EMISSION (2 TO 150 KHZ) FROM A LIGHT INSTALLATION

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ABSTRACT

This paper presents results from measurements of the emission from an installation containing of about 50 fluorescent lamps with high-frequency ballast. It is shown that the emission from one individual lamp in the installation is completely different from the emission by the installation as a whole. Emission in the frequency range of a few kHz adds in the current from the total installation, whereas emission around 50 kHz does not show up in the total current.

INTRODUCTION

The use of power-electronic switching in the power-supply of end-user equipment is increasing due to a number of benefits, such as higher efficiency, lower weight, longer lifetime etc. It is well known that these products generate harmonic distortion that can have an adverse impact on the power system. Emission standard IEC 61000-3-2 [1] has resulted in some equipment e.g. light equipment > 25 W and some computers to be equipped with active power factor correction to minimize the harmonic emission. Standards however only apply to frequencies up to about 2 kHz, for higher frequencies no standards or less-strict standards exist. The switching used to achieve active Power Factor Correction (PFC), results in frequency components being found up to above 100 kHz.

It remains unclear for example what the impact of distortion in the frequency range between 2 and 150 kHz is on end-user equipment and on equipment in the grid. However, there are indications of rising disturbance levels and anecdotal but consistent information on equipment damage [2][3][4][5]. Also, power line communication used by distribution network operators has a dedicated frequency range from 9 to 95 kHz which is in the same frequency range as the disturbances we are considering in this paper [6]. This range in the power grid is used widely in Sweden due to demands on the power companies to collect the meter readings monthly. Out of the 5.2 million meters installed approximately 40% uses the power grid to transmit the data.

MEASURMENT SETUP

An installation in the lab consisting of 48 lamps has been build. The installation resembles as much as possible a "real" installation in e.g. a grocery store. The installation in different stores have a large variety of e.g. one, two or three phase coupling, different cable length and type etc. One typical design was chosen where four lamps where hanged on twelve cables as shown in Fig. 1. The lamps are connected via an outlet and a 1.8 m cable. Measurements were performed of the current taken by one lamp and of the current taken by the installation as a whole. The voltage was only measured at connection point of the installation to the low-voltage network in the building.

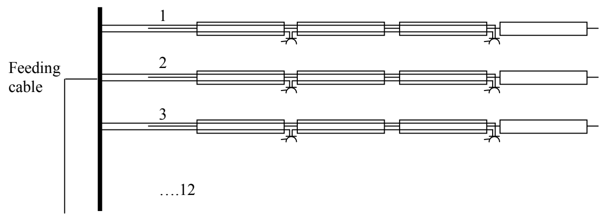

Fig. 1 Experimental light system setup in the laboratory.

CURRENT AT ONE OF THE LAMPS

The upper graph of Fig. 2 shows the current drawn by one lamp while the rest is also turned on. The current appear to be close to sinusoidal and the THD of the current is 3.5 percent and the total PF is 0.99. Minor distortion is seen at the negative and positive peak of the fundamental waveform and also close to the zero-crossing of the fundamental.

When applying a HP filter to the current the high frequency distortion at the peaks gets more visible. Note however that the recurrent oscillations close to the zero-crossing is not so prominent.

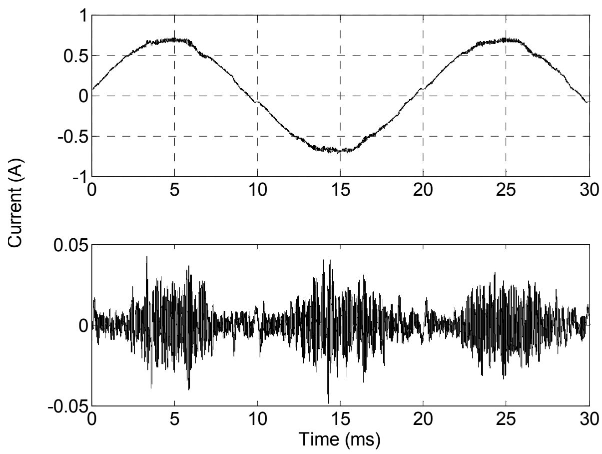

Fig. 2 Current drawn by one of the 48 lamps (upper) and filtered version of the same current (lower).

When applying a DFT to the measured current at one of the lamps, as shown in Fig. 3 it shows some narrow band components in the lower frequency range and a wideband component starting at 50 kHz and stretching up to 90 kHz. The component is also decreasing in amplitude with the frequency.

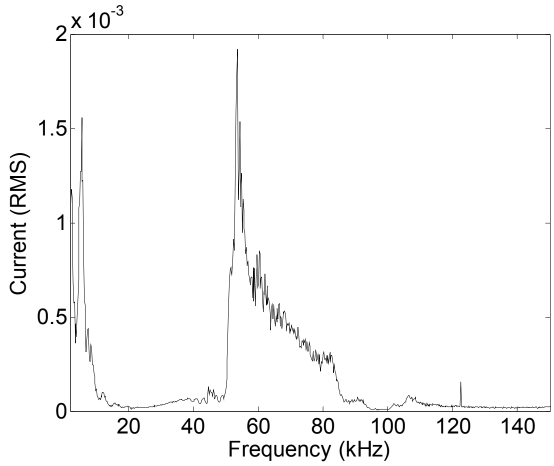

Fig. 3 Resulting spectrum of the current feeding one of the 48 lamps.

To analyze the current further the Short Time Fourier Transform (STFT) was applied to the measured current, resulting in Fig. 4. The length of the sub-window was set to 1 ms time with 0.5 ms overlap between sub-windows; resulting in 1 kHz frequency separation. The time is shown on the horizontal axis, the frequency on the vertical axis and the resulting amplitude of the current is shown as different colors shifting from blue (low amplitude) to red (high amplitude).

The resulting spectrogram of the STFT shows that the wideband component shown above in Fig. 3 is indeed a narrow band signal shifting over time with a period of 10 ms or half the period time. This signal is related to the active PFC circuit of the ballast which is used to reduce the harmonic distortion. The highest amplitude (red) at 50 kHz is found at 5, 15, 25 etc. ms which indicates that this is high frequency distortion seen in the lower graph of Fig. 2. There are also a harmonic of the frequency shifting signal visible and some narrow band signals with a fixed frequency.

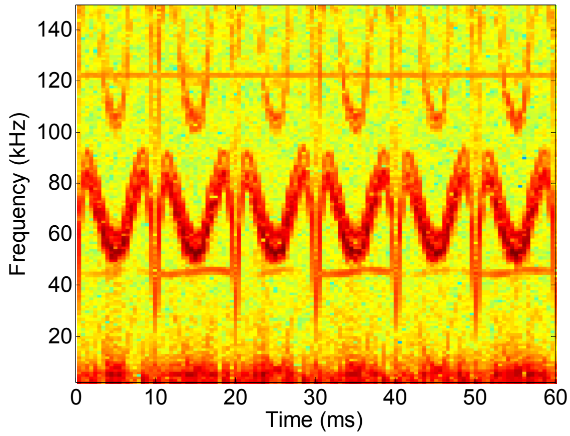

Fig. 4 Resulting spectrogram of the filtered current feeding one of the 48 lamps.

TOTAL CURRENT WITH 48 LAMPS

The total current feeding the 48 lamps is shown in the upper graph of Fig. 6. This current is measured at the same moment as the current of one lamp discussed in the previous section. The total harmonic distortion I_{THD} is about the same as for one lamp, at 5 percent and the PF remains high at 0.99.

Applying the filter to the current, as in the lower graph, shows that the HF signal at the peak of the current is not visible in the total current. Instead, recurrent oscillations are the most prominent visible component close to the zero-crossing of the current.

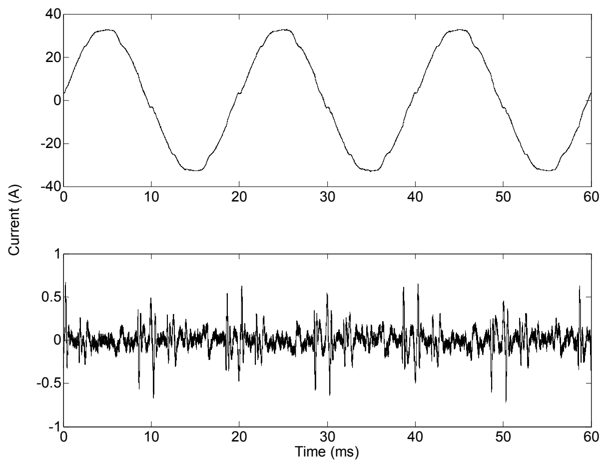

Fig. 5 Current feeding 48 lamps (upper) and HP filtered version of the same current (lower)

The resulting spectrum of the total current, Fig. 6, also shows that almost no signal is visible in this frequency range. Note that the spectrum is divided by 48 to make it more comparable with the spectrum of one lamp shown in Fig. 3.

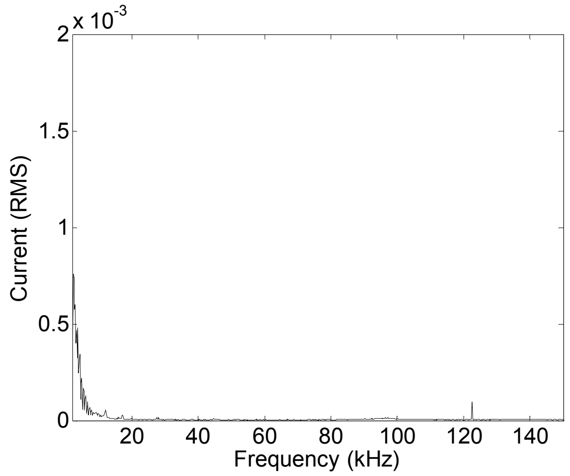

Fig. 6 Resulting spectrum of the total current feeding 48 lamps.

Also the spectrogram from the STFT shows the same result as the spectrum above. Only the recurrent oscillations close to the zero-crossing are showing up, as wide frequency bands with a short duration of about 1 ms.

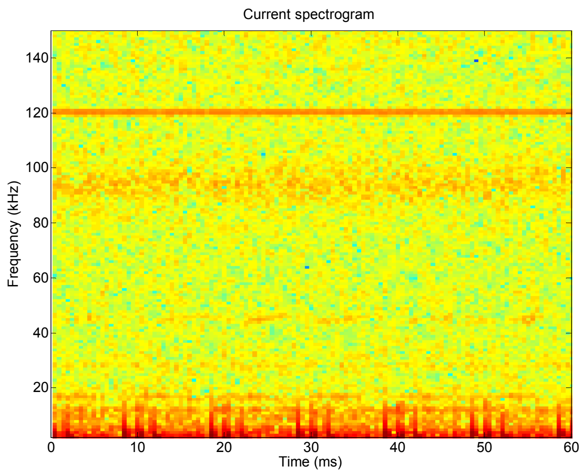

Fig. 7 Resulting spectrogram of the current feeding the 48 lamps

ONE THROUGH 48 LAMPS

In a next step a series of measurements were performed where the lamps were turned on one by one. The resulting DFT spectrum of the voltage at the PCC was then calculated and is presented in an intensity graph, Fig. 8. The frequency is represented by the horizontal axis and the number of lamps being turned on by the vertical axis. The representation of the amplitude is made in the same way as with the spectrogram where blue is representing the lowest amplitude and red the highest. From the figure we can see a number of components are showing up. The wide band signal starting at 50 kHz is present during the whole measurement but is decreasing with the number of lamps being turned on. There are also some components showing up from 20 to 40 kHz that is decreasing with the number of lamps being turned on. These frequency components are also visible when the light is off and therefore these are most likely generated elsewhere in the building.

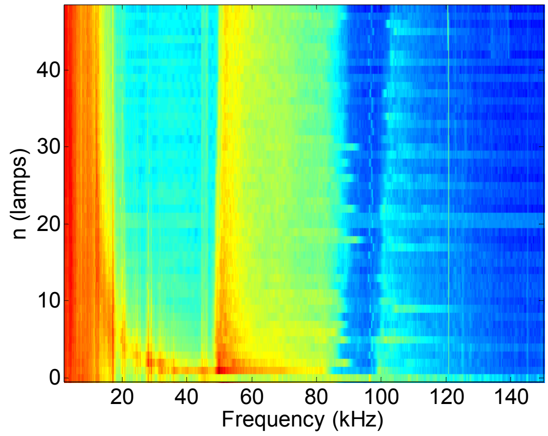

Fig. 8 Resulting voltage spectrums.

The same spectrums were also calculated for the current feeding the first of the lamps that are turned on, in Fig. 9. The wide band signal starting at 50 kHz is in this case present during the whole measurement. The narrow band signals between 20 and 40 kHz are also decreasing in the current with the number of lamps being turned on.

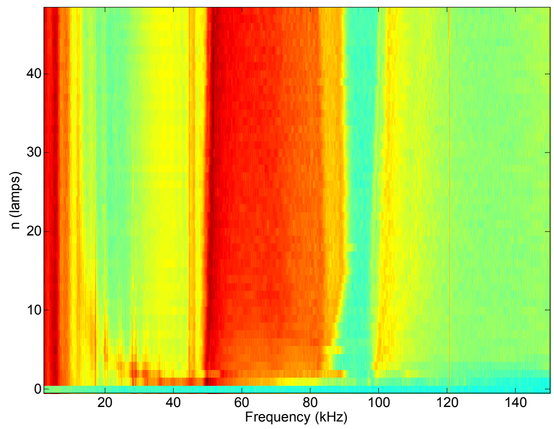

Fig. 9 Resulting spectrums of the current feeding one lamp when the rest of the lamps are turned on one by one.

The spectrums of the total current as number of lamps being turned on also shows the same decrease with the number of lamps being turned on. The main difference is that the wideband signal generated by active PFC is also decreasing rapidly with the number of lamps being turned on. Note that the spectrum is also here divided by the number of lamps turned on.

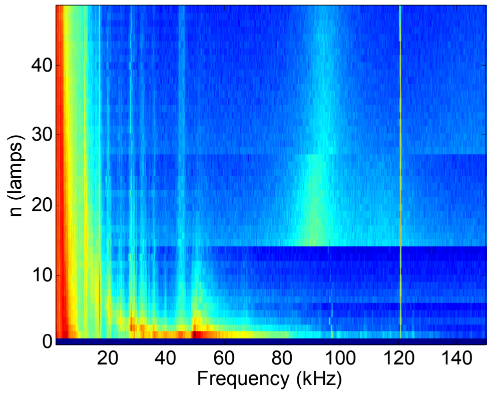

Fig. 10 Resulting spectrums of the total current when the lamps are turned on one by one.

RECURRENT OSCILLATIONS

The recurrent oscillations visible in the filtered version of the total current in the lower graph in Fig. 5 have also been investigated further. The maximum value of each filtered version of the total current is plotted against the number of lamps being turned on in Fig. 11. The result shows that the amplitude of the recurrent oscillations increases with the number of lamps turned on *(n)* to the power of 0.7, indicated by the red line in the figure $\left(0.05 \cdot n^{0.7}\right)$.

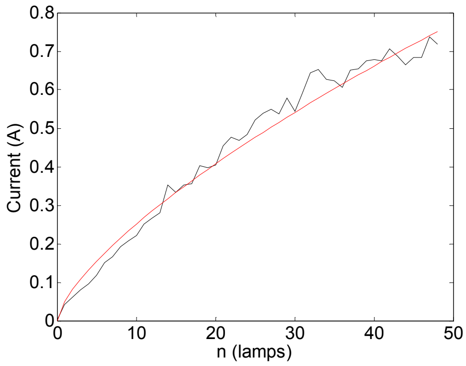

Fig. 11 Maximum value of the recurrent oscillation as a function of the number of lamps being turned on.

The recurrent oscillations are due to the performance of the power-electronics in the active power-factor-correction, close to the zero-crossing. They are visible at upper graph of both Fig. 2 and Fig. 5. These oscillations occur close to the current zero-crossing and are therefore synchronized with the power system frequency. As all lamps have the zero-crossing at the same time, the oscillations all occur at the same time and therefore add up with increasing number of lamps being turned on.

CONCLUSION

The measurements shown in this paper indicate that there are two types of emission by fluorescent lamps with high-frequency ballast, in this frequency range: recurrent oscillations (a few kHz) and high frequency components generated by the active PFC (some tens of kHz). These two components behave completely different with increasing number of lamps in an installation.

The recurrent oscillations increase in amplitude with the number of lamps turned on since the oscillations from each lamp are synchronized with the fundamental. Both this measurement and a previous measurement on a smaller installation shows that the increase is somewhere around the power of 0.7.

The high frequency part generated by the active PFC does not add in the same way as the recurrent oscillation and decreases fast with increasing number of lamps. This signal is somewhat higher at one lamp when all the other lamps are on than when only one lamp is lit. This part of the disturbance is going between the lamps rather than upstream as in the case with the recurrent oscillation. Similar results have also been seen earlier with other types of equipment's [7].

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