Measurements of primary and secondary emission in the supraharmonic frequency range 2 – 150 kHz

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ABSTRACT

This paper presents an analysis of current emission from low-voltage devices in the frequency range from 2 to 150 kHz. Measurements on an installation with a photovoltaic (PV) inverter together with common household appliances are presented. It is shown to be important to distinguish between emission driven by a certain device ("primary emission") and emission driven by other devices ("secondary emission"). Measurements show that primary emission can be strongly impacted by neighbouring devices. Moreover it is shown that supraharmonic currents flow between connected appliances and measurements of supraharmonic distortion should be performed on site, inside the installation.

INTRODUCTION

When introducing modern energy efficient appliances into the low-voltage network new types of power quality phenomenon will occur. In addition to the injection of harmonic current, most energy efficient appliances also inject emission into the installation in the frequency range between 2 and 150 kHz, hereafter referred to as supraharmonics [1-5]. Limits are set to harmonic emission for PV installations and low voltage equipment in [6, 7] but for most equipment no limits are set for supraharmonics. Within this frequency range there are frequency bands where power line communication is allowed and there is a risk for interference between communications signals and emission from non-communicating devices [8]. Spread of emission in the frequency range 2 kHz to 150 kHz from low voltage devices is still not fully understood but it is evident that the propagation differs from that of harmonic emission [1, 9-14] especially in the way in which different appliances influence each other. A measurement at one location (e.g. in a laboratory using a line impedance stabilization network, LISN) might not be relevant for other locations.

PRIMARY AND SECONDAY EMISSION

Primary emission

When analyzing measurements of end-user equipment made in a real live power-grid i.e. when not using an LISN it is important to distinguish between primary emission and secondary emission [13, 15]. Primary emission is here defined as the emission originating from the equipment under test, EUT. Using an LISN only primary emission will be present. The level of primary emission in the field is mainly affected by:

- ✓ Topology of the EUT
- ✓ Impedance at the connection point
- ✓ Resonances

The impedance seen at the connection point of a device on the low voltage network consist of the impedance of transformers and cables, referred to as "the grid" and the impedance of the wiring inside a building together with other devices connected there. This could be referred to as the impedance of the installation. The impedance of the grid is dominated by inductance in the frequency range 2 to 150 kHz and is therefore relatively high compared to the impedance of the installation (that is often dominated by the capacitance of connected devices).

Secondary emission

Secondary emission is defined as the emission that is generated elsewhere and propagates to the EUT due to the low impedance level at the terminal of the equipment. The secondary emission is not always present and is not seen at the terminal of the EUT when connected to a LISN. For equipment connected to the low voltage network the secondary emission is affected by:

- ✓ Emission from the neighboring equipment
- ✓ Impedance at the terminal of the EUT in relation to impedance of the grid and of the installation

A device will be subjected to secondary emission if there is emission present at a frequency where the device offers a low enough impedance to allow a current to flow. In Figure 1 the current measured at the terminal of an 8 W light emitting diode (LED) lamp is shown. The measurement on the left hand side shows the primary emission from the LED, i. e. when the lamp is the only device connected. On the right hand side in the figure the current at the terminal of the same lamp is shown when the lamp is connected near other home appliances. The secondary emission is visible, in this case, as narrowband components at 42 kHz, 55 kHz, 85 kHz and 100 kHz. Neither of these components originates from the LED lamp.

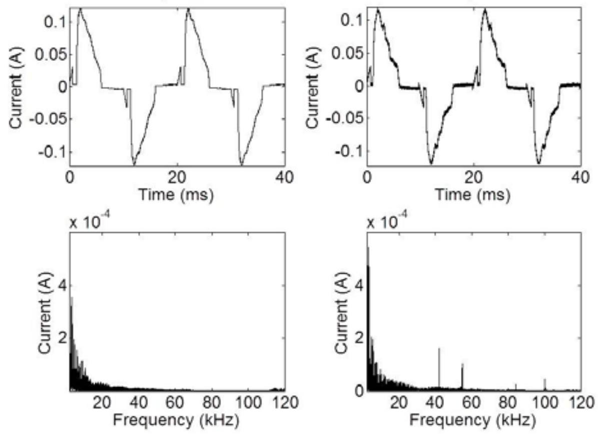

Figure 1 Current measured at terminal of a 8 W LED lamp when connected alone (left) and close to a number of other home appliances (right) both in the time domain (upper) and the frequency domain (lower)

High levels of secondary emission were shown to arise, in [8], due to power-line communication, although the term "secondary emission" was not used in that publication.

MEASUREMENTS

In the forthcoming section a number of measurements of primary and secondary emission will be presented. The primary and secondary emission measured at individual equipment and the total emission from the installation propagating to the grid will be discussed.

As described, among others in [15], the emitted signals in this frequency range will to a high extent propagate towards neighboring equipment inside the installation if there are any. The reason being that modern equipment often is capacitive and therefor has low impedance for higher frequencies, as seen from the grid.

Experimental setup

Measurements have been performed in the Pehr Högström laboratory at Luleå University of Technology Skellefteå where a full-scale model of a house has been built. In the test-house a number of common household appliances have been connected. In addition to that, a PV-installation of 2.5 kW has been built on the roof of the laboratory and connected via a DC/AC single-phase inverter to the test-house. During the experiment, the household equipment has been connected and disconnected while the current emission has been recorded. The currents have been measured at the inverter as well as at some of the other appliances connected in the house. All equipment, including the PV system, has been connected to the same phase. The current has also been measured at the delivery point to the house covering all devices connected. Prior to the experiment, individual measurements have been made of all the equipment used to be able to determine the most likely source of the signals found during the experiment.

PV Inverter connected alone

The inverter used is a single-phase inverter with a High Frequency transformer. It has a rated output of 2.5 kW at 230 V, 50 Hz. The primary emission originating from the PV-inverter consists most likely of the residues from the switching circuit, which is constant in frequency. The main component of the primary emission can be measured at 16 kHz at all time when the inverter is operating and also harmonics of that frequency can be seen (32 kHz, 48 kHz etc.) with decreasing amplitude. During production, the peak value of the 16 kHz component varies between 25 mA and 30 mA. When the production is idle, the value is zero. From this it is concluded that the PV inverter is the source of the 16 kHz component.

PV inverter and other equipment

A number of experiments have been performed with other equipment, beyond the PV installation, connected. To examine how responsive the inverter is to secondary emission, a number of devices were connected and disconnected to the same phase as the inverter in the test-house. The following devices were connected in different combinations; a laptop, a TV, a stove, a microwave oven and three different LED lamps. The pattern of how these appliances were connected and disconnected is shown on the right hand side in Figure 2. The current was measured at the terminal of the inverter for every alteration made, making it a total of 45 snapshots. In Figure 2 (left hand side) the current spectrogram of those measurements is shown. The primary emission at 16 kHz remains the dominating component in the spectrum. Secondary emission is however clearly visible at most other frequencies. Worth mentioning here is that the fundamental current as well as the amplitude of the emission of the neighboring appliances are in most cases significantly lower than for the inverter.

From Figure 2 some interactions between the inverter and other equipment can clearly be seen; for instance during measurement 28 to 32 when LED lamp no 3 is connected. The lamp is most likely responsible for the high emission from 85 kHz and onwards. The conclusion that the lamp is the source of this emission is also supported by individual measurements taken of the lamp where these frequency components can be seen. It can also be observed that when the TV is connected and operating, a signal appears at 55 kHz, it disappears when the TV is either in stand-by mode or disconnected so this 55 kHz signal is likely a residue from the switching circuit in the TV.

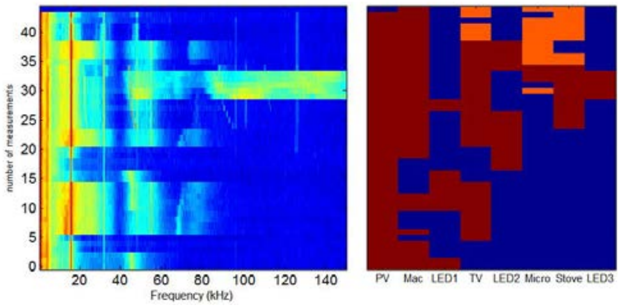

Figure 2 The image on the left is the spectrogram of the current taken by the PV-inverter for 45 measurements while neighboring equipment is connected and disconnected. The image on the right shows at what time each appliance was connected. The horizontal axis indicates different appliances and the vertical axis number of corresponding measurement in the spectrogram. Red fields indicates time when equipment is connected and operating; orange when equipment was connected but in stand-by mode and finally blue indicates times when equipment was disconnected.

Primary emission affected by neighboring devices

The experiments described in the previous section revealed that not only the secondary emission but also the primary emission at 16 kHz is impacted by the presence of neighboring equipment. For example, the connection of the TV also affects the magnitude of the primary emission from the inverter. During the times when the TV is connected (both operating and in stand-by mode) the magnitude of the 16 kHz component increases as well as the magnitude of the harmonics of that component. This indicates that there could be a resonance between the inverter and the EMC-filter of the TV. When looking at the peak value of the 16 kHz components for the 45 snapshots the value varies more than for the measurements where the inverter is the only device connected. The peak value varies between 22 mA and 202 mA. The lowest value corresponds to the instant when, in addition to the inverter, the laptop is connected as well as the stove and micro are connected but in stand-by mode. The highest value corresponds to the instant when the laptop, TV, LED2, micro and stove are all connected and operating. When comparing the instances when the TV is not connected to the instances when the TV is connected the peak value of the 16 kHz component increases with a minimum of 30 mA. This makes the value of the component, measured at the terminal of the inverter, at least twice as high when the TV is connected compered to when it is not as shown in Figure 3.

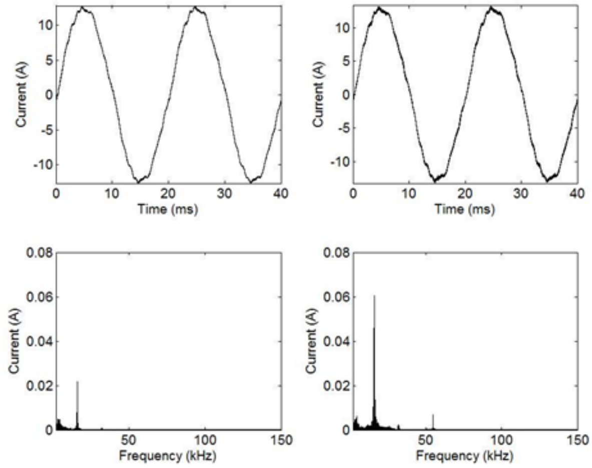

Figure 3 Upper left, current at the inverter shown in the time domain when the TV is not connected. Upper right, current at the inverter shown in the time domain when the TV is connected. Lower left, current at the inverter shown in the frequency domain when the TV is not connected. Lower right, current at the inverter shown in the frequency domain when the TV is connected

Emission propagating towards the grid

The level of the 16 kHz components as measured at the point of connection of the test-house remains rather constant except a slight drop during the time the stove is connected and operating. The connection of the TV seems to have no impact on the amplitude neither in the voltage nor in the current at the point of common coupling (PCC). The amplitude of the 16 kHz components is lower at the PCC than at the terminal of the inverter as can be seen in Figure 4 where both the amplitude measured at the PCC and at the PV are shown for the 45 consecutive snapshots.

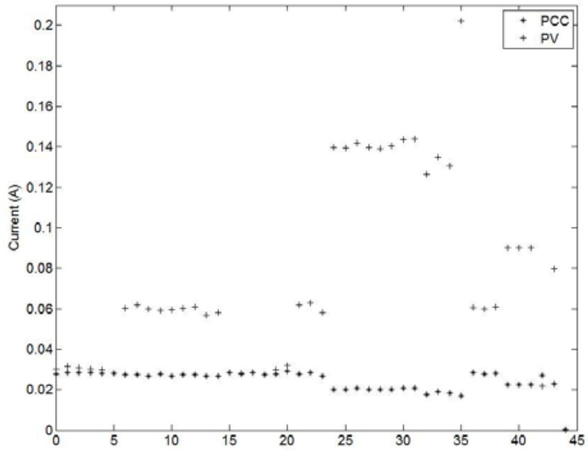

Figure 4 Peak value of the 16 kHz component for 45 measurements both at the PCC (stars) and at the terminal of the inverter (crosses)

The connection and disconnection of different appliances can be seen also at the PCC in the test-house but not as clearly as at the PV. The dominating signal is the 16 kHz component visible as long as the inverter is operating. The emission seen from 85 kHz and up to 150 kHz (during measurement 28 to 32) that was easily spotted in Figure 2 is could not be measured at all at the PCC. It is concluded that these frequency components only propagate between appliances, and not into the grid.

CONCLUSIONS

To understand the current at the terminals of an electronic device, like a PV inverter, operating in an installation, a distinction should be made between primary and secondary emission. The secondary emission for a device is driven by the primary emission from neighboring devices. It has been confirmed by measurements that both the primary and secondary emission depend strongly on the presence of neighboring devices.

Both primary and secondary emission should be taken into consideration when compatibility levels and immunity levels for end-user equipment are discussed.

High levels of currents within the frequency range between 2 kHz and 150 kHz can lead to shortening of the life time of electrolyte capacitors used in filters [16] or produce audible noise if the frequency is below 20 kHz.

It is also shown that measurements for an installation as a whole do not give a correct representation of the emission levels inside the installation. The emission levels at the terminal of a device can be substantially higher than those found at the delivery point of the installation.

The other way around, emission measurements at equipment terminals do not give a good indication of the emission from a complete installation into the grid.

Results from emission tests in the laboratory also do not give a good indication of the emission in practical situations. The emission in the field can be several times higher than the test results.

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