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AC Grid-Connected Solar PV Systems Using Single-Stage Buck-Boost Transformer Less Inverter

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1.1 ABSTRACT

This project presents an AC Grid-Connected Solar PV Systems using Single-Stage Buck-Boost transformer less Inverter. In this, the input PV source shares the common ground with neutral of the grid which eliminates the leakage currents. The buck-boost ability which tracks the maximum power point even under the wide variation of input PV voltage. Another feature of this project 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 inverter circuit is analyzed at all operating modes and explained in detail. Experiments are carried out on the 300W laboratory prototype and all the major results are included in the paper, which shows that the proposed system gives higher efficiency with lower THD in output current.

1.2 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 transformer-less 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 transformer-less 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 transformer less topologies. The authors in 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.

1.3 BUCK-BOOST TOPOLOGIES

1.3.1Buck-Boost transformer less Inverter Topology

A "buck-boost derived transformer less inverter" refers to a type of inverter design that utilizes the principles of a buck-boost DC-DC converter to achieve voltage step-up or step-down functionality without the need for a transformer, commonly used in applications like grid-tied solar photovoltaic systems where a wide input voltage range might be encountered; it essentially combines the buck-boost converter's ability to adjust voltage with a full-bridge inverter to produce AC output directly from the DC source, eliminating the need for a separate transformer to isolate the grid from the source 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.

Key points about buck-boost derived transformer less inverters:

1. **Function:** This design allows the inverter to both increase (boost) or decrease (buck) the DC input voltage depending on the required output voltage, making it suitable for situations where the input voltage fluctuates significantly.
2. **No transformer:** Unlike traditional inverters, this design eliminates the need for a bulky and heavy transformer, leading to a more compact and lightweight system.
3. **Leakage current reduction:** By directly connecting the negative terminal of the DC source to the grid neutral, the buck-boost topology can effectively suppress leakage currents drawn from the input power source.
4. **Wide input voltage range:** Due to its buck-boost capability, this inverter can operate efficiently across a wide range of input voltages, making it ideal for renewable energy applications like solar panels where voltage can vary based on weather conditions.

1.3.2 Buck-Boost Derived Topology

The Buck-Boost Derived Topology consists of 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 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 in also works for a wide range of PV system. In this topology, three switches conduct in every switching cycle which increases the conduction losses.

1.4 PROPOSED BUCK-BOOST TRANSFORMER LESS INVERTER

1.4.1 General layout of a single-phase transformer less inverter

A general layout for a single-phase trans- formerless inverter for small-scale PV systems. As can be seen, without a galvanic isolation, a direct ground-current path may form between the PV panel and the grid. Due to the presence of large stray capacitance (C_{PV}) between the PV and grid grounds, the varying voltage [also known as common-mode voltage (CMV)] can excite the resonant circuit formed by the parasitic capacitor and inverter filter inductor and this produces a high CM ground current i_{cm}.

This capacitive i_{cm} comprises line low-frequency and switching high-frequency components which inject harmonics into the grid current, increase the system losses, impair the electromagnetic compatibility, and can cause safety problems such as electric shock.

In order to understand the grid-connected PV systems to satisfy various grid codes and their safety standards, numerous inverter related issues have been thoroughly investigated.So far, many transformer less inverter topologies have been presented with the aim of eliminating the leakage current. To achieve this, various decoupling techniques have been adopted, such as decoupling the dc from the ac side and/or clamping the common mode (CM) voltage (CMV) during the freewheeling period or using common ground configurations.

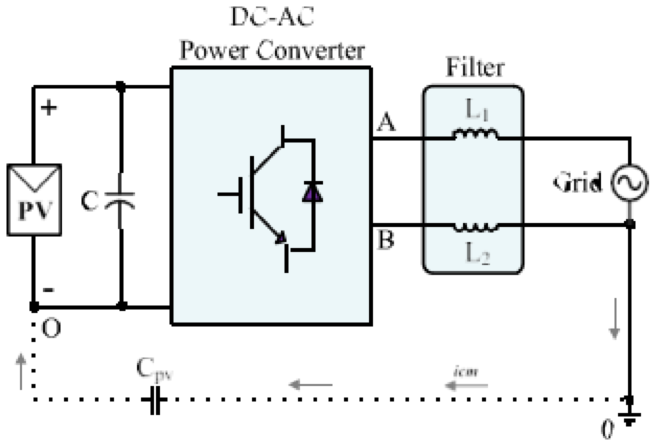


Fig 1 General layout of a single-phase transformer less inverter

The combinations of these decoupling techniques with integrated MPPT circuits form an immense number of topologies and configurations which are often confusing and difficult to follow. Therefore, to present a clear picture on the development of the transformer less inverter for the next-generation grid-connected PV systems, this paper aims to review and classify various transformer less inverters. Further, it aims to provide an analytical overview and analysis of well- known single-phase transformer less inverter topologies as well as a comparison of the transformer less inverters based on a loss and efficiency analysis through the means of detailed calculations. This categorization and analysis can help researchers to understand the advantages and disadvantages of various transformer less inverter topologies in terms of their CMV and leakage current behavior.

1.4.2. Structure of the proposed Buck-Boost transformer less inverter topology

The proposed Buck-boost transformer less inverter (BBTI) topology is shown in Fig 2. 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.2) 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) and their corresponding switching states are given in Table-I.

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. The various switching states corresponding to all modes of operation are shown in Table I.

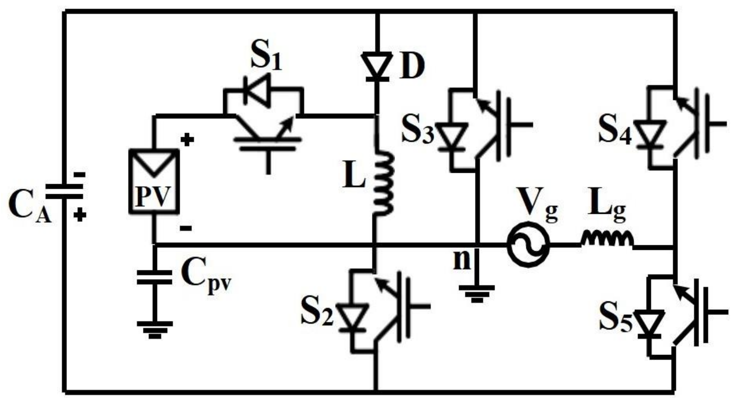


Fig 2 The proposed buck-boost transformerless inverter (BBTI) topology

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

TABLE I. OPERATING MODES CORRESPOND TO SWITCHES STATE

1.5 OPERATING MODES OF BBTI TOPOLOGY

MODE-(A):

During this mode, the BBTI provides power to the grid. 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.

MODE-(B):

In this mode of operation, the power switch S5 is turned ON and all the remaining switches are turned OFF. 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.

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.

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.

1.6 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.

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

$$\int_0^{m_i T_S} V_{pv} dt + \int_{m_i T_S}^{T_S} \left(-V_{C_A}\right) dt = 0 \tag{1}$$

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

$$V_{C_A} = \left(\frac{m_i}{1-m_i}\right) V_{PV} \tag{2}$$

The maximum AC output voltage of the BBTI can be expressed as:

$$V_{AC} = m_i \times V_{C_A} \tag{3}$$

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

$$G = \frac{V_{AC}}{V_{PV}} = \left(\frac{m_i^2}{1-m_i}\right) \tag{4}$$

1.7 MODULATION AND CONTROL STRATEGIES OF THE BBTI TOPOLOGY

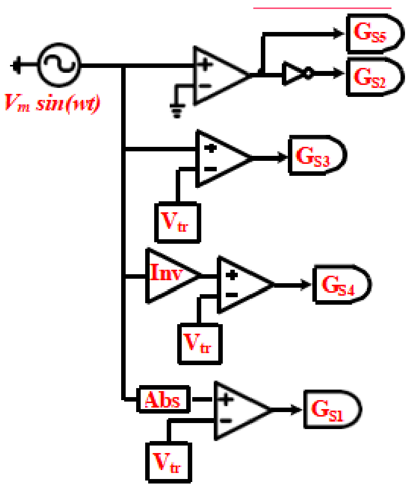


Fig 3 The proposed modulation strategy of the BBTI topology.

In this modulation strategy, the modulating waveform ($V_m\sin(wt)$) and it's absolute ($|V_m\sin(wt)|$), inverse ($-V_m\sin(wt)$) wave forms are compared with a triangular waveform (V_{tr}) to generate switching pulses to the switches (S_1 to S_5). The switches S_2 and S_5 operate at line frequency (i.e. 50Hz).

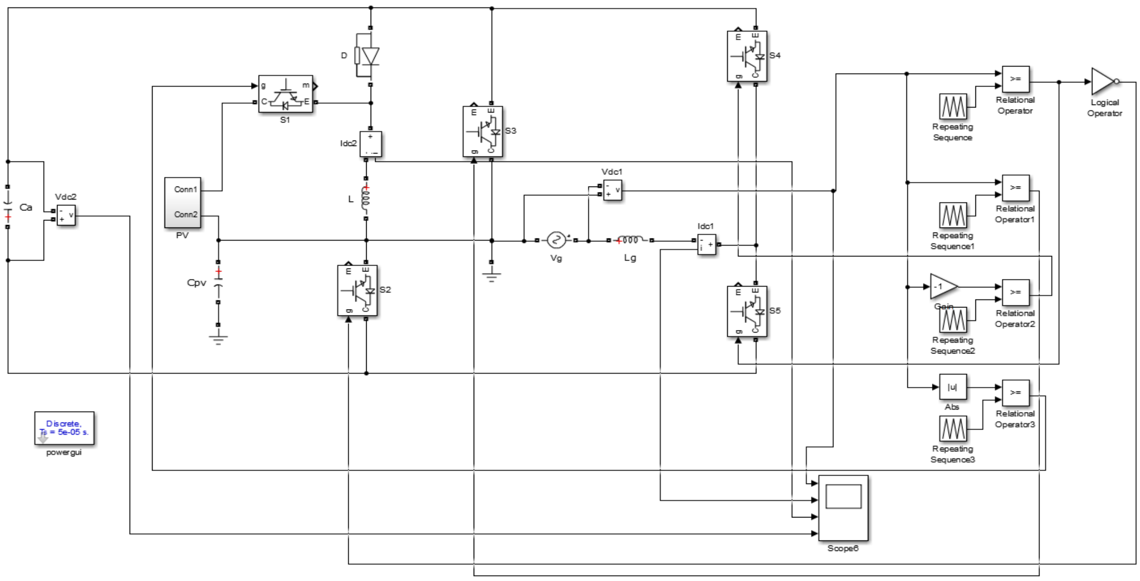
The switching pulse to is generated by comparing $V_m\sin(wt)$ with a triangular waveform (V_{tr}). Similarly the switching pulses to the switches S_1, S_4 are generated by comparing $|V_m\sin(wt)|$ and $-V_m\sin(wt)$ with the triangular waveform V_{tr}.

1.8 SIMULATION MODEL

The grid-connected BBTI system is simulated in MATLAB/Simulink for 300W power rating. The system parameters used for MATLAB simulations are given in Table-III. 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 3.31%. Some of the main simulated wave forms such as the grid voltage (V_g), grid current (I_O), input inductor current (i_L) and auxiliary capacitor voltages (V_{CA}).

Power rating	300W
Switching frequency	10kHz
Input voltage	75V
Input inductor (L)	115µH
Auxiliary capacitor(C_A)	50 µF
Output inductor (L_g)	1mH
Filter capacitor (C_f)	10 µF
DSP Controller	TMS320F28335

TABLE II SYSTEM PARAMETERS FOR SIMULATION STUDIES



The grid-connected BBTI topology is validated on a laboratory prototype for 300W power rating. The important experimental wave forms such as the grid voltage (Vg), grid current (Ig), input inductor current (iL) and auxiliary capacitor voltages (VCA).

1.9 RESULT AND DISCUSSION

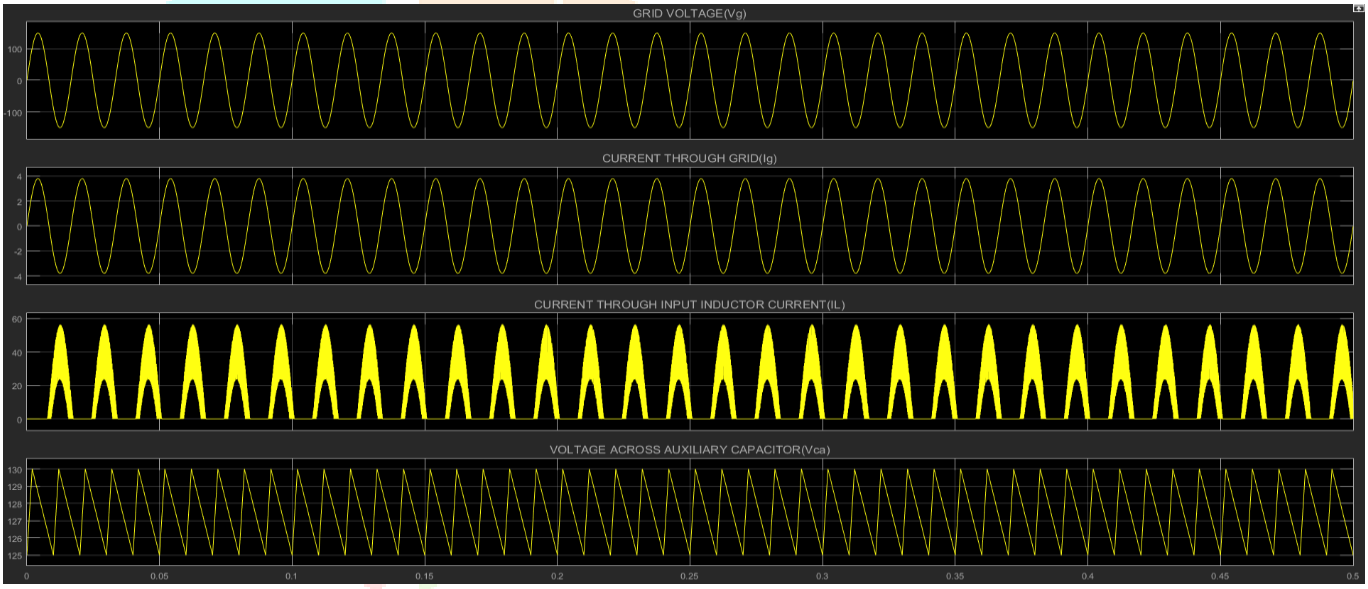


Fig 4 Simulation results

The PV developed DC voltage is going to be merged with alternating voltage of grid system with a THD level of 3.8%. In this process the energy storage elements plays an important role to conversion of voltage levels and reduced hormonics in system. After successfully conversion of voltages the grid voltage can match as purely sinusoidal without any causing disturbances in the system. And other four parameters are shown in above Fig 4.

2.0 CONCLUSION

A novel 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 3.8% which is in good agreement with the IEEE standards.

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