MEASUREMENTS OF INTERACTION BETWEEN EQUIPMENT IN THE FREQUENCY RANGE 9 TO 95 KHZ

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ABSTRACT
A number of measurements have been performed on a full-scale electric model of a house to study equipment emission and impedances in the frequency range 9-95 kHz. Most equipment forms a much lower impedance path that the grid. The result is that conducted disturbances in this frequency range mainly flow between individual devices instead of between devices and the grid. It is also shown that the input impedance of equipment can be highly time dependent at a time scale below one cycle of the power-system frequency.

INTRODUCTION
With the change from inductive/resistive loads to capacitive/electronic loads it becomes vital to examine how this change affects our grid and other loads connected to the grid. This paper shows that there are currents in higher frequencies flowing between loads but the consequences, if any, remains to be investigated. It is important to reduce our power consumption and there must not be any questions unanswered about the impact on the grid from “new” loads or else the replacement of old energy consuming equipment to new energy saving equipment is at risk of being delayed.

The research on voltage and current distortion has mainly been constrained to the frequency range up to 1 or 2 kHz. Through the years a large amount of knowledge has been gathered here. However the amount of research covering higher frequencies is still very limited. One of the reasons for this lack of interest is the apparent absence of well documented cases of interference that can be clearly attributed to this frequency range. Another reason, and probably a more fundamental one, is the lack of appropriate measurement equipment for higher frequencies.

This paper presents some of the results from a set of measurements performed in a full-scale electric model of a house with a range of electronic equipment. The interaction between the devices in the frequency range 9-95 kHz is the main subject of this paper. The choice of the frequency range is identical to the frequency range allowed for power-line communication by the network operator.

EXPERIMENTAL SETUP
A full-scale electric model of a house was built in the laboratory at EMC on SITE, Luleå University of Technology. The setup is shown in Fig. 1: the load consists of equipment commonly found in a resident and are selected to represent equipment found in large quantities in ordinary households. All equipment is approved for the Swedish market. Measurements were performed to examine how these loads interact with each other and how they together and individually affect the impedance levels for higher frequencies. Measurements were done on individual loads as well as on the total. Focus has been on conducted emission in form of the high frequency currents (9-95 kHz) produced by modern electronic equipment and the propagation of the high frequency signals injected by power-line communication.

During the experiments a number of currents have been measured, including the total current and the current to individual equipment. Not all equipment currents could be measured due to the limited number of channels available on the measurement device.

EXPERIMENTAL RESULTS
During one of the measurements, four identical compact fluorescent lamps (CFLs) were connected one at the time to the experimental setup. For each lamp added the
currents were measured. No other electronic equipment was connected in the neighbourhood so that the waveform distortion observed would mainly be due to the load in the experimental setup. Fig. 2 shows the current harmonic content for three individual lamps as well as for all three together at the connection point. The spectrum was obtained by taking a discrete Fourier transform (DFT) over a 200 ms window. The amplitude of the harmonics at the connection point is the sum of the amplitude of the harmonics measured at each lamp.

Fig. 2. Current spectrum (up to harmonic 20) for the sum of three lamps (top left) and for the three individual lamps.

For higher frequencies however this is no longer the case. Fig. 3 shows that the current amplitude at the connection point is smaller than the current amplitude at the terminals of each individual lamp. The current at the connection point decreased for every lamp added and at the same time the current measured at the terminals of the lamps increased. This phenomenon was observed with other measurement setups with other loads connected as well [4]. In one setup a 30µF capacitor was connected in parallel with the lamps with the purpose to lower the impedance for higher frequencies and the current were again measured. For this measurement the frequency components between 40 and 50 kHz originating from the lamps were not visible at the connection point but instead a continuous noise-like spectrum appeared.

Fig. 3. Current spectrum (30-60 kHz) for the sum of three lamps (top left) and for the three individual lamps. (Y-axis in mA)

INTERACTION BETWEEN DEVICES

Influence between devices was measured at many occasions. One of the most interesting and unexpected ones is illustrated in Fig. 4. A compact fluorescent lamp (CFL) is connected close to an induction cooker. The current to the CFL is measured for different states of the induction cooker, corresponding to different amounts of energy delivered to the cooking process. The figure shows that a neighbouring device can have a strong influence on the emission and that this influence does not have to be time-independent.

Fig. 4. Spectrum of the current taken by a CFL close to an induction cooker. The different colors correspond to different states of the cooker.
LOADS EQUIPPED WITH DIODE RECTIFIER BRIDGES

Most modern household and office equipment contains a power-electronic converter as the interface with the grid. Therefore non-linear and time-dependent behaviour is expected. Time-dependent behaviour was observed as well. Some examples are shown in Fig. 5 and Fig. 6; the PLC source was connected on the grid-side of the delivery point. Fig. 5 shows the current measured at the terminals of a compact fluorescent lamp (CFL) and at the terminals of the PLC transmitter. The CFL shows the typical spectrum of a 4-pulse (single-phase) diode rectifier with a small capacitor on dc side. During the 20-ms time window shown in the figure, the PLC transmitter generates two burst of 43 kHz signals, seen as the high-frequency ripple on the current trace. The current is highest when the diode rectifier in the CFL is conducting. As the PLC transmitter operates as a voltage source, the conclusion can be drawn that the total impedance seen by this source (i.e. for all equipment connected) drops to about 30% once the diode rectifier starts to conduct. This reduction in impedance is most likely due to the dc-side capacitor in the CFL. Similar behaviour is shown in Fig. 6, this time the PLC transmitter generates a continuous signal at 12.5 kHz with rms voltage of about 7 V. As seen in Fig. 6 the non-linear character of the CFL results in additional frequencies being generated in the frequency range.

CONCLUSIONS

For equipment connected to a “clean” supply, the currents in the frequency range 9 – 95 kHz flow mainly between neighbouring devices, not between the devices and the grid. The individual devices form a low-impedance path in this frequency range. As a result of this, the emission in this frequency range will show much less spread over other customers than emission at lower frequencies. The impact of high-frequency distortion is likely to be limited to neighbouring equipment.

As a result of this when measuring the current distortion one has to be careful when selecting where to connect the instrument. The point of common coupling may not be the most suitable place.

It is not possible to use standard emission models, as each device appears to be unique. The emission from different devices will thus add less at these frequencies than at lower frequencies. The resulting spectrum from a large number of devices will thus more likely be a rather flat continuous spectrum. The emission and even the state of neighbouring equipment impact the current taken by a device. The emission measured by one device against a clean supply (like when using a LISN) is not a reliable prediction for the emission in a realistic environment.

Power line communication in the low-voltage network will result in significant currents through electronic devices due to the low impedance of the latter in the frequency range used by PLC (9-95 kHz). Future immunity requirements should be based on the permitted levels of PLC.

Equipment with a diode rectifier shows non-linear as well as time-dependent behaviour. The impedance of the device is lowest when the diodes are conducting, so that the current amplitude may be significantly higher than would be concluded from looking at the spectrum only. The non-linear character of the device results in additional frequencies being generated. The spectrogram (time-frequency-domain representation) is a suitable tool for studying these phenomena.
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REFERENCES


Fig. 6. Time-frequency representation of the current taken by a CFL while a PLC is transmitting. The large rectangular in the figure shows the actual spectrogram with time-axis horizontal and frequency axis vertical. To the left of the spectrogram the conventional spectrum (over the whole 200-ms window) is shown. Below and above the spectrogram the time-domain representation is reproduced: the original waveform below and the sliding window rms above. The scale to the right relates the colours to a logarithmic (dB) magnitude scale.

Fig. 7. Spectrogram of the current taken by an LCD screen in standby; no other loads connected (left); heat pump connected nearby (center) and PLC transmitter connected nearby (right).