Influence of power supply distortion on power conversion harmonics measurements

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Acknowledgements

This research was part of the project INCASE and was funded by the European Union through the Interreg Va 2 Seas program.

Keywords

«EMC/EMI», «Harmonics», «Power Supply», «Electronic Ballast»

Abstract

The frequency range 2 – 150 kHz, typically occupied by switching harmonics and communication signals, is still a gap in the IEC emission standards. The main difficulty in reaching a standardized measurement method is finding a suitable power source. The low-frequency and high-frequency content of the power supply is deterministic for the measured emission, as well as the source impedance. Measurements and analyses are done on both PV-inverters and compact fluorescent lamps to see the influence of the source on the emission.

Introduction

The low voltage distribution networks experience a large shift in consumer topology. These new topologies and applications change the emission and immunity behavior on the low voltage grid. Most household appliances contain SMPS (switched mode power supplies), which are sources of high frequency disturbances. The increased use of decentralized energy sources, using grid connected inverters to inject the generated power into the grid, causes higher frequency (HF) harmonics which pollute the grid voltage. The customers demand for more energy efficiency, increases the use of modern lighting, which again are using high-frequency switching technologies. All these devices emit PCH (Power Conversion Harmonics) ranging from 2 kHz to several MHz and are related to the PWM switching behavior.

Additionally, the grid's nature turns from resistive-inductive to resistive-capacitive, due to the presence of EMI-filters in most devices. This lowers the grid impedance, especially at those higher frequencies. Consequently, EMC and power quality specialists see the number of problems related to the 2 to 150 kHz range increase. CENELEC publishes every two year a list of the reported problems in the frequency range [1].

To cope with this problem, immunity and emission standards are required in the considered frequency range. The first exists; the latter is still under consideration. Although measurements of the HF harmonics (>2 kHz) are quite common, making reproducible measurements seems to be difficult. This explains the current lack of a basic emission measurement standard. A definition of compatibility levels is also under consideration for years.

The paper is further elaborated as follows. The current state of the emission standards is discussed in the first section. The research of the authors focuses on emission measurements in the range above 2 kHz. In the following section several influencing parameters are discussed and the used measurement setup is explained. This paper only focuses on the main influencing parameters, meaning the power supply impedance and the low-frequency (LF) and high-frequency (HF) harmonic content. This is further researched in the last sections.

Standards in the range 2 – 150 kHz

For making accurate emission measurements in the range 2 – 150 kHz a well-defined measurement setup is required. For making reproducible emission measurements, a standardized measurement method is necessary. At current state, there is no basic measurement standard in this frequency range available. IEC 61000-4-7 [2] and 61000-4-30 [3] mention possible advisory methods to measure harmonics above 2 kHz, but none of the methods are adequately defined to perform reproducible measurements. CISPR16/EN55016 [4] and EN50065 [5] describe possible AMN (artificial mains networks) and the necessary bandwidth of the EMI-receiver. CISPR15/EN55015 [6] describes provisional limits for lighting equipment and CISPR11/EN55011[7] describes limits for induction cooking devices. Technical specifications are provided for the emission of PV and frequency inverters. The main problem in all the standards is that the source is not well defined.

Measuring parameters

In [8], an in-depth discussion is given on the different parameters, which are influencing the emission measurement. That work concludes that the power supply voltage (amplitude, RMS-value and harmonic content) and impedance are determining the emission. In this work, these parameters are further investigated. Consider the measurement setup in fig. 1. The device under test (right) can be considered as a source with internal impedance. The power supply (left) is the main subject of this paper. This can be the public voltage grid or specific power sources. Following both the harmonics standards (below 2 kHz) and the conducted emission standards (above 150 kHz), the current is measured between 2 and 150 kHz. Above 150 kHz this is done with a voltage measurement across a defined 50 Ω impedance. The current measurement is done with a 30A LEM DC-100 MHz current probe. The measurements are captured with a Rohde&Schwarz RTE1024 oscilloscope. The data is visualized with Matlab.

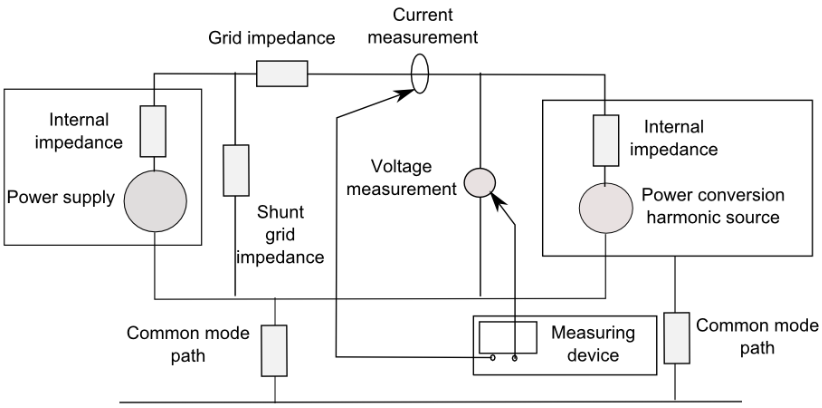

Fig. 1: Basic measurement setup

Fig. 2 shows the researched problem. For research on power conversion harmonics, a measurement on a compact fluorescent lamp (CFL) is performed. The left figure shows the measurement when supplied by a synchronous generator, the right figure shows the measurement of the same CFL, supplied by a 61000-3-2 [9] full compliant source. As can be seen, the measurements are very different. The noise floor is higher and unexpected frequencies appear. For unknown devices, it is not possible to know what is generated by the source and what is generated by the DUT (device under test). Other full complaint sources show different results. The measurements contain supplementary harmonics, due to the source.

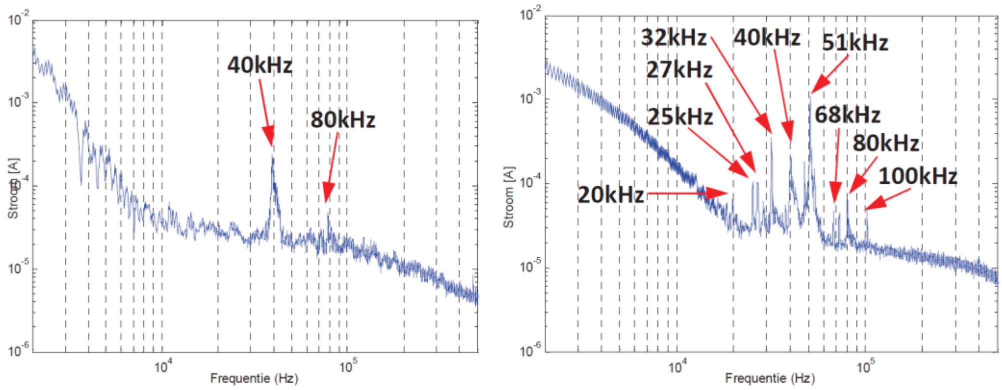

Fig. 2: Left: emission measurement of CFL, supplied by synchronous generator. Right: emission measurement on same CFL, supplied by 61000-3-2 full compliant source

The measurement cannot be performed with the public voltage grid as power supply. As the voltage is not stable and both LF and HF distortion can occur, measurements will be influenced.

Influence of the source impedance on the emission

Switching harmonics can be modeled as voltage or current sources, injecting harmonics into the grid. As Ohm's law is valid, the high frequency current in the grid will depend on the grid impedance, built by the source impedance, cables and all connected devices. When performing reproducible measurements, the grid impedance should be defined in both magnitude and nature. An AMN normally does this. The main drawback is that the lower the frequency, the larger the defined impedance will depend on the connected source. Research shows that the grid-impedance should be as low as 0.5 Ohm for compliance measurements. The second problem is the nature of the impedance. The low-voltage grid is nowadays more resistive-capacitive, due to the presence of EMI-filters in most electronic devices. This capacitive nature, including the decrease of impedance with increase of frequency, must be represented by the source or AMN. Fig. 3 shows two time domain measurements on the same CFL. The left figure gives the measurement on the public grid, the second gives the measurement on the power source. As can be seen, due to the different impedance, to amplitude is different, but also the waveform (and in this way the related spectrum) differs. This can be due to the nature of the impedance or due to the distortion of the power supply sinusoidal voltage.

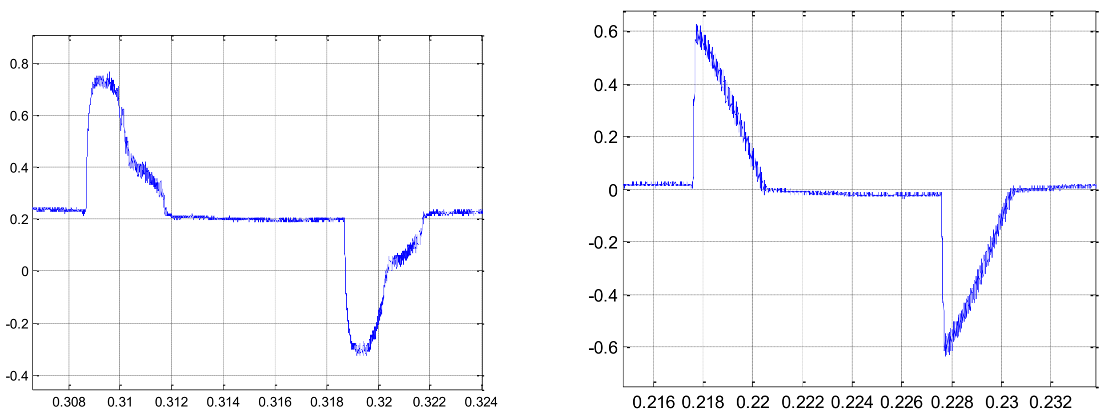

Fig. 3. Time domain measurement: (left) CFL on public grid, (right) CFL on power source

Influence of low frequency distortion (<2 kHz) on the emission

Fig. 4 shows the same current measurement on the synchronous generator. The peak value of the current is lower, but especially the LF distortion is obvious. This is due to the voltage distortion in small generators (11 kVA). In this section the influence of this LF harmonics on the HF harmonics is investigated.

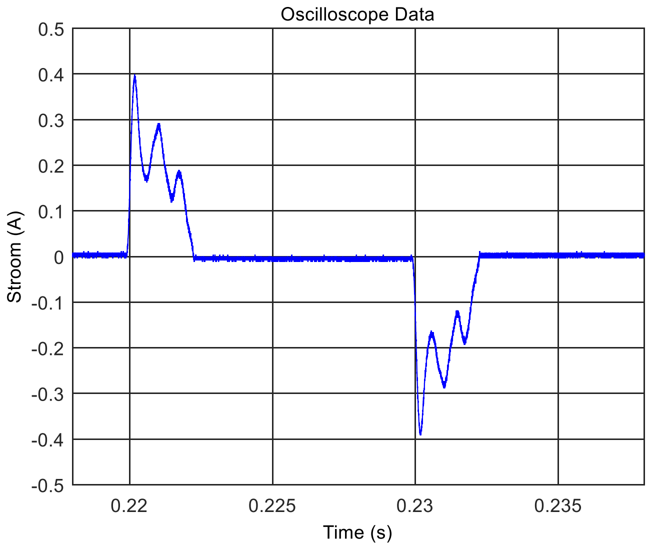

Fig. 4. Time domain measurement: CFL on synchronous generator

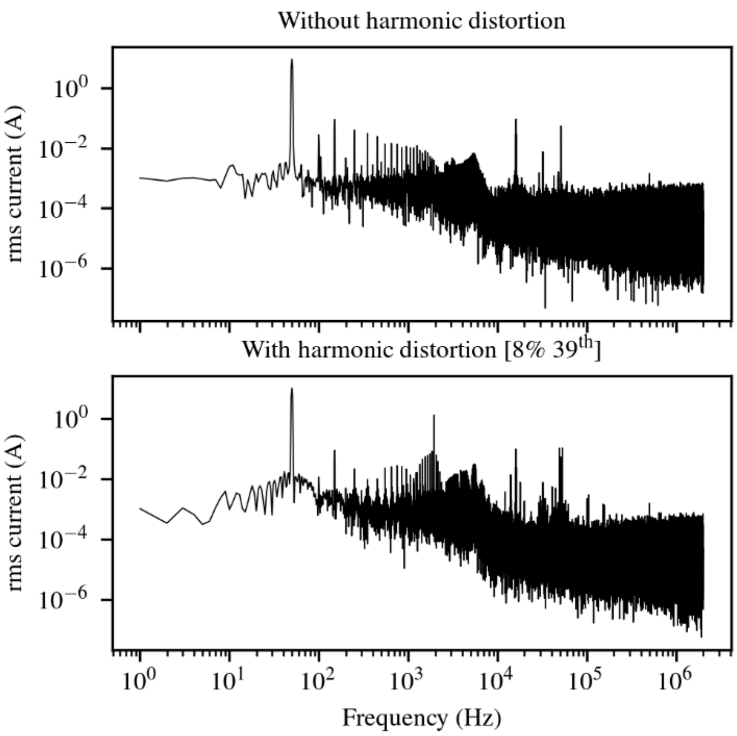

Fig. 5: Emission of PV-inverter with non-distorted and distorted power supply

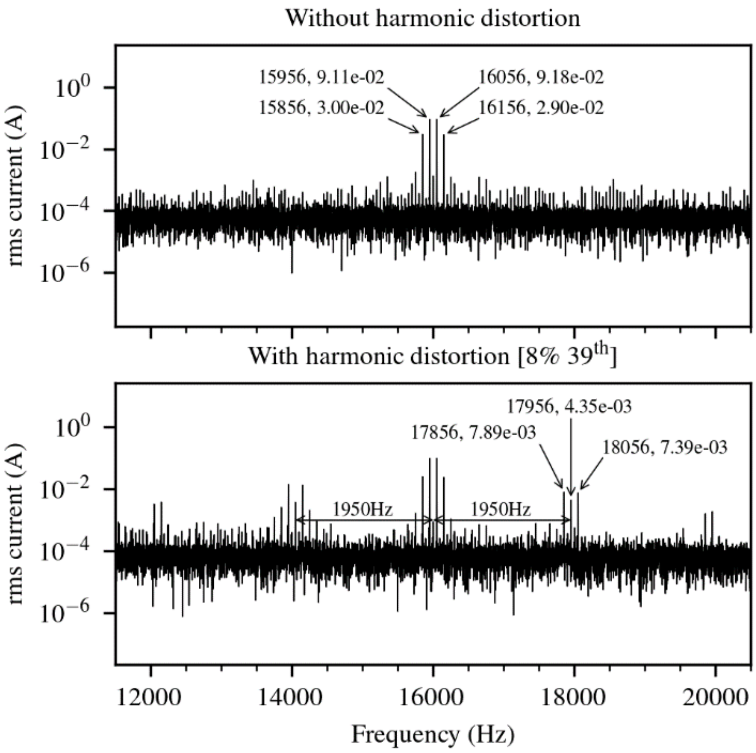

Fig. 6: Sidebands created by the LF-distortion

Fig. 5 gives the measured emission of a PV-inverter, connected to the power source. It is more interesting to investigate this device than a CFL, as a constant small band emission is generated at 16 kHz. The influence of harmonics in the power supply is in this way much easier to investigate, as discrete frequencies will occur. The CFL has, in comparison a broadband emission. The second harmonic caused by the PV-inverter can be found at 32 kHz. It can be noticed that two other frequencies are visible, which are due to the source (29 and 51 kHz).

The emission of the PV-inverter is situated at approximately 16 kHz ± k.50Hz (with k odd). When adding a 39th harmonic (1950 Hz) it is obvious that not only the 39th harmonic changes, but also sidebands around 16 kHz, meaning 16 kHz ± 1950 Hz ± k.50Hz (with k odd). The same appears at 51 kHz. This means that LF distortion will influence the measured spectrum (fig. 6), as the switching harmonics of the DUT and the distortion of the source create new harmonics.

Influence of high-frequency distortion (>2 kHz) on the emission

Reconsider figs. 3 and 4. You can notice that the present noise is much higher on fig. 3 in comparison to fig. 4. The same can be noticed when comparing the related spectra (fig. 2). The HF spectrum of the synchronous generator can be considered as clean.

In the previous section, the influence of LF distortion on HF distortion could be measured. The same can be told for distortion above 2 kHz. The authors tested several high-end sources (several Spitzenberger & Spies, Keysight, Kikusui). Several sources contain a 51 kHz component, one contained an 83 kHz component. This internal harmonic is caused by the internal PWM waveform generator, creating the output voltage. As the full compliant sources only need to create harmonics up to 2 kHz, a 51 kHz PWM is sufficient to create the waveform. Unfortunately, for performing measurements up to 150 kHz, this harmonics are problematic. Once the switching DUT was connected, the distortion in the source voltage had a large influence on the emission measurement. Equidistant sidebands around 51 kHz are appearing (fig. 7), due to the combination of the 51kHz and 16 kHz disturbances.

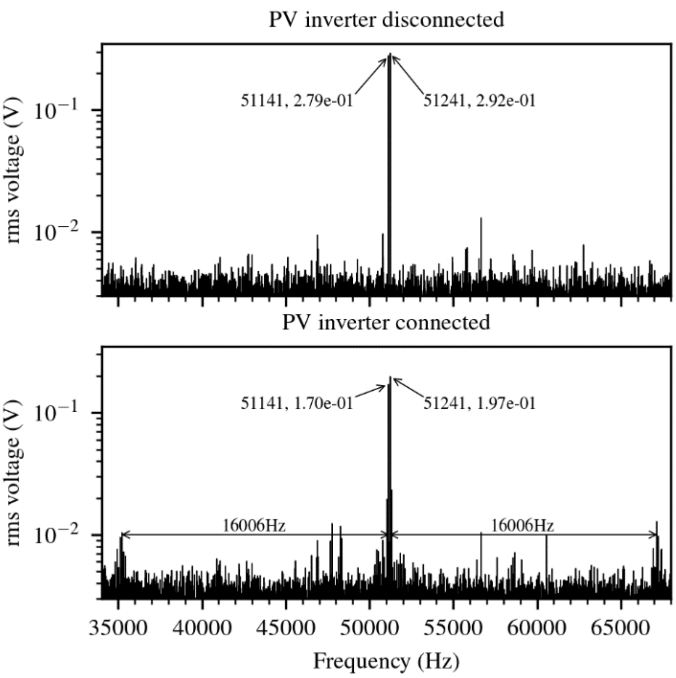

Fig. 7: Sidebands created by the HF-distortion

Conclusion

The initial research problem was to have reproducible emission measurements in the range 2 to 150 kHz. The paper showed that both LF and HF distortion in the power supply voltage highly influences the measured spectra. Additionally, the impedance magnitude and nature will influence the measurements. To reach standardized measurements, the following source definition is required:

- Clean power source, having no LF distortion
- Clean power source, having no HF distortion above 150 kHz
- A source impedance, both defined in magnitude and nature in the specified range

In the research of the authors, none of the tested sources were adequate to perform the measurements. To have reproducible measurements four options were tested:

- Search on power sources containing no voltage components up to 150 kHz. Several sources were tested, none complied. Several other manufacturers were contacted but they could not deliver what was necessary.
- An option is to filter the output. This gave better results, but changes the impedance. The definition of the combined filter-source impedance will be a part of the solution.
- The best results were reached with the synchronous generator as there is no high frequency distortion. The main drawback of this method is that there is a low frequency distortion, but this can be considered as constant during the measurements. The second drawback is that the impedance is rather high.
- Good results were also reached with an asynchronous generator in island operation. The LF spectrum is clean, but depends highly on the saturation of the generator. The HF spectrum is also clean and similar to the results of the synchronous generator. The main drawback is the influence of the capacitors needed for the magnetization of the generator. To adjust the voltage, the capacitance is changed. This will change the impedance and so the amplitude of the current.

References

[1] CENELEC: SC 205A - Study Report on Electromagnetic Interference between Electrical Equipment / Systems in the Frequency Range below 150kHz (Ed.2)
[2] IEC 61000-4-7: Part *4-7*: Testing and measurement techniques –. General guide on harmonics and interharmonics measurements and instrumentation, *for* power supply systems and equipment connected thereto, 2002.
[3] IEC 61000-4-30: Part *4-30*: Testing and measurement techniques - Power quality measurement methods, 2015.
[4] CISPR 16 −1 Ed. 2.1: 'Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus', 2002.
[5] EN50065-1: 'Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz – Part 1: General requirements, frequency bands and electromagnetic disturbances', 2011.
[6] CISPR15: Methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment,2013.
[7] CISPR11: Industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement,2016.
[8] Knockaert J. e.a.: Discussion on preconditions for reproducible measurements on power conversion harmonics between 2 and 150 kHz, CIRED 2017, paper 1359.
[9] EN61000-3-2 Ed.4: 'Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase', 2014.