



HAL
open science

Determination of Power Factor and Harmonic Distortion of AC/DC LED Driver

Abdelhakim Zeghoudi, Abdelber Bendaoud, Laurent Canale, Amar Tilmatine,
Helima Slimani

► **To cite this version:**

Abdelhakim Zeghoudi, Abdelber Bendaoud, Laurent Canale, Amar Tilmatine, Helima Slimani. Determination of Power Factor and Harmonic Distortion of AC/DC LED Driver. 2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Sep 2021, Bari, Italy. 6 p., 10.1109/EEEIC/ICPSEurope51590.2021.9584665 . hal-03413976

HAL Id: hal-03413976

<https://ut3-toulouseinp.hal.science/hal-03413976>

Submitted on 4 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Copyright

Determination of Power Factor and Harmonic Distortion of AC/DC LED Driver

Abdelhakim ZEGHOUDI
*Laboratory of Applications of Plasma,
Electrostatics and Electromagnetic
Compatibility (APELEC)
Djillali Liabes University
of Sidi Bel-Abbès
Sidi Bel-Abbès, Algeria
hakooumzeghoudi@gmail.com*

Abdelber BENDAOU
*IEEE Senior member
Laboratory of Applications of Plasma,
Electrostatics and Electromagnetic
Compatibility (APELEC)
Djillali Liabes University
of Sidi Bel-Abbès
Sidi Bel-Abbès, Algeria
babelber@gmail.com*

Laurent CANALE
*IEEE Senior member
LAPLACE Laboratory,
Université de Toulouse,
CNRS, INPT, UPS,
Toulouse, France
laurent.canale@laplace.univ-tlse.fr*

Amar TILMATINE
*IEEE Senior member
Laboratory of Applications of Plasma,
Electrostatics and Electromagnetic
Compatibility (APELEC)
Djillali Liabes University
of Sidi Bel-Abbès
Sidi Bel-Abbès, Algeria
atilmatine@gmail.com*

Helima SLIMANI
*Laboratory of Applications of Plasma,
Electrostatics and Electromagnetic
Compatibility (APELEC)
University of Tiaret
Tiaret, Algeria
slimani.halima@yahoo.fr*

Abstract—The efficiency of electrical energy has become the most important elements in the part of electrical and electronic systems partially in the lighting systems, for this reason the light-emitting diode (LED) lamps are widely used in recent years. Nevertheless, LED is a non-linear load which causes a very high harmonic current, and a low power factor PF, thus a poor power quality. Research is focused on reducing current harmonics and improving the power factor (PF) has intensified. In this paper, a comparative study between Passive Power Factor Corrector (PPFC) with different topologies and Active Power Factor Corrector (APFC). These types were modeled using the LTspice software and the input power factor (PF) and total harmonic distortion (THD) of each type is determined and analyzed.

Keywords—LED driver, active PFC, passive PFC, THD, AC/DC converter, DC/DC converter, Flyback.

I. INTRODUCTION

Light-emitting diode (LED) is the most widely used light source in many lighting application areas in recent years. In fact, they are considered the future trend in lighting because of their remarkable advantages over conventional lighting (CFL, incandescent, halogen, fluorescent) [1-4], this choice is justified by their energy efficiency, and their environmental friendliness, their life span is very long, about 50,000 hours depending on the driving technique, their use in intelligent lighting. Less heat than other conventional lamps, good color rendering, hue and intensity or even detects people in indoor environments [5, 6].

Nevertheless, the energy quality of electrical systems and has a direct impact on system efficiency, safety and reliability. However the energy quality is affected by many disturbances creates in power systems such as harmonics, voltage fluctuations, electromagnetic disturbances, the behavior of non-linear systems, magnetic fields, etc... these contaminating disturbances can decrease power quality and negatively affect

system performance in several ways such as reducing the FP power factor, increasing conductor losses, and harmonic emission (THD) overload the unprotected neutral conductor, even a totally malfunction the system itself or neighbor [7, 8].

The problem of electrical energy quality caused by the use of electronic equipment such as LED lamps which can generate low frequency harmonics and electromagnetic interference (EMI) because it consists of an AC/DC rectifier, it is therefore important to control the reduction of harmonic emission and improvement of the power factor.

This work presents a comparative study between passive power factor correction types and active correction with electronic switches for driving LED lamps in order to improve the power factor and reduce harmonic emissions to low frequency. Each type is simulated using LTspice.

This paper is organized as follows: in section II, the active and passive power factors are defined. In section III the power factor (PF) and the total harmonic distortion (THD) are presented. In section IV the modeling of passive PFC and active PFC are introduced and their simulation results are compiled and analyzed. In section V, the conclusion is drawn from the simulation results and the comparison between the passive PFC and active PFC.

II. POWER FACTOR CORRECTION (PFC)

Power factor correction (PFC) is a circuit that is added to the power circuit for a power factor close to unit to reduce low frequency harmonics and creates a current waveform close to a fundamental sine. Among the power circuits, the lighting systems using LEDs are used. This application deals with the basic topologies of the PFC circuits and their operations.

There are two techniques of PFC: the first technique is Passive Power Factor Corrector (PPFC) as a traditional method which used a reactor to eliminate harmonic distortion in the line current and improve the power factor of the source, the second technique is Switching PFC (active) which controls a high-frequency current with the help of a switching

component e.g. (MOSFET, IGBT ...); which turns on and off by a very fast control device to control the current several times per mains cycle.

Topologies are used as PFC: parallel switching devices, interleaved PFC, and bridge-less PFC that offers even higher efficiency. In addition, there are three current conduction modes: 1) continuous conduction mode (CCM) that continuously passes current to a switching reactor; 2) critical conduction mode (CRM) that turns on switching devices at zero current; and 3) discontinuous conduction mode (DCM) that passes current with an interval of time [9].

III. POWER FACTOR AND HARMONICS

Non-linear loads have large THD values and considerable distortion to the normal sine wave. The more deformed the sine wave, the lower the total power factor. Usually, the total power factor is associated only with the phase shift of the voltage curve to the current waveform, but harmonics also affect the total power factor [9].

A well-designed PFC should be able to deal with power factor and THD problems. First, PF distortion and total harmonic distortion (THD) are derived in the presence of non-sinusoidal line current and/or voltage waveforms as shown in Fig. 1 [10].

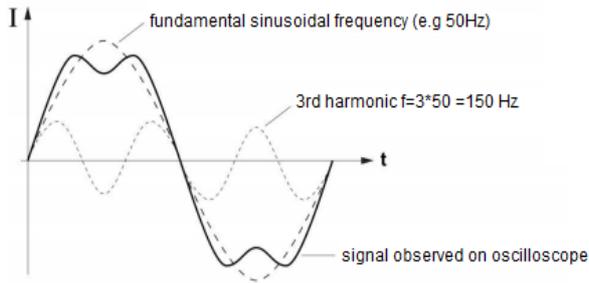


Fig. 1. Input current distortion due to non-linear load [11].

The Fourier expansion for line current and voltage are derived in (1) and (2): [10]

$$I_S = I_{DC} + I_{S1} \sin(\omega t + \theta_{i1}) + \sum_{n=2}^{\infty} I_{Sn} \sin(n\omega t + \theta_{in}) \quad (1)$$

$$V_S = V_{DC} + V_{S1} \sin(\omega t + \theta_{v1}) + \sum_{n=2}^{\infty} V_{Sn} \sin(n\omega t + \theta_{vn}) \quad (2)$$

Then, the PF can be rewritten as:

$$\text{Power Factor (PF)} = \frac{\text{Active power}}{\text{Total apparent power}} \quad (3)$$

$$PF = \frac{\sum_{n=1}^{\infty} I_{Sn,rms} V_{Sn,rms} \cos \theta_{Sn}}{\sqrt{\sum_{n=1}^{\infty} I_{Sn,rms}^2 \sum_{n=1}^{\infty} V_{Sn,rms}^2}} \quad (4)$$

The total harmonic distortion is the ratio of the sum of the root mean square value of the different harmonic components to the root mean square value of the fundamental signal. It is normally expressed as a percentage and mathematically can be written as: [12]

$$THD \% \text{ fundamental} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots}}{I_1} \quad (5)$$

Where I_n is the RMS current of n^{th} harmonic and $n=1$ is the fundamental frequency

For this case, the International Electrotechnical Commission (IEC) introduces several regulations to limit the low frequency harmonic of electronic equipment at the grid. Table 1 gives The IEC 61000-3-2 regulation, which limits harmonic injection in Lighting equipment with a power rating greater than 25 W is classified as Class C and lighting equipment with a power rating between 5 W and 25 W is applied to Class D harmonic current [13]

TABLE I. THE EMC STANDARD THAT CONTROLS THE HARMONIC CURRENT OF LIGHTING FIXTURES IS ON IEC61000-3-2 CLASS C AND D [14].

Harmonic order(n)	Class C	Class D	
	Maximum Permissible harmonic current Expressed as a percentage of the input current at the Fundamental Frequency	Maximum Permissible Harmonic (mA/W)	Maximum Permissible harmonic current (A)
2	2	3.4	2.3
3	30*(power factor)	1.9	1.14
5	10	1.0	0.77
7	7	0.5	0.4
9	5	0.35	0.33
11=<n<39 odd harmonic only	3	3.85n	see another spesity table for relevant delay in the standard

IV. SIMULATIONS AND RESULTS

A. Bridge AC/DC converter without PFC

Fig. 2 shows the simulation of diode bridge rectifier with a voltage filter capacitor, the load present 4 LED lamp type LXHL-BW02 and diode bridge type MBR5140, the rectifier directly connected with the line voltage, their RMS value is 220 V. We measured the current and line voltage and then the current harmonics generated by this topology, also the voltage and current rectified.

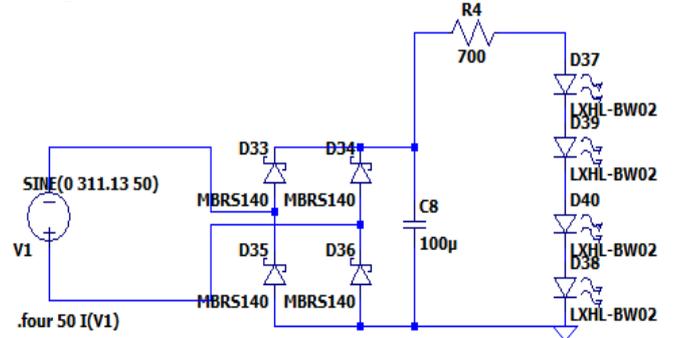


Fig. 2. AC/DC converter in diode bridge to drive the LEDs.

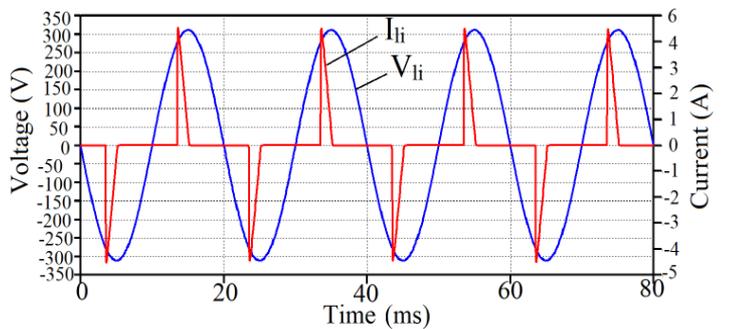


Fig. 3. AC/DC input voltage and current.

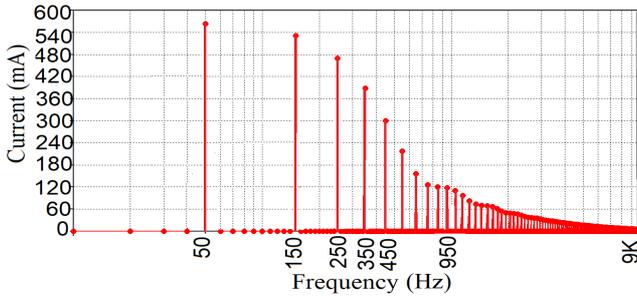


Fig. 4. Frequency spectrum of harmonics generated by the AC/DC converter.

Based on the results obtained, we observe in Fig. 3 that the current signal is non-sinusoidal, on the other hand, the input voltage are sinusoidal, the current signal shows the presence of odd harmonics with very intense amplitudes as shown in Fig. 4 such as harmonics in the order of 3, 5, 7 and 9 of their values respectively 749.2 mA, 62.9 mA, 549 mA, 424.4 mA, therefore the total harmonic distortion presents a large value that is equal to $THD = 153.01\%$ and the power factor low of value $PF = 0.52$.

Fig. 5 shows the voltage and current at the terminals of the LED lamps.

❖ Inductance effect at the AC/DC rectifier input

Fig. 6 shows the AC/DC converter simulation circuit with different values of the inductance at the input of the AC/DC converter. The line current for 3 values of inductance is measured.

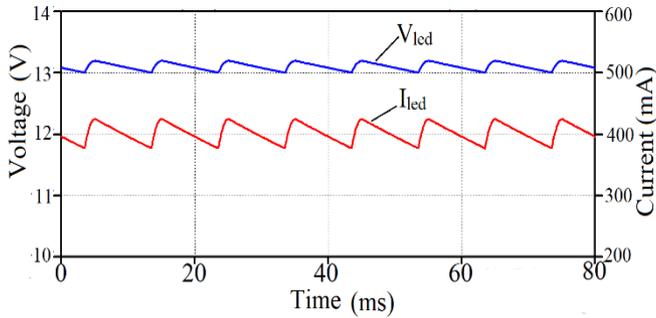


Fig. 5. Current and voltage at the AC/DC converter output.

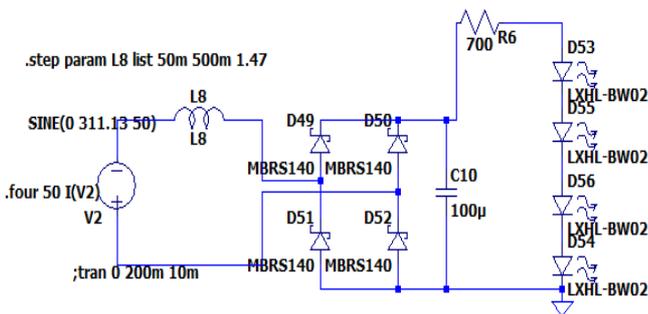


Fig. 6. AC/DC converter with inductance with various values.

Fig. 7 shows the effect of the inductance on the input current. We notice that with the increase of the inductance, the line current signal becomes sinusoidal but with an amplitude reduction.

Table 2 shows the power factor and the total harmonic distortion for each value of inductance, we observe that with the increase of the inductance the power factor reduces that

means the reactive power increases but the THD becomes reduced. So the current waveform will be improved as shown in the previous figure.

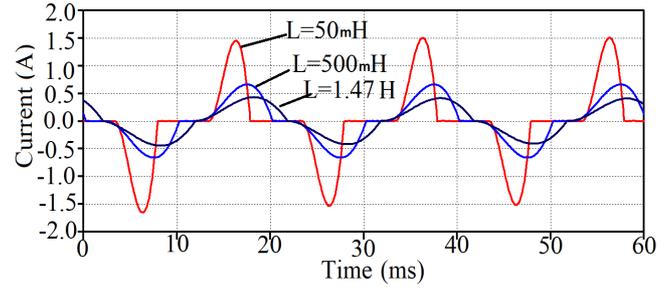


Fig. 7. Inductive effect on the input current.

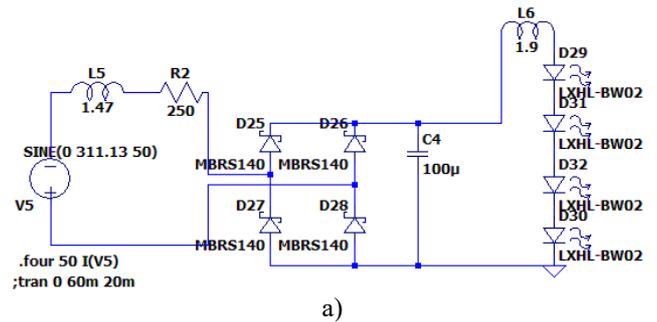
TABLE II. POWER FACTOR AND TOTAL HARMONIC DISTORTION FOR THE 3 INDUCTANCE VALUES.

Inductance L	Power factor (PF)	Total Harmonic distortion (THD) %
50 mH	0.79	57.41
500 mH	0.64	13.85
1.47 H	0.37	5.02

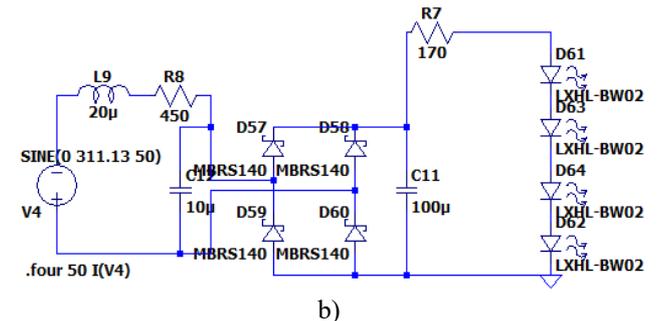
B. AC/DC with PFC passive

Passive PFC circuits can be divided into two types either with inductors or capacitors [15]. The passive inductive PFC circuit is simply the use of an inductor in the input circuit, which forms a RL filter, or with the DC bus capacitor in bulk a series RLC filter [16] as shown in Fig. 8 (a) and (b) The main problem with this technique is the volume of passive components.

The second technique of PFC based on capacitor-diode and named Valley-Fill PFC which can improve the power factor and reduce the harmonic distortion of the input line current [17] as shown in Fig. 8 (c) and (d). The original valley fill circuit is shown in Fig. 8 (c). The capacitors C1 and C2 are charged in series and discharged, via diodes D5 and D6, in parallel. One of the solutions for further improvement of PF and THD of this Valley-Fill -PFC circuit is to increase the number of capacitors (Fig. 8 (d)).



a)



b)

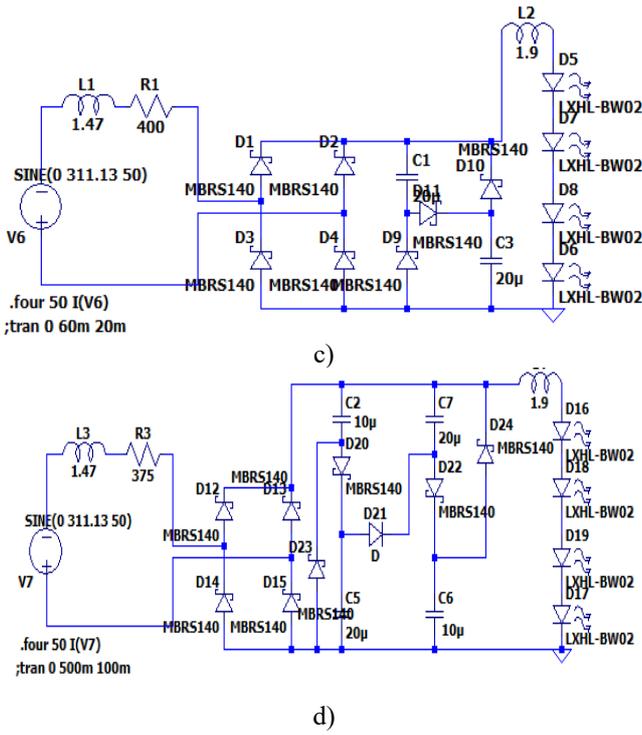


Fig. 8. AC/DC PFC passive types : a) RL filter; b) RLC filter; c) conventional valley fill filter; d) Valley filling filter with 03 capacitors.

Fig. 9 presents the current waveform of 4 types that we have simulated on LTspice software. The curves b), c) and d) are identical, the curve a) delayed because of inductive filter RL. Fig. 10 shows the harmonic emissions between [0-1 kHz], we notice the decrease in odd harmonics of order 3, 5, 7, corresponding respectively to the frequency 150 Hz, 250 Hz, 350 Hz and type d) presents the better solution compared to other types. Table 3 defines the power factors and total harmonic distortion of each passive PFC technique.

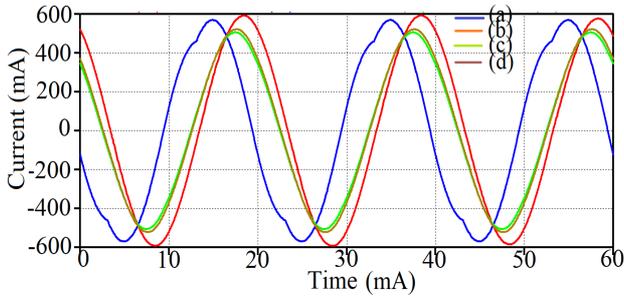


Fig. 9. Line current of the 4 types.

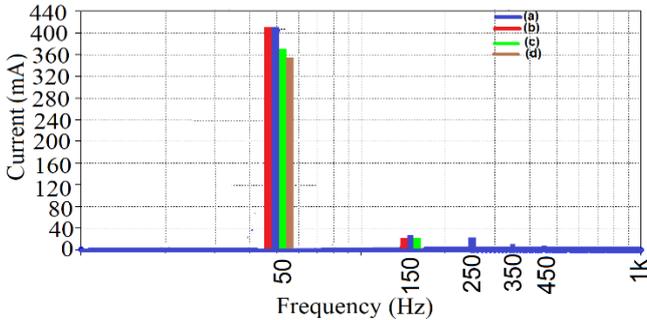


Fig. 10. Harmonic spectra of the AC/DC input current.

TABLE III. POWER FACTOR AND THD OF EACH PASSIVE PFC TECHNIQUE.

Type	Power factor (PF)	Total Harmonic Distortion (THD %)
a)	0.51	1.35
b)	0.99	5.84
c)	0.71	1.31
d)	0.69	1.14

C. AC/DC with PFC active

In this part, we simulate by using the Fig. 11 which presents a circuit of driving the LED lamps AC/DC PFC active (the Switches), the PFC active in this figure is represented a DC/DC converter controlled by an Electronic Switch.

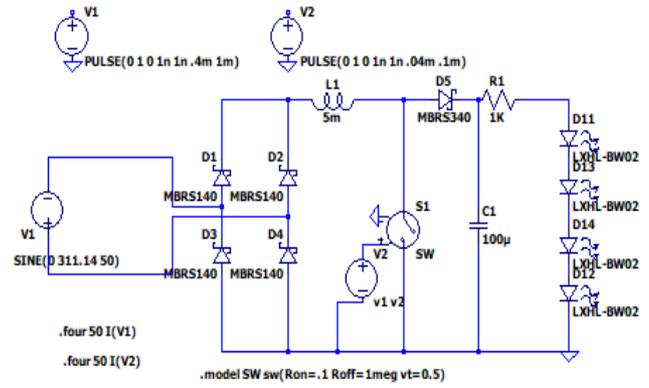


Fig. 11. AC/DC PFC parallel chopper with two different commands (AC/DC PFC boost converter).

Two square wave control signals with frequencies of 1 kHz and 10 kHz respectively. We have simulated the temporary input current and frequency of the two types of control pulse V₁ and pulse V₂.

Fig. 12 shows the waveform of the line current, we notice that the sinusoidal triangle waveform, the period of the pulse waveform V₂ is equal to 10 times the period of pulse V₁ as shown in Fig. 13, due to the switching frequency of the electronic switch for both types. For this, we notice a peak of disturbances created at the frequency 1 kHz (the frequency of pulse signal V₁) as well as the reduction of current harmonics of the order 3, 5, 7 and 9 (Fig. 14), the first type pulse V₁ THD and PF results is equal 14.44 % and PF = 0.98 respectively, the second type pulse V₂ THD and PF results is equal 13.21 % and 0.99 respectively. According to an improvement of THD and PF in the second type which presents the high control frequency.

❖ Effect of the inductance on the active PFC AC/DC

In this part we simulated an AC/DC PFC rectifier for LEDs driver with variable inductances. The inductance values are: 5 µH, 50 µH and 500 µH (Fig. 15). we used a MOSFET type IRF 1503 with a control frequency equal to F = 25 kHz and a diode type 1N5818. After the simulation under Ltspice software, we obtained the results shown in Fig. 16 and Fig. 17.

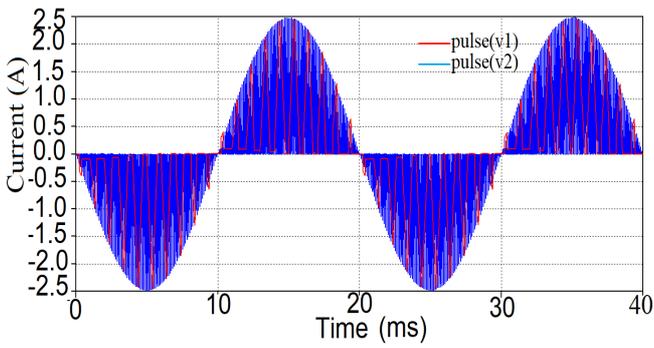


Fig. 12. AC/DC converter input current PFC parallel chopper.

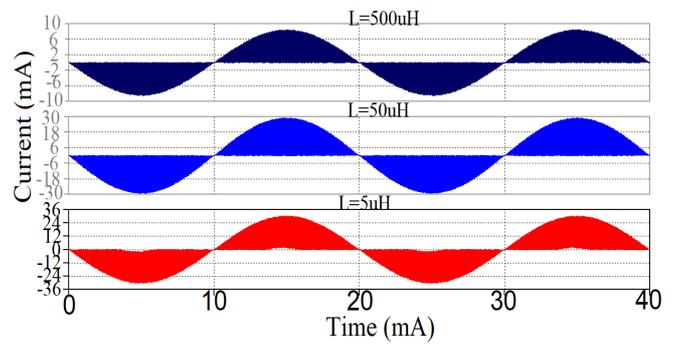


Fig. 16. Input current AC/DC PFC boost.

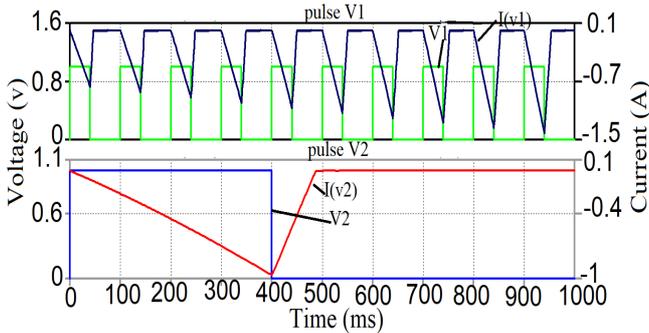


Fig. 13. Comparison between the two pulse (v_1) and pulse (v_2) cases for input current and control.

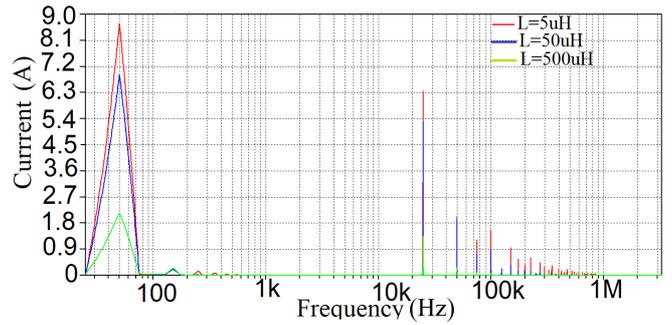


Fig. 17. Frequency response of line current.

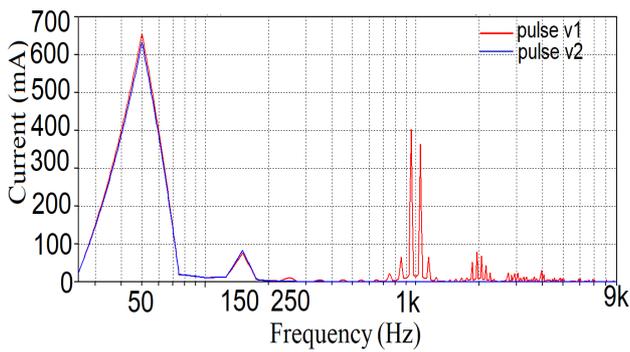


Fig. 14. Low frequency harmonic emissions

D. AC/DC Flyback PFC Active

Fig. 18 shows the AC/DC flyback PFC topology in a single stage. The primary and secondary flyback. Fig. 19 shows the AC/DC flyback PFC topology in two stages (chopper + flyback). According to the simulation on LTSpice software, we obtained the results shown in figures 20, 21 and 22.

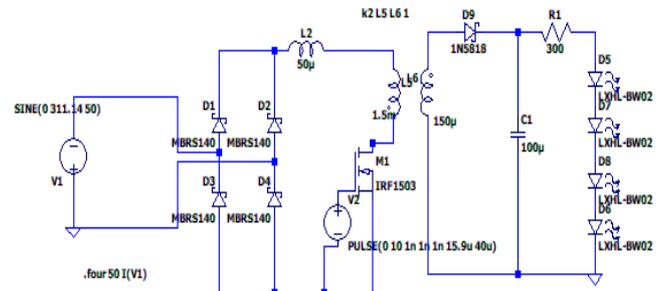


Fig. 18. AC/DC flyback PFC Boost, single stage .

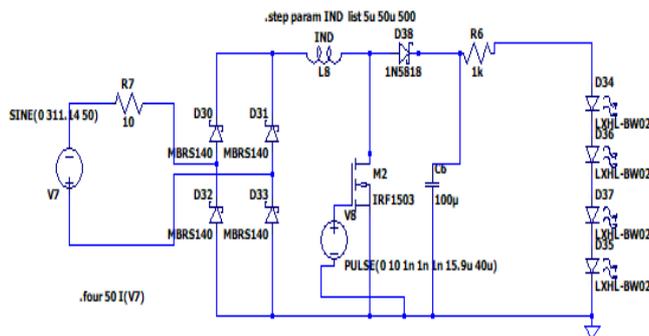


Fig. 15. AC/DC PFC boost converter to driver LED lamps.

Fig. 16 shows the input current of the AC/DC PFC boost converter. Fig. 17 presents the current frequency response of the line, we observe the harmonic emissions of low-frequency and zero-frequency current in each position, but at high-frequency, disturbances created with amplitudes of interest due to the fast current servicing and voltage as a function of time (the switching of MOSFET).

Fig. 20 shows the waveform of the current of the line, we notice an identical between the two results with the amplitude included of 3 A. Fig. 21 presents the harmonic emissions of current for the two topologies, we notice a good between the two results, as well as a reduction of the odd harmonics with a power factor very high close to unity and the total harmonic distortion is very low.

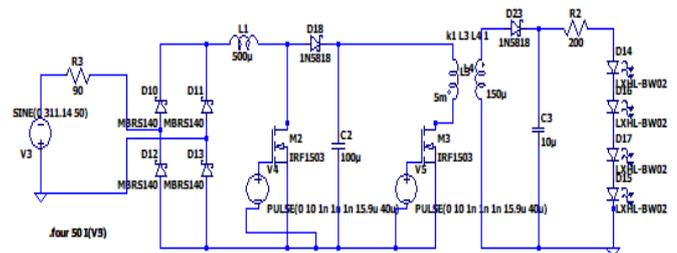


Fig. 19. AC/DC Flyback PFC boost ,two stages (PFC chopper +flyback).

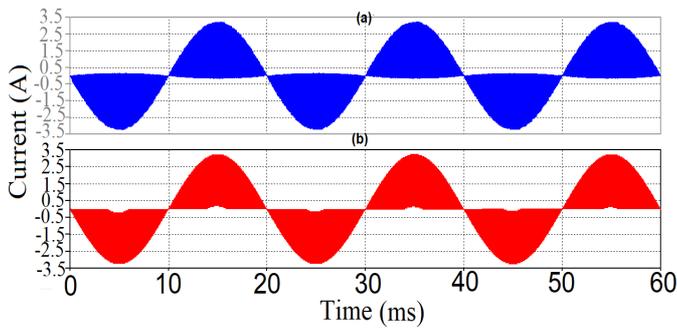


Fig. 20. AC/DC converter input current PFC flyback: a) single stage; b) two stages

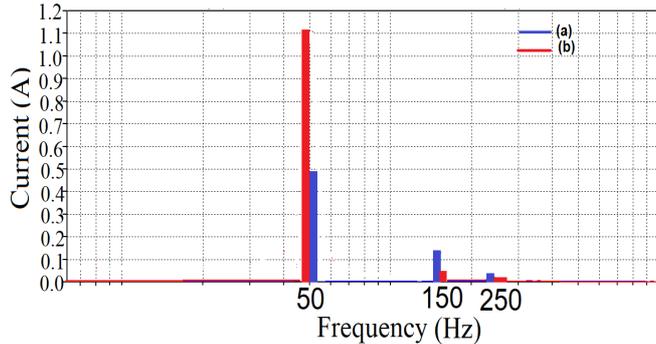


Fig. 21. Odd harmonics at low frequencies: a) single stage; b) two stages

The table 4 shows a comparison between the two topologies (single stage and two stages).

TABLE IV. COMPARISON OF THE TWO TOPOLOGIES AT PF AND THD

Topologies (PFC flyback)	Power factor (PF)	Total Harmonic Distortion (THD %)
Single stage	0.9997	2.28
Two stages	0.9960	9.01

V. CONCLUSION

LED drive circuits are sources of current harmonics due to non-linear loads. This presents a poor power quality. To improve this, there are two techniques either with passive or active PFC.

In this paper, we studied some topologies of active and passive LEDs driver through an AC/DC bridge rectifier, connected with the line directly, in order to reduce the harmonic emission and improve the power factor, thus reducing the topology size and increasing the lifetime by using LTspice software. From the simulation we notice that the active PFC has a power factor close to 1.0 and very low THD and less volume compared to passive PFC, Although the result of the total harmonic distortion depends on the inductance in the passive and active PFC cases and depends on the switching time of the MOSFETs in the active PFC case.

ACKNOWLEDGMENT

This research is part of the PHC “Maghreb” (Programme Hubert Curien) MELINA (Mastering Efficient Lighting In North Africa) granted to L. CANALE and funded via Campus France by the French Ministry of Europe and Foreign Affairs and Algerian Ministry of Higher Education and Scientific Research.

REFERENCES

- [1] X. Long, R. Liao, and J. Zhou, "Development of street lighting system-based novel high-brightness LED modules," *Optoelectronics, IET*, vol. 3, pp. 40-46, 2009.
- [2] B. Lehman and A. Shteynberg, "Professional Education Seminars: LED lighting: trends, standards, optics and power electronics," presented at Applied Power Electronics Conference and Exposition (APEC), Fort Worth, 2011. C. Van Dam, "Efficient Power Solutions for LED Lighting Installations," *Bodo's Power Systems*, pp. 54-55, 2011. D. Bailey, "An Idea to Simplify LED Lighting Purchase Decisions," *Bodo's Power*, pp. 18, 2011.
- [3] W. Beibei, R. Xinbo, Y. Kai, and X. Ming, "A Method of Reducing the Peak-to-Average Ratio of LED Current for Electrolytic Capacitor-Less AC-DC Drivers," *Power Electronics, IEEE Transactions on*, vol. 25, pp. 592-601, 2010.
- [4] R. Simanjuntak, P. Dupuis, L. Canale, N. I. Sinisuka and G. Zissis, "Power quality of energy saving lamps under wide voltage variations," 2014 IEEE Industry Application Society Annual Meeting, 2014, pp. 1-7, doi: 10.1109/IAS.2014.6978427.
- [5] R. F. Karlicek, "Smart lighting - Beyond simple illumination," 2012 IEEE Photonics Society Summer Topical Meeting Series, Seattle, WA, 2012, pp. 147-148.
- [6] R. F. Karlicek, "Smart lighting and the Future of Illumination Markets," Industry Session, 2016 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, 2016.
- [7] M. A. S. M. Ewald Fuchs, "Introduction to Power Quality," in *Power Quality in Power Systems & Electrical Machines*, ed, 2008, pp. 1-54.
- [8] S. M. Halpin, "Power Quality," in *Power Electronics Handbook*, ed: Academic Press, 2011, pp. 817-828.
- [9] power factor correction (PFC) circuit. Application note Toshiba Electronic Devices & Storage Corporation 2019 <https://toshiba.semicon-storage.com/>
- [10] Ibrahim M. Safwat, Wu Xiahua "Comparative study between Passive PFC and Active PFC based on Buck-Boost Conversion" IEEE 2 nd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC) march 2017 ,china
- [11] Dugan R C, McGranaghan M F, Santoso S and Beaty H W 2002 *Electrical Power System Quality* (New York: McGraw-Hill)
- [12] Piyush Verma, Nitlish Patel, Nirmal Kumar "CFL to LED Transition: An Analysis From Harmonics Perspective" International conference on power suestem Technology (POWERCON) IEEE 2016; Wollongong, Australia .
- [13] Nathanon Phannil, Chaiyan Jettanasen and Athapol Ngaopitakkul "Harmonics and Reduction of Energy Consumption in Lighting Systems by Using LED Lamps" *Energies* 2018, 11, 3169; doi:10.3390/en11113169
- [14] International Electrotechnical Commission (IEC). IEC 61000-3-2:2018. Electromagnetic Compatibility (EMC)—Part 3-2: Limits—Limits for Harmonic Current Emissions (Equipment Input Current ≤16 A per Phase). Available online:
- [15] Drapela, J. *Disturbing Influences of the Illuminating Systems to the Supply Network (in Czech)*. Ph.D. Thesis, Brno University of Technology, 2006, 233pp
- [16] Jiri Drapela ,Jaromir Bok "An improved Valley-fill passive Power Factor circuit For electronic ballast" conference. Proceeding of the 9th International Scientific conference Emeetric Power Engineering 2008. EPE 2008 BRNO Czech Republic
- [17] Spangler, J., et al. *Electronic Fluorescent Ballast using Power Factor Correction Techniques for Loads Greater than 300 Watts*. Proc. Sixth Annual Applied Power Electronics Conf., Hyatt Regency, Dallas, Texas, 1991, pp. 393-399.