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Buck Bridgeless PFC Rectifier with Less Semiconductor Count

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Abstract:- In recent years AC-DC converters have found wide applications in industry.AC-DC converters with step down voltage are required in to be used in many applications from simple home appliances to complex industrial facilities with applications such as LED drivers, dc motor drivers, battery chargers and dc power supplies. Therefore, it is generally required that the ACDC conversion includes some form of power factor correction (PFC) so as to mitigate harmonic pollution of the grid voltage. It also requires a circuit with less number of passive elements to increase the efficiency. A Buck Bridgeless power factor correction converter with low semiconductor count is studied and analysed. The rectifier employs reduced number of semiconductor devices. Two parallel capacitors provide a path for the input current during the discharge mode to improve the current quality. Comparing with the other rectifiers this buck PFC rectifier has characteristics of high gain, high efficiency, low semiconductor devices and have few power loss. The operation principles and steady-state characteristics analysis of the rectifier is discussed in detail. Results are obtained by simulating the rectifier in MATLAB/SIMULINK R2021b. The simulation results shows that the rectifier has high voltage gain and achieves a peak efficiency of 89%. Index Terms—Buck Converter, Bridgeless, Gain, Efficiency.

I. INTRODUCTION

Ac to dc converters are widely utilised in many applications from simple home appliances to complex industrial facilities with applications such as battery chargers, and dc power supplies. For distributed power-level applications, the ac-to-dc conversion includes some form of power factor correction (PFC) so as to mitigate harmonic pollution of the grid voltage. One of the most common ways of implementing this is the use of a dc-to-dc converter after the conventional diode bridge rectifier to shape the grid-side current and regulate the dc output voltage. A family of bridgeless PFC topologies have been developed. In Bridgeless PFC rectifiers , at least two diodes are conducting and operating simultaneously, which generates unnecessary power losses, thus impacting efficiency and quality.

As a following approach to improve the current quality of the buck-type PFC rectifiers, an auxiliary converter which operates during the dead zones of the input current instead of the main converter. These auxiliary converters are mainly based on the buck-boost and fly back converters, which successfully improve the power factor . However, the aforementioned techniques incur a recognizable distortion on the input current waveform at the instant of changing the operating converter. In addition, many components are needed for these rectifiers leading to a low efficiency and a high cost. Therefore, these rectifiers cannot be applicable in those applications, where the buck capability and the high-quality input current and also the buck type rectifiers also need an additional input LC filter to reduce the total harmonic distortion (THD) and improve the PF of the current drawn from the input ac source [7][8]. In addition to these circuits, the application of the well-known Cuk and Sepic converters are widely discussed as the PFC rectifiers, which inherently offer voltage buck-boost capability and a continuous input current waveform [5][12] at the cost of a high number of passive components. As an overall conclusion, the aforementioned topologies mainly suffer from a high number of components, comparably high power losses and a low input current quality, which higher costs and increased converter volume are incurred to solve these issues, respectively.

In order to eliminate high number of components, comparably high power losses and a low input current quality and total harmonic distortion a Buck Bridgeless PFC rectifier with low semiconductor count is proposed. The proposed rectifier employs a low number of semiconductors to reduce the total size of the converter devices in the current conduction path compared to the conventional buck PFC and provide advantages in terms of efficiency, quality, costs, power density, and size. Utilizing the MOSFETs lets increase the switching frequency to reduce the passive components size. .Considering the aforementioned features along with the ability to operate with the maximum of two semiconductors conducting during any operation mode, the highly efficient operation of the proposed rectifier is guaranteed. As a clear contribution, it can be claimed that the proposed rectifier offers highly sinusoidal input current with a low THD and a closeto unity PF compared to the Cuk and the Sepic-based rectifiers of [5][12] while they can also provide higher efficiencies than the buck-boost-type rectifiers of [10], [7]. Therefore, the proposed rectifier reduces the cost and improves the efficiency.

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II. METHODOLOGY

The modified Buck Bridgeless PFC Rectifier consists of two switches (S1 and S2), two diodes (D1 and D2), three inductors (L1 , L2 and Lf) and three capacitors (C1, C2 and Cf). Figure 1 shows the Modified Buck Bridgeless PFC rectifier with Less semiconductor Count.

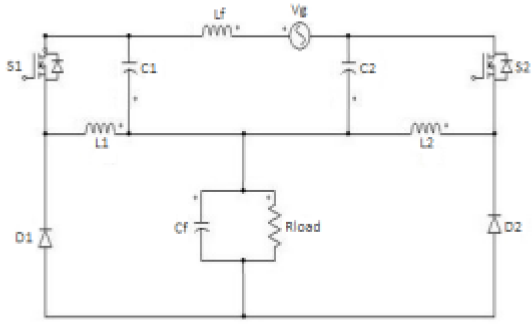

Fig. 1. Buck Bridgeless PFC Rectifier

A. Modes of Operation

The Buck Bridgeless PFC rectifies with positive dc output circuit contains two active switches S1 and S2, two diodes D1 and D2, three inductors Lf ,L1 and L2 and three capacitors C1, C2 and Cf and a load resistor R0.The operation modes are analysed with assuming that the same pulse width modulated gating signal goes to both Mosfets simultaneously. Each mode contains a positive half cycle operation and negative half cycle operation.The positive half cycle operation is disscussed.

- *Mode 1:* In this interval at the positive half-cycle, S1 is turned ON. As a result, the input filter inductor Lf and L1 is charged by the input ac source, . The capacitor C1 is discharged and the stored energy of Cf supplies the dc resistance load, i.e., Rload.Figure 2 shows the operating circuit of mode 1.

- *Mode 2:* In this interval, at the positive half cycle switch S1 is turned OFF. Inductor L1 discharges to output load though Diode D1. The input current flows through capacitor C1 to charge it. The input current doesnot flow through L1. Inductor Lf discharges. Figure 3 shows the operating circuit of mode 2.

- *Mode 3:* In this interval, at positive half cycle the input current flows through capacitor C1 and charges it. Inductor L1 and Lf discharges.The output load is fed by the output filter capacitor Cf .Figure 4 shows the operating circuit of mode 3.

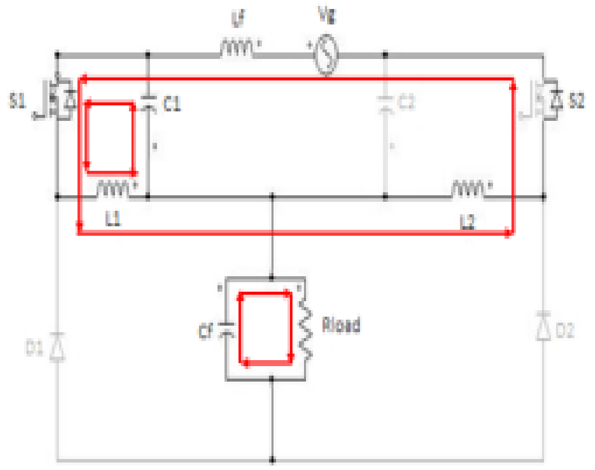

Fig. 2. Operating circuit of of Mode 1

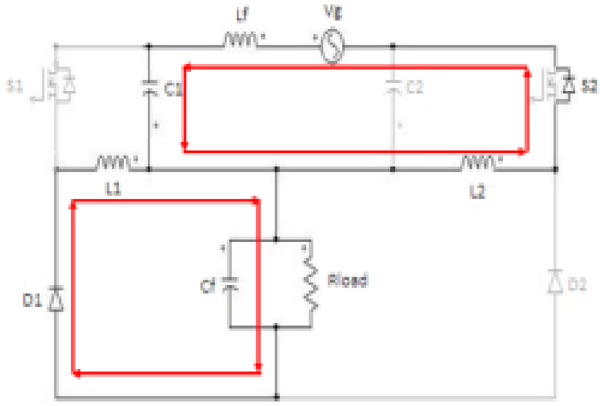

Fig. 3. Operating circuit of of Mode 2

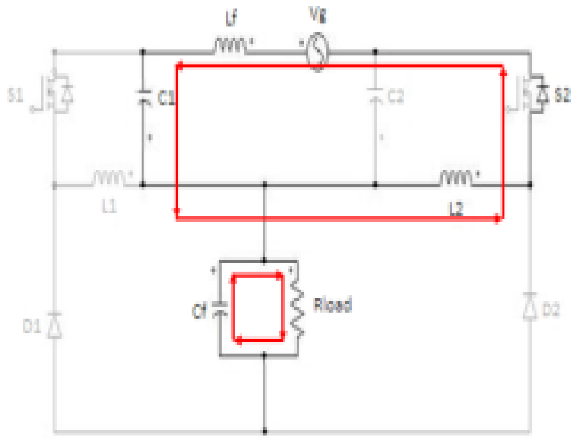

Fig. 4. Operating circuit of of Mode 3

Figure 4 shows the theoretical waveforms for mode 1 and mode 2 and mode 3.

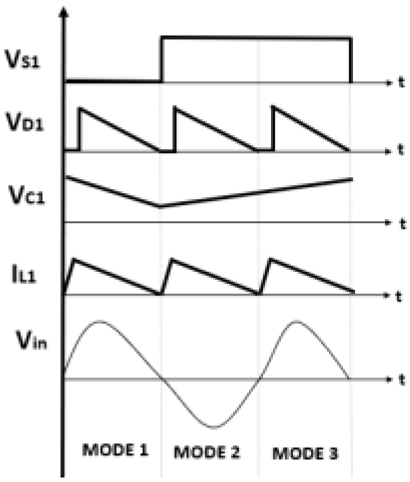

Fig. 5. Theoretical waveform

B. *Design of Components*

The input voltage is taken as Vin = 220V. The output power and output voltage are taken as Po = 500W and Vo = 48V. Switching frequency, fs = 50kHz, so time period, Ts = 1/fs = 0.00002sec.

Load resistance can be found by the equation,

$$R_o = \frac{V_o^{\,2}}{P_o} = \frac{48^2}{500} = 4.60\Omega \qquad (1)$$

Duty ratio,

$$\frac{V_o}{V_{\ in}} = \frac{D}{1-D} = 0.20 \qquad (2)$$

The inductors L1 & L2 are obtained from the following equations.

$$L_1 >= \frac{2f_s}{R_{load}(1-D^2)} - \frac{1}{L_f} = \qquad (3)$$

\

$$\frac{2*50}{4.6*(1-0.25^2)} - \frac{1}{1.5} = 0.08mH \qquad (4)$$

Given that, L1 = L2
So, the value of inductor is set as L1 and L2 = 0.2mH.
Capacitors values are found from the following equations.

$$C_1 >= \frac{1}{(2\pi * f_r)^2 * (L_f + L_1)} = \qquad (5)$$

$$\frac{1}{(2\pi * 29.05 * 10^3)^2 * (1.5+0.2) * 10^{-3}} = 1.7\mu F \qquad (6)$$

Given that, C1 = C2
So, the value of capacitor is set as C1 and C2 = 2.2µF.
Filter Inductor,

$$L_f = \frac{DV_m}{\delta i_{Lf} f_s} = \frac{0.25*155}{0.5*50*10^3} = 1.469mH \qquad (7)$$

So, the value of filter inductance is set as L2 = 1.5mH
Filter Capacitor,

$$C_f = \frac{P_{out}}{2\pi f_g * \delta V_{out} V^2{}_{out}} = \frac{500}{2\pi * 50 * 2.8 * 48^2} = 2.19F \qquad (8)$$

So, the value of filter capacitance is set as L2 = 20000µF

III. SIMULATIONS AND RESULTS

The Buck Bridgeless PFC Rectifier is simulated in MATLAB/SIMULINK by choosing the parameters listed in Table 1. The switch is MOSFET with constant switching frequency of 50 kHz. A dc input voltage, Vin of 220V gives

Table 1 Simulation parameters of buck bridgeless pfc rectifier

Parameters	Value
AC input voltage, V_{in}	220 V
DC output voltage, V_o	48 V
Switching frequency, f_s	50 kHz
Rated power, P_o	500 W
Inductor L_1 , L_2	0.2mH
capacitor C_1 , C_2	2.2µF
Filter inductance, L_f	1.5 mH
Filter capacitor, C_{out}	20000 µF

a dc output voltage, Vo of 48V dc for an output power, Po of 500W. Fig. 5 shows the input voltage and current, Fig. 6 shows the output voltage and current . Thus, the voltage gain is obtained as 3.2.

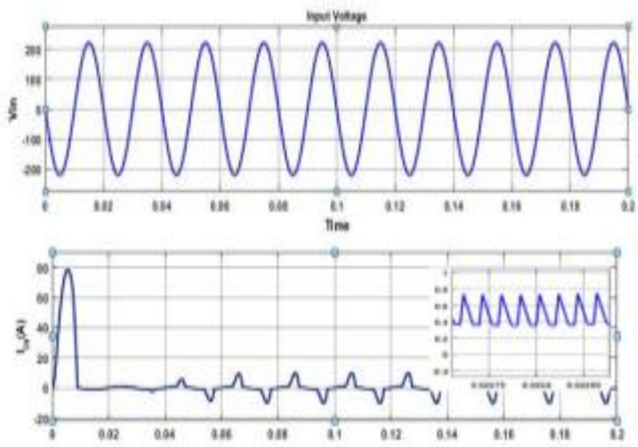

Fig. 6. (a) Input Voltage (Vin) and (b) Input Current (iin/iL1

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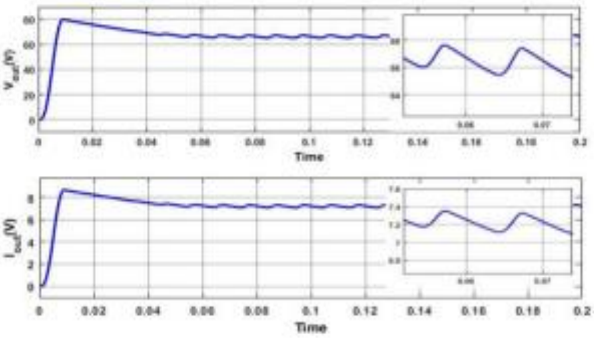

Fig. 7. (a) Output Voltage (V0) and (b) Output Current (I0)

Fig. 8 and Fig.9 shows the gate pulse and voltage stress across the switch. Voltage stress across the switch is 63.49 V and 84.03V for switch 1 and switch 2 respectively

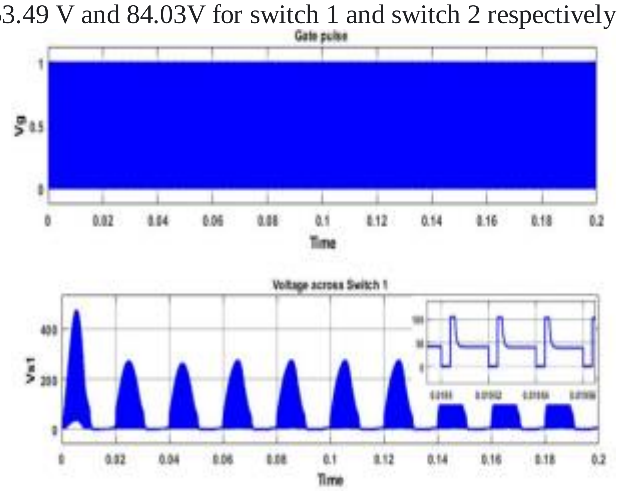

Fig. 8. (a) Gate pulse to S1 (Vg1) and (b)Voltage Stress to S1(VS1)

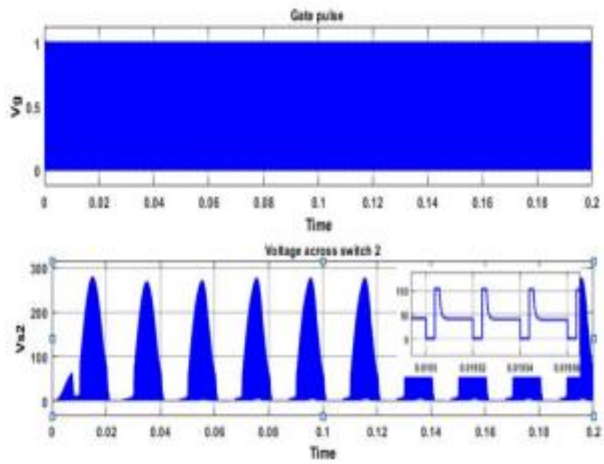

Fig. 9. (a) Gate pulse to S2 (Vg2) and (b)Voltage Stress to S2(VS2)

The voltage across capacitors is obtained as VC1 = 163.65 V & VC2 = 147.7 V. which is shown in Fig 10. Fig. 11 shows the current across inductances L1 and L2. It can be seen that the current across inductances iL1 is 8.32A, iL2 is 8.14A.

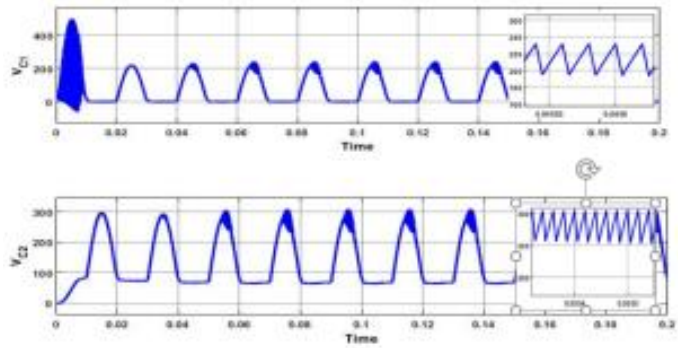

Fig. 10. Voltage across Capacitor (a)VC1, (b)VCZ , (c)VCO, (d)VC2, (e)VC3

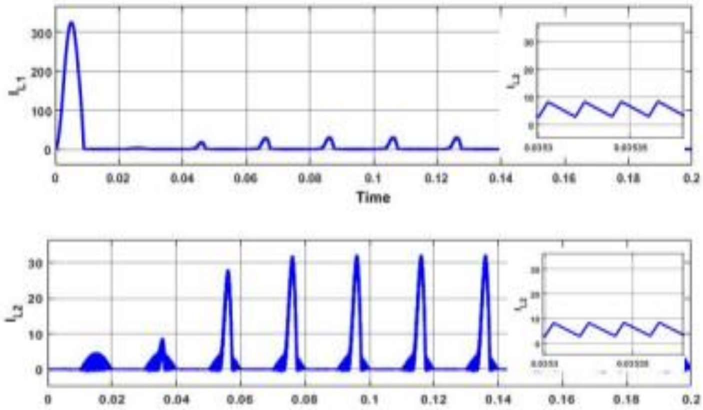

Fig. 11. Current across Inductance (a)iL1, (b)iL2

IV. PERFORMANCE ANALYSIS

Efficiency of a power equipment is defined at any load as the ratio of the power output to the power input. Here the efficiency Vs output power with R load for Buck Bridgeless PFC rectifier is done and shown in Fig. 12. The maximum converter efficiency for R load is obtained as 89% . The variation of efficiency with power output is medium for R load ie about 500 W. Thus, tBuck Bridgeless PFC rectifier can be used in medium power applications.

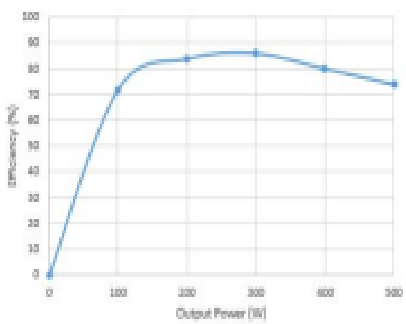

Fig. 12. Efficiency Vs Output Power for R load

The plot of gain of Buck Bridgeless PFC rectifier as a function of duty ratio is shown in figure 13. The gain increases as the duty ratio is varied.

The plot of output voltage ripple as a function of duty Ratio for Buck Bridgeless PFC rectifier is shown in figure 14.

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The plot of output voltage ripple as a function of Switching Frequency for modified boost converter is shown in figure

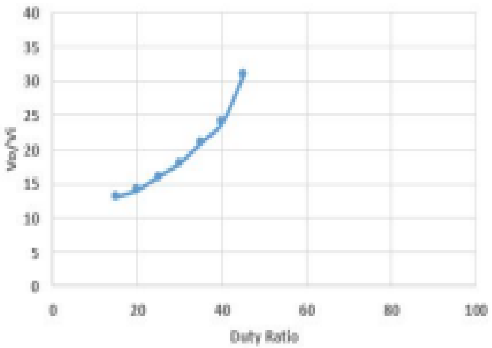

Fig. 13. Voltage gain VS Duty ratio

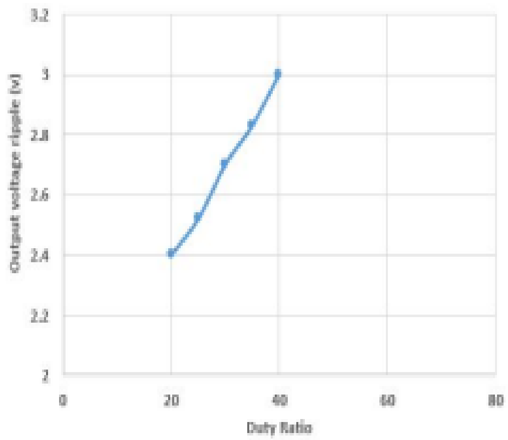

Fig. 14. Output Voltage Ripple VS Duty Ratio

14. The ouptut voltage ripple is decreased as the switching frequency is increased.

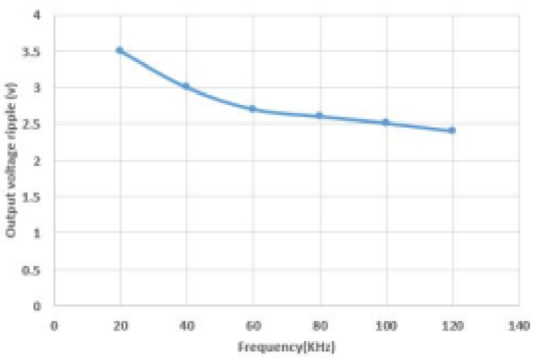

Fig. 15. Output voltage ripple VS frequency

V. COMPARATIVE STUDY

The comparison between a Buck Bridgeless PFC rectifier with same input voltage ans swtching frequency & the proposed Buck Bridgeless PFC rectifier with less semiconductor cout is given in table 2. On the comparison it can be observed that,with same values for input voltage as 220V & switching frequency as 50kHz. the output voltage ripple is reduced from 2.6 to 2.2. But, voltage gain in proposed converter.

Table 2 Comparison between buck-boost common ground bridgeless pfc rectifier & buck bridgeless pfc rectifier with less semiconductor count

Parameters	Buck-Boost common ground bridgeless pfc rectifier	Buck bridgeless pfc rectifier with less semiconductor count
No. of switches	2	2
No. of Inductor	3	3
No. of Capacitor	3	3
No. of Diode	4	2
Voltage gain	0.47	0.45
Output Voltage Ripple	2.6V	2.2V
Output Current Ripple	0.65A	0.65A
Stress across switch	63.69V	63.45V
Input Current	0.026A	0.013A

Table 3 shows the component wise comparison Buck Bridgeless PFC rectifier and other rectifiers. Comparison is based on the components used in the different rectifiers.

Table 3 Comparison between buck bridgeless pfc rectifier with less semiconductor count & other rectifiers

parameters	Conventional buck-boost rectifier	Active clamping buck-boost rectifier	Common ground buck-boost rectifier	Buck pfc rectifier with less semiconductor count
No.of switches	1	2	2	2
No.of inductor	1	2	3	3
No.of capacitor	1	2	3	3
No.of diodes	1	4	4	2

VI. EXPERIMENTAL SETUP WITH RESULT

For the purpose of implementing hardware, the input voltage is reduced to 5V and the switching pulses are generated using TMS320F28335 processor . The switch used is MOSFET IRF3205. Driver circuit is implemented using TLP250H, which is an optocoupler used to isolate and protect the microcontroller from any damage and also to provide required gating to turn on the switches.

Experimental setup of Buck Bridgeless PFC rectifier is shown in Fig. 16. Input 5V with 1.4A DC supply is given from DC source. Switching pulses are taken from TMS320F28335 microcontroller to driver circuit. Thus, an output voltage of 48V is obtained from power circuit that is

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shown in Fig. 17. Output voltage of rectifier is taken from the DSO oscilloscope.

Fig. 16. Experimental Setup

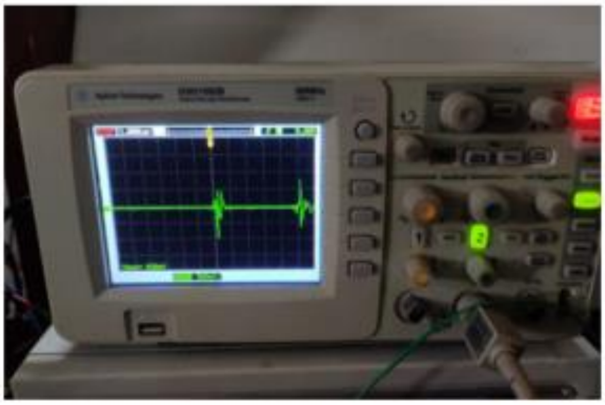

Fig. 17. Output Voltage of Proposed Converter

VII. CONCLUSION

A Buck bridgeless PFC rectifier with low semiconductor count for dc power supply applications are presented. The main advantage of the proposed converter is that it employs the lowest number of semiconductors which results in low power loss. The rectifiers utilize only two MOSFET switches without the reverse recovery problem of their body diodes. In addition,the two parallel capacitors provide a current path for the input current during the discharge mode of the inductors to improve the power quality factor. These converters also achieve a high efficiency, a low number of switches, and good PFC capability. The proposed converter has relatively higher efficiency. The efficiency obtained is nearly 89 %. The control of the proposed converter is implemented using TMS320F28335 microcontroller. Converter prototype of 10W provides the expected performance with an output voltage of nearly 48V, considering the drop across the components. The overall analysis confirms that the proposed rectifier is suitable for medium voltage reducing applications such as renewable energy, microgrid, and uninterruptible power supplies (UPS).

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