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# Overall performance analysis of a resonant driver with different LED output stages

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***Abstract*— The paper highlights the results achieved based on a practical implementation of a front-end AC-AC converter for LED lighting application. The converter has unique properties of obtaining a quasi-constant current for the LED and high power factor without a special closed-loop control. Different output LED circuit arrangements are used, and the overall performances of the LED drivers attained are being presented, considering both the electrical and optical characteristics.**

***Keywords—AC-AC converters; Light emitting diodes; Current control; Power control; Flickering light; Energy efficiency.***

## I. Introduction

LED drivers have an important role on the development of new lighting devices for sustainable electrical energy usage. Mainly based on the advances made on the light emitting diodes (LED), the developers of the devices that control the current flow need to focus on different aspects on their development so that the entire equipment can be considered a high-performance application. Besides the classic constant LED current control and high LED efficacy characteristics found on most applications [1-3], the developments need to weight the impact of these devices on other aspects as well, as the current drown from the public grid [4-5], the system efficacy [6-7] and light quality [8-10]. Many research applications are focused on some of these characteristics, by rarely all the aspects are being represented. The objective of the paper is to present the analyses made on an LED lighting device that is based on a resonant LC driver topology, highlighting all the above characteristics.

The paper is organized with an introduction that is followed by the section 2 wherein the LED driver topology is presented, and the basic working principles are briefly shown. The chapter 3 is focused on the practical measurements of the studied topology with different output LED stage arrangements. The results are presented in correlation with: the electric efficiency, system efficacy, power factor correction capabilities and flicker parameters implications. Finally, the conclusion states the relative performances of the studied topologies and point out some target applications.

## II. LED driver topology

In this section the considered LED driver topology is introduced. The studied topology presented in Fig. 1 represents the fundamental circuit topology based on a patent [11], initially presented in the book chapter [12] and is originated on an AC-AC quasi-resonant LC parallel converter driving an output LED stage. For the study conducted in the paper, different output stages are being considered. Thus, the circuit has the flexibility to use different output LED circuit arrangements (not limited on these examples) as it is represented in Fig. 2.

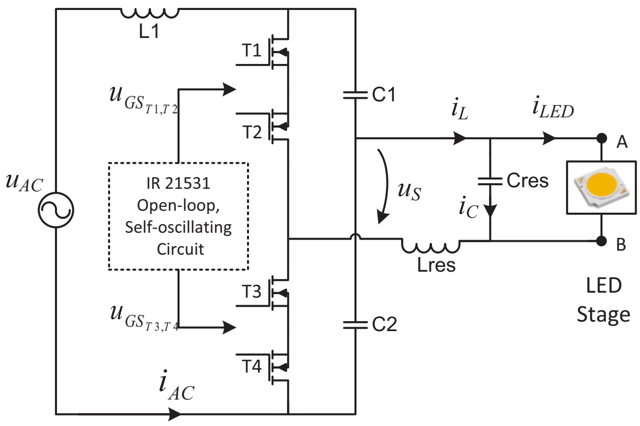



Fig. 1. Basic electronic schematic of the studed AC/AC LED driver

Not using input or output diode rectifiers, the LED driver with the antiparallel LED arrangement from Fig. 2.a can be considered a “true” single-stage AC-AC converter. As for the other LED arrangements, the resulted topologies are two-stages AC-DC converters. For these cases the AC-AC converter is used for the first conversion stage, whereas the second stage is composed by different diode rectifiers.

In close correlation with the Fig. 1 and Fig. 2a, the presumptive waveforms of the main signals are displayed in the Fig. 3. From the upper part of the image the transistors command signals are represented by 50% duty-cycle signals.

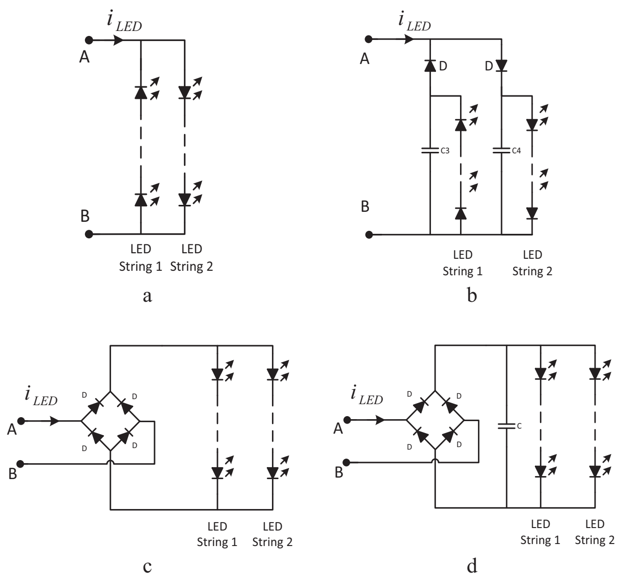



Fig. 2. Different output LED stages

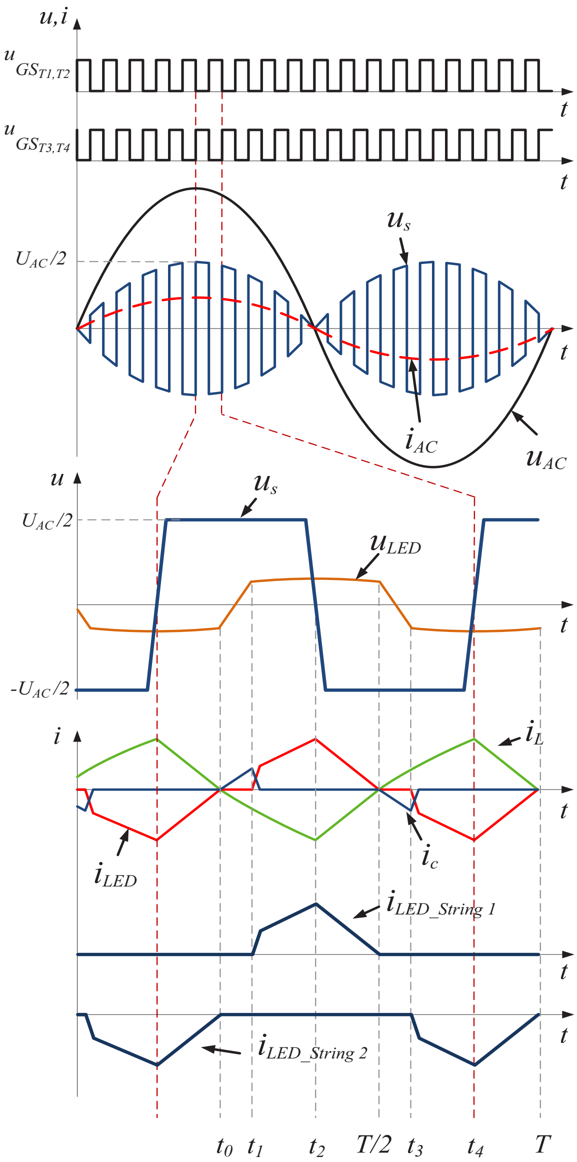



Fig. 3. AC/AC LED driver presumtive waveforms

The simulations results depicted in Fig.4. obtained by using the PSim Software, are using the AC-AC stage from Fig. 1 in combination with all the LED output arrangements presented in Fig. 2. One can notice that the different LED output arrangements have a minimum impact on the input current shape $I_{in}$. Furthermore, the output current waveform from the AC-AC converter, $i_{LED}$ , remains the same, regardless of the output LED arrangement considered.

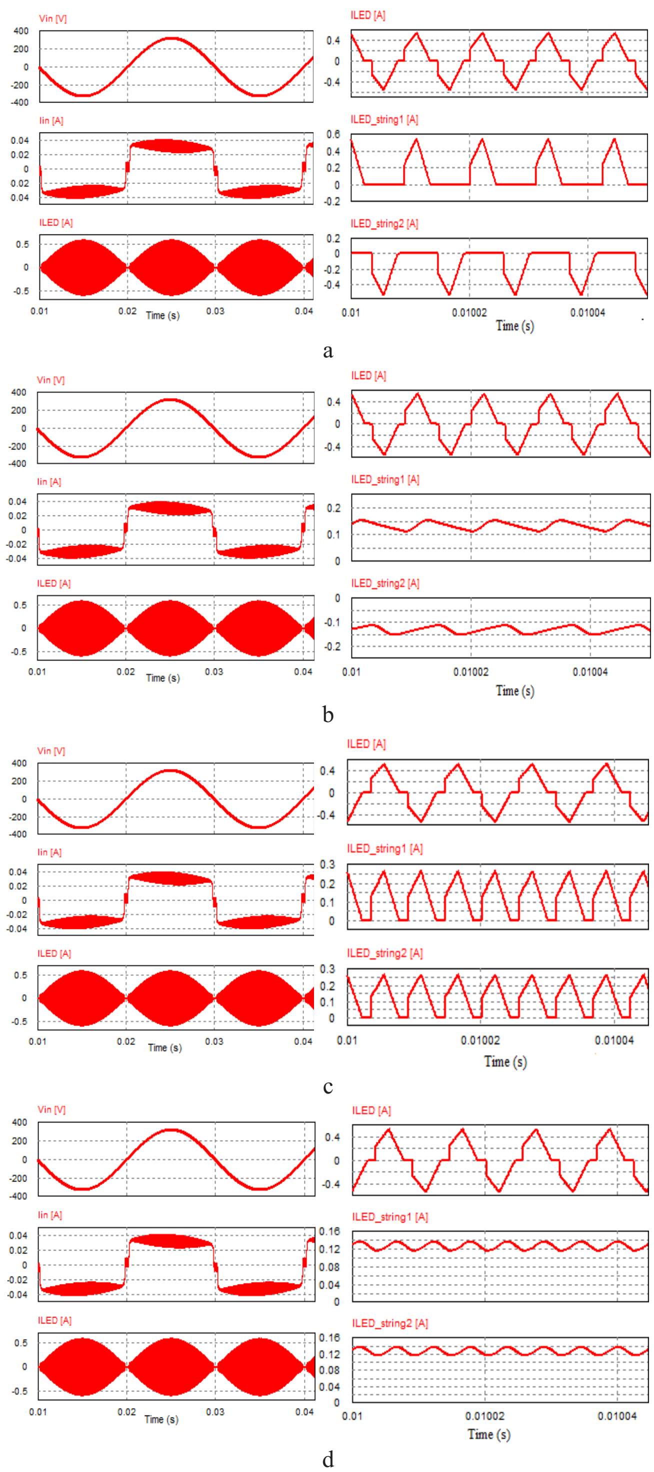



Fig. 4. Simulated results. Input voltage/current and output current $i_{LED}$ (left) and output current waveforms (right) for the studed AC-AC LED circuit with different LED output arrangements: a- AC antiparallel (Fig.2a); b - String rectified and capacitor filtering (Fig.2b); c- Rectified with no filtering (Fig.2c); d. Rectified and capacitor filtering (Fig.2d).

### III. LED DRIVER OVERALL PERFORMANCE ANALYSIS

During the practical measurements the converter topology from Fig.1 and the LED circuit arrangements from Fig. 2 are considered: AC/AC-A (Fig.5a-d), AC/AC-B (Fig.6a-d), AC/AC-C (Fig.7a), AC/AC-D (Fig.7b-d). Some other converter components used, or characteristics are: IR21531 self-oscillating IC, IRF640 transistors, L_RES - 2mH resonant coil, C_RES- 2.2nF resonant capacitor, C1-C2 100nF voltage divider, L1- 4mH input filter and 82 kHz switching frequency. The tests were carried out for three types of LEDs, CREE- XLamp CXA1304, CITIZEN-CLU028-1202C4-40AL7K3 and OPTOFLASH-OF-LM002-5B380. For the direct AC-AC converter (AC/AC-A), because the CREE module has an antiparallel diode, the circuit AC/AC-$A_1$ is proposed where a fast diode, with low voltage drop has been introduced in series with each LED String.

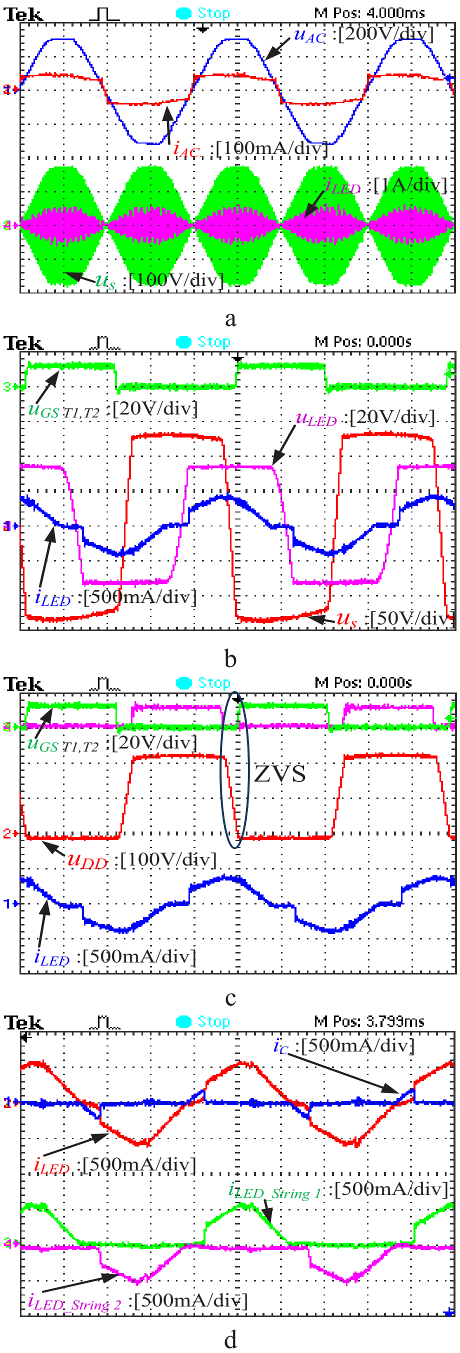



Fig. 5. AC/AC LED driver waveforms

This diode type, STPS2L40, has been used in all the other schematics for the output rectifying stages. To reinforce the presumptive waveforms from Fig. 3, the experimental results for the direct AC/AC-A driver are shown in Fig. 5a-d, wherein the signals are being presented both at low and high frequencies. The input voltage and current, together with the output waveforms of the LED driver for the other remaning three output circuit configurations from Fig.2b, Fig.2c, Fig.2d are being shown in Fig. 6a-d, Fig.7a and Fig.7b-d, respectively.

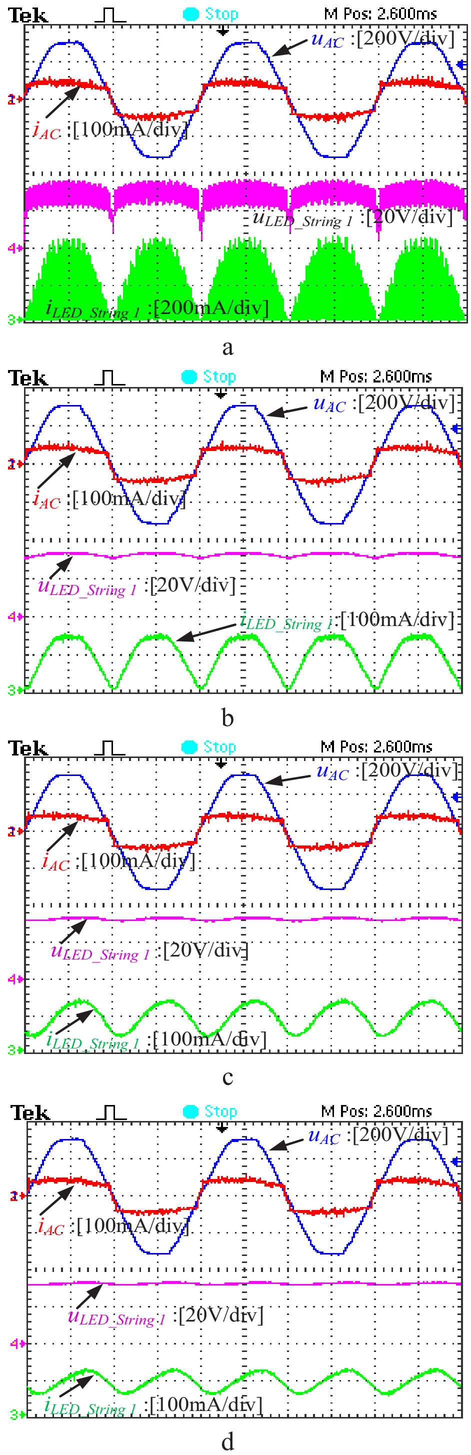
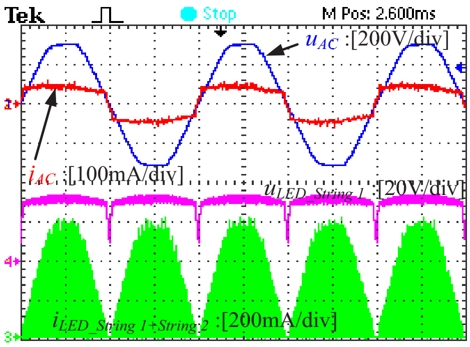


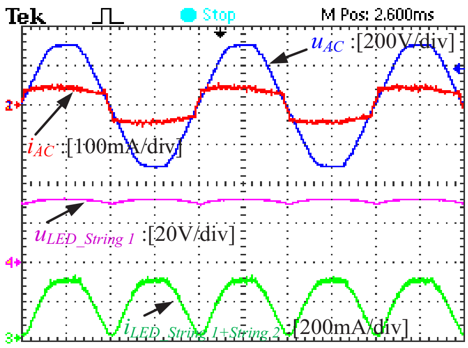

Fig. 6. LED driver waveforms; Input voltage ($u_{AC}$) and current ($i_{AC}$); LED voltage and current; a.AC/AC-B; b. AC/AC-B-10µF/string; c. AC/AC-B-110µF/string; d. C/AC-B-220µF/string

Furthermore, one can notice that the input current waveforms have small changes for all the four output LED arrangements and different output capacitor filtering.

The flicker measurements in relation with the LED low frequency current ripples, both represented in Fig.8 have been performed with the light sensor OPT101 from Texas Instruments. From these waveforms the Percent Flicker and the Flicker Index are being deducted for all practical measurements.




a

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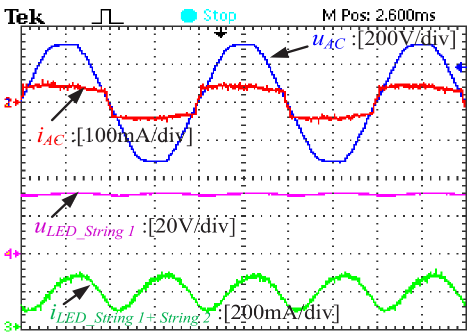
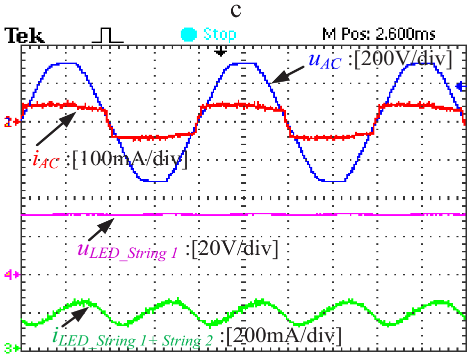
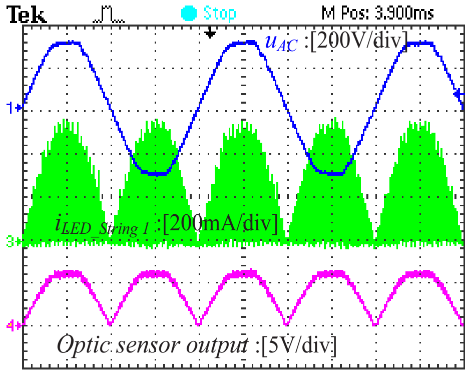



c

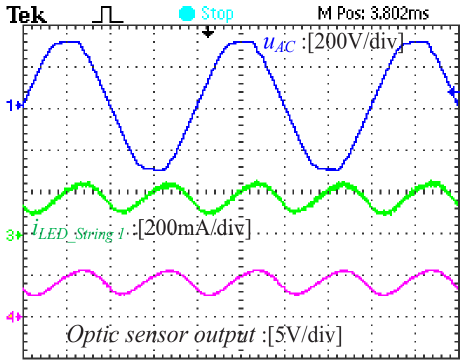



d

Fig. 7. AC/AC LED driver waveforms. Input voltage ($u_{AC}$) and current ($i_{AC}$); LED voltage and current; a.AC/AC-C; b. AC/AC-D-20µF; c. AC/AC-D-220µF; d. AC/AC-D-440µF




a




b

Fig. 8. AC/AC LED driver waveforms

The overall performances of the converter with different output arrangements and different LED types are centralized in: Table I for the Cree LED, Table II for the Citizen LED and Table III for the OptoFlash LED. The Cree LED module has an antiparallel diode, therefore for this LED the AC/AC-A arrangement measurement could not be accomplished. The Precision Power Analyzer KinetiQ PPA2530 was used for the power and power quality measurements.

For all types of LED used, the converter components and the switching frequency were kept the same. Because the forward voltage of the LED modules was different, different values of the input power were obtained. As can be observed the highest electrical efficiency is not directly translated into the best system efficacy. More, the power factor is negatively influenced by the lower input power level.

In all the cases, the best electric efficiency and the lowest cost is reached by the AC-AC LED driver with no rectifying stage (AC/AC-A), which is an expected result. The overall efficacy is not the highest in this cases, one reason being the high value of the low frequency current ripple. This can be observed in correlation with the percent flicker, where the lowest efficacy is attained at 100% percent flicker.

By analyzing the duty-cycle (the time in a period were the LED is conductive) implications, it can be concluded that the lower duty-cycle of the AC/AC-A and AC/AC-$A_1$ cases is translated in lower system efficacy. For the increased duty-cycle in the AC/AC-C case, the system efficacy is higher, in the proximity of the maximum obtained for each LED arrangement. For these applications, to some extent, the system performance (higher system efficacy, lower flicker index and percent flicker) can be improved using low capacitance non-electrolytic capacitors.

The cases AC/AC-B-220 μF/string and AC/AC-D-440μ have the best performance in light output quality, with the lowest flicker index and percent flicker, together with the best system efficacy.

Regarding the power quality, in all the cases, the power factor was above 0.909, with a maximum of 0.952, while the THD is around 30%. The best performances are obtained in the cases where no capacitance was used. Considering the low power level, the results are fairly good.

TABLE I. PRACTICAL MEASUREMENTS - LED- CREE

| | Input power [W] | Electric Effi-ciency [%] | System Efficacy [lm/W] | Power Factor | THD [%] | Flicker Index | Percent Flicker [%] |
|---|---|---|---|---|---|---|---|
| AC/AC-A | - | - | - | - | - | - | - |
| AC/AC-$A_1$ | 5.03 | 79.6 | 102.39 | 0.916 | 28.0 | 0.35 | 100 |
| AC/AC-B-10μF/string | 4.76 | 76.8 | 113.73 | 0.912 | 29.0 | 0.36 | 93.93 |
| AC/AC-B-110μF/string | 4.73 | 76.9 | 115.06 | 0.911 | 29.7 | 0.34 | 61.11 |
| AC/AC-B 220μF/string | 4.72 | 76.9 | 115.6 | 0.909 | 30.7 | 0.24 | 40 |
| AC/AC-C | 4.8 | 77.9 | 110.47 | 0.914 | 28.6 | 0.32 | 100 |
| AC/AC-D-20 μF | 4.74 | 77 | 113.38 | 0.913 | 28.8 | 0.31 | 93.75 |
| AC/AC-D-220 μF | 4.73 | 76.7 | 113.53 | 0.913 | 29.8 | 0.28 | 53.84 |
| AC/AC-D-440 μF | 4.71 | 76.5 | 113.84 | 0.91 | 30.2 | 0.29 | 36.58 |

TABLE II. PRACTICAL MEASUREMENTS - LED- CITIZEN

| | Input power [W] | Electric Effi-ciency [%] | System Efficacy [lm/W] | Power Factor | THD [%] | Flicker Index | Percent Flicker [%] |
|---|---|---|---|---|---|---|---|
| AC/AC-A | 7.9 | 91 | 134.36 | 0.95 | 29.8 | 0.3 | 100 |
| AC/AC-$A_1$ | 7.97 | 90.3 | 128.68 | 0.952 | 29.1 | 0.30 | 100 |
| AC/AC-B-10μF/string | 7.66 | 88.3 | 141.37 | 0.949 | 30.3 | 0.25 | 86.66 |
| AC/AC-B-110μF/string | 7.61 | 88.3 | 142.11 | 0.947 | 31.1 | 0.20 | 38.98 |
| AC/AC-B 220μF/string | 7.6 | 88.4 | 142.97 | 0.945 | 31.3 | 0.14 | 25.80 |
| AC/AC-C | 7.7 | 89.1 | 139.24 | 0.95 | 29.8 | 0.33 | 100 |
| AC/AC-D-20 μF | 7.64 | 88.5 | 143.19 | 0.949 | 30.3 | 0.33 | 89.47 |
| AC/AC-D-220 μF | 7.61 | 88.4 | 143.5 | 0.946 | 30.9 | 0.26 | 42.85 |
| AC/AC-D-440 μF | 7.59 | 88.4 | 143.73 | 0.945 | 31.3 | 0.17 | 25 |

TABLE III. PRACTICAL MEASUREMENTS - LED-OPTOFLASH

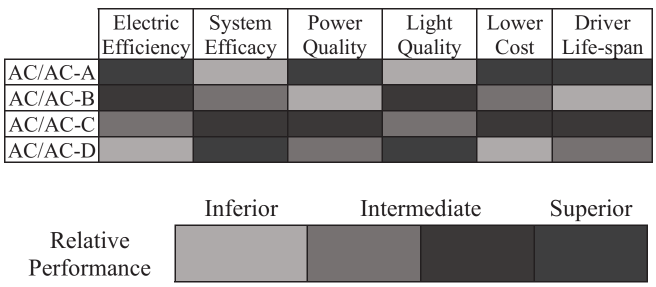
| | Input power [W] | Electric Effi-ciency [%] | System Efficacy [lm/W] | Power Factor | THD [%] | Flicker Index | Percent Flicker [%] |
|---|---|---|---|---|---|---|---|
| AC/AC-A | 7.15 | 89.7 | 97.45 | 0.952 | 28.8 | 0.34 | 100 |
| AC/AC-$A_1$ | 7.24 | 88.2 | 96.91 | 0.926 | 29 | 0.34 | 100 |
| AC/AC-B-10μF/string | 6.83 | 85.8 | 101.74 | 0.919 | 30.6 | 0.34 | 94.02 |
| AC/AC-B-110μF/string | 6.75 | 86 | 102.19 | 0.944 | 31.4 | 0.29 | 50.61 |
| AC/AC-B 220μF/string | 6.74 | 86 | 103.15 | 0.943 | 31.6 | 0.21 | 31.76 |
| AC/AC-C | 7.02 | 84.1 | 106.73 | 0.95 | 29 | 0.33 | 100 |
| AC/AC-D-20 μF | 6.82 | 84.8 | 112.13 | 0.949 | 29.7 | 0.34 | 94.11 |
| AC/AC-D-220 μF | 6.76 | 84.9 | 113.29 | 0.946 | 30.8 | 0.29 | 49.39 |
| AC/AC-D-440 μF | 6.75 | 84.8 | 113.57 | 0.944 | 31.3 | 0.20 | 30.23 |

## IV. CONCLUSION

The paper introduces a method of using the benefits of soft switching, by implementing an LED lighting driver based on a resonant LC converter. The converter topology is composed by an AC-AC converter stage followed by an output LED circuit, that can achieve a high power factor inherently without a feedback control loop. Moreover, the circuit has a strong current source behavior, as can be seen on the input current evolution, which is quasi-constant on both half-cycles, regardless of the natural sinusoidal evolution of the input voltage and the output LED stage used. Thus, no LED constant current control is imperatively required.

Considering the comparison results presented in the previous section, in Table IV, the relative performances of the considered topologies are depicted. Based on this, the user can formulate an optimization strategy by incorporating these main characteristics and based on importance, a decision can be made for a certain topology to be chosen. Quantitatively, four out of six parameters are superior for the AC/AC-A topology, thus one can conclude that this topology can be used for outdoor LED lighting, where 100% Percent Flicker is acceptable. Based on higher System Efficacy, for a capacitor-free driver, the best compromise solution is the AC/AC-C.

TABLE IV. RELATIVE TOPOLOGY PERFORMANCE



More, for indoor applications the AC/AC-D topology seems to be the more appropriate solution since this approach has the best results in system efficacy and light quality.


## ACKNOWLEDGMENT

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