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Enhanced Gain Boost Converter with Reduced Voltage Stress

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***Abstract*—A DC-DC converter with a high gain is now required due to the growing usage of photovoltaic energy resources. A traditional boost converter running at a high duty ratio to achieve high gain will result in low efficiency and increased voltage stress. High gain with a a reduced duty ratio and reduced voltage stress is what the suggested converter is intended to accomplish. This structure is constructed by modifying the conventional boost converter by substituting a control switch for one of the diodes and adding a voltage multiplier cell at the back-end to reduce the voltage stress between the switches. Switches with low voltage ratings can therefore be utilized.In addition, the converter features a positive output voltage polarity, common ground, and zero source transient current. The steady-state characteristics and principles of operation of the converter are thoroughly examined. The converter is simulated in MATLAB/SIMULINK R2023b to provide the results. The simulation's findings show that the converter has a high voltage gain and an efficiency of 90.3%A˙ TMS320F28027F microprocessor powers the hardware prototype, producing 19.1V as an output from a 2V input.**

***Index Terms*—Boost Converter, Gain, Efficiency.**

I. INTRODUCTION

Photovoltaic (PV) power systems have seen a sharp increase in popularity in recent years. Many PV markets across the world have implemented solar photovoltaic technology to replace traditional energy sources. PV modules can be used either as a grid-connected system or as an independent system. Photovoltaic (PV) systems generally produce low voltages. To ensure a steady voltage for the load or the grid's input side, converters must be connected to PV systems in order to raise their output voltage. Thus, there is a considerable demand for DC-DC converters that are tiny, inexpensive, efficient, and have a high voltage conversion ratio.

In step-up applications, the conventional boost converter is frequently used. It is affordable and has a straightforward design. However, the high duty cycle causes a significant diode reverse recovery loss and conduction loss in the active switch [2]. High voltage stress on the switching devices, parasitic capacitance produced by the transformer's secondary winding, leakage inductance, and high voltage and current spikes are additional challenging problems that impair system performance by raising switching losses as a result of high power dissipation and noise [3].However, switching devices would suffer from higher voltage stress and decreased efficiency if high voltage gain were achieved at a very high duty ratio [4].Other types of isolated DC-DC converters used for step- up applications include flyback, full bridge, half bridge, and push-pull types. High gain can be achieved by these converters by altering the turns ratio [5]. Notwithstanding the advantages of this strategy, there are a number of disadvantages. The transformer's secondary winding might develop parasitic capacitance and leakage inductance, which result in high voltage stress across the switching devices as well as excessive ripple in voltage and current. These characteristics increase switching losses as a result of increased noise and power dissipation, which degrades system performance [6]. Because linked inductors are easier to operate, they can also be utilized in DC-DC converters to generate high gain by varying the turns ratio of the coupled inductor. Unfortunately, decreased converter efficiency is caused by voltage overshoots across the power switches and leakage inductance losses from the use of linked inductors. Consequently, the circuit becomes more complex as more snubber circuits are required [7]. Large voltage gain can be achieved most easily with cascaded boost topologies. These conversions are referred to as cascade boost converters or quadratic boost converters [8]. Nevertheless, there will be a lot of phases in cascaded architectures. As a result, it requires numerous pieces, which ultimately leads to a complex circuit, poor efficiency, and high cost. A switched inducer or capacitor cell is an additional method to increase voltage gain. There have been discussions on a variety of switched inductor and switched capacitor topologies. These are accomplished by changing the inductor and capacitor's parallel and series connections. Nevertheless, the switch undergoes considerable voltage stress equal to the output voltage, and the voltage gain attained is constrained.[1] creates a higher gain boost converter with reduced voltage stress by altering the traditional switching inductor or voltage multiplier cell capacitor converter. The converter puts less voltage stress on the switches than the earlier topologies did. To create this converter, a voltage multiplier cell is added to the output side and a diode is used in place of the enhanced gain boost converter's input capacitor. Hence, the transitory current is removed. The voltage gain is increased by the proposed converter's voltage multiplier cell. There is also a significant decrease in the voltage stress across the switches as compared to other converters. As a result, the suggested converter may achieve low voltage stress across the switches, high gain throughout a broad duty cycle, and constant input current without transients. The converter's two operating modes are examined in continuous conduction mode.

II. METHODOLOGY

Two synchronously controlled power switches, S1 and S2, make up the improved gain boost converter. The five energy storage components are loading resistor R, capacitors C1 to C2, diodes D1 to D5, and inductors L1 and L2. The improved gain boost converter under low voltage stress is depicted in Figure
1. The duty ratio for the two power switches, S1 and S2, is 0.75.

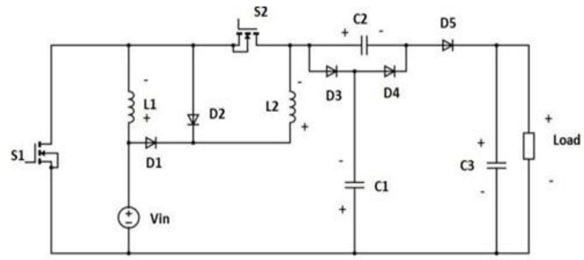

Fig. 1. Enhanced gain boost converter with reduced voltage stress

A. Modes of Function

Current DC-DC converters can be modified to create new DC-DC converter topologies. An enhanced gain boost con- verter is one potential transformerless boost converter upgrade. Although it uses a control switch and a capacitor in place of two diodes, the transformer-less boost converter itself is based on the traditional SIBC. The continuous conduction method was used.

1) Mode 1: At t = t0, this mode involves turning on switches S1 and S2, as well as diodes D1 and D4 is forward biased, while turning off D2, D3, and D5 is reverse biased. The source is now used to charge the inductors L1 and L2. Capacitor C1 charges capacitor C2. Both inductors' current grows linearly. The load was charged by the output capacitor C3. Figure 1 shows operating circuit of mode 1.

2) Mode 2: At t = t1, In mode 2, the switches S1 and S2 are off, and the diodes D1 and D4 are reverse biased while D2, D3, and D5 are forward biased. Currently, inductor L1

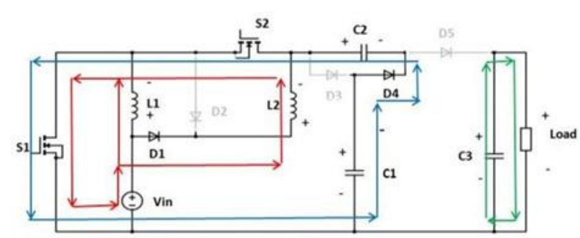

Fig. 2. Functioning circuit of Mode 1

and L2 discharge and charge capacitor C1, and inductor L1 and L2 charge capacitor C2, charge C3, and support the load. Figure 2 shows the operating circuit of mode 2.

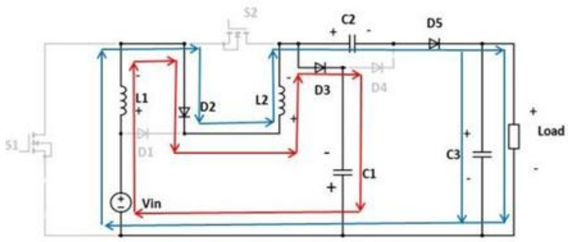

Fig. 3. Functioning circuit of Mode 2

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

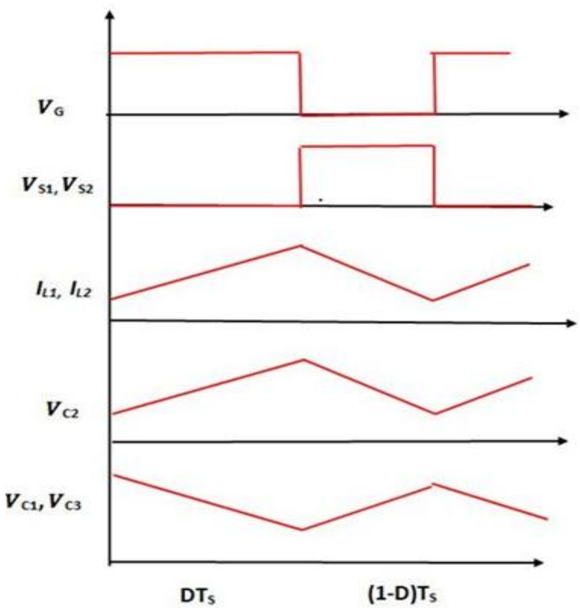

Fig. 4. Theoretical waveform of circuit

B. Design of Components

The input voltage, Vin = 40V, is utilized. The output power and voltage are set to Po = 500 W and Vo = 400V, respectively. The time interval during which the switches are operated with a duty ratio of D = 0.75 and a switching frequency of fs = 100kHz is Ts = 1/fs = 0.00001sec.

From the following equations, the inductors L1 and L2 are derived.

$$R_o = \frac{V_o^2}{P_o} = \frac{400^2}{500} = 320\Omega \quad (1)$$

Duty ratio,

$$\frac{V_0}{V_{IN}} = \frac{2(3D-1)}{(1-D)} = 10 \quad (2)$$

$$D = 0.75 \quad (3)$$

The following formulas are used to determine the inductors L1 and L2

$$I_o = \frac{V_o}{R_o} = \frac{400}{320} = 1.25A \quad (4)$$

$$I_{L1}, I_{L2} = \frac{V_o * I_o}{V_{IN} * 2} \quad (5)$$

$$I_{L1}, I_{L2} = \frac{1.25 * 400}{\ } = 6.25A \quad (6)$$

Assume ΔI_{L1} *and* ΔI_{L2} $= 30\%$ *of* I_{L1} *and* I_{L2}

$$= 0.30 * 6.75 = 1.875A \quad (7)$$

$$L_1 >= R_L * T * \frac{(1-D)^4}{0.3} \quad (8)$$

$$L_1, L_2 = \frac{V_{IN} * D * T}{\Delta i_{L1}} \quad (9)$$

$$L_1, L_2 = \frac{0.75 * 40}{100000 * 1.875} = 160.4\mu = 1mH \quad (10)$$

L_1 and L_2 is approximated to 1 mH

The following formulas are used to determine the capacitor

C1 & C2

$$V_{C1}, V_{C2} = \frac{V_{IN} * (3D-1)}{(1-D)} \quad (11)$$

Assume ΔV_{C1} *and* ΔV_{C2} $= 1\%$ *of* C_1 *and* C_2

$$= 0.01 * 200 = 2V \quad (12)$$

$$I_{C_1 C_2} = \frac{(3D-1) * D * T * V_0}{(1-D) * \Delta V_C * R} \quad (13)$$

$$C_1, C_2 = \frac{(3 * 0.75 - 1) * 0.75 * 400}{(1 - 0.75) * 100000 * 2 * 320} = 24.4\mu F \quad (14)$$

C_1 & C_2 is approximated to 47 μF.

The following formulas are used to determine the values of capacitors.

$$V_{C3} = V_0 = 400V \quad (15)$$

Assume $\Delta V_{C3} = 1\%$ *of* C_3

$$C_3 = \frac{V_0 * D * T}{R * \Delta V_{C3}} \quad (16)$$

$$C_3 = \frac{0.75 * 400}{4 * 100000 * 320} = 2.34\mu F \quad (17)$$

C_3 is taken as $3.3\mu F$

III. SIMULATIONS AND RESULTS

Select the values in Table 1 to use MATLAB/SIMULINK to simulate the transformerless boost converter. This MOSFET switch has a 1000 kHz steady switching frequency. With an output power (Po) of 500 W and a dc input voltage of 40 V, a dc output voltage (V0) of 400 V is produced. Both the input and output voltages and currents are displayed in Figure 5 and Figure 6, respectively. Hence, 10 is the voltage gain.

TABLE I
SIMULATION PARAMETERS OF QUADRATIC BOOST CONVERTER

Parameters	Value
Input voltage, V_{in}	40 V
Output voltage, V_O	400 V
Output load, R	320 Ω
Switching frequency, f_s	100 kHz
Inductance(L_1, L_2)	1mH, 26A
Capacitance C_1, C_2	47 µF, 240V
Capacitance C_3	3.3 µf, 480V

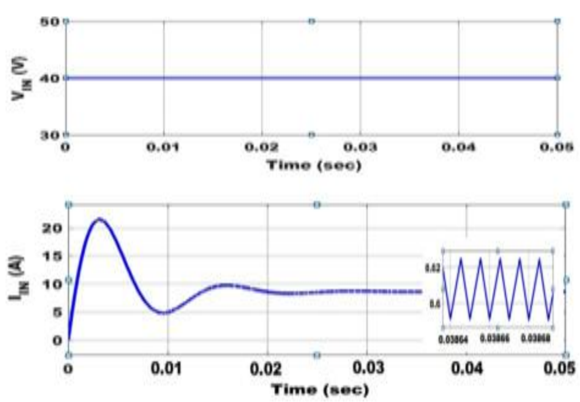

Fig. 5. (a) Input Voltage (Vin) and (b) Input Current (Iin)

The gate pulse and voltage stress across the switch are displayed in Fig. 7. The switch is under 122 V of voltage stress. The gate pulse and voltage stress across the switch are displayed in Fig. 8. There is 88.3 V of voltage stress across the switch.

The Voltages across the capacitors VC1 and VC2 and VC3 are shown in Fig. 9. The capacitor voltage of VC1 measured as 197V with 0.9V as voltage ripple. The capacitor voltage

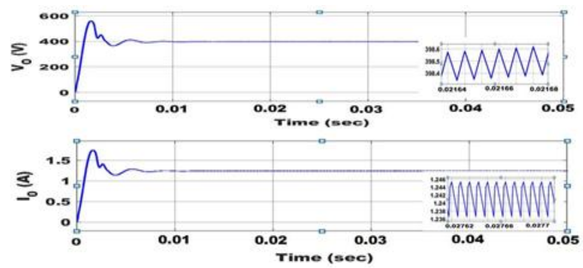

Fig. 6. (a) Output Voltage (V0) and (b) Output Current (I0)

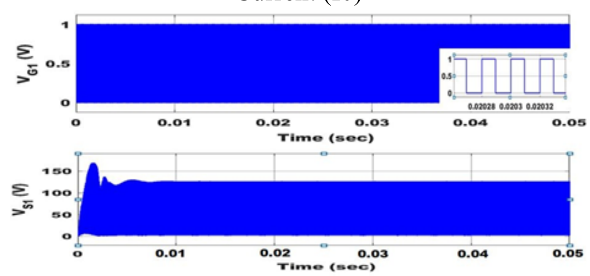

Fig. 7. Gate Pulse (Vg1) and Voltage Stress (Vs1) of switch S1

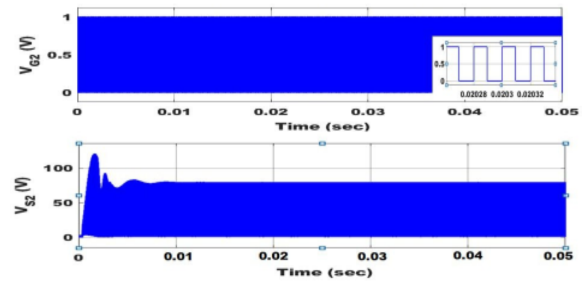

Fig. 8. Gate Pulse (Vg2) and Voltage Stress (Vs2) of switch S2

of V_{C2} measured as 201.2V with 0.65V as voltage ripple.The capacitor voltage of V_{C3} measured as 398.6 V with 0.23V as voltage ripple. Fig. 10 shows the current across Current through inducor IL1, inductor IL2. Current through inductor (IL1) is measured as 8.72A and the ripple current is 0.34A. Current through inductor (IL2) is measured as 8.61A with current ripple of 0.04 A.

IV. ANALYSIS OF PERFORMANCE

A power equipment's efficiency is determined by dividing its power output by its power input at any given load. Efficiency vs output power with R load for transformer- less and enhanced boost converters is analyzed in the figure. transformerless boost converter has maximum efficiency of R load is 88.5% and Enhanced boost converter has efficiency of 93.3% By comparing the enhanced boost converter has high efficincy. Efficiency versus output power under R load is depicted in the figure. The resistive load is changed here. By analyzing efficiency vs output power with RL load, we can determine the percentage of input power that is supplied to the load. In this analysis the resistive load is fixed and

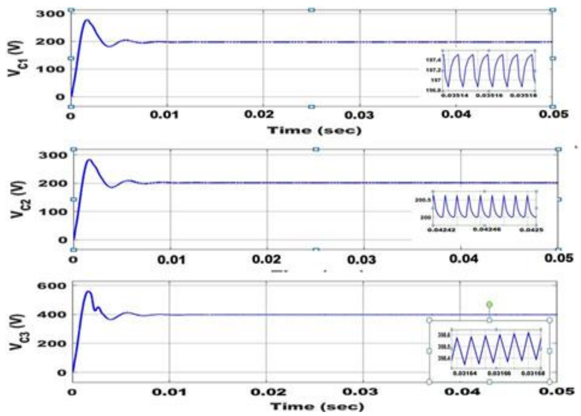

Fig. 9. Voltage across Capacitor (a)VC1, (b)VC2

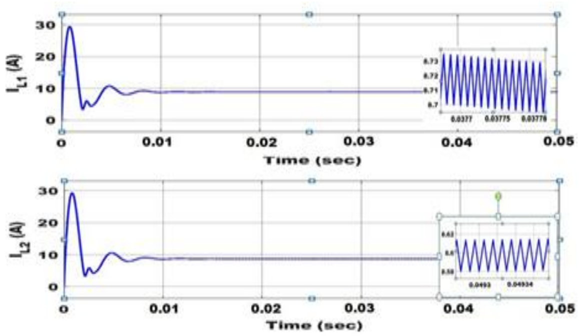

Fig. 10. Current across Inductance (a)iL1, (b)iL2, (c)iL3

inductive load is varied. Here the analysis gives the efficiency of 87.8%0utput power for the boost converter and enhanced boost converter has maximum efficiency of 91.1% for RL load

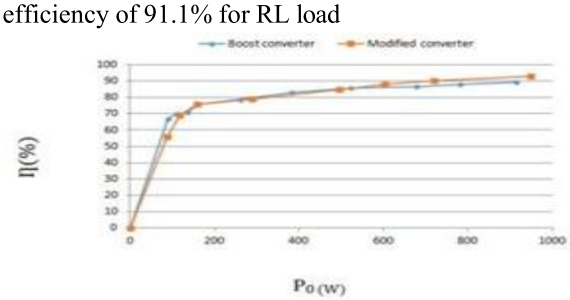

Fig. 11. Efficiency Vs Output Power for R load

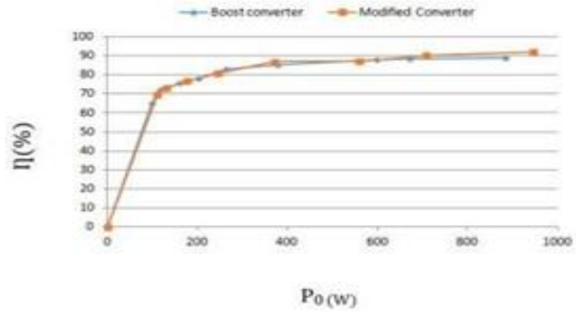

Fig. 12. Efficiency Vs Output Power for RL load

In analyzing the graph in figure 12, it is evident that the voltage gain rises as the duty ratio does. Compared to a transformer-less boost converter, the enhanced gain boost converter's voltage gain is seen to increase more quickly for the same duty ratio.

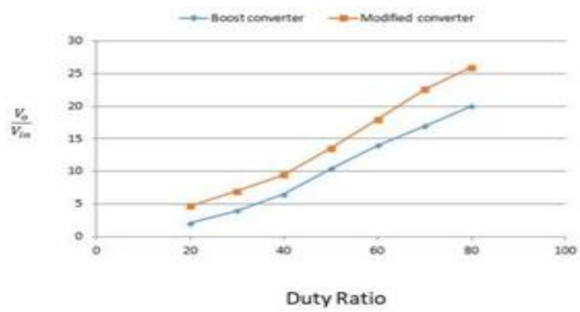

Fig. 13. Voltage gain VS Duty ratio

In figure 13. It has been noted that the output voltage ripple rises with duty ratio and that the enhanced boost converter's output voltage ripple increases somewhat faster than that of the transformer-less boost converter.

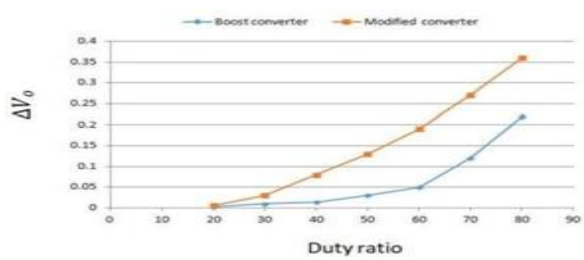

Fig. 14. Output Voltage Ripple VS Duty Ratio

In figure 14 When the switching frequency is raised, it is found that the output voltage ripple of the enhanced boost converter decreases more quickly than that of the transformer- less boost converter. F=100kHz is chosen as the high switching frequency in order to achieve a lower output voltage ripple.

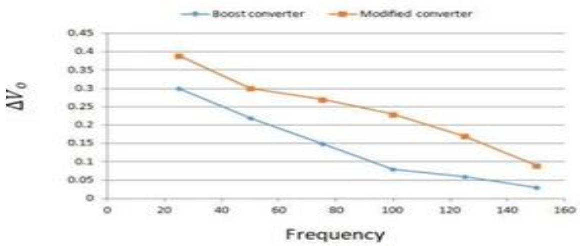

Fig. 15. Output voltage ripple VS frequency

V. COMPARITIVE STUDY

Table I presents the results of a comparison between transformer-less boost converters and increased gain boost converters while maintaining constant input voltage, switching frequency, duty ratio, and load. Based on the comparison, it is evident that the enhanced gain boost's voltage gain has grown while the voltage stress across the switches and diodes has decreased.

TABLE II
COMPARISON BETWEEN TRANSFORMER LESS BOOST CONVERTER AND
ENHANCED GAIN BOOST CONVERTER

Parameters	Base Circuit	Modified Circuit
No. of Switches	2	2
No. of Inductor	2	2
No. of Diode	2	5
No. of Capacitor	2	3
Duty ratio	0.82	0.75
Frequency	100 KHz	100kHz

A comparison of the enhanced gain boost converter's com- ponents with those of other converters is presented in Table
II. The basis for comparison is how many parts are utilized in various converters. From the table, it is evident that the increased gain converter uses the fewest large components.

TABLE III
COMPARISON BETWEEN ENHANCED GAIN BOOST CONVERTER AND
OTHER CONVERTER

Converter	Boost converter in [6]	Boost converter in [7]	Boost converter in [9]	Modified Boost converter
No. of Switches	2	2	1	2
No. of Diodes	2	2	3	5
No. of Inductors	2	2	3	2
No. of Capacitors	2	2	5	3
Power	50 W	40 W	500 W	500 W
Voltage Gain	$\frac{1-D}{1+D}$	$\frac{2}{1-D}$	$\frac{3-2D}{1-2D}$	$\frac{2(3D-1)}{1-D}$

VI. EXPERIMENTAL SETUP WITH RESULT

The input voltage is lowered to 2V for hardware implemen- tation, and the TMS320F28335 processor is used to generate the switching pulses. The switch is a MOSFET IRF3205. The TLP250H optocoupler, which is used in the driver circuit, acts as a barrier to prevent external damage to the microcontroller as well as the gate required to activate the switches.
Fig. 15 illustrates the transformerless boost converter ex- perimental setup. 2V of input with DC supply is provided by the DC source. The TMS320F28335 microcontroller provides switching pulses to the driver circuit. As a result, Fig. 16's power circuit yields an output voltage of 20 V. The converter's output voltage is obtained using a DSO oscilloscope.

Fig. 16. Proposed Converter

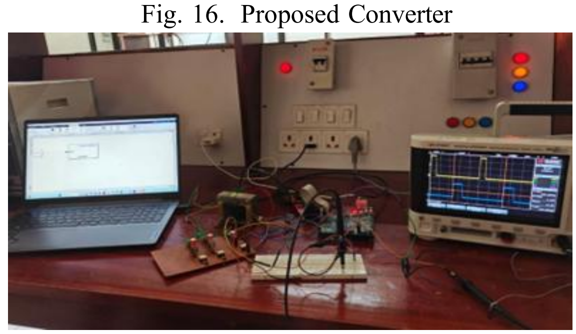

Fig. 17. Experimental Setup

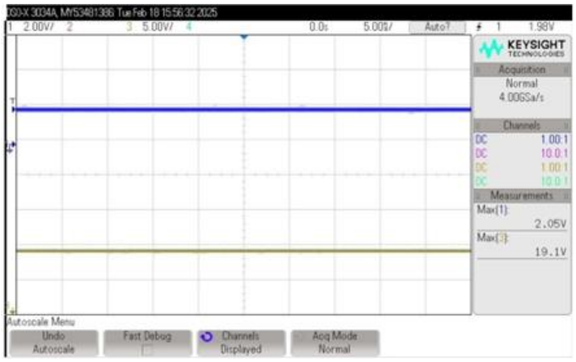

Fig. 18. Output Voltage of Proposed Converter

VII. CONCLUSION

A novel increased gain boost converter is suggested and put into use, including minimal voltage stress across the switches. Voltage multiplier cells and switched inductors are combined in this configuration. The suggested converter delivers high gain and lower voltage stress across the switching devices as compared to previous boost DC-DC converters. The input current is continuous, and the voltage stress on switches S1 and S2 is comparatively low. Analysis and simulation are done on the suggested converter. The simulation shows that, for a 500W output power, the converter achieves an efficiency of 93.3Additionally, the suggested topology has benefits like common gound and wide-range operating in terms of duty ratio.

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