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Fuzzy Logic Controller based Bridgeless (BL) Isolated Interleaved Zeta Converter for LED Lamp Driver Application

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ABSTRACT

In recent times, high-brightness light emitting diodes (HB-LEDs) are developing rapidly and it is confirmed to be the future development in lighting not only because of their high efficiency and high reliability, however also because of their other exceptional features: chromatic variety, shock and vibration resistance, etc. In this paper, a bridgeless (BL) Isolated Interleaved Zeta Converter is proposed for the purpose of reducing the diode failures or losses; the value of output ripples also gets decreased. The proposed BL isolated interleaved zeta converter operating in discontinuous conduction mode (DCM) is used for controlling the brightness of LED Driver with inherent PFC at ac mains using single voltage sensor. The fuzzy logic controller (FLC) is used to adjust the Modulation Index of the voltage controller in order to improve the dynamic response of LED Lamp driver. Based on the error of converter output voltage, FLC is designed to select the optimum Modulation Index of the voltage controller. The proposed LED driver is simulated to achieve a unity power factor at ac mains for a wide range of voltage control and supply voltage fluctuations.

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1. INTRODUCTION

High-brightness (HB) LEDs are extremely smart light sources because of their exceptional features (high efficiency and prolonged existence, and low-maintenance conditions) [11]. Since they are driven from a DC source, several categories of power switching converter can be employed to adapt primary energy sources to the constraints of HB LEDs [13]. Several researchers have formulated different DC–DC converter topologies in accordance with the conventional DC–DC switching power converters [9, 15 and 16].

In contrast, when the primary energy source is the AC line, subsequently certain category of AC–DC converter must be positioned between the line and the HB LEDs [10, 12]. It is found that, when the total power managed by these converters is above 25 W, at that time the low-frequency harmonic content of the line current have to satisfy particular rules. For the purpose of lighting equipment, the most extensively employed standard is EN 61000-3-2, Class C [18] [23, 24].

The bridge rectifiers contribute to high total harmonic distortion (THD), small PF, and low efficiency to the power system. These harmonic currents source for numerous complications are like voltage distortion, noises, heating results in diminished efficiency of the power system. Due to this fact, there is a need for power supplies that obtain current with low harmonic content and have PF close to unity [9]. The traditional boost topology is the most extensively employed topology for the purpose of PFC applications. It includes a front-end full-bridge diode rectifier next to the boost converter. The diode bridge rectifier is employed for the purpose of rectifying the AC input voltage to DC, which is subsequently provided to the boost segment. This scheme is excellent for a low to medium power range applications. During upper power levels, the diode bridge is a significant part of the application and it is essential to cope with the complication of heat dissipation in limited surface area [1, 14].

The selection of the type of operation of a PFC converter is a significant subject since it directly has an effect on the cost and rating of the elements employed in the PFC converter. The Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM) are the two types of operation wherein a PFC converter is intended to function [14, 1]. In case of CCM, the current in the inductor or the voltage in the intermediary capacitor remains continuous; however, it needs the sensing of two voltages (DC link voltage and supply voltage) and input side current for the purpose of PFC operation, which is not cost-effective. In contrast, DCM needs a single voltage sensor for DC link voltage control, and intrinsic PFC is accomplished at the AC mains, however, at the cost of higher stresses on the PFC converter switch; for this reason, DCM is chosen for the purpose of low-power applications [6, 17 and 19].

In order to further enhance the efficiency, bridgeless (BL) converters are employed which permit the exclusion of DBR in the front end [5, 6, and 17]. A buck–boost converter arrangement is well-matched among several BL converter topologies for applications need an extensive range of DC link voltage control. [3, 4, and 8] have formulated BL buck and boost converters, respectively. These converters can offer the voltage buck [3] which restricts the operating range of DC link voltage controlA new family of BL SEPIC [25] and Cuk converters has been described in the literature [5, 6] however needs a huge number of elements and has losses connected with it. In this work, a conventional DBR based isolated zeta converter has been considered for simulation analysis which is shown in Figure 1.

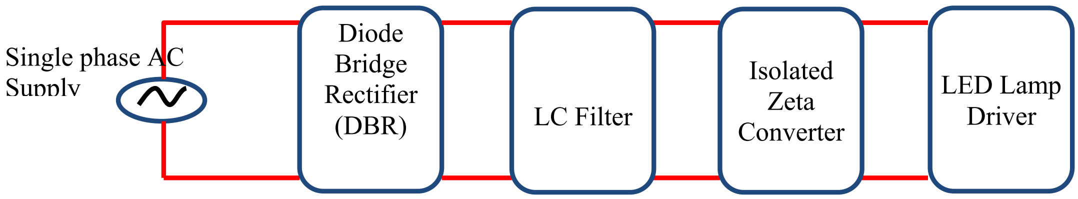


Figure 1. Conventional DBR based Isolated Zeta Coverter

In this paper, a PFC Zeta converter based power supply is proposed for HB-LED lamp with universal input voltage. In proposed LED driver, PFC AC-DC converter assists in enhancing the input PF and also helps in reducing THD of AC mains current to the required level in accordance with the limits provided by various international standards. The circuit maintains stable lamp voltage to accomplish stable operation of lamp for the purpose of retrofit applications. The fact that PFC converter is controlled at high switching frequency of 60 kHz, it diminishes the size and weight of passive constituents like inductor and capacitor.

2. PROPOSED BRIDGELESS (BL) ISOLATED INTERLEAVED ZETA CONVERTER-FED LED LAMP

Figure 2 illustrates the proposed BL isolated interleaved zeta converter-fed LED lamp. Here, a single-phase supply is employed to provide a DBR followed by a filter and a BL isolated interleaved zeta converter. The filter is intended to keep away from any switching ripple in the DBR and the supply system. A BL isolated interleaved zeta converter is intended to function in DCM to take action as an inherent PFC. This arrangement of DBR and PFC converter is employed to feed a LED lamp as illustrated in Figure 2. The output voltage of the converter is managed by means of changing the duty ratio of the PWM pulses of PFC converter switch. In the mean time, a single voltage sensor is employed for controlling the converter output voltage. This arrangement is designed and its effectiveness is validated using simulation results for enhanced power quality at AC mains for an extensive range of voltage control. Requirements of the LED lamp chosen for simulation investigations are provided in Table 1.

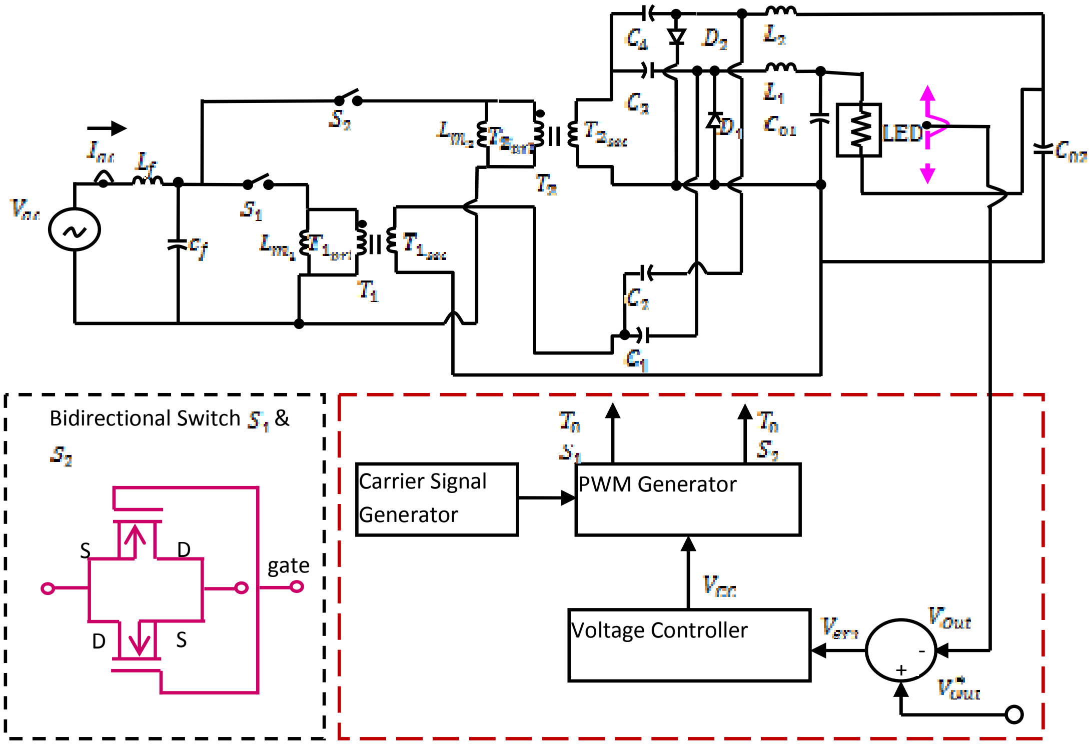


Figure 2. Overall Proposed BL Isolated Interleaved Zeta Converter

Table 1. The Performance of Fuzzy Rules

de \ e	NL	NS	ZE	PS	PL
NL	NL	NL	NM	NS	ZE
NS	NL	NM	NS	ZE	PS
ZE	NM	NS	ZE	PS	PM
PS	NS	ZE	PS	PM	PL
PL	ZE	PS	PM	PL	PL

2.1. Operation of BL Isolated Interleaved Zeta Converter

The operation of the BL isolated interleaved zeta converter is categorized into two components which comprise the operation at some point in the positive and negative half cycles of supply voltage.

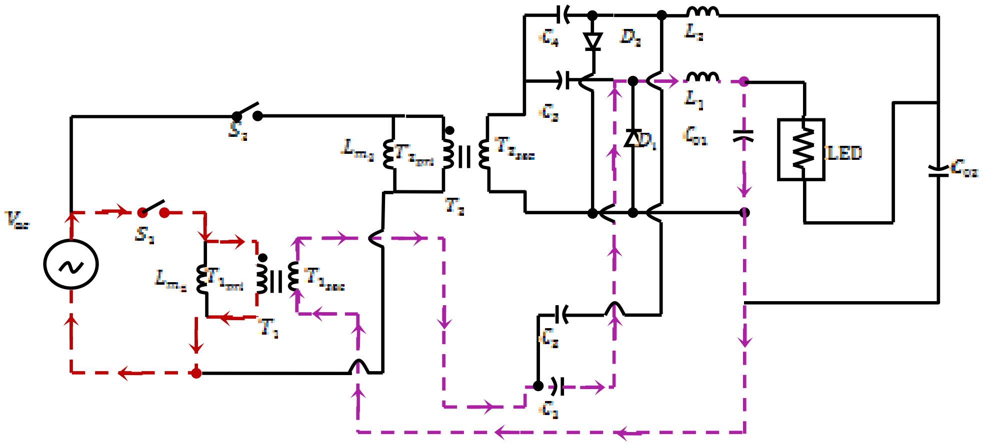
Operation during Positive Half Cycles Of Supply Voltage

The operation of the proposed BL isolated interleaved zeta converter is further categorized into three modes, they are, switch turn-ON, switch turn-OFF and DCM. Three modes are illustrated in Figure 3(a)–(c) and their related waveforms are provided in Figure 3. These modes are briefly discussed as follows.

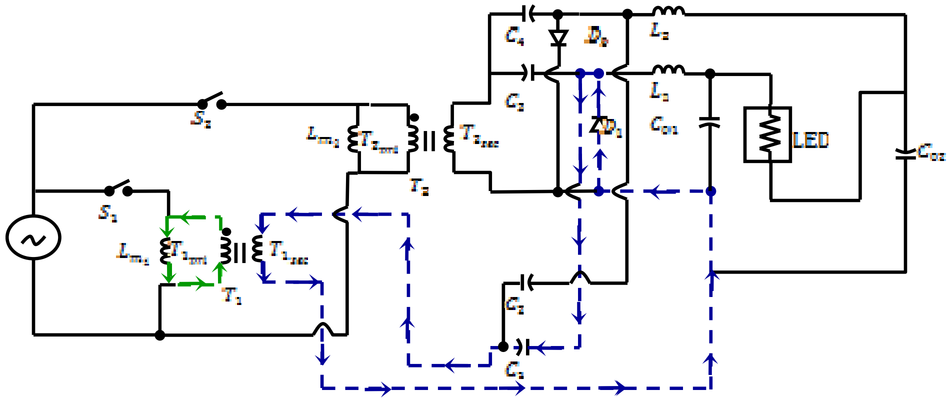
Conduction Modes of Switch S_1

Mode 0:

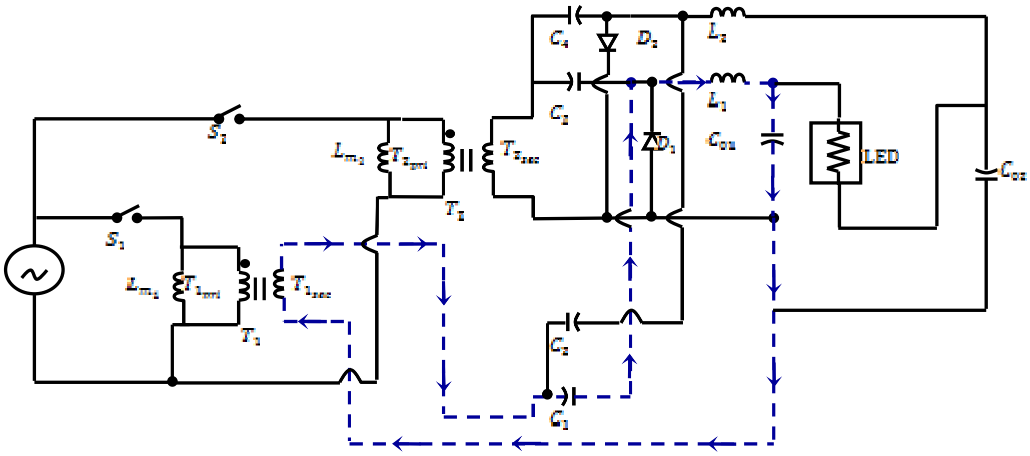
When switch(S_1)is in “ON” condition, a current in magnetizing inductance (L_{m_1}) of high frequency transformer (T_1) boosts as illustrated in Figure 3(a). The intermediary capacitor (C_1) provides energy to an output inductor (L_1) and the output filter capacitor (C_{01}). Consequently, voltage across intermediary capacitor (C_1) decreases and the current in output inductor (L_1) and output capacitor voltage (C_{01}) are increased.



(a). Mode 0 Operation



(b). Mode 1 Operation



(c). Mode 2 Operation

Figure 3. Conduction Modes of Switch S_1 during Positive cycle

Mode 1:

When switch (S_1) is turned "OFF," the current in magnetizing inductance (L_{m_1})of high frequency transformer (T_1) and output inductor (L_1) starts reducing. This energy of high frequency transformer is transferred to the intermediate capacitor (C_1), and therefore voltage across it increases. Diode (D_1) conducts in this mode of operation and theoutput capacitor voltage (C_{01}) increases as shown in Figure 3.

Mode 2:

This mode is DCM in order that the energy of high frequency transformer (T_1) is fully released as illustrated in Figure 3(c). The intermediary capacitor (C_1) and the output capacitor (C_{01}) provide the energy to the output inductor (L_1) and the load, correspondingly. Therefore, the output capacitor voltage (C_{01}) and intermediary capacitor's voltage (C_1), are decreased, and the output inductor current (L_1), boosts in this mode of operation as illustrated in Figure 3.

Conduction Modes of Switch S_2

Mode 3:

When switch (S_2) is "ON" condition, a current in magnetizing inductance (L_{m_2}) of high frequency transformer (T_2) raises as illustrated in Figure 4 (a). The intermediary capacitor (C_3) provides energy to an output inductor (L_1) and the output filter capacitor (C_{01}). Consequently, voltage across intermediary capacitor (C_3) decreases and the current in output inductor (L_1) and output capacitor voltage (C_{01}) are raised as illustrated in Figure 4(a).

Mode 4:

When switch (S_2) is in "OFF" condition, the current in magnetizing inductance (L_{m_2}) of high frequency transformer (T_2) and output inductor (L_1) begins to drop. This energy of high frequency transformer is transmitted to the intermediary capacitor (C_3), and as a result voltage across it raises. Diode (D_1) conducts during this mode and the output capacitor voltage (C_{01}) increases as illustrated in Figure 4(b).

Mode 5:

This mode is DCM in order that the energy of high frequency transformer (T_2) is fully released in Figure 4(c). The intermediary capacitor (C_3) and the output capacitor (C_{01}) provide the energy to the output inductor (L_1) and the load, correspondingly. Therefore, the output capacitor voltage (C_{01}) and intermediary capacitor's voltage (C_3), are diminished, and the output inductor current (L_1), boosts during this mode.

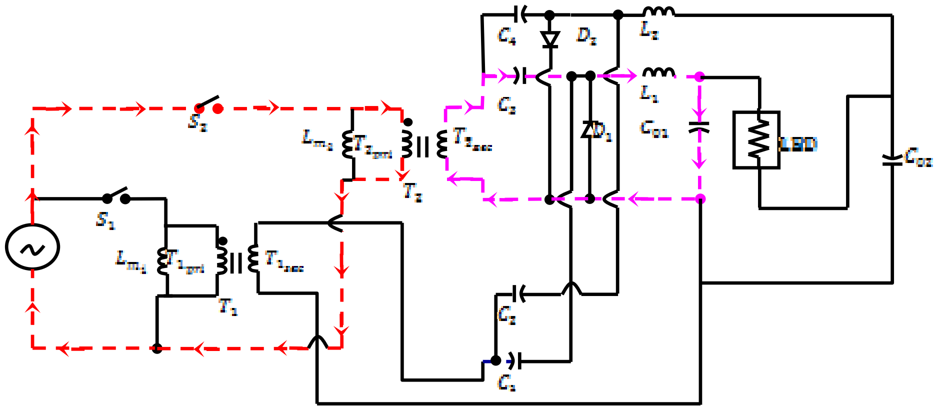
2.2. Control Loop Operation of BL Isolated Interleaved Zeta Converter

In this research work, a Mamdani-type Fuzzy Logic Controller (FLC) is built for the purpopse of adjusting the Modulation Index of the output voltage controller with the intention of reducing the Peak Over Shoot (POS), Peak Under Shoot (PUS), Settling Time (ST) and Starting Current (SC). Depending on the distinction between actual and set converter voltage, FLC is devised to decide on the optimum Modulation Index of the output voltage controller. The fuzzy systems are a kind of universal function approximators [21, 22]. The FLC is utilized as a nonlinear function approximator produce an appropriate transformation in the Modulation Index of the output voltage controller with the intention of keeping the Peak Over Shoot (POS), Peak Under Shoot (PUS), Settling Time (ST) and Starting Current (SC) minimum. Figure 5 demonstrates the proposed converter based LED driver voltage control loop.

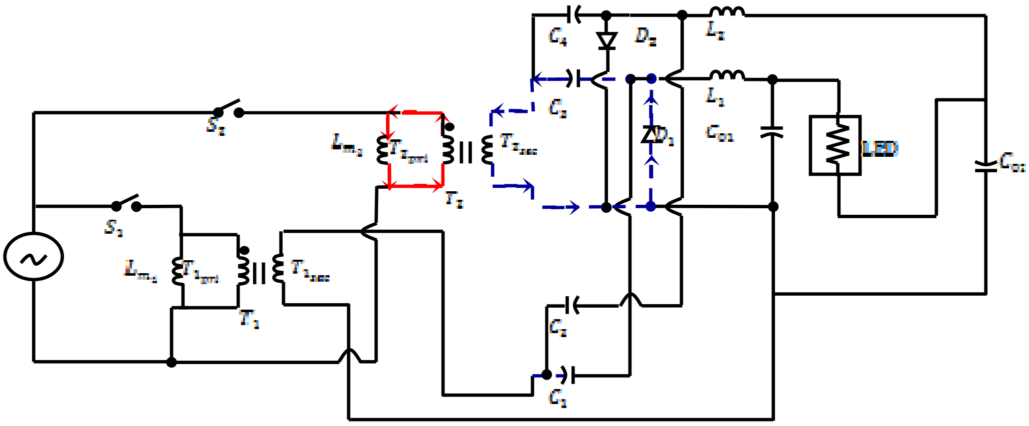
Fuzzy Based Voltage controller

In the process of fuzzy based voltage controller, two inputs are taken into account, specifically, variation of actual and set converter voltage error(e) and delayed error (de).

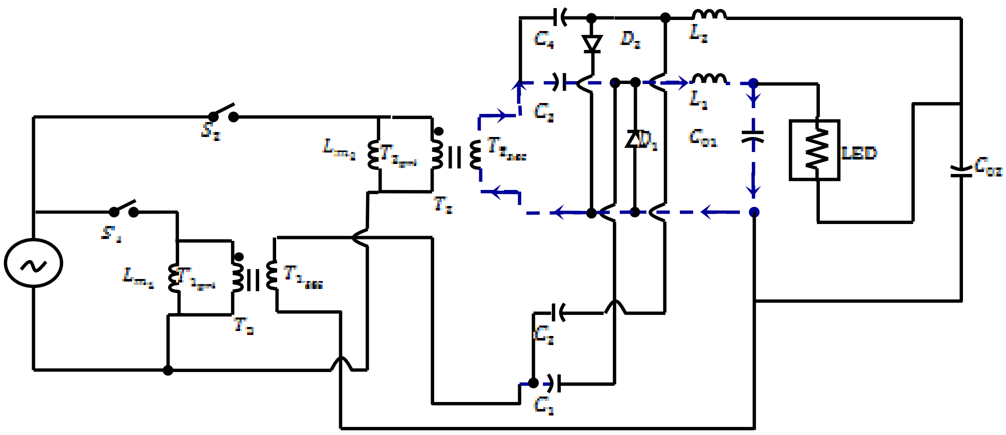
There are five membership functions for both inputs (e) and (de) as shown in figure 6. By design, there will be 25 rules. Triangular membership functions are taken into account for both inputs and output, with the intention that the Modulation Index will be transformed easily.



(a). Mode 3 Operation of (S_2)



(b). Mode 4 Operation of (S_2)



(c). DCM configuration that the energy of high frequency transformer (T_2)

Figure 4. Conduction Modes of Switch S_2during Positive cycle

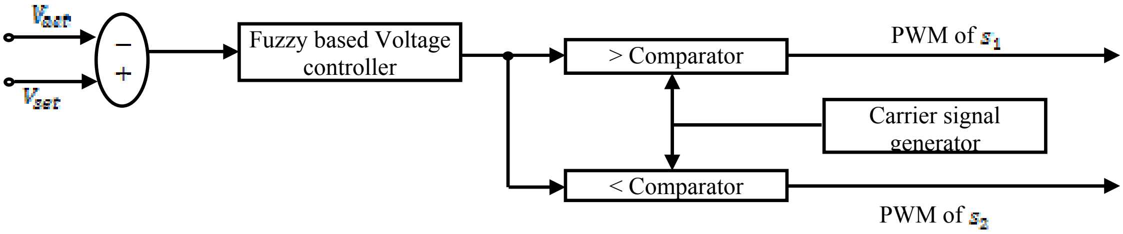


Figure 5. Proposed LED Driver Voltage Control Loop

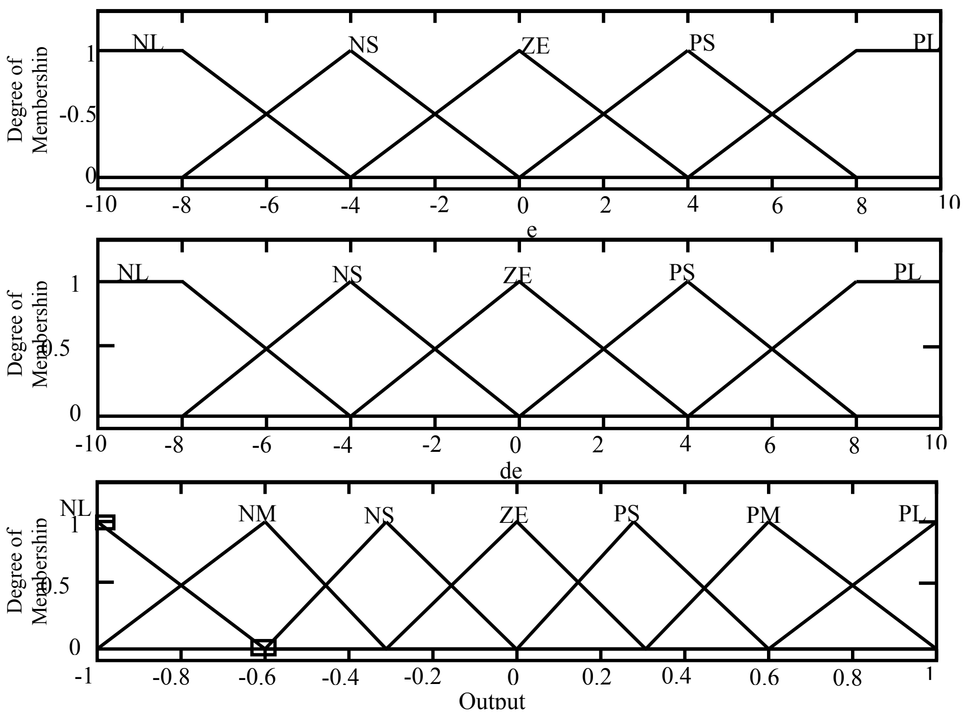


Figure 6. Fuzzy Membership Functions

The non-linear mapping from the input to the output of FLC is done through the basis of trial and error experience. Initially, the membership functions and fuzzy rules were formulated in simulation program through trial-and-error method, in order that the converter output voltage can go after the command voltage with enhanced dynamic performance. The error(e) and delayed error (de) during a sampling phase are selected as inputs to the FLC which is given below:

$$e = \text{setvoltage} - \text{actualvoltage}$$
$$de = e(n) - e(n-1)$$

Where e(n) and e (n −1) indicate the present and previous samples of converter output voltage, correspondingly. Set voltage is kept as 90V.

The FLC is designed on the basis of observation of simulation results of the PI controller. Based on the study of PI controller, the input and output range of the FLC is decided. The fuzzy rules are as follows. FLC's output (controlled error) is evaluated with the triangular carrier signal of frequency 5 KHz to generate PWM pulse of switch S_1. The PWM pulse of switch S_2 is totally out of phase of PWM pulse of switch S_1 which is clearly shown in Figure 5.

3. RESULTS AND DISCUSSIONS

The performance of the Proposed BL Isolated Interleaved Zeta Converter is simulated in a MATLAB / Simulink environment using the Sim Power-System Toolbox. The proposed system is evaluated based on the steady state performance and the dynamic performance of BL Isolated Interleaved Zeta Converter and the achieved power quality indices obtained at ac mains. Moreover, the performance of the BL Isolated Interleaved Zeta Converter is compared with the conventional Bridged zeta converter.

Parameters such as supply voltage(V_{ac}), supply current(I_{ac}), Proposed Fuzzy based Converter output voltage($V_{out} - FU$), Fuzzy based Converter output Current ($I_{out} - FU$), Fuzzy based Converter output Power ($P_{out} - FU$), of the BL Isolated Interleaved Zeta Converter are evaluated to demonstrate its proper functioning. The evaluation is based on the voltage ripples of the conventional Bridged Zeta converter termed as 'Vout Ripple-Exist' and the proposed BL Isolated Interleaved Zeta Converter which are termed as 'V_{out} Ripple-Proposed' in the simulated results.

Moreover, power quality indices such as power factor (PF), displacement power factor (DPF), and Total Harmonic Distortion (THD) of supply current are analyzed for determining power quality at ac mains. The specifications used for the simulations are given in Table 2.

Table 2. Specifications

Parameter	Value
V_{ac_peak}	113.12 V
V_{ac_RMS}	80 V
I_{ac_peak}	1.682 A
I_{ac_RMS}	1.19 A
Input Power	94.75 watts
Rated Output Voltage V_{Out}^{*}	90 V
Rated Output Current I_{Out}^{*}	1 A
Rated Output Power P_{Out}^{*}	90 watts
Efficiency	94.98%
Power Factor (PF)	0.9954

3.1. Steady-State Performance

The steady-state behaviour of the proposed BL Isolated Interleaved Zeta Converter fed LED driver at rated condition is shown in Figure 7.

Supply voltage is considered as V_{ac_peak} 113.2V for the proposed LED lamp driver application. LED lamp power and voltage are considered as 90 W and 90V respectively. So, the supply current attained is I_{ac_peak} 1.682 A. The corresponding supply voltage and current waveforms are shown in Figure 7(a), (b).

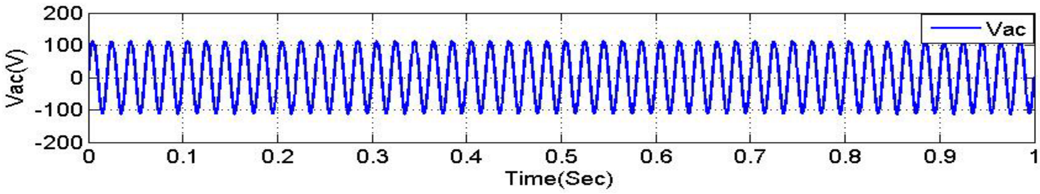
Then, the proposed BL isolated interleaved zeta converter is used to control the output voltage. It is a DCM type of converter. So, the converter output voltage is taken as feedback compared with rated output voltage. Now, the pulse width will be adjusted based on the error value and the converter output voltage is maintained constant. The converter output voltage and current waveforms are shown in Figure 7 (c) (d) (e).

The power factor of the proposed converter at rated condition is attained as 0.9954 which is near unity. Now, the converter input power is measured by

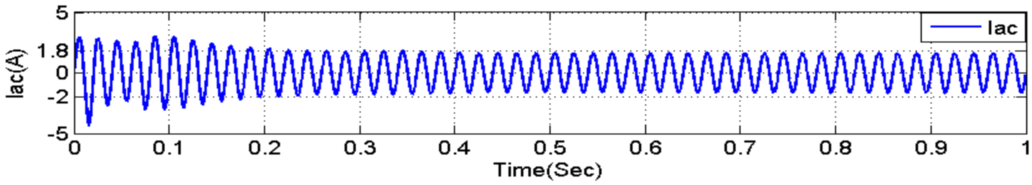
$$V_{ac\ peak} = \frac{113.12\ V}{\sqrt{2}} = 80\ V_{rms}$$

$$I_{ac\ peak} = \frac{1.682\ A}{\sqrt{2}} = 1.19\ I_{rms}$$

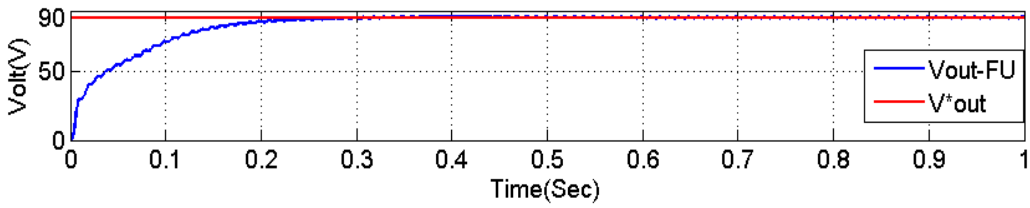
The measured Input Power attained by the steady state analysis is 94.75 W.



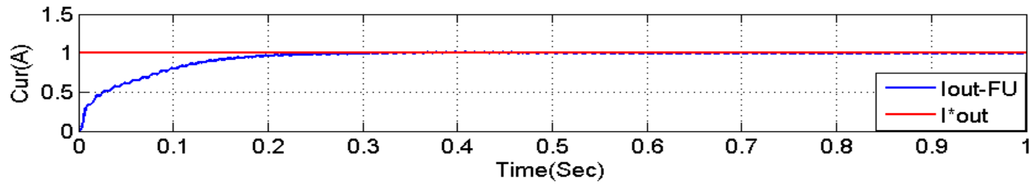
(a). Supply Voltage



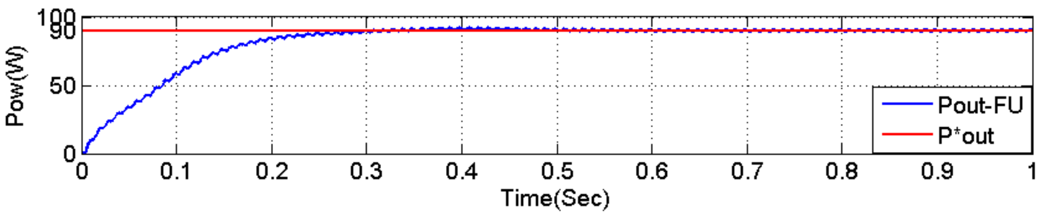
(b). Supply Current



(c). Converter output voltage



(d). Converter output current



(e). Converter output power

Figure 7. Steady State Performance

3.2. Evaluation of PI and Fuzzy Controller

Figure 8 shows the performance comparison of the PI and fuzzy controller for the converter output voltage response. The impact and the demerits of POS, PUS, ST and starting current problem are clearly discussed in section 1. The reference voltage considered here is 90 V. It is observed from the figure that, converter output voltage tuned by PI controller settles at 90 V with high POS and PUS with poor ST. However, converter output voltage tuned by FLC settles at 90 V with minimum POS, PUS and ST.

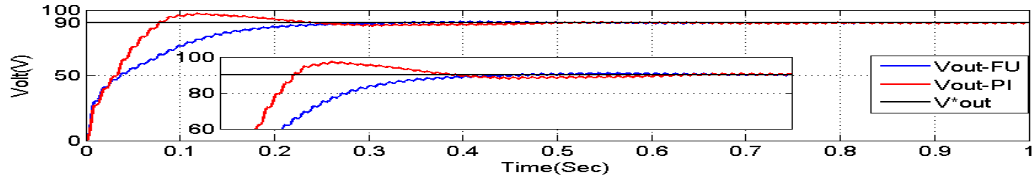


Figure 8. PI and Fuzzy response of Converter Output Voltage

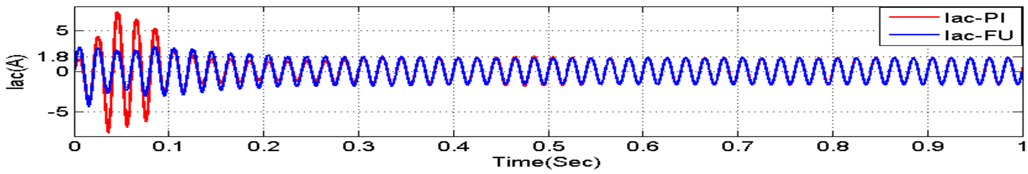
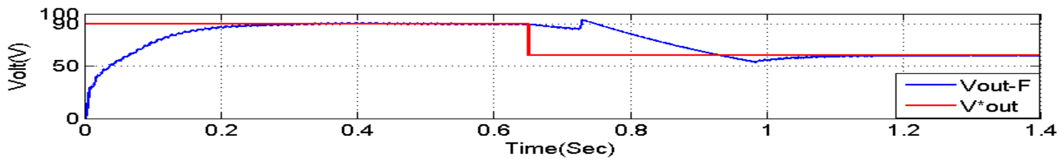


Figure 9. PI and Fuzzy response of Converter Output Voltage

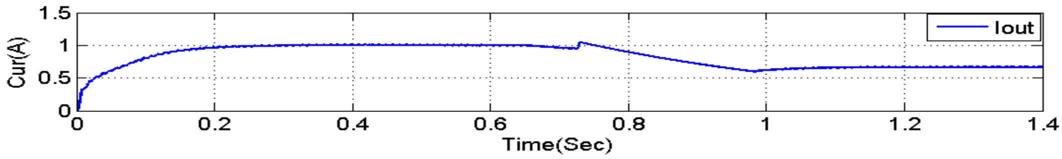
The response of starting current is analysed in figure 9. The figure shows current response of PI and FLC. It is clearly observed from the figure that, the current response tuned by the FLC produces less starting current compared with the current response tuned by the PI controller. The above scenarios show the improved efficiency of the FLC over the PI which is mainly due to proper tuning of modulation index.

3.3. Performance Evaluation under VDC Change (Brightness control)

The performance of the proposed BL isolated interleaved Zeta Converter is analyzed by varying dc link voltage as shown in Figure 10. The voltage response of the proposed converter is analyzed by a sudden change at 0.65 second from 90 V to 60 V. The actual voltage response (V_{out}) of the proposed converter and the rated output voltage are shown in the Figure 10 (a). Based on the voltage variation of the converter, the output current response is in Figure 10 (b).



(a). Converter output voltage response when sudden change in rated output voltage



(b). Converter output current response when sudden change in rated output voltage

Figure 10. The performance of the proposed BL isolated interleaved Zeta Converter

The achieved power quality indices obtained at ac mains are tabulated in table 3 when the output voltage is varied from 90 V to 60 V.

Table 3. Converter Output Voltage (Vout) Response at rated condition with PI and Fuzzy controllers

V_{out}(V)	DPF	PF	I_{ac}(A)(Rms)
90 V	0.9963	0.9954	1.19
85 V	0.9961	0.9951	0.86
80V	0.9959	0.9948	0.81
75 V	0.9951	0.9943	0.76
70 V	0.9943	0.9936	0.71
65 V	0.9937	0.9930	0.66
60 V	0.9927	0.9921	0.61

4. CONCLUSION

A new bridgeless ac-dc converter with a low input current ripple and lower conduction losses has been proposed. This topology concentrates on the drawbacks of the conventional Zeta PFC converter through the development of a new bridgeless topology. Bridgeless (BL) Isolated Interleaved Zeta Converter-Fed LED Lamp is proposed and it operated in various modes which provide significant performance. The performance of the proposed system is evaluated based on the steady state performance and the dynamic performance of BL Isolated Interleaved Zeta Converter and the achieved power quality indices obtained at ac mains. The converter voltage and current is maintained constant with varying dynamic response of LED Lamp driver. In order to show the performance of the fuzzy controller, the proposed fuzzy based approach has been compared with PI controller. The proposed system provides significant results in terms of settling time, peak overshoot and peak under shoot for the fuzzy controller compared with PI controller.

REFERENCES

[1] Rajappan, *et al.*, 2013. "An Efficient AC/DC Converter with Power Factor Correction". *International Journal of Emerging Technology and Advanced Engineering*, 3(3).
[2] Fardoun, A., *et al.*, 2012. "New 'real' bridgeless high efficiency ac-dc converter". in Proc. 27th Annu. *IEEE APEC Expo*., pp. 317–323.
[3] Jang, Y. *et al.*, 2011. "Bridgeless high-power-factor buck converter". *IEEE Trans. Power Electron*., 26(2):602–611.
[4] Mahdavi, *et al.*, 2011. "Bridgeless SEPIC PFC rectifier with reduced components and conduction losses". *IEEE Trans*. Ind. Electron., 58(9):4153–4160.
[5] Sabzali, J., *et al.*,2011. "New bridgeless DCM Sepic and Cuk PFC rectifiers with low conduction and switching losses". *IEEE Trans*. Ind. Appl., 47(2):873–881.
[6] Singh, B., *et al.*, 2011. "Comprehensive study of single-phase ac-dc power factor corrected converters with high-frequency isolation". *IEEE Trans. Ind. Informat*., 7(4):540–556.
[7] Lamar, *et al.*, 2009. "A Very Simple Control Strategy for Power Factor Correctors Driving High-Brightness LEDs". *IEEE Transactions on Power Electronics*, 24(8):2032-2042.
[8] A. Purna Chandra Rao, Y.P. Obulesh, Ch. Sai Babu, "Power Factor Correction in Two Leg Inverter Fed BLDC Drive Using Cuk Dc-Dc Converter", *International Journal of Power Electronics and Drive System (IJPEDS)*, Vol. 6, No. 2, June 2015, pp. 196~204
[9] Hu, Y. *et al.*, 2008. "A novel LED driver with adaptive drive voltage". in Proc. *IEEE APEC*, pp. 565–571.
[10] Zhou, K., J *et al.*, 2008. "Quasiactive power factor correction circuit for HB LED driver". *IEEE Trans. Power Electron*., 23(3):1410–1415.
[11] Carraro, G., 2007. "Solving high-voltage off-line HB-LED constant-current control-circuit issues". in Proc. *IEEE APEC*., pp. 1316–1318.
[12] Chen, *et al.*, 2007. "Sequential color LED backlight driving system for LCD panels". *IEEE Trans. Power Electron*., 22(3): 919–925.
[13] Van der Broeck, *et al.*, 2007. "Power driver topologies and control schemes for LEDs". in Proc. *IEEE APEC* 2007., pp. 1319– 1325.
[14] De Gusseme, *et al.*, 2005. "Digitally controlled boost power-factor-correction converters operating in both continuous and discontinuous conduction mode". *IEEE Transaction on Industrial Electronics*, 52(1):88-97.
[15] Rico-Secades, *et al.*, 2004. "Driver for high efficiency LED based on flyback stage with current mode control for emergency lighting system". in Proc. *IEEE IAS* 2004, pp. 1655–1659.
[16] Rico-Secades, *et al.*, 2003. "Evaluation of a low cost permanent emergency lighting system based on high efficiency LEDs". in Proc. *IEEE IAS*, vol. 1, pp. 542–546.
[17] Singh, B., *et al.*, 2003. "A review of single-phase improved power quality acdc converters". *IEEE Trans. Ind.* Electron., 50(5): 962–981.
[18] Draft of the Proposed CLC Common Modification to IEC 61000-3-2 Ed. 2.0, 2000.
[19] Sebasti´an, J et al., 1991. *Improving power factor correction in distributed power supply systems using PWM and ZCS-QR SEPIC topologies*. in Proc. IEEE PESC 1991, pp. 780–791.
[20] Vashist Bist, and Bhim Singh, "A Brushless DC Motor Drive With Power Factor Correction Using Isolated Zeta Converter", *IEEE Transactions on Industrial Informatics*, Vol. 10, No. 4, 2014.

[21] Veronica Indrawati, Agung Prayitno, Thomas Ardi Kusuma, "Waypoint Navigation of AR.Drone Quadrotor Using Fuzzy Logic Controller", 13(3), *TELKOMNIKA Telecommunication Computing Electronics and Control*, Vol. 13, No.3, 2015, pp. 930-939

[22] R. Balamurugan, R. Nithya, "FC/PV Fed SAF with Fuzzy Logic Control for Power Quality Enhancement", *International Journal of Power Electronics and Drive System (IJPEDS)*, Vol. 5, No. 4, April 2015, pp. 470-476.

[23] M. Gopinath, S. Ramareddy, "Simulation Of Closed Loop Controlled Bridgeless PFC Boost Converter", *International Journal of Theoretical and Applied Information Technology*, Vol 10, No. 1, 2009, pp. 103-108.

[24] M. Gopinath, V.S. Bharath, "Closed Loop Analysis Of Multilevel Inverter FED Drives", *International Journal of Power Electronics and Drive System*, Vol. 4, No. 3, 2014, pp. 337-342.

[25] M. Gopinath, G. Gopu, "Closed Loop Analysis Of Bridgeless SEPIC Converter for Drive Application" *International Journal of Power Electronics and Drive System*, Vol. 6, No. 2, 2015, pp. 253-259.