

A NOVEL SINGLE-STAGE BUCK-BOOST TRANSFORMER LESS INVERTER FOR 1- Φ GRID-CONNECTED SOLAR PV SYSTEMS

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ABSTRACT

This paper presents a novel singlestage buck-boost transformerless inverter (BBTI) topology for single-phase gridconnected solar PV applications. In this topology, the input PV source shares the common ground with neutral of the grid which eliminates the leakage currents. Further, the proposed topology has the buck-boost ability which tracks the maximum power point even under the wide variation of input PV voltage. Another feature of the proposed topology is that it uses only one energy storage inductor which provides symmetric operation during both half cycles of the grid. In addition, the two out of five switches of the proposed topology operate at a line frequency, thereby, it exhibits low switching losses and the other three switches conduct in any mode of operation which incurs low conduction losses. A simple sine-triangle pulse width modulation strategy is proposed to control the proposed inverter topology is analyzed at all operating modes and explained in detail.

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I INTRODUCTION

Generally, the PV fed transformer less inverters suffer from leakage currents. To overcome the leakage currents the researchers have come up with numerous PV fed transformerless inverter topologies and control strategies. For example, gridconnected central or string inverter configurations consist of strings of PV panels which doesn't require boost stage. However, the low voltage PV source requires a boost stage which reduces the efficiency of the system. Several researches have come up with the buck derived transformerless inverters which may not work during the low voltage PV source or PV source with shaded conditions. It is advisable to have transformerless inverter topologies with the buck-boost capability to have a wide operational range of PV sources. In this context, it can be understood that nowadays researchers have been showing more interest in proposing buckboost based transformerless topologies. The authors in proposed a buck-boost derived transformerless 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 , a buck-boost based transformerless 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 half cycles which may lead to DC current injection. Another disadvantage of this topology is that the THD in current is more than 5% which is well beyond IEEE limits. The authors in 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 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 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 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 proposed a buck-boost topology with only two power switches. But this topology doesn't have a symmetrical operation in both positive and negative half cycles 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 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 transformerless 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: 1. Zero leakage current due to the common terminal is shared between PV and grid neutral. 2. Negligible DC current injection due to the symmetry of operation in both positive and negative half-cycles. 3. Lesser number of controllable switches which makes the system more reliable and highly efficient. 4. A wide range of PV power tracking is possible due to the presence of buckboost operation.

II SYSTEM DISCRPTION PROPOSED TRANSFORMERLESS TOPOLOGY BUCK-BOOST INVERTER This section discusses the structure of the proposed buck-boost transformerless inverter topology and its modes of operation. Structure of the proposed Buck-Boost transformerless inverter topology The proposed Buck-boost transformerless inverter (BBTI) topology is shown in Fig. 1. This BBTI topology is derived by combining the buck-boost DCDC 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, S3 and S4 operate at high frequency (i.e. switching frequency) and S2, 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. 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. $i_L > 0$).

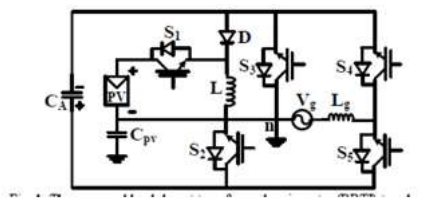
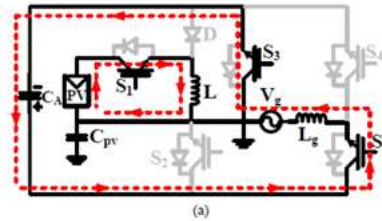


Fig 1: The proposed buck-boost transformerless inverter (BBTI) topology

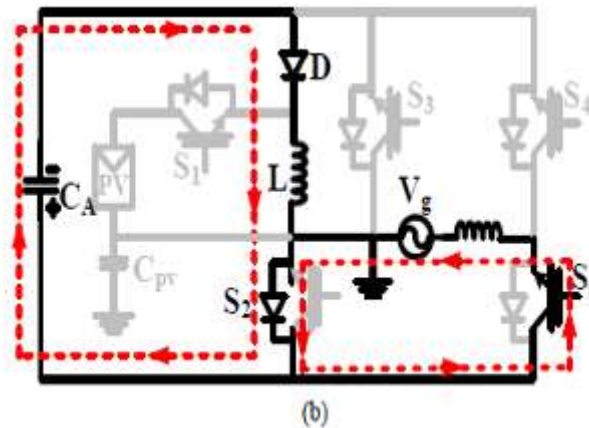
Operation of BBTI		Switches states (1=ON, 0=OFF)						Mode
		S ₁	S ₂	S ₃	S ₄	S ₅	D	
+Ve half cycle	$i_L > 0$	1	0	1	0	1	0	a
		0	0	0	0	1	1	b
-Ve half cycle	$i_L > 0$	1	1	0	1	0	0	c
		0	1	0	0	0	1	d

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 half cycle and mode-(c), mode(d) correspond to the negative half cycles 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:

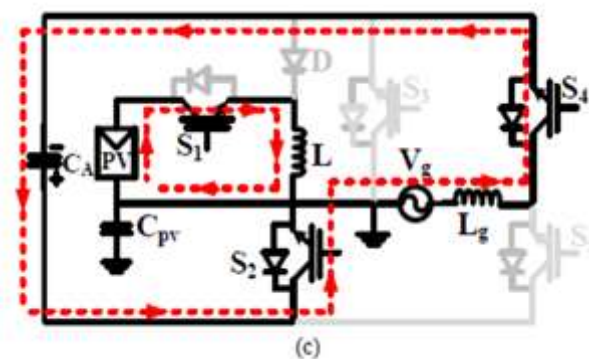
Mode-(a): During this mode, the BBTI provides power to the grid as shown in Fig. 2(a). In this mode, the power switches S1, S3, and S5 are turned ON. The energy storage inductor (L) stores energy from the PV source through power switch S1 and auxiliary capacitor CA supplies energy to the grid through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



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. 2(b). 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

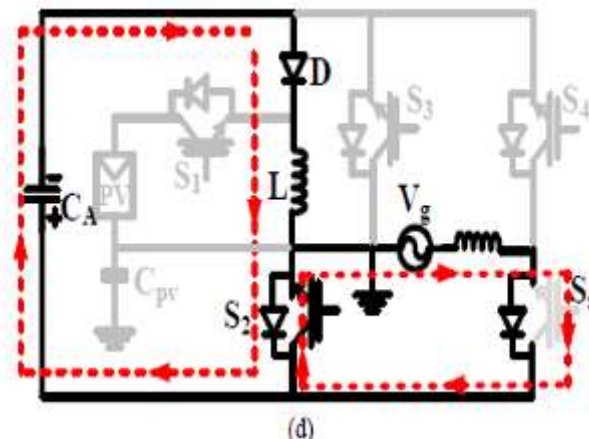


Mode-(c): This mode corresponds to the powering of the grid in the negative half cycle. During this mode, the power switches S1, S2, and S4 are turned ON. The auxiliary capacitor CA supplies energy to the grid through power switches S2 and S4. The energy storage inductor stores energy from the input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



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.



Steady-state analysis of the proposed BBTI topology To perform the steady-state analysis of the BBTI topology, the following assumptions are considered: 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. The proposed BBTI topology feeds power from the input PV source to the grid by using the current control strategy [11]. The maximum power point of input solar PV source is tracked by using perturb and observe MPPT algorithm

B. Comparison of the proposed BBTI topology with existing buck-boost transformerless inverter topologies The proposed BBTI topology incurs lower switching and conduction losses because less number of switches (only three) operate at high frequency and less number of switches (only three) conduct during any mode of operation (shown in Fig.). Therefore the BBTI topology has lower switching and conduction losses compared to existing buck-boost based transformerless inverter topologies which make the efficiency of the system is high. The detailed comparison of proposed BBTI topology with the existing buck-boost based transformerless inverter topologies is given in Table-II.

TABLE II COMPARISON OF BBTI WITH OTHER TRANSFORMERLESS TOPOLOGIES

Parameters	BBTI	Ref [11]	Ref [13]	Ref [15]
Number of switches	5	6	5	5
Number of diodes	1	0	2	0
Number of inductors	1	1	2	1
Number of capacitors	1	1	0	1
DC offset	No	No	Yes	Yes
% THD	3.31	<5	<5	4.5

CONCLUSIONS A novel buck-boost transformerless 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 3.8% which is in good agreement with the IEEE standards.

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