Energy Channeling Led Driver Technology to achieve Flicker Free Operation with Zeta Converter for Power Quality Improvement

Bhaskar K B[1], Paramasivam Alagumariappan[2,*], and Mohamed Shuaib Y[3]

[1]*Adhi College of Engineering and Technology, Tamilnadu, India*

[2, 3]*B. S. Abdur Rahman Crescent Institute of Science and Technology, Tamilnadu, India*

(**Received** 27 December 2018; **Accepted** 17 October 2019; **Published on line** 1 June 2020)

*Corresponding author: paramasivam_a@ieee.org

DOI: 10.5875/ausmt.v10i1.2086

Abstract: This paper presents a flicker free operation of light emitting diode (LED) driver with Zeta converter for low power applications. In this work, the power factor of the LED driver is achieved by Zeta converter and it is operated in Continuous Conduction Mode (CCM). Further, the Zeta converter provides continuous current for an output system. Further, the design and simulation of the proposed circuit is done using MATLAB/Simulink software. Results demonstrate that the closed loop control system using fuzzy logic controller for the proposed LED driver provides good voltage regulation. In addition, the proposed design and operations have been practically verified with a 40W LED driver module.

Keywords: Continuous Conduction Mode (CCM); LED driver; fuzzy logic controller; power factor correction

Introduction

For around last hundred years, the light-emitting diode (LED) plays a vital role within the field of lighting. Due to the aggressive growth of LED lighting, it create new tasks for power designers to advance new luminaries at the lowest possible prices without having to work fast and improve power quality. Therefore, the purpose of using the lighting increases to 11% and for administrative purposes to 20% [1]. Nowadays, there is a growing interest in the economical use of electrical energy. The light emitting diode technology is so enormously economical and it has more significance over other lighting systems. However, the light-emitting diode lamps still have greater capital investment. Therefore, it is important to synthesis each of their components (driver and diode itself) in an affordable way.

Drive circuit or Drivers can be employed to control the facility flow between the mains and the semiconductor device itself. It is necessary to limit the low-frequency components on the semiconductor diode current to attenuate flicker. Some engineering resolution has been planned to unravel the issues of power quality and flicker in semiconductor diode drivers [2]. Many researchers have proposed driver circuits for LED's [3-10].

The buck converter is a less expensive converter, but it is only effective when the DC output voltage is well below the AC input voltage. In addition, it distorts AC mains current at the time of AC mains crossover instant. Therefore, the buck converter is not an honest choice for Power Factor correction applications.

On the other hand, the boost converter offers higher power quality performance with high potency and this is often extensively utilized in industries. However, this converter provides the next output voltage as the input voltage for an economic PFC operation. Typically, LEDs area unit, low-tension devices. To drive such a high voltage load, many numbers of LED units must be switched asynchronously, resulting in an undesirably higher load and price level. Hence, for low-power lighting loads, this convertor is also not appropriate. The Zeta convertor springs from a buck–boost convertor, whereas the SEPIC and Cuk convertors square measure derived from the boost converter [11-12]. Normally, the Power Factor Correction is meted out by Zeta convertor operational in CCM. With the exception of the Zeta convertor all others (Buck, Boost, Buck-Boost, Cuk and Sepic) are used to correct the Power Factor of power suppliers but they need their intrinsic limitations [3].

This paper presents an exciting application of the Zeta converter with low - power LED lighting applications using a fuzzy logic controller. Further, the Zeta converter preference has come together from the constraints inherent in alternative converters.

Methodology

Fig. 1. shows the proposed circuit which consists of a cascade-connected uncontrolled bridge diode rectifier with non-isolated Zeta converter. An inductive and capacitive (LC) input filter is also incorporated to adjust the EMI level. Further, the proposed circuit consists of switch S_1, inductor L_1, capacitor C and the output inductance and capacitance is L_0 and C_0 respectively. The freewheeling diode D is also connected to this circuit and the fuzzy logic controller is used for voltage regulation.

Dr. K. B. Bhaskar received the B.E. degree in electrical and electronics engineering from Anna University, Chennai, Tamil Nadu, India in 2008 and M.E. degree in Power Electronics and Drives from Anna University, Chennai, Tamil Nadu, India in 2011. He received his Ph.D. at Bharath University in the field of Electrical and Electronics Engineering. He is currently working as Head of Department at Adhi College of Engineering and Technology, Chennai, India. His area of interest is Power Electronics and Drives, machine design and Intelligent control.
Email: jaibhaskar15@gmail.com

Dr. Paramasivam Alagumariappan has completed his Ph.D. in the field of Biomedical Instrumentation at the Department of Instrumentation Engineering, Madras Institute of Technology Campus, Anna University, Chennai, India. He has completed his M.E. at Karpaga Vinayaga College of Engineering and Technology in the field of Power Electronics and Drives. He has research collaborations/projects with Global Hospitals and Health City, Chennai. He has authored two book chapters and has published several research papers in international journals and conferences. His area of interest is Power Electronics and Drives, Machine Learning and Robotics.
Email: paramasivam_a@ieee.org

Dr. Y. Mohamed Shuaib graduated from Crescent Engineering College, University of Madras, in 1994 and completed his Post Graduation in Power System in 2002. He obtained his Ph.D. from Jawaharlal Nehru Technological University, Hyderabad in the year 2015. He has teaching experience of more than 15 years. He is currently serving as Head of the Department, Department of EEE in B.S. Abdur Rahman Crescent Institute of Science & Technology, Tamilnadu, India. He has publications in several International Conferences and in refereed journals. His area of interest is Power System Operation & Control and Renewable Energy systems.
Email: mdshuaiby1970@gmail.com

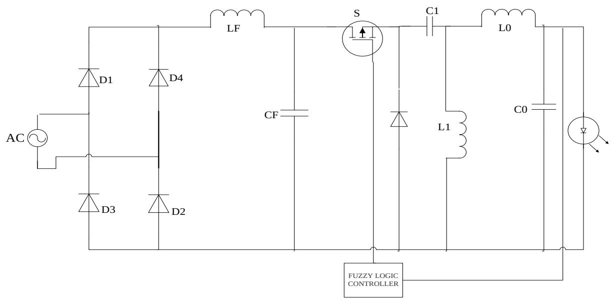


Fig. 1. Circuit diagram for proposed system.

Operating Principle

The operating principle of Zeta converter is explained with the help of following two stages:

Stage 1

Fig. 2. shows the stage 1 operation. In this stage 1, the switch S_1 is ON and the current flows through the inductance L_1 and L_0.

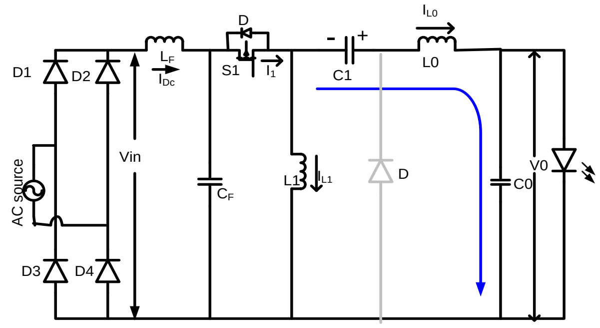


Fig. 2. Stage 1 operation.

The circuit current comes from voltage source and the inductive currents are increased linearly. In this condition, the diode D will be in reverse biased. The switch current I_1 is divided into two components namely I_{L0} and I_{L1}. In this mode, the discharging of capacitance C_1 and charging of C_o takes place. The switch current $I_1 = I_{L1} + I_{L0}$.

Stage 2

Fig. 3. shows the stage 2 operation. In this stage 2, the switch S_1 is turned OFF, the freewheeling diode D is forward biased and it starts to conduct.

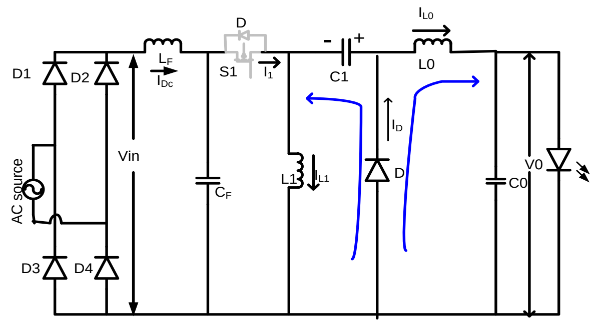


Fig. 3. Stage 2 operation.

The energy stored in the inductances is discharged through capacitor and the inductor currents are decreasing gradually. The voltages across the inductance L1 and Lo are equal to the output voltage Vo. The diode current $I_1 = I_{L1} + I_{L0}$. The operating waveforms at both the stages are clearly shown in the fig. 4.

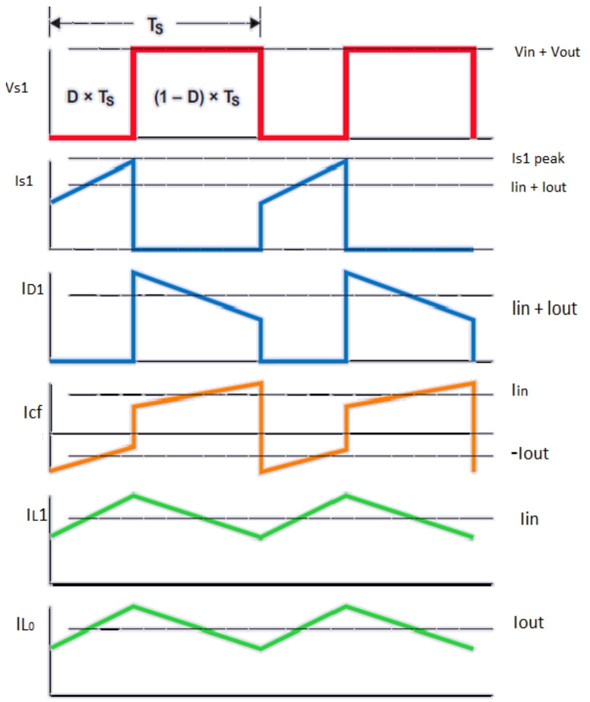


Fig. 4. Operating waveform.

Closed loop Control using FLC

Fuzzy logic is a rule-base structure for decision-making. To determine the output of faded logic, there must be a mechanism [13]. A substantial part of the Fuzzy Control literature deals with using fuzzy policies for non - linear Proportional-Integral-Derivative (PID) controls. As a result, many control engineers believe that using fuzzy rules with nonlinear PID control is the primary use of fuzzy logic for control. A mamdani Fuzzy Logic Controller (FLC) is built in this proposed system to alter the output voltage as desired which is shown in fig. 5. In the Fuzzy-based voltage controller process, two inputs are specifically taken into consideration, the variation of the contemporary and set converter voltage the error is build and the change in error is achieved automatically.

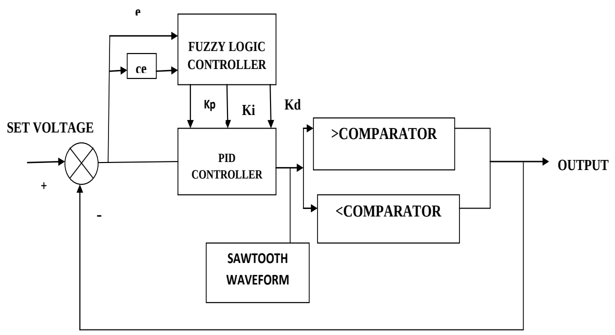


Fig. 5. Fuzzy Logic Controller.

The error (e) and change in error (CE) during a sampling phase are selected as inputs to the fuzzy logic which is given below:

$$e = set\ voltage\ ?\ actual\ voltage \quad (1)$$

$$ce = e(n)\ ?\ e(n-1) \quad (2)$$

where e(n) and e(n-1) indicate the contemporary and earlier samples of converter output voltage, the set voltage is reserved as 40V.

Design of the Proposed Circuit

The design process comprises calculations of the Zeta DC - DC converter components based on PFC as follows: The value of duty cycle, for a Zeta converter functioning in continuous conduction mode (CCM) is calculated as,

$$D = \frac{V_{dc}}{V_{in} + V_{dc}} = \frac{15}{10+15} = 0.6 \quad (3)$$

A rule of thumb is to assign a value for K between 0.2 and 0.4 of the average input current. A desired ripple current can be calculated as follows:

$$desired\ \ \Delta I_L = K + I_{in} \quad (4)$$

$$\Delta I_L = K \times I_{out} \times \frac{D}{1-D} \quad (5)$$

$$\Delta I_L = 0.2 \times 1 \times \frac{0.6}{1-0.6} = 0.3 \quad (6)$$

The critical value of inductance L_1 and L_2 is determined by allowing the change in peak-to-peak ripple current to be 100% of the average output current. The critical value of inductances L_1 and L_2 are expressed as,

$$L_1 = L_2 \geq \frac{1}{2} \times \frac{V_{in} \times D}{\Delta I_L \times fsw} \quad (7)$$

$$L_1 = L_2 \geq \frac{1}{2} \times \frac{10 \times 0.6}{0.3 \times 1000} = 1mH \quad (8)$$

The coupling condenser (C_1) is designed according to its ripple voltage content. The voltage over the coupling condenser is the peak value of the input voltage. Thus the design of capacitor C_1 is very important and it can be expressed as,

$$C_1 \geq \frac{D}{V_{in} \times fsw \times \Delta I_L} \quad (9)$$

$$C_1 = \frac{0.6}{10 \times 1000 \times 0.6} = 20\mu F \quad (10)$$

The DC connecting condenser (C_o) must have sufficient capacity to maintain a constant DC connecting voltage with less ribbon content and must provide a continuous load current at a high frequency. The value of DC link capacitor (C_o) is defined as,

$$C_O = \frac{D}{8 \times fsw \times \Delta V_{C2}} \quad (11)$$

$$C_o = \frac{0.6}{8 \times 1000 \times 0.0025} = 3000\mu F \quad (12)$$

RESULTS AND DISCUSSION

Simulation results

The model of the proposed PFC based Zeta converter for LED driver is simulated using MATLAB/Simulink and under normal running condition, the Lamp is considered as a resistor at high frequency. Fig. 6. shows the input voltage and current which are in phase for the full load condition.

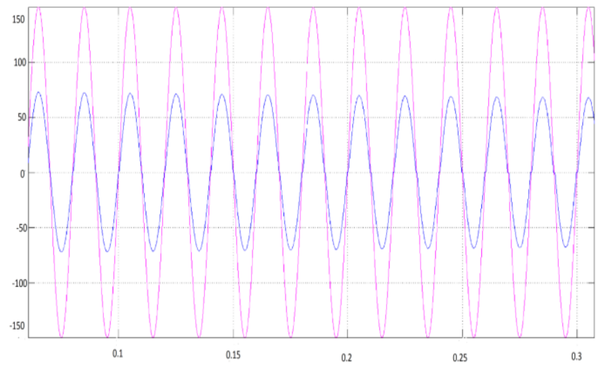
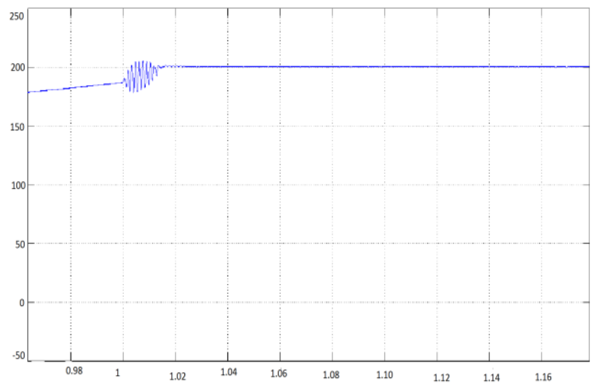
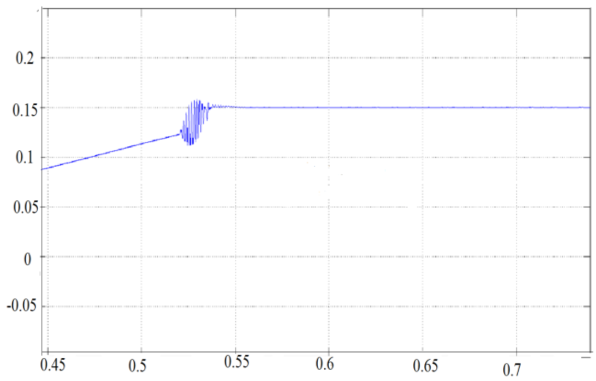


Fig. 6. Input voltage and current.

Fig. 7. (a) and (b) show the output voltage and current of the proposed circuit respectively. It is clear that the output voltage is maintained in a constant value with the help of closed loop fuzzy logic controller. Further, the start-up transient is also clearly observed and after sometime both output and current values are maintained equal to the set constant values.



(a)



(b)

Fig. 7. (a) Output voltage (b) Output current.

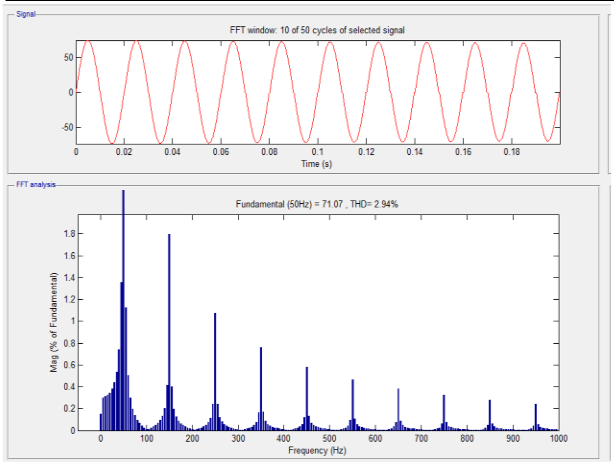


Fig. 8. Input current waveform with harmonic spectrum.

The Fast Fourier Transform (FFT) is used to calculate the total harmonic distortion (THD) of the proposed circuit. Fig. 8. shows the input current waveform with harmonic spectrum of the proposed circuit. Further, the THD value of the proposed circuit is 2.94%.

Experimental results

The zeta converter for proposed system is designed using the following specifications:

- Input voltage V_1=20 V
- Output voltage V_o=40V_{DC} Maximum output power =40 w
- Switching frequency f_s=10kHz

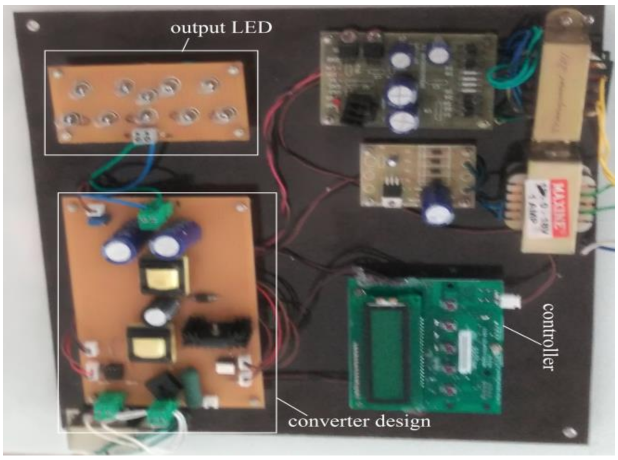


Fig. 9. Proposed Hardware prototype.

A 40W, 40V/1A output experimental prototype is built to verify the proposed topology. The hardware prototype is as shown in fig. 9. Also, the design specification of the proposed system is presented in the table 1. Based on the values zeta converter was designed.

Table 1 Design specifications of proposed converter using zeta topology

Parameter	***Value***
Duty Cycle	0.6
Inductor L_1	1 mH
Inductor L_2	1 mH
Capacitor C_1	20*uf*
Output Capacitor C_o	3000*uf*

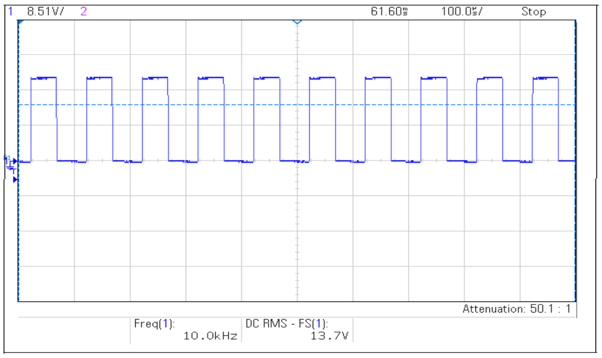
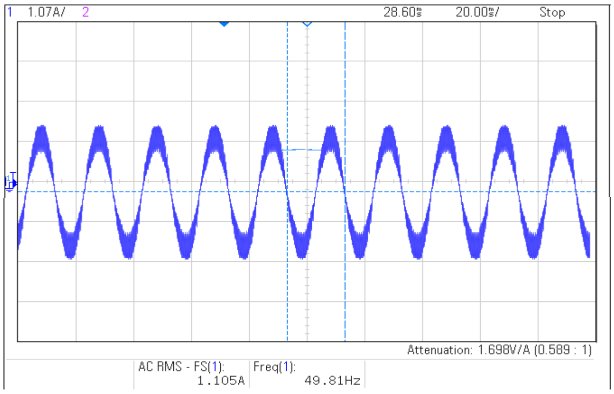
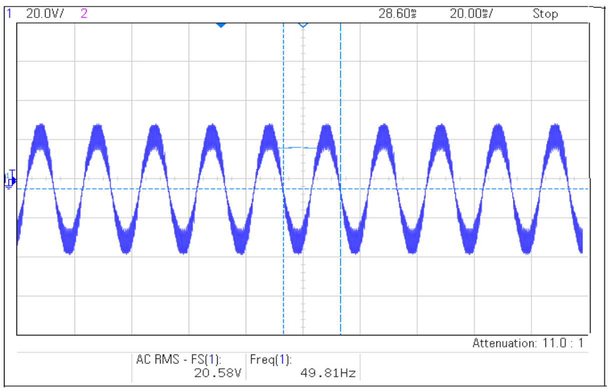


Fig. 10. Pulse signal for switch



(a)



(b)

Fig. 11. (a) Input current (b) Input voltage for 20V supply respectively.

Fig. 10. shows the pulse signal, which is generated by the controller for switch operation. Fig. 11. (a) and (b) show the variation of voltage and current in the supply respectively and it is observed that both contain some oscillations respective waveform.

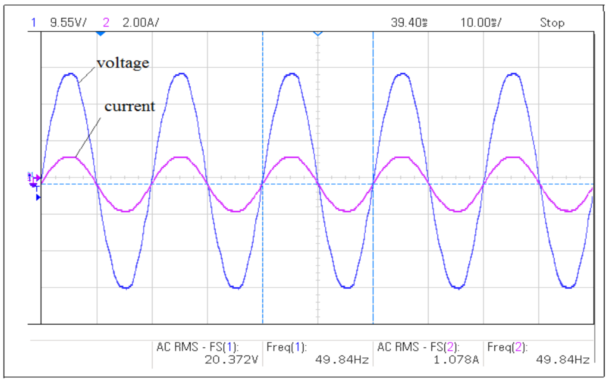
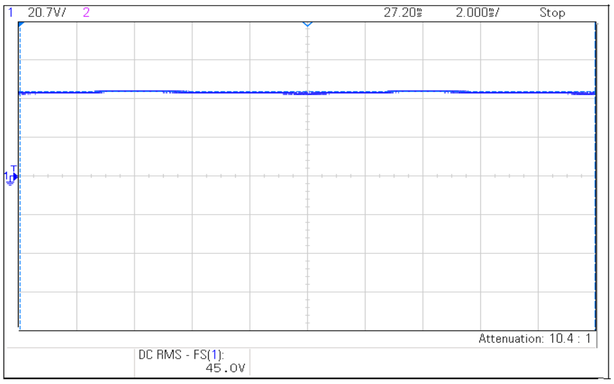
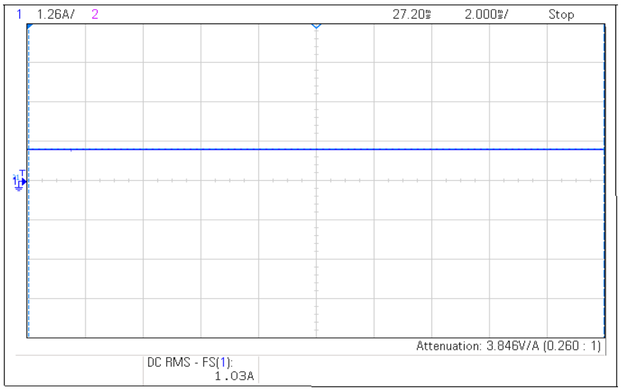


Fig. 12. Input voltage and current

Fig. 12. shows the supply current and supply voltage and it is seen that both are in phase with each other. Fig. 13. (a) and (b) show the output voltage and output current of the developed hardware prototype.



(a)



(b)

Fig. 13. (a) Output voltage (b) Output current of the proposed hardware prototype

Fig. 14. shows the total harmonic distortion in the supply with respect to output power. Even though, the THD of 2.94% is observed in the simulation, it is observed that the maximum of 4.5% THD is produced by developed hardware at the maximum output power of 40 watts. Also, it is placed between 2% and the fig. 15. shows the efficiency versus output power.

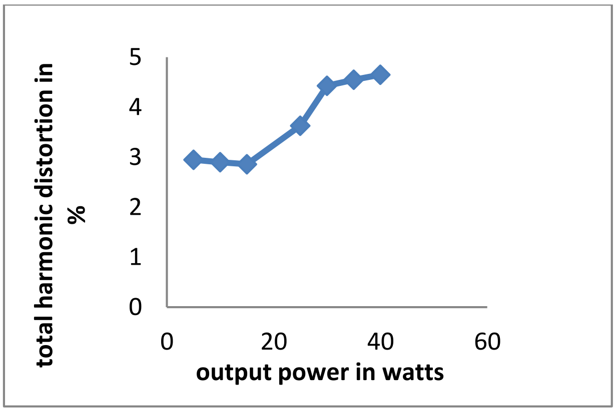


Fig. 14. Measured THD versus the output power

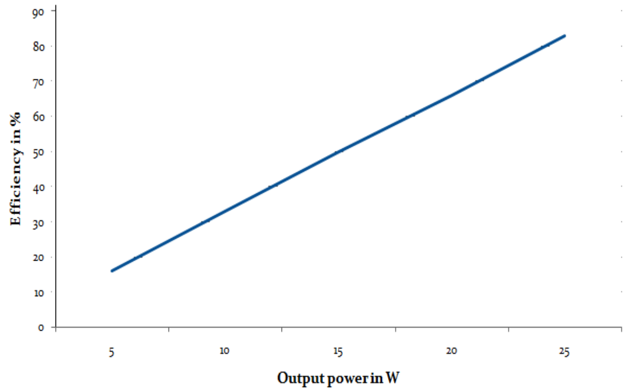


Fig. 15. Measured power efficiency versus the output power

It is demonstrated that the proposed zeta converter saves the input power factor close to maximum efficiency.

CONCLUSION

This paper analyzed a non-insulated dc-dc zeta converter with a high PF function in CCM. It is very difficult to preserve high PF at low electricity, but the zeta converter has saved the input PF close to maximum efficiency. Using the non-insulated zeta converter, a new low - cost flicker free LED driver was implemented. The proposed low - cost LED with fuzzy concept was developed which could be useful in the development of an industrial platform for future LED systems. Therefore, according to the results obtained, the proposed circuit have following features

- It's far specially simple and robust.
- It presents CCM PF correction and is thus more suitable for low - power applications.
- It has one controlled switch.
- It operates both mode in step-up and step-down voltage.
- A regulated output voltage with only one power conversion stage can be allowed.
- The switch can open and protect the structure in case of failure.

Both simulation and experiment were performed to verify the suggested energy channeling LED driving method for 40W, 40V/1A prototype, achieves 0.99 power factor.

References

[1] B. Singhand, and V. Bist, “A Brushless DC Motor Drive With Power FactorxCorrection Using Isolated Zeta Converter,” *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, pp. 2064-2072, 2014. doi: 10.1109/TII.2014.2346689

[2] P. Fang, Y.-F. Liu and P.-C. Sen, “A Flicker-Free Single-Stage Offline LED Driver With High Power Factor,” *IEEE Journal Of Emerging And Selected Topics In Power Electronics*, vol. 3, no. 3, pp. 654-665, 2015. doi: 10.1109/JESTPE.2015.2436390

[3] S. Narula, and G. Bhuvaneswari, “Power Factor Corrected Bridgeless Modular Zeta Converter Based SMPS,” in proceeding of *2016 IEEE 7th Power India International Conference (PIICON)*, Bikaner, November 25-27, 2016. doi: 10.1109/POWERI.2016.8077322

[4] G. R. Pedrollo, F. S. d. Reis, C. E. B. Rambo and I.r L. Guisso, “OCC Applied to a 180W HPF Single-Stage LED Driver Based on Zeta Converter in CCM,” in proceeding of *2014 11th IEEE/IAS International Conference on Industry Applications,* Juiz de Fora, December 7-10, 2014. doi: 10.1109/INDUSCON.2014.7059406

[5] A. Shrivastava, B. Singh, and S. Pal, “A Novel Wall-Switched Step-Dimming Concept in LED Lighting Systems Using PFC Zeta Converter.” *IEEE Transactions On Industrial Electronics*, vol. 62, no. 10, pp. 6272-6283, 2015. doi: 10.1109/TIE.2015.2416338

[6] P. Fang, Y.-F. Liu, and P. C. Sen, “A Flicker-Free Single-Stage Offline LED Driver With High Power Factor,” *IEEE Journal Of Emerging And Selected Topics In Power Electronics*, vol. 3, no. 3, pp. 654-665, 2015. doi: 10.1109/JESTPE.2015.2436390

[7] H. Zhang, Y. Zhang, and X. Ma, “Distortion Behavior Analysis of General Pulse-Width Modulated Zeta PFC Converter Operating in Continuous Conduction Mode,” *IEEE Transactions on Power Electronics,* vol. 27, no. 10, pp. 4212-4223, 2012. doi: 10.1109/TPEL.2012.2191161

[8] D. M.-Bellur, and M. K. Kazimierczuk, “Isolated Two-Transistor Zeta Converter With Reduced Transistor Voltage Stress,” *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 58, no. 1, pp. 41-45, 2011. doi: 10.1109/TCSII.2010.2092829

[9] D. C. Martins, and M. M. Casaro, “Isolated Three-Phase Rectifier with High Power Factor Using the Zeta Converter in Continuous Conduction Mode,” in proceeding of *Proceedings of Power and Energy Systems in Converging Markets,* Melbourne, October 23-23, 1997. doi: 10.1109/INTLEC.1997.645908

[10] P. Fang, and Y.-F. Liu, “Energy Channeling LED Driver Technology to Achieve Flicker-Free Operation With True Single Stage Power Factor Correction,” *IEEE Transactions on Power Electronics*, vol. 32, no. 5, pp. 3892–3907, 2017. doi: 10.1109/TPEL.2016.2586502

[11] H.-S. Gu, and S.-K. Han, “A Current-balancing Modular Driver for Multi-channel LEDs,” in proceeding of *8th IET International Conference on Power Electronics, Machines and Drives (PEMD 2016)*, Glasgow, April 19-21, 2016. doi: 10.1049/cp.2016.0146

[12] HauzKhas, and B. Singh, “Zeta Converter for Power Quality Improvement for Multi-String LED Driver,” in proceeding of *2016 IEEE Industry Applications Society Annual Meeting*, Portland, October 2-6, 2016. doi: 10.1109/IAS.2016.7731894

[13] Thenmozhi, Sharmeela, Natarajan, and Velraj, “Fuzzy Logic Controller based Bridgeless (BL) Isolated Interleaved Zeta Converter for LED Lamp Driver Application,’’ *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 7, no. 2, pp. 509-520, 2016. doi: 10.11591/ijpeds.v7.i2.pp509-520

©The Authors. This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.