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MEASUREMENT ANALYSIS OF FLUCTUATIONS BETWEEN POWER GRID AND CONSUMERS AT LOW VOLTAGE AND HIGH FREQUENCY RANGE

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ABSTRACT

The quality of energy is a matter to get a many more information from last four decades to industrialize interaction with the power grids and customers to use of instruments supported in its at representation in voltages and currents. The implementation in this field has to relatively slow at low frequency range with being of voltage dips about magnitude of voltage in milliseconds and frequency harmonics about of some kilo hertz's. At high frequency range the modern energy equipments included in power grid system with grid communication like meter readings and controls at same frequency range.

In this dissertation report, implemented the frequency range measurement techniques in time domain and frequency domain both to use of fluctuated waveforms and key of measurement factors will fluorescent light. So due to limit of harmonics will use high switching method and get more frequent use in all other small energy instruments for precision of emission and immunity systems. Reaction mechanism of fluctuations from frequency range will define several methods like narrowband, wideband and oscillations during recurrent. This is the major precision in values to understand the standard of thesis work.

KEYWORDS: Power Grid, Harmonics, Fluctuations, Frequency Analysis.

INTRODUCTION

The use of power electronics is getting more common and one of the main driving forces is the flexibility, control benefits and energy saving features that many times outweigh the higher investment cost. Smaller equipment has additional benefits such as lower weight and size. Switched-mode power supplies (SMPS), further allows better control of electrical parameters such as voltage and current. From the grid point of view the power electronics is known to produce harmonics. The emissions of harmonics are well known. Some examples of current waveforms from different types of electronic loads are shown in the forthcoming section.

MATERIALS AND METHODS

Instruments

Electronic devices can have a range of diverse topology depending upon the application but the front-end (grid-side of the device) is often similar. The front-end typically contains an EMC-filter, a rectifier, a smoothing capacitor and a chopper. Since this thesis mainly looks upon signals in the grid generated by electronic loads the main focus is upon the front end of the device. In Fig. 2.1 a simplified scheme of SMPS is shown.

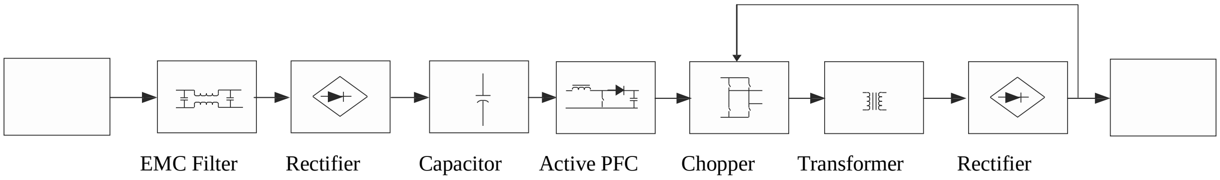

Figure 1: SMPS for power filtration

The rectifier is normally in single phase applications a two-pulse rectifier. Mainly in older applications occasionally a one pulse rectifier with only one diode was used. The drawback with the single-diode solution is a much higher ripple on the DC side. The use of this solution also produces a DC component in the current which can be stressful for the distribution transformer. The purpose of the smoothing capacitor is to reduce the ripple in the pulsating voltage from the rectifier. The active power factor correction unit following the smoothing capacitor is used in some cases to maintain the harmonic contents below certain limits. The chopper is typically working in the kHz range and in most cases we can find the switching-frequency in the range from a few kHz up to more than 100 kHz. The benefit of using a high switching frequency for the chopper is that the transformer can be much smaller. This in its turn leads to smaller and lighter power supplies and still maintains the galvanic insulation which is desirable e.g. for laptops, mobile chargers etc. The reason for the smaller transformer can be understood from the transformer formula:

$$U_1 = \frac{2\pi}{\sqrt{2}}.B.f.A.N_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where U1 is applied voltage across a winding on an iron core, f is the frequency of the applied voltage, A is the cross section, N_1 represents the number of turns of the winding and B is the resulting maximum flux density. Consider the maximum flux density B before saturation, number of primary turns N_1 and input voltage U_1 is constant. The required cross section A of the iron core is also reduced by 1000 times. This is the main reason to use a higher frequency. Older equipment, from a time when power-electronics components were expensive, used an ac/ac transformer to bring the ac voltage down to the appropriate level. A four-diode bridge and a smoothing capacitor were next used to obtain the required dc voltage. This resulted in much lower harmonic distortion but was a more bulk and heavy solution mainly due to the iron core in the ac/ac transformer.

Fluctuations of Low Frequency

As mentioned in the previous section, the front-end has in almost all cases about the same topology. But small changes in the topology can result in differences in the current waveform. A time domain waveform containing no harmonic is perfectly sinusoidal at the power system frequency of 50 or 60 Hz. Any deviation from this perfect sine wave indicates the presence of harmonics. The current waveform drawn by low-voltage equipment. The different current waveforms show different deviation from the ideal sine wave. Note that these measurements are just showing some examples and not claimed to be fully representative for all types of electronic loads. The top left graph shows the current drawn by a single phase adjustable speed drive feeding an idling 0.65 kW asynchronous motor at 8 Hz. By the shape of the waveform it is likely that this speed drive has a so called voltage-stiff DC link. The next example, an 11 W compact fluorescent lamp (CFL) is in the top right graph. The experience from many measurements on CFL's is that the spike on the waveform is quite characteristic for this type of load. The next two examples are for a laptop and for an LCD-TV. These currents have a similar general shape: they are close to sinusoidal except from some deviations around the zero-crossing. These deviations look like the current takes some small pause around the zero-crossing. This so-called "zero- crossing fluctuations" will be discussed more in more detail in Chapter 3, 5 and 6. The next two measurements shown are for a 25 to 40 year old video recorder and Cathode Ray Tube TV. These two devices also show large deviations from a sinusoidal waveform. This shows that the emission of harmonics is not a new phenomenon that comes only from modern equipment. The current waveform at the bottom left is taken from a mobile charger. The current magnitude is quite low and the shape of the waveform shows some similarities to the one of the CFL. The current waveform shown to the bottom right is taken with a 100 W incandescent lamp. The incandescent lamp is a linear load, for which the current waveform follows the voltage waveform.

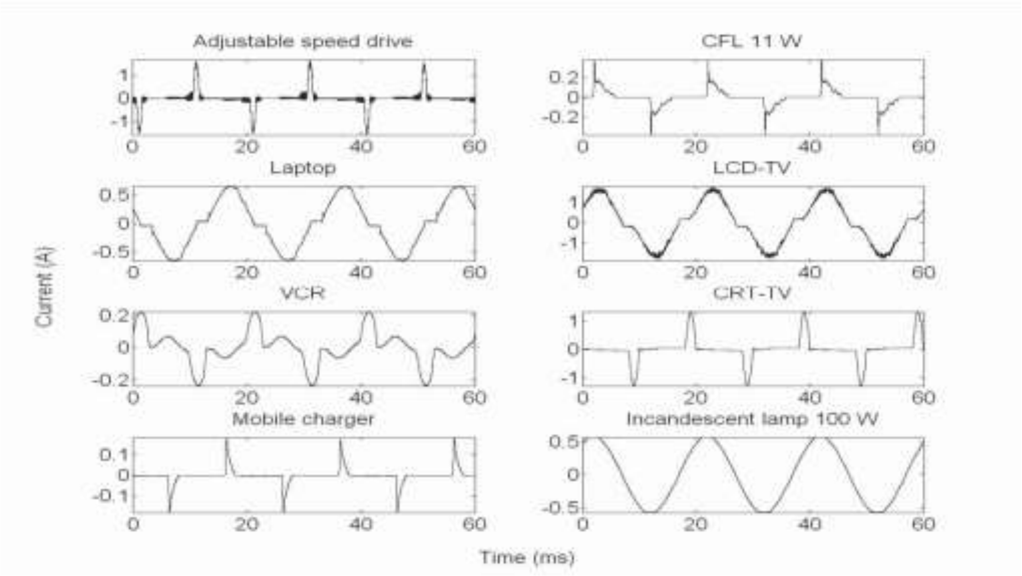

Figure2 : Electronic devices including power electronics (with incandescent lamp). The difference in vertical scale between the different waveforms.

If the front end techniques are about the same the resulting current waveform is different, as shown above. There are a number of reasons for this: different loading of the power supply; different bulk capacitor size; different control of the chopper; or the presence of an active power factor correction.

Due to the diversity of the topology the harmonic spectra from these electronic loads are also different. The output resulting spectrum of the measured current waveforms. Note that the measurement is done with an oscilloscope and not with classified power quality instrument since the purpose here is just to show some examples of waveform distortion. In all cases the spectrum is obtained over a window of exactly 200 ms. Both the adjustable speed drive and the CFL have a large harmonic content while the Laptop and the LCD TV have a much smaller harmonic content. The older equipment also present a large harmonic content as this load is using power electronics as well.

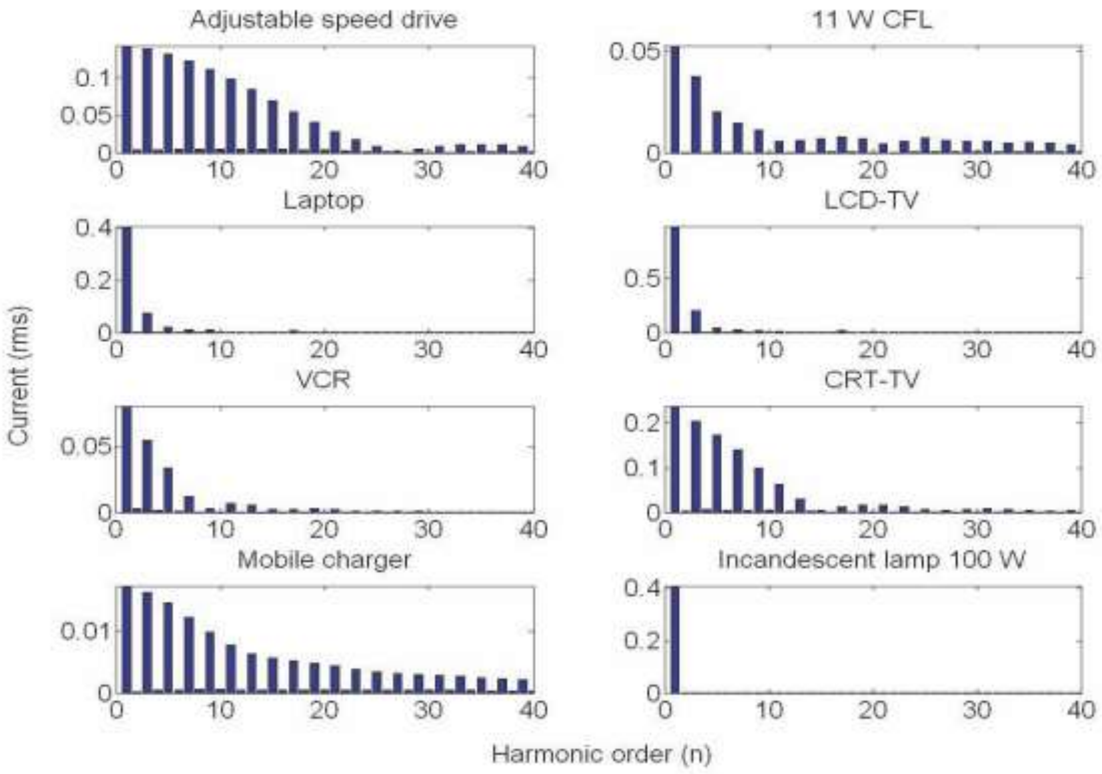

Figure 3: Harmonic spectrum of the current waveforms.

Table 1 summarizes the rms value of the current and the THD, in percent, of the measured current with the fundamental value as reference. The apparent power S is given in volt ampere and the active power P in watt. The power factor (PF), which is a common performance index for light products, is close to 1 for the laptop, LCD- TV and the incandescent lamp. This index gives some indication on how distorted the current is but note that if the load current is leading or lagging the voltage it will also produce a low PF without any distorted current. The displacement power factor (DPF) is only determined by the angle between the fundamental voltage and current.

Table 1	IRMS (A)	ITHD (% of fund.)	S (VA)	P (W)	PF	DPF
Adjustable speed drive	0.34	212.8	76.6	32.4	0.423	0.998
CFL 11 W	0.076	98.8	17.1	10.5	0.614	0.886
Laptop	0.41	20.0	93.0	89.5	0.962	0.983
LCD-TV	1.0	21.3	228.3	218.5	0.957	0.981
VCR	0.1	82.1	23.4	17.2	0.733	0.948
CRT-TV	0.40	137.9	91.2	53.3	0.584	0.999
Mobile Charger	0.037	183.6	8.4	3.9	0.464	0.982

Incandescent lamp	0.41	1.43	92.95	92.93	0.999	0.999

The reported trend over a time of several years of the harmonic content in the grid is a little diverse. Some reports show an increase of harmonic content while others report a decrease in harmonic content. Note that references and are from the same survey but looking upon different time spans. There is concern expressed by some researchers that the replacement of incandescent lamps by other types of lighting will remove the last linear device from the system. This could, according to those researchers, result in very high levels of harmonic voltage fluctuation. There is however no indications yet, neither any detailed studies showing, that this will be the case

The power quality measurements at LAN-Parties have been performed. To study LAN-parties brings some advantages; the load consists of mainly modern and state of the art computers. The computers that the participants (almost exclusively youngsters in the age group of 18 to 30 years) are bringing are always reasonable new models since the computer gaming requires that. The main conclusion from measurements at these LAN-parties over this 9 years period is a decrease in harmonic content in the load current. More details of this study can be found in Paper A. IEC are the international standards regulating the harmonic emission from loads. These standards are adopted by Sweden and most other European countries. The first mentioned standard applies to small loads, up to and including 16 A. This standard divides small loads into four different classes: A through D; where A includes most of the equipment not specified in other classes, B includes portable tools and non professional arc welding equipment, C includes lighting equipment and D includes PC, monitors and TV receivers.

When it comes to lighting equipment, Class C, harmonic emission limits are more restrictive than for the other classes. Some type of power factor correction (PFC) is needed to comply with the standard. Note that this class is restricted to equipment above 25 W; lighting equipment below this is restricted by Class D or a similar limit. The most common way to handle these harmonic limitations at lighting equipment with HF-ballast is to use active PFC. A number of different solutions and topologies are in use for this.

Even though the main topology is about the same, the time-domain measurement shown above shows that the current drawn can differ quite extensive between different types of equipment. There are however also differences between same types of equipment. The current taken by six different high frequency (HF) 2x49 W ballasts. From the time-domain measurement we can tell that the current waveform is close to sinusoidal for all these ballasts. The harmonic emission of light equipment over 25 W is regulated in which means in reality that almost all HF ballasts have a close-to-sinusoidal current waveform. Note that these waveforms are quite similar to the ones for the Laptop and LCD-TV. The deviations from a sinusoidal waveform can be observed around the current zero crossing and around both negative and positive peak of the waveform.

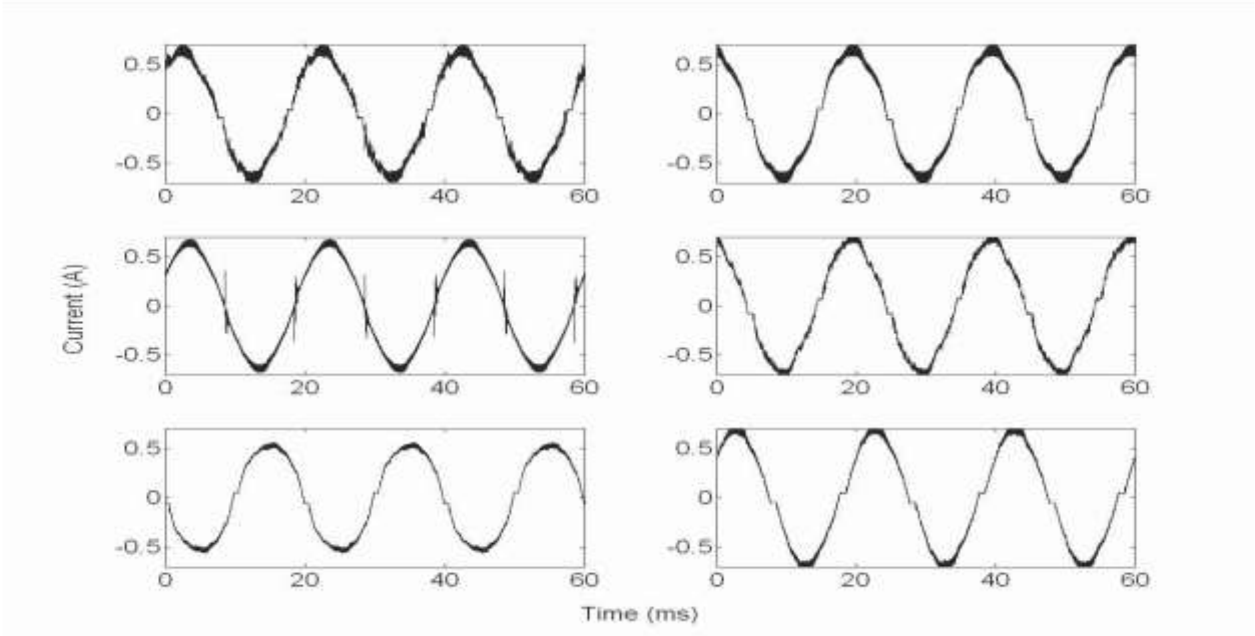

Figure 4: Current waveforms for six different HF-ballast feeding into 49 W fluorescent tubes.

Measurement Verification Methods

There are many possible sources of errors when measuring in a higher frequency range. This holds even more for measurements in the field than for measurements in the laboratory. Below examples are given of some of the ways used to verify the measurements. Note that the measurements in this thesis are not claimed to be fully accurate; the measurements are used for showing phenomena on the grid in this frequency range. But the strive is to make the accuracy as good as possible.

Measurement of Current Flows

The experimental setup of a measurement of the currents feeding two different loads, a Compact Fluorescent Lamp (CFL) and a fluorescent lamp driven by high frequency ballast. The current was measured simultaneously at three different points. According to Kirchhoff's current law these current should sum up. Kirchhoff's current law holds under the assumption that the radiated emission from the currents is small, which holds for this frequency range. Deviations from Kirchhoff's current law, any external influence on the measurement signal, and measurement errors, will likely show up as a difference.

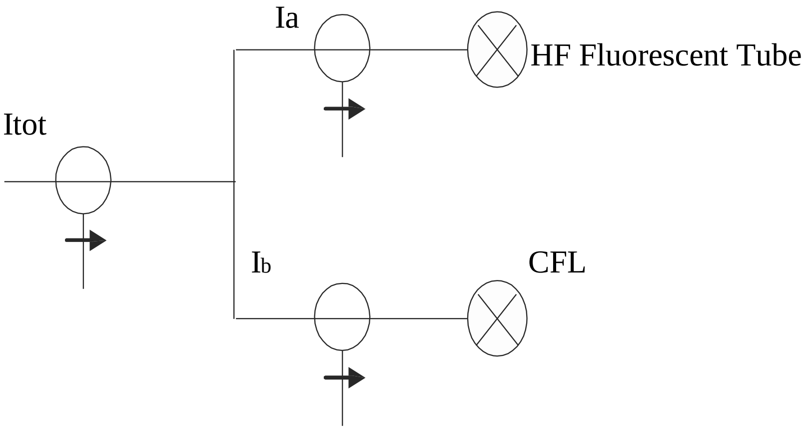

Figure 5: Laboratory setup of test to current measurement

From Kirchhoff's current law we obtain:

$$Itot = Ia + Ib \ldots\ldots(2)$$

$$I^{*}tot = Itot + \Delta I\, tot \ldots\ldots(3)$$

$$I^{*}a = Ia + \Delta Ia \ldots\ldots(4)$$
$$I^{*}b = Ib + \Delta Ib \ldots\ldots(5)$$

When joint together we receive:

$$I^{*}tot - (I^{*}a + I^{*}b) = \Delta I\, tot - (\Delta Ia + \Delta Ib) \ldots (6)$$

When the left-hand statement is close to zero this is likely due to the fact that the individual errors given by the right-hand part of the expression are small. It can however not be ruled out that the individual errors are larger but cancel each other out in comparison. With an external influence, capacitive or inductive coupling, it is more likely to be about the same for the three signals, so that it will give a non-zero result and thus show up in the comparison. Aliasing can however not be detected by this method, because Kirchhoff's current law also holds for those frequency components.

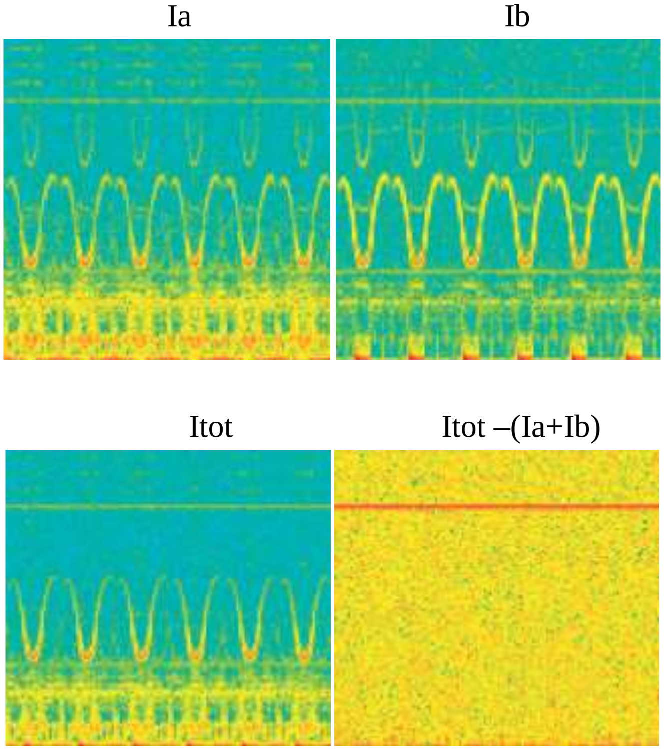

Figure 6: Output spectrogram of the three measured currents.

RESULTS AND DISCUSSION

When doing measurements at the supermarkets it was noticed that the wiring of the lighting system can differ. The lamps can be fed via a three phase cable all the way to the lamps or a split of the three phases is made earlier in the feeding system. The lamps can also either be directly connected to the feeding cable or via an outlet and a short connection cable. So one typical method has been used for the installation in the laboratory where the lamps are connected with a three phase cable where only one phase is used. This was done to at a later stage be able to evaluate how different wiring methods effect the emission from the installation. The outlet at the lamps is also used when making the measurements.

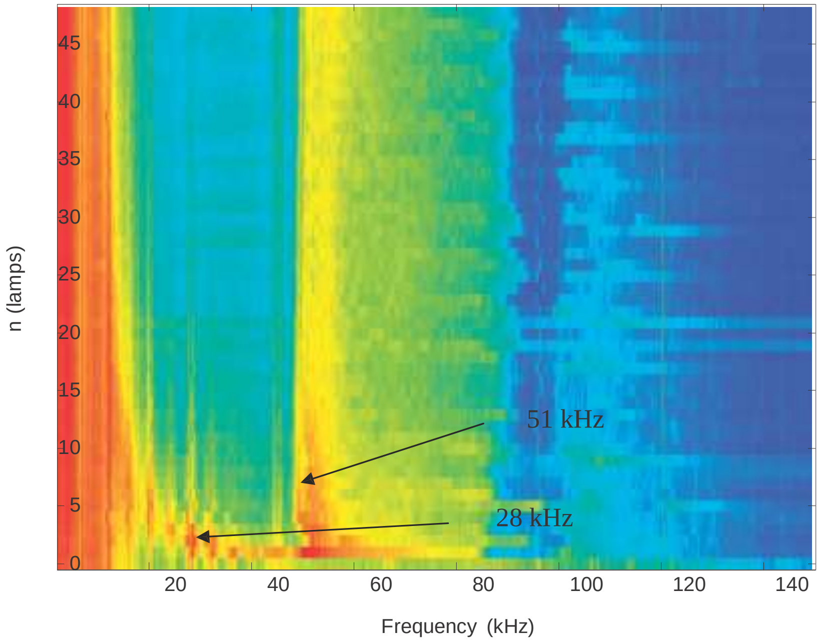

Figure 7: Fluctuated Voltage spectrum

To get a clearer picture of what happens with the different components in the voltage spectra, the rms value over different frequency ranges for each measurement has been calculated. This is done by grouping the 200 Hz bands in the frequency range of interest, from flow to fhigh, into one value according and then plot this against the number of lamps (n) turned on.

$$V^{n}(n) = \sqrt{\sum_{flow}^{\text{fhigh}} V^{2}(\text{n})}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

The plots the rms of the voltage over the spectral band between 50 and 60 kHz. This frequency band holds most of the remnants of the active PFC switching. Notice that when turning on the first lamp the rms value is increasing about 15 times but is decreasing rapidly with the number of lamps being turned on. When about half of the lamps is turned on the voltage rms is just about twice of what it was when all lamps where turned off.

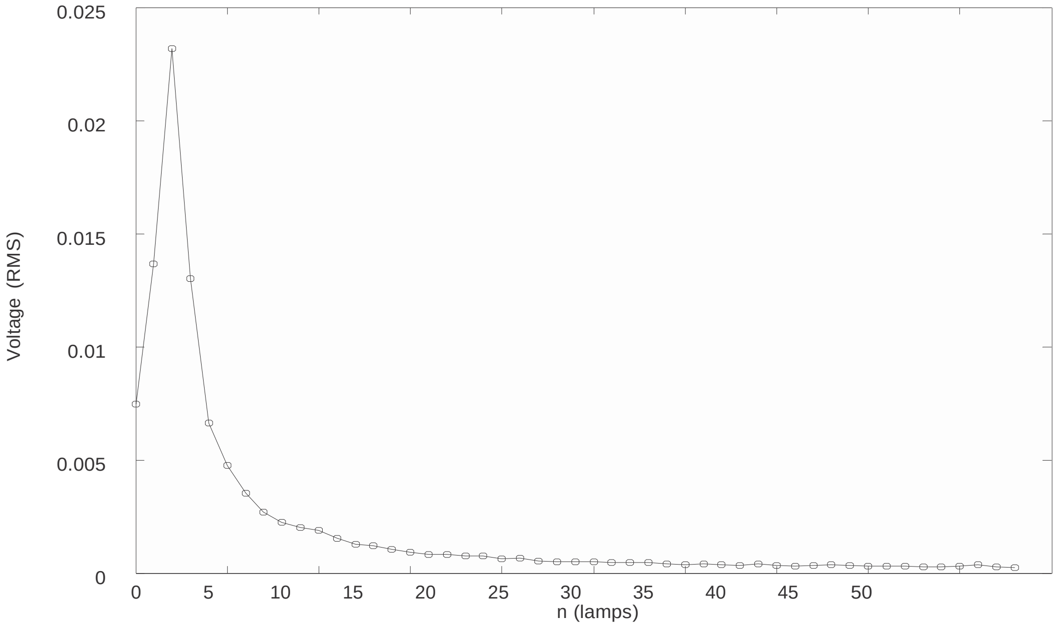

Figure 8: Output rms value of the spectrum of a secondary voltage Fluctuation in the range from 27.4 to 29.2 kHz.

CONCLUSION

Signal components in the frequency band 2 to 150 kHz emitted from small equipment have been identified and characterized into narrowband components, broadband components and recurrent oscillations. The general trend is that the emission level decreases with frequency. This is the same general trend as for emission below 2 kHz. The narrowband components mainly originate from remains of the switching at the output converter of the ballast. These components are typically found in the frequency range from 10 kHz up to about 100 kHz. When observing the narrowband components in time-frequency domain some ballasts show that this component is changing in amplitude synchronized with the power system frequency. In the laboratory measurement the narrowband components appears both as a primary and secondary emission. The broadband components originate from remains of the switching as part of the active PFC. A closer look at the broadband component, using the time-frequency plane with sufficient time resolution, shows that it is a narrowband signal that shifts frequency over time. The highest amplitude is found at the lowest frequency. The switching frequency of the active PFC is shifting, every 10 ms, from about 40 kHz up to slightly above 100 kHz.

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