GRID-CONNECTED SOLAR PV SYSTEMS FOR SINGLE-STAGE BUCK-BOOST TRANSFORMERLESS INVERTER

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Abstract: This paper presents a novel single-stage buck-boost transformer less inverter (BBTI) topology for single-phase grid-connected 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 conductions 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.

Keywords: Buck-Boost converter; Two-level inverter; Leakage currents, sine-triangle pulse width modulation.

1. 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, grid-connected 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 transformer less 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 buck-boost 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 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 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

2. LITERATURE REVIEW

The relative weight of the energy generated by means of renewable sources is constantly increasing. Among all these sources, the photovoltaic (PV) systems present the higher and more stable relative growth. However, the PV system is still too expensive and a significant effort is being done to increase the efficiency and reduce the cost. Concerning the PV inverters, this has lead to the elimination of the low frequency (LF) transformer that has been traditionally included. The LF transformer provides isolation from the grid but reduces the PV inverter efficiency and increases its size and cost. However, the elimination of the transformer might generate strong ground currents, which become now an important design parameter for the PV inverter. The ground currents are a function of the system stray elements. However, there is no simple model and procedure to study the common mode behavior of a PV system, which is required to analyze the ground currents. In this paper, a comprehensible model is proposed which provides a better understanding of the common mode issue in single-phase transformerless PV systems. In addition, a procedure is developed to analyze the global performance, efficiency, grid current quality, and common mode behavior of a PV inverter as a function of its particular structure and modulation technique.

For low-power grid-connected applications, a single-phase converter can be used. In photovoltaic (PV) applications, it is possible to remove the transformer in the inverter to reduce losses, costs, and size. Galvanic connection of the grid and the dc sources in transformerless systems can introduce additional ground currents due to the ground parasitic capacitance. These currents increase conducted and radiated electromagnetic emissions, harmonics injected in the utility grid, and losses. Amplitude and spectrum of the ground current depend on the converter topology, the switching strategy, and the resonant circuit formed by the ground capacitance, the converter, the ac filter, and the grid. In this paper, the ground current in a 1.5-kW PV installation is measured under different conditions and used to build a simulation model. The installation includes a string of 16 PV panel, a full-bridge inverter, and an LCL filter. This model allows the study of the influence of the harmonics injected by the inverter on the ground current. Photovoltaic (PV) power systems have been in the spotlight of scientific research for years. However, this technology is still undergoing developments, and several new architectures are proposed each year. This study describes the main challenges facing grid-connected PV systems without galvanic isolation, then carries out a review of the state-of-the-art of single-phase systems. The converter topology review is focused on the match between the different types of converters and the different PV panel technologies, determined by the common-mode voltage between the PV string terminals and the ground. The ground leakage current, due to time variations of this voltage, is a source of electric safety and electromagnetic interference (EMI)-related problems, and its amplitude is constrained by international standards. The basic principles of operation of the different solutions are described, along with their strengths and drawbacks. Conversion efficiency is evaluated qualitatively comparing the semiconductor power losses. Finally, the future trends regarding semiconductor devices, PV panels and international regulations for single-phase grid-connected equipment are discussed, and indications on how these might steer future research efforts in PV converters are inferred.

A novel, high-efficiency inverter using MOSFETs for all active switches is presented for photovoltaic, non-isolated, AC module applications. The proposed H6-type configuration features high efficiency over a wide load range, low ground leakage current, no need for split capacitors, and low output AC-current distortion. The detailed power stage operating principles, PWM scheme, and novel bootstrap power supply for the proposed inverter are described. Experimental results of a 300 W hardware prototype show that not only are MOSFET body diode reverse-recovery and ground leakage current issues alleviated in the proposed inverter, but also that 98.3% maximum efficiency and 98.1% European Union efficiency are achieved.

3. SYSTEM DISCRIPTION

This section discusses the structure of the proposed buck-boost transformerless inverter topology and its modes of operation.

The proposed Buck-boost transformerless 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, 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. iL>0) are shown in Figs. 2(a)-(d) and their corresponding switching states are given in Table-I.

Table-I: Operation of BBTI

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		1	1	0	1	0	0	c
		0	1	0	0	0	1	d

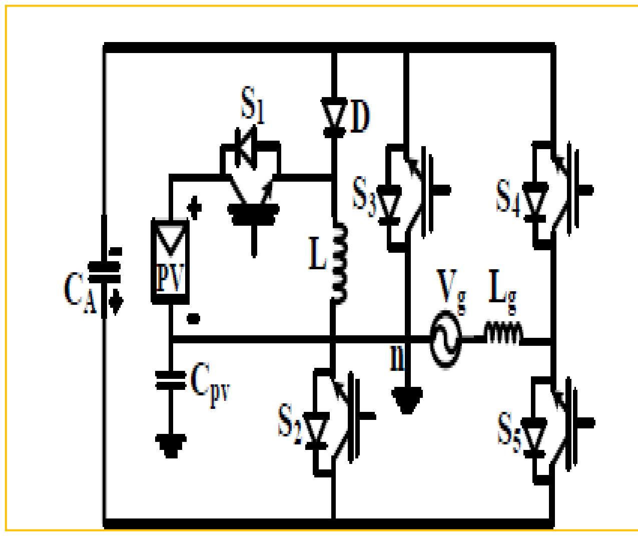

Fig.1. The proposed buck-boost transformerless inverter (BBTI) topology.

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 in Fig. 2.

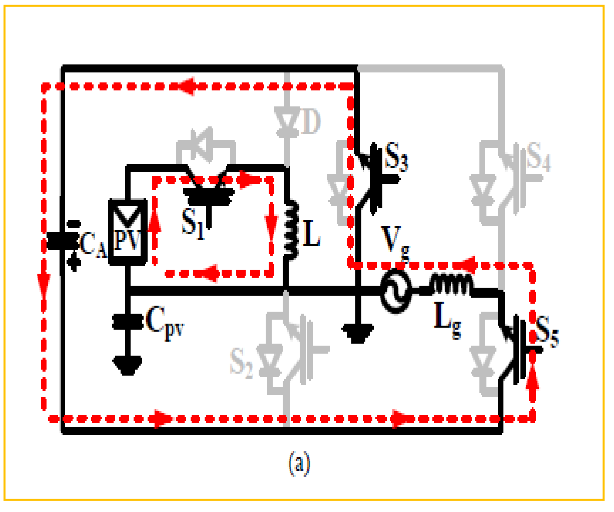

Fig.2. The Operation of Mode-(a)

***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 anti parallel diode of S2. The current in the grid inductor 'Lg' freewheels through switch S5 and anti parallel diode of switch S2. All the conducting paths correspond to this mode of operation are highlighted with thick lines as shown in Fig.3.

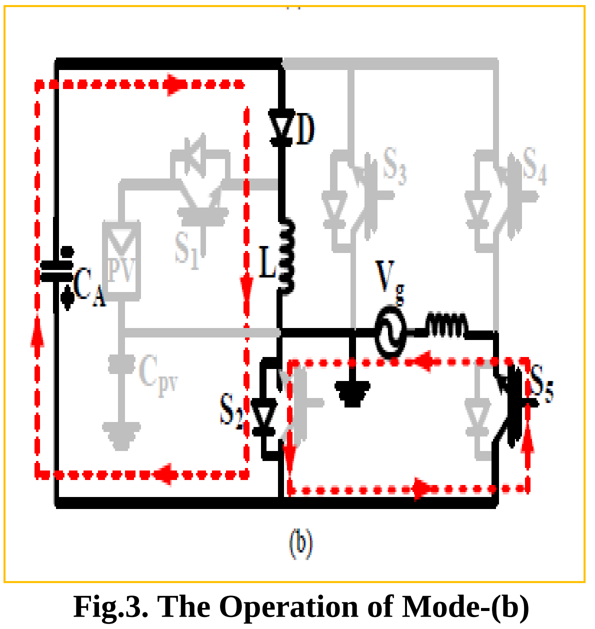

Fig.3. The Operation of Mode-(b)

***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.

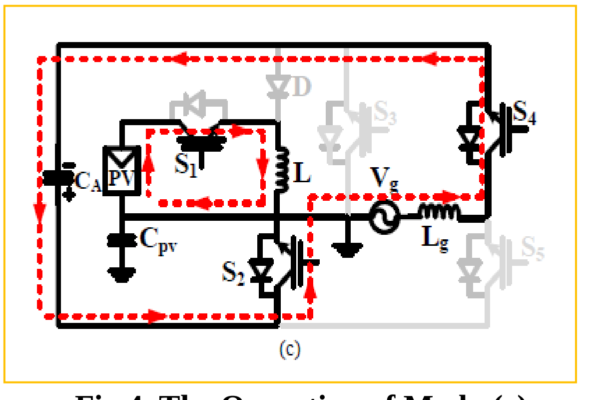

Fig.4. The Operation of Mode-(c)

***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 anti parallel diode of switch S2. The current in the inductor Lg freewheels through switch S2 and anti parallel diode of switch S5. All the conducting paths corresponding to this mode of operation are highlighted with thick lines as shown in Fig. 5.

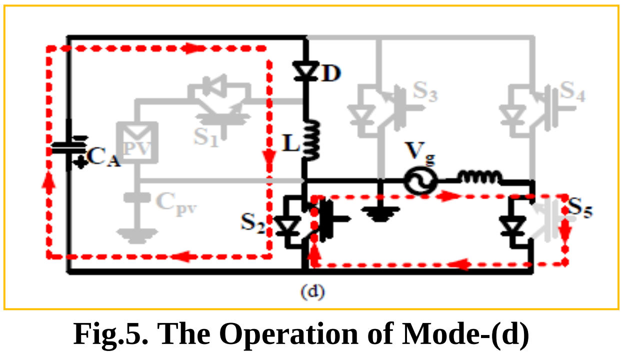

Fig.5. The Operation of Mode-(d)

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

4. 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 Buck-Boost Transformerless Inverter 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

5. PROPOSED SYSTEM:

The proposed topology has the Buck Boost ability which tracks the maximum power point even under the wide variation of the input PV voltage. Another future used only one energy storage which provides symmetrical operation during both half cycle's of the grid. So, we are introducing the fuzzy controller for this network for easy operation and controlling. Which eliminates the higher amount of Total harmonic distortion compare to the PI controller. Fuzzy create the error value by using the member ship functions. the error is to be positive or negative and it is a big or small which should calculate . fuzzy will give the high performance of PI controller.

MAT LAB SIMULATION MODELS:

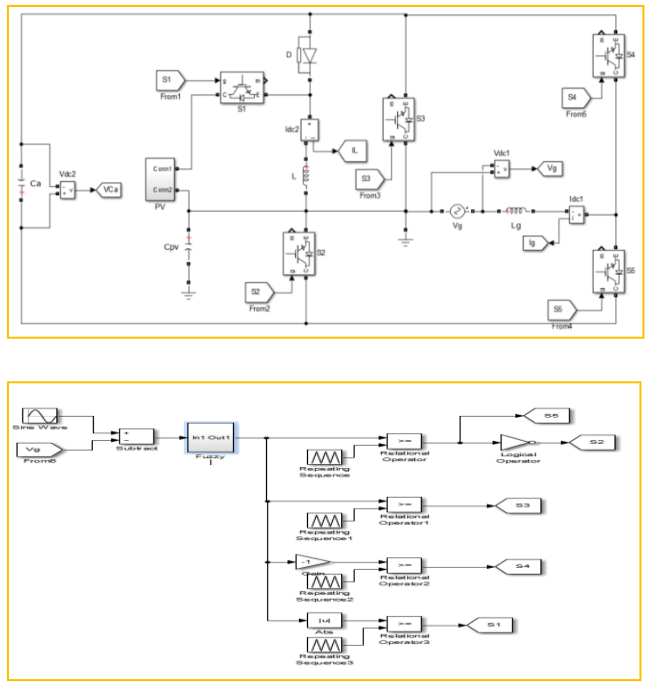

Fig.6. The proposed simulation model.

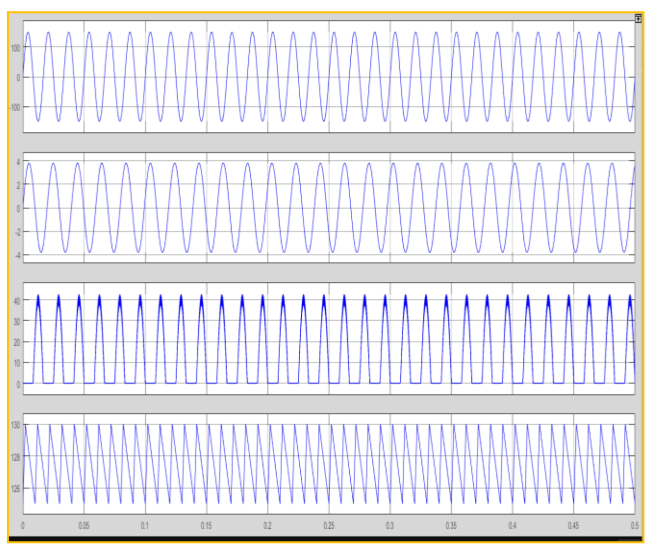

Fig. 7. The simulated waveforms of the PV fed grid-connected BBTI topology; (a) the grid voltage (Vg); (b) Current through grid (Ig); (c) Current through input inductor current (iL); (d) Voltage across auxiliary capacitor (VCA)

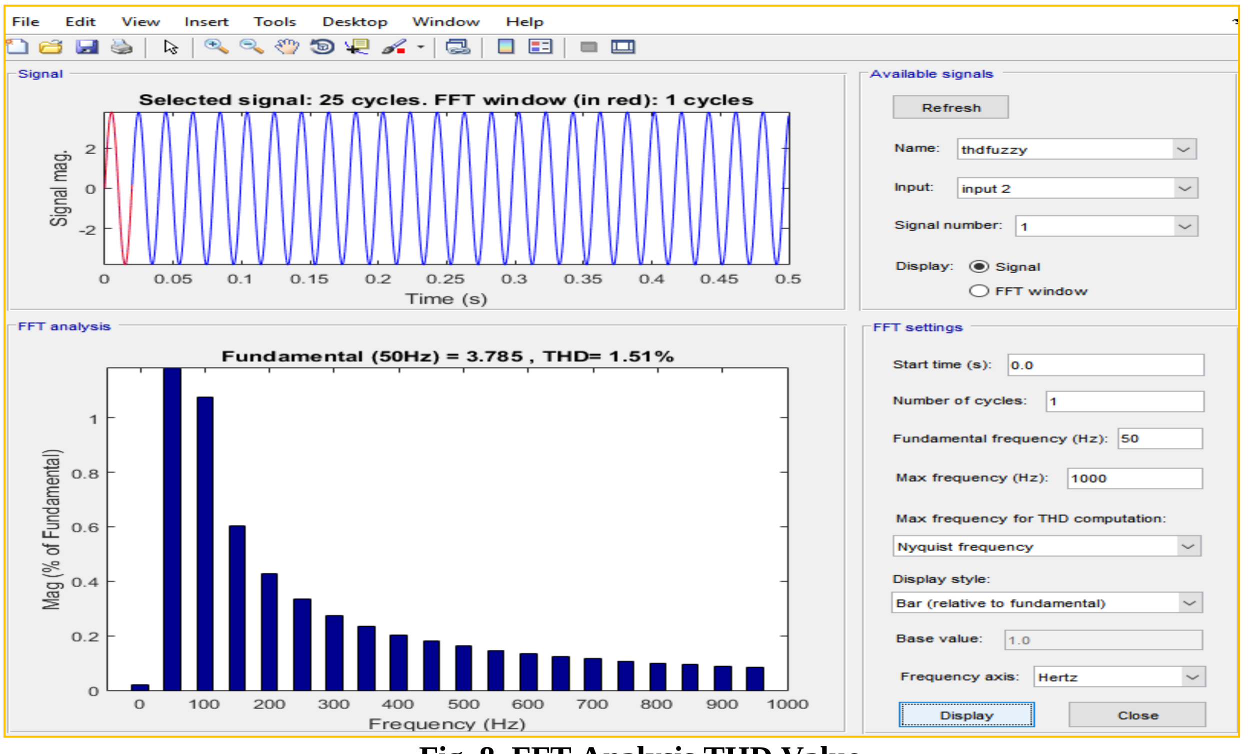

Fig. 8. FFT Analysis THD Value

CONCLUSION

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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