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A TRANSFORMER LESS HIGH GAIN MULTI STAGE BOOST CONVERTER FED H-BRIDGE INVERTER FOR PHOTOVOLTAIC APPLICATION WITH LOW COMPONENT COUNT

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Abstract

This paper describes a new form of multi stage DC-DC boost converter based on switched inductor structure and switched capacitor. These multi stage outputs sequentially fed to H-Bridge inverter to generate nine level single phase alternating current (AC) supply. The converter that is proposed in this paper is Switched Inductor Multi Stage Boost Converter (SIMSBC) which eliminate the need of conventional line frequency transformers and enables non isolated compact size high dc gain converter. Switched Inductor and Switched Capacitor function provides multilevel output voltages at different stages. SIMSBC boosts up 12V DC to 110V in first stage, 220V in second stage, 330V DC in third stage and 440V in fourth stage. These levels are used to generate 9-levels single phase AC supply. By adding 2 inductors, (2N+2) number of diodes and (2N-1) number of capacitors to conventional boost converter N level output voltage designed. Again, eight switches and four diodes are used to generate nine level AC output voltage. Simulation results in MATLAB and PSIM proved that the theoretical analysis of the SIMSBC fed H-bridge converter.

Keywords: DC-DC converters, H-Bridge inverters, Multi stage boost converters, Photovoltaic generation system, Switched inductors.

1. Introduction

Nowadays, the energy demand growth is increasing drastically. World's energy demand heavily depending on fossil fuels buy they may runout in few years. International Energy Agency said 'The world may lug towards renewable sources to diminish greenhouse gas emissions but the pace isn't speedy enough to balance the knock of world-wide growing population and economic expansion'. photovoltaic (PV) renewable energy sources are inexhaustible, absolutely free and without causing harm to the environment but they can't generate their power at high voltages levels. PV's output voltage has to be boosted up higher enough for providing any electrical appliances

Conventional dc-dc converters with low voltage gain not suitable for PV applications unless multiple cells are connected in series but it may affect efficiency of the system. High step-up voltage gain dc-dc converters are using for the applications DC distribution systems, data centres, power in space, military uses, transportation, stand-alone power, radar systems and renewable energy harvesting [1, 2]. These converters convert unregulated low level DC output voltage of PV panel to regulated high level DC voltages.

Conventional boost converter step-up DC voltages are extremely high duty cycles with low frequency but voltage stresses across components increases and in addition, the magnetic element ensures that the conduction mode remains constant., which decreases the power density and increases weight of the converter [3].

Cascading conventional boost converters in series decrease some voltage stresses and increase voltage gain without having to use a very high duty cycle, [4-6]. Its voltage gain Vo/Vin=1/(1-d) m where d=duty cycle and m=number of cascaded converters but it ensures low efficiency. Adding more converters will increase their output voltages, but voltage balance problems may arise. [7].

Three level boost converters reduce inductor size and minimize voltage stresses, but they are still impractical because of the low voltage gain [8]. Isolated converters increase voltage gain by increasing secondary number of turns of the transformers [9-11]. but the problems with isolated converters are their weight, size, and voltage stress across switches due to spikes caused by leakage inductance.

By charging and discharging capacitors, switched capacitors (SC) and hybrid converters can boost voltage gain. SC circuits do not use large magnetic storage elements it would reduce the weight of the converter and increased power density [12-15]. Multilevel boost converter (MBC) and Switched inductor boost converter (SIBC) have high voltage gain without scarifying its performance [16-18].

Voltage source or current source inverters can convert these DC output voltages to AC voltages [19]. Trebles faced by these inverters are high switching loses, only two-level output and total hormonic distortion (TDH). Multi-level inverters (MLI) obtain pure sinusoidal waveform by overcome harmonics. Diode-clamped multilevel inverter, cascaded multilevel inverter and Flying capacitor multilevel inverter are popular. H-bridge inverter produce AC voltage by DC voltages.

A transformer less SIMSBC fed H-bridge Nine Level Inverter is described here.

The proposed system block diagram is shown in Fig. 1

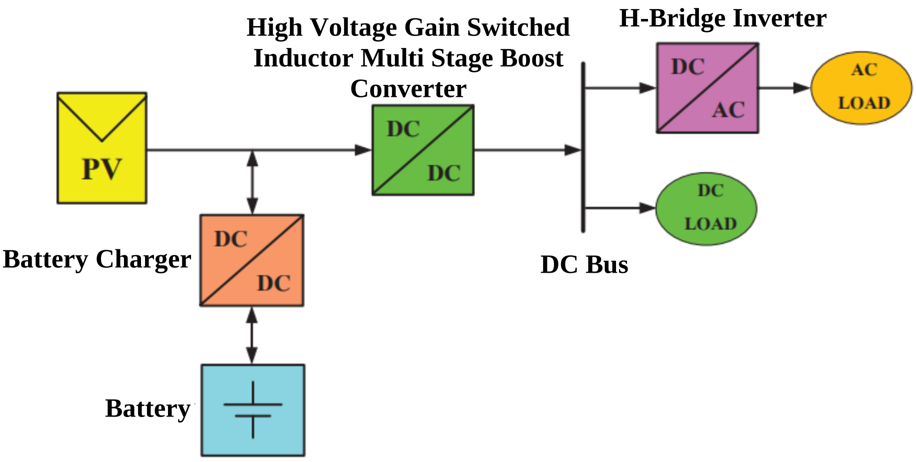


Fig. 1. Block diagram of proposed system.

The converter design incorporates a High Voltage Gain Switched Inductor Multi Stage Boost Converter to produce self-balancing high voltage gain outputs without compromising performance. This High voltage DC may use to DC load and H-bridge inverter can produce AC outputs for AC loads. Battery used to store and backup the power when needed. This topology requires only two magnetising components, seven capacitors and nine switches to produce nine level output voltage.

2. Operating Modes of SIMSBC fed H-bridge converter

The principle of operation of these converters can be explained by two operating modes.in this section Power circuit, operating principle and Switching States of proposed SIMSBC fed H-bridge Inverter are explained.

2.1. Power circuit

Figure 2 shows schematic diagram of proposed SIMSBC fed H-bridge nine level inverter. It consists of two switched inductors named L1 and L2, three diodes named DS1, DS2 and DS3 are used for switching of inductors, seven capacitors named C1, C2, C3, C4, C5, C6 and C7 are sequentially switched to produce different level voltages, nine switches named S for boost converter, SL1, SL2, SL3, SL4 for level switching, SH1, SH2, SH3 and SH4 for inverting operation. seven diodes named D1, D2, D3, D4, D5, D6, D7 are used for switching of capacitors. L is the Line reactor which stabilize, or smooth, the current waveform. This converter has two stages SIMSBC and level switching H-bridge inverter. SIMSBC has two operating modes and inverter has four level switching modes which were explained in the following sections.

2.2. SIMSBC operating principle

The principle of operation of these converters can be explained by two operating modes, first one is when the switch S is turned ON and second one is Switch S is turned OFF. The two operating modes of these converter are shown in Figs. 3 and

4. It is designed to operate in continuous conduction mode (CCM). The operating characteristics in two modes are described below.

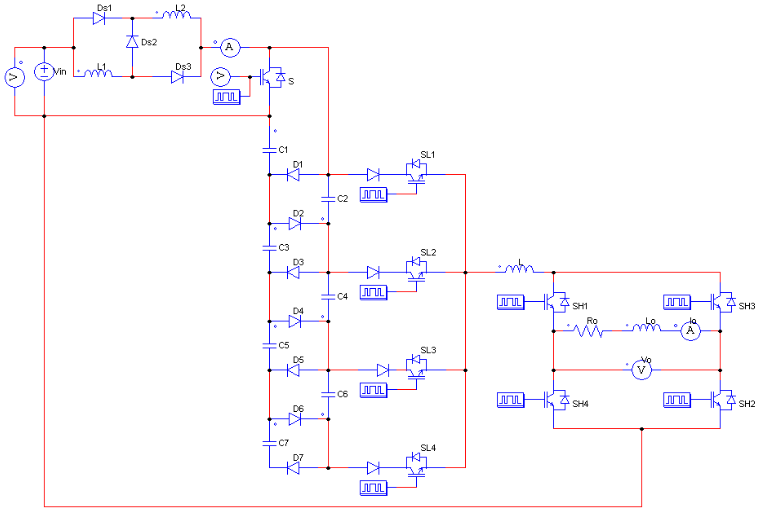


Fig. 2. SIMSBC fed H-bridge nine level inverter.

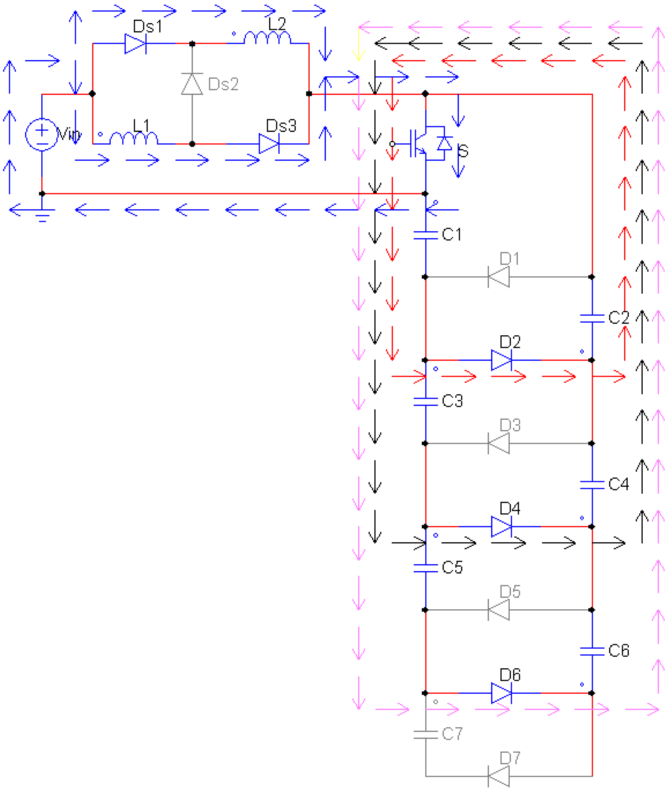


Fig. 3. Operation of SIMSBC when the Switch S is ON.

Mode 1: SIMBC operating under mode 1 as shown in Fig. 3. when the switch S is turned ON, the inductors L1 and L2 are connected to input voltage through diodes DS1 and DS3. If the voltage across capacitor C1 is smaller than C2 then capacitor C1 charges C2 through diode D2 and switch S until voltages are equal. Similarly, if the volage across C1 + C3 is less then C2 +C4, then C1 and C3 charge C2 and C4 through the diode D4 and switch S until voltages are equal. if the voltage across C1 + C3 + C5 is smaller than C2 +C4 + C6, then C1, C3 and C5 charge C2, C4 and C6 through the diode D6 and switch S until voltages are equal.

Mode 2: SIMBC operating under mode 2 as shown in Fig. 4. Diode D1 conducts when switch S is switched off, and the energy stored in inductors L1, L2 and the capacitor C1 is charged by the input voltage until the voltage across the capacitor equals the sum of the input voltage V_{IN} and the voltages of the inductors V_{L1} and V_{L2}. as shown in Fig. 3. simultaneously diode D3 conducts so that V_{IN}, V_{L1}, V_{L2}, V_{C2} charges capacitors C1 and C3. When $V_{C1}+V_{C3}$ is equal to $V_{IN}+V_{L1}+V_{L2}+V_{C2}$ then diode D3 turn off and diode D5 conducts so that V_{IN}, V_{L1}, V_{L2}, V_{C2} and V_{C4} charges the capacitors C1, C3 and C5 until $V_{C1}+V_{C3}+V_{C5}$ is equal to the voltage $V_{IN}+V_{L1}+V_{L2}+V_{C2}+V_{C4}$ then diode D5 turn off and diode D7 starts conducting and V_{IN}, V_{L1}, V_{L2}, $V_{C2,}$ V_{C4} and V_{C6} charges the capacitors C1, C3, C5 and C7 until $V_{C1}+V_{C3}+V_{C5+}V_{C7}$ is equal to the voltage $V_{IN}+V_{L1}+V_{L2}+V_{C2}+V_{C4}+V_{C6}$.

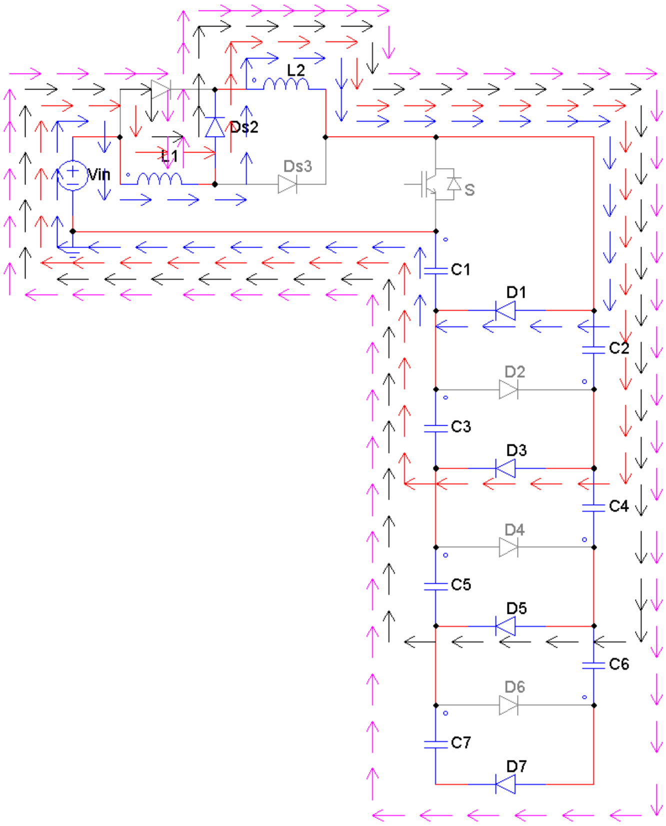


Fig. 4. Operation of SIMSBC when the Switch S is OFF.

2.3. Switching States of proposed SIMSBC fed H-bridge Inverter

Figures 5(a) to 5(h) show the operating switching states of proposed inverter. Figure 6(a) shows the proposed inverter's control mechanism is based on pulse-width modulation (PWM). In positive half cycle, circuit operation consists of four states (stage 2-5, Figs. 5(a) to 5(d)) and seven stages. H-Bridge inverter switches SH1 and SH2 are turned ON, SH3 and SH4 turned OFF for entire positive half cycle. Switches and capacitors are changed in each stage. The time intervals t0-t7 for each cycle are indicated in Fig. 6(b).

Stage 1 (Level 1) [t_0-t_1, Fig. 5(a)]: In this stage switches S_{L1}, S_{H1} and S_{H2} are turned ON remaining switches are turned OFF. then the current flows through input voltage, inductors L1 and L2, switches SL1, SH1 and SH2. voltage $V_{IN}+V_{L1+}V_{L2}$ or V_{C1} appears across the load.

Stage 2 (Level 2) [t_1-t_2, Figs. 5(b)]: In stage 2 switch S_{L1} turned OFF and switch S_{L2} turn ON. Capacitor C2 come into the circuit. now the current flows through the C2 and SL2 now the voltage appears across load is $V_{IN}+V_{L1}+V_{L2}+V_{C2}$ or $V_{C1}+V_{C3.}$

Stage 3 (Level 3) [t_2-t_3, Figs. 5(c)]: Stage 3 starts when switch S_{L2} turned OFF and switch S_{L3} turn ON. Capacitor C_3 starts conducting and now the current flows through V_{IN}, L1, L2, C2 and C4 now the voltage across load is either $V_{IN}+V_{L1}+V_{L2}+V_{C2}+V_{C4}$ or $V_{C1}+V_{C3}+V_{C5}$

Stage 4 (Level 4) [t_3-t_4, Figs. 5(d)]: when switch SL3 turn OFF and switch SL4 turn ON this stage begins. Now the elements V_{IN}, L1, L2, C2, C4 and C5 come into the circuit and the voltage $V_{C1}+V_{C3}+V_{C5+}V_{C7}$ or $V_{IN}+V_{L1}+V_{L2}+V_{C2}+V_{C4}+V_{C6}$ appears across load. Stage 5 [t4-t5, Fig. 5(c)]: Similar to stage 3 (Level 3).

Stage 6 [t5-t6, Fig. 5(b)]: Similar to stage 2(Level 2).

Stage 7 [t6-t7, Fig. 5(a)]: Similar to stage 1 (Level 3).

Similarly, in negative half cycle, circuit operation consists seven stages and four states (stage 2-5 Figs. 5(e) to 5(h)). For the entire negative half cycle, H-Bridge converter switches SH3 and SH4 are switched on, while SH1 and SH2 are turned off. Switches and capacitors are changed in each stage.

Level 0 is achieved [at t0 and t7] by turn off the switches SH1, SH2, SH3, SH4

The following Table 1 summarises the proposed inverter operating states in Nine level inverter mode.

Table 1. Switching states of the SIMSBC fed H-bridge nine level inverter.

Levels	Level switches	Inverter switches	Capacitors	V_{out}
	SL_1, SL_2, SL_3, SL_4	SH_1, SH_2, SH_3, SH_4	CL_1, CL_2, CL_3, CL_4	
4	0001	1100	1111	4*V* dc
3	0010	1100	1110	3*V* dc
2	0100	1100	1100	2*V* dc
1	1000	1100	1000	1*V* dc
0	0000	0000	0000	0
-1	1000	0011	1000	-1*V* dc
-2	0100	0011	1100	-2*V* dc
-3	0010	0011	1110	-3*V* dc
-4	0001	0011	1111	-4*V* dc

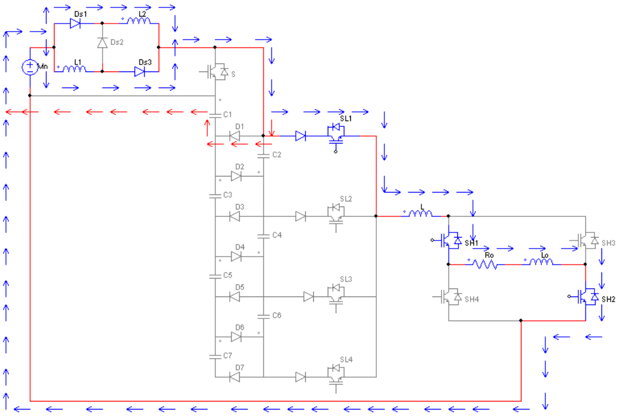


Fig. 5(a). Switching modes and current paths of SIMSBC fed H-bridge Inverter Level 1.

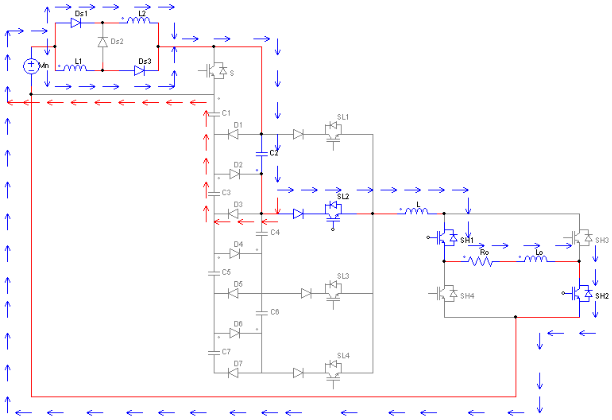


Fig. 5(b). Switching modes and current paths of SIMSBC fed H-bridge Inverter Level 2.

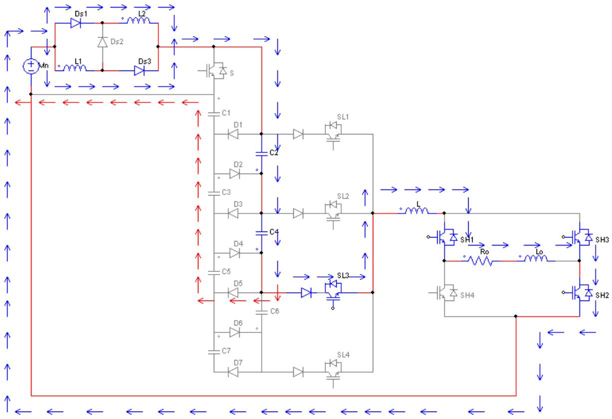


Fig. 5(c). Switching modes and current paths of SIMSBC fed H-bridge Inverter Level 3.

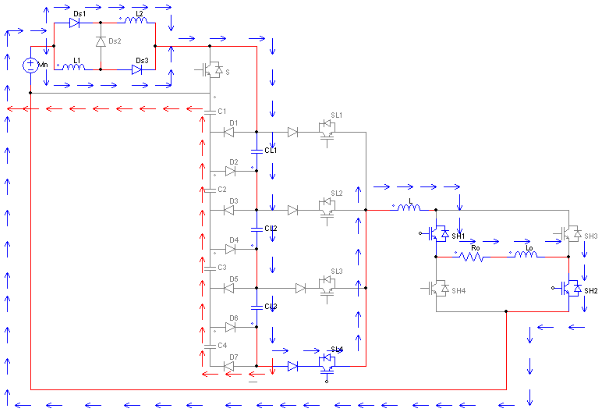


Fig. 5(d). Switching modes and current paths of SIMSBC fed H-bridge Inverter Level 4.

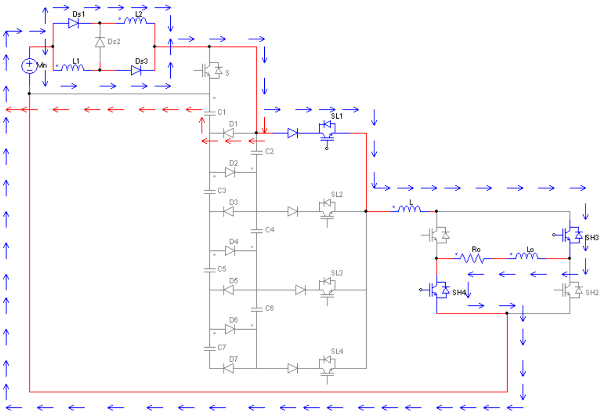


Fig. 5(e). Switching modes and current paths of SIMSBC fed H-bridge Inverter Level -1.

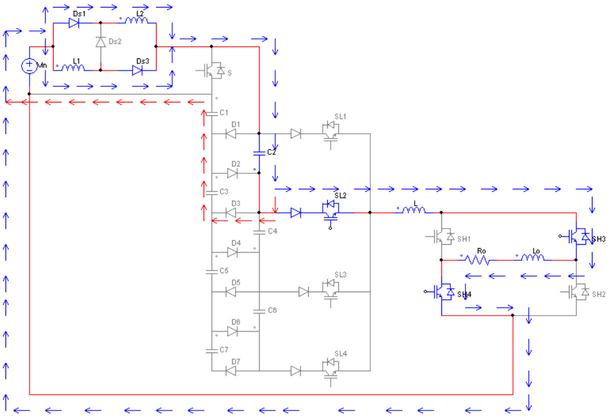


Fig. 5(f). Switching modes and current paths of SIMSBC fed H-bridge Inverter Level -2.

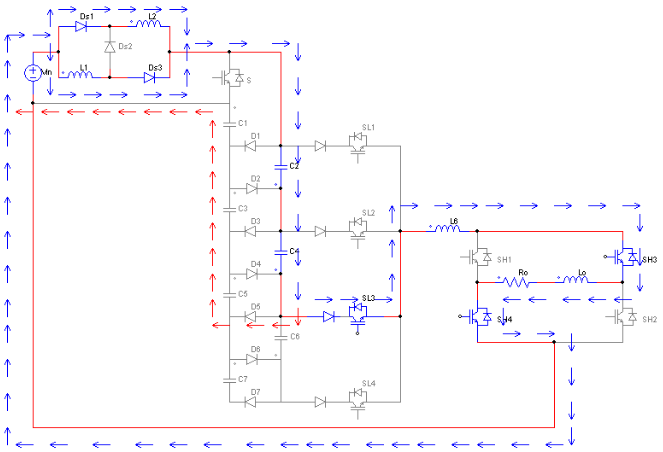


Fig. 5(g). Switching modes and current paths of SIMSBC fed H-bridge Inverter Level -3.

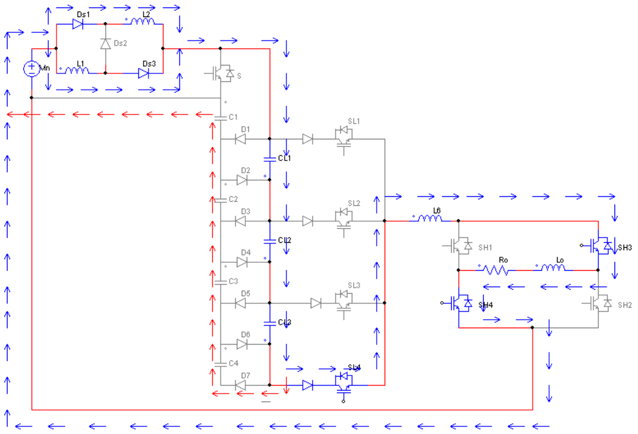


Fig. 5(h). Switching modes and current paths of SIMSBC fed H-bridge Inverter Level -4.

3. Analysis of the SIMSBC fed H-bridge converter in CCM

In the SIMSBC circuit, the input power is transferred to the output doubling the voltage through charging and discharging the switched-capacitor. For an idealized traditional boost converter, the average voltage of the inductor, which is zero across the whole switching cycle, can be represented as [20]:

$$V_l = (V_{in})\,D + (V_{in} - Vo)\,(1 - D) = 0 \tag{1}$$

where V_l is the inductor voltage, D is the duty cycle, V_{in} is the input voltage and Vo is the output voltage.

The steady state voltage is calculated using conventional analysis as follows:

$$\frac{Vo}{V_{in}} = \frac{1}{1-D} \tag{2}$$

The inductor current is determined by equating the input and output powers while ignoring losses, as shown below.

$$P_{out} = \frac{Vo\ 2}{R_o} \tag{3}$$

$$I_l = \frac{Vo\ 2}{V_{in}R_o}$$

From Eqs. (2) and (3), the inductor current is:

$$I_l = \frac{Vo}{(1-\mathrm{D})R_o} \tag{4}$$

However, with a switched inductor multi-stage boost converter, the optimum inductor equation is

$$V_l = V_{in}D + \left(\frac{Vin}{2} - \frac{Vo}{2\mathrm{N}}\right)(1 - \mathrm{D}\ ) \tag{5}$$

As a result, the new topology's gain ratio will be as follows:

$$\frac{Vo}{V_{in}} = \frac{\mathrm{N}(1+\mathrm{D})}{1-D} \tag{6}$$

ESR of the inductor for standard boost converter and the SIMSBC are taking into account Eq. (1) can be updated as:

$$V_l = (V_{in} - I_lR_l)D + (1 - D) * (V_{in} - Vo - I_lR_l) = 0 \tag{7}$$

The gain conversion ratio from equations (4) and (7) will be as:

$$\frac{Vo}{V_{in}} = \frac{1}{1-D+\frac{R_C}{(1-D)R_O}} \tag{8}$$

And for the SIMSBC, the solutions to equations (5) and (6) will be:

$$\frac{Vo}{V_{in}} = \frac{1}{\frac{1-D}{N(1+D)}+\frac{R_lN}{(1-D)R_O}} \tag{9}$$

The output voltage of the suggested topology is greater than that of a standard boost converter with N(1+D), where N seems to be the dc output voltage levels as well as D is the duty cycle, as shown in Equations (8) and (9).

The design values for inductors and capacitors of the SIMSBC can be found from conventional boost converter by replacing the voltage gain conversion ratio as given in Equations (10) and (11) below [21].

$$L = \frac{\mathrm{D}(1-D^2)R}{2N^2} \tag{10}$$

$$C = \frac{\mathrm{D}}{\mathrm{FR}\Delta V_C} V_{out} \tag{11}$$

4. Comparison among other High Gain Boost Converter

The proposed converter's features with other similar high gain DC-DC boost converters are listed in Table 2. The proposed converter's comparative analysis is based on its component count and voltage gain.

The converters described in Pires et al. [22], Fardoun and Ismail [23], and Mohamed and Fardoun [25] use the same number of inductors and switches as the converter that was originally proposed, but their voltage gains are lesser.

Table 2. Comparison with other high-gain DC/DC converters for two levels

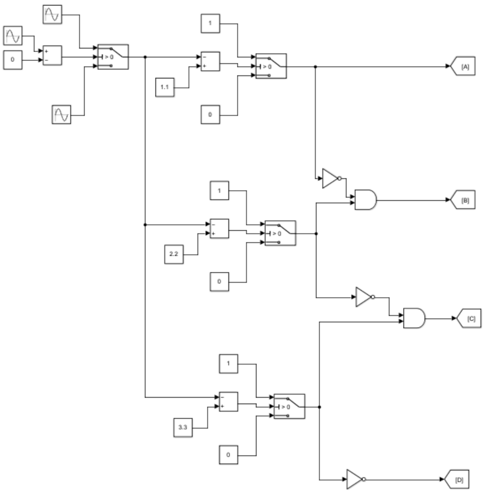
Topology	Number of Switch	Number of Inductors	Number of Diodes	Number of Capacitors	Voltage Gain	Voltage gain
Proposed	1	2	5	4	$\frac{N(1+D)}{1-D}$	12
[22]	1	2	4	5	$\frac{(1-D)}{(1-D)^2}$	6
[23]	1	2	5	4	$\frac{3+D}{1-D}$	7
[24]	1	3	5	3	$\frac{2}{(1-D)^2}$	8
[25]	1	2	5	4	$\frac{2-D}{(1-D)^2}$	6
[26]	6	6	14	8	$\frac{3+D}{1-D}$	7
[27]	2	4	9	1	$\frac{1+3D}{1-D}$	5

The converter analysed by Ahmad et al. [24] has a voltage gain that is 2 times that of CQBC, which is lower than the converter that was suggested, and the stress across the switch in this converter is identical to that of CQBC. Despite the fact that this converter uses three inductors, which makes it heavier.

When compared to the proposed converter, which uses six inductors, six switches, and four inductors, two switches, respectively, the converters in Maalandish et al. [26] and Gupta et al. [27] have very low gain.

5.PWM control Strategy

The most widely used method is sinusoidal PWM. The goal is to create desired frequency AC waveform. In this control strategy a sine wave is compared with e1 to e3 levels and corresponding output signals are produced. These signals are used to triggers the corresponding level switches.



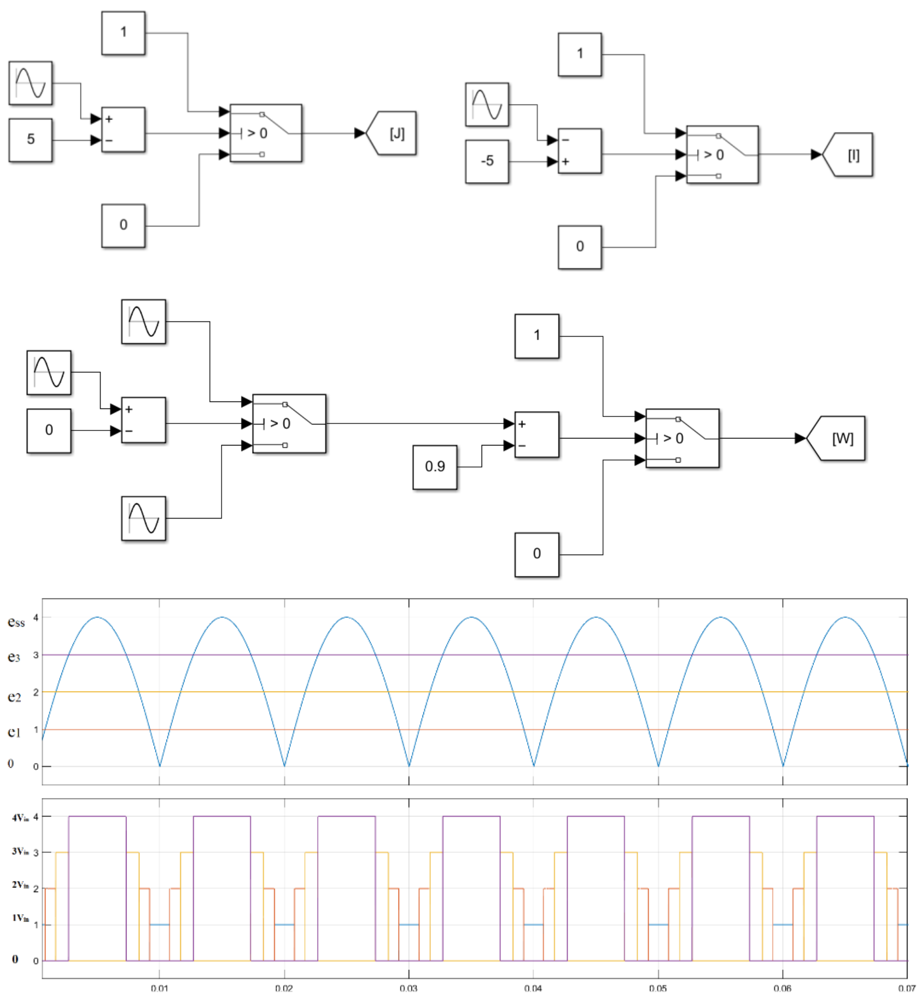


Fig. 6. The proposed inverter's SPWM control mechanism (a) controlled Logic scheme (b) control logic waveforms of the output in a half-period, where e0-e3 are carrier waveforms and es are the reference waveform.

6. Simulation Results

This section demonstrates the functionality of the proposed SIMSBC fed H bridge nine level inverter and simulation in MATLAB 2021(b) and PSIM are presented here. Table 3 lists the parameters of the suggested topology. The simulations were performed for a load of 200 ohm and 5 mH. Figure 7 shows the Simulation results for Output Voltage and output current waveform for SIMSBC fed nine level H-Bridge inverter. Here the maximum value of output voltage is 440V and current is 2.3 amps and the power handled by the converter is 1KW. And its efficiency is 95.8 (440×2.3)/ (12×88). Figure 8 shows the simulation results for SIMSBC fed H-Bridge inverter (a) Input Voltage waveforms Vin (b) input current waveform I_{in}. Figure 9 shows the THD of Output Voltage and current (Vab and Io). Figure 10 shows the harmonic spectrum of output voltage and output current.

Table 3. parameters of the SIMSBC.

Power rating	1 kW
Input voltage	12 V
Capacitor C1 to C7	500 μF
Carrier frequency	10 kHz
Output voltage (V_{ab})	440 V
Output frequency	50 Hz
Resister	200 ohm
Inductor	5mH

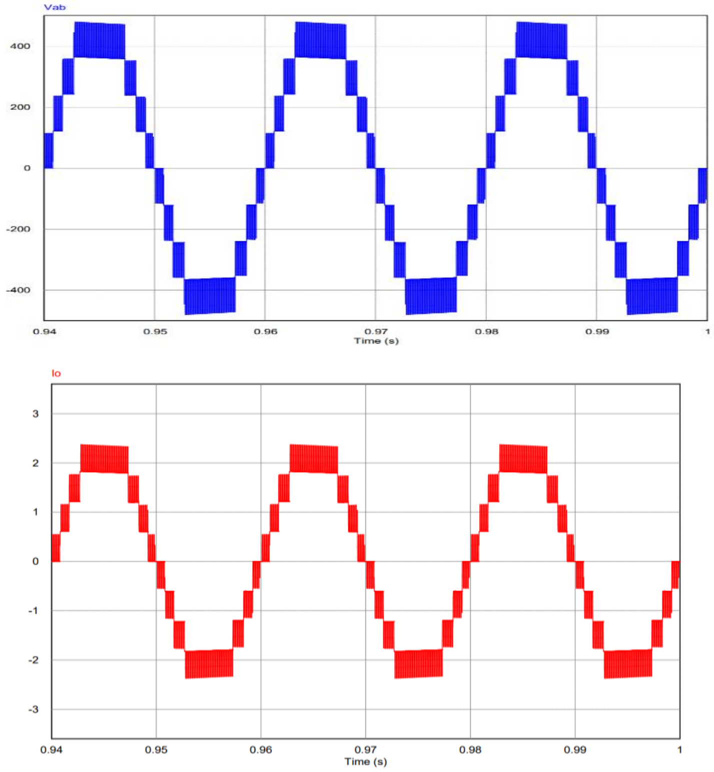


Fig. 7. Simulation results for SIMSBC fed H-Bridge inverter (a) Output Voltage waveforms V_{ab} (b) output current waveform.

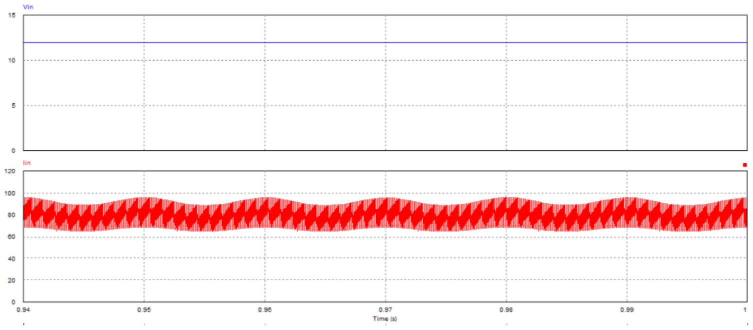
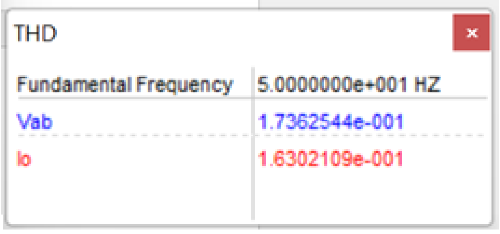


Fig. 8. Simulation results for SIMSBC fed H-Bridge inverter (a) Input Voltage waveforms V_{IN} (b) input current waveform I_{IN}.


THD

Fundamental Frequency	5.0000000e+001 HZ
Vab	1.7362544e-001
Io	1.6302109e-001

Fig. 9. THD of Output Voltage and current (Vab and Io).

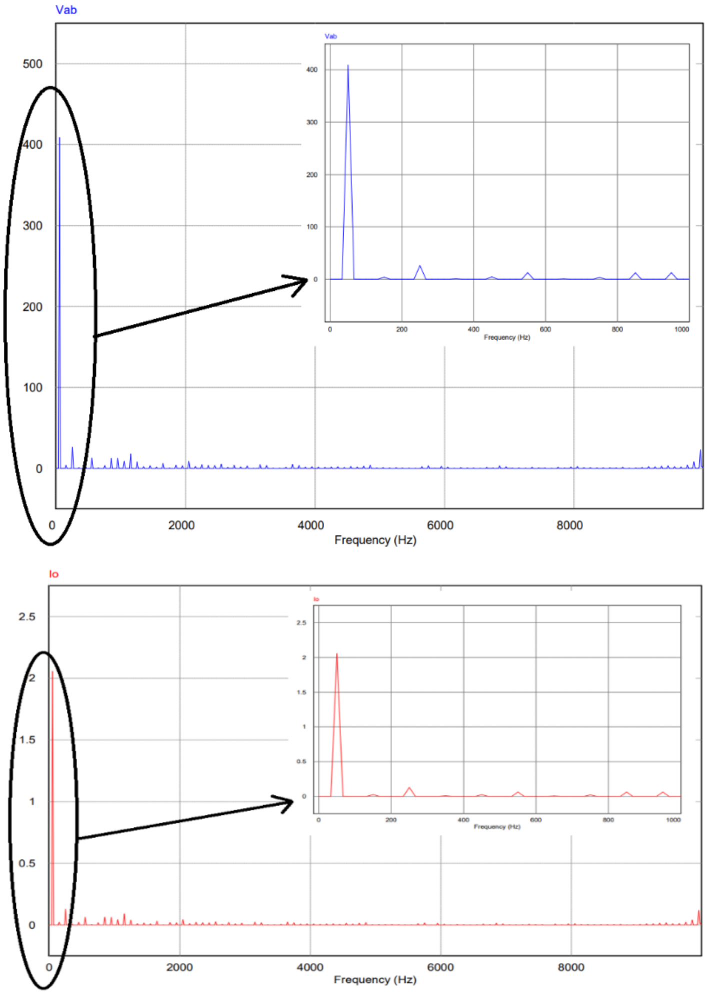


Fig. 10. Harmonic spectrum of (a) output voltage, (b) output current.

7. Conclusion

This paper describes a new form of multi stage DC-DC boost converter relies on switched capacitor and switched Inductor Structure. The real advantage of this topology is the high boosting ratio without the use of a transformer with minimum number of switches. This topology requires only two magnetising components, eight capacitors and nine switches to produce nine level output voltage with low TDH value, ultra-high voltage gain and high efficiency, but it suffers from voltage balancing problem at capacitors above four levels, hence its DC gain is limited to 36, four levels of output only, with this we can get nine level output voltage.

In comparison to earlier SCMIs, the SIMSBC fed H-bridge converter has fewer components, as a result, the power circuit's size and cost are lowered. SIMSBC fed H-bridge converter nine-level SC inverter's operating theory and PWM mechanism were given. This converter is ideal for single-phase applications with low power. The suggested inverter can be used for high-power applications with a Low component count and a nine levels of AC output.

Nomenclatures

I_l	Inductor Current
I_o	Output Current
V_{in}	Input Voltage
V_l	Inductor Voltage
V_o	Output Voltage

Abbreviations

AC	Alternating Current
DC	Direct Current
MBC	Multilevel boost converter
PV	Photo Voltaic
SIMSBC	Switched Inductor Multi Stage Boost Converter
THD	Total Harmonic Distortion

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