Modified Bridgeless Buck Rectifier with Single Inductor for Power Factor Correction

Shabana J

Assistant Professor,Dept. of Electronics & Communication Engineering

Eranad Knowledge City Technical Campus ,Manjeri, Kerala

Abstract

Today Ac/dc power supplies find its applications in most of the appliances such as battery chargers, note book adapters, desktop computers etc. These Ac/dc power supplies should possess features such as high Power factor, improved efficiency, minimum THD and component count. In this paper, a Bridgeless buck Rectifier with Single Inductor is presented which considerably increases the efficiency of conventional buck power factor correction converters by reducing the number of simultaneously conducting semiconductor components. Moreover, the low utilization of the magnetic component in the conventional bridgeless buck rectifier is improved by modified bridgeless buck rectifier with single inductor. Simulation of closed loop controlled bridgeless buck PFC rectifier with two inductors and modified converter is performed in MATLAB software to verify its operation. The performance of the Modified Converter is evaluated on a 1-kHz, 5-W prototype circuit that is designed to produce an Output Voltage of 12 V for battery chargers Applications.

Keywords: *bridgeless converters, Buck converter, magnetic utilization, power factor correction*

I. INTRODUCTION

Today ac-dc power supplies are used in many electrical and electronics applications such as in battery chargers, note book adapters, desktop computers etc. This power supplies should meet certain international standards in order to have required efficiency at different power levels. Designers are continuously looking for opportunities to increase PF, reduce THD count, improve efficiency in this power supplies. Bridgeless power factor correction circuits are one of the solutions to meet all these requirements.

Presently, maintaining high efficiency along the entire line range (90-264V) becomes a challenge for the ac-dc converters that are used for power factor correction. There is also requirement of high power factor and low total harmonic distortion in the current drawn from the utility. Several topologies have been introduced in this aspect for attaining high power factor and low harmonic distortion. The boost topology was the most popularly used topology for power factor correction at the earlier stage. Conventional boost bridge PFC rectifier that comprises of full bridge rectifier followed by a boost converter has high conduction losses due to the simultaneous conduction of three semiconductor devices and hence it has less efficiency [1]. To reduce this loss a bridgeless boost topology which eliminates the use of bridge rectifier was introduced and discussed in [2]-[7].But, bridgeless boost PFC topologies has got the same drawbacks of conventional boost converter such as: high voltage stress, high common mode noise, no inrush current protection and low magnetic utilization. The drawbacks of boost PFC converter can be overcome by implementing buck PFC topology and is proposed in [8]. Several buck topologies with additional analysis and circuit modifications were discussed in [9]-[16].However, conventional buck converter has high conduction loss and line current distortion [10]. To overcome the drawbacks of conventional buck converter, bridgeless buck rectifier with improved low line efficiency is introduced [17].

This paper analyzes the operation of both the bridgeless buck rectifier with two inductor and single inductor. Since bridgeless buck rectifier has its output voltage twice that of a conventional buck rectifier, it is designed in such a way that it meets harmonic limit specifications. Moreover switching losses of dc/dc output stage of bridgeless buck rectifier are effectively lower than that of the boost PFC counterpart [17]. Moreover, bridgeless buck rectifier has improved low line efficiency than the bridgeless boost converter.

Bridgeless buck PFC rectifier employs two back to back connected buck converter each of which conducts during alternative positive and negative half cycles. During a half cycle of line voltage, only one inductor is utilized while the other inductor remains idle. This low utilization of the components results in a serious penalty in terms of power density, weight and cost. However, the utilization can be improved by minimizing the number of components through component integration. So a modified bridgeless buck rectifier is introduced which results in better magnetic component utilization by replacing two inductors in the bridgeless buck PFC rectifier with a single inductor. Hence, modified bridgeless buck topology will improve magnetic utilization and hence can save cost.

II. OPERATION OF BRIDGELESS BUCK RECTIFIER

The circuit of bridgeless buck rectifier is shown in fig.1. This circuit employs two back to back connected buck converter that operates in alternative positive and negative half cycles of line voltage. During positive half cycle the upper buck converter comprising of diode D1, switch S1,

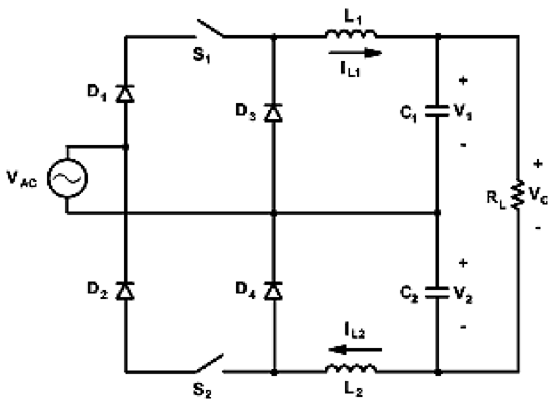


Fig.1 Bridgeless buck PFC rectifier [17]

inductor L1, capacitor C1 and freewheeling diode D3 is operating. When switch S1 is on, the inductor L1 stores energy and the current path is through diode D1,switch S1,inductor L1,capacitor C1.When the switch S1 is off the current freewheels through the diode D3 thus releasing the energy stored in inductor L1.The voltage across the capacitor is regulated by the pulse width modulation of switch S1.

During negative half cycle the lower buck converter comprising of switch S2, diode D2,inductor L2,capacitor C2 and the freewheeling diode D4 operates. When the switch S2 is on the inductor L2 stores energy and when the switch is off, the energy is discharged through the freewheeling diode D4. The output voltage of each buck converter is available across the capacitors. The direction of load current in both the output capacitors is in the same direction, thus the output voltage obtained across the load resistor is twice the voltage obtained at any of the buck converter. Thus the bridgeless buck rectifier satisfies the relationship:

$$V_o = 2DV_{in} \qquad (1)$$

Thus the output voltage obtained across output capacitors is the sum of voltages across capacitors C1 and C2. Hence, the output voltage of the bridgeless buck rectifier is twice that of the conventional buck PFC rectifier.

III. MODIFIED BRIDGELESS BUCK RECTIFIER WITH SINGLE INDUCTOR

Bridgeless buck PFC rectifier employs two back to back connected buck converter each of which conducts during alternative positive and negative half cycles. During one half cycle of ac supply voltage, only one inductor is utilized while the other inductor remains idle. This low utilization of the components results in a serious penalty in terms of power density, weight and cost. However, the utilization can be improved by minimizing the number of components through component integration. So a modified bridgeless buck rectifier is introduced which results in better magnetic component utilization by replacing two inductors in the bridgeless buck PFC rectifier with a single inductor.

A. Operation of the Bridgeless buck rectifier with single inductor

Operation of the modified circuit is same as that of the bridgeless buck rectifier with two inductor. Modified bridgeless buck rectifier with single inductor is shown in fig.2

During positive half cycle the upper buck converter comprising of diode D1,switch S1,inductor L, capacitor C1 and freewheeling diode D3 is operating. When switch S1 is on, the inductor L1 stores energy and when the switch S1 is off the current freewheels through the diode D3 thus releasing the energy stored in inductor L. The voltage across the capacitor C1 is regulated by the pulse width modulation of switch S1.Operation of the upper buck converter during positive half cycle is shown in fig.3. During negative half cycle the lower buck converter comprising of switch S2, diode D2,inductor L2,capacitor C2 and the freewheeling diode D3 operates. When the switch S2 is on the inductor L stores energy and when the switch is off, the energy is discharged through the freewheeling diode D4.The voltage across C2 is regulated by pulse width modulation of switch S2.Operation of the lower buck converter during negative half cycle is shown in fig.4.

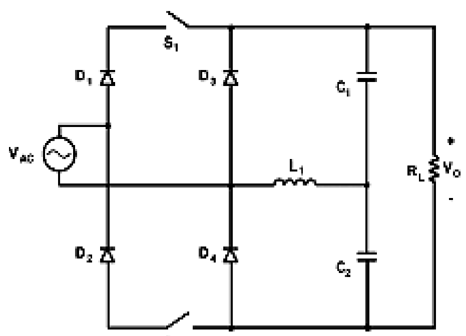


Fig.2 Bridgeless buck rectifier with single inductor [17]

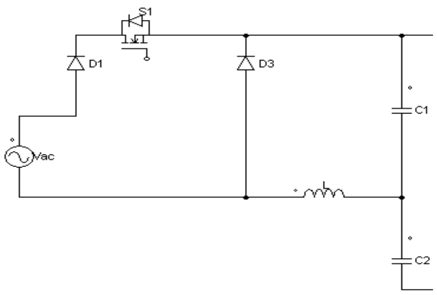


Fig.3 Operation of the bridgeless buck rectifier with single inductor during positive half cycle

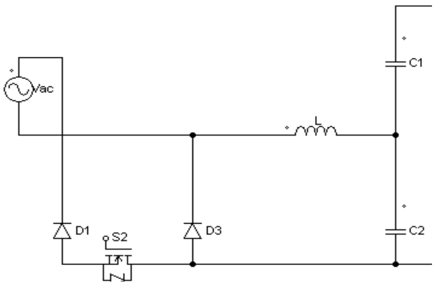


Fig.4 Operation of the bridgeless buck rectifier with single inductor during negative half cycle

Modified bridgeless buck rectifier with single inductor has the same voltage conversion ratio as the bridgeless buck rectifier. However, the modified circuit has high dv/dt across the inductor as it conducts during both the half cycles.

B. Control Strategy

The control strategy employed in bridgeless buck rectifier for its successful operation is the PWM control. PWM control can be of voltage mode control and current mode control for switching mode power supplies. To verify the line voltage regulation and load regulation of the bridgeless buck rectifier and modified Converter, closed loop control is performed. Here the conventional bridgeless buck rectifier employs voltage mode control to achieve line and load regulation. By adjusting the proportional and integral gain of PI Controller voltage regulation is obtained

In Voltage mode control method, Output voltage is regulated at a constant value by comparing the sensed output voltage V_o with the reference voltage using an error amplifier. The amplified output voltage is then given to a PI controller for improving the stability of the system by controlling the gain of the controller. Then the control voltage output from the PI Controller is then compared with a Ramp signal using a Comparator to produce the gating signals for the two switches S1 and S2. The PWM controller is controlled in such a way that upper switch S1 conducts only during positive half cycle of line voltage and the lower switch S2 only during negative half cycle of line voltage.

IV. DESIGN OF MODIFIED CONVERTER

As the input to the modified converter is an Ac voltage V_{ac}, we have to calculate the rectified ac input voltage Vac for calculation of voltage conversion ratio. The Voltage conversion ratio of bridgeless buck rectifier with single inductor is $V_o = 2DV_{in}$. Value of load resistance is calculated from the desired output power level and output voltage level. Then the value of load current can be calculated as shown below:

$$I_o = \frac{V_o}{R} \quad (2)$$

We can choose the value of Inductor ripple current arbitrarily and the value chosen should be low as possible. From the Inductor ripple current value we can calculate the value of Inductance as given below.

$$L = \frac{V_1(1-D)}{\Delta IL_1 * fs} \quad (3)$$

Capacitance value of the output capacitor is chosen in such a way that it produce 1% voltage ripple in dc output voltage.

$$C_1 = C_2 \frac{(1-D)*Vo}{8*Fs^2*L*\Delta Vo} \quad (4)$$

V.Table I- Converter Parameters

Specification	Rating
Output Power(Po)	5W
Output voltage(Vo)	12V
Switching frequency(Fs)	1KHZ
Input voltage(Vin)	(14-30)Vrms
Inductor, (L)	9mH
Output capacitor(C1=C2)	1000μF

Circuit parameters of the modified bridgeless buck rectifier with single inductor are shown in Table I.

VI. SIMULATION RESULTS

Simulation of both the bridgeless buck rectifier and modified circuit with single inductor is performed in MATLAB software at low power level to compare and verify its operation with the experimental setup of the modified converter. The controlled switch implemented is the power MOSFET with its inherently slow body diode. In this simulation, MOSFETs and diodes are assumed as ideal devices and the other parameters of the power stage are the same as design specifications. The gating signals for the switches are shown in fig.5.

Gating signals for switch S1 is produced only during positive half cycle of line voltage. Gating signals for switch S2 is produced only during negative half cycle of line voltage. Circuit parameters for the modified bridgeless buck rectifier are as follows: L=9mH, C1=C2=1000µF

To verify the line voltage regulation and load regulation of the bridgeless buck rectifier and modified circuit with single inductor, closed loop control is performed. Both the conventional bridgeless buck rectifier and modified circuit employ voltage mode control to achieve power factor correction, line and load regulation.

In closed loop control of both the bridgeless buck rectifier and modified circuit with single inductor, the two input voltage conditions applied are 14Vrms and 30Vrms and the load resistance conditions applied are 28.8Ω and 57.60Ω. In all these cases of input voltage and load resistances, corresponding output voltage is kept constant at a value of 12V .Fig.6a-6b shows the line regulation waveforms obtained for the conventional bridgeless buck rectifier.

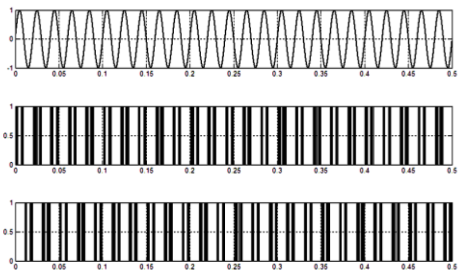
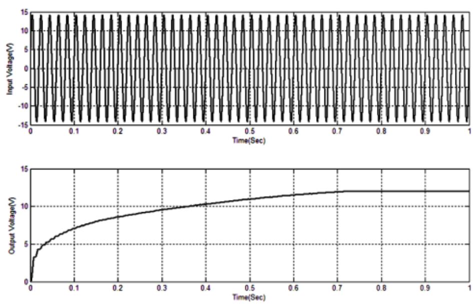


Fig.5 PWM for switches S1&S2



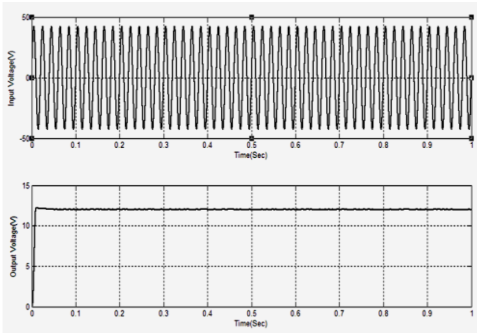


Fig.6a DC Output voltage waveform at 14 Vrms line voltage

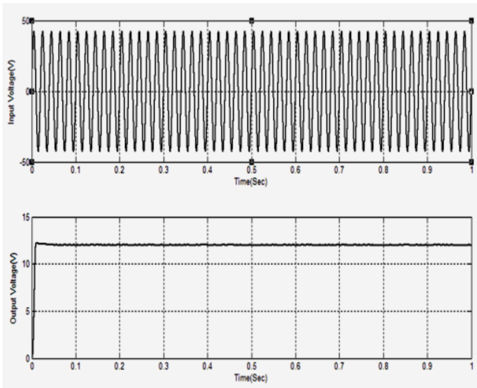


Fig.6b DC Output voltage waveform at 30 Vrms line voltage

Fig.6c-6d shows the load regulation waveforms obtained for the conventional bridgeless buck rectifier. Input voltage and input current waveforms of conventional bridgeless buck rectifier is shown in fig.7. FFT analysis of conventional bridgeless buck rectifier is shown in fig.8 and a THD of 26.05% is obtained.

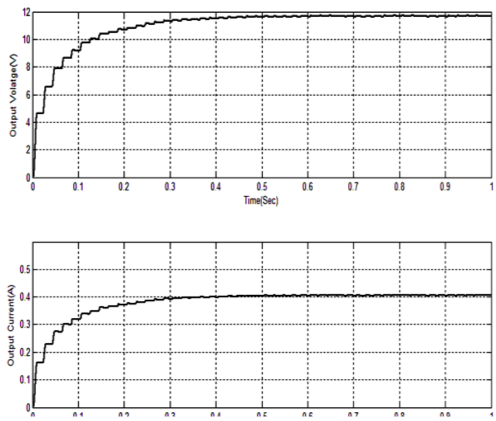


Fig.6c Dc output voltage and dc output current when Ro =28.8Ω

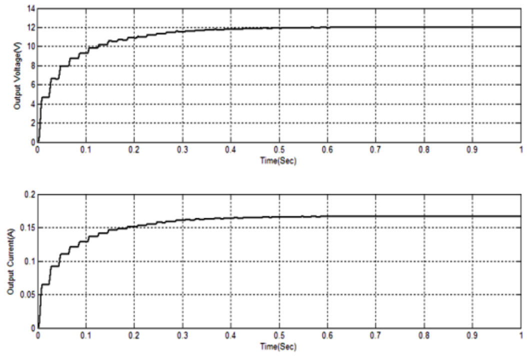


Fig.6d Dc output voltage and dc output current when Ro =57.60Ω

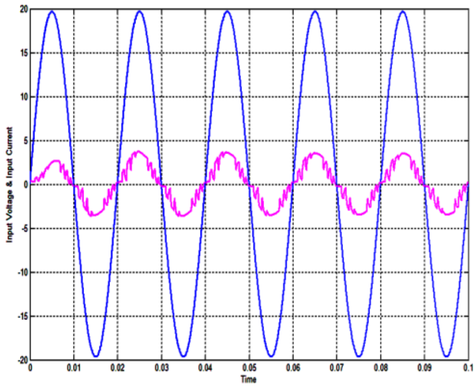


Fig. 7 Input voltage and input current waveforms of conventional bridgeless buck rectifier

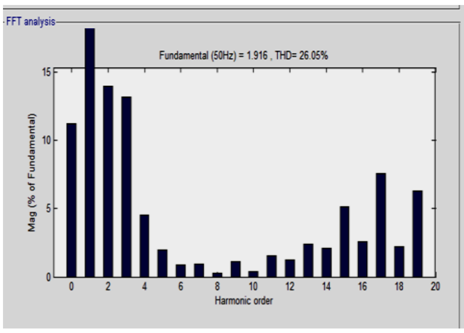


Fig.8 FFT analysis of conventional bridgeless buck rectifier

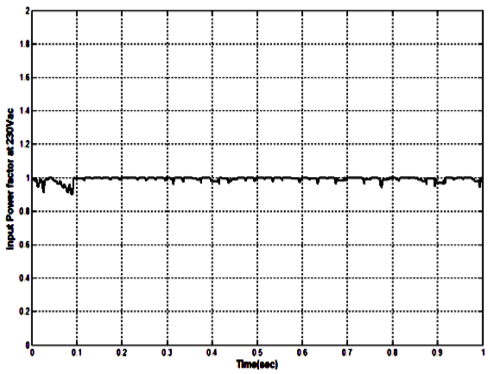


Fig.9 Input power factor waveform of conventional bridgeless buck rectifier

Input power factor waveform of conventional bridgeless buck rectifier is shown in fig.9 and input power factor of 0.87 is obtained. This low power factor of the conventional converter is due to the harmonic distortion in the Input current waveform.

Simulation of Modified converter is done at low power level in MATLAB software to verify and comparison its operation with the simulation results of conventional bridgeless buck rectifier and to validate the experimental results obtained for the Modified Converter.

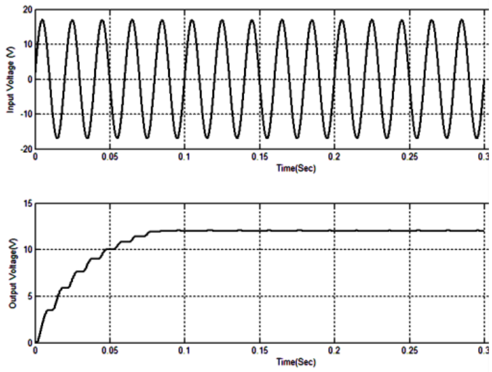


Fig.10a DC Output voltage waveform at 14 Vrms line voltage for the modified converter

Gate signals applied to the two Mosfet switches of the modified converter is the same as in fig.5. Fig.10a & Fig.10b shows the line regulation waveforms obtained for the Modified converter for input voltages of 14Vrms and 30Vrms respectively. In both these cases of input voltages, output dc voltage is maintained constant at 12V.

Fig.10c-10d shows the load regulation waveforms obtained for the modified converter. Input voltage and input current waveforms of modified bridgeless buck rectifier with single inductor is shown in fig.11.

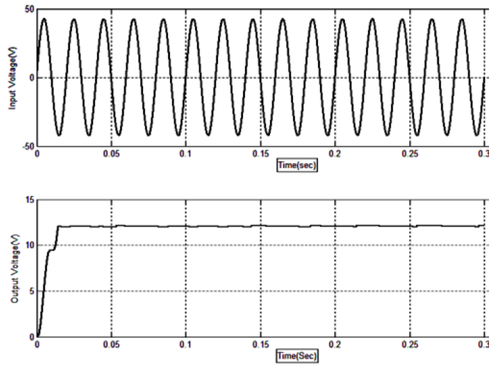


Fig.10b DC Output voltage waveform at 30 Vrms line voltage for the modified converter

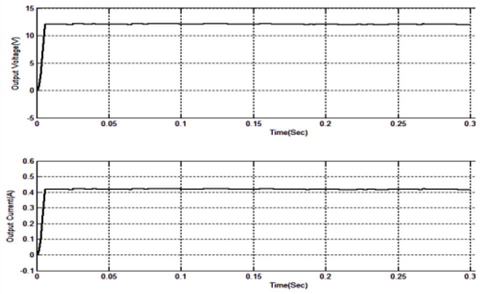


Fig.10c Dc output voltage and dc output current when Ro =28.8Ω for the modified converter

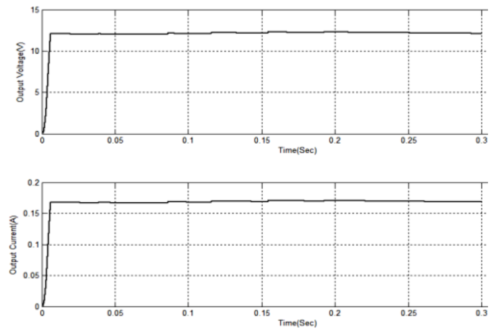


Fig.10d Dc output voltage and dc output current when Ro =57.60Ω for the modified converter

From Fig.11 we can see that the Input voltage and Input current waveforms of modified converter with Single Inductor is in phase to each other and it has only negligible didtortion in the Input current waveform compared to the input current current waveform of the Conventional Bridgeless Buck Rectifier with Two Inductor.

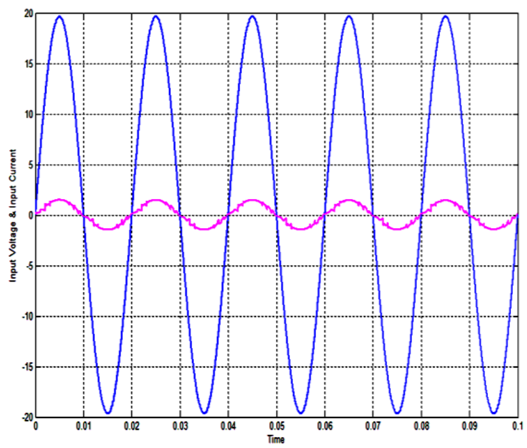


Fig. 11 Input voltage and input current waveform of bridgeless buck rectifier with single inductor

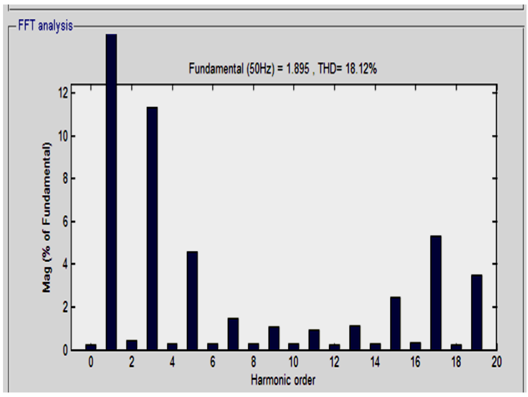


Fig.12 FFT analysis waveform of bridgeless buck rectifier with single inductor

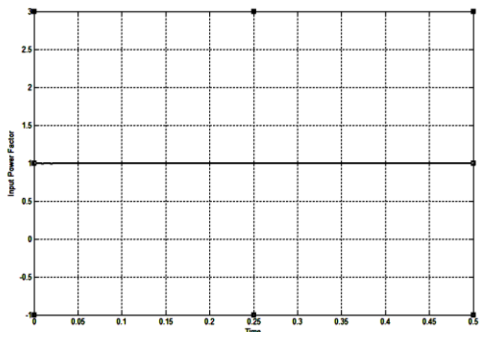


Fig.13 Input power factor waveform of bridgeless buck rectifier with single inductor

FFT analysis of bridgeless buck rectifier with single inductor is shown in fig.12 and a THD of 18.12% is obtained.

Input power factor waveform of bridgeless buck rectifier with single inductor is shown in fig.13 and an improved input power factor of 0.94 is obtained.

From the simulation results, we can see that better line and load regulation is obtained for the modified bridgeless buck rectifier with single inductor when compared to the conventional bridgeless buck PFC rectifier. Input power factor of modified bridgeless buck rectifier with single inductor is improved to 0.94 and THD is reduced to 18.12% when compared to the Conventional bridgeless buck rectifier.

VII. HARWARE SET-UP & RESULTS

A prototype of the Modified Converter is designed and experimentally demonstrated in the laboratory. The performance of the Modified Converter is evaluated on a 1-kHz, 5-W prototype circuit that is designed to produce an Output Voltage of 12 V for battery chargers Applications. The experimental prototype circuit is designed as per the design specifications as given in Table I.

Fig.14 shows the experimental setup of the Bridgeless buck Rectifier with single Inductor used for experiments in the laboratory to validate the results.

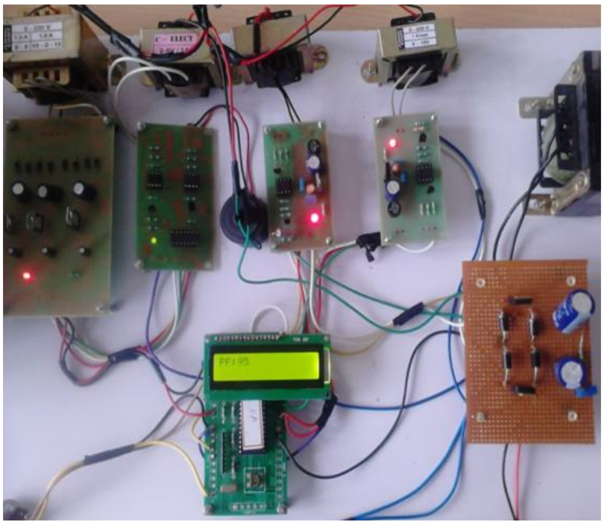


Fig.14 Hardware set-up of the Bridgeless Buck Rectifier with Single Inductor

Details of components used for experimental set up are given in Table. II

VIII. Table II- Hardware Design

Components	Specifications
Inductor, L	9 mH
Capacitors, C_1, C_2	1000 µF
Power MOSFET, S_1, S_2	IRF 840
Diodes, D_1, D_2, D_3, D_4	UF 5408
Controller IC	PIC16F877a
Voltage Regulators	LM7805, LM7812
Mosfet Driver IC	6N137

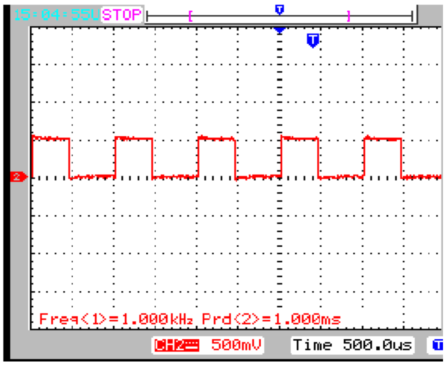


Fig.15 PWM pulse to switches

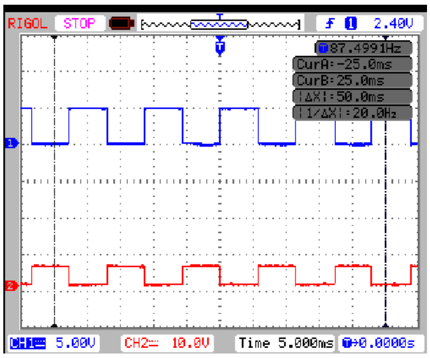


Fig.16 Voltage across switches S1 and S2

Fig.15 shows the PWM pulse obtained from the PIC microcontroller for driving the MOSFET switches. The PWM pulse obtained has a time period of 1ms which corresponds to a switching frequency of 1Khz.

Fig.16 shows the measured voltage waveforms across switches S1 and S2 with a duty cycle of 48%. The PIC microcontroller is programmed in such a way that the inverting pulses is obtained, hence upper switch operates only during positive half cycle and the lower switch during negative half cycle.

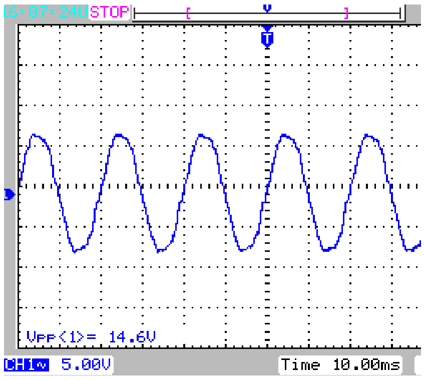


Fig.17(a)

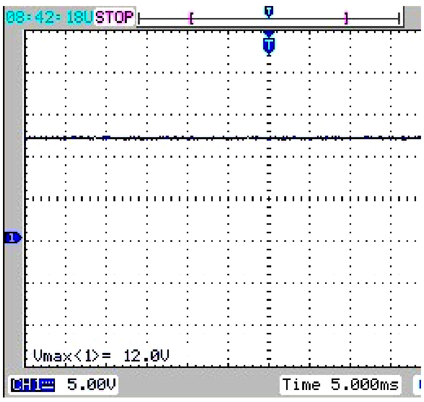


Fig. 17(b)

Fig. 17(a) Input ac voltage waveform of Vac=14Vrms.(b) Corresponding 12V DC Output voltage

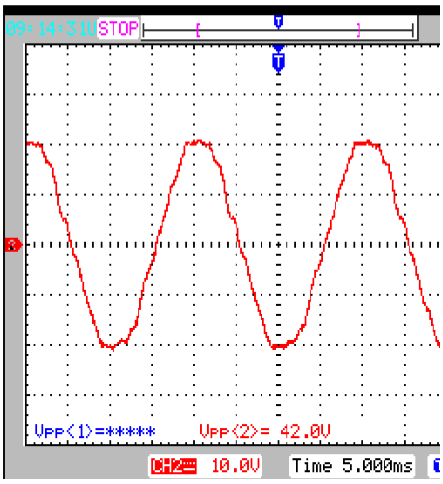


Fig. 18(a)

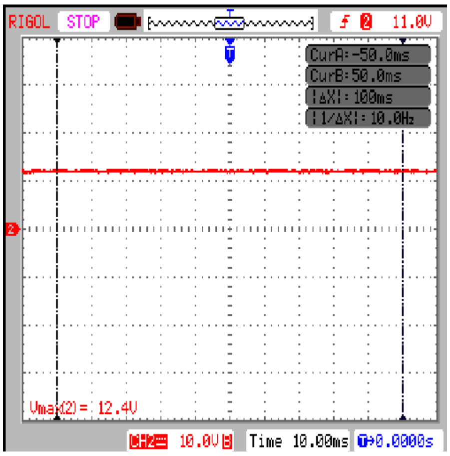


Fig. 18(b)

Fig. 18(a) Input ac voltage waveform of Vac=14Vrms.(b) Corresponding 12V DC Output voltage

Fig. 17(a)-(b) and Fig. 18(a)-(b) shows the measured Ac input voltage and Dc Output voltage waveform of the Closed loop hardware set-up for an Input voltage of Vac = 14Vrms and 30Vrms respectively. In both these cases of Input voltages, Output voltage is maintained constant at 12V and better line line regulation is obtained for the Modified Converter with Single Inductor.

Input power factor of the modified converter is measured using a power factor measuring circuit which monitors the power line voltage and current through the potential and current transformer respectively. Then the measured input voltage and input current is given to a Zero crossing detector circuit. The Zero Crossing Detector is used to convert the sine wave to square wave signal.

Then the both ZCD's outputs are given to logical XOR gate 74LS86 to find the phase angle difference between the voltage and current. The XOR gate output is given to microcontroller or PC and calculates the power factor with help of software.

Hence an input power factor 0.95 is obtained for the Modified converter and it is displayed in the LCD display as shown in Fig.14.

IX. CONCLUSION

In this paper analysis and design of bridgeless buck rectifier and modified bridgeless buck rectifier with single inductor is presented. With the simulation results obtained in MATLAB software a comparison between the conventional bridgeless buck rectifier with two Inductors and modified converter with Single Inductor is performed. The results show that the modified converter has better voltage regulation and power factor than the conventional converter. Moreover, as the modified converter employs only one Inductor compared to the conventional converter, it has Improved the overall utilization of the Inductor during each half cycles compared to the conventional converter and also it has reduced weight and cost than the conventional converter. These Features make the modified converter suitable for portable batter chargers applications.

REFERENCES

[1] D. M. Mitchell, "AC-DC converter having an improved power factor," U.S. Patent 4 412 277, Oct. 25, 1983

[2] J. C. Salmon, "Circuit topologies for single-phase voltage-doubler boost rectifiers," in Proc. IEEE Applied Power Electronics Conf., Mar.1992, pp. 549–556

[3] L. Huber, Yungtaek Jang ,et al., "Performance Evaluation of Bridgeless PFC Boost Rectifiers," IEEE Trans. on Power Electron., Vol. 23, No. 3, pp. 1381-1390, May. 2008.

[4] Yungtaek Jang and M. M. Jovanovic, "A Bridgeless PFC Boost Rectifier with Optimized Magnetic Utilization," IEEE Trans. on Power Electron., Vol. 24, No. 1, pp. 85-93 Jan. 2009.

[5] Dylan Chuan Lu and W. Wang ," Bridgeless power factor correction circuits with voltage-doubler configuration", IEEE. spec. conf. Power Electronics and drive systems, Dec 2011.

[6] W.Y.Choi, J.M. Kwon, E.-H.Kim, J.J. Lee, and B.-H. Kwon, "Bridgeless boost rectifier with low conduction losses and reduced diode reverse-recovery problems," IEEE Trans. Ind. Electron., vol. 54, no. 2, pp. 769–780, Apr. 2007

[7] Y. Chen and W.P.Dai," Classification and comparison of BPFC Techniques: A review", PRZEGLAD ELEKTROTECHNI-CZNY, ISSN 0033-2097,2013.

[8] H. Endo, T. Yamashita, and T. Sugiura, "A high-power-factor buck converter," in Proc.IEEE Power Electron, Spec. Conf. (PESC) Rec., Jun.1992, pp. 1071–1076.

[9] L. Huber, L. Gang, and M. M. Jovanovic, "Design-Oriented analysis and performance evaluation of buck PFC front-end," IEEE Trans. Power Electron., vol. 25, no. 1, pp. 85–94, Jan. 2010.

[10] G.Spiazzi, "Analysis of buck converters used as power factor pre-regulators," in Proc. IEEE Power Electron. Spec. Conf. (PESC) Rec., Jun. 1997, pp. 564–570.

[11] C. Bing, X. Yun-Xiang, H. Feng, and C. Jiang-Hui, "A novel single-phase buck pfc converter based on one-cycle control," in Proc. CES/IEEE Int. Power Electron Motion control(IPEMC),2006.

[12] V. Grigore and J. Kyyr¨ a, "High power factor rectifier based on buck converter operating in discontinuous capacitor voltage mode," IEEE Trans.Power Electron., vol. 15, no. 6, pp. 1241–1249, Nov. 2000.

[13] W. W. Weaver and P. T. Krein, "Analysis and applications of a current-sourced buck converter," in Proc. IEEE Appl. Power Electron. Conf.(APEC), Feb. 2007.

[14] Y.S.Lee, S. J.Wang, and S.Y.R.Hui, "Modeling, analysis, and application of buck converters in discontinuous-input-voltage mode operation," IEEE Trans. Power Electron., vol. 12, no. 2, pp. 350–360, Mar. 1997.

[15] R. Redl and L. Balogh, "RMS, dc, peak, and harmonic currents in high frequency power-factor correctors with capacitive energy storage," in Proc. IEEE Appl. Power Electron. Conf. (APEC), Feb. 1992, pp. 533–540.

[16] Y. W. Lo and R. J. King, "High performance ripple feedback for the buck unity-power-factor rectifier,"IEEE Trans. Power Electron., vol. 10, no. 2,pp. 158–163, Mar. 1995

[17] Y. Jang and Milan M. Jovanovic " Bridgeless High-Power-Factor Buck Converter" IEEE Trans, power electronics, vol. 26, no. 2, Feb 2011.

[18] J.C. Salmon, "Techniques for Minimizing the Input Current Distortion of Current-Controlled Single-Phase Boost Rectifiers," IEEE Trans. on Power Electronics, Vol. 8, Issue 4, pp. 509-520, Oct. 1993

[19] D. Maksimovi´ c, "Design of the clamped-current high-power-factor boost rectifier," IEEE Trans. Ind. Appl., vol. 31, no. 5, pp. 986–992, Sep./Oct.1995.

[20] R. Redl, A. S. Kislovski, and B. P. Erisman, "Input-current-clamping: An inexpensive novel control technique to achieve compliance with harmonic regulations," in Proc. IEEE Appl. Power Electron. Conf. (APEC),Mar.1996, pp. 145–151.

[21] L. Huber and M. M. Jovanovi´ c, "Design-oriented analysis and performance evaluation of clamped-current-boost input-current shaper for universal-input-voltage range," IEEE Trans. Power Electron., vol. 13,no. 3, pp. 528–537, May 1998.

[22] R. D. Middlebrook, "Topics in multiple-loop regulators and current-mode programming," IEEE Trans. Power Electron., vol. PE-2, no. 2, pp. 109–124, Apr. 1987.

[23] G. C. Verghese, C. A. Bruzos, and K. N. Mahabir, "Averaged and sampled data models for current mode control: A re-examination," in Proc. IEEE Power Electron. Spec. Conf. (PESC), 1989, pp. 484–491.