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Modified Transformer-Less Single Switch High Voltage Gain Boost Converter

Ijas Mohammed,
PG Scholar Dept of Electrical & Electronics Engg,
Mar Athanasius College of Engineering
Kothamangalam, Kerala

Anu George
Dept of Electrical & Electronics Engg,
Mar Athanasius College of Engineering
Kothamangalam, Kerala

Kavitha Issac
Dept of Electrical & Electronics Engg,
Mar Athanasius College of Engineering
Kothamangalam, Kerala

Geethu James
Dept of Electrical & Electronics Engg,
Mar Athanasius College of Engineering
Kothamangalam, Kerala

Abstract:- The transformer-less single-switch dual-inductor boost converter configuration can realize high voltage gain with low voltage and current stresses; therefore, it is suitable for high gain applications. It has low voltage stress on components compared to other typical transformer-less single-switch high voltage gain converters like switched inductor boost converter, quadratic boost converter and quasi-Z-source boost converter. Moreover, the current stress of the front-end diode and the rear- end inductor is also relatively low. Therefore, the conversion efficiency is enhanced while keeping the cost low. The operation principles and steady-state characteristics analysis of the con- verter is discussed in detail. Results are obtained by simulating the converter in MATLAB/SIMULINK R2021b. The simulation results shows that the converter has high voltage gain and achieves a peak efficiency of 89%. The converter is controlled using TMS320F28335 microcontroller. The experimental results obtained from a 6W converter prototype confirm the theoretical considerations and the simulation results.

Keywords:- *Boost Converter, Transformerless, Gain, Efficiency.*

I. INTRODUCTION

As the global energy demand is escalating, renewable energy systems are becoming more popular as it meet the demand while keeping the environment eco-friendly and sus-tainable [5]. Generally, renewable energy sources such as solar photovoltaic (PV) and fuel-cell produce a low and variable dc output voltage. Thus, dc-dc step-up converters with sufficient voltage gain are usually required to meet the load or gridvoltage requirements [3]. The conventional boost converter is of the most widely adopted converters for step-up applicationsdue to simple structure, continuous input current, ease of control and low cost. Theoretically, the ideal voltage gain of boost converter can tend to infinity; however, the induc- tor winding resistance limits the maximum practical voltage gain. Moreover, the high voltage gain can only be achievedby applying the duty cycle close to one. In this situation,the current stress significantly increases, and the component non-idealities such as semiconductor forward voltage drops and diode reverse recovery lead to significant power losses.

Therefore, the efficiency decreases dramatically at high duty cycle operation [4].

In order to overcome the limitations imposed by the boost converter, several high-gain dc-dc converters utilizing various voltage boosting techniques have been proposed. One groupof the converters is classified as the transformer-less high voltage gain converters. There are many high voltage gain topologies evolved from three typical transformer-less single- switch dual-inductor topologies, including, switched inductor boost converter, quadratic boost converter and quasi-Z-source boost converter. The switched inductor boost converter can realize high voltage gain and is suitable for high step-up applications. However, switched inductor boost converter has several drawbacks, such as more diodes (four) and consider- able input current fluctuation, which can result in noticeable EMI. Moreover, the voltage stress on the power switches is substantially high. The quadratic boost converter is derived bysharing the switches of cascaded boost converters and adding an additional blocking diode. Consequently, its voltage gainis expreby a quadratic function in terms of the voltage gain of conventional boost converter, and it can easily realize high conversion ratio without extremely high duty cycle operation. However, the voltage stress on the switch and the rear-end diode is still equal to the output voltage. In order to realize the high voltage gain, a quasi-Z-source network is integrated into the boost converter. The quasi-Z-source boost converter employs the fewest diodes compared to the quadratic and the switched inductor topologies, but their maximum duty cycle cannot exceed 0.5. Thus, the conversion efficiency is difficult to improve at low duty cycle operation. Also, the voltage gain is sensitive to the change in duty cycle, and the slope of the gain curve is large, which increases the control complexity. Besides, both the inductor and the diode in the quasi-Z-source network suffer from high current stress. Furthermore, the issueof high voltage stress is still retained, which limits the further optimization of efficiency and cost.

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In order to address the aforementioned issues, a transformer- less single-switch dual-inductor high voltage gain boost con- verter is presented. It is constructed by introducing an inter- mediate capacitor CZ with the diode of the conventional boostconverter, and integrating a charging circuit consisting of an inductor, capacitor and diode. Also, a voltage multiplier circuitis introduced between the input and output which increases thevoltage gain. The voltage stress on the switch and the rear-enddiode and the average current stress through rear-end inductor and front-end diode are significantly reduced compared toother typical dual-inductor high-gain boost converters. There- fore, the proposed converter reduces the cost and improves thevoltage gain.

II. METHODOLOGY

The modified transformer-less high gain boost converterconsists of single switch (S), four diodes (D1, D2, D3 and D4), two inductors (L1 and L2) and five capacitors (C1, CZ, C2, C3 and Co). Figure 3.6 shows the Modified transformer- less high gain boost converter.

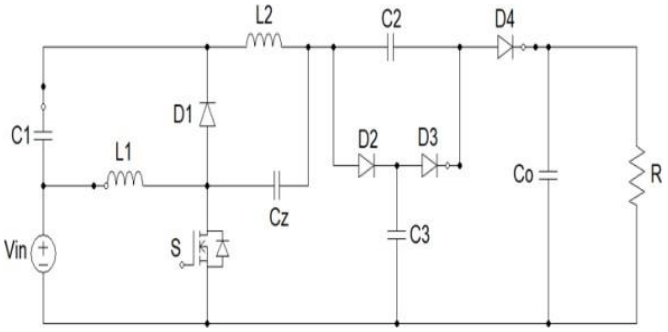

Fig 1:- Transformer-less Boost Converter

A. *Modes of Operation*

The proposed boost converter has two main operation modes: Continous conduction mode (CCM) and Continous bidirectional conduction mode (CBCM). In both modes, the input inductor current iL1 continuously flows in one direction.The difference between the operation in CCM and CBCM is that the rear-inductor current iL2 flows continuously in a unidirectional and bidirectional fashion in CCM and CBCM, respectively.

1) *Mode 1:* At t = t0, when switch S is turned ON, diodes D1, D2 and D4 are reversed biased. The input inductor L1is being charged by the input voltage source Vin, while the rear-end inductor L2 and the intermediate capacitor CZ are charged by C1 and Vin. C3 charges C2 and CZ Therefore, the output filter capacitor Co delivers energy to the load. Figure2 shows operating circuit of mode 1.

Mode 2: At t = t1, when switch S is turned OFF, diodes D1 and D2 conduct and become forward biased. A part of the energy stored in L1 transfer to C1 and the remaining goes to Co and load. The stored energy in L2 directly transfers to the output side. The intermediate capacitor CZ discharges in this state. Figure 3 shows the operating circuit of mode 2.

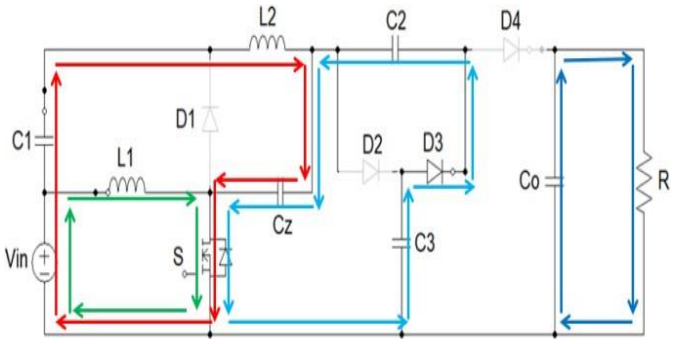

Fig 2:- Operating circuit of of Mode 1

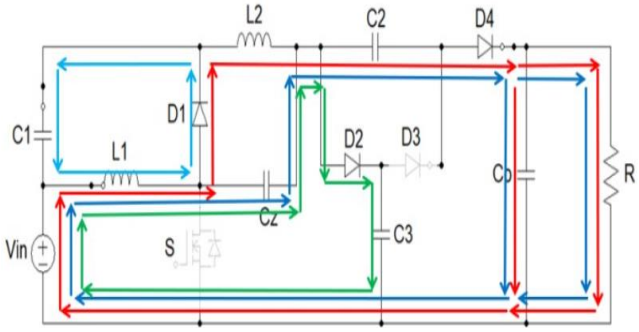

Fig 3:- Operating circuit of of Mode 2

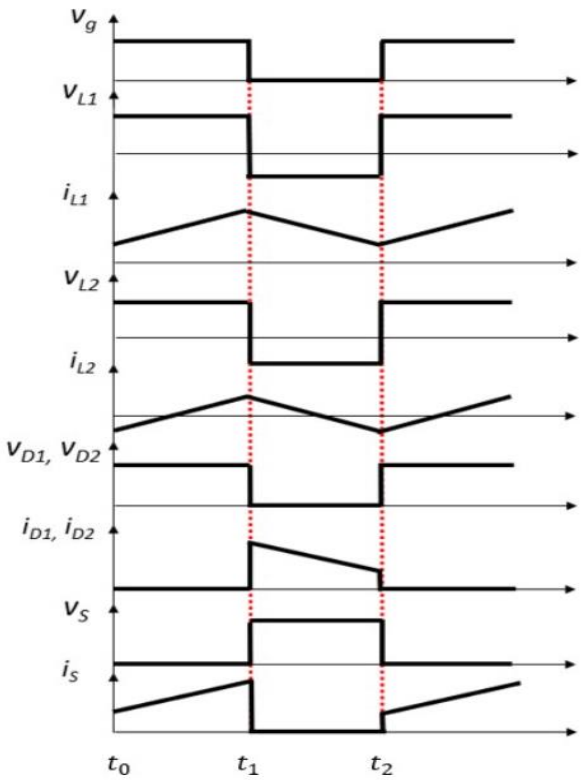

Fig 4:- Theoretical waveform

B. *Design of Components*

The input voltage is taken as Vin = 48V. The output power and output voltage are taken as P_o = 590W and V_o = 462V. Switching frequency, fs = 100kHz, so time period, Ts = 1/fs
= 0.00001sec.

Load resistance can be found by the equation,
Duty ratio,

$$R_o = \frac{V_O^2}{P_o}$$

$$= \frac{462^2}{590}$$

$$= 360\Omega \quad (1)$$

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

$$D = \frac{V_o - V_{in}}{V_o + V\,in} = \frac{300 - 48}{300 + 48} = 0.728 \quad (2)$$

The inductors L_1 & L_2 are obtained from the followingequations.

$$I_{L1} = I_o * \frac{1 + D}{1 - D} = 0.83 * \frac{1 + 0.728}{1 - 0.728} = 5.3A$$

(3)

$$L1 >= \frac{V_{in}DT_s}{0.2I_{L1}} \quad (4)$$

It is approximated to 2 mH.

$$I_{L2} = I_o = 0.83A$$

(5)

$$L2 < \frac{V_{in}DT_s}{2II_{L2}} \quad (6)$$

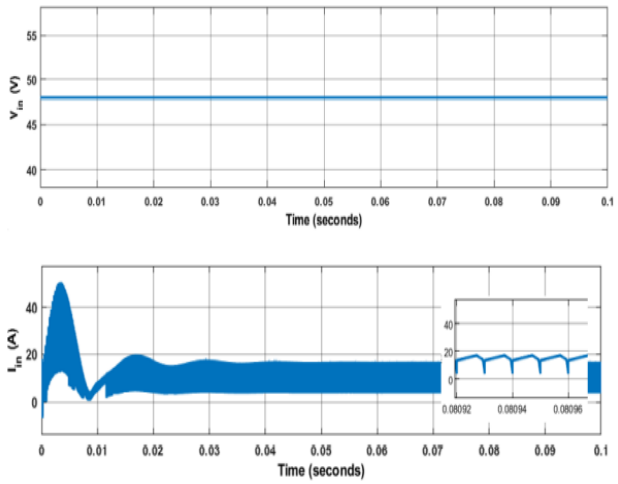

Fig 5:- (a) Input Voltage (V_{in}) and (b) Input Current (I_{in})

The value is chosen to be 100μH.

Capacitors values are found from the following equations.

$$C_1 >= \frac{I_oT_sD^2}{0.01V_{in}(1 - D)}$$

$$C_Z >= \frac{I_oT_sD^2}{0.01V_{in}(1 - D)} \quad (7)$$

(8)

C_1 and C_Z is taken as 20 μF

$$C_2 >= \frac{I_oT_sD^2}{0.01V_o(1 - D)}$$

(9)

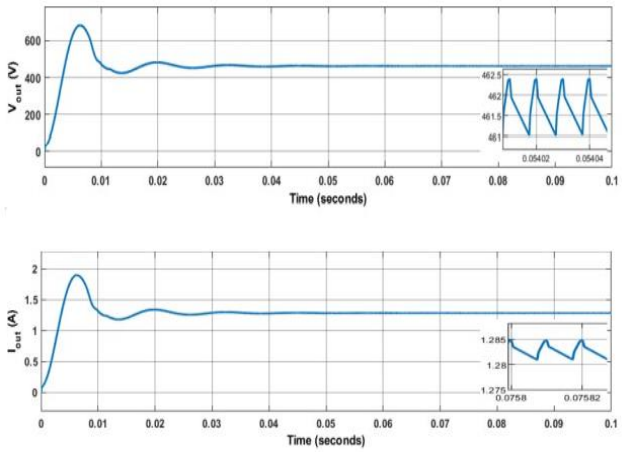

Fig. 6. (a) Output Voltage (V_0) and (b) Output Current (I_0)

$$I_oT_sD^2$$

the voltage across the diodes. It can be seen that the voltage

$$C_3 >= \frac{0.01V_o(1 - D)}{I_oT_sD^2}$$

(10)

across diodes D1 and D2 are the same which is 176V.

$$C_o >= \frac{I_oT_sD^2}{0.01V_o(1 - D)} \quad (11)$$

C_2, C_3 and C_o are taken as 10 μF

III. SIMULATIONS AND RESULTS

The transformer-less boost converter is simulated in MAT-LAB/SIMULINK by choosing the parameters listed in Table
1. The switch is MOSFET with constant switching frequencyof 100 kHz. A dc input voltage, Vin of 48V gives a dc output

Parameters	Value
Input voltage, V_{in}	48V
Output voltage, V_o	462 V
Switching frequency, f_s	100 kHz
Rated power, P_o	593 W
Inductance, L_1	2 mH
Inductance, L_2	100 µH
Capacitance, C_1, C_Z	20 µF
Capacitance, C_2, C_3, C_o	10 µF

Table 1 Simulation Parameters of Transformerless Boost Converter

voltage, V0 of 462V for an output power, Po of 590W. Fig. 5 shows the input voltage and current, Fig. 6 shows the output voltage and current . Thus, the voltage gain is obtained as 9.6.

Fig. 7 shows the gate pulse and voltage stress across the switch. Voltage stress across the switch is 173 V. Fig. 8 shows

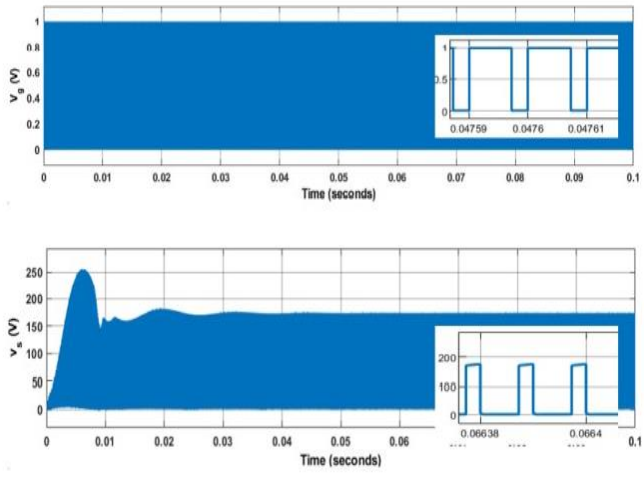

Fig. 7. Gate Pulse (V_g) and Voltage Stress (V_S) of switch S

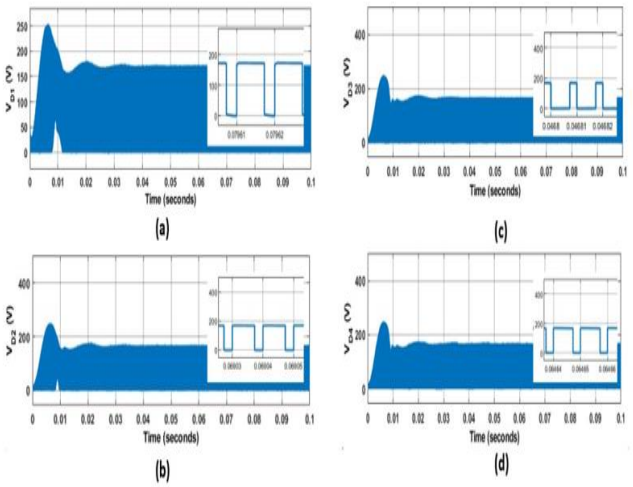

Fig. 8. (a) Voltage across diode (D1) (b) Voltage across diode (D2) (c) Voltageacross diode (D3) (d) Voltage across diode (D4)

The voltage across capacitors is obtained as V_{C1} = 125 V,

V_{CZ} = 124 V, V_{C2} = 166 V, V_{C3} = 297 V, & V_{CO} = 462

V which is shown in Fig 8. Fig. 9 shows the current across inductances L_1 and L_2. It can be seen that the current acrossfilter inductances i_{L1} is 13.7A, i_{L2} is 0.4A.

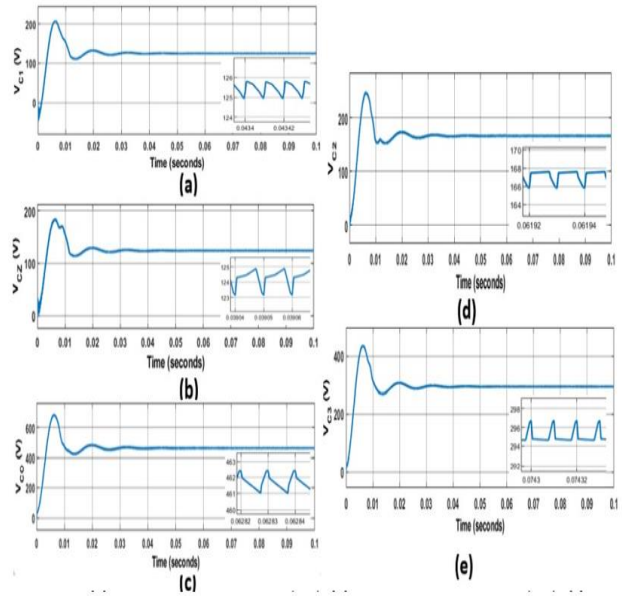

Fig. 9. Voltage across Capacitor (a)V_{C1}, (b)V_{CZ}, (c)V_{CO}, (d)V_{C2}, (e)V_{C3}

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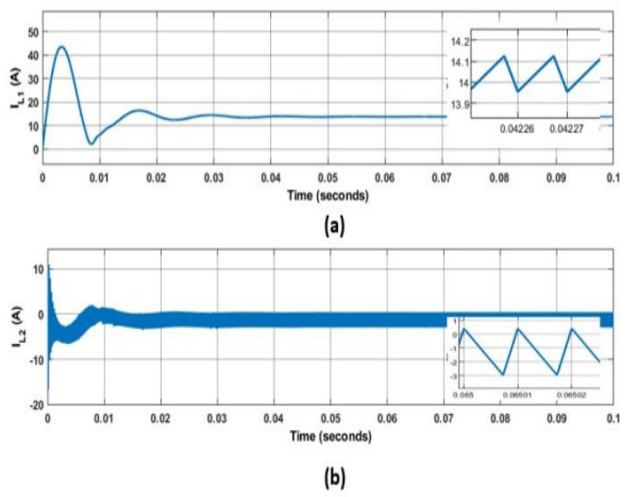

Fig. 10. Current across Inductance (a)i_{L1}, (b)i_{L2}

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 and RL load for transformerless boost converter is done and shown in Fig. 11. The maximum converter efficiency for R & RL load are obtained as 89% and 90.4% . The variation of efficiency with power output is medium for both load ie about 590 W. Thus, the transformerless boost converter can be used in medium power applications.

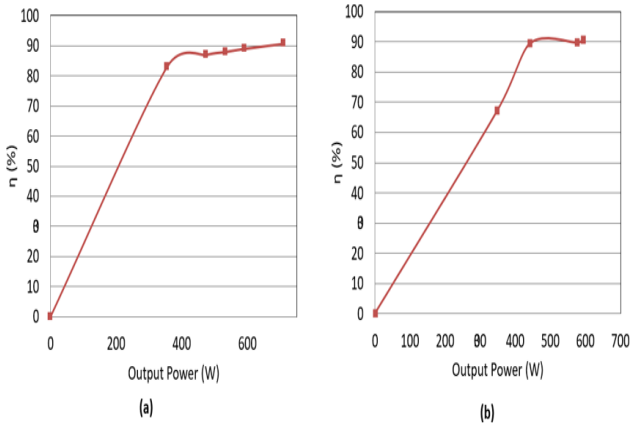

Fig. 11. Efficiency Vs Output Power for (a) R load (b) RL load

The plot of gain of transformer-less boost converter as a functionof duty ratio is shown in figure 12. The gain increases as the duty ratio is varied.

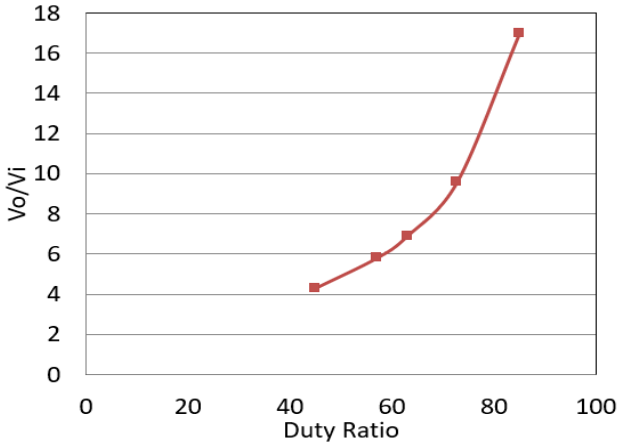

Fig. 12. Voltage gain VS Duty ratio

The plot of output voltage ripple as a function of duty Ratiofor transformerless boost converter is shown in figure 13.

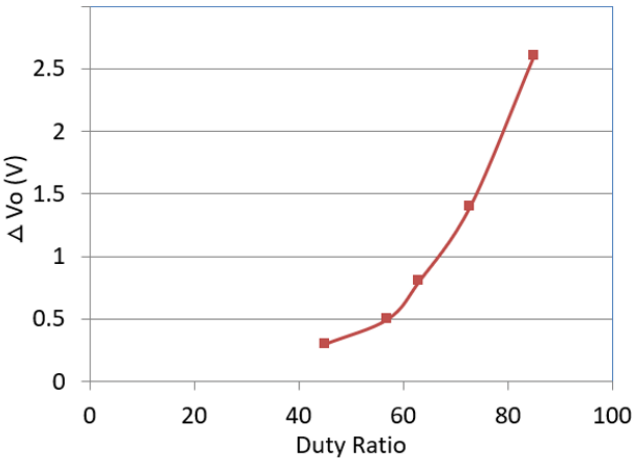

Fig. 13. Output Voltage Ripple VS Duty Ratio

The plot of output voltage ripple as a function of SwitchingFrequency for modified boost converter is shown in figure 14. The ouptut voltage ripple is decreased as the switchingfrequency is increased.

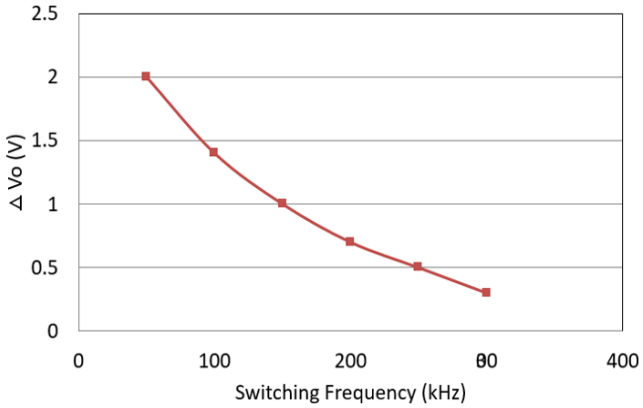

Fig. 14. Output voltage ripple VS frequency

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V. COMPARATIVE STUDY

The comparison between a transformer less boost converter with same input voltage ans swtching frequency & the pro- posed transformer less boost converter is given in table 2. On the comparison it can be observed that, with same values for input voltage as 48V & switching frequency as 100kHz, the gain is increased from 6.35 to 9.6. But, output voltage and current ripple is more in proposed converter.

Parameters	Transformer less Boost Converter	Proposed Transformer less Boost Converter
No. of switches	1	1
No. of inductor	2	2
No. of capacitor	3	5
Voltage gain	6.35	9.6
Efficiency	92.38%	89%
Output Voltage Ripple	0.35 V	1.4 V
Output Current Ripple	0.0005 A	0.005 A
Voltage Stress across Switch	$3.7V_{in}$	$3.6V_{in}$

Table 2 Comparison Between Transformerless Boost Converters & Proposed Transformerless Boost Converter

Table 3 shows the component wise comparison between pro- posed transformerless boost converter and other converters. Comparison is based on the components used in the different converters.

Converters	Proposed Transformer less Boost Converter	Switched inductor Boost converter	Quadratic boost converter	Quasi-Z-source boost converter
Switches	1	1	1	1
Inductors	2	2	2	2
Capacitors	5	1	2	3
Diode	4	4	3	2

Table 3 Comparison Between Transformerless Boost Converter & Other Converters

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 MOS- FET 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 requiredgating to turn on the switches.

Experimental setup of transformerless boost converter is shown in Fig. 15. 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 45V is obtained from power circuit that is shown in Fig. 16. Output voltage of converter is taken from the DSO oscilloscope.

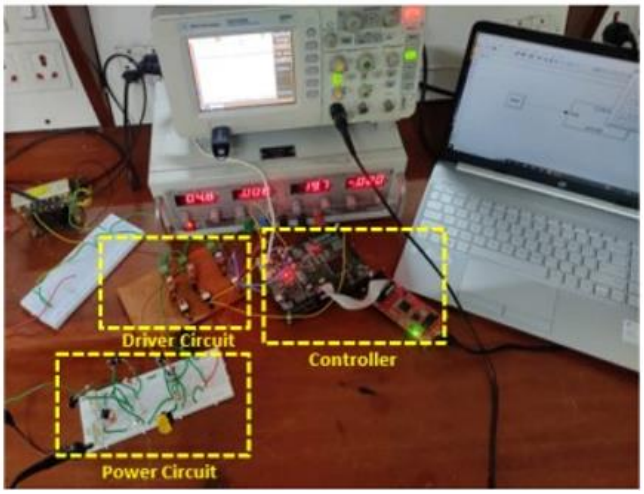

Fig. 15. Experimental Setup

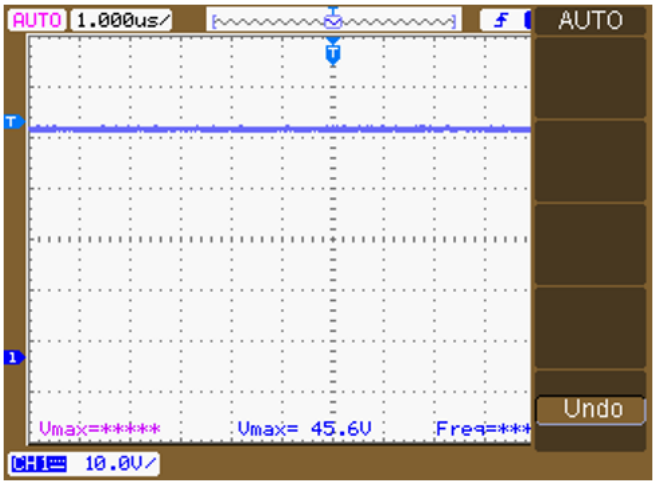

Fig. 16. Output Voltage of Proposed Converter

VII. CONCLUSION

The transformerless boost converter proposed can realizea high voltage gain with low voltage and current stresses.The gain is improved by using a voltage multiplier circuit. However, this resulted in a slight decrease in efficiency as the component count is increasesd. The operation principles and the steady-state characteristics, including voltage gain, voltage stress, and average current stress in both CCM and CBCM, are the same. A lower value of inductance for L2 is selected to operate the proposed converters in CBCM, which reduces the converter size and cost. The proposed converter has relatively higher efficiency in CBCM than CCM. Theefficiency obtained is nearly 89 %. The control of the proposedconverter is implemented using TMS320F28335 microcon- troller. Converter prototype of 6W provides the expected performance with an output

voltage of nearly 45V, considering the drop across the components. The overall analysis confirmsthat the proposed converter is suitable for medium voltage boosting applications such as renewable energy, microgrid, and uninterruptible power supplies (UPS).

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