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Research Article

An Efficient Bridgeless (Bl) Isolated Interleaved Zeta Converter for Led Lamp Driver Application

[1]R. Thenmozhi, [2]C. Sharmeela, [3]P. Natarajan and [4]R. Velraj
[1]Anna University,
[2]A.C Technology, Anna University, Chennai,
[3]Priyadarshini Engineering College, Vaniyambadi,
[4]Department of Mechanical Engineering, CEG, Anna University, Chennai, India

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 study, a Bridgeless (BL) Isolated Interleaved Zeta Converter is proposed for the purpose of reducing the diode failures or losses, the value of output capacitor gets lessened and the output ripples also gets decreased. Conduction Mode (DCM) which guides to a simplified control circuit. In addition, the converter is composed of bidirectional switches which removes the Diode Bridge Rectifier (DBR) of the converter. 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 proposed drive is implemented to achieve a unity power factor at ac mains for a wide range of voltage control and supply voltage fluctuations.

Keywords: Bridgeless (BL) isolated interleaved zeta converter, Diode Bridge Rectifier (DBR), Discontinuous Conduction Mode (DCM), high-brightness light emitting diodes, LED lamp, power factor correction, zeta converter

INTRODUCTION

High-Brightness (HB) LEDs are extremely smart light sources because of their exceptional features (high efficiency and prolonged existence and low-maintenance conditions) (Carraro, 2007). 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 (Van der Broeck *et al*., 2007). Several researchers have formulated different DC-DC converter topologies in accordance with the conventional DC-DC switching power converters (Rico-Secades *et al*., 2003, 2004; Yuequan and Jovanovic, 2008). On the other hand, while DC-DC converters are classically intended to manage their output voltages, HB LEDs necessitate a controlled output current.

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 (Chen *et al*., 2007; Kening *et al*., 2008). 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 (IEC, 2000). This class creates an extremely severe harmonic content, in order that only extremely sinusoidal line waveforms are capable of satisfying the abovementioned rule. As a result, the only sensible technique to satisfy the EN61000-3-2 Class C rule is to make use of active high-Power-Factor (PF) converters, usually known as Power Factor Correctors (PFCs).

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 like voltage distortion, noises, heating etc., which results in diminished efficiency of the power system. Owing to this fact, there is a requirement for power supplies that obtain current with low harmonic content and moreover have PF close to unity (Lamar *et al*., 2009).

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

Corresponding Author: R. Thenmozhi, Anna University, Chennai, India
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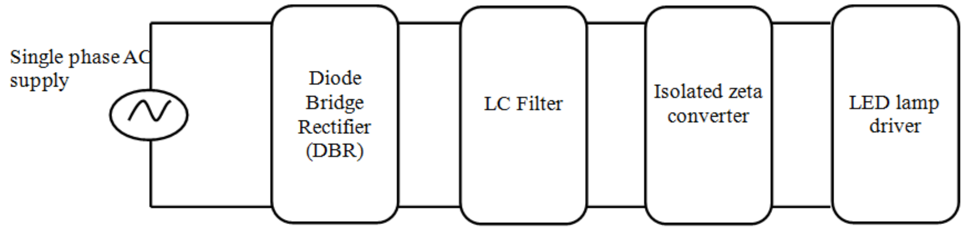


Fig. 1: Conventional DBR based isolated zeta coverter

of the application and it is essential to cope with the complication of heat dissipation in limited surface area (De Gusseme *et al*., 2005; Rajappan *et al*., 2013).

The selection of the type of operation of a PFC converter is a significant subject since it directly have 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 (De Gusseme *et al*., 2005; Rajappan *et al*., 2013). 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 (Sebastian *et al*., 1991; Singh *et al*., 2003, 2011).

In order to further enhance the efficiency, Bridgeless (BL) converters are employed which permit the exclusion of DBR in the front end (Sebastian *et al*., 1991; Singh *et al*., 2003, 2011). A buck-boost converter arrangement is well-matched among several BL converter topologies for applications needs an extensive range of DC link voltage control (i.e., bucking and boosting mode). (Jang and Jovanovic, 2011; Huber *et al*., 2008) have formulated BL buck and boost converters, respectively. These converters can offer the voltage buck (Jang and Jovanovic, 2011) or voltage boost (Huber *et al*., 2008; Fardoun *et al*., 2012) which restricts the operating range of DC link voltage control. Sabzali *et al*. (2011) have formulated a BL buck-boost converter, however the use of three switches is a costly solution. A new family of BL SEPIC and Cuk converters has been described in the literature (Sabzali *et al*., 2011; Mahdavi and Farzanehfard, 2011) however needs a huge number of elements and has losses connected with it. In this study, a conventional DBR based isolated zeta converter has been considered for simulation analysis which is shown in Fig. 1.

In this study, a Power Factor Corrected (PFC) Zeta converter based power supply is proposed for HB-LED

Table 1: Specification

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

lamp with universal input voltage. In proposed LED driver, PFC AC-DC converter assists in enhancing the input PF and also helps in reducing Total Harmonic Distortion (THDi) 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. In view of 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.

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 Fig. 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.

Operation of BL isolated interleaved zeta converter: The operation of the BL isolated interleaved zeta converter is categorized into two components which

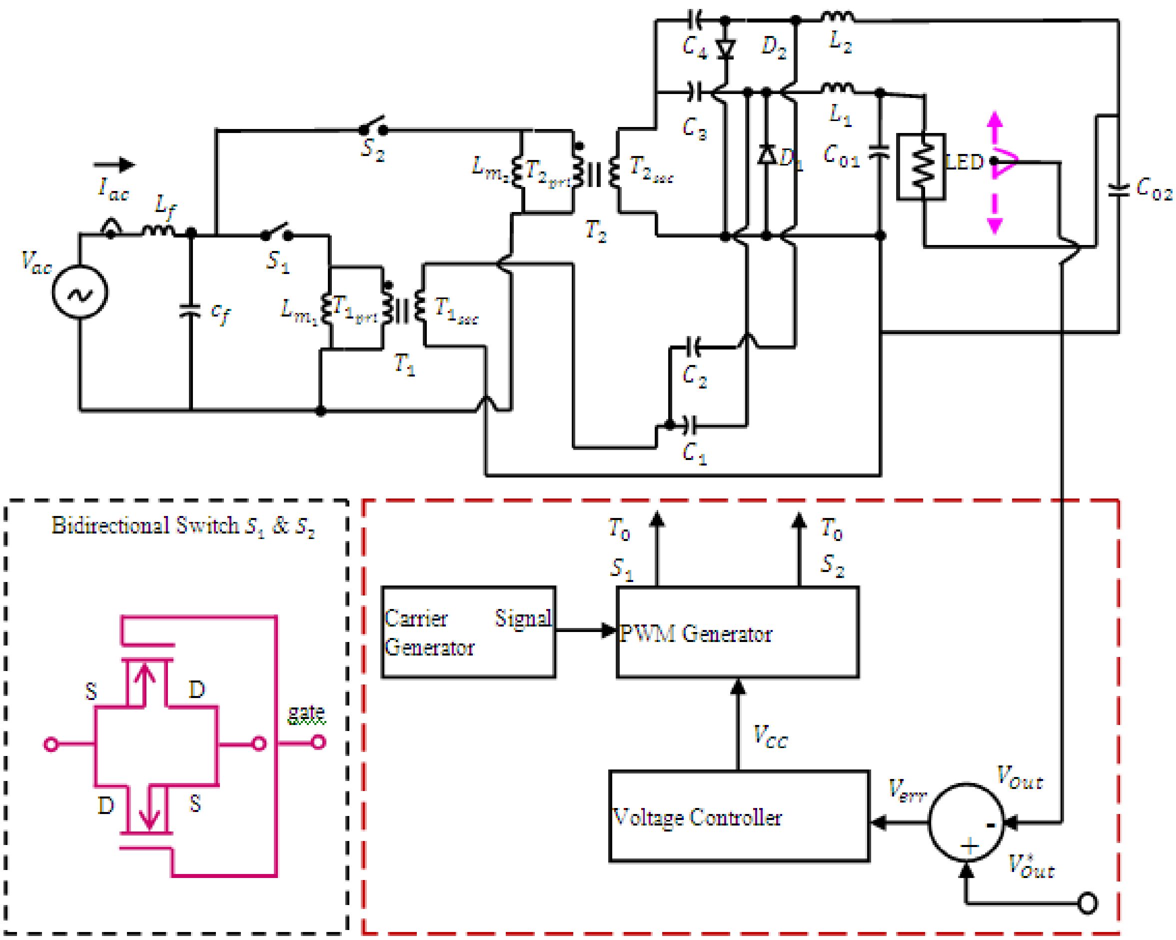


Fig. 2: Overall proposed BL isolated interleaved zeta converter

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 Fig. 3a to c and their related waveforms are provided in Fig. 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 Fig. 3a. 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 as illustrated in Fig. 3.

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 Fig. 3.

Mode 2: This mode is DCM in order that the energy of high frequency transformer (T_1) is fully released as illustrated in Fig. 3c. 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 Fig. 3.

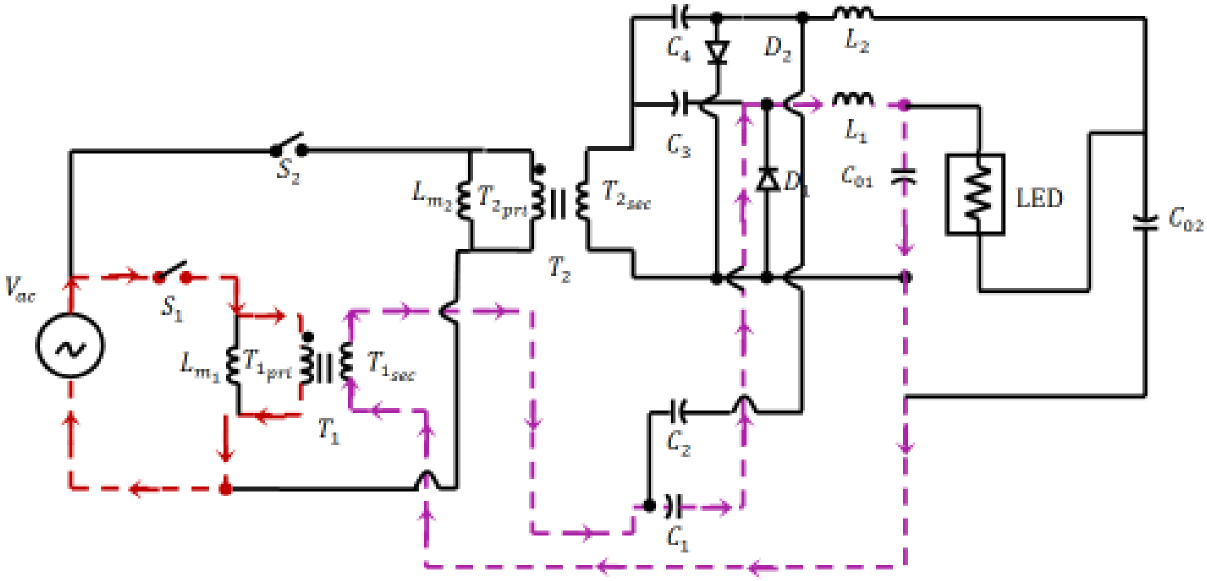
Conduction modes of switch S_2:
Mode 3: When switch (S_2) is "ON" condition, a current in magnetizing inductance (L_{m_2}) of high frequency transformer (T_2) raises as illustrated in Fig. 4a. The intermediary capacitor (C_3) provides energy to an output inductor (L_1) and the output filter capacitor

(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 Fig. 4a.

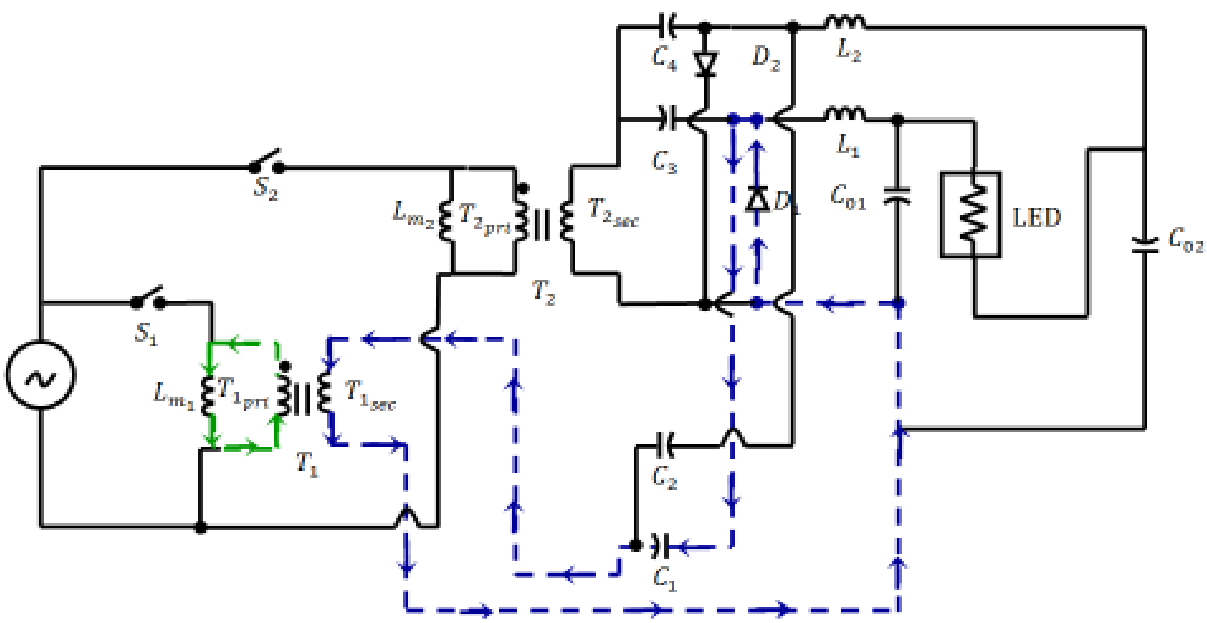
Mode 4: When switch (S_2) is in "OFF" condition, the current in magnetizing inductance (L_{m_2}) of high frequency transformer (T_2) and output inductor (L_1) begins to drop. This energy of high frequency transformer is transmitted to the intermediary capacitor (C_3) and as a result voltage across it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

Mode 5: This mode is DCM in order that the energy of high frequency transformer (T_2) is fully released as illustrated in Fig. 4c. 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 as illustrated in Fig. 4

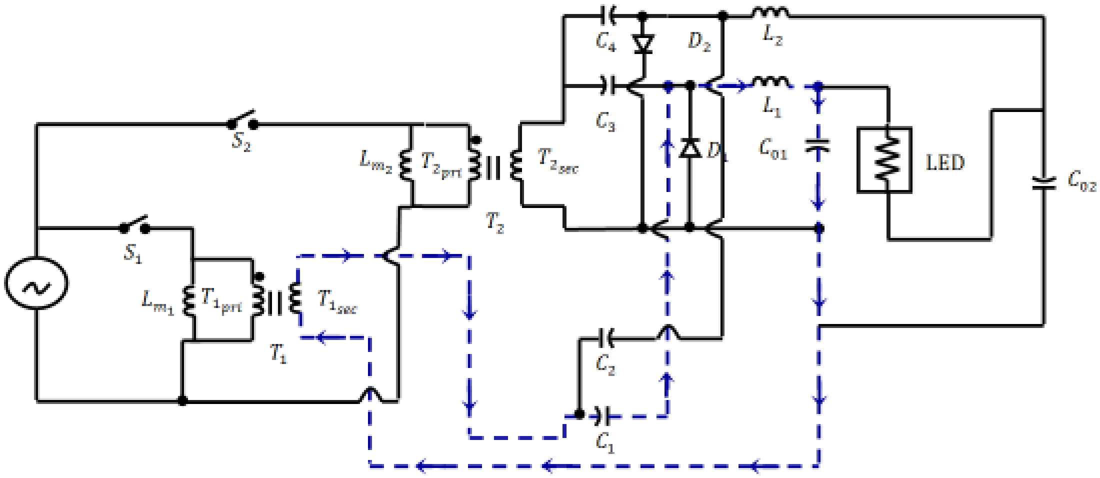
In this waveform, the theroritical analysis of the overall proposed BL isolated interleaved zeta converter is shown in the Fig. 5. When Switch S_1 is ON, theroritcal waveform of Magnetizing Inductance



(a) Mode 0 operation

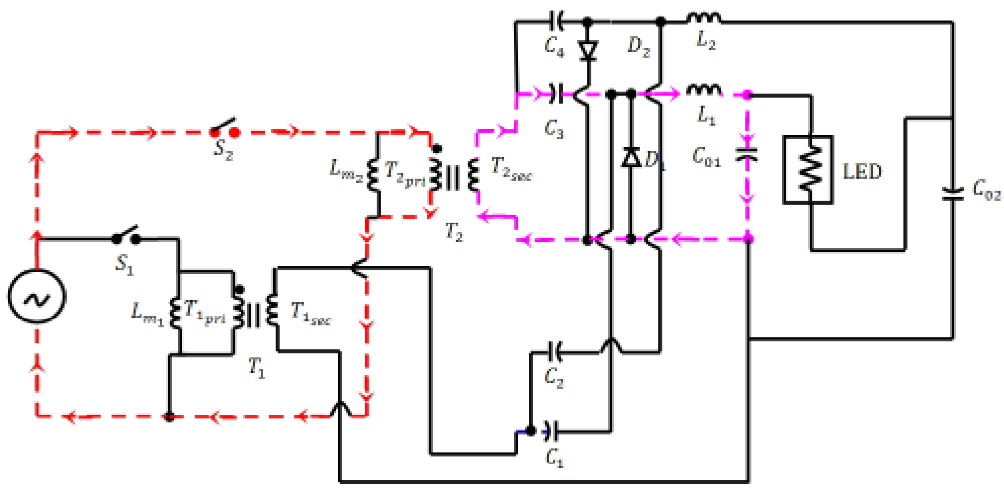


(b) Mode 1 operation

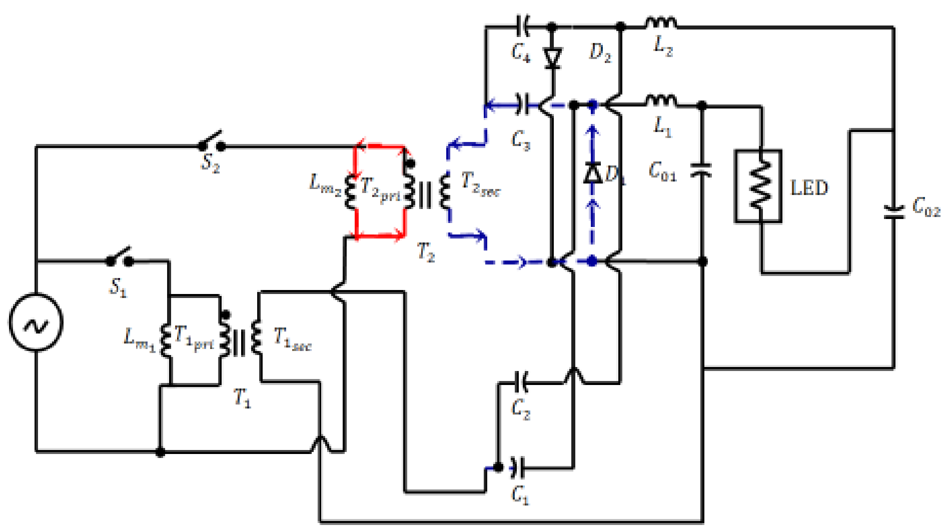


(c) Mode 2 operation

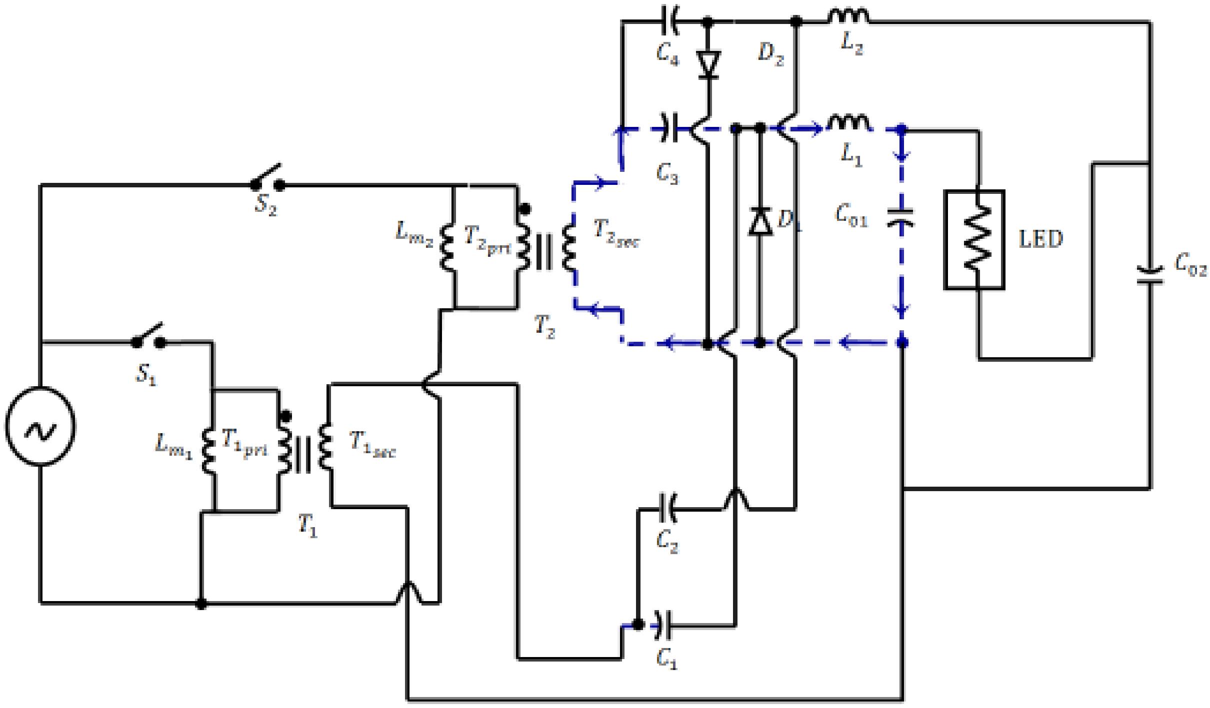
Fig. 3: Conduction modes of switch S_1 during positive cycle



(a) Mode 3 operation of (S_2)



(b) Mode 4 operation of (S_2)



(c) Mode 5 operation of (S_2)

Fig. 4: Conduction modes of switch S_2 during positive cycle

current (i_{Lm1}), primary current of the transformer ($i_{T_{1_{pri}}}$), intermediary capacitor current (i_{C_1}), Diode Current (i_{D_1}) and output inductor current (i_{L_1}) is shown. Similiary, When Switch S_2 is ON, theroritcal waveform of Magnetizing Inductance current (i_{Lm2}), primary current of the transformer ($i_{T_{2_{pri}}}$), intermediary capacitor current (i_{C_2}), Diode Current (i_{D_2}) and output inductor current (i_{L_2}) is shown Fig. 5.

Control loop operation of BL isolated interleaved zeta converter: Proportional Integral (PI) is a kind of control loop feedback process which has been extensively employed in several industrial and house-hold applications. On the whole, PI controller tries to accurate the error involving a computed process variable and preferred set point by means of computation to provide the accurate output that can fine-tune the process consequently.

The actual converter output voltage V_{act} is deducted with the set voltage V_{set} and the error is provided as input to the PI controller. At this point, V_{set} is taken as 90 V.

In this study, the foremost contribution depends on the converter design, as a result, traditional PI controller is ideal. The PI controller computation engages two separate modes the proportional mode, integral mode. In case of the proportional mode, it determines the response to the current error, on the other hand, integral mode determines the response based recent error. The weighted sum of the two modes output as corrective action to the control element. PI controller is extensively utilized in industries because of its simplicity in design and uncomplicated structure. PI controller algorithm can be put into practice as given below:

$$\mathrm{output\ (t)} = K_P\,\mathrm{err\ (t)} + K_I \int_0^t \mathrm{err\ (t)dt}$$

where,

$$\mathrm{err\ (t)} = \mathrm{set\ voltage} - \mathrm{actual\ voltage}$$

The output of the PI controller (controlled error) is compared against the triangular carrier signal of frequency 5 KHz to produce 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 evidently represented in the Fig. 6.

RESULTS AND DISCUSSION

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 depicted in Fig. 1.

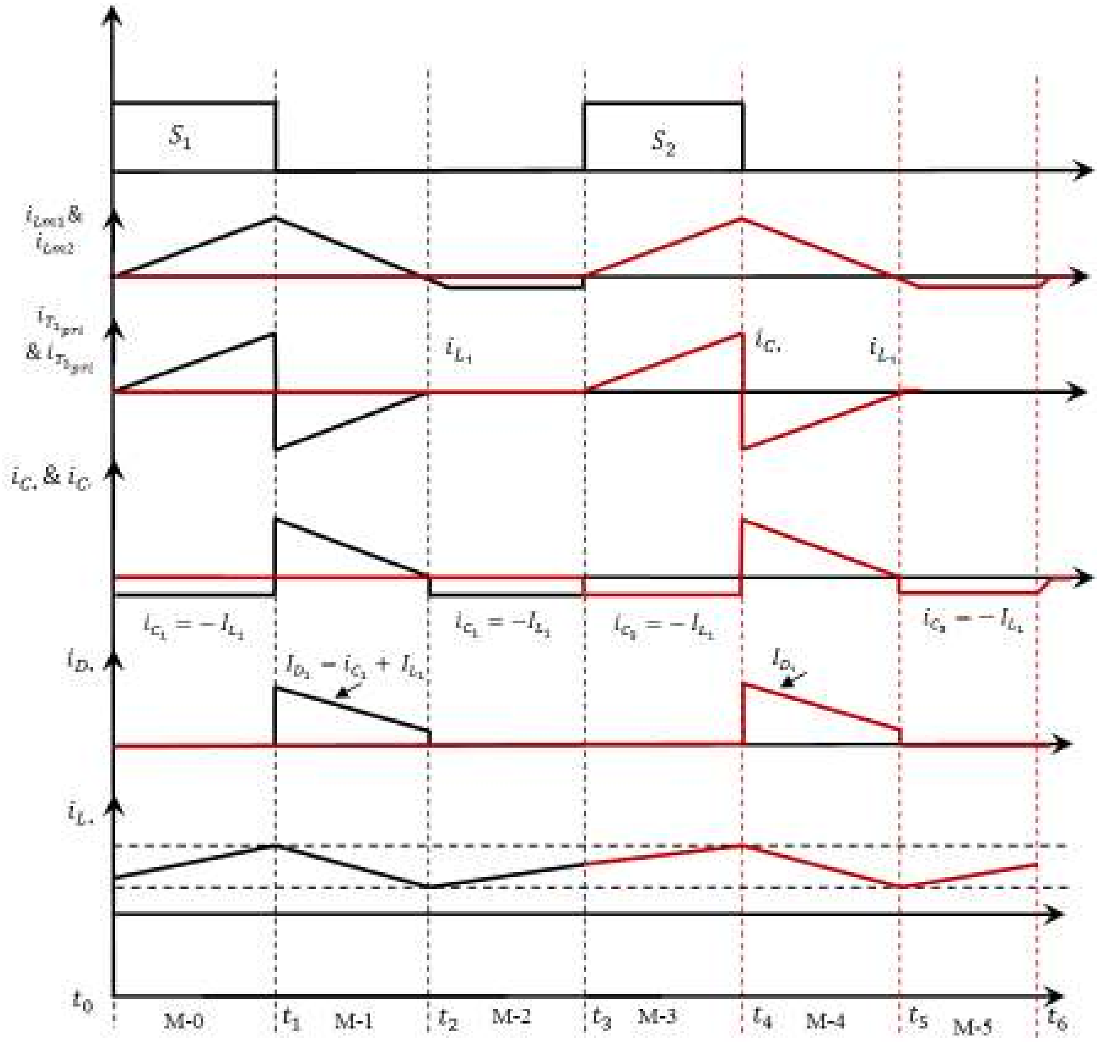


Fig. 5: Theoritical analysis waveform

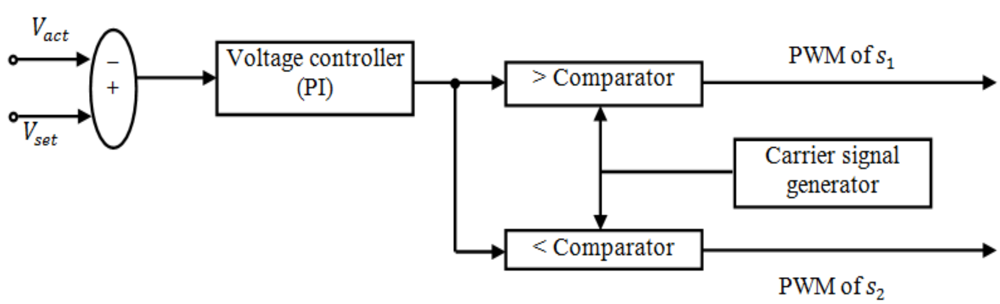


Fig. 6: Proposed converter based LED drive voltage control loop

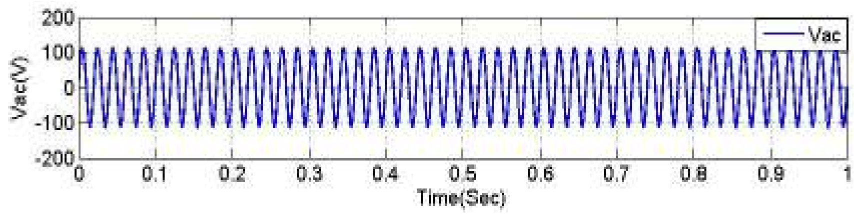
Parameters such as supply voltage (V_{ac}), supply current (I_{ac}), Converter output voltage (V_{out}), Converter output Current (I_{out}), Converter output Power (P_{out}), of the BL Isolated Interleaved Zeta Converter are evaluated to demonstrate its proper functioning. The evaluation is based on 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 1.

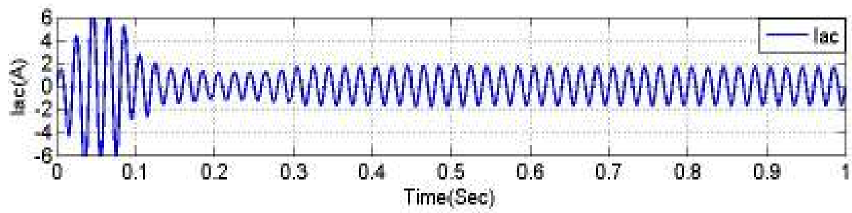
Steady-state performance: The steady-state behaviour of the proposed BL Isolated Interleaved Zeta Converter fed LED driver at rated condition is shown in Fig. 6.

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

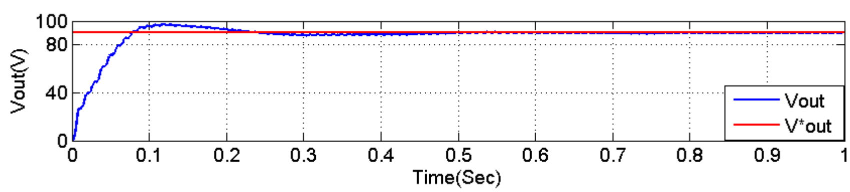
Then, the proposed BL isolated interleaved zeta converter is used to control the output voltage. It is a DCM type of converter. So, the converter output voltage is taken as feedback and is compared with rated output voltage. Now, the pulse width will be adjusted based on the error value and the converter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



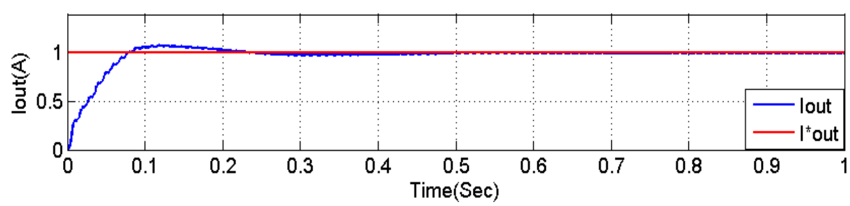
(a) Supply voltage



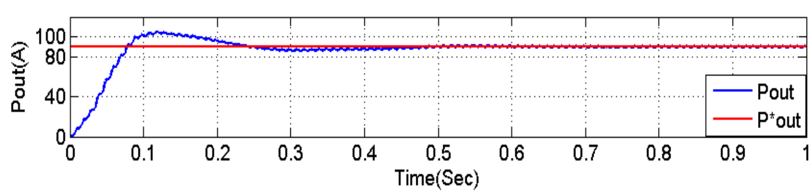
(b) Supply current



(c) Converter output voltage



(d) Converter output current



(e) Converter output power

Fig. 7: Steady state performance

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.

Evaluation of ripple factor for proposed bl interleaved converter and existing bridge converter: Figure 8a shows the ripple factor response of the proposed BL Interleaved converter and the existing bridge converter. It is inferred from the result that, the voltage ripple of the proposed BL interleaved converter is less when compared with the conventional bridge type converter as shown in Table 2. This is mainly due to the interleaved nature of the proposed converter.

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. The voltage response of the proposed converter is analyzed by a sudden change at 0.65 sec from 90 to 60 V. The actual voltage response (V_{out}) of the proposed converter and the rated output voltage are shown in the Fig. 9a.

Based on the voltage variation of the converter, the converter output current and supply current responses are shown in Fig. 9b and c.

The achieved power quality indices obtained at ac mains are tabulated in Table 3 when the output voltage is varied from 90 to 60 V. It is inferred from the table that, the voltage variation is directly proportional to the supply current.

Performance under supply voltage variation: The behavior of the Proposed BL Isolated Interleaved Zeta Converter fed LED driver is simulated and the performance is evaluated for supply voltage V_{ac_RMS} with a sudden change at 0.65 sec from 80 to 50 V as shown in Fig. 10a. Based on this sudden change in supply voltage, the response of the converter output voltage is shown in Fig. 10b. It is inferred from the figure that, the converter output voltage is maintained constant at 90 V, but due to the sudden change in supply voltage at 0.65 sec, there is slight deviation in the converter output voltage. However, the deviation quickly settles to maintain the converter output voltage constant from 0.85 sec.

Table 2: Voltage ripple evaluation

Conventional bridge converter			Proposed BL interleaved converter		
Low voltage value	High voltage value	Voltage ripple	Low voltage value	High voltage value	Voltage ripple
89.1 V	90.9 V	1.8 V	89.6 V	90.4 V	0.8 V

Table 3: Output voltage variation-dynamic response

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
80 V	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

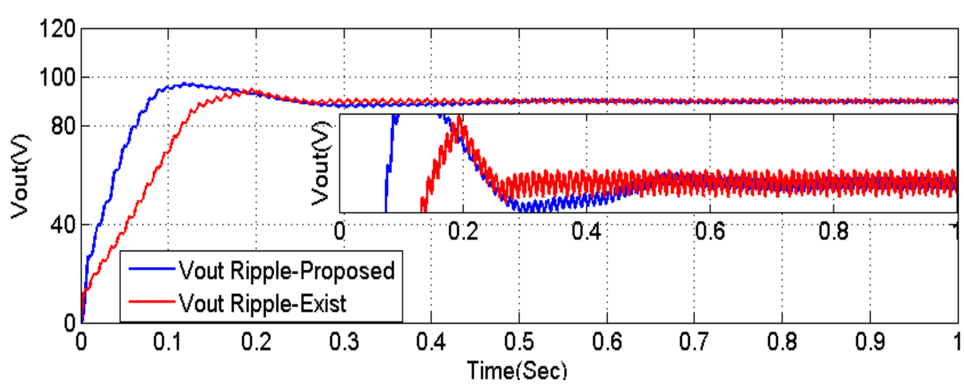


Fig. 8: Ripple factor response of the proposed BL Interleaved converter and the existing bridge converter

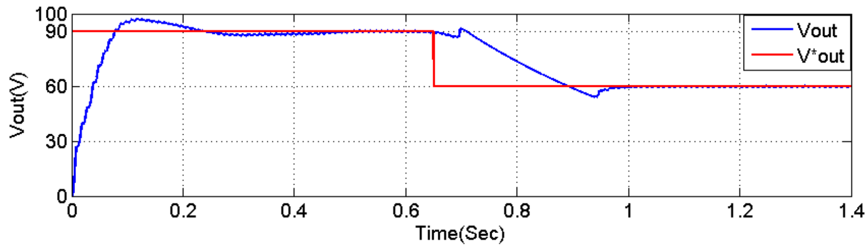


Fig. 9a: Converter output voltage response when sudden change in rated output voltage

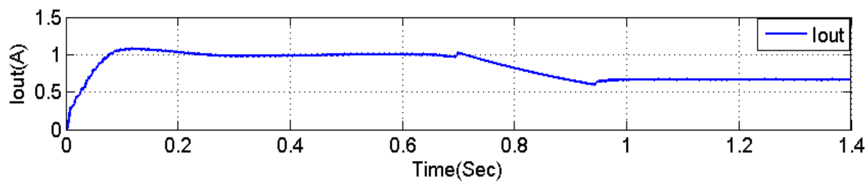


Fig. 9b: Converter output current response when sudden change in rated output voltage

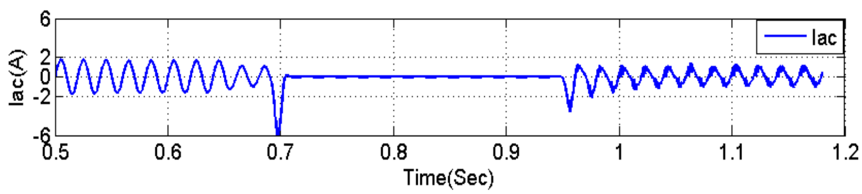


Fig. 9c: Supply current response when sudden change in rated output voltage

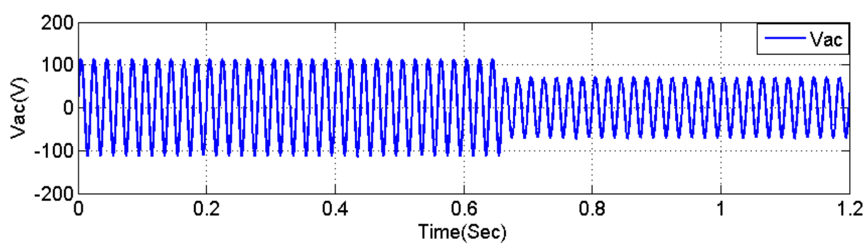


Fig.10a: Change in voltage

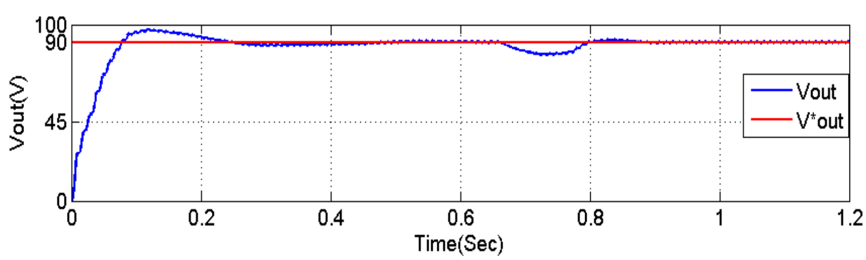


Fig.10b: Response of the converter output voltage

Table 4: Supply voltage variation-dynamic response

V_{ac} (V) (Peak)	V_{ac} (V) (Rm	DPF	THD of I_s (%)	PF
80	113	0.9959	0.80	0.9954
75	106	0.9961	0.78	0.9957
70	98.9	0.9964	0.78	0.9961
65	91.91	0.9966	0.76	0.9962
60	84.8	0.9967	0.76	0.9963
55	77.7	0.9959	0.76	0.9955
50	70.7	0.9956	0.74	0.9951

Table 4 shows different power quality indices with variation in supply voltage. The THD of supply current obtained is within the limits of EN61000-3-2. An acceptable THD of supply current is obtained for both the cases which show an improved power quality operation of the proposed LED driver at universal ac mains.

CONCLUSION

In this study, 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. The bridgeless isolated interleaved zeta converter is proposed and it operated in various modes which provides significant performance. The Proposed BL Isolated Interleaved Zeta Converter is simulated in a MATLAB. 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 advantages of the proposed design are high efficiency of about 94.98%, an enhanced PF is 0.9954 and operation across an extensive range of input and output voltages. Furthermore, an improved power quality is achieved with power quality indices within limits of EN61000-3-2 standard.

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