FIELD AND LABORATORY MEASURMENTS OF INTERFERENE WITH LIGHTING EQUIPMENT DUE TO WAVEFORM DISTORTION ORIGINATING FROM A LARGE RECTIFIER

Anders LARSSON
LTU – Sweden
anders.larsson@ltu.se

Aurora GIL-de-CASTRO
University of Cordoba – Spain
agil@uco.es

Mats WAHLBERG
Skellefteå Kraft – Sweden
mats.wahlberg@skekraft.se

Math BOLLEN
LTU – Sweden
math.bollen@ltu.se

ABSTRACT

This paper will present a case study where light in an office building is disturbed and do not function properly. From measurements it is shown that a UPS system is causing distortions. One lamp from the office was brought to laboratory where the distortions was repeated and subjected to the lamp. When doing so the lamp showed the same immunity problem.

INTRODUCTION

There are no immunity limits regarding luminaries in the harmonic range, nor in the higher range above 2 kHz for conducted disturbances. There are however reported cases of interference with different types of lamps under certain conditions, especially in the frequency range above 2 kHz [1][2][3] where power line communication is the most common source of high disturbance levels. However the duration of the emission from power-line communication is short. Emission from equipment connected to the grid is present large part of the time and the overall impact and risk of interference may be higher. In the harmonic range there seems to be less impact besides some minor effects like audible noise at fluorescent lamps powered by magnetic ballast and shortened lifetime of incandescent lamps[4]. The harmonic voltage levels in the network are still in most cases below the compatibility levels and light manufactures have had many years to ensure that light equipment is immune to those levels of voltage distortion. On the other hand is for instance LED light a fairly new lamp and interference due to harmonics might not have been reported yet.

In the first section this paper will present a disturbance at a light installation in a 7000 square meter office building. Since the opening of the office in 2009 the office light has not worked properly. The problem with the light is that its control functions (dimming, corridor and attendance control) are not always working properly. The lamps remain in low dimming mode and light intensity cannot be increased.

In the next section the immunity of the lamp is tested in the lab by subjecting the light to a similar waveform as measured at the office.

RESULTS FROM MEASUREMENT

Measurements at the office building have been carried out at: different times, different places and with different loads connected and disconnected. Fig. 1 below shows a simplified scheme of the electrical installation at the office. The building has two busbar's, B1 and R1. Busbar B1 serves general loads in the building, such as computers, light, etc. Busbar R1 is used for preferential loads like sprinklers, ventilation, elevators, etc. which is backed up by a backup generator (G). Additionally there is also a server hall connected to this busbar, via two online Uninterruptible Power Supply (UPS).

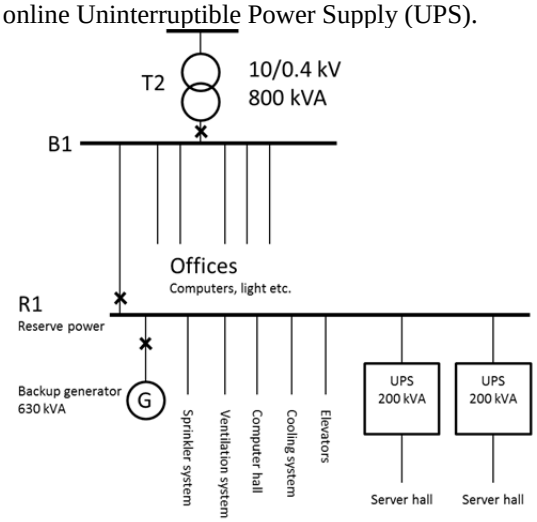

Fig. 1 Scheme of the electrical system at the office building

Measurement in one office

Fig. 2 shows the resulting voltage waveform at the connection point of the fluorescent light during normal operation in one office. As can be seen, the voltage waveform is heavily distorted, at least for this type of load (office-building). The waveform contains several repeating notches over a period.

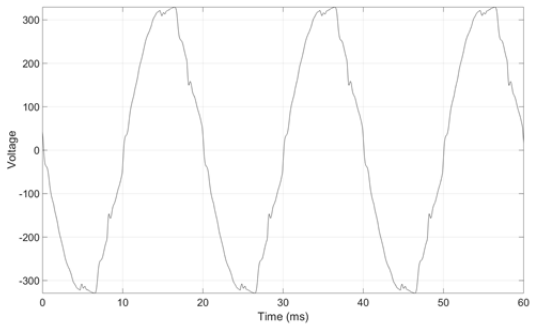

Fig. 2 Voltage waveform at the connection point of a distorted fluorescent lamp in one of the offices

It was predicted that the UPS's was the most likely load causing these waveform distortions. Therefore a trial was preformed where the backup generator was started and busbar R1 was disconnected from B1. The result from a measurement of the voltage waveform at the same office, during this trial, is shown in Fig. 3 below.

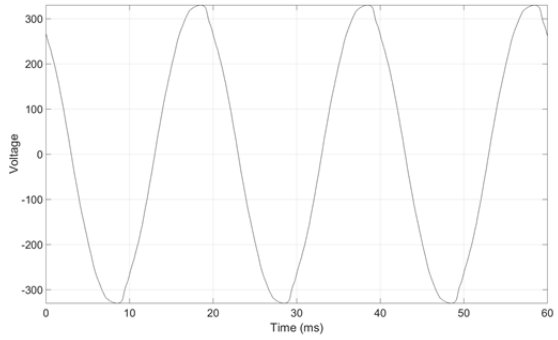

Fig. 3 voltage waveform when busbar R1 is disconnected

If subtracting the voltage waveform before the disconnection of R1 with the waveform after, we end up with the waveform shown in Fig. 4. The result shows that the lamp is exposed to recurrent voltage peaks of about 40 V.

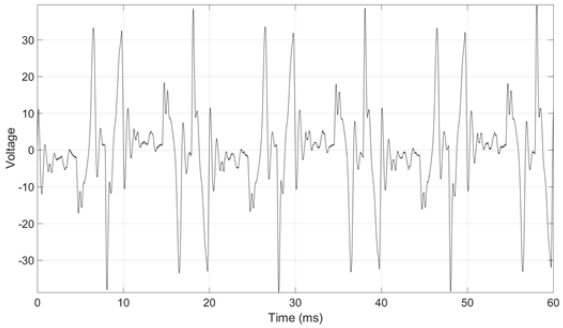

Fig. 4 Resulting waveform when subtracting the waveform before disconnection from the waveform after

Some parameters obtained from the voltage waveform are shown below in Table 1. In the harmonic range, both Vthd and the highest individual harmonic (H7) drop more than 3 times after disconnecting busbar R1. While busbar R1 was disconnected all lamps at the office worked perfectly.

Table 1. Some voltage harmonic values (in % of fund.) before and after the disconnection of busbar R1.

% of fund.	Vthd	H7	$Vthd_{2\text{-}9kHz}$	$Vthd_{9\text{-}150kHz}$
Before	5.1	3.1	0.84	0.18
After	1.6	0.93	0.12	0.085

In the frequency range between 2 and 9 kHz, $Vthd_{2\text{-}9kHz}$, drops around 7 times and between 9 and 150 kHz, $Vthd_{9\text{-}150kHz}$, drops more than 2 times. This indicates that the largest change in distortion happens between 2 and 9 kHz.

Fig. 5 shows the resulting voltage harmonic spectra, before (blue) and after (red) disconnecting R1. From the harmonic spectra we can notice that the characteristic harmonics are $h=n\cdot6\pm1$ which indicates a 6-pulse rectifier creating the voltage distortion.

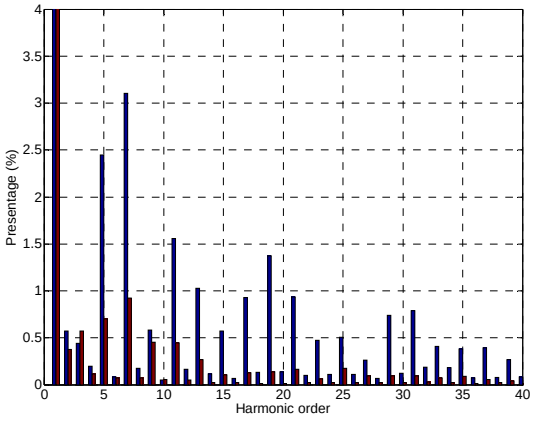

Fig. 5 Voltage harmonic content before (blue) and after (red) busbar R1 was disconnected

The largest change among the characteristic harmonics is H19 which reduces about 10 times between the two measurements.

When comparing the measured harmonic spectra of the voltage waveform with immunity test levels given by IEC 61000-4-13 [5], the individual harmonics at the lamp terminals are all below class 1 test levels. These test levels are intended for immunity test of very sensitive equipment.

The voltage measurement shown in Fig. 2 and Fig. 3 above was performed with a sampling speed of 200 kS/s. The resulting Discrete Fourier Transform (DFT) of the

measured windows, before (black) and after (red), is shown below in Fig. 6 in the higher frequency range (between 2 and 9 kHz).

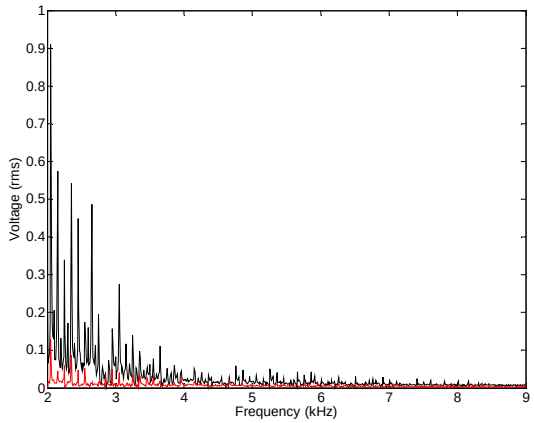

Fig. 6 Resulting spectra between 2 and 9 kHz, before (black) and after (red) disconnecting busbar R1

The spectra of the two measurements, between 9 and 150 kHz are not shown here since this part of the spectra does not reveal any large differences, as indicated by $Vthd_{9\text{-}150kHz}$ in Table 1.

When comparing the spectra between 2 to 9 kHz with lowest immunity test levels given by IEC 61000-4-19 [6] the only component that is higher is at 2055 Hz. Note that both above immunity test standards do not, so far apply to lighting equipment.

Controlled island operation

During the test, when busbar R1 was disconnected from B1 and instead feed from the backup generator, a measurement of the voltage and current feeding one of the 200 kVA UPS's were carried out. The voltage and current drawn by the UPS is shown in Fig. 7. The result shows that the UPS system is most likely the cause of the voltage distortion in the office. Note that the waveform distortion is much larger due to higher (mostly inductive) source impedance. The current shows a typical pattern for a six pulse, diode or thyristor rectifier with a voltage stiff DC link. The differences in magnitude of the current pulses are most likely due to an unbalanced voltage supply.

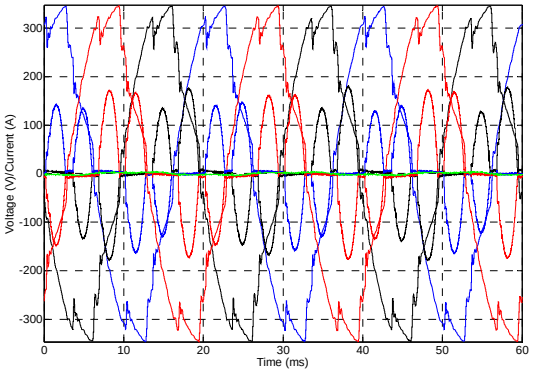

Fig. 7 Voltage and current waveform at busbar R1 when running on backup generator (G)

IMMUNITY TEST IN THE LAB

The voltage waveform, shown in Fig. 2 has been replicated in the Pehr Högström Laboratory at Luleå University of Technology in Skellefteå, Sweden. The measured voltage waveform was first filtered with a high-pass filter starting at 500 Hz. Then the waveform was generated, amplified and superimposed onto the grid voltage via Coupling and Decoupling Network (CDN) as specified in [6] and shown in Fig. 8.

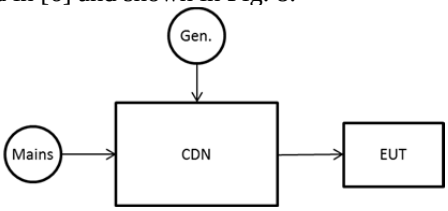

Fig. 8 Simplified scheme of the immunity test setup in the lab

Note that the standard prescribes the use of sinusoidal waveform while in this test the frequency content of the measured signal at the office was used instead. The result of the generated waveform is shown in red color in Fig. 9. As a reference the original measured waveform is shown in black.

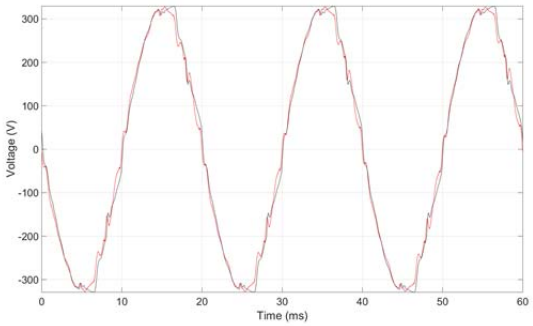

Fig. 9 Replicated voltage waveform supplied to the lamp in the laboratory (red) and the original waveform (black)

The test voltage is obtained by adding the measured high-frequency disturbance to the laboratory voltage. The latter shows only limited distortion as the laboratory is supplied from a dedicated transformer and almost no other equipment is connected to this transformer.

While the lamp is supplied with the voltage shown in red in Fig. 9 it disclosed similar behavior as in the office (where it was supplied with the voltage shown in black). The dimming function of the light is in this case affected by being slowed down. It takes longer time to change the light intensity but the built in functions are though still working correctly.

Both the harmonic spectra, up to 2 kHz, and the spectra between 2 and 9 kHz are shown in Fig. 10 and Fig. 11. The harmonic spectra show that the lower order harmonics are lower in the laboratory test. This is because the almost absence of other equipment supplied from the same transformer, as mentioned above.

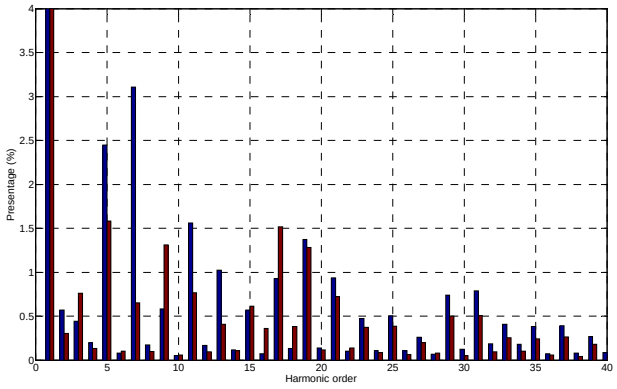

Fig. 10 Harmonic spectra of the replicated waveform (red) and original spectra at the office (blue)

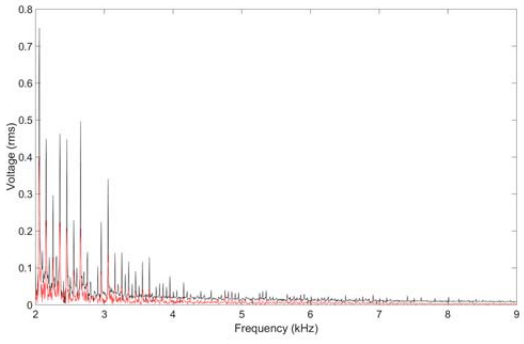

Fig. 11 Resulting spectra of the waveform (Fig. 9) feed to the lamp during the test

As can be seen from fig 11 the spectra in the higher frequency range had about half the amplitude in that case. Another trial was made, with a higher level of distortion; by using a high-pass filtered version of the measured voltage at busbar R1, shown in Fig. 7. The resulting waveform feed to the lamp in this case, is shown in red in Fig. 12. The function of the lamp was now heavily disrupted. The diming function was somewhere in between not functioning at all or very slow.

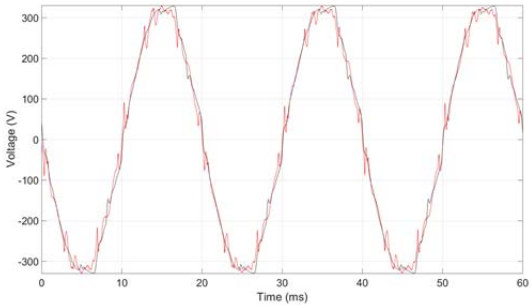

Fig. 12 Replicated voltage waveform from measurement at busbar R1 feed to the lamp in the laboratory (red) and original waveform measured at the office (black) as a reference.

The resulting spectra of the waveforms in Fig.12 are shown in Fig. 13. As can be seen it is not identical in magnitude but the characteristic frequency components are there and causing disturbances to the lamp control.

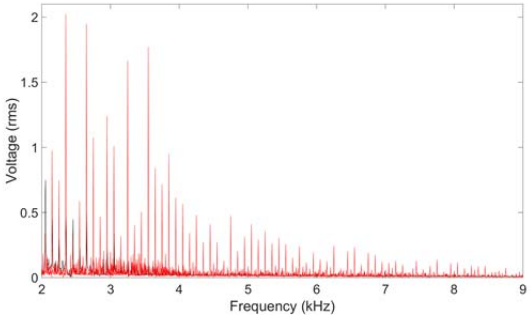

Fig. 13 Resulting spectra of the waveform (Fig. 12) supplied to the lamp during the test

CONCLUSIONS

Waveform distortion can interfere with, among others, the control functions of a lamp.

The waveform measured at the office causing interference was reproduced in the laboratory, and applied to the same lamp as in the office building. The lamp showed the same behavior. The voltage measured at the office contains both harmonics and higher frequency components which can disturb the function.

It is not proven yet, but from the spectra between the office and the lab test it is most likely components above 2 kHz that causes the problem to the lamp since these are the components amplified and bringing on the

disturbance to the lamp. Note however that in this case the main waveform distortion is just a few kHz.

Both immunity test standards use sinusoidal waveforms and this results show that there are other types of waveform distortions that are more severe for the lamp controls. This indicates that more complicated immunity test may be required to fully ensure that lamps function correctly. Even a combination of the two standards could be necessary.

Acknowledgments

The project presented in this paper was funded by Swedish Energy Agency, Skellefteå kraft, Polaris, Boliden Minerals, Skellefteå city airport, Philips, Osram, Nordic light and SKEBO.

REFERENCES

[1] CENELEC, "Study Report On Electromagnetic Interference Between Electrical Equipment / Systems In The Frequency Range Below 150 kHz" SC205A/Sec0260/R, April 2010

[2] Pikkarainen, M.; Vehmasvaara, S.; Siddiqui, B.A.; Pakonen, P.; Verho, P., "Interference of touch dimmer lamps due to PLC and other high frequency signals," Electric Power Quality and Supply Reliability Conference (PQ), 2012 , vol., no., pp.1,6, 11-13 June 2012

[3] S.K. Rönnberg, M.H.J. Bollen, M. Wahlberg, Interaction between narrowband power-line communication and end-user equipment, IEEE Transactions on Power Delivery, Vol.26, No.3 (July 2011), pp.2034-2039.

[4] Wagner, V.E.; Balda, J.C.; Griffith, D.C.; McEachern, A.; Barnes, T.M.; Hartmann, D.P.; Phileggi, D.J.; Emannuel, A.E.; Horton, W.F.; Reid, W.E.; Ferraro, R.J.; Jewell, W.T., "Effects of harmonics on equipment," *Power Delivery, IEEE Transactions on* , vol.8, no.2, pp.672,680, Apr 1993

[5] IEC 61000-4-13, 2009, Testing and measurement techinques – Harmonic and interharmonics including mains signaling at a.c. power port, low frequency immunity tests, Ed. 1.1

[6] IEC 61000-4-19, 2014, Testing and measurement techinques – Test for immunity to conducted, differetioal mode disturbances and signaliling in the frequency range 2 kHz to 150 kHz at a.c. power ports, Ed. 1.0