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Case studies on voltage distortion not covered by harmonic standards

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Abstract. Nowadays, the presence of voltage distortion due to conducted disturbances coming from electronic converters is creating some problems, including damage to industrial or domestic equipment or control failure of the devices among other troubles.

An important point to consider is the insufficient regulation of disturbances in the range from 2 kHz to 150 kHz, since present Electromagnetic Compatibility (EMC) standards cover the typical disturbances produced by loads with rectifiers. Disturbances produced by other type of converters, especially those used to connect distributed generation to the network, are still not included in EMC standards.
On the other hand, filters used in some equipment are not designed for the characteristics of the grid to which they are connected nor are standardized.

And, as a consequence, conducted disturbances are transmitted through the grid, creating problems in different points.
This problem will be analysed in three different cases: industrial converters, wind plants and Low Voltage (LV) photovoltaic generators.

Keywords

Conducted disturbances, converters, inverters, filters, ECM standards

1. Introduction

Some voltage distortion problems −different from the typical approach used by harmonic standards, since they involve frequencies higher than 2 kHz or interharmonics not reproducible in laboratory − are taking place in electricity distribution networks. In many cases these disturbances are not measured by conventional power quality analysers, which leads to additional difficulties to assess the problems.
A common characteristic is the combination of presence of resonant phenomena and power converters. The impedance and LC characteristics of the grid become an important factor in these situations.

In certain circumstances, high power converters or rectifiers could produce high frequency disturbances which are transmitted through the medium voltage over long distances. In other cases, the disturbances have to do with inverters for the connection to grid of distributed generation.

Two aspects have to be analysed: the behaviour of the converter with special attention to the design of their filters and the regulation of electrical issues. Firstly, filters should be adapted to the characteristics of the grid to which they are connected, different from the normal conditions in laboratory tests. Secondly, these disturbances related to interharmonics or frequencies in the range from 2 kHz to 150 kHz are not included in the EMC standards in force at present.

2. Applicable legislation and normative

According to European Directive 2004/108/EC [1] on electromagnetic compatibility, equipment shall be so designed and manufactured, having regard to the state of the art, as to ensure that:
(a) the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended;
(b) it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.

To that aim, the design and manufacture of equipment is subject to essential requirements in relation to electromagnetic compatibility.

Those requirements are given technical expression by harmonised European standards, especially the generic standards on immunity and emission in any kind of environments [2], [3], [4], [5] or, specifically for the case of aspects related to voltage distortion, EN 61000-3-2 [6] and EN 61000-3-12 [7].
However, those standards deal with limits for harmonic emission up to 2 kHz and only for LV equipment up to 75 A.
Therefore, several aspects are not covered by harmonised standards:

- Frequencies higher than 2 kHz
- Interharmonics
- Equipment bigger than 75 A or with nominal voltage equal or higher than 1 kV.

The technical report IEC/TR 61000-3-6 [8] provides guidance on principles which can be used as the basis for determining the requirements for the connection of distorting installations to MV, HV and EHV public power systems. Although it includes some interharmonic values, it is only informative so it does not affect equipment design, it does not include equipment connected to LV networks and it does not deal with frequencies higher than 5 kHz.

A new Basic EMC Publication pr IEC 61000-4-19 on test for immunity to conducted, differential mode disturbances in the frequency range from 2 kHz to 150 kHz, at a.c. ports is currently under development.

3. Voltage distortion out of the harmonic range

The presence of conducted disturbances related to power converters has to do not only with the characteristics of these electronic devices but also with the electrical grid in which these devices are connected. In the next sections it will be discussed in three different cases: industrial converters, large wind plants and low voltage photovoltaic plants.

A. Industrial rectifiers

An industrial customer with a 5 MW induction furnace was connected to a 30 kV network. It integrated a filter with a capacitor bank with an inductance tuned to prevent resonances with frequencies of order higher than 5th harmonic in its facilities. Figure 1 shows a schematic representation of the facility, in which it can be seen the induction furnace fed by a 12 pulses rectifier.

When this furnace worked, a voltage of 4 kHz superimposed to fundamental was observed in the network, instead of the characteristic harmonics of a rectifier.
The distortion spread through the medium voltage network causing failure of control equipment, contactors, overheating in auxiliary transformers, and audible noise in electrical appliances –even in those that were not in operation− in a town 13 km away from the factory.

This voltage appeared and disappeared. After a first investigation, it was observed that the voltage distortion disappeared when a capacitor bank was connected in the substation that fed the affected customers with a 6 km line. A later investigation of the feeders of that substation gave no clues to identify the origin of the voltage distortion, since it was no possible to find a feeder with a 4 kHz current more significant than the other. Finally, the identification had to be made by investigating the consumption of the main industrial customers of the area.

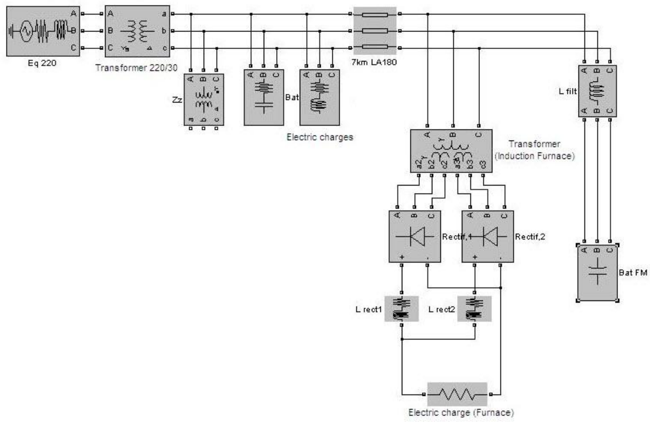

Fig. 1. Simplified diagram of the facility

In the measurements within the factory it was observed that an underdamped transient occurred in each commutation, 12 per cycle, having the appearance of a continuous disturbance (Figure 2).

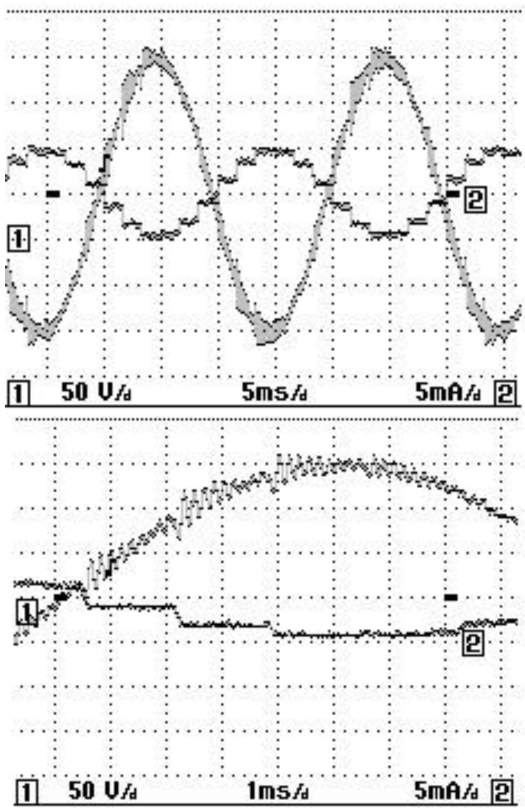

Fig. 2. Induction furnace current and effect on voltage

The origin of the voltage disturbance was the abrupt change in current during the commutation of the diodes in the 12 pulses-rectifier, which performed the AC-DC conversion in this large induction furnace. This change was especially abrupt due to the big power of the furnace and the presence of a relatively low series inductance at its input.
Since the network cannot provide current brusquely because of its inductance, the initial current required by the load is supplied by the capacitance of the line, which is discharged to be recharged again. This results in a voltage transient whose frequency does not depend on the converter characteristic but on the LC parameters of the feeder. In this case, an overhead line and, therefore with little capacitance, ends up having a characteristic frequency of 4 kHz.

The solution implied making changes in the facility. One solution would be the modification of the inductances in the 800V system. However, this solution was unfeasible, both economically and for lack of the needed space. The second and more suitable solution was the substitution of the 30 kV filter to one damped of 3rd order (Figure 3). This filter eliminates high frequency components and consequently allows operating normally.

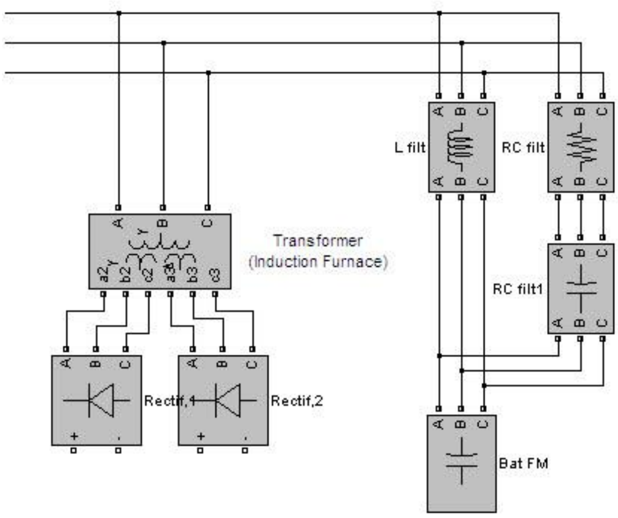

Fig. 3. Modification of the filter

After the modification of the filter, the high frequency components disappeared (Figure 4) and consequently, the disturbance.

B. Distortion in large wind plants

When a wind park with full inverter generators by means of an IGCT bridge was put into operation, some anomalies were detected. These anomalies affected not only the auxiliary services of the park but also the performance of the wind turbines. The main consequence was the impossibility to achieve high power generation because the protections of the wind turbines continually operated switching the generation off.

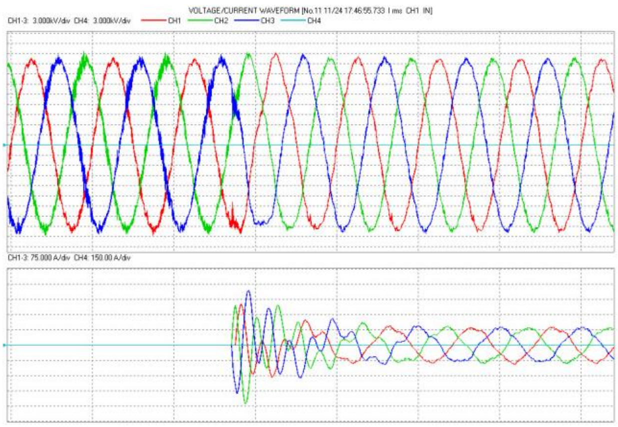

Fig. 4. Filter connection and elimination of the disturbance

Figures 5 and 6 show the results of the measurements, both the times when there were not any incidents and also when the protections of some wind turbines operated. These measures proved an important distortion in the voltage, even higher than the current distortion. It was linked to the presence of interharmonics at frequencies close to 800 Hz, including other frequencies too.

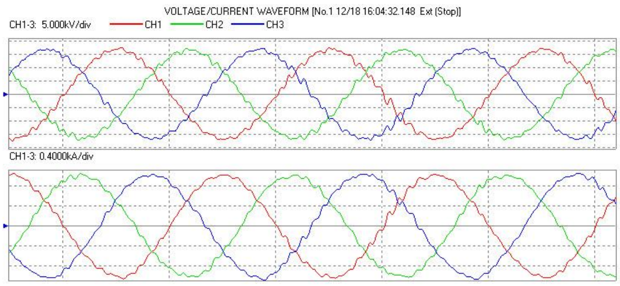

Fig. 5. Voltages and currents at 20kV, without any incident in wind turbines

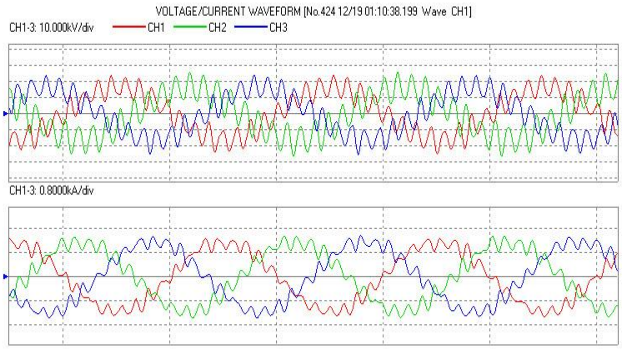

Fig. 6. Voltages and currents at 20kV, with incidents in wind turbines

The distortion of currents and –especially− voltages was noticeable from lower power generation, decreasing slightly with the increase of power. However, the maximum distortion occurred when the generation was 60% of the nominal power, with the interharmonic 15.5 reaching 50% of the fundamental frequency, as can be seen in figure 7.

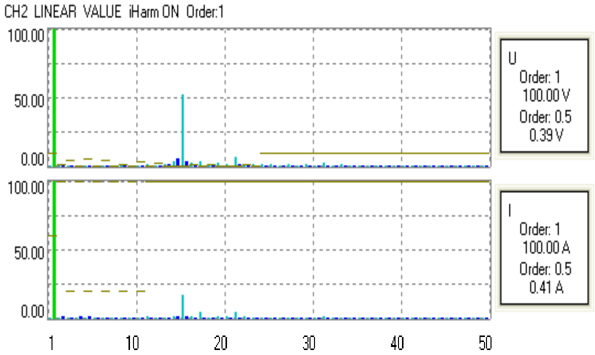

Figure 7: Harmonics (dark blue) and interharmonics (light blue)

This huge voltage distortion affected mostly the auxiliary services in low voltage (control, fluorescent lighting and UPS).

As in the induction furnace case, the cause of the voltage distortion is the interaction between the LC characteristics of the elements in Medium Voltage (wires and transformers) and the converters −in this case inverters− used in the wind turbines. The frequency difference it is due to the use of large section underground cables, which have lower inductance and much higher capacitance than an overhead line.

The solution is, consequently, the modification of one of these two parameters (grid configuration and operation of inverters).

In the first case, the grid characteristics should be modified to avoid resonances. This would be accomplished by using a damped filter in order to avoid resonances of the capacity MV underground cables. One example of this solution can be seen in figure 7, which represents the impedance of a wind park network, in which a third order type C damped filter eliminates the resonance caused by underground cables, in this case at frequencies close to harmonics 19th and 20th., as shown in figure 7, .

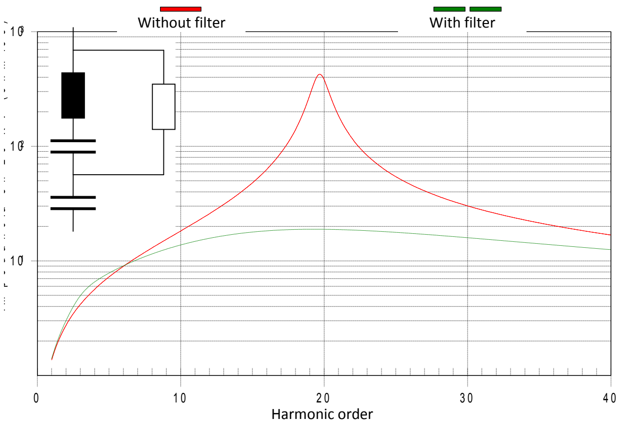

Fig. 7. Effect of damped filter on cable resonance

An alternative option consists on changing the control loops of the inverters, with limited switching frequency due to the IGCT, in order to prevent interactions between the inverters and the feeders, reducing the level of interharmonics.

After applying this last option, the wind park generated powers close to the nominal. However, there were still existing distortions at low and middle powers, usually under 8% of fundamental frequency. In addition, as it could seen in figure 8, the lack of damping with this kind of solution still allows some transients, although they were corrected in a cycle not causing protections trips.

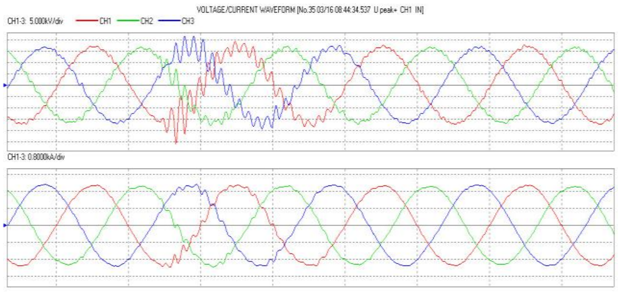

Fig. 8. Voltages and currents at 20kV, after modifications in the wind turbines

C. *Distortion in LV systems due to photovoltaic generators*

Photovoltaic inverters are one example of electrical devices that have to comply with the European EMC Directive, by means of the corresponding Declaration of Conformity with the above-mentioned harmonised standards. In this case, the converters used are IGBT bridges with switching frequencies of several kHz.

Figures 8 and 9 show a voltage distortion of 2.4 kHz during the two operation periods of a 100 kW PV inverter connected to an unloaded transformer. The first one is representative of the normal behaviour, while figure 9 corresponds to the initial synchronization moment.

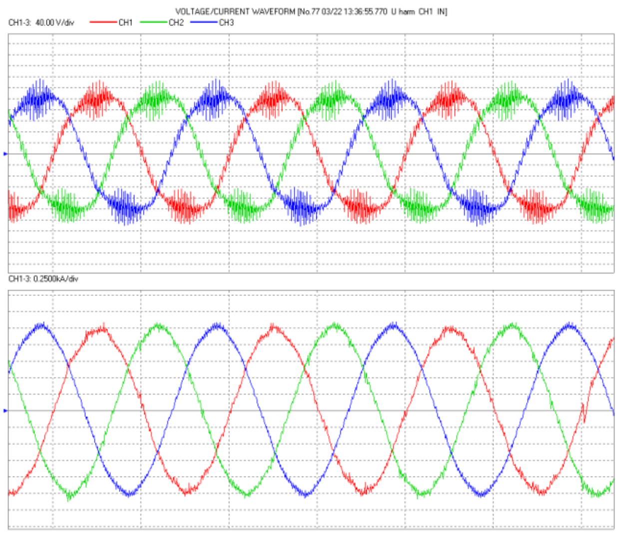

Fig. 8. Voltage and current distortion in normal operation of LV photovoltaic generator

As in the two previous cases, it can be seen that the voltage distortion is clearly higher than the current distortion. The reason is, once again, the effect of the inverter switching on the LC characteristics of the system, including the network impedance and the generator filter. The distortion in these measurements is quite extreme, due to the lack of damping because of the absence of loads and the high power of the generator. However, some problems −such as audible noise or failures of electronic devices, particularly wrong measurements of revenue meters− have been detected in normal distribution networks with loads and smaller generators.

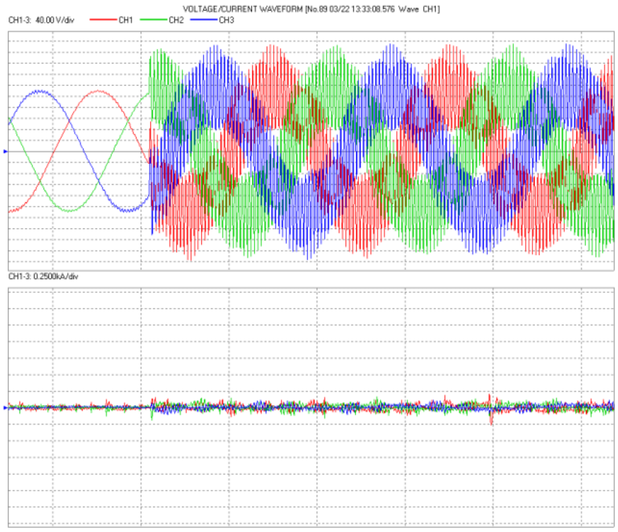

Fig. 9. Voltage and current distortion during synchronization of LV photovoltaic generator

In all these cases, the frequency of the disturbances detected has been higher than 2 kHz, so the behaviour of the inverters was correct according to the existing harmonic standards.
In addition, some cases are difficult to identify since the superimposed frequency can exceed 10 kHz, making the measurement with many power quality analysers impossible.

4. Conclusion

Present EMC standards cover the typical disturbances produced by loads. However, there is a gap in the standardization since interharmonics and voltage distortion in the range from 2 kHz to 150 kHz are insufficiently covered.
On the other hand, a real network may have impedances –in particular LC characteristics− very different from the impedances of laboratory tests used for EMC certification.

As a consequence, the installation of power converters, for instance inverters used for the connection of distributed generation to the network, can lead to voltage distortions that impair the normal behaviour of other elements.

New standards on immunity to conducted disturbances in the frequency range from 2 kHz to 150 kHz will represent a significant improvement. Nevertheless, several aspects are still to be addressed, firstly because cases of high distortion cannot be solved by requiring an extraordinary immunity, making normal equipment unnecessarily expensive. Other aspects are not included in the scope of the standard under development, such as the immunity to interharmonics –out of the scope of the standard−, or non-functional aspects.
Examples of non-functional aspect are audible noise or overheating, which are not included in normal EMC laboratory tests.

Therefore, disturbance emission in the range from 2 kHz to 150 kHz should be also addressed, particularly in the case of inverters that usually operate within this frequency range. EMC tests should take into account the effect of normal networks, including representative LC and damping characteristics in the laboratory tests.

In the case of high power converters, which are not covered by harmonised standards, attention should be paid to the parameters of the particular network to which they are connected, especially in systems with little damping, in which LC characteristics predominate.

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[3] CENELEC, EN 61000-6-2 Electromagnetic compatibility (EMC): Generic standards – Immunity for industrial environments

[4] CENELEC, EN 61000-6-3 Electromagnetic compatibility (EMC): Generic standards – Emission for residential, commercial and light-industrial environments

[5] CENELEC, EN 61000-6-4 Electromagnetic compatibility (EMC): Generic standards – Emission for industrial environments

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[7] CENELEC, EN 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

[8] International Electrotechnical Commission (IEC) IEC/TR 61000-3-6 Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems