Maximum Utilization Of Pv Based Sine Pwm Control Of Switched Boost Inverter For Ac Drives

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ABSTRACT
The Z-source inverter (ZSI) employs an LC impedance network between the main inverter bridge and the power source. The unique feature of the ZSI is that it can operate either in buck or boost mode with a wide range of obtainable output voltages from a given input voltage. This topology also exhibits better electromagnetic-interference noise immunity when compared to a traditional voltage-source inverter (VSI). However, the LC impedance network of ZSI significantly increases the size and cost of the power converter and can make it unsuitable for low-power applications. This paper proposes a novel topology called switched boost inverter (SBI) which exhibits similar advantages of ZSI with lower number of passive components and more active components compared to ZSI. The steady-state and small-signal analyses of SBI, along with its unipolar sine pulse width modulation (PWM) control strategies for AC drives have been discussed in this paper. This paper also presents a Zero current switching (ZCS) and comparison of SBI and ZSI with the same input and output parameters. The theoretical analysis given in this paper has been validated using a laboratory prototype of SBI, and the experimental results are presented for verification. The experimental harmonic spectrum of the inverter’s output voltage with the proposed PWM technique is also plotted and compared with that of a traditional VSI. All the experimental results show good correlation between theory and experiments.

KEYWORDS: Harmonic Analysis, Zero current switching (ZCS), Switched Boost Inverter, MPPT technique, Sine PWM.

INTRODUCTION
The Z-Source inverter (ZSI) consists of an X-shaped passive network to couple the main power converter and the power source as shown in Fig. 1. Unlike a traditional voltage-source inverter (VSI), the ZSI has the advantage of either stepping up or stepping down the input voltage by properly utilizing the shoot-through state of the inverter bridge [1]. As a result, the output voltage of the converter can be either higher or lower than the input voltage as per the requirement. In addition, the ZSI also possesses robust electromagnetic interference (EMI) noise immunity, which is achieved by allowing the shoot-through of the inverter leg switches. These features make the ZSI suitable for various applications such as renewable power systems, adjustable speed drive systems, uninterruptible power supplies [2]–[4], etc.

However, the impedance network with two inductors and two capacitors used in the ZSI significantly increases the size and cost of the power converter. Therefore, this topology may not be suitable for low-power applications where size, weight, and cost are the main constraints.
This paper presents a novel power converter called switched boost inverter (SBI) which works similarly to a ZSI. This converter uses more active components and lower number of inductors and capacitors compared to the original ZSI while retaining its operational advantages.

In this paper, the steady-state and small-signal analyses of the SBI are presented. Also, two different pulse width modulation (PWM) control strategies suitable for the SBI are described in this paper. Sections II and III present the steady-state and small-signal analyses of the SBI, respectively. In Section IV, the PWM control strategies of the converter are described. In Section V, a comparison of SBI and ZSI is given. The experimental results are given in Section VI to validate the theoretical analysis.

Fig. 1: Schematic of a ZSI

Note that, in this paper, $G_S$, $G_{S1}$, $G_{S2}$, $G_{S3}$, and $G_{S4}$ represent the gate control signals of switches $S$, $S_1$, $S_2$, $S_3$, and $S_4$, respectively, fed through a non inverting gate driver. Also, $X$ and $x$ represent the steady-state and peak values of a signal $x(t)$, respectively, while $x^*$ represents the small-signal variation in $x(t)$.

In this paper, to establish the suitability of the SBI in solar PV based AC drives application, a simulation work has been performed with interfacing it with solar PV module for establishing its suitability for micro-grid application with solar energy resources and also maximum power point tracking is applied in the converter operation to verify whether it is capable to extract optimum power from the solar modules at varying insolation.

II. Proposed SBI Topology:

Fig. 2 shows the proposed schematic of the SBI in which a switched boost network comprising of one active switch ($S$), two diodes ($D_a$, $D_b$), one inductor ($L$), and one capacitor ($C$) is connected between voltage source $V_g$ and the inverter bridge. A low-pass $LC$ filter is used at the output of the inverter bridge to filter the switching frequency components in the inverter output voltage.

Fig. 2: Proposed Circuit diagram of SBI topology.

Similar to a ZSI, the SBI also utilizes the shoot-through state of the H-bridge inverter (both switches in one leg of the inverter are turned on simultaneously) to boost the input voltage $V_g$ to $V_C$.

A. MPPT Technique
As the output of a solar module varies strongly with the load impedance and insolation and temperature of the solar module, it is essential to use a suitable power electronics interface to track the maximum power available from the solar module under different conditions. According to the maximum power transfer theorem the load impedance should be equal to the source impedance. The load impedance as shown in fig. 3 reflected back to the PV side with switched boost inverter (or boost converter)

Duty ratio is given by,

$$R_L' = \left(\frac{1-2D}{1-D}\right)^2 R_L.$$  \hspace{1cm} (1)

For maximum power transfer is,

$$R_{PV} = \frac{V}{I} = R_L'$$  \hspace{1cm} (2)

\[R_{PV}\rightarrow PV \text{ panel impedance}  \\
V\rightarrow PV \text{ Voltage}  \\
I\rightarrow PV \text{ Current} \]

The very common algorithm used for MPPT is the perturb & observe (P&O) algorithm. In this technique perturbation in the PV panel voltage is done to achieve the MPP. The PV panel voltage is perturbed with the change in the duty ratio of the boost converter. For this a fixed step size is used to change the duty ratio and according to change in duty ratio the PV voltage changed to achieve the MPP. In this paper, P&O algorithm is used in the MATLAB simulation of SBI.

Fig. 4: Proposed MPPT Controller P&O Method.

Fig4. represents the proposed MPPT Controller based Sine PWM generation for Switched Boost inverter. It helps to achieve the maximum power with reduced harmonics content in output A.C voltage.

Fig. 5: Proposed PV Module output Voltage.
Fig 5 represents the proposed P&O MPPT algorithm based PV output voltage. In order to achieve the maximum PV voltage by using P & O MPPT Controller.

B. Steady State Operation:
To explain the steady-state operation of the SBI, assume that the inverter is in shoot-through zero state for duration $D.T_S$ in a switching cycle $T_S$. The switch $S$ is also turned on during this interval. As shown in the equivalent circuit of Fig. 6(a), the inverter bridge is represented by a short circuit during this interval. The diodes $D_a$ and $D_b$ are reverse biased (as $V_C > V_g$), and the capacitor $C$ charges the inductor $L$ through switch $S$ and the inverter bridge. The inductor current in this interval equals the capacitor discharging current.

For the remaining duration in the switching cycle $(1 - D).T_S$, the inverter is in non-shoot-through state, and the switch $S$ is turned off. The inverter bridge is represented by a current source in this interval as shown in the equivalent circuit of Fig. 3(b). Now, the voltage source $V_g$ and inductor $L$ together supply power to the inverter and the capacitor through diodes $D_a$ and $D_b$. The inductor current in this interval equals the capacitor charging current added to the inverter input current. Note that the inductor current is assumed to be sufficient enough for the continuous conduction of diodes $D_a$ and $D_b$ for the entire interval $(1 - D).T_S$.

Fig. 6(c) shows the steady-state waveforms of the converter operation for one switching cycle $T_S$ with respect to the gate signal $G_S$ of switch $S$. From Fig. 3(a) and (b), one has

$$v_L(t) = \begin{cases} v_C(t), & \text{if } 0 < t < D.T_S \\ V_g - v_C(t), & \text{if } D.T_S < t < T_S \end{cases}$$

(3)

$$i_C(t) = \begin{cases} -i_L(t), & \text{if } 0 < t < D.T_S \\ i_L(t) - i_i(t), & \text{if } D.T_S < t < T_S \end{cases}$$

(4)

$$v_i(t) = \begin{cases} 0, & \text{if } 0 < t < D.T_S \\ v_C(t), & \text{if } D.T_S < t < T_S \end{cases}$$

(5)

Using small ripple approximation, (1)–(3) can be rewritten as

$$v_L(t) = \begin{cases} V_C, & \text{if } 0 < t < D.T_S \\ V_g - V_C, & \text{if } D.T_S < t < T_S \end{cases}$$

(6)

$$i_C(t) = \begin{cases} -I_L, & \text{if } 0 < t < D.T_S \\ I_L - I_i, & \text{if } D.T_S < t < T_S \end{cases}$$

(7)

$$v_i(t) = \begin{cases} 0, & \text{if } 0 < t < D.T_S \\ V_C, & \text{if } D.T_S < t < T_S \end{cases}$$

(8)
III. MODIFIED UNIPOLAR SINE PWM CONTROL OF SBI:

The SBI utilizes the shoot-through state of VSI to boost the input voltage $V_g$, whereas the modified SINE PWM techniques [3] of VSI do not permit the inverter bridge to be in shoot-through state. This section describes two different PWM techniques suitable for SBI.

For switched boost inverter, a modified unipolar sine PWM switching technique is used [9]. In the conventional sine PWM switching technique, a shoot-through period is added to build the modified sine PWM technique. As in simple unipolar sine PWM technique, two sinusoidal modulating or reference signal $V_{ref}(t)$ & $-V_{ref}(t)$ and a very high frequency carrier signal $V_c(t)$ (triangular wave) of frequency $f_s$ are used to generate the PWM signals. But in this technique an extra signal $V_{shoot}$ which is a constant signal is used. Due to this constant shoot-through signal the shoot-through period to the inverter legs which is compatible with the gating signal of the boost stage switch $S$ is added.

A. Gating signal for four Switches:

Gating signals for switch $S_1$ and $S_2$ are obtained by comparing $V_{ref}(t)$ & $-V_{ref}(t)$ respectively as shown in Fig (7) after obtaining the gating signal for switch $S_1$ and $S_2$ the gating signals for switch $S_3$ & $S_4$ are obtained with the use of constant shoot through signal $V_{shoot}$ as shown in fig 7.

Fig. 7: Reference signal, carrier (triangular signal) & shoot-through signal.

$m$ $\rightarrow$ modulation index  
$V_p$ $\rightarrow$ max value of carrier signal  
$V_m$ $\rightarrow$ max value of reference signal  
$m = V_m/V_p$  
(9)

The carrier wave switching frequency is much higher than the modulating signal frequency and is in the range of KHz.

The fundamental output voltage of the inverter is-

$V_{AB} = m \cdot V_c$  
(10)
The duty ratio $D$ of the boost converter should be chosen such that it does not disturb the power interval. Thus for that the duty ratio is given by the following relation

$$D < 1 - m$$
$$D + m < 1$$  \quad (10)

So for successful operation of the SBI the sum of the duty ratio & modulation index should be less than or equal to 1 such that shoot through period does not affect the power interval. The shoot through duty ratio $D$ can be varied by varying the shoot through constant $V_{\text{shoot}}$. The relation between the shoot through constant & duty ratio is given by the following equation

$$D = 1 - V_{\text{shoot}}/V_p$$  \quad (12)

IV PROPOSED SIMULATION:

In this simulation work, firstly simulation of the proposed topology is done with a fixed insolation profile in MATLAB simulink as shown in fig.8 for the topological verification of SBI.

![Proposed MATLAB/simulink model for A.C drive.](image)

Fig. 8: proposed MATLAB/simulink model for A.C drive.

Fig.8 represents the Proposed simulation with Motor load. The $Pv$ Output voltage is 38V and the output power of the motor load is 248W. And Fig.9 represents the PV model with MPPT controller it tracks the maximum output power is 48W.

The various waveforms got from this simulation are shown in fig. 10. The input voltage of the PV module is 38V when interfaced with the SBI as shown in fig.8. The capacitor ($C_{\text{in}}$) in parallel with the PV module is the input of the switched boost inverter as shown in fig. 8. The voltage across the DC bus (i.e. voltage across capacitor C) is 48V as shown in fig. 8, which is the boosted voltage from 38V with duty ratio of 0.2. With this DC bus voltage, a bank of batteries of nominal voltage 48V can be charged. The battery voltage may be 12V, 24V, 48V or may be higher than this DC bus voltage and in that case a bi-directional DC-DC converter has to be used in between the DC output terminal of the SBI and the battery/batteries.

![Proposed PV model with MPPT Controller.](image)

Fig. 9: Proposed PV model with MPPT Controller.
Fig. 10: PV output voltage 38V

Fig. 11: Zero Current switching (ZCS) of Switch $S_1$

Fig. 12: Zero Current switching (ZCS) of Switch $S_2$

Fig. 13: PWM pulses of Switch $S_1, S_2, S_3$ & $S_4$
Fig. 14: Switching Voltage & Current waveform

Fig. 15: Voltage across the Capacitor(Vc) waveform.

Fig. 16: Output voltage of Ac Motor V0=5

Fig. 17: Motor torque & Speed Waveform
Fig. 18: THD Analysis of Existing PWM method (THD=5.33%)

Fig. 19: THD Analysis of proposed PWM method with R Load (THD=2.33%)

Fig. 20: THD Analysis of proposed PWM method with Motor Load (THD=9.82%)

Fig. 21: THD comparision Chart

Fig 18,19 & 20 Shows the Total Harmonic Distortion of the existing and proposed method. The proposed method shows the better performance compare than existing method. So the efficiency of the system improved.
Table 1: The parameters used in the simulation of the SBI topology with MPPT at varying insolation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open circuit voltage</td>
<td>217.8V</td>
</tr>
<tr>
<td>Short-circuit current</td>
<td>31.36A</td>
</tr>
<tr>
<td>Voltage at max. power point</td>
<td>174V</td>
</tr>
<tr>
<td>Current at max. power point</td>
<td>29.4A</td>
</tr>
<tr>
<td>Power of the PV array</td>
<td>6830 W</td>
</tr>
<tr>
<td>Max power of PV array</td>
<td>5115W</td>
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<tr>
<td>Fill factor</td>
<td>74.89%</td>
</tr>
</tbody>
</table>

Table 2: Comparison between existing pwm & proposed sine pwm method

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Output For existing method</th>
<th>Output for proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>38V(DC)</td>
<td>38V(Solar power)</td>
</tr>
<tr>
<td>Input current</td>
<td>3.6A</td>
<td>3.6A</td>
</tr>
<tr>
<td>Output voltage</td>
<td>62V</td>
<td>62V</td>
</tr>
<tr>
<td>Output power</td>
<td>49.6W</td>
<td>248W</td>
</tr>
<tr>
<td>THD</td>
<td>5.33%</td>
<td>2.28%</td>
</tr>
</tbody>
</table>

Conclusion:
This paper explained the operation principle of switched-boost inverter topology powered from solar PV module and the operation is verified using MATLAB simulation. MPPT is applied to the converter to extract maximum power at varying insolation. The Advanced Sine PWM technique was used in this paper to reduce the harmonics and also reduce the torque pulsations of the output of the Ac Motor. The harmonic spectrum of the inverter’s output voltage with the proposed PWM technique was plotted experimentally and compared with that of a traditional VSI. It was proven that the shoot-through state of the SBI will have no effect on the harmonic spectrum of its output voltage, provided that the sum of the shoot-through duty ratio and modulation index is less than unity.

REFERENCES