A Single Stage Buckboost Transformerless Inverter For Single Phase Grid Connected Solar PV System

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Abstract—For single phase grid-connected solar PV applications, the single-stage buck-boost transformer less inverter (BBTI) topology is the basic foundation of this study. In this design, leakage currents are eliminated because the input PV source shares a common ground with the grid's neutral. Also, the suggested design includes a buck-boost converter that maintains the maximum power point despite a wide range of input PV voltage. One less energy storage inductor is used in the suggested design, allowing for symmetric grid functioning during both half cycles. Moreover, the suggested topology's two out of five switches that operate at line frequency incur low conductivity losses, while the remaining switch operates at high frequency incurs low conductivity losses. To manage the suggested inverter topology, a straightforward sine-triangle pulse width modulation approach is suggested. All operational modes are examined, and a thorough explanation is provided. The suggested approach provides more efficiency while reducing output current THD.

Keywords — Buck-Boost Converter, Two Level Inverter, Leakage Currents, Sine-triangle pulse width modulation.

1. INTRODUCTION (HEADING I)

Generally, the PV fed transformer less inverters suffer from leakage currents [1]. To overcome the leakage currentsthe researchers have come up with numerous PV fed transformer less inverter topologies and control strategies [2],[3]. For example, grid-connected central or string inverter configurations consist of strings of PV panels which don’t require boost stage.

However, the low voltage PV source requires a boost stage which reduces the efficiency of the system. Several researchers have come up with the buck derived transformer less inverters which may not work during the low voltage PV source or PV source with shaded conditions [4], [5]. It is advisable to havetransformer less inverter topologies with the buck-boost capability to have a wide operational range of PV sources [6]-[16]. In this context, it can be understood that nowadays researchers have been showing more interest in proposing buck-boost based transformer less topologies [10]-[15].

The authors in [10] proposed a buck-boost derived transformer less inverter topology which suits for wide range operation of the PV system. But the disadvantage of this topology is that it requires two separate PV sources for each half cycle of the output voltage. In [11], a buck-boost based
transformer less topology is also proposed, which uses only four power switches and two input inductors. In this topology, each input inductor operates in either positive or negative halfcycles which may lead to DC current injection.

Disadvantage of this topology is that the THD in current is more than 5% which is well beyond IEEE limits. The authors in [12] also proposed a buck-boost derived topology with a single input inductor and 5 switches. But this topology requires three extra diodes. Even though this topology has one single input inductor it requires a large input capacitor to track the maximum power from the PV source. Another disadvantage of this topology is that it has low voltage gain.

The topology in [13] can operate for a wide range of PV system. But it requires eight power switches and one single inductor. The higher switch’s count reduces the efficiency, reliability and increases the cost of the system. In [14], the proposed buck-boost derived topology reduces the switch count (i.e. five switches). However, this topology requires larger input capacitance to track maximum point of solar PV. The topology in [14] also works for a wide range of PV system. In this topology, three switches conduct in every switching cycle which increases the conduction losses. Another disadvantage of this system is that it requires high current capability inductor which is large in size at the input which increases the system size, cost and reduces the efficiency. Further to reduce the switch’s count, researchers in [15] proposed a buck-boost topology with only two power switches. But this topology doesn’t have a symmetrical operation in both positive and negative halfcycles of the output voltage. Another disadvantage of this topology is that the voltage across input PV should be greater than the required output voltage. Another topology was proposed in [16] by using coupled inductor. This topology can provide high voltage gain at the output but in this topology also three power switches conduct during one switching cycle which increases the conduction losses and reduces the efficiency of the system. Taking a cue from the aforementioned shortcomings, in this paper, a buck-boost transformer less inverter topology is proposed with only five power switches and a single input inductor at the input. The major advantages of the proposed topology are as follows:

- Zero leakage current due to the common terminals shared between PV and grid neutral.
- Negligible DC current injection due to the symmetry of operation in both positive and negative half-cycles.
- Lesser number of controllable switches which makes the system more reliable and highly efficient.
- A wide range of PV power tracking is possible due to the presence of buck-boost operation.

II. OBJECTIVE

1. Eliminating Leakage Currents.
2. Negligible DC Current into the grid connected solar PV system.
3. Buckboost Converter is used to track the maximum power point tracking under wider variations of voltage.
4. Improving the Grid Current in order to improve the THD with in IEEE standard limits.

III. METHODOLOGY

The proposed Buck-boost transformer less inverter (BBTI) topology is shown in Fig. 1. This BBTI topology is derived by combining the buck-boost DC-DC converter and full-bridge inverter. The BBTI consists of five controllable switches S1 to S5, one input inductor ‘L’, one power diode ‘D’ and one auxiliary capacitor CA. Out of five switches S1, S2 and S4 operate at high frequency (i.e. switching frequency) and S3, S5 operate at line frequency (i.e. 50Hz). It can be observed that in the BBTI topology shown in Fig. 1 the negative terminal of the PV is directly connected to the neutral of the grid which completely eliminates the leakage currents.

Fig. 1. Proposed Topology

A. Operating Modes corresponds to switch states:

The operating modes of the BBTI for the positive and negative half cycles of grid voltage for the case of continuous conduction mode (i.e. \( I_L > 0 \)) are shown in Fig. 2(A)-(D) and their corresponding switching states are given in below table.

| TABLE I. | SWITCHING MODES |
The continuous conduction mode (CCM) of the BBTI is mainly divided into four modes (Mode-(A) to Mode-(D)) corresponding to the positive and negative half cycles of the grid. The mode-(A), mode-(B) correspond to the positive halfcycle and mode-(C), mode-(D) correspond to the negative halfcycles of the grid (shown in Figs. 2(A)-(D)). The various switching states corresponding to all modes of operation are shown in Table I. The modes of operation of the BBTI for the four important modes of operation are explained as follows:

1) Mode (A):  
During this mode, the BBTI provides power to the grid as shown in Fig. 2. In this mode, the power switches S1, S3, and S5 are turned ON. The energy storage inductor (L) stores energy from the PV source through power switch S1 and auxiliary capacitor CA supplies energy to the grid through switches S3 and S5. All the current flowing paths correspond to this mode of operation are highlighted with thick lines as shown in Fig. 2.

2) Mode (B):  
In this mode of operation, the power switch S5 is turned ON and all the remaining switches are turned OFF as shown in Fig. 3. The inductor (L) supplies its stored energy to the auxiliary capacitor CA through diode ‘D’ and antiparallel diode of S2. The current in the grid inductor ‘Lg’ freewheels through switch S5 and antiparallel diode of switch S2. All the conducting paths correspond to this mode of operation are highlighted with thick lines as shown in Fig. 3.

3) Mode (C):  
This mode corresponds to the powering of the grid in the negative half cycle. During this mode, the power switches S1, S2,
and S4 are turned ON. The auxiliary capacitor CA supplies energy to the grid through power switches S2 and S4. The energy storage inductor stores energy from the input PV source through switch S1. All the conducting paths corresponding to this mode of operation are highlighted with thick lines as shown in Fig. 4.

By substituting (2) in (3) the gain of the proposed BBTI can be obtained as

\[ \frac{V_{AC}V_{PV}}{m_{i}V_{PV}} \geq 1 - m_{i} \]

Fig. 4. Mode C Operation

4) Mode (D):
This mode corresponds to the freewheeling period of inductor Lg. During this mode, the power switch kept ON while the remaining power switches are turned OFF. In this mode, the inductor ‘L’ supplies its stored energy to the auxiliary capacitor CA through diode D and antiparallel diode of switch S2. The current in the inductor Lg freewheels through switch S2 and antiparallel diode of switch S5. All the conducting paths corresponding to this mode of operation are highlighted with thick lines as shown in Fig. 5.

V. DESIGN OF ENERGY STORAGE ELEMENTS OF THE BBTI TOPOLOGY

The section presents the design of various energy storage elements of the BBTI topology.

A. Design of energy inductor storage (L)
The energy storage inductor (L) at the input of BBTIs is designed in a similar way to the conventional buck-boost DC-DC converter. The value of inductance is chosen in such a way that the BBTI should operate in CCM. The chosen inductance value is more than critical inductance (LC) to work the BBTI in CCM. The expression to calculate the LC is given as

\[ \frac{(m_{i}V_{PV})^2}{2 p_{0}f_{s}} \]

Where, mi is Modulation index, VPV is Input PV voltage, Po is Output AC power, and fS is Switching frequency.

Design of auxiliary capacitor (XA) The output power (Po) and the voltage ripple of the corresponding capacitor are used to calculate the value of the capacitor. Generally, the voltage ripple of the capacitor considered being 5%. The expression to calculate the value of auxiliary capacitor is given as (6):

Fig. 5. Mode D Operation

IV. STEADY-STATE ANALYSIS OF THE PROPOSED BBTI To perform the steady-state analysis of the BBTI topology, the following assumptions are considered:
\[\Delta V_{CA} V_{CAf_s}\]

1) The voltage across the DC capacitor is constant (i.e. DC capacitor is large).
2) All semiconductor devices are lossless.
3) Parasitic parameters are neglected.

By applying the voltage balance across the inductor (L) the following equation is obtained:

Here, \(X_A\) is the value of the auxiliary capacitor. \(V_{CA}\) is the voltage across auxiliary capacitor and \(\Delta V_{C}\) is the ripple voltage of auxiliary capacitor. \(f_s\) is the switching frequency.

B. Modulation and Controlling Technique for the Proposed BBTI:

Modulation strategy of the BBTI topology is shown in Fig. 6. In this modulation strategy, the modulating waveform \((V_{msin(wt)})\) is compared with a triangular waveform \((V_{tr})\) to generate switching pulses to the switches (S2 to S4). \((-V_{msin(wt)})\) is compared with the triangular waveform to generate the switching pulses to the switches (S3 and S5).

From (1), the voltage across the auxiliary capacitor \((CA)\) is obtained as

\[
\frac{mi}{1-mi}
\]

Fig. 6. Control Technique

VI. SIMULATION RESULTS

The grid-connected BBTI system is simulated in MATLAB/Simulink for 300W power rating as shown in Fig. 7. The system parameters used for MATLAB simulations are given in Table.02. The voltage rating of input solar PV source is considered to be 75V. The proposed BBTI topology feeds the maximum available power from PV source to the grid with THD of 3.39%. Some of the main simulated waveforms such as the grid voltage \((V_g)\), grid current \((I_o)\), input inductor current \((i_L)\) and auxiliary capacitor voltages \((V_{CA})\) are shown.
Fig. 8. Grid Voltage (Vg)

Fig. 9. Grid current after adding filter (Io)

Fig. 10. Auxiliary capacitor Voltage Waveform. (VCA)

Fig. 11. Inductor Current Waveform. (IL)

The grid-connected BBTI topology is validated on a laboratory prototype for 300W power rating. The important experimental waveforms such as the grid voltage (Vg), grid current (Ig), input inductor current (iL) and auxiliary capacitor voltages (VCA) are shown in Fig. 8 to Fig. 11. It can be observed from the experimental studies that the proposed BBTI feeds good quality of power into the grid with a THD of 3.39%.
TABLE II. SYSTEM PARAMETERS FOR SIMULATION STUDIES

<table>
<thead>
<tr>
<th>S. NO</th>
<th>Parameter</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power rating</td>
<td>300W</td>
</tr>
<tr>
<td>2</td>
<td>Switching frequency</td>
<td>10kHz</td>
</tr>
<tr>
<td>3</td>
<td>Input voltage</td>
<td>75V</td>
</tr>
<tr>
<td>4</td>
<td>Input inductor(L)</td>
<td>115e-6H</td>
</tr>
<tr>
<td>5</td>
<td>Auxiliary Capacitor</td>
<td>50e-6F</td>
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<tr>
<td>6</td>
<td>Output inductor</td>
<td>1mH</td>
</tr>
<tr>
<td>7</td>
<td>Filter capacitor</td>
<td>10e-6</td>
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</tbody>
</table>

VII. CONCLUSIONS

A buck-boost transformer less inverter topology was proposed, analyzed and validated through experimental results. It has been verified that the BBTI topology injects zero leakage current and negligible DC current into the grid for grid-connected PV application. Due to the buck-boost property of the BBTI, the maximum power point can be tracked for PV under the wide voltage variation. The BBTI was tested at the switching frequency of 10 kHz and it has been observed that the THD in current is 3.59% which is in good agreement with the IEEE standards.

REFERENCES