TOTAL CONDUCTED EMISSION FROM A CUSTOMER IN THE FREQUENCY RANGE 2 TO 150 KHZ WITH DIFFERENT TYPES OF LIGHTING

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ABSTRACT

Harmonic studies in almost all cases are limited to the frequency range up to 2 or 2.5 kHz. In the frequency range above 2 kHz, almost no standards exist and measurements are rare. This paper presents measurements of the emission from a total installation in the frequency range 2 to 150 kHz. A physical model (electrically full-scale) of a domestic customer was built in the laboratory. Field measurements were performed on a medium-sized hotel. The impact of different types of lighting is shown to be small.

INTRODUCTION

In the frequency range between 2 and 150 kHz, almost no standards exist and therefore measurements are rare. As part of our group's on-going effort to increase the knowledge on voltage and current distortion in this frequency range, measurements were performed of the emission of a domestic customer. These measurements were parts of a series of experiments to study the impact on the harmonic emission of the replacement of incandescent lamps by electronic lighting [1].

A detached house was reproduced as a full-scale electrical model in the laboratory using real domestic equipment. A 108-minute switching pattern was defined representing the different types of equipment that are in use with a domestic customer during the course of a day. The voltage and current waveforms were captured over a 200-ms window with a sampling frequency of 10 MHz every minute during the 108-minute experiment. The experiment has been repeated for four different lighting loads, next to the normal equipment present in a house.

- ✓ In the scenario named "past" all lights were incandescent.
- ✓ In the scenario named "present" half of the lights have been switched to CFL's.
- ✓ For the scenario "future" all the remaining incandescent lights were replaced with 7-W LED lights and all the CFL's were left as they were.
- ✓ For the "far future" scenario all lights were 7-W LED lights.

A second experiment was made at a medium-sized hotel in Sweden [1]. All incandescent lamps at the hotel were replaced by LED and CFL lamps. Measurements were done before, during and after the change. The voltage and current waveform was captured for 200 ms with a sampling frequency of 10 MHz once every 10min during a 24 hour period resulting in 144 snapshots for every stage. The measurements were done at the point-of delivery for the hotel.

All lamps used in the experiments were low-power-factor lamps, with a power factor around 0.6.

MEASUREMENTS FOR A DOMESTIC COSTUMER

2 – 9 kHz

To quantify the emission in the frequency range 2 to 9 kHz, the root sum square over all components in this frequency range has been determined for every captured waveform. The results for 2-9 kHz are shown in Figure 1 for the four scenarios:

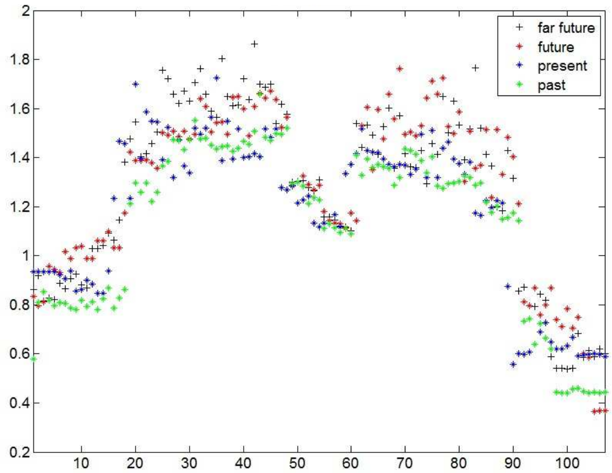

Figure 1 the root sum square of all components in the current between 2 and 9 kHz for the four scenarios

In this frequency range we see a modest increase in distortion (minutes 20 through 45 and 60 through 90 the highest values occur when the kitchen equipment (induction cooker and dishwasher) are operating. The shift from incandescent lamps to CFL and LED lamps does result in some increase in current distortion, but no significant increase. This increase may be due to an increase in the actual emission or in an increase of the current absorbed by the equipment due to distortion of the background voltage in this frequency range. In the latter case, the presence of CFL and LED does actually reduce the voltage distortion.

A remarkable observation is that during the first half of the measurement period (when the heat pump is on) the distortion is highest for “far future”, where for the second half (when the heat pump is off) it is highest for “future”. This confirms the complex interaction between equipment in this higher frequency range.

9-95 kHz

The spectrum of the high frequency distortion for the current measured at the delivery point was calculated for the 108 waveforms. The 95% value for each of the frequencies is displayed in Figure 2. The mean components are visible at the lower end of the spectrum up to about 15 kHz. These components show a minor decrease when replacing the incandescent lamps. There are also some components visible between 20 and 30 kHz and around 50 kHz and around 55 kHz. The component around 50 kHz doubles from “Past” to “Far Future” but is barely visible in the scenario “Future”.

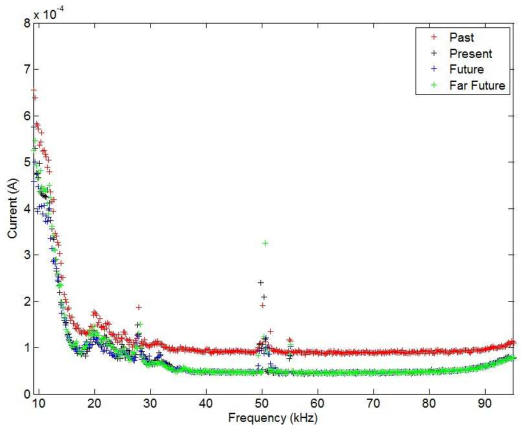

Figure 2 95% value of the current 9-95 kHz for the four different scenarios

The overall highest values are found in the “past” scenario but the highest value for a single frequency is found at 50 kHz in the “far future” scenario. The four scenarios are quite similar, which would suggest that the impact on the grid from the lamps is small. A possible explanation for the reduction in emission for the customer is the increased amount of capacitance with modern lamps. This would result in the high-frequency emission flowing between neighbouring devices instead of into the grid.

The flat part of the spectrum above about 35 kHz corresponds to the quantization noise. The higher level of quantization noise for the scenario “Past” is due to the higher scale needed for the measurements, as the currents are higher in this scenario with only incandescent lamps. This also explains at least in part the higher values for the “Past” scenario.

Above 95 kHz the level of emission is dominated by the quantization noise, for all four scenarios.

Emission from a group of lamps

The current drawn by one group of 12 individual lamps was measured separately for the four different scenarios and the result is shown in Figure 3. This current was measured at the same time as the total current discussed before. For two of the scenarios “Past” (all incandescent) and “Far Future” (all LED) the level of high frequency current measured at the terminal of the group of lamps is nearly constant during the 108-minute measurement.

The level for the scenario ”Past”, where the load consists of only incandescent lamps, is almost exclusively due to quantization noise. As was shown in Figure 2, the quantization noise in the “Past” scenario is about twice the level for the other scenarios. The reference level (i.e. the quantization noise) in Figure 3 is thus about half the level for the “Past” scenario, i.e. about 0.25 A.

For the scenarios “Present” (combination of incandescent and CFL) and “Future” (combination of CFL and LED) the total high frequency current distortion between 2-150 kHz shows large steps. The largest steps correspond with the switching on and off of the computer and the television. The minor drop between 45 and 50 minutes correspond with the period when two 20-W dimmable CFL’s are switched off.

For the “Far-Future” scenario (only LED) the level remains constant, like for the “Past” scenario, but at a higher level. It appears to the interaction between the CFL’s and the other equipment that causes these currents.

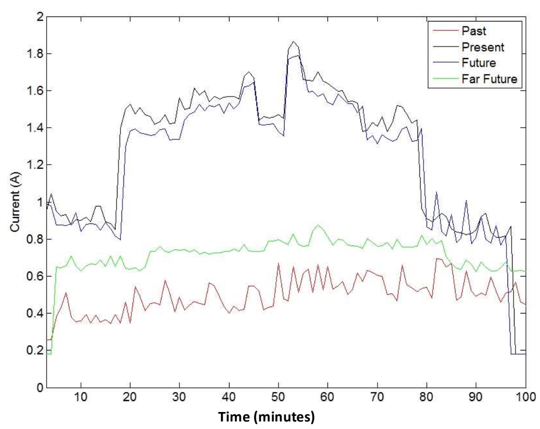

Figure 3 the root sum square for all frequency components between 2 and 150 kHz for a group of 12 lamps for the four different scenarios

The high-frequency part of the total current flowing from the installation into the grid is shown in Figure 4. During certain periods the replacement results in a reduction in emission, whereas the emission increases during other periods. There appears to be no correlation between the variations in total emission (Figure 4) and the emission from the 12 lamps (Figure 3).

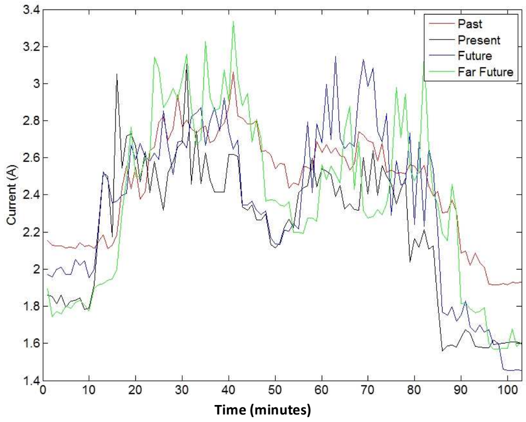

Figure 4 the root sum square for all frequency components between 2 and 150 kHz for the total load for the four different scenarios

To get a better view of which loads and which frequencies are responsible for the variations in the distortion pattern in Figure 3 and Figure 4 a spectrogram is used. A spectrogram of the total load current and the current drawn by the group of 12 lamps for the two scenarios "future" and "far future" is shown in Figure 5. For the total load current the two scenarios are similar, the levels for "future" are somewhat higher but the patterns are the same.

For the current drawn by the group of 12 lamps the difference is visible as in Figure 3. The components at 45 kHz and 90 kHz shown in the "future" scenario most likely originate from the lamps themselves as they are visible throughout the measurement period, the dark blue areas in the top and the bottom of the spectrogram for the 12 lamps corresponds to the time where the lamps were turned off. As these components are not visible in the "Far Future" scenario they are most likely emitted by the CFL's.

For the "far future" no single frequency component is visible for the whole duration when the lamps are turned on indicating that the LED lamps do not emit high frequency currents to the same extent as CFL's. The TV and computer seem to emit both a broadband spectrum around 10 kHz and a narrowband component at 55 kHz. This narrowband component is visible in the "far future" scenario as well but with lower amplitude. The two 20-W dimmable CFL's emit a disturbance throughout the frequency range, most visible in the spectrogram of the current drawn by the twelve lamps in the "future" scenario, due to the sharp edge caused by the dimmer. This spectrum from the dimmable CFL's is more visible when the heat pump is off, as are the emission around 50 kHz originating most likely from the induction cooker. The heat pump, when connected, seems to be shunting some of the high frequency currents emitted by the other loads and when disconnected some of those currents reach the lamps instead.

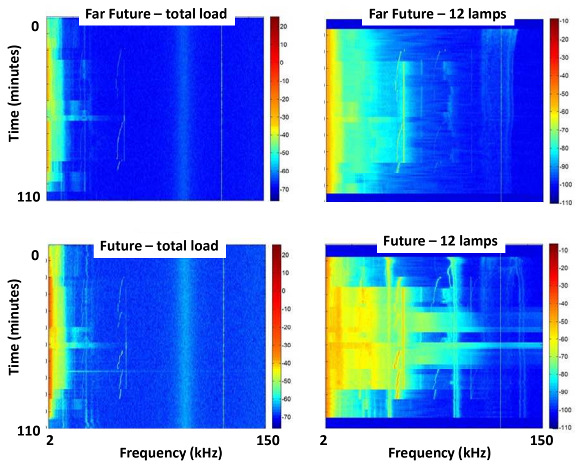

Figure 5 Spectrogram 2-150 kHz for the total load current for scenario Far Future (upper left) and Future (lower left) and for the current drawn by 12 lamps for scenario Far Future (upper right) and Future (lower right)

MEASUREMENTS FOR A HOTEL

A second experiment was made at a medium-sized hotel in Sweden [1].

The 95% value of the high frequency current for one of the phases before and after the shift is presented in Figure 6 and Figure 7

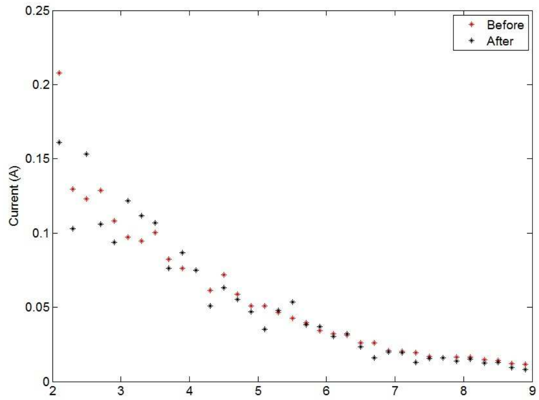

Figure 6 95% value of the current in the frequency range 2 to 9 kHz before (red curve) and after (black curve) the change from incandescent lamps to energy efficient lamps

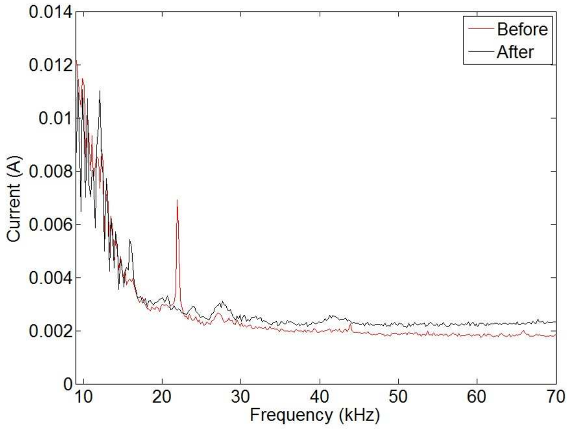

Figure 7 95% value of the current in the frequency range 9 to 70 kHz before (red curve) and after (black curve) the change from incandescent lamps to energy efficient lamps

The overall level of the emission has slightly increased for the entire frequency range but the narrow band component at 23 kHz is no longer visible after the replacement of the lamps. The most likely explanation is that the load emitting this specific frequency component is turned off during the time the second round of measurements were made.

Above 70 kHz the level of emission is less than the quantization noise both before and after the replacement of the lamps.

POWERLINE COMMUNICATION

In Sweden and in many other countries the power lines are used for remote reading of the power meters, so called Automatic Meter Reading (AMR). The frequencies used in Europe for AMR via the power grid are 9-95 kHz, with some exceptions. This is the same frequency range often used for the switching of the active power electronics in energy saving equipment. One concern has therefore been that a large number of CFL's of LED lamps could have an adverse impact on power-line communication [2]

The results presented in this paper support the theory presented in [3] that the emission from end-user equipment will not be the main challenge for the communication. End-user equipment forming a low impedance path for frequencies between 9-95 kHz could be a far more severe problem.

CONCLUSIONS

Modern energy saving lighting can emit high frequency currents, CFL's more so than LED's but the high frequency currents emitted by modern energy saving equipment seems to flow between equipment to a higher degree than towards the grid. Both a slight increase and a slight decrease in the overall emission level have been observed with different lamps.

In the frequency range 2 to 150 kHz equipment can both emit and shunt high frequency currents making the interaction between loads quite complex. Individual frequency components propagating to the grid with high enough amplitude to disturb for instance automatic meter reading have not been found during this project.

The measurements done in this project as well as in [3] support the theory that modern energy saving equipment like CFL's and LCD TV's lowers the impedance for higher frequencies and in that sense decreases the high frequency distortion on the grid. High frequency currents shunted by small end-user equipment could pose a threat to the function of that equipment. For this reason future immunity levels should be based on permitted levels for power line communication.

Overall the conclusion from this study is that the replacement of incandescent lamps by low-power-factor CFL's or LED lamps does not result in potential high emission levels in the frequency range above 2 kHz. It is not possible to draw any conclusions from this study about the impact of high-power-factor lamps.

REFERENCES

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[2] “Study Report from the SC205A Task Force on EMI between Electrical Equipment/Systems in the Frequency Range below 150 kHz (SC205A/Sec0260/R)”, TC210/Sec0635/INF, Cenelec, May 2010

[3] Rönnberg S.K, Wahlberg M, Larsson E.O.A, Bollen M.H.J, Lundmark C.M ”Interactions between equipment and Power Line Communication: 9-95 kHz”, 2009 IEEE Bucharest PowerTech Proceedings