LABORATORY AND FIELD MEASUREMENTS OF HARMONIC EMISSION FROM ENERGY-EFFICIENT LAMPS

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ABSTRACT

This paper presents measurements of the harmonic current distortion before and after the replacement of all incandescent lamps with compact fluorescent and LED lamps. Measurements were performed in the laboratory for a physical full-scale model of a residential customer; field measurements were performed for a hotel. In all cases the lamps used were low-power-factor ones (0.6 power factor). The emulated domestic customer showed a small increase in harmonic emission; for the hotel no difference in emission was noticeable before and after the replacement.

INTRODUCTION

The ongoing discussion on the potentially adverse impacts of energy-efficient lamps on the harmonic voltage levels in the power grid and the introduction of power-factor requirements for such lamps has been the background for a set of measurements to look at this issue in more detail. It is well known, and published in several good publications, that individual compact fluorescent lamps and their most modern version, the LED lamps, often show a current with a very high harmonic distortion [1,2]. This often leads to the conclusion that this will result in an increase in harmonic distortion. It is however not obvious if this increase will be significant. Therefore a set of measurements have been performed to quantify the increase.

LABORATORY MEASUREMENT

A first set of measurements has been performed in the laboratory, where a full-scale electric model of a detached house was equipped with standard domestic equipment including incandescent lamps. All equipment installed in the house was fairly modern and selected so that they would represent what could be found in stores today. A 108-minute pattern of use was defined were equipment was switched on and off at predefined instants. This was to reproduce the various combinations of equipment that could be expected with a domestic customer during the course of a day. A power-quality monitor was used to obtain the standard set of power-quality parameters, including harmonics up to order 40, over every 1-minute interval. The incandescent lamps were replaced first by compact fluorescent lamps and next by LED lamps. The 108-minute measurement series was repeated after ever replacement so as to be able to compare the harmonic emission of domestic customers with different types of lighting. The lights were chosen so that they had the same level of light emitted. All non-incandescent lamps were of the high-distortion type with a power factor of around 0.6.

- ✓ 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.

MEASUREMENTS AT A HOTEL

As part of the same project, measurements of the harmonic emission have been performed at a medium-sized hotel before and after the replacement of all incandescent lamps with CFL and LED lamps. Before the change, the lighting in the hotel consisted of 447 incandescent 40-W lamps with E27 fitting and 116 incandescent 40-W lamps with E14 fittings. The E27 lamps have been replaced by 7-W LED lamps and the E14 lamps by 8-W CFLs. About 30 lamps were replaced in the common areas of the hotel; the others were replaced in the guest rooms. In total this would give a reduction in active power up to 18 kW. The highest 1-minute average load measured before the replacement was 108 kW. Measurements were performed at the delivery point at the hotel before, during and after the replacement. A Dranetz Power Visa monitor was used to obtain the harmonic distortion and several other parameters over each 10-minute interval. The measurement results are presented in the forthcoming sections, where the time axis includes about two weeks before the replacement, the whole replacement period and two weeks after the replacement.

MEASUREMENT RESULTS

Laboratory measurement

The one-minute average of the 10-cycle harmonic and interharmonic subgroups, in accordance with IEC 61000-3-40, was recorded during 108 minutes for each of the four scenarios. The fifth and seventh harmonics versus time are shown in Figure 1 and Figure 2, respectively. With the harmonics the overall pattern does not change despite the replacement of all incandescent lamps first by compact fluorescent lamps and next by LED lamps. For both harmonics the values are significantly higher during the first half of the measurement than during the second half. This is most likely due to the presence of the heat pump during the first half. The replacement of the incandescent lamps does result in some increase in the harmonic distortion, especially for the "future" scenario.

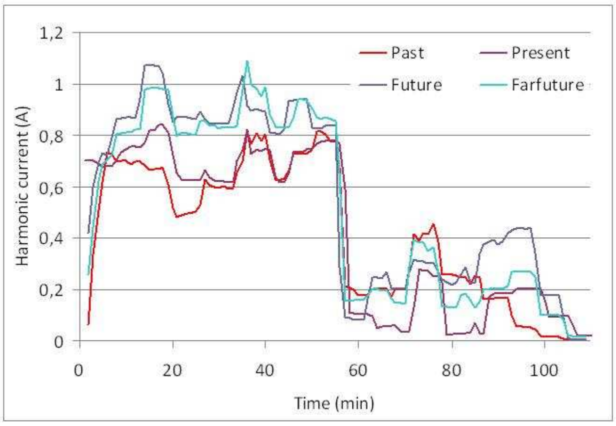

Figure 1. Fifth harmonic current versus time for the four different scenarios

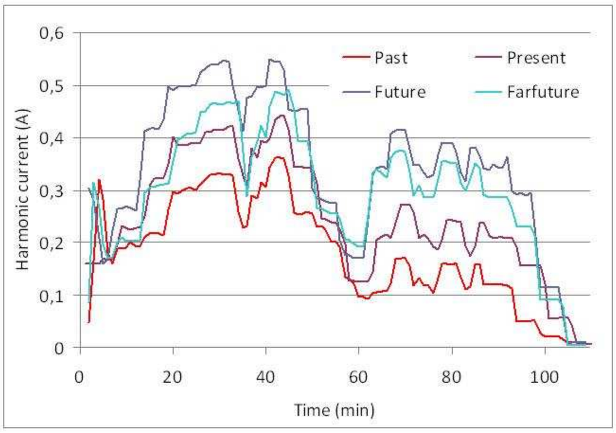

Figure 2. Seventh harmonic current versus time for the four different scenarios

The total harmonic distortion (THD) of a voltage or current waveform is defined as the ratio between the root sum square over all harmonic components and the fundamental component [3]. The THD is typically expressed in percent. What matters for the power system is not the THD in percent but the THD expressed in Ampere. The latter is the root sum square over all harmonic components, which can also be calculated as the product of the THD in percent and the fundamental current. The THD in Ampere is shown in Figure 3. The highest values for the harmonic emission of the installation occur during the first half of the measurement period, when the heat pump is connected.

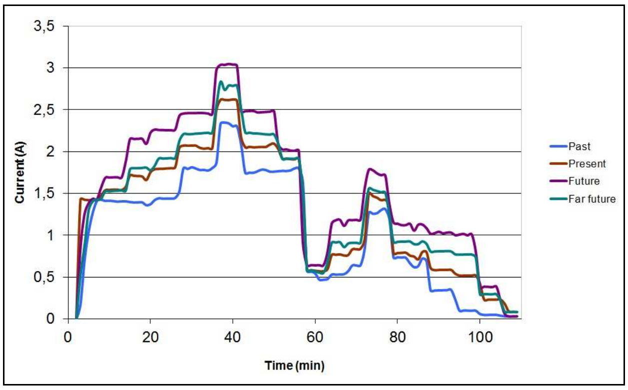

Figure 3. Current THD in ampere for the four different scenarios

The measurements for a domestic customer emulated in the laboratory show that the replacement of incandescent lamps by LED lamps and CFL's results in some increase of the harmonic current emission, as expected. The increase is however rather small and the emission of the test house, despite its high amount of lighting, is still more than a factor of two below the limits set in IEC 61000-3-12 (the most strict limits, for Rsce=33). The presence of other equipment, like a heat pump or a dish washer, impacts the harmonic distortion much more than the replacement of the lamps.

A comparison of the 99% spectra for "past" and "far future" is made in Figure 4, so as to better view the differences. The even harmonics do not show any significant increase; whereas also most of the odd harmonics show some only minor changes. Significant increase is only visible for harmonics 9, 13, 19, 21, 23 and 25. The 99% spectra of the interharmonics are compared in Figure 5. There is no significant difference in the interharmonic spectra for the two scenarios.

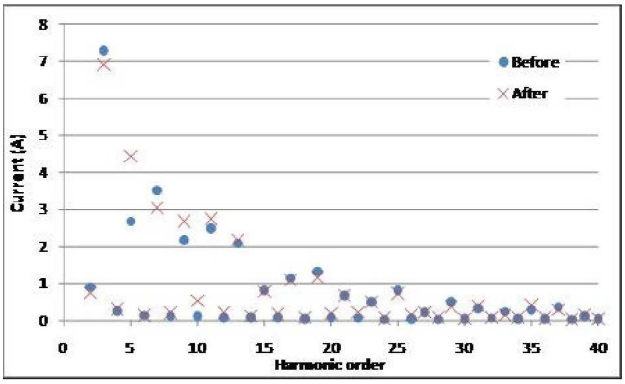

Figure 4. 99% harmonic spectrum of the current in one of the phases before and after the replacement

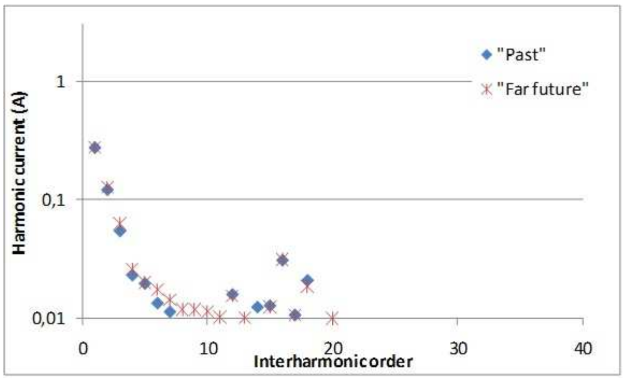

Figure 5. 99% interharmonic spectra for the "past" and "far future" scenarios.

The harmonic emission does show some increase with the highest values being reached for "future". The increasing trend is also clear when calculating the maximum and 95-percentile values. The 95-percentile of the harmonic emission increases from 2 A in "past" to 2.8 A in "future". In "far future" the emission decreases again somewhat to 2.5 A.

Hotel measurements

To quantify the impact of a load on the power system, the 95% value of the harmonic currents is a commonly-used value. The 95% values of the third, fifth and seventh harmonic for each phase before and after the replacement are shown in Figure 6. It shows an increase in third harmonic in two of the phases and a decrease in the third phase. The changes in third harmonic are minor however: -3%; +5% and +2%. We conclude that there is no observable difference in the third harmonic current due to the replacement.

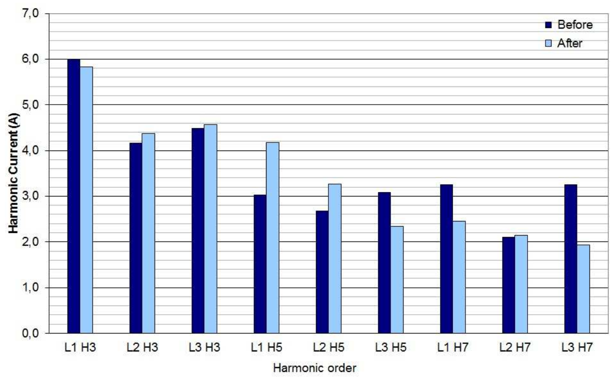

Figure 6. 95% values of the third, fifth and seventh harmonic before and after the replacement

The fifth harmonic current shows an increase in two of the phases, with the increase being about 40% in phase A. The third phase does show a decrease in harmonic current however. The increase is biggest in the 95% value; the increase in 99% value is only 15%. It should also be noted that the maximum rms current is over 150 A; the fifth harmonic current after replacement is thus still less than 3% of the rated current.

The seventh harmonic goes down in two phases and remains about the same in the third phase.

In order to get a fair assessment of the impact of the replacement of the lamps, two 24-hour periods were selected where the number of room reservations were similar, 57 rooms before the replacement and 59 rooms after. Here it is implicitly assumed that a similar number of room reservations also results in similar amount of lamps and other devices being powered. In Figure 7 the third harmonic current during two 24-hour periods is plotted. The two curves start and end at 2 pm so as to cover the overnight stay. The maximum value of the third harmonic current after replacement is very similar to the one before. However the maximum is only reached short and later than before replacement. This difference is most likely not related to the replacement of the lamp; it just shows that every night is different.

Figure 7. Third harmonic in one phase during two 24 hour periods with similar number of guests before and after the replacement

The changes in harmonic spectrum before and after the replacement are small, show increases as well as decreases and no impact is visible of the replacement of incandescent lamps by energy savings lamps.

Power Factor

The power factor is often used as an indicator for the impact of a specific load on the grid. A lower power factor is in that case associated with a larger impact. The 95% value of the power factor for the four different scenarios is presented in Figure 8. In the scenario Past all lamps have a power factor of one, in the scenario Present half of the lamps are replaced by CFL's with a power factor of 0.6 and for the scenarios Future and Far Future all lamps have a power factor of 0.6. There is a slight decrease in power factor but the difference from Past to Far Future is only one percent and the 95% value for the "worst" scenario is still 0.988. It should also be noted that part of the reduction in power factor is due to the reduction in active power.

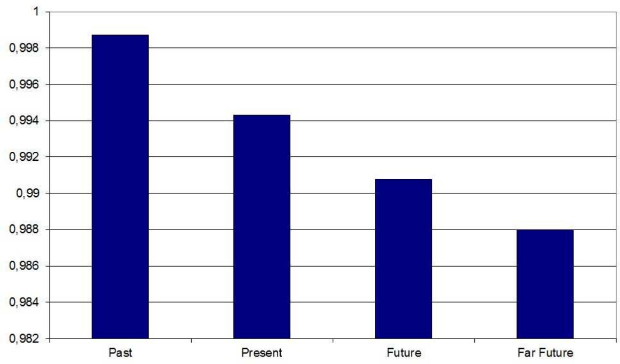

Figure 8 95% value of the power factor for the four scenarios; note the vertical scale

The same calculation was done on the measurement from the hotel. In Figure 9 the result is presented for the three phases. The biggest drop is found in phase one and three where the power factor decreases with 2%. The lowest value is 0.932 in phase one.

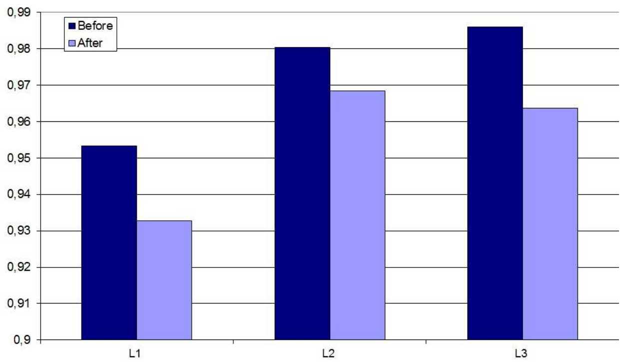

Figure 9 95% value of power factor before and after the replacement of the lamps

The decrease with the hotel is however almost exclusively due to the reduction in displacement power factor, which in turn is due to the reduction in active power whereas the reactive power remains the same. The total power factor is, throughout the measurement period, 99% or more of the displacement power factor. The waveform distortion thus causes 1% or less of the non-unity power factor, despite all unity-power factor lamps having been replaced non-incandescent lamps with 0.6 power factor.

CONCLUSIONS

These two experiments show that the increase of emission due to the replacement of incandescent lamps by energy-saving lamps is not as large as would be expected from the heavy-distorted waveform of individual lamps. For the domestic customer there is a small increase in emission, but for the hotel no change can be observed. Measurements in the frequency range 2 to 150 kHz, presented in [4], show that there is no large increase in emission in that frequency range either.

The two studies also show that the total power factor is not a good indicator to compare different equipment or installations. The power factor is mainly impacted by the reduction in active power, not by the increased emission.

The replacement of incandescent lamps by CFL and LED's shows a clear reduction in energy consumption, in peak current, and in losses in the system. The latter has been estimated by comparing the integral of the squares of the current rms over the whole measurement period.

For the laboratory measurements the reactive power is negative (i.e. the load is producing reactive power) most of the time for all four scenarios. The replacement will result in a further increase of the reactive-power production.

The harmonic current emission of the load increases due to the replacement. For LED's this holds especially for harmonics 9, 13, 19, 21, 23 and 25. None of the other harmonics shows a significant increase.

Overall, these measurements have shown that the replacement of incandescent lamps results in a reduction of the power-system loading at the fundamental frequency, but in some increase in harmonic distortion. The impact is however minor and the overall harmonic distortion is mainly determined by other equipment.

It is more difficult to draw conclusions from the hotel measurements; there are uncertainties of the other loads connected during the measurement, the number of guests is known but their behavior is not. The measurements do not show a clear impact from the replacement of the lamps on the overall power quality.

When assessing the impact of new equipment, like CFL or LED, it is important to consider them as part of the total load. The current distortion of a new device cannot be used to directly estimate the its impact on the voltage distortion in the grid.

It is also important to quantify the load using parameters that have a direct relation with the impact on the power system. Power factor and total harmonic distortion in percent are not seen as suitable indicators for this.

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