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Research Article

For use in photovoltaic applications, high voltage gain hybrid boost converter mathematical modelling

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Abstract **–**On this research, a high voltage-gain Hybrid boost converter (HVHBC) is developed to achieve high voltage gain, good transient responsiveness, low voltage ripples, and sufficient efficiency when compared to a basic conventional boost converter and to lower the harmonic content on the output side. The suggested topology's voltage gain is 96% at a duty ratio of 0.55 and a frequency of 50 KHz. The suggested converter's circuit schematic has a switched inductor and switch capacitor architecture. As a result, the inductor reduces the voltage stress on the active switch, the output voltage of the proposed converter is high, and the reaction of different parameters is examined using the simulation tool PSIM.

Keywords – Include, Boost Converter, Duty Cycle, Continues Conduction Mode (CCM), Switched Inductor, Switched Capacitor

I. Introduction

Globally, the energy situation has recently gotten worse by the day. Among all renewable energy sources, solar PV (Photovoltaic) technology is one of the most dependable methods for producing power. Numerous benefits of this technology include its lack of noise, reduced environmental impact, lack of moving components, and ease of use. This study first proposes mathematical modelling of a high voltage gain hybrid boost converter, which is guaranteed to raise voltage from 12V to 47V [1]. The cost of installing a solar power system is quite expensive. Therefore, the price of PV installation may be decreased by improving manufacturing technologies and solar power generating efficiency. Utilizing our finite energy resources to run electrical equipment effectively is a crucial aspect of electrical and electronics engineering [2]. Such a current may lead to increased weight, cost, and power losses. To increase efficiency and lower overall leakage current, the converter without a transformer is being studied. We provide a high static gain hybrid DC/DC converter with a single switch that is appropriate for solar applications. To maximize voltage-gain and lower voltage across all power components, the suggested design includes two standard DC/DC converters [3,4]. As a consequence, this converter may be used in a two-stage DC module layout without a mid-point transformer to link to a voltage source inverter [5]. To offer a large step-up voltage gain while keeping a low duty ratio, many topologies have been suggested [6,7]. But each of these varieties is more-costly and difficult. good voltage-gain, low voltage stress on the active switch, and good efficiency may all be attained using the switch inductor and switch capacitor architecture approaches without suffering from a high duty ratio [8]. High gain and efficiency are therefore provided by the high voltage-gain hybrid boost converter (HVGHBC) type. This work offers a hybrid boost converter type with high voltage gain and minimal voltage ripple. Combining switch inductor and switch capacitor technology, this (HVGHBC) architecture offers output voltage at a level appropriate for grid connection applications [9].

The structure of this essay is as follows: The literature study was covered in part II, and the high voltage gain hybrid boost converter's (HVGHBC) operating concept is covered in section III. In section IV, a modest signal analysis of the SIBC is shown. The MPPT methods are then provided in section V. Then, sections VI present the findings of the simulation and the experiment. Section VII concludes by summarizing the paper's findings.

II. Literature Review

The methodology used in this study [10] entails suggesting a high-voltage gain DC-DC boost converter for cascade connection with an MPPT boost converter, using switched-inductor cells to reduce input current source ripples and switched-capacitor cells to enhance voltage gain and reduce voltage stress on power switches. Using a laboratory-scale prototype, the study compares hardware test results with theoretical/simulation studies to assess converter performance under various weather conditions. The suggested method has the advantages of improved component longevity, reduced input current source ripples, increased voltage output for MPPT systems, and alignment between theoretical, simulation, and experimental results. For use in electric vehicle (EV) applications, this paper [11] introduces a soft switching interleaved boost converter (SS-IBC) with an auxiliary resonant circuit. The SS-IBC can be set up as a multiphase interleaved boost converter with identical phases controlled by PWM strategy, enabling grid-integrated battery charging that is affordable and reliable from various sources, including renewable energy. Experimental validation reaches a maximum efficiency of 98.78% on a downsized hardware system rated at 1.0 kW, and simulation and experimental results show high efficiency, exceeding 97% over a wide power range. This study [12] uses the Dingo Optimization Algorithm (DOA) technique, which is based on Incremental Conductance (IC) for maximum power point tracking (MPPT), to address the nonlinear power production of photovoltaic (PV) systems. The DOA method performs significantly better than traditional techniques (PI, P&O, IC), offering accurate and quick tracking with little fluctuation. It outperforms earlier methods with an impressive efficiency of over 99.961% in various weather conditions and validates results using MATLAB/Simulink software. In this study [13], a high-gain DC-DC converter (HGBC-PVS) is introduced for tying rooftop solar panels to a DC micro grid. This converter uses adaptive incremental conductance MPPT to increase voltage gain and efficiency. The converter's importance is shown by simulation results, and measured outputs confirm its efficacy for a variety of parameters.

Our work surpasses earlier work by developing a high-voltage gain hybrid boost converter (HVHBC), which has advantages such as increased voltage gain (96% at a duty ratio of 0.55, 50 kHz frequency), improved transient response, reduced voltage ripples, and increased efficiency. Your work also employs a switched inductor and capacitor topology to increase output voltage while reducing voltage stress on the active switch and reducing harmonic content in the output.

III. Proposed High Voltage Gain Hybrid Boost Converter

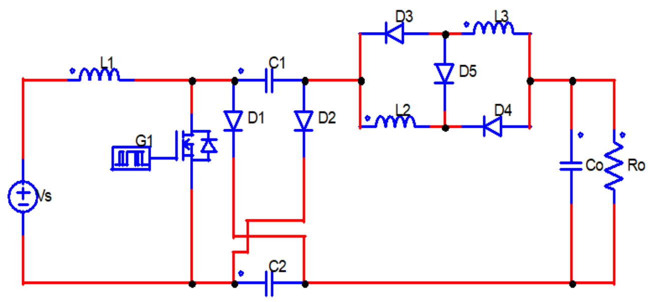

Fig. 1. Proposed HVHBC Topology

The proposed new topology is a non-isolated DC-DC converter that boosts the various voltages by a specific multiplier. The HVGHBC consists of three inductors (L1, L2, and L3) which have the same inductance value, three capacitors (C1, C2, and Co), having the same value of capacitance, five diodes (D1, D2, D3, D4, and D5) and a MOSFET switch. The proposed topology comprises a conventional boost converter, switch capacitor, and switch inductor topology, as shown in Fig.1. It provides an excellent transient responsiveness, minimal voltage ripples, adequate efficiency, high voltage gain, and low voltage stress across the switch as compared to a straightforward traditional boost converter. The circuit schematic for the High Voltage Gain Hybrid Boost Converter (HVHBC) architecture is shown in Fig. 1. A duty cycle D on the PWM signal controls the power transistor's switching.

A power switch that periodically switches to allow electricity to flow from input to output is the foundation of the total conversion. With the exception of one piece of the switched inductor since it only has one electronic switch, the proposed new HVHBC architecture operates similarly to how the converter does. The switch inductor and capacitor cells that replace the capacitor and inductor at the end are the primary distinction between the cuk converter and the recently suggested architecture.

The proposed HVHBC topology has two operational states: ON when switch S1 is conducting, and OFF when switch S1 is not.

Mode I. The voltage source charges the input inductor in series through Switch S while the switch is conducting. The switch allows the current to return to the source. Inductors receive a simultaneous discharge of the capacitors' stored energy. Since both inductors are the same, the same amount of current passes through both L1 and L2 inductors. Both inductors have the same amount of energy stored in them. In Fig.2, the entire function is shown.

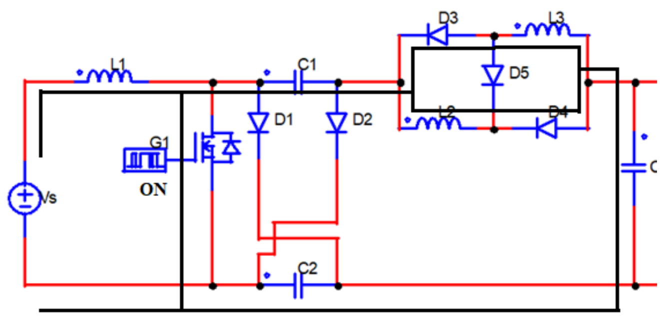

Fig. 2. Mode I

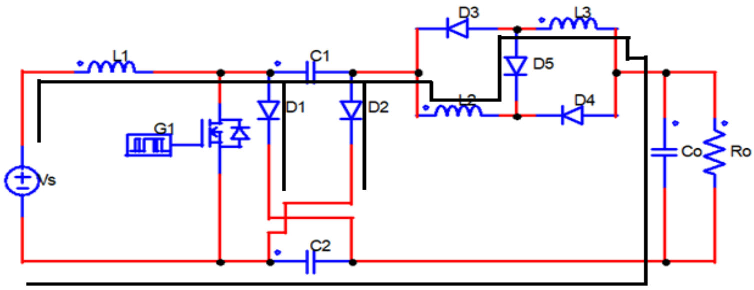

Fig. 3. Mode II

Mode II. The input supply and input inductor L1 also charge the capacitors C1 & C2 and supplies the load, while input supply and input inductor L1 also charge the capacitors C1 & C2 and turn off the diodes D1, D2, & D5 when the switch S is not conducting (turned off). Following the change in polarity on C1 and C2, the diode D5 becomes reverse biassed, and the whole energy stored in the capacitors is discharged to Co, where the output is obtained as illustrated in Fig. 3. When the total of the voltages on the input source, two capacitors, two inductors, and two capacitors equals the voltage on the capacitor Co. The entire process is recycled, and the diode D5 is forward biassed.

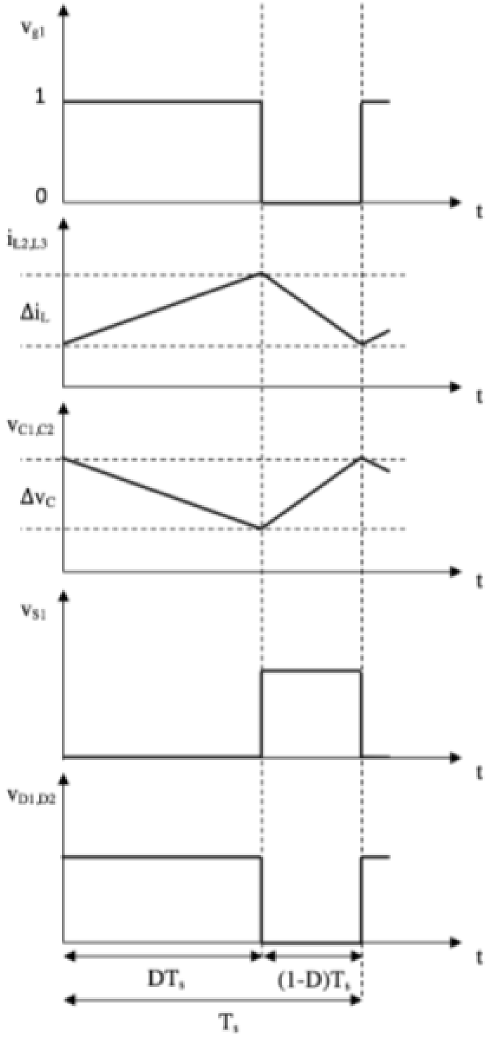

Fig.4. Steady-state waveforms of HVHC topology

In Fig.4, switching diagrams for the SLSC topology's primary steady-state waveforms with increased variations are displayed in CCM.

IV. ANALYSIS OF PROPOSED HVHBC TOPOLOGY

To make the analysis simpler, the suggested converter runs in steady-state. Additionally, it is assumed that every component is perfect (100 percent efficient), that input voltage V_s is pure dc, and that every capacitor is designed to have a negligibly tiny voltage ripple at switching frequency (f_s).

The voltage across inductors L1, L2, and L3 is given as follows when MOSFET S is conducting as seen in Fig. 4.1: $V_{L1}(t) = V_S$ (1)

$$V_{L2}(t) = V_{L3}(t) = 2V_C - V_o = V_L \quad (2)$$

$$Vs = V_{L1}(t) = (L1).\frac{dI_L}{dt} \quad (3)$$

Where $\frac{dI_{L1}}{dt} = \frac{dI_L}{dt}$

The current is therefore written as follows for the circuit's first portion (1):

$$\Delta I_{c(1)} = D.\frac{V_s}{L1} \quad (4)$$

The current in the closed state is now stated as for the second component (2) of the circuit:

$$\Delta I_{c(2)} = D.\frac{2V_C - V_O}{L} \quad (5)$$

Apply the Kirchhoff voltage law (KVL) to Figs.1 and 2's circuit to determine the inductor voltage. $V_S = V_{L1}(t) + V_C$ (6)

Where V_{c1} is the voltage across capacitor C1 and $Vl1(t)$ is the voltage across L1.

$$V_{L1}(t) = V_S - V_C \quad (7)$$

When the switch is not conducting, the inductor voltage second balance for L1 is given by:

$$V_C = \frac{1}{1-D} V_S \quad (8)$$

Where $V_C = V_{C1} = V_{C2}$

$$V_O = \frac{(1+3D)}{(1+D)} V_C \quad (9)$$

By putting Equation, we get:

$$V_O = \frac{(1+3D)}{(1+D)(1-D)} V_S \quad (10)$$

$$\frac{V_O}{V_S} = \frac{(1+3D)}{(1+D)(1-D)} \quad (11)$$

Equation 11 is the required DC voltage gain of the proposed topology

The peak-to-peak variation of the inductor's current at the input ($\nabla I_{L1} = \nabla I_{Lin}$) and output ∇I_{Lo} sides are expressed in (12) and (13), respectively.

$$\nabla I_{Lin} = \frac{DTV_S}{L_{in}} = \frac{DV_S}{fL_{in}} \quad (12)$$

As $\nabla I_{L3} = \nabla I_{L2} = \nabla I_{Lo}$

And

$$\nabla I_{LO} = \frac{DT(2V_C - V_O)}{L_O} = \frac{D(2V_C - V_O)}{fL_O} \quad (13)$$

The peak-to-peak variation of the capacitor's voltage ($\nabla V_{C1} = \nabla V_{C2} = \nabla V_C$) is expressed in (14) and (15).

$$\nabla V_C = \frac{DTI_{out}}{C} = \frac{DI_{out}}{fC} \quad (14)$$

We can write it also:

$$\nabla V_C = \frac{DP_{out}}{M_{CCM} V_S f C} \tag{15}$$

Where $M_{CCM} = \frac{V_O}{V_S}$

Equation (10) describe the dc gain conversion ratio of the conventional boost converter and HVHBC respectively.

V. CIRCUIT PERFORMNACE ANALYSIS

Table.1. Parameter with its values

Parameters	Values
Input Voltage	12 V
Inductors L1=L2	600 Uh
Capacitors C1=C2	22 UF
Output Capacitor Co	22 UF
Output Resistor Ro	10 Ohm
Duty Cycle D	55%
Voltage Stress Vsw	49 V
Output Power Pout	194 watt
Switching Frequency	50 KHz
Input Power Pin	202 watt
output voltage Vo	47 V

Several simulation experiments were carried out to verify the correctness of the theoretical analysis of the proposed High Voltage Gain Hybrid Boost Converter (HVHBC) topology in Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM) and to assess the performance of the entire circuit. The simulations were run using PSIM, a programme that is often used in the field of power engineering. On the basis of the parameters listed in Table 1, the High Voltage Gain Hybrid Boost Converter (HVHBC) architecture was modelled.

With a duty cycle of 55% and an output voltage of 47 volts, the input voltage is 12 volts. At 50 kHz, which is the switching frequency, these parameters were selected.

A. *INPUT CURRENT AND VOLTAGE*

Using the PSIM programme, Fig. 4.1(a) displays the input voltage and current. When the switch is in the ON position, the input inductor is charged in series. As a result, the input current is 16.88 A, and when a switch is turned off, the input current drops to 50% of its original amount.

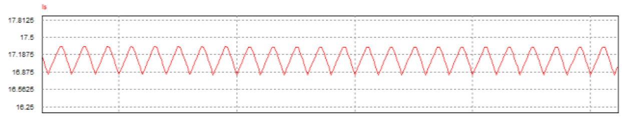

Fig.4.1 (a) Input Current

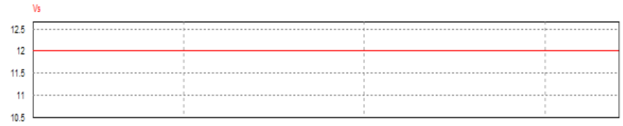

Fig. 4.1 (b) Input Voltage

B. *OUTPUT CURENT AND VOLTAGE*

In Fig.4.2(a) and Fig.4.2(b), respectively, the output current and output voltage via PSIM and practical experiment are depicted. In order to increase the output voltage, which is close to 47 V, the output current is reduced to 4.57 A. It is evident that a significant DC voltage gain (47/12 V) is obtained, supporting the hypothesis.

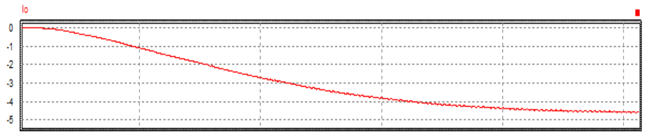

Fig.4.2 (a) Output Current

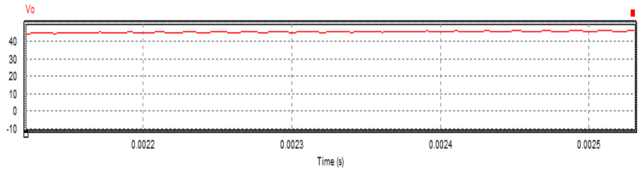

Fig.4.2 (b) Output voltage

C. *VOLTAGE STRESS ON SWITCH*

Comparing this design to switched inductor and switched capacitor boost converters as well as traditional boost converters, the key benefit is that it reduces the voltage stress on each component. As demonstrated in Fig.4.3 by PSIM, a switch is subject to a voltage stress of 29 volts.

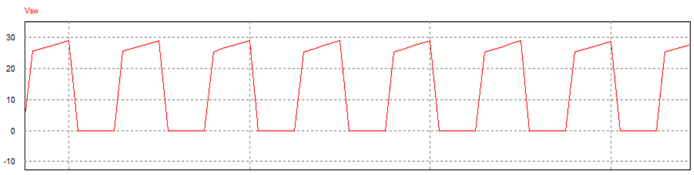

Fig. 4.3. Voltage Stress on Switch

D. *PWM SIGNAL WITH DUTY CYCLE*

The duty cycle value may be modified to alter the output voltage. The waveform of the PWM signal at various levels, together with the switch signal, are shown in Fig.4.4. A greater duty cycle will result in a broader pulse, which will increase the output voltage.

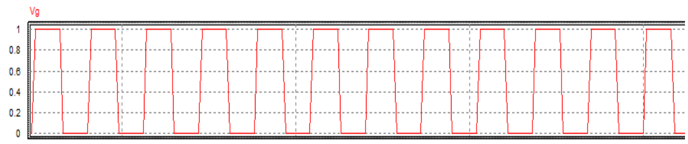

Fig. 4.4. PWM Signal

E. *VOLTAGE STRESS ACROSS DIODES*

Voltages across various diodes are shown in Fig. 4.5. VD1 and VD2 represent the same voltage stresses across D1 and D2, respectively, while VD3 represents the voltage stress across D3, VD4 and VD5 represent the same voltage stresses across D4 and D5, respectively.

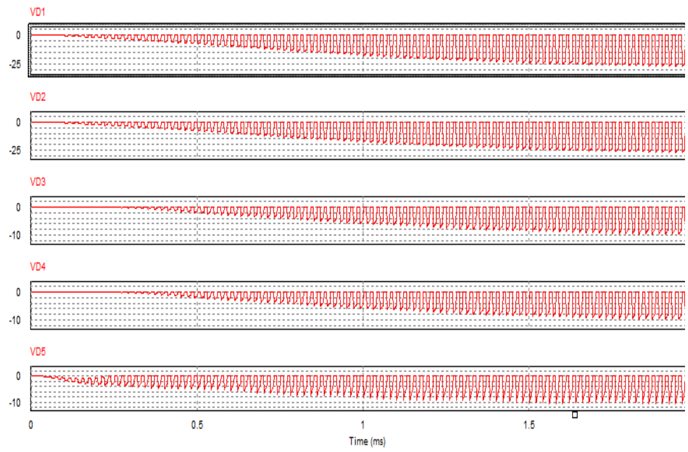

Fig. 4.5. Voltage Stress across Each Diode

F. *VOLTAGE ACROSS EACH CAPACITOR*

The curve of voltages across various capacitors is shown in Fig.4.6. While VCo is the voltage across the output capacitor that is utilised for filtering, VC1 and VC2 are the same values across C1 and C2, respectively.

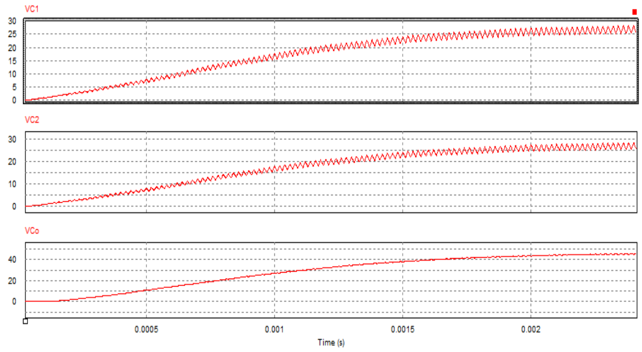

Fig. 4.6. Voltages across Each Capacitor

G. *VOLTAGE ACROSS EACH INDUCTOR*

The curve of voltages across various inductors is shown in Fig.4.7. While VL2 and VL3 are the voltages across L2 and L3, respectively, and both have the same value due to their parallel connection, VL1 is the voltage across the input L1 inductor.

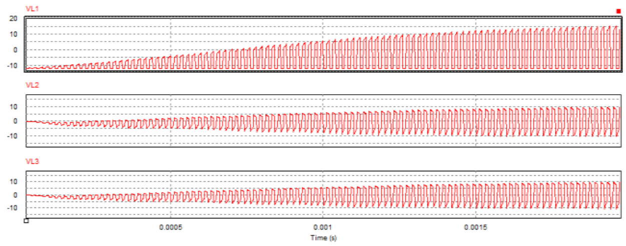

Fig. 4.7 Voltages across Each Inductor

H. *CURRENT THROUGH EACH INDUCTOR*

The current flowing through various inductors is shown in Fig.4.8. Io is the output current via inductor Lo, whereas IL1 and IL2 are both the same current in values through L1 and L2, respectively.

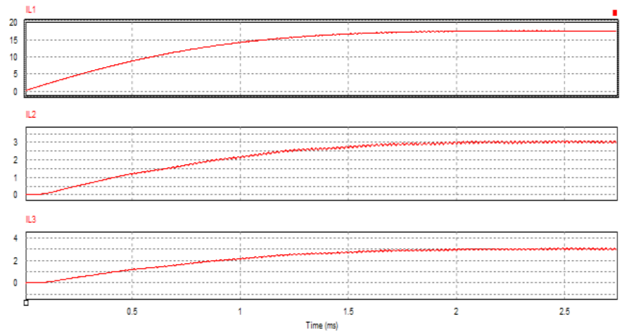

Fig. 4.8. Current through Each Inductor

VI. EFFICIENCY OF THE PROPOSED SLSC DC-DC CONVERTER

After D=0.55, the efficiency of the suggested topology leads towards lowering by increasing the duty cycle. The efficiency of the proposed topology improves by increasing the duty cycle when D>0.1. Therefore, as shown in Fig. 4.9, we defined the duty cycle D at 0.55 for the constant frequency of 50 KHz.

Duty Cycle	0.1	0.2	0.3	0.4	0.5	0.55	0.6	0.7	0.8	0.9
Efficiency (%)	95.6	91.24	65.56	84.39	95.9	96	93.41	68.41	61.12	28.3

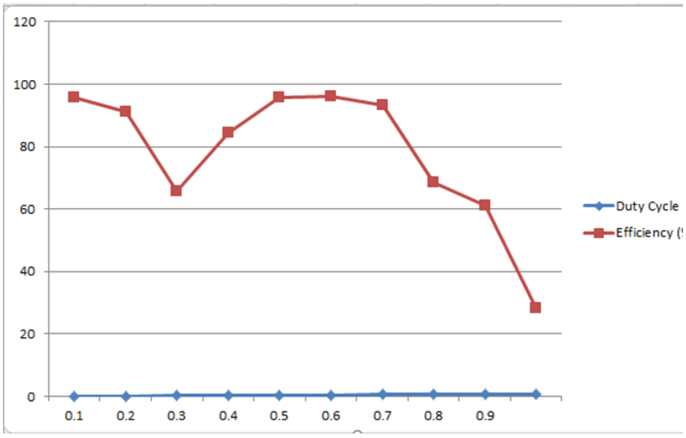

Fig. 4.9. Efficiency of the Proposed Topology

VII. CONCLUSION

This article introduces a ground-breaking High Voltage Gain Hybrid Boost Converter DC-DC converter that significantly outperforms a standard boost converter regarding voltage gain while overcoming complexity and high-duty cycle issues. This converter is a great option for applications like increasing the output voltage of solar panels because of its benefits, like maintaining low-stress voltage, high efficiency, and a wide voltage gain range by turn ratio. The ability to achieve high voltage gain with low-duty cycles (D = 0.55), eliminate output diode reverse recovery concerns, and significantly increase voltage gain without changing the inductor turn ratio are some of the key advantages. Successful testing successfully converted a 12V input to a 47V output with 194W of power, matching the results of the computations. DCM analysis, high-power, high-frequency applications, MPPT, droop management in microgrids, and the proposed Z-source converter in inverter mode could all be the subject of future research.

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