MEASUREMENT AND ANALYSIS OF HIGH-FREQUENCY CONDUCTED DISTURBANCES

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ABSTRACT

The frequency range above the "traditional" harmonic range up to about 2 to 3 kHz has been under investigation for a while but less attention has been paid to the frequency range slightly above. This paper presents measurements both in laboratory environment and in the field on different types of equipment and general long- term measurement on site in the low voltage network. The general aim of this paper is to increase the knowledge about voltage and current distortion in the frequency range above 2 kHz.

INTRODUCTION

The development of power electronic and the efforts to save energy has among others lead to the use of various types of switching techniques. There are many benefits of using this technology but also some drawbacks. Besides that these types of equipments produces lower-order harmonics (up to 1 or 2 kHz) they also produce high-frequency (HF) components. These components can be measured in the low-voltage network.

To handle the problems with lower-order harmonics the standards are in place to limit emission by equipment [1]. Emission limits have among others resulted in the use of active power factor correction (APFC) circuits. For example, lighting equipment larger than 25 W has quite stringent limits and therefore the use of APFC is common with this type of equipment. The APFC circuit is an additional source of these HF signals next to the switching frequencies used for the dc/dc conversion in the electronic equipment.

In this paper, measurement results will be presented of voltages and current distortion in the frequency range from 2 kHz up to a few hundred kHz. Measurements of current distortion for different devices will be presented first, followed by measurements of voltage distortion at a number of locations in the low-voltage network.

MEASUREMENT EQUIPMENT USED

Measurements in the higher frequency range, above the traditionally harmonic range, have been getting easier due to the development in measurement technology and in commercially available software to perform a wide range of analyses on the data. However a number of technical challenges remained. The signals in this frequency range have much lower amplitude than the fundamental (50 or 60 Hz) amplitude. The dynamic range of the A/D converter would be taken up completely by the fundamental component; resulting in a high level of quantification noise. A band-pass filter has been used, with the lower cut- off around 2 kHz to suppress the 50-Hz component, and the higher cut-off around 1 MHz to prevent aliasing [2]. For the current measurements only the high cut-off was used.
The sampling frequency used is 10 MS/s and the instrument has a 12 bits resolution.

The current measurements were performed in the laboratory, but by using the normal supply. No artificial mains network (as for instance proposed in CISPR 16-1-2 [3]) was used. The measurements are a specific case with a specific network voltage quality affecting the current drawn by the loads. The currents are thus representative for the currents that will occur in practical applications of the equipment.

The voltage measurements were performed at different domestic and commercial locations. A 100-ms snapshot of the voltage was taken every 10 minutes during a period between 20 and 30 hours.

MEASUREMENTS ON DIFFERENT LOADS

A number of ordinary small electronic end-user devices have been tested. Both the voltage and the current at the terminals have been measured and some of the results are shown below. More measurement results, including the interaction between different devices are presented in [4] and [5]. In the forthcoming sections the measurements will be presented in three different ways.

Time domain

The first measurement, shown in fig. 1, is on a computer with a switch mode power supply equipped with active power factor correction. The figure shows both the current and voltage supplying the computer. The voltage was filtered by using an analog filter whereas a digital filter was used for the current.

The current drawn by the computer is close to sinusoidal with the exception of some small deviations especially around the zero crossing. The current is slightly leading the voltage. The filtered voltage shows some minor recurrent oscillations that are synchronized with the fundamental frequency at 50 Hz. The waveform distortion of APFC circuits is discussed in further detail in [5] and [6].

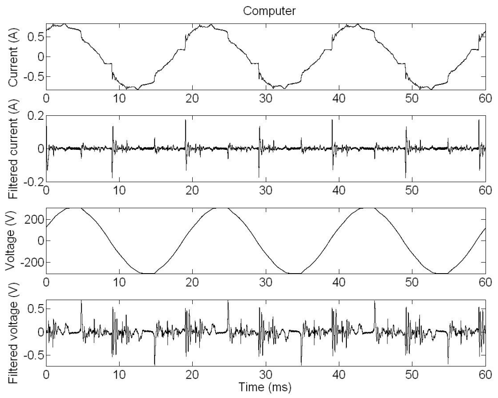

Fig. 1. Measured waveform of voltage and current at the terminals of a computer. From the top: Current, Filtered current, Voltage and filtered voltage.

More measurements are shown in Fig.2: the current drawn by a compact fluorescent lamp (CFL), a laptop charger, and a TFT screen. In all three cases the waveform is more distorted than in Fig.1, as no APFC is used.

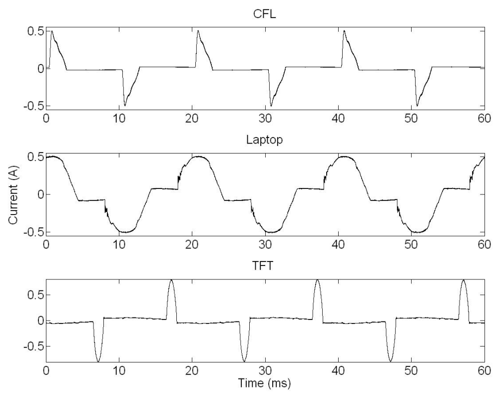

Fig. 2. Current taken by a CFL (top), Laptop (middle) and TFT screen (lower).

Frequency domain

A discrete Fourier transform (DFT) is applied on the voltage and the current at the terminals of the computer; the resulting spectra are shown in Fig.3. To show the difference between the voltage with and without load the background distortion (voltage before connection of the computer) is also shown. Some narrow band components are visible in the background distortion, which also show up the current. Most likely it is the voltage distortion that causes the current distortion. Also typically, the plot shows that in general the magnitude of both voltage and current distortion is higher in the lower frequency range. The middle and lower plot shows the spectrum of the voltage and current when the computer is connected. In the voltage spectrum a visible wideband components is visible from about 125 to 280 kHz. These components can also be seen in the current drawn by the computer. Therefore we can assume that these components are generated by the computer.

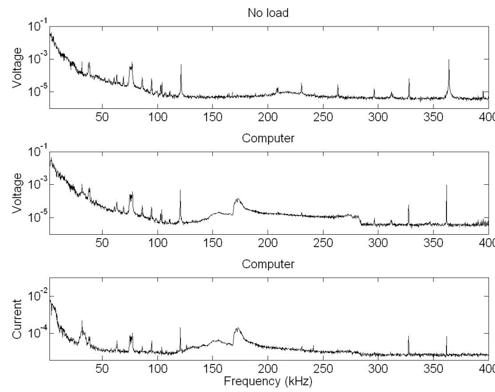

Fig. 3. The spectrum of the background distortion (upper). The voltage (middle) and current (lower) at the terminals of the computer.

The spectrum of the current drawn by the CFL, Laptop and TFT screen are shown in Fig. 4. The spectrum of the CFL shows wideband components around 35 and 65 kHz. The latter is also visible in the spectrum of the TFT. The laptop charger shows a rather smooth spectrum. The narrow-band components visible in the three spectra probably have their origin in the voltage distortion.

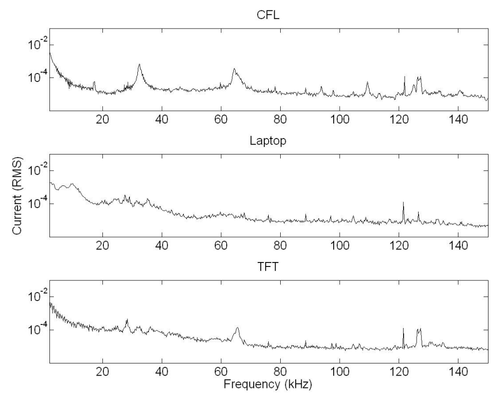

Fig. 4. The spectrum of the current drawn by a CFL upper, Laptop (middle) and TFT screen (lower) between 2 to 150 kHz.

Spectrogram

The spectrogram is a common method for presenting time-varying spectra e.g. in speech processing [7]. The short time Fourier transform was applied to the current in Fig. 1, resulting in the spectrogram in Fig. 5. The spectrogram shows how the frequency content of a signal varies over time. The magnitude is shown in colour shift where blue indicates the lowest and red the highest amplitude. The spectrogram reveals that, what appears in Fig. 3 to be a broadband component from 175 to 280 kHz, is in fact a time-varying narrow-band signal. The signal shifts in frequency with a period of 10 ms and is therefore synchronized with the power system frequency at 50 Hz.

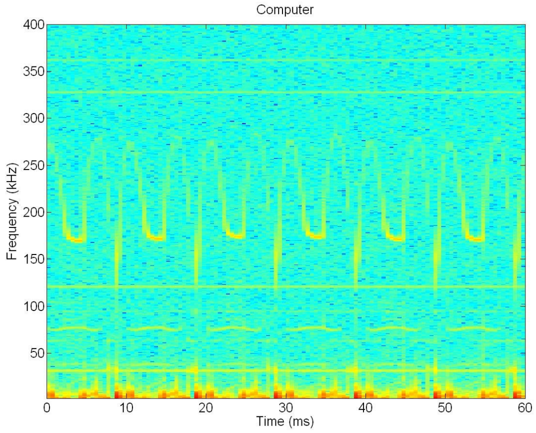

Fig. 5. The spectrogram of the current drawn by the computer.

Similar patterns have been found in the current taken by other devices equipped with APFC; see [5] for more examples. Equipment without APFC does in most cases not show clear patterns.

VOLTAGE MEASUREMENTS

At a shopping mall

Fig. 6 shows a long term measurement of the phase to neutral voltage at a shopping mall. The measurement was carried out at the circuit breaking panel feeding the lights in the shop. A 100 ms snapshot window was taken every 10 minutes from approximately 2.00 p.m. to 10.30 a.m. the following day. A DFT was applied on each snapshot and the resulting spectrum was grouped into 200 Hz band from 2 to 150 kHz as described in annex B in IEC 61000-4-7 [2]. The resulting spectra from the each snapshot were then plotted together in as shown in Fig. 6. Each horizontal band in Fig.6 represents the spectrum of one 100-ms window, where red indicated the highest amplitude and blue the lowest amplitude.

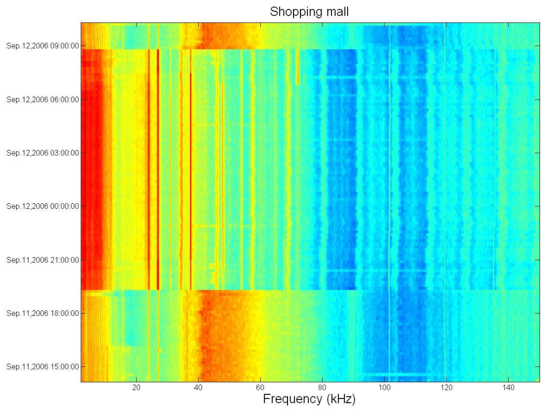

Fig. 6. Long-term measurement at a shopping mall.

Changes in daily pattern are clearly visible in the figure. The opening hours of the shop was between 10.00 a.m. and 7.00 p.m. but staff works approximately 1 to 2 hours before and after the opening hours. It can be seen that the spectrum is dramatically between 7.30 p.m. and 8.40 a.m. and outside of this period. This was correlated with the period during which the light in the shop was on.

Some components are present the whole day, like the narrow band components visible around approximately 24 and 27 kHz. The broad band signal from 35 to 60 kHz seems to be only present when the light is on. There are also narrow band components at that are not synchronized with the opening hours of the shopping mall as e.g. around 50 and 75 kHz.

Two individual spectra are shown in Fig. 7. The increase in amplitude of the narrow band components around 24 and 27 kHz during night may imply that these are attenuated when the light is on, possibly by the EMC filter of the lamps

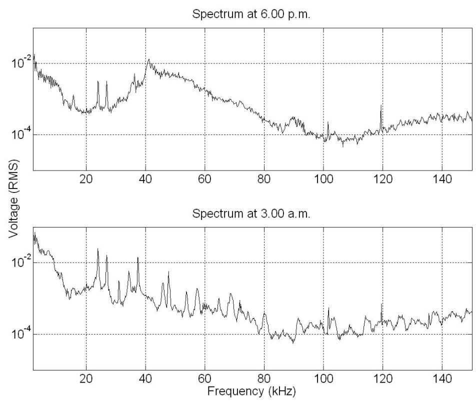

Fig. 7. The spectrum of the voltage at 6.00 p.m. (upper) and 3.00 a.m. (lower).

Another way to look upon the trend of variations in the frequency domain over time is to use statistics. Fig. 8 shows the peak values, 95 % values and mean values for the measurement at the department store. When interpreting the difference between the spectra, one has to consider that the difference between the 95 % and mean spectrum is due to daily variations, whereas the differences between the 95 % and peak spectrum is due to short durations peaks. In this case there was significant daily variation, but only limited variation in the form of short-duration peaks (with the exception of the range around 100 kHz)

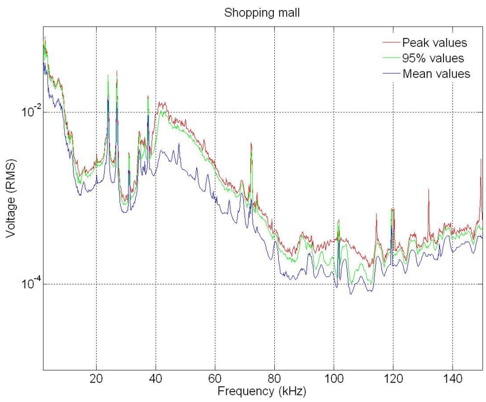

Fig. 8. The Peak (red) 95 % (green) and Mean values of all 100 ms snapshots in 200 Hz bands.

Measurements at different locations

The voltage distortion has been measured at five different locations. The statistics of these results are shown in Fig. 9. There are large deviations between the different locations, approximately about 10 to 100 times.

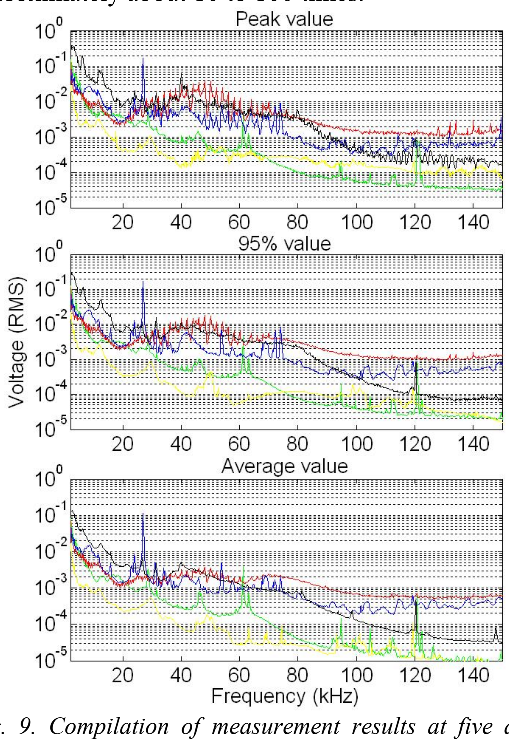

Fig. 9. Compilation of measurement results at five different locations.

CONCLUSION

The occurrence of distortion at frequencies above 2 kHz is often synchronized with the fundamental frequency. Especially APFC circuits results in such high-frequency distortion. The spectrogram is shown to be a useful tool to present the distortion due to APFC curcuits. The background distortion has a significant impact on the current distortion.

Waveform distortion in the frequency range from 2 to 150 kHz is also visible in the voltage at different locations. The distortion level shows large variation between different locations and can be partly correlated to local activities. However some components clearly originate (far) outside of the local premises.

The measurement methods presented in this paper can, among others, be used to correlate signal characteristics in time, frequency or time-frequency domain with equipment mal-operation or damage suspected due to high-frequency distortion.

Acknowledgments

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