Design and Performance Analysis of Novel Boost DC-AC Converter

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***Abstract*—The Boost inverters are intended to be used in system like uninterruptible power supply (UPS), where an ac output voltage should be larger than the dc input voltage. Such inverters need more number of switches and two stages of power conversion. This work proposes a novel dc to ac boost based on sinusoidal-pulse-width-modulation (SPWM) control which generates output in single stage and whose peak value can be greater than the dc input one depending on the instantaneous duty cycle. This property is not found in the classical VSI, which produces an ac output voltage always lower than the dc input voltage. The proposed inverter performs single stage power conversion, which minimizes switching losses and attains higher efficiency as compared with conventional boost inverter, in spite of the 35% reduction in the number of switches. This paper describes a new PWM strategy for proposed boost inverter. This modulation strategy reduces the energy loss and harmonics in the proposed inverter. This technique allows the proposed inverter to become a new feasible solution for many applications like PV systems, automotive electronics, solar home applications and other power supply systems.**

Keywords-Boost inverter, inverter and sinusoidal-pulse-width-modulation.

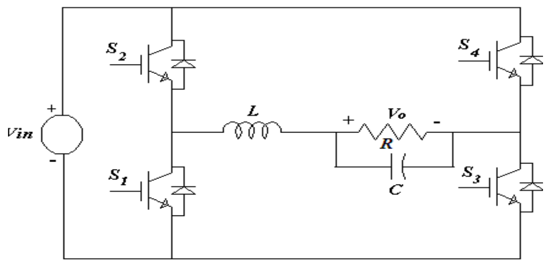

Figure 1. The conventional VSI or buck inverter

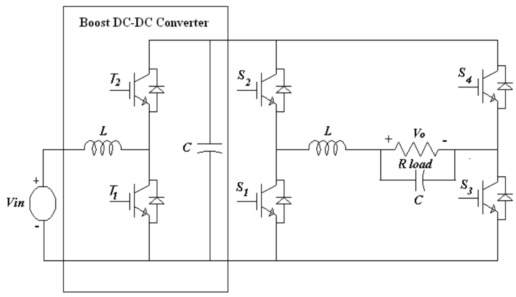

Figure 2. Conventional boost inverter

I. Introduction

The single phase voltage source inverter (VSI) shown in figure 1, uses the buck topology, which has the characteristic that the instantaneous average output voltage is always lower than the input dc voltage.

As a consequence, when an output voltage larger than the input one is needed, a boost dc-dc converter must be used between the dc source and inverter as shown in figure 2.

Depending on the power and voltage levels, this can result in high volume, weight, cost and reduced efficiency.

In this paper, a new VSI is proposed, referred to as boost inverter, which generates an output ac voltage larger than the input dc voltage depending on the duty cycle [1-4].

The classic solution for this kind of conversion is a boost regulator plus a P.W.M. voltage source inverter [5].

II. Basic Principle Of The New Proposed Inverter

The proposed boost inverter achieves dc–ac conversion, as shown in Figure 3, by connecting the load differentially across two dc–dc converters and modulating the dc–dc converter output voltages sinusoidally.The two converters 1 and 2 produces dc-biased sine wave output, so that each source only produces a unipolar voltage. The modulation of each converter is 180 degree out of phase with respect to other, which maximizes the voltage excursion across the load.

The output voltages of the converters are,

For converter 1, $V_1(t) = V_{dc} + V_m \sin wt$ (1)

For converter 2, $V_2(t) = V_{dc} + V_m \sin wt$ (2)

Output Voltage across the load is,

$$V_0(t) = V_1(t) - V_2(t) = 2V_m \sin wt = V_{op} \sin wt \quad (3)$$

The output voltage of the inverter is the difference between the outputs of the two converters. So, the differential dc voltage across the load is zero. The generation of the bipolar voltage at the output is solved by a push-pull arrangement [12]. Thus, the dc-dc converters need to be current bidirectional. Figure 4 shows the output voltage of the each converter alone.

The current bidirectional boost dc–dc converter is shown in Figure 5. A circuit implementation of the boost dc–ac converter is shown in Figure 6.

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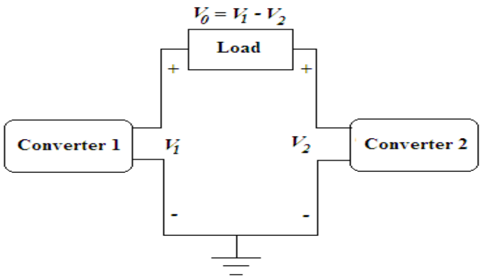

Figure 3. Block diagram of the proposed boost inverter

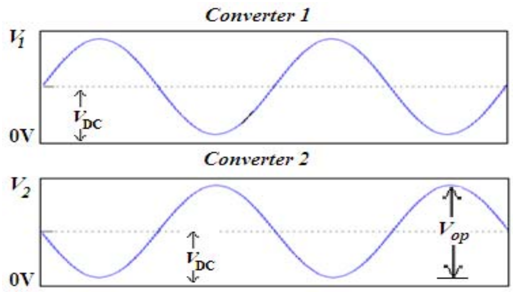

Figure 4. Output voltage characteristics of the converters

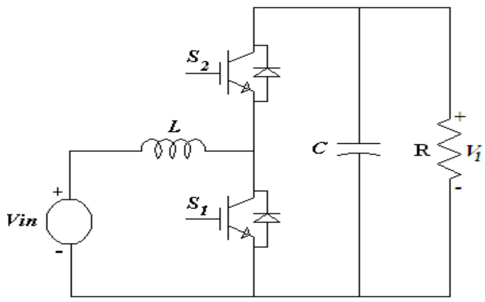

Figure 5. The current bidirectional boost dc–dc converter

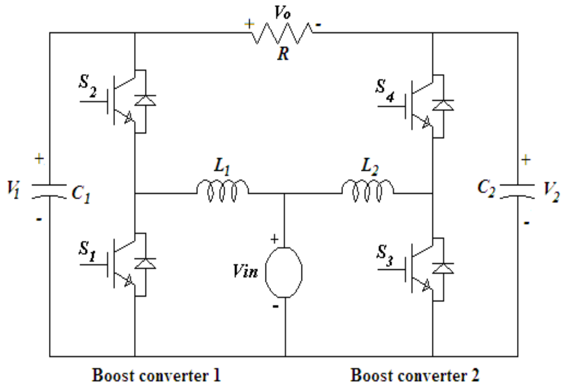

Figure 6. The proposed boost inverter

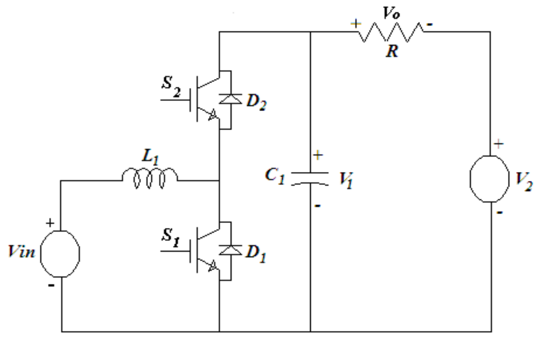

Figure 7. Equivalent circuit for the boost inverter

III. Principle Operation Of The Proposed Inverter

The operation of the boost inverter is analyzed using the equivalent circuit for the boost inverter shown in Figure 7. To do this the boost inverter is modeled as two dc/dc boost converters, but one is considered as an ideal sinusoidal voltage source. On the other hand, there are two possible positions of the switch (0 and 1). Figure 8 shows two topological modes for a period of operation.

Mode 1:

When the switch S_1 is closed and S_2 is open Figure 8(a), current i_{L1} rises quite linearly, diode D_2 is reverse polarized, capacitor C_1 supplies energy to the output stage, and voltage V_1 decreases.

Mode 2:

Once the switch S_1 is open and S_2 is closed Figure 8(b), current i_{L1} flows through capacitor and the output stage. The current i_{L1} decreases while capacitor C_1 is recharged.

The state-space modeling of the equivalent circuit with state variables i_{L1} and V_1 is given by

$$\begin{bmatrix} \frac{diL1}{dt} \\ \frac{dV1}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L1} \\ \frac{1}{C1} & \frac{-1}{RC1} \end{bmatrix} \begin{bmatrix} iL1 \\ V1 \end{bmatrix} + \begin{bmatrix} \frac{V1}{L1} \\ \frac{-iL1}{C1} \end{bmatrix} \gamma + \begin{bmatrix} \frac{Vin}{L1} \\ \frac{V2}{RC1} \end{bmatrix} \quad (4)$$

A. *DC Gain Characteristic of the Proposed Boost Inverter*

For a boost converter, by using the averaging concept, we obtain the following voltage relation for the continuous conduction mode:

Average output voltage of converter 1:

$$V_1 = \frac{V_{in}}{1-D} \quad (5)$$

Average output voltage of converter 2:

$$V_2 = \frac{V_{in}}{D} \quad (6)$$

Then the Output voltage can be obtained as:

$$V_0 = V_1 - V_2 = \frac{V_{in}}{1-D} - \frac{V_{in}}{D}$$

$$G_{dc} = \frac{V_0}{V_{in}} = \frac{2D-1}{D(1-D)} \quad (7)$$

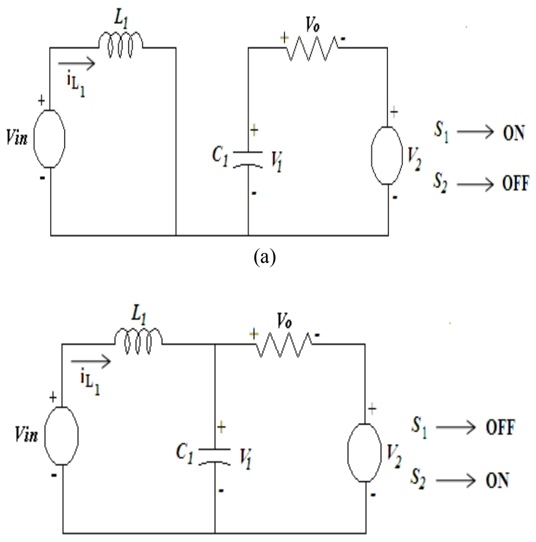

Figure 8. Modes of operation

Where D is the duty cycle. It should be noted that V_0 becomes zero at D=0.5.If duty cycle is varied around the quiescent point of 50% duty cycle, there is an ac voltage across the load.

B. *AC Gain Characteristic of the Proposed Boost Inverter*

Peak output voltage of the boost inverter:

$$V_{op} = 2V_m = 2V_1 - 2V_{dc} \tag{8}$$

A boost converter cannot produce an output voltage lower than the input voltage. So the dc component must satisfy the condition

$$V_{dc} \geq \frac{V_{op}}{2} + Vin \tag{9}$$

This implies there are many possible values of $V_{dc.}$ However equal term produces the least stress on the devices. From the equation (5),(8) and (9),we get

$$V_{op} = \frac{2V_{in}}{1-D} - 2\left(\frac{V_{op}}{2} + V_{in}\right) \tag{10}$$

$$G_{ac} = \frac{V_{op}}{V_{in}} = \frac{D}{1-D} \tag{11}$$

Thus, V_{op} becomes V_{in} at D =0.5.

The gain characteristic of the boost inverter is shown in Figure 9.

IV. CONTROL DESIGN METHODOLOGY

In the design of the converter, the following are assumed:

- ideal power switches;
- power supply free of sinusoidal ripple;
- converter operating at high-switching frequency.

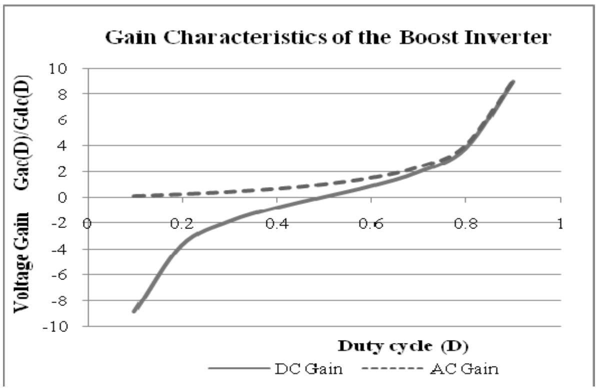

Figure 9. Gain characteristic of the boost inverter

A. *Selection of Control Parameters*

Once the boost inverter parameters are selected, inductances L_1 and L_2 are designed from specified input and output current ripples, capacitors C_1 and C_2 are designed so as to limit the output voltage ripple in the case of fast and large load variations, and maximum switching frequency is selected from the converter ratings and switch type.

B. *Design Example*

The design of the boost inverter is made considering that the switching frequency (f_s) is higher than 50 Hz and a resistive load is used.

The parameters used are P_o=200W,f_{smax}=5 kHz (should be high),V_{in}=48V,V_0= 120 V_{rms}. The implementation is based on the maximum ripple desired in the inductor current and capacitor voltage.

Output voltage V_0=170 sin314t

Peak output voltage $V_{op} \approx 170$

First, the dc component of the capacitor voltage is calculated from the equation(9),

$$V_{dc} \geq \frac{V_{op}}{2} + Vin$$

V_{dc} results 133 V. In order to avoid a "trimed"output voltage,V_{dc} is chosen 150 V.

The maximum capacitor voltage and inductor current is determined by

$$V_{cmax} = V_{dc} + \frac{V_{op}}{2} \tag{12}$$

$$I_{Lmax} = \frac{2D_{max} - G_{m'}(1 - D_{max})}{(1 - D_{max})^2} \tag{13}$$

Where

$$D_{max} = 1 - \frac{V_{in}}{V_{dc} + \frac{V_{op}}{2}} \tag{14}$$

$$G_{m'} = \frac{2(V_{dc} - V_{in})}{V_{in}} \tag{15}$$

Solving, $D_{max} \approx 0.8$, V_{cmax}=235V and i_{Lmax} = 12.5A. The inductance and capacitance are calculated with a 20% and1.5% of ripple, respectively

$$L = \frac{t_{on}}{\Delta I_L \, I_{Lmax}} Vin \tag{16}$$

$$C = \frac{t_{on}}{\Delta V_C \, V_{Cmax}} I_{op} \tag{17}$$

Where I_{op} = Peak output current ≈2.35A

As the switching bounder technique used is maintaining the turn on time constant, t_{on} is calculated with

$$t_{on} = \frac{D_{max}}{f_{s\,max}} \tag{18}$$

t_{on}= 160 Substituting, the inductance and capacitance are L≈3055µH and C≈106 µF.

V. SPWM CONTROLLER

Sliding mode (SM) controllers are well known for their robustness and stability. Most of the previously proposed SM controllers for switching power converters are hysteresis modulation (HM) (or delta-modulation) based [1]–[7]. An alternative solution to this is to change the modulation method of the SM controllers from HM to pulse-width modulation (PWM)[8]. To the authors' knowledge, this concept was first published in [9]. The idea is based on the assumption that at a high switching frequency, the *control action* of a sliding mode controller is equivalent to the *duty cycle control action* of a PWM controller. Hence, the migration of a sliding mode controller from being HM based to PWM based is made possible. This proof was shown in a companion paper [10] by the same authors.

Modulation Index:

Amplitude Modulation Index: $$M = \frac{A_r}{A_c} \tag{19}$$

Where,

A_r – Amplitude of sinusoidal reference signal

A_c – Amplitude of triangular carrier wave signal

A. PWM Generator Circuit

PWM generator circuit produces gating signal for the switches S1-S4.It is generated by comparing the sinusoidal reference signal with triangular carrier wave signal.PWM generator circuit is shown in figure 10.

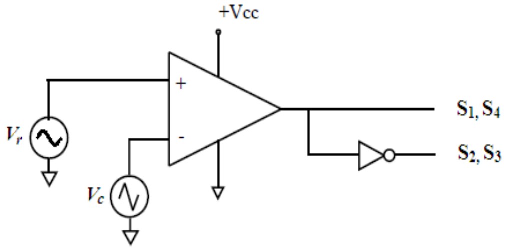

Figure 10. PWM Generator Circuit

The detailed operation of the SPWM control is as follows:

When $V_c < V_r$, S_1,S_4 = ON and S_2,S_3 = OFF.

When $V_c > V_r$, S_2,S_3 = ON and S_1,S_4 = OFF.

Where,

V_c – Voltage amplitude of triangular carrier wave signal.

V_r – Voltage amplitude of sinusoidal reference signal.

The theoretical waveforms of SPWM control is shown in figure 11.

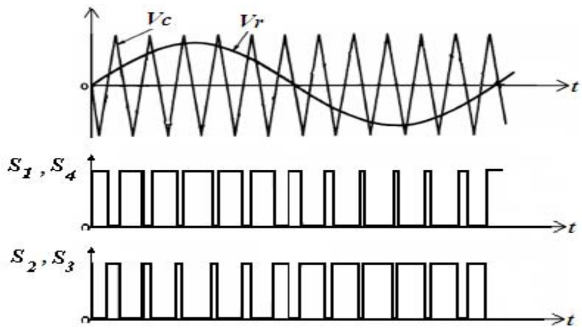

Figure 11. Theoretical waveforms of SPWM control

VI. SIMULATION RESULTS

The performance of the proposed boost inverter is verified via computer simulation. The simulations are conducted using MATLAB SIMULINK software package. The simulated circuit for resistive load is shown in Figure 12.

Figure 13-16 show simulation waveforms of the converter for resistive load of R=72Ω. The circuit parameters in the simulation are given as follows: Vin =48V, V0= 120 Vrms, L1=L2= 3055 µH, C1=C2=106 µF, R=72Ω.

Figure 13 shows the waveforms of converter1 and Figure 14 shows the waveforms of converter2. The waveforms of converter shows current through the inductor & diode, voltage across the capacitor and collector current and collector to emitter voltage of switch IGBT.

Figure 15 shows the output current waveform and Figure 16 shows the voltage across each converter side capacitor and R-load.For the above circuit parameters, THD is measured using FFT analysis and the THD value is 19.10%.

VII. CONCLUSION

This study has proposed a novel boost DC-AC converter topology, which is designed by the DC-DC boost converter. As a result, it offers the advantages of ease in implementation and reduced complexity of the circuit. The other advantages of proposed boost inverter over conventional boost inverter scheme can be summarized as follows:

(1) Reduced switching loss.
(2) Improved efficiency and reliability.
(3) Simplified PWM control scheme.
(4) Reduced cost, size and weight compared to conventional systems.

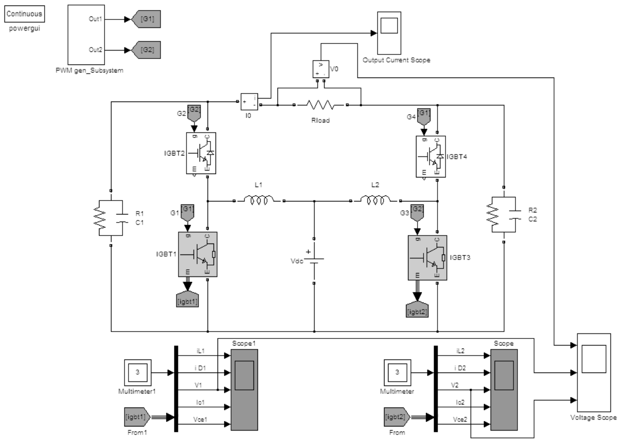

Figure 12. Simulation circuit of Boost inverter

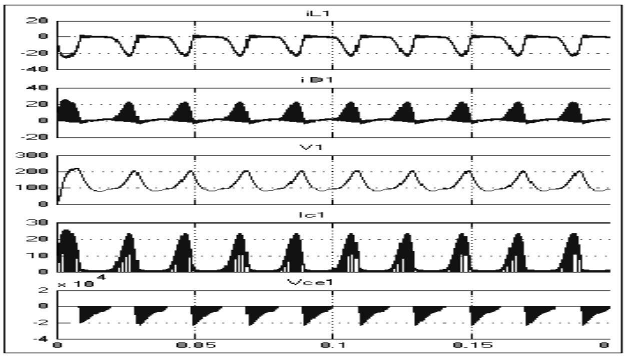

Figure 13. Waveforms of Converter 1

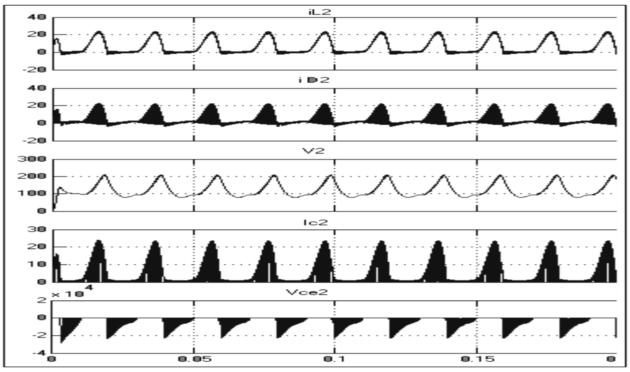

Figure 14. Waveforms of Converter 2

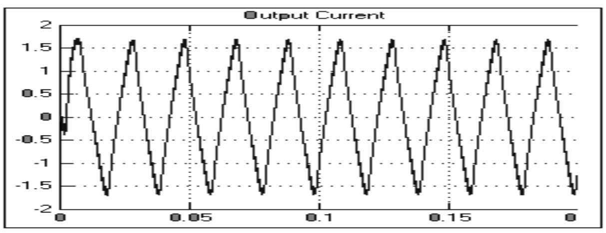

Figure 15. Output current

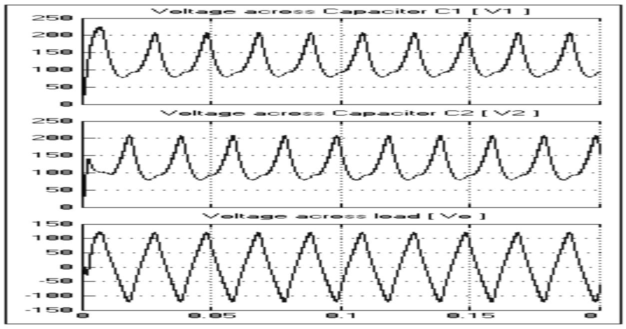

Figure 16. Voltage across each converter side Capacitor and Load

Therefore, the proposed boost inverter circuit is a good choice for many applications such as PV systems, UPS, automotive electronics and other power supply systems

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