

High Power Factor Bridgeless Buck Converter Based Isolated Supply For Led

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Abstract: This paper proposes a circuit based on bridgeless buck converter topology with a single power switch. The front end bridgeless buck converter designed in such a way to operate in discontinuous capacitor voltage mode (DCVM), it simplifies the control circuit. A high frequency transformer with centre tapped secondary used for energy transferring and isolation. Voltage at the secondary side of transformer is rectified using a full bridge rectifier circuit. The converter switch is controlled using a voltage follower approach which is the simplest control method adopted for DCVM operation. Low power output with almost unity power factor will be available with a better isolation. A design example of a 60W converter supplied from a 100V /50 Hz mains used for LED lighting application is considered. Simulation results demonstrate that the proposed LED supply with an isolated front end PFC gains a power factor of 0.9995. Due to the properly designed control technique converter output voltage can be stably maintained at 48V. The experimental results are shown to substantiate this design. This converter can be used to provide power factor correction in street lighting; and is best suited for low power LED applications such as matrix lighting. The circuit is analyzed using MATLAB/Simulink is also presented.

Keywords- Bridgeless Buck Converter, Discontinuous capacitor voltage mode (DCVM) operation, Half Bridge Inverter, PI Controller, Power LED Lamp.

I. Introduction

Now a days Power converters are widely used for high power factor low power applications. This paper introduces an improved power factor bridgeless buck converter with isolation as an offline power supply for LED. The recently modified isolated LED supply circuits are based on converters with diode bridge rectifier circuits or bridgeless converters operating in CCM. Like many other energy-efficient technologies, efficient lighting will boost global prosperity. This lighting revolution is already underway. It is being driven by advances in one technology: light-emitting diodes, or LEDs. The highly efficient LED system needs the high efficiency power supply to feed the LED. For lighting applications either an active or a passive circuit can be used for power factor correction. The passive circuit consists of inductors and capacitors along with a diode bridge rectifier circuit. In active power factor correction circuit, front end PFC is used to achieve high power factor and good output voltage regulation. Bridgeless converter at the front end of the isolated LED supply is expected to draw a sinusoidal input current which is in phase with the supply line voltage. Improvement in power quality also results in better efficiency.

LED driver consists of a diode bridge rectifier (DBR) and a resistor which provides a constant current to avoid the damage of LEDs. Such circuits introduce power quality issues like poor power factor and higher harmonic contents in the AC mains current as well as poor efficiency since only 20-30% of input power is converted into light. To comply with IEC-61000-3-2 class C equipments, a PFC stage is required between DBR and the LED module to improve the power quality at AC mains.

A review of literature shows that a wide variety of LED power supplies and driver solutions with or without isolation, which can accurately control the current of the LED while achieving a near-unity input power factor, have been proposed [9],[11]. This drive is currently implemented based on switch mode power supplies (SMPS). However, an electrolytic capacitor is required in these applications. Unfortunately, the operating life of such capacitors is by far shorter than the life of the HB LEDs, and usually are the shortest of all the devices in the power supply. From the comprehensive analysis of different power factor pre regulator topologies and their operational performance evaluations [2] it is found that, single switch topologies adopting current multiplier control in CCM operation having better stability. While comparing to single switch converters the push-pull and half-bridge (two-switch) converters have equal switching losses. But it uses a more complex control scheme.

A unity power factor switching mode power supply with isolation using a single switch offers a better power factor operation [3]. It uses a SEPIC converter operating in continuous conduction mode. Unity power factor and reduced conduction losses can be achieved for a bridgeless SEPIC rectifier using a single bidirectional switch and two fast diodes. Even though it is bridgeless in nature and simple in control it requires an additional gate drive transformer. But SEPIC converter has a discontinuous output current resulting in a relatively high output ripple this is one of the main disadvantage. The SEPIC topology has to use a large number of components [5] also CCM operation requires a complex control circuitry.

Bridgeless cuk rectifiers are also an important topology widely used for PFC applications [4]. It is bridgeless in nature and uses only two power switches which are designed to operate in discontinuous conduction mode (DCM) to achieve almost unity power factor [14].

Bridgeless buck power factor correction converters will improve the efficiency at low line voltage [6]. Buck PFC can operate in both discontinuous mode and continuous current mode. Due to the reduction in number of simultaneously conducting components conduction losses will be low. Discontinuous current mode operation of the converter requires a large input filter circuit. For CCM operation mode the power factor will not be improved as much. Buck converter operation in discontinuous voltage mode reduces the input filter requirements and results in simple control circuit [7], [15].

This paper deals with the development of high power factor bridgeless buck converter with isolation as a supply for LED lamps. It uses a bridgeless high power factor buck converter followed by a half bridge inverter circuit connected to the primary side of a high frequency transformer with centre tapped secondary. At the secondary side there is a rectifier - filter arrangement prior to the LED. The isolated supply provides a high degree of safety. The bridgeless buck converter is designed to operate in Discontinuous Capacitor Voltage Mode (DCVM), which reduces the complexity in control as well as the input filter requirements.

II. Study of proposed system

The proposed topology consists of a bridgeless buck converter operating in discontinuous capacitor voltage mode with an isolated rectifier circuit as the supply for an LED light. Fig. 1 shows the basic circuit diagram of the proposed topology. AC input is given to the bridgeless buck converter. The two input inductors of large value make a constant input current for the bridgeless topology. Thereby input filter size can be reduced or completely avoided. The average line current will be in phase with the line voltage, results in near unity input power factor, this is important for the converters operating from mains voltage in a grid.

The converter circuit consists of only a single power switch, quadrant in nature which is operated with a duty cycle of 48%. The duty cycle is selected in such a way that the input capacitors operate in DCVM with its maximum voltage. Since the converter is operated with α lower than 0.5, the output converter voltage ratio will be lower than unity, thus reducing the low frequency voltage ripple. The switch is connected in series with two diodes D_p and D_n . D_p conducts during the positive half cycle of the supply voltage and D_n conduct during the negative half cycle of the supply. The single converter switch is controlled by using DC link voltage follower approach which is the best suited method for DCM operation of PFC converters.

A half bridge inverter with two switches used for inverting constant DC voltage. The inverted voltage available across DC link is sensed back to control the converter switch. The primary of the high frequency isolation transformer is connected to the inverter. At the secondary side, there is a full wave diode rectifier followed by a filter circuit, which makes a pure DC output.

Need for Isolation: Non isolated voltage regulators are always suffers from one disadvantage in that there is an electrical connection between the input and output. But they are widely used because of their simple construction and low cost. An isolated DC-DC converter will have a high frequency transformer providing connected between the input and output provides a barrier, which can withstand a few hundred volts to several thousand volts. Also for an isolated converter the output can be configured to be either positive or negative.

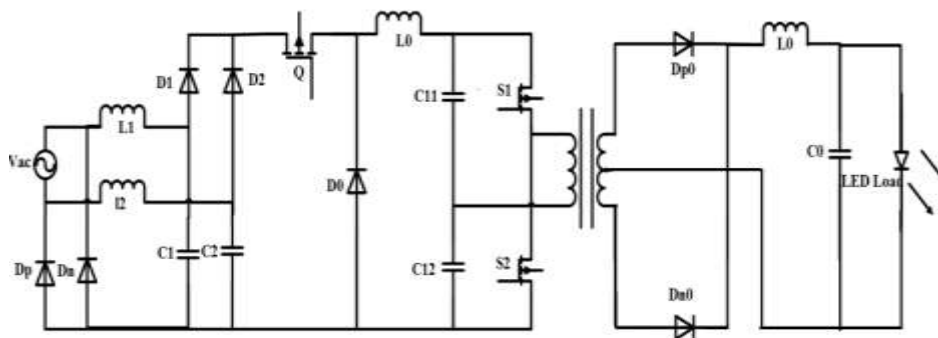


Fig .1.Configuration of the proposed system

a. Bridgeless buck converter

The bridgeless buck converter circuit operation can be explained in three operational stages. Considering the following assumptions,

- The converter operate in steady state condition
- The input is purely sinusoidal.
- L_1 and L_2 are large enough such that the current through them can be assumed constant over a switching cycle.
- C_0 is large enough so that converter output voltage is assumed to be constant.
- All the components of LED driver are assumed to be ideal
- During steady state LED behaves as a pure resistor.

During the positive half cycle diode D_p is conducting, which connects the input ac source through $L_1-C_1-D_1-Q-L_0-D_0$ to the output ground. $L_2-C_2-D_2-Q-L_0-D_0$ is active through diode D_n during the negative half-line cycle, which connects the input ac source to the output ground. Fig. 2 shows the theoretical switching waveforms of the converter operation during a complete cycle.

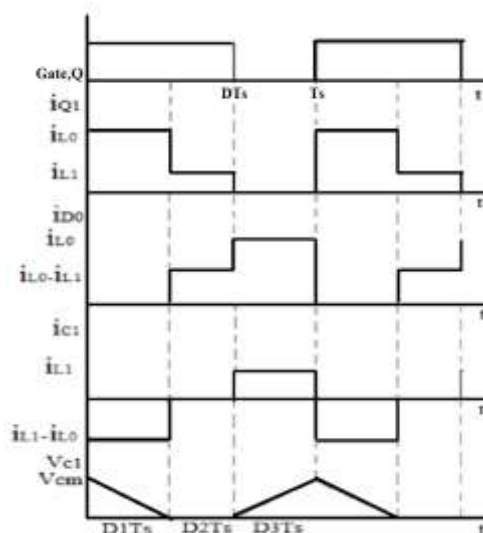


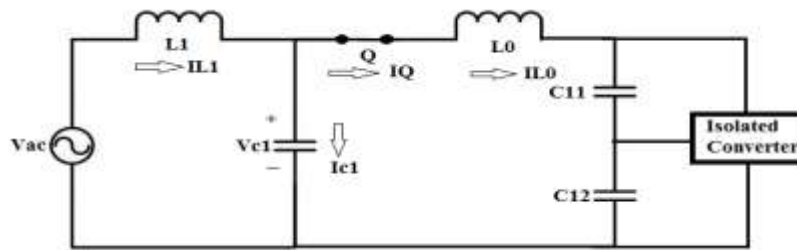
Fig.2 Theoretical switching waveforms

Mode 1 ($0 \leq t \leq D_1T_s$): Mode 1 starts when switch Q is turned on. Input capacitor C_1 connected to the source is discharging from its maximum voltage V_{cm} . At the time output inductor current will be equal to the switch current. Freewheeling diode is kept reverse biased by the voltage across the capacitor C_1 . This mode ends when the capacitor discharges completely..

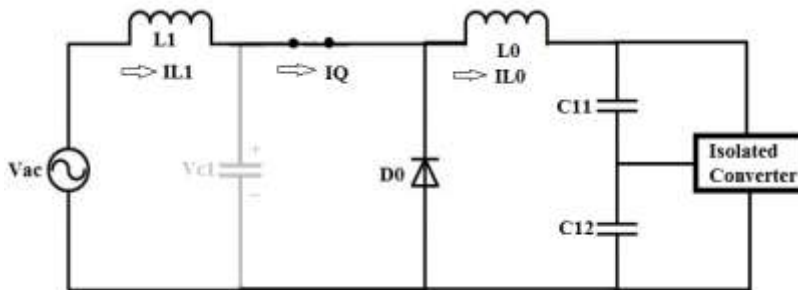
Mode 2 ($D_1T_s \leq t \leq DT_s$): The converter switch Q is still conducting. The switch current will be equal to the input inductor current since the capacitor C_1 stays completely discharged. This makes the freewheeling diode become forward biased and starts conducting. Removal of switch gating pulse indicates end of the stage.

Mode 3 ($DT_s \leq t \leq T_s$): During this interval switch Q is kept off. Completely discharged input capacitor C_1 starts charging from the supply through the input inductor to its maximum voltage V_{cm} . Freewheeling diode is still conducting.

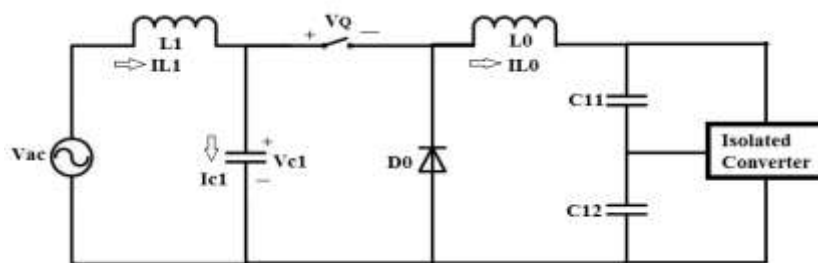
Fig.3 (a), (b) and (c) shows the bridgeless buck converter operating modes.



3. (a) Mode 1 operation



3. (b) Mode 2 operation



3. (c) Mode 3 operation

b. Half bridge inverter

The regulated DC output voltage of the bridgeless buck PFC converter is fed to the half bridge voltage source inverter circuit for inverting the voltage prior to the isolation and scaling stage. The circuit operation of the half bridge inverter over one switching cycle can be explained in four stages.

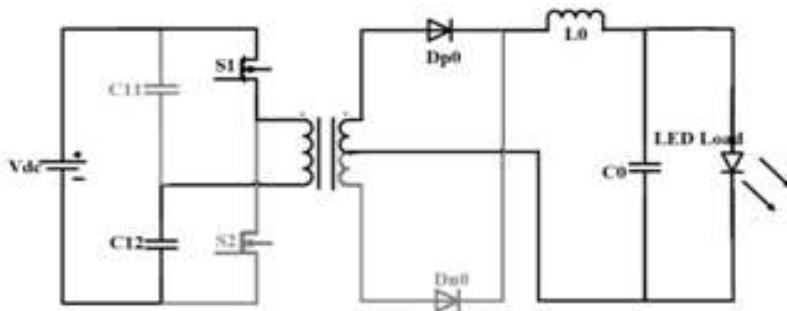
Mode 1: In the first mode, switch S_1 of the half bridge inverter is turned on; the input current circulates through the primary winding of the high frequency isolation transformer to the lower input capacitor C_{12} . Upper diode at the secondary side of the isolation transformer starts conducting. Output inductor L_0 will charge through the upper diodes and capacitor C_0 is discharging.

Mode 2: During this interval S_1 and S_2 stay as open. Diodes D_{p0} and D_{n0} will be freewheeling due to the inductor discharge current. And capacitor will be charging.

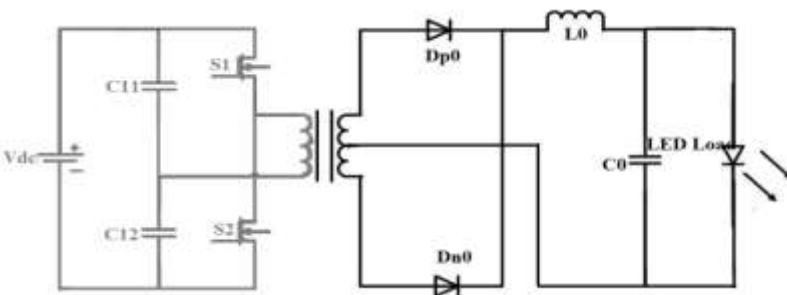
Mode 3: In this mode half bridge inverter switch S_2 is turned on, and the input current flows to the primary winding of the isolation transformer through upper capacitor C_{11} . Diode D_{n0} in the secondary windings forward biased, and output inductor start storing energy.

Mode 4: Mode for is same as mode 2, where both the switches at the primary side are off and the secondary diodes freewheeling due to the inductor discharging.

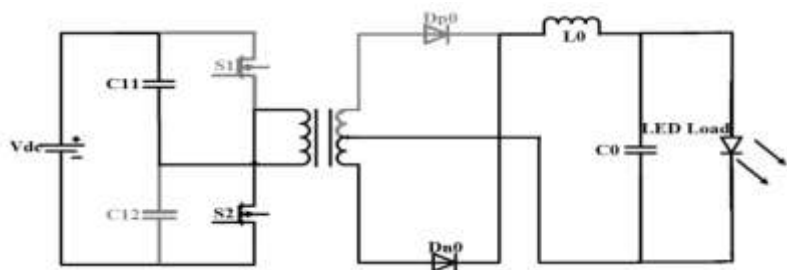
Fig.4 (a),(b)and(c) shows the half bridge inverter operating modes.



4. (a) When the first switch S_1 is on



4. (b) When both switches are off



4. (c) When switch S_2 on.

III. Simulation results and analysis

To verify the validity of the proposed system Matlab/Simulink Software is applied. The simulink model consists of a single phase AC power supply, DC-DC converter, half bridge inverter, isolation transformer and a full bridge rectifier circuit connected to the LED load. Instead of a LED simulink model uses a RL load.

This supply is given to a DC -DC converter. The bridgeless high power factor converter produces a constant DC voltage, which is given to the primary of an isolation transformer through a half bridge inverter circuit. The inverter output is sensed back for the control of the converter switch. Pulses are generated by PWM method

Table I: simulation parameters

Component	Value
$L_1=L_2$	2.2 mH
L_0	180 μ H
$C_1=C_2$	47 nF
$C_{11}=C_{12}$	3000 μ F
C_0	330 nF

The system is modeled with input voltage $V_{ac} = 100 V_{rms} @ 50 Hz$ and $f_s = 20 kHz$. Performance of the proposed high power factor bridgeless buck converter based isolated LED supply is simulated in MATLAB/Simulink environment using Sim-Power- System toolbox and discrete time sampling. The converter duty cycle is set to 48% in order to ensure DCM operation.

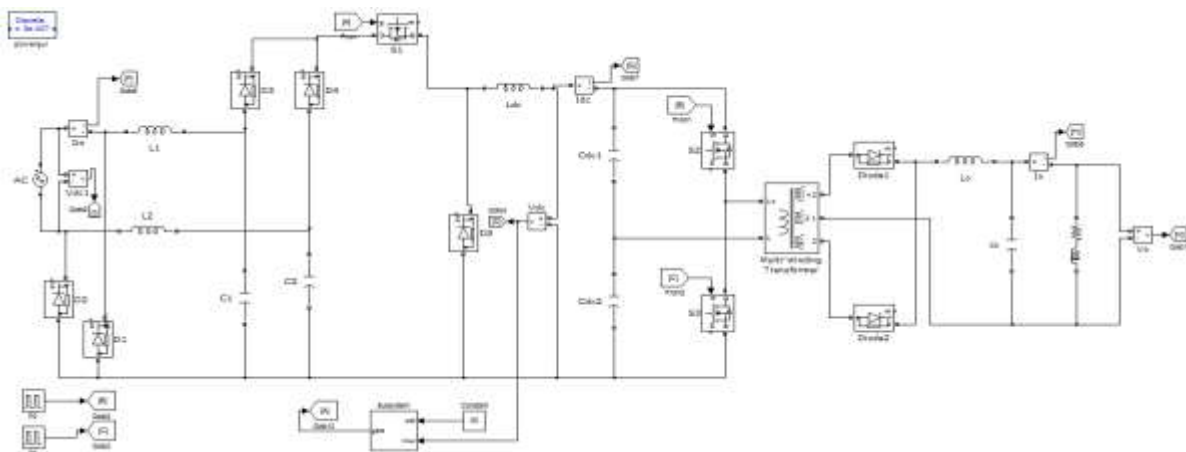


Fig. 5.Simulation model for a proposed system

Fig. 5 shows the simulink model of the proposed system. The converter switch is controlled using a voltage follower approach which senses the DC link volatge of the converter and compare it with a reference value for generation of gating pulses. Half bridge inverter switching pulses are generated by pulse generator at a switching frequency of 20 kHz.

Fig. 6 shows the input voltage waveform. A sinusoidal input voltage of 100 v_{rms} at 50 Hz is applied at the input.

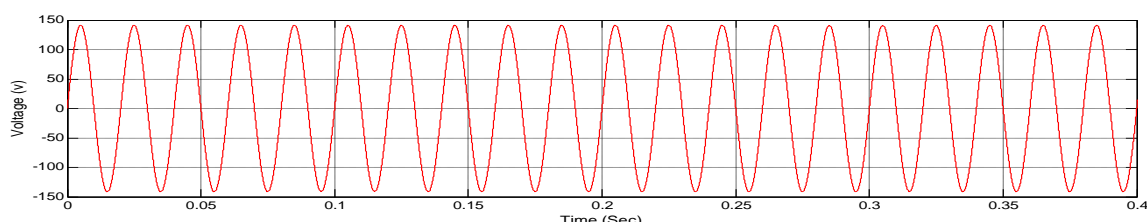


Fig. 6 Input voltage.

Fig. 7 shows input current waveform. It is clear from the figure that the input current is in phase with the ac input voltage, with an input power factor of 0.9995. Input current has an average value of 1.4 A.

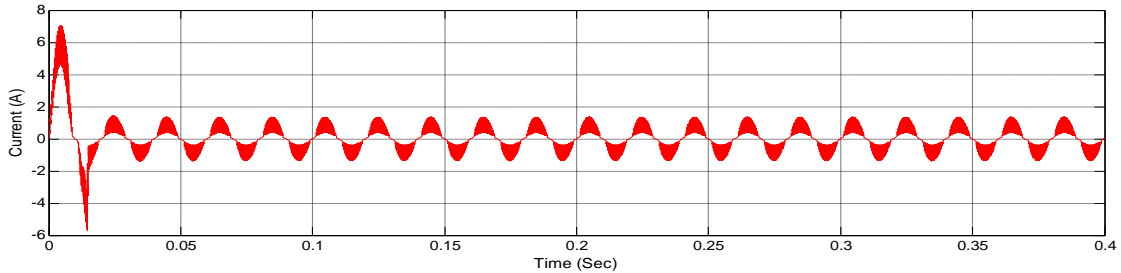


Fig .7 Input Current

Fig. 8 shows the converter switching pulses. The converter switch is operating with a duty cycle of 48% at a frequency of 50 kHz. Duty cycle is selected in such a way that the input capacitors operate in DCM. The switching pulses are generated by PWM method using a voltage follower feedback approach.

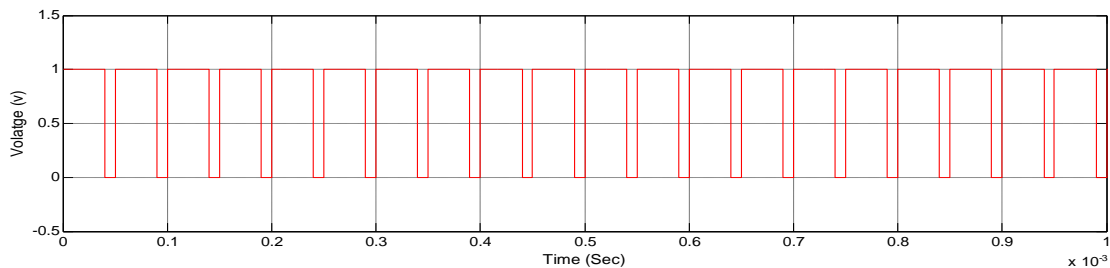


Fig. 8 Converter switching pulses

Fig.9 and Fig. 10 shows the switching pulses for the half bridge inverter switches. They are working with a duty cycle of 20% and at a frequency of 50 kHz. These switching pulses are generated by PWM generator.

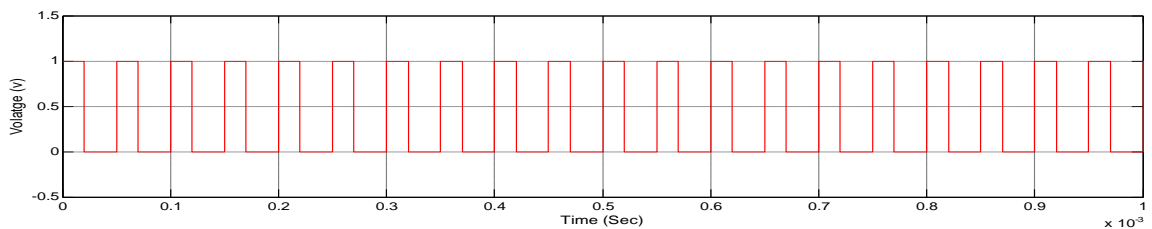


Fig. 9 Switching pulses for HBI switch S_1

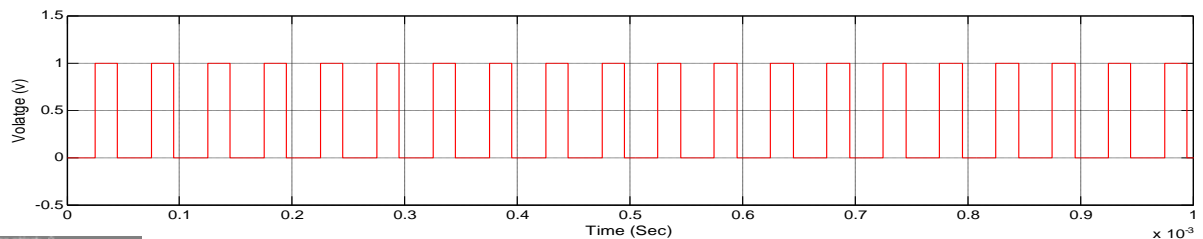


Fig. 10 Switching pulses for HBI switch S_2

Enlarged view of capacitor voltages under positive and negative half cycles is shown in Fig.11 and Fig. 12. The input capacitors are operating in the discontinuous capacitor voltage mode.

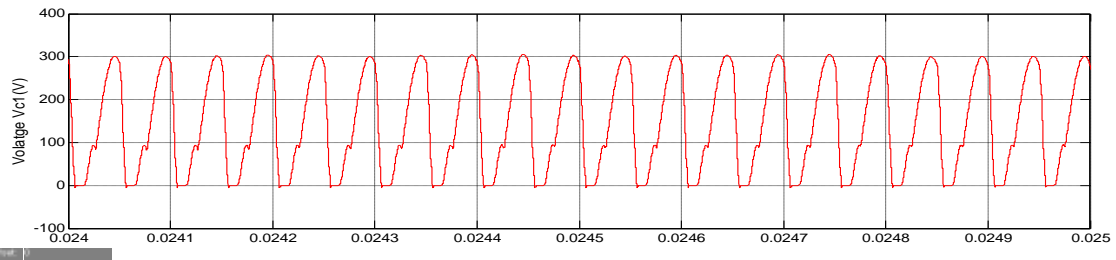


Fig. 11 Input Capacitor Voltage V_{c1}

The capacitor C_1 operates during positive half cycle and C_2 operate in the negative half cycles of the input voltage

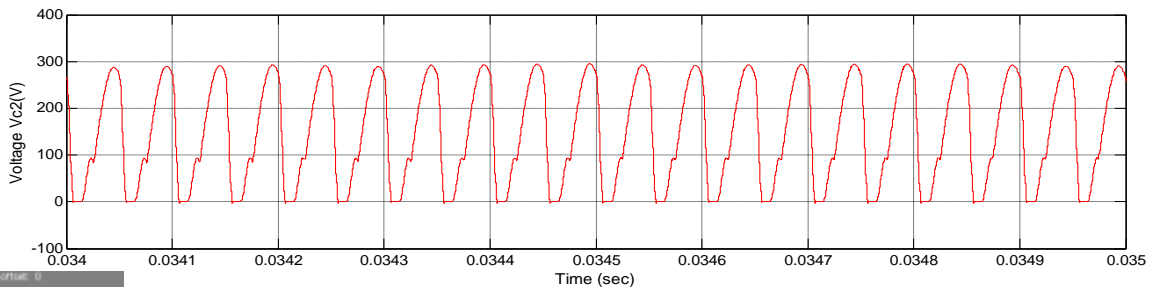


Fig. 12 Input capacitor voltage V_{c2}

Fig.13 shows the Bridgeless buck converter output voltage. Due to the DC link voltage follower approach a constant output voltage of 48V obtained.

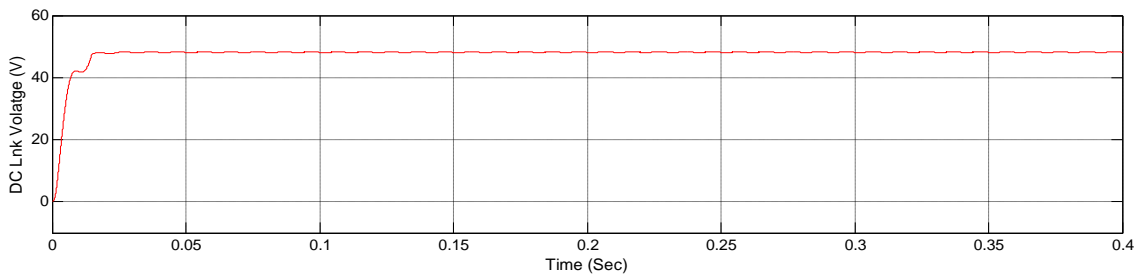


Fig. 13 DC link voltage

14 shows the DC link current waveform. An average value of 1.6 A is obtained at the bridgeless converter output.

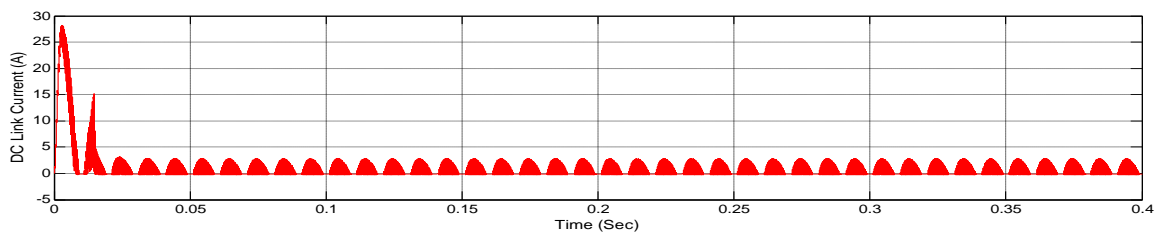


Fig.14 DC link current Waveform

Fig.15 Shows the Output voltage across the LED load. A constant DC voltage of 8V is obtained with minimum ripples. The output voltage is getting controlled within three switching cycles due to the efficient DC link voltage follower approach adopted for the converter switch control.

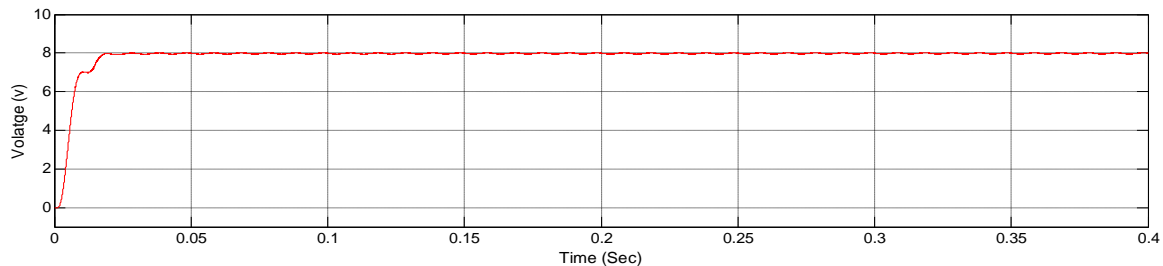


Fig. 15 Output voltage

Fig. 16 shows the controlled output current waveform. Output current is constant with a magnitude of 0.8 A and is almost free from ripples.

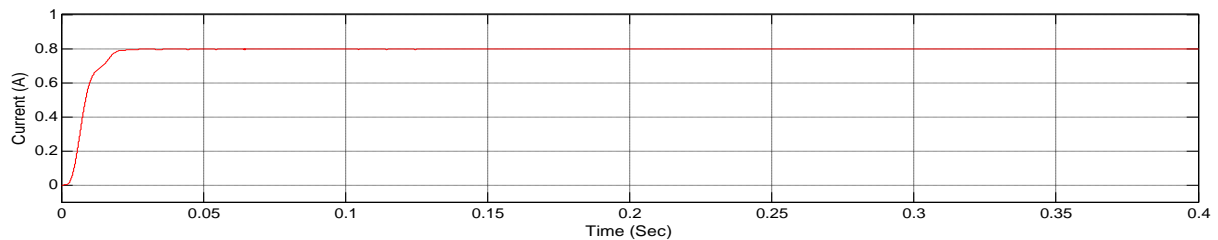


Fig. 16 Output Current

IV. Conclusion

A high power factor bridgeless buck converter based isolated LED supply has been designed and simulated. From the simulation results it is found that the proposed system can operate with improved power factor over the designed voltage range. Also due to the reduced component count, cost reduction is achieved. And DCVM operation of the converter results in simple control. By the careful selection of input capacitors it is possible to obtain DCVM operation of the front end converter. The operation of circuit is analyzed, and simulated the performance characteristics. From the simulation results it is found that for a 100 V input the front end converter produces a 48 V output voltage with 96 % conversion efficiency. A steady output voltage of 8V at 0.8A is obtained at the secondary of the isolation transformer. The Circuit operates at a power factor of 0.9995 for an input voltage range of 90 to 110 V. Hence a high power factor bridgeless converter based isolated LED supply is successfully analyzed.

References

- [1] B. Singh *et al.*, "A review of single-phase improved power quality AC–Dc converters," *IEEE Trans. Ind. Electron.*, vol. 50, no. 5, pp. 962–981, Oct. 2003
- [2] A. Canesin and I. Barbi, "A unity power factor multiple isolated outputs switching mode power supply using a single switch," in *Proc. IEEE APEC*, Mar. 1991, pp. 430–436
- [3] A. A. Fardoun, E. H. Ismail, A. J. Sabzali, and M. A. Al-Saffar, "New efficient bridgeless Cuk rectifiers for PFC applications," *IEEE Trans. Power Electron.*, vol. 27, no. 7, pp. 3292–3301, Jul. 2012
- [4] E. H. Ismail, "Bridgeless SEPIC rectifier with unity power factor and reduced conduction losses," *IEEE Trans. Ind. Electron.*, vol. 56, no. 4, pp. 1147–1157, Apr. 2009
- [5] Y. Jang and M. M. Jovanović, "Bridgeless high-power-factor buck converter," *IEEE Trans. Power Electron.*, vol. 26, no. 2, pp. 602–611, Feb. 2011
- [6] Abbas A. Fardoun *et al.*, "Bridgeless High-Power-Factor Buck-Converter Operating in Discontinuous Capacitor Voltage Mode," *IEEE Trans. Ind. Appl.*, vol. 50, no. 5, pp. 3457–67, Sept. 2014.
- [7] J. Chen, D. Maksimovic, and R. W. Erickson, "Analysis and design of a low stress buck–boost converter in universal-input PFC applications," *IEEE Trans. Power Electron.*, vol. 21, no. 2, pp. 320–329, Mar. 2006
- [8] H. Broeck, G. Sauerl'ander, and M. Wendt, "Power driver topologies and control schemes for LEDs", in *Proc. IEEE APEC 2007*, pp. 1319–1325.

- [9] K.Matsui *et al.*, "A comparison of various buck-boost converters and their application to PFC," in *Proc. 28th IEEE IECON, 2002, vol. 1, pp. 30-36*
- [11] S. Y. (ron) hui, Sinanli, Xuehuitao, Wuchen, and W.M.ng , "A novel passive offline led driver with long lifetime", in *IEEE Transactions on Power electronics, vol.25, no.10, October 2010.*
- [12] J. Y. Lee, G. W. Moon, and M. J. Youn, "Design of a power-factor correction converter based on half bridge topology," *IEEE Trans. Ind. Electron., vol. 46, no. 4, pp. 710-723, Aug. 1999*
- [13] J. M. Kwon, W. Y. Choi, H. L. Do, and B. H. Kwon, "Single stage half bridge converter using a coupled inductor," *IEE Proc.-Elect. Power Appl., vol. 152, no. 3, pp. 748-756, Apr. 2005*
- [14] W.-Y. Choi and J.-S. Yoo, "A bridgeless single stage half bridge AC/DC converter," *IEEE Trans. Power Electron., vol. 26, no. 12, pp. 3884-3895, Dec. 2011*
- [15] D. S. L. Simonetti, J. Sebastian, F. S. dos Reis, and J. Uceda, "Design criteria for SEPIC and Cuk converters as power factor pre-regulators in discontinuous conduction mode," in *Proc. IEEE Ind. Electron. Motion Control Conf., 1992, vol. 1, pp. 283-288.*
- [16] Ye, Zhongming, Fred Greenfeld, and Zhixiang Liang. "A topology study of single-phase offline AC/DC converters for high brightness white LED lighting with power factor pre-regulation and brightness dimmable." *Industrial Electronics, 2008. IECON 2008. 34th Annual Conference of IEEE. IEEE, 2008.*