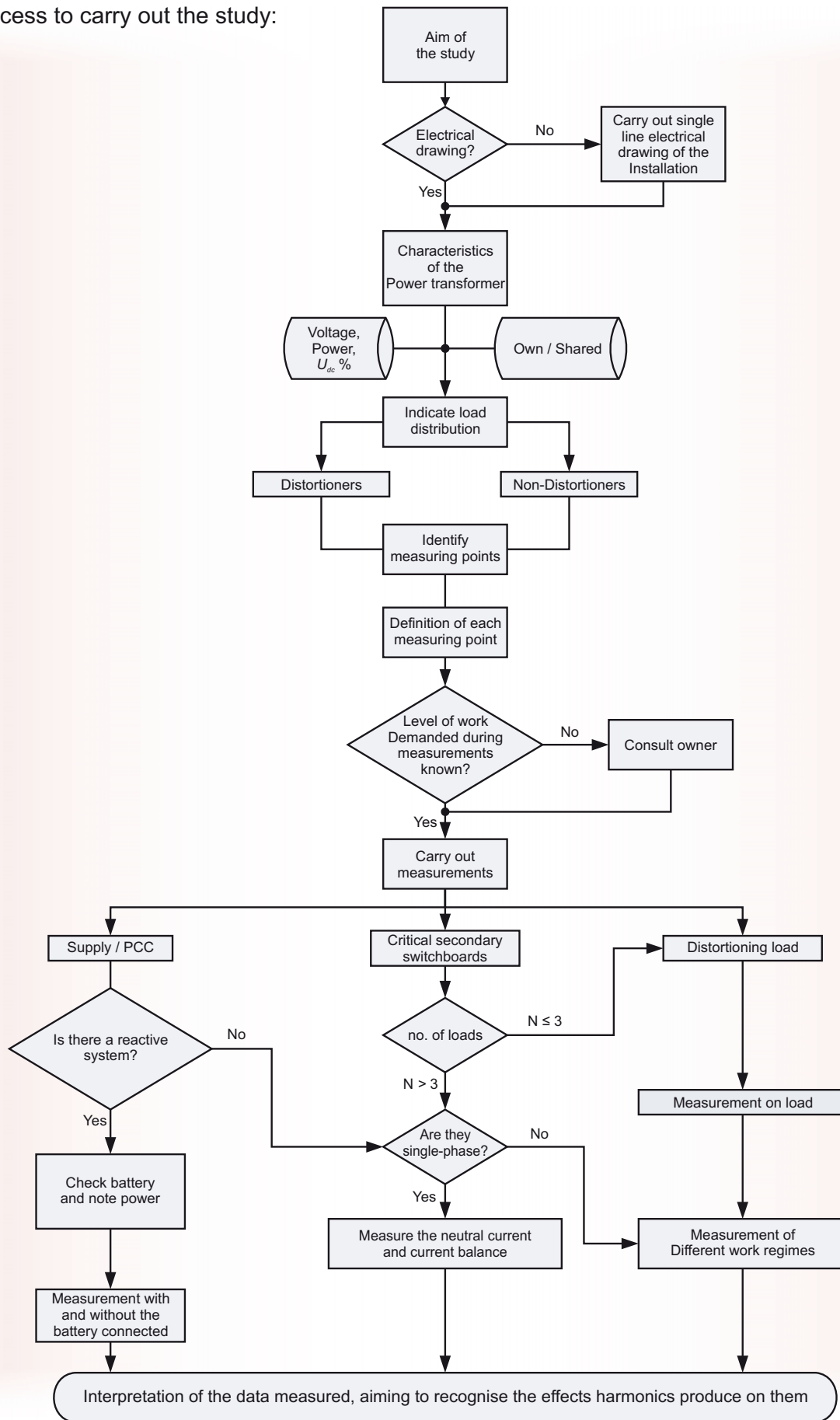
There is no a standardized way to carry out a study, but we the following steps can be considered :

- Previous identification of the symptoms which may exist on the installation:

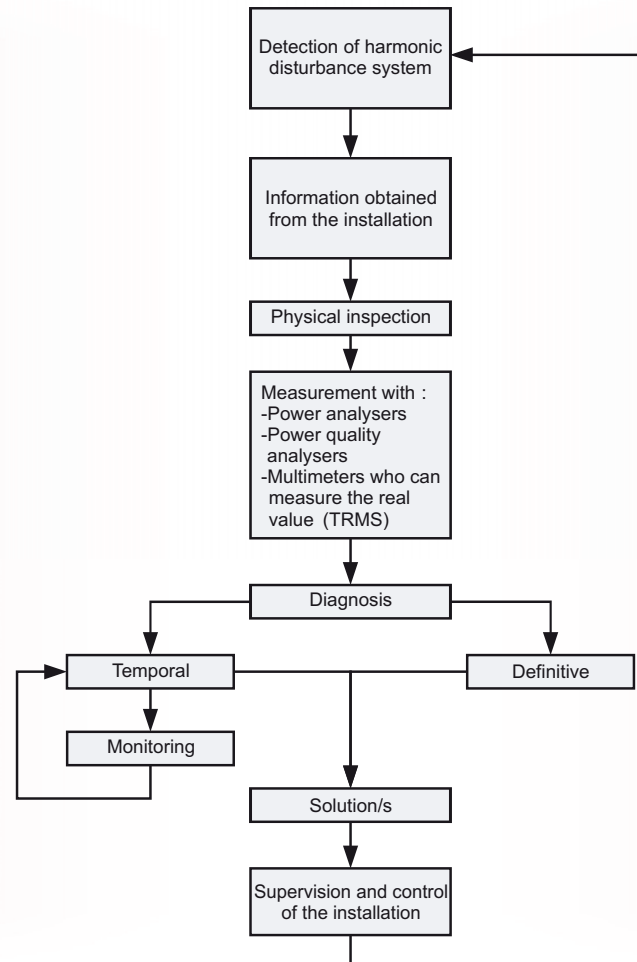
Component / Element	Symptoms	Yes	NO	?
Conductor	- Cable heating - Tripping of protection	<input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/>
Neutral Conductor	- Heating of the neutral conductor - Conductor degradation - Tripping of protection	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
Capacitors	- Heating of the capacitors - Premature aging of the capacitors (loss of capacity) - Capacitor destruction	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
Transformers	- Overheating of the windings. - Overheating of the winding - Decrease in performance - Extra-large transformer.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
Motors	- Overheating of the windings. - Winding degradation - Decrease in performance - Vibrations on the shaft - Mechanical wearing on bearings - Eccentricity of the axis - Surges that destroy the windings	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
Power supply unit	- Difficultly in synchronisation and switching of the unit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Control and measuring equipment	- Incorrect magnitude values - Interferences in sensitive equipment	<input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/>	<input type="checkbox"/> <input type="checkbox"/>

The fact that we are unaware of the existence of the symptoms (?) does not make the installation exempt for suffering them, quite the opposite; we must be more careful and supervise the installation for example: By monitoring the electrical parameters of different points of the installation with fixed network analysers and an ADA system **PowerStudio-SCADA**.

- Process to carry out the study:



- Process for the diagnosis of the installation:



Once the symptoms have been identified and we have information on the installation (see previous points) we can offer the appropriate diagnosis and offer a solution/s which is more suitable for the symptoms.

4. Standards

The results measured results can be evaluated in accordance with the following standards and regulations⁽¹⁾:

- Spanish Low Voltage Regulation (REBT) RD 842/2002
- Spanish Law RD 1955/2000, 1st December ruling on electrical energy installations
- European Directive 2004/108/CE relative to the approach of the legislations of the Member States on the Electromechanical Compatibility, replacing directive 89/336/CEE
- European directive on lifts 95/16/CEE
- Standard EN 12015 “Electromagnetic compatibility. Product family standard for lifts, escalators and passenger conveyors. Emission”

(1) Bear in mind possible changes and updates. Some of these Standard and regulations are only valid within Spain.

- Standard IEC 60364-5-52 “Electrical Installations of Buildings - Part 5-52: Selection and Erection of Electrical Equipment - Wiring Systems-Second Edition; Compiled from and Replaces IEC 60364-5-523(1999)”
- Standard EN 50160 “Voltage characteristics of electricity supplied by public distribution systems”
- Standard EN 61642:2000 “Industrial a.c. networks affected by harmonics. Application of filters and shunt capacitors”
- Standard IEC 61800-3 “Adjustable speed electrical power drive systems. EMC requirements and specific test methods”
- Standard IEC 61000-3-2 “Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)”
- Standard IEC 61000-3-12 “Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase”
- Standard IEC 61000-3-4 “Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A”
- Standard IEEE 519-1992 “Recommended Practice and Requirements for Harmonic Control in Electric Power System”
- Standard G5/4-1 “Managing Harmonics: ENA Engineering Recommendation”

5. Solutions

After the diagnosis and the assessment of the disturbances we move onto the treatment or solution. We must always look for a balance between the technical solution and the economic one. The ideal technical solution will be to filter directly the disturbing loads (**LR** reactance, **LCL** filter, **FB3**, **EMI** filter and **FAR-H/Q**), avoiding the propagation of the harmonic currents against other loads and installation, and a greater drop in harmonic voltage which would provoke the distortion of the voltage wave. In other cases, the solution is to look for a solution as near as possible to the loads (**AF/APF** active filter, **TSA**, blocking filter of blockade **FB3T**, absorption/hybrid filter **FAR-H/Q**, **FR** rejection filter).

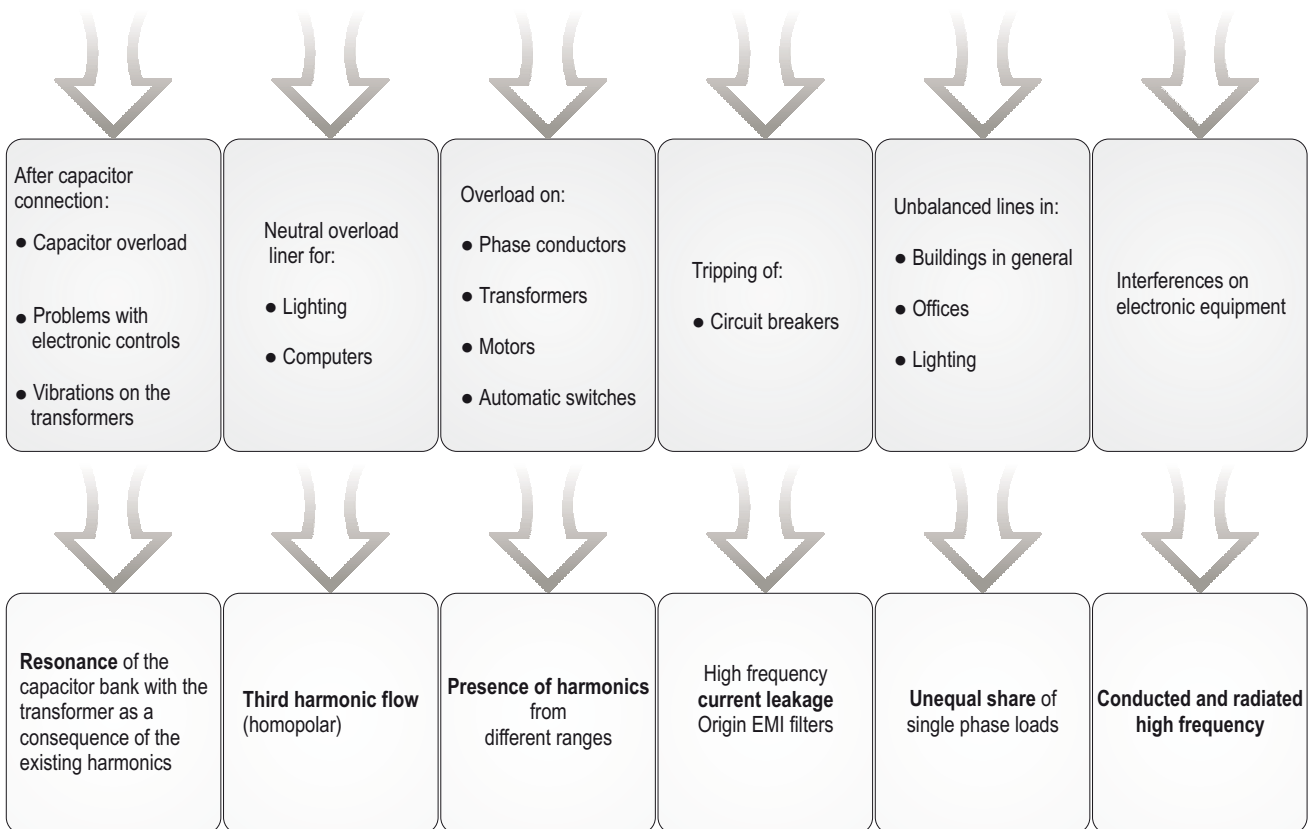
FILTERING STRATEGIES

Main switchboard	↔	<ul style="list-style-type: none"> • Reduce the THD(<i>I</i>)% level that is generated towards the grid (Point of Common Connection) • Decrease the declassification of the transformer
Secondary circuit board	↔	<ul style="list-style-type: none"> • Reduce the effective value of the current in the installation lines without power loss • Loss of reduction • Distortion current flow towards other equipment • Slight attenuation of THD(<i>U</i>)%
Individual filtering	↔	<ul style="list-style-type: none"> • Reduce the distorting and effective current at the point where it is generated • Loss reduction on the entire system • Distorting current flow towards other equipment • Slight attenuation of THD(<i>U</i>)%

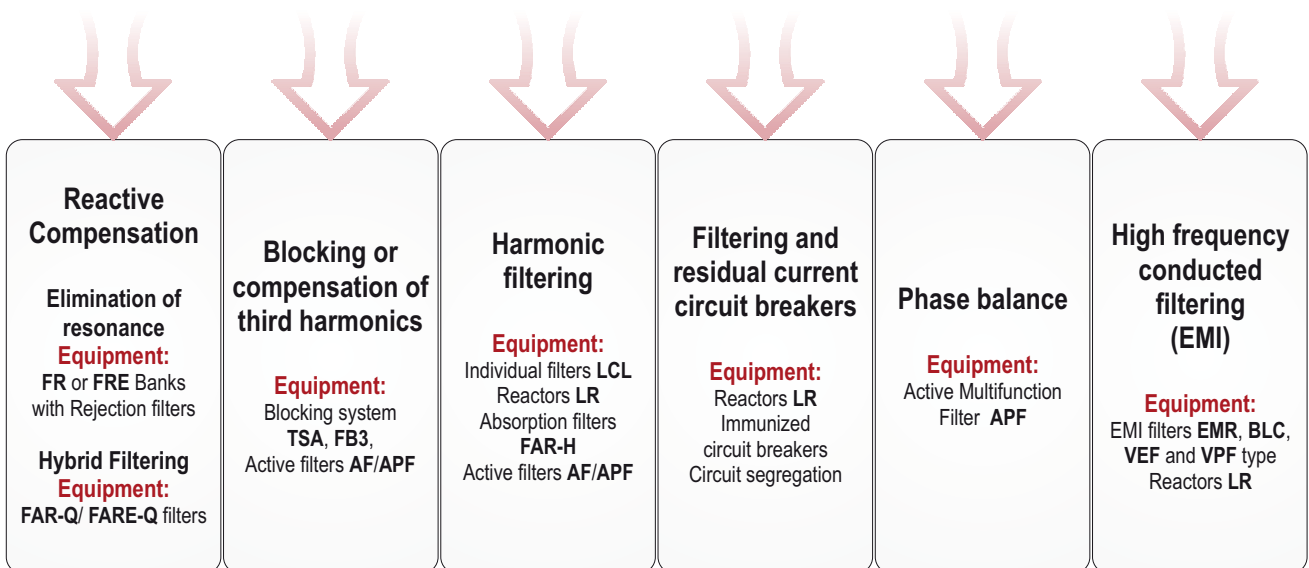
As we can verify there is no single procedure, but that in each case different solutions can be contributed depending on the point where the filters are installed.

It is not possible to generalise, but in the following figure we will try to represent some of the typical anomalies that we can find and the different solutions that **CIRCUTOR** can provide on the matter.

Habitual types of anomalies



CIRCUTOR solutions and equipment



6. Summary

As we have seen, the existence of harmonic distortion in our installation becomes greater the larger the disturbance loads we use.

The problems caused by the harmonics are well defined; we cannot justify an incident on the installation due to their presence. The effects can be shown instantly (switch failure, incorrect operations in static equipment, etc.) and in the long term (capacitor battery resonance, transformer overheating, conductors and motors, measurement errors from measurement instruments, thermal losses, etc.). By exceeding the maximum conductor isolation temperature by only 10°C motors and transformers reduce their working life practically by half.

It is essential to follow the procedure for the study of the analysis of harmonic disturbance, if we omit any of the steps, the measurement and study process will be very complicated and in many cases we will be unable to give a possible solution to our solution.

In short, the following should be carried out:

- Define the objective of the study
- An electrical drawing of the installation and how the loads are distributed.
- To define measurement points and to identify them in the drawing
- Load level during measuring
- Interpret the data measured attempting to recognise the effects of the harmonics and/or depending on what the standard, directive or regulation establishes.

As an example, we can show some of the most common anomalies and some of the possible solutions. The result obtained will depend on the filtering strategy we use (general switchboard, secondary switchboard and/or individual filter) and of the installation study process. It is obvious, that with one measurement in the switchboard the possibility of offering a solution is very limited and only offers a solution for the point of measurement.

This guide offers us the essential knowledge to begin an analysis of harmonic disturbances and enables solutions to be established correctly and efficiently.

