

## A NEW TECHNIQUE OF PWM BOOST INVERTER FOR SOLAR HOME APPLICATION

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### ABSTRACT

This paper analyzes the procedural approach and benefits of applying optimization techniques to the design of a boost dc-ac converter with solar cell as an input. The analysis is performed based on the particular 12V DC to 220 V AC conversion for home applications. A traditional design methodology is the use of buck inverter. One of the characteristics of the most classical inverter is that it produces an AC output instantaneous voltage always lower than the DC input voltage. Thus, if an output voltage higher than the input one is needed, a boost dc-dc converter must be used between the DC source and the inverter. This paper describes a new P.W.M. strategy for a voltage source inverter. This modulation strategy reduces the energy losses and harmonics in the P.W.M. voltage source inverter. This technique allows the P.W.M. voltage source inverter to become a new feasible solution for solar home application.

**Key words:** Boost Inverter, PWM, duty cycle, solar cell and inverter.

### I. INTRODUCTION

Solar Cells supply electric energy renewable from primary resources. Solar cells are rarely used individually. Cells with similar characteristics are under peak sunlight ( $1 \text{ W/m}^2$ ) the maximum current delivered by a cell is approximately  $30 \text{ mA/cm}^2$ . Cells are therefore paralleled to obtain the desired current [1]. So, it can charge a battery up to 12 volt DC. For residential use, all equipments require a pure sinusoidal 220V ac power supply. For this a static DC-AC converter is inserted between the solar cells and the distribution network. DC to AC conversion has been established as one of the most common operations in power electronics. The solar cell transforms the light energy into continuous electric energy. It represents a source with a good energy density. From an electric point of view, the solar cell is considered as a voltage source. This source is nevertheless imperfect. Therefore it is necessary to insert an inverter between the solar cell and the network in order to obtain the alternating electric source, assuming the transfer of light energy to the network. One of the characteristics of the most classical inverter is that it produces an AC output instantaneous voltage always lower than the DC input voltage [2]. Thus, if an output voltage higher than the input one is needed, a boost dc-dc

converter must be used between the DC source and the inverter. Depending on the power and voltage levels involved, this solution can result in high volume, weight, cost and reduced efficiency. The full-bridge topology can, however, be used as a boost inverter that can generate an output ac voltage higher than the input dc voltage [3].

### II. PHOTOVOLTAIC SYSTEM

Photovoltaic is the art of converting sunlight directly into electricity using solar cells. A silicon solar cell is a diode formed by joining p-type (typically boron doped) and n-type (typically phosphorous doped) silicon. Light shining on such a cell can behave in a number of ways as illustrated in figure 1 and the behavior of light shining on solar cell is shown in figure 2. It has six properties. To maximize the power rating of a solar cell, it must be designed so as to maximize desired absorption (3) and absorption after reflection (5).

1. Reflection and absorption at top contact;
2. Reflection at cell surface;
3. Desired absorption;
4. Reflection from rear out of cell-weakly absorbed light only;
5. Absorption after reflection;
6. Absorption in rear contact.

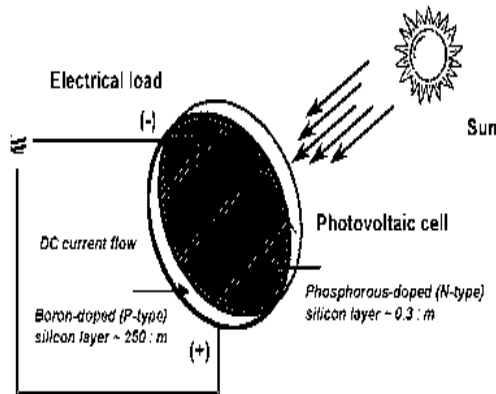


Figure 1. Diagram of a photovoltaic cell.

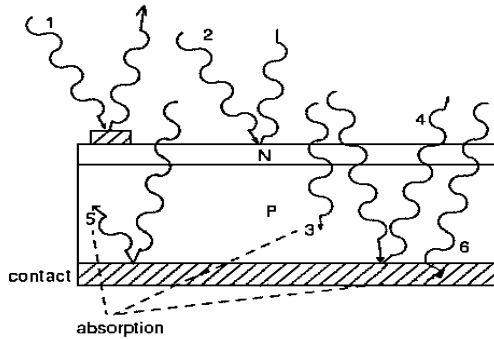


Figure 2. Behavior of light shining on solar cell

## II.II PV CELL INTERCONNECTION AND MODULE DESIGN

Solar cells are rarely used individually. Rather, cells with similar characteristics are connected and encapsulated to (arrays) which, in turn, are the basic building blocks of solar arrays. Usually about 36 cells are used for a nominal 12 V charging system.

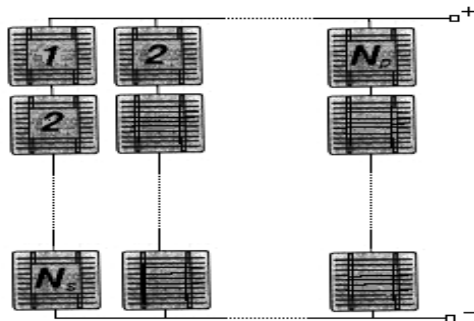


Figure 3. Cells in series and in parallel.

## III. DESCRIPTION OF THE CIRCUIT

### A. Boost Inverter:

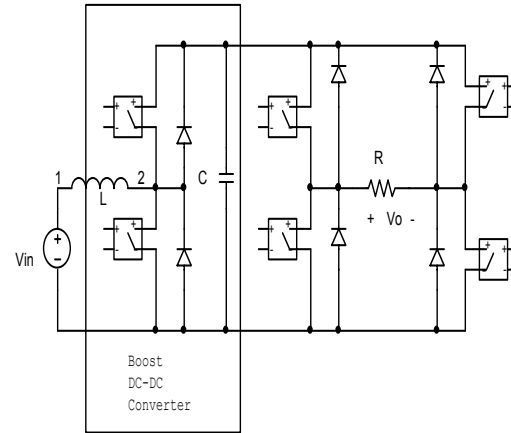


Figure 4. Circuit used to generate an AC voltage larger than DC input voltage

The typical single phase VSI uses the topology which has the characteristic that the average output voltage is always lower than the input dc voltage. Thus if an output voltage higher than the input one is needed, a boost dc-dc converter must be used between the dc source inverter, shown in figure 4. Depending on the power and voltage levels involved, this solution can result in high volume, weight, cost and reduced efficiency. The full bridge topology can, however, be used as a boost inverter that can generate an output ac voltage than the input dc voltage [4,5].

### B. Basic Principle:

Let us consider two dc-dc converters feeding a resistive load R as shown in figure 5a. The two converters produce dc-biased sine wave output such that each source only produces a unipolar voltage as shown in figure 5b. The modulation of each converter is 180 degrees out of phase with the other so that the voltage excursion across the load is maximized. Thus, the output voltage of the converters are described by

$$v_a = V_{dc} + V_m \sin \omega t \dots \dots \dots (i)$$

$$v_b = V_{dc} - V_m \sin \omega t \dots \dots \dots (ii)$$

Thus, the output voltage is sinusoidal as given by

$$v_o = v_a - v_b = 2V_m \sin \omega t \dots \dots \dots (iii)$$

Thus, a dc bias voltage appears at each end of the load with respect to ground, but the differential dc voltage across the load is zero.

### C. Principle of Boost Inverter

Each converter is a current bidirectional boost converter as shown in figure 5a. The boost inverter consists of two boost converters as shown in fig.5b. The output of the inverter can be controlled by one of the two methods: (1) use a duty cycle  $D$  for converter A and a duty cycle of  $(1-D)$  for converter B or (2) use a differential duty cycle for each converter such that each converter produces a dc-biased sine wave output. The second method is preferred and it uses controllers A and B to make the capacitors voltage  $v_1$  and  $v_2$  follow a sinusoidal reference voltage.

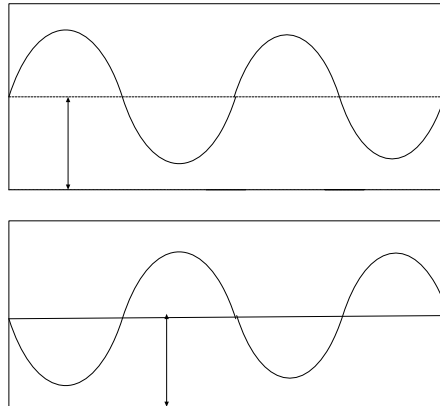
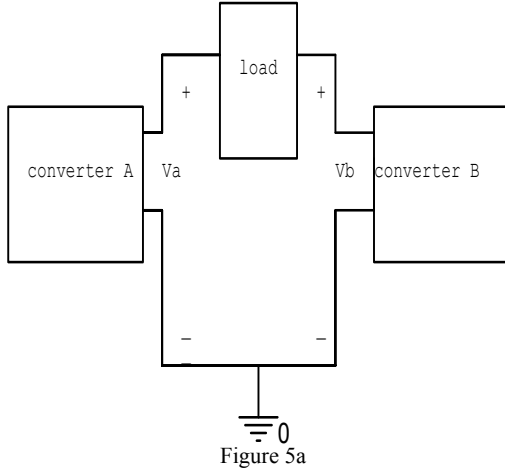


Figure 5b

Figure 5. Principle of boost inverter

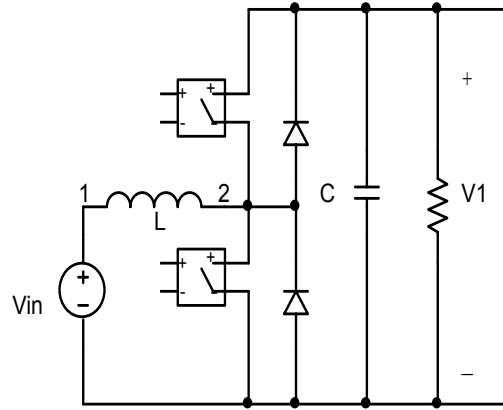


Figure 6a. The current bi-directional boost converter

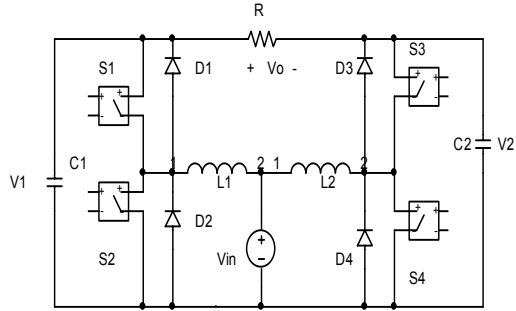


Figure 6b. The proposed DC-AC boost converter

### D. Circuit operation

The operation of the Inverter can be explained by considering one converter A only as shown in figure 7. There are two modes of operation: mode 1 and mode 2.

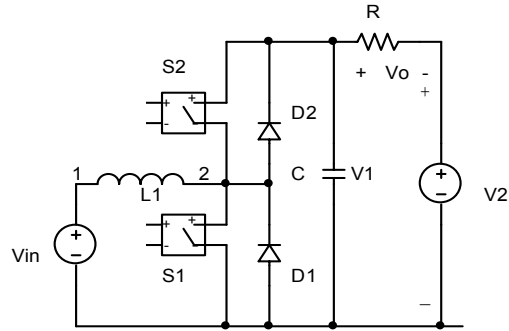


Figure 7. Equivalent circuit for the boost inverter

**Mode 1:** When the switch  $S_1$  is closed and  $S_2$  is open as shown in fig.8a, 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:** When switch  $S_1$  is open and  $S_2$  is closed as shown in fig.8b, current  $i_{L1}$  flows through capacitor and the output stage. The current  $i_{L1}$  decreases while capacitor  $C_1$  is recharged.

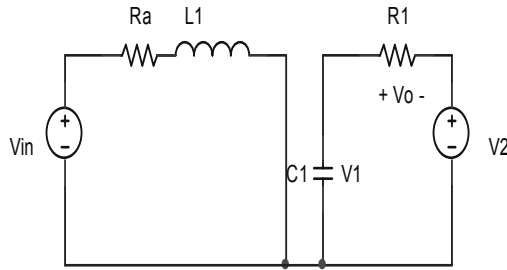


Figure 8a. Mode 1:  $S_1$  is closed and  $S_2$  is open

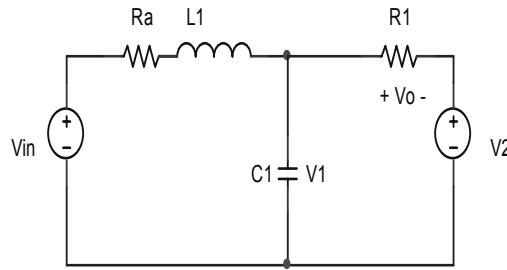


Figure 8b. Mode 2:  $S_1$  is open and  $S_2$  is closed

The average output of converter A, which operates under the boost mode, can be found from

$$\frac{V_1}{V_{in}} = \frac{1}{1-D} \dots\dots\dots (iv)$$

The average output of converter B, which operates under the buck mode, can be found from

$$\frac{V_2}{V_{in}} = \frac{1}{D} \dots\dots\dots (v)$$

Therefore, the average output voltage is given by

$$V_o = V_1 - V_2 = \frac{V_{in}}{1-D} - \frac{V_{in}}{D} \dots\dots\dots (vi)$$

This gives the dc gain of the boost inverter as

$$G_{dc} = \frac{V_o}{V_{in}} = \frac{2D-1}{D(1-D)} \dots\dots\dots (vii)$$

where  $D$  is the duty cycle. It should be noted that  $V_o$  becomes zero at  $D=0.5$ . If the duty cycle  $D$  is varied around the quiescent point of 50% duty cycle, there is an ac voltage across the load. Because the output voltage in equation in (iii) is twice the sinusoidal component of converter A, the peak output voltage equals to

$$V_{o(pk)} = 2V_m = 2V_1 - 2V_{dc} \dots\dots\dots (viii)$$

Because a boost converter cannot produce an output voltage lower than the input voltage, the dc component must satisfy the condition

$$V_{dc} \geq (V_m + V_{in})$$

Which implies there are many possible values of  $V_{dc}$ . However, the equal term produces the least stress on the devices. From the equation (iv), (vii) and (viii), we get

$$V_{o(pk)} = \frac{2V_{in}}{1-D} - 2\left(\frac{V_{o(pk)}}{2} + V_{in}\right).$$

It gives the ac voltage gain

$$G_{ac} = \frac{V_{o(pk)}}{V_{in}} = \frac{D}{1-D}$$

Thus,  $V_{o(pk)}$  becomes  $V_{in}$  at  $D=0.5$ .

#### IV. CIRCUIT SIMULATIONS AND RESULTS

Fig. 9 shows the conversion structure proposed in this paper. It consists of the cascade connection of two stages. The first stage is a boost-regulator and the second stage is the boost inverter.

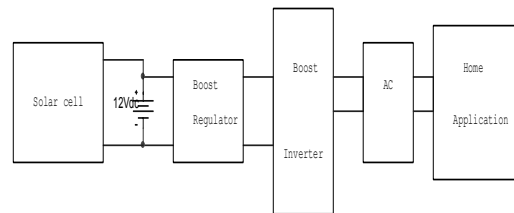


Figure 9. The conversion structure from solar cell to home

##### A. System description

The boost dc-ac converter is shown in Fig. 10. It includes dc supply voltage  $V_{in}$ , input inductors  $L_1$ ,

$L_2$  and  $L_3$ , power switches  $S_1 - S_5$ , transfer capacitors  $C_1 - C_3$ , free-wheeling diodes  $D_1-D_5$  and load resistance  $R$ . The principal purpose of the controllers A and B is to make the capacitor voltages  $V_1$  and  $V_2$  follow as faithfully as possible a sinusoidal reference. The operation of the boost inverter is better understood through the current bidirectional boost dc-dc converter shown in Fig. 7. In the description of the converter operation, we assume that all the components are ideal and that the converter operates in a continuous conduction mode. Fig. 8 shows two topological modes for a period of operation.

### B. 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.

### C. Selection of control parameters

Once the boost inverter parameters are selected, inductances  $L_1$ ,  $L_2$  and  $L_3$  are designed from specified input and output current ripples, capacitors  $C_1 - C_3$  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.

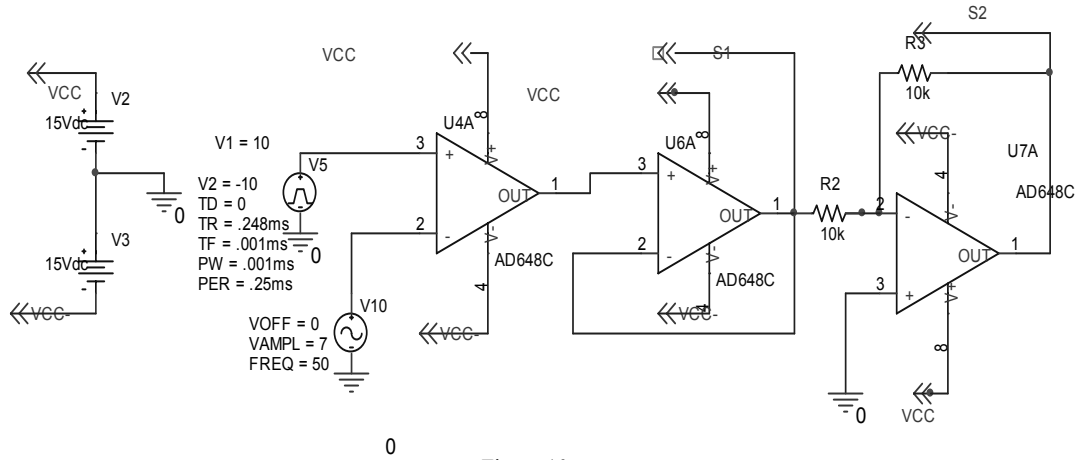


Figure 10 a.

### V. SIMULATION AND EXPERIMENTAL RESULTS

The parameters of the circuit for fig. 10 are as follows:

$S_1 - S_5$  : IRGBC40U (IGBT);

$D_1-D_5$  : MUR850 (diodes);

$C_1-C_2-C_3$  : 400  $\mu$ F

$L_1-L_2-L_3$  : 10 mH

Frequency,  $f=50$ Hz.

$R=200$  ohm

$V_{in} = 12$  V<sub>dc</sub>

$V_{out} = 220$  V<sub>ac</sub>

### VI. CONCLUSION

This paper presents a new type of DC - AC converter, referred to as boost inverter. The active switches (IGBT's) are operated at a fixed frequency with the duty cycle around 50 %, which allows the use of a simple gate drive. From the circuit operation it is shown that it takes 423 ms to achieve 220V AC. The new inverter is applicable in UPS design, whenever a AC voltage larger than the DC link voltage is needed, with no need of a second power conversion stage. This circuit arrangement is better for solar cell to home application. Reviewing the proposal and contributions made in this paper, we can suggest some future works to be done to achieve the same or related goals.

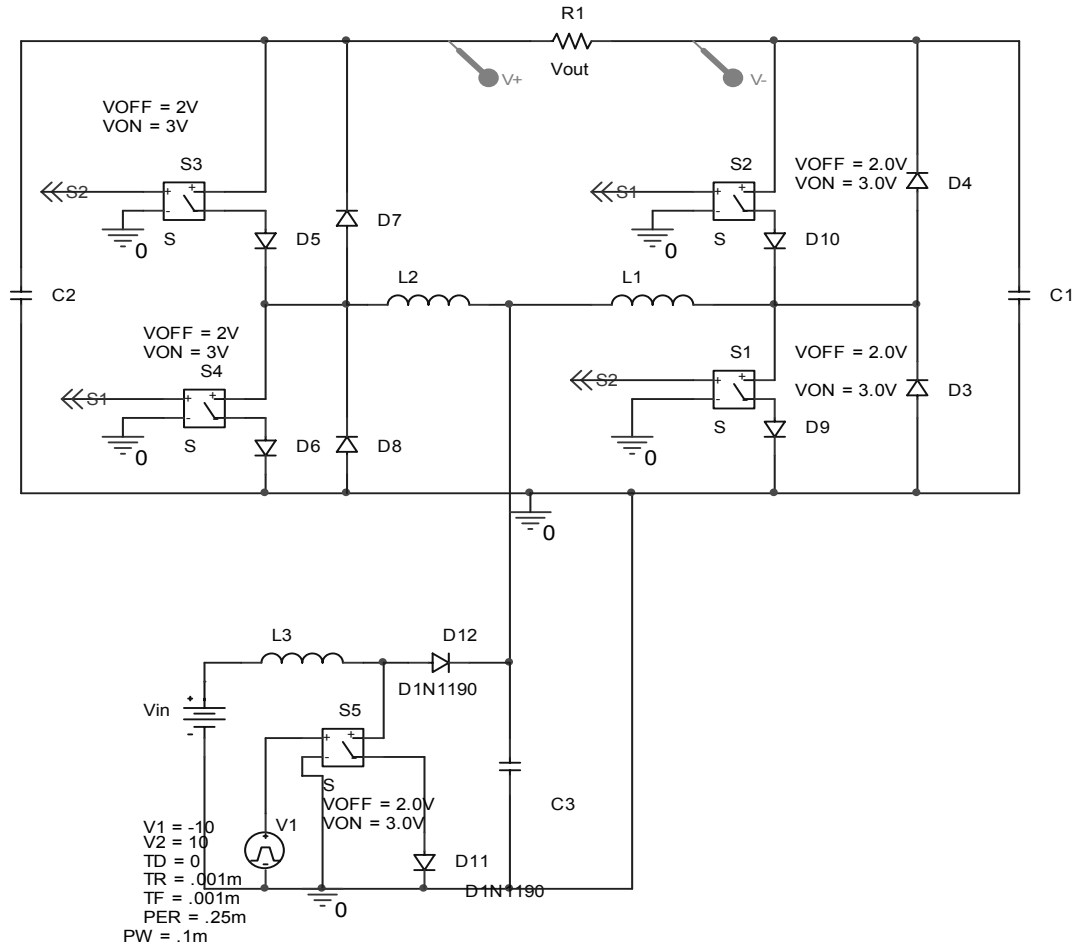


Figure 10b

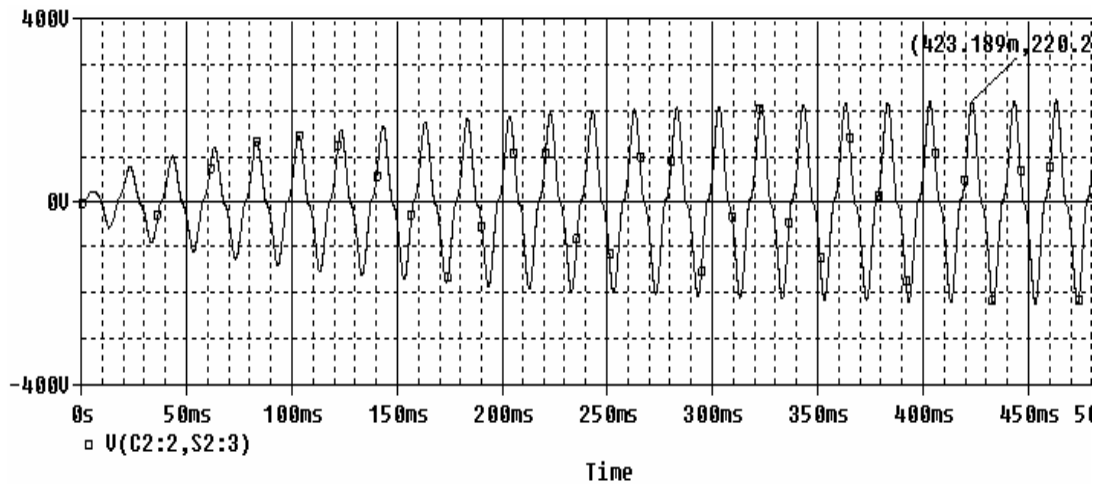


Figure 10 c

Figure 10. (a) Gate signal in circuit, (b) Boost Inverter using boost regulator as DC input and (c) AC wave shape

- Research can be done on minimizing the time to achieve the desired sinusoidal values.
- Research can be done on minimizing the capacitor current spikes in the inverter circuit.

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