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Optimization Measures for Increased Immunity against High Frequency Disturbances and Reduced Emission in the Range of 2 kHz to 150 kHz Realized on Different LED Lamps

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Abstract. In this paper, optimization measures to increase the immunity against high frequency (HF) disturbances by simultaneously reducing the impact on the grid through non sinusoidal input currents in the frequency range of 2 kHz to 150 kHz are presented. Two different light-emitting diode (LED) lamps as an example for typical electronic mass-market products are optimized. Currently, LED lamps are state of the art in the range of efficient lamps. But long-term experiences concerning their immunity against HF disturbances are not investigated so far. In order to assess the additional stress on the built-in components of the LED lamps caused by HF disturbances, the power supplies of two exemplary LED lamps are considered and their input current, the current of the electrolytic capacitor and the current of the LED are depicted. Based on these measurements, the electrolytic capacitor can be identified as one mainly weak point of the LED lamp's power supply. Subsequently, possible measures to increase the immunity of the identified stressed components and the LED lamp by itself are presented. Finally, the overall efficiency of the optimizations and their effect on the grid's power quality are shown.

Key words

Lifetime estimation, immunity enhancement, emission reduction, high frequency disturbances, LED lamps.

1. Introduction

As part of the German Energy Transition, energy efficiency topics play an important role to achieve the defined targets. Therefore, inefficient lamps like incandescent light bulbs are banned and replaced by more efficient LED lamps. Additionally, more and more power electronic components are used for the efficiency enhancement in electric devices. The increasing amount of these high frequency switching techniques like photovoltaic (PV) inverters or active power factor correction (PFC) circuits in switched-mode power supplies with typical switching frequencies above 2 kHz cause increasing HF emissions in the frequency range of 2 kHz to 150 kHz [1][2]. Therefore, the influence of these HF disturbances on electronic mass-market products like LED lamps have to be investigated in more detail. Especially the additional stress on each of the built-in components has to be considered to identify the circuits' weak points. Thus, optimization measures can be developed and used to increase the immunity of the circuits.

This paper aims to present optimization measures for the power supplies of two exemplary LED lamps and to assess the used optimizations concerning their efficiency and their effect on the grid´s power quality. In section 2, the tested power supplies are described and the initial laboratory measurement of the currents of a capacitive LED power supply with additional HF disturbances is shown. In section 3, a capacitor less power supply is tested as an alternative with potentially no affected component. Based on the initial measurements, two exemplary simple optimization measures are presented and applied on both power supplies to show their potential. Finally, in section 4, conclusions are drawn.

2. Laboratory Measurements

The two considered LED power supply circuits are a self-made capacitive power supply (see Figure 1) which design is derived from customary LED lamps as an example for low power LED lamps (< 5 W) and a switched-mode power supply with PFC as an example for higher power lamps (> 10 W). The switched-mode power supply consists of a single stage flyback topology. The technical specifications of these power supplies are given in Table 1.

Table 1: Specifications of the considered power supplies

	Capacitive power supply	Switched-mode power supply with PFC
Rated Power	*4 W*	*15 W*
LED Voltage	*197 V*	*31 V*
LED current	*20 mA*	*485 mA*

A. Capacitive LED power supply

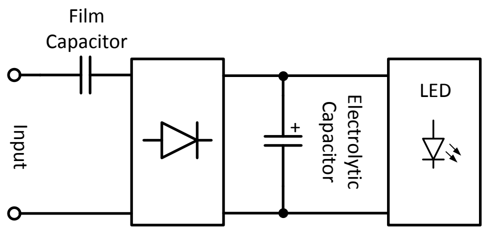

Figure 1: Capacitive power supply (LED lamp)

The advantage of a capacitive power supply is the simple low-cost design with only a few passive components and the possibility to obtain a power supply with a low voltage output, a current source characteristic that is optimal for the use with LED´s and a high efficiency. It consists of a classical bridge rectifier with an electrolytic capacitor that is dimensioned for the LED voltage. The required voltage drop is introduced by a film capacitor in series to the bridge rectifier which acts in combination with the load as a voltage divider. Compared to voltage dividers with resistors, the film capacitor ideally consumes no active power.
The LED voltage and current can be adjusted to the given needs. For higher power lamps, the series capacitor has to be excessive and this will repeal the benefit in cost and size of this circuit. Disadvantages are the high reactive power consumption and possibly the missing galvanic isolation. However, for LED lamps with a complete plastic housing, this is insignificant.

B. Switched-mode LED power supply with PFC

For higher power lamps, switched-mode power supplies are more attractive because of a higher power density and a compact design with small components. In addition, active PFC techniques are easy to implement without the need of large passive filter components. The examined switched-mode power supply consists of a simple flyback topology that is shown in Figure 2. The controller has an implemented additional PFC technique that improves the input current waveform to obtain a power factor of approx. 0.95. The switching frequency is variable and limited to 166 kHz. The total harmonic distortion (THD) of the input current is 18 % when no grid voltage distortion is applied. Due to the PFC function with a desired sinusoidal input current shape, there is no large electrolytic capacitor after the diode bridge. For EMI filtering, an input filter is applied that consists of two film capacitors and one inductor.

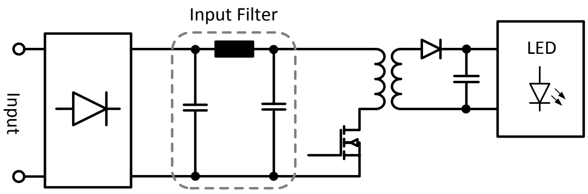

Figure 2: Switched-mode LED power supply with PFC

C. Laboratory set up

The considered LED power supplies are tested in a laboratory set up with a grid simulator that is capable of injecting additional high frequency components up to 150 kHz into the grid voltage. The power supplies are tested with ideal grid voltage of 230 V and 50 Hz and with an additional superimposed high frequency sweep from 1 kHz to 150 kHz and 2 V peak amplitude. After a warm up time, the sweep is started and every frequency test point is held for 500 ms. The data analysis is done by extracting 200 ms of each dataset and calculating the desired values for every frequency test point.

D. Initial measurements

For the capacitive power supply, measurements of the grid current, the electrolytic capacitor current and the LED current are performed. The results are given in Figure 3. The significant increase of the grid current indicates that there are components inside the circuit that are stressed by the additional HF current. The electrolytic capacitor is primary affected with an up to more than doubled current flow compared to the undisturbed operation. Higher voltage distortions will lead to even higher values. The LED itself is not affected in this circuit. With regard to the predication that already in an undisturbed operation the electrolytic capacitor and not the LED is the limiting factor of the lamps' lifetime, the additional current and therefore the higher thermal stress leads to a reduction of the lamps' lifetime [3].

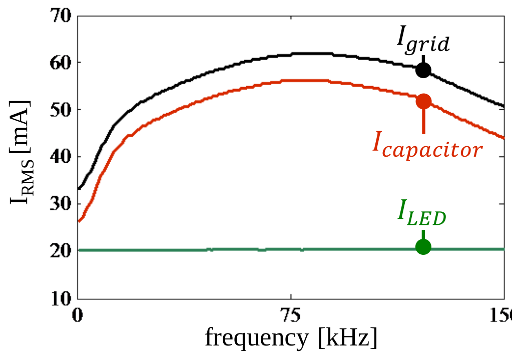

Figure 3: Currents of the capacitive LED power supply with additional HF grid voltage distortion of 2 V

The measurements for the switched-mode power supply are given in the next section together with the optimization results. Overall, it can be seen that there is also a significant increase in the input current through the high frequency distortion.

3. Circuit Optimization

There are many optimization possibilities to obtain an increased immunity in the considered frequency range. At a first glance, the elimination of the affected component, the electrolytic capacitor, is obvious and already discussed in the actual research [4]. In Figure 4, the grid current of a capacitor less LED power supply (Rated power = 7 W) with additional HF grid voltage distortion is shown for the considered frequency range. Despite the elimination of the probably most affected component, the grid current still increases. So, the HF disturbances lead to a high amount of input current distortions that impact the grid or even lead to malfunction of the capacitor less power supply. A general recommendation for circuits without capacitors is so far not possible and has to be assessed in detail for every single circuit.

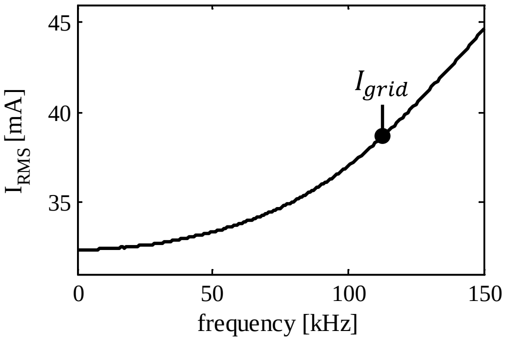

Figure 4: Input current of a capacitor less LED power supply without optimization

A more general approach is the extension of the existing circuits with passive components to obtain a more sufficient HF behavior. Its objective is the reduction of the additional HF current on the circuits to achieve lower thermal stress and a higher lifetime.

As an example, the robustness enhancement of the two typical LED driver circuits that are given in Section II is performed and verified in laboratory measurements. The optimization with only a few additional components has to be as simple as possible to avoid significant increase in circuit volume, circuit complexity and the overall circuit costs. The additional insertion of a single inductance in the circuit is sufficient for the achievement of a much higher robustness against HF disturbances and leads to a significant decrease in the additional stress on the built-in components. The laboratory measurement for the LED's capacitive power supply with and without optimization is given in Figure 5 and shows the potential of a single additional inductor with a value of 1 mH (*Optimization 1*) that is connected in series to the power supply. Additionally, as an alternative, the potential of a single inductor with a value of 4.7 mH *(Optimization 2)* is shown. The higher inductance leads to an even bigger decrease in the additional stress on the circuit, especially on the electrolytic capacitor.

Compared to the existing circuit, the additional volume of both alternatives is quite small.

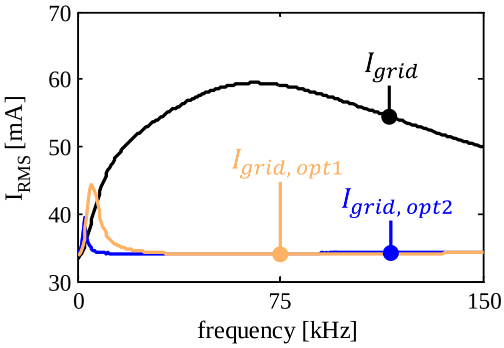

Figure 5: Input current of the capacitive LED power supply without (black) and with (orange 1 mH, blue 4.7 mH) optimization

In Figure 6, the measured currents of the switched-mode LED power supply with and without optimization are shown. Based on the additional HF grid voltage distortion, the input current of the circuit without optimization increases from 85 mA up to 175 mA at 150 kHz. Furthermore, the resonance frequency of the input filter and the corresponding high input current (117 mA) can be noticed at 27 kHz. With the additional inductor of 1 mH, the input current can be kept constant at 81 mA. The resonance frequency shifts to 14 kHz. The input current at the resonance frequency also decreases to 105 mA.

The inductor of 4.7 mH amplifies these effects on the circuit's robustness against HF disturbances.

Additionally, the LED current is shown. As with the capacitive LED power supply, the LED itself is also not affected in the switched-mode LED power supply.

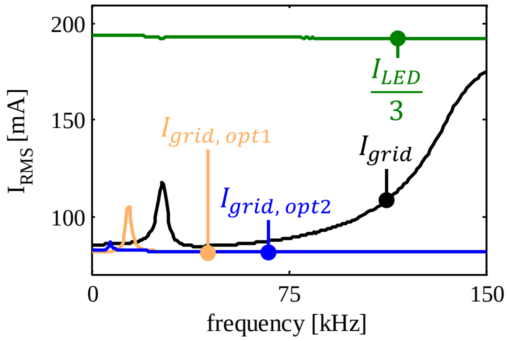

Figure 6: Input current of the switched-mode LED power supply with PFC technique without (black) and with optimization (orange 1 mH, blue 4.7 mH) and LED current (green)

In Figure 7, both in the laboratory built up power supplies without the attached LED for comparison of the dimension of the circuits are shown. For illustration of the additional volume that is needed for the optimization the different inductors are placed besides the circuits.

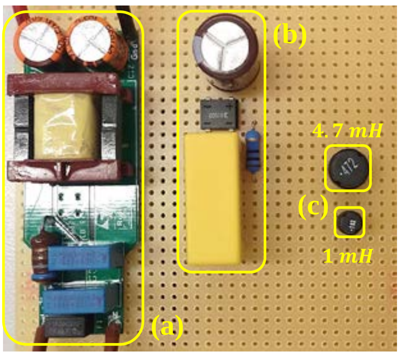

Figure 7: Comparison of the dimension of the switched-mode power supply (a), the capacitive power supply (b) and the two inductors for the optimization (c)

Further, the overall efficiency of the circuit has to be considered. The optimization should not lead to a significant decrease in the efficiency which may lead to a lower rating of the energy label and will consequently affect the attractiveness of the products. In the following Table 2, the overall efficiency of the two considered power supplies with and without both optimization alternatives is listed. The efficiency was measured for the undisturbed operation with ideal grid voltage of 230 V and 50 Hz.

Table 2: Overall efficiency of the power supplies with and without optimization

	Non-optimized	Optimization	
		1	2
Capacitive LED power supply	*96,20 %*	*96,12 %*	*95,59 %*
Switched-mode LED power supply	*84,54 %*	*84,35 %*	*83,77 %*

The high amount of additional HF current affects not only the devices itself, but also the grid's power quality. The HF current will lead to voltage drops on the grid impedances that results in an even more distorted grid voltage and vice versa. Besides that, the higher reactive current flow and therefore the high amount of reactive power transfer will lead to more losses, higher peak currents and heating of equipment. For the estimation of the impact on the grid the THD is measured for all circuits and operating points. As before, the grid voltage is composed of the ideal grid voltage with a superimposed HF sweep of 2 V peak amplitude. In Figure 8, the THD of the input current for the capacitive power supply is shown. Compared to the non-optimized case, both optimizations will lead to a much lower THD of the input current, when grid voltage distortions in the considered frequency range occur.

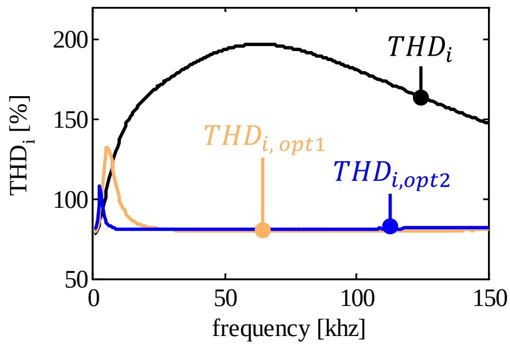

Figure 8: THD of the input current (capacitive LED power supply)

The results for the switched-mode power supply are given in Figure 9. Here, the resonance point is shifted to lower frequencies and damped so that the overall THD of the input current is significant reduced. Especially in the higher frequency range above 25 kHz a "neutral" behavior of both circuits against the grid is achieved.

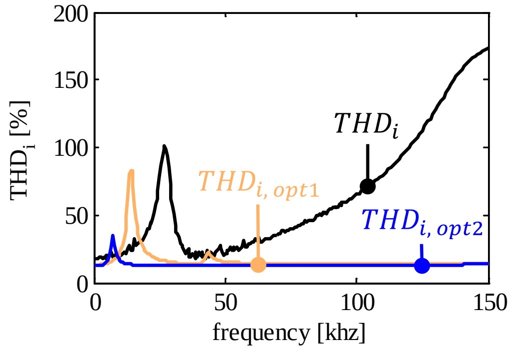

Figure 9: THD of the input current (switched-mode LED power supply with PFC technique)

The detailed component design have to be considered separately for each topology because other values will be needed for the optimization of the corresponding topologies. Overall, the measures can be well applied to different topologies for a better power quality, to increase their immunity against HF disturbances and, furthermore, to achieve a longer lifetime.

4. Conclusion

In this paper, the influence of HF disturbances in the frequency range of 2 kHz to 150 kHz on two power supplies of LED lamps and their built-in components are presented based on laboratory measurements. These measurements have shown that, if there is one, the electrolytic capacitor is the primary affected component. In contrast, the LED is nearly unaffected. So, firstly, a capacitor less LED power supply is investigated. The measurement results show that this topology is not an optimal alternative because the HF disturbances stress the other built-in components with much higher current amplitudes. This also applies to power supplies with PFC technique. In order to reduce the additional stress on the built-in components and to increase the immunity of the circuits in total against these disturbances, two optimization measures are used and their results are presented to assess their potential. The optimization measures are especially adapted for electronic mass-market products like LED lamps with low power because of their quite small additional volume and their low additional costs. Additionally, the efficiency of the optimized and non-optimized circuits is compared because the overall efficiency of the circuits should not decrease too much through the optimization.
The additional HF input current could also lead to various power quality problems in the grid. So, finally, the measures' effect on the grid´s power quality is investigated by measuring the THD for both circuits and all operating points.
All in all, the measurement results show that, on the one hand, already simple optimizations lead to an increased circuits' immunity against HF disturbances and, on the other hand, have a positive impact on the grid's power quality.

References

[1] C. Unger, "Frequencies above the harmonic range - Challenge of the future?", in Proc. 2010 IEEE International Power and Energy Conference (IPEC), pp. 763-766.

[2] M. Klatt, A. Koch, J. Meyer, P. Schegner, J. Myrzik, C. Körner, T. Darda, and G. Eberl, "Emission levels above 2kHz - Laboratory results and survey measurements in public low voltage grids", 22nd International Conference on Electricity Distribution (CIRED), Stockholm, Sweden, 2013.

[3] L. Han, and N. Narendran, "An accelerated test method for predicting the useful life of an LED driver", IEEE Transaction on Power Electronics, vol. 26, no. 8, pp. 2249-2257, 2011.

[4] S. Wang, X. Ruan, K. Yao, and Z. Ye, "A flicker-free electrolytic capacitor-less AC-DC LED driver", IEEE Energy Conversion Congress and Exposition (ECCE), Phoenix, USA, 2011.