

Design and Implementation of Single-Stage Single- Phase Buck-Boost Transformerless Inverter for PV System using H5 Topology

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Abstract— The fast growth of photovoltaic (PV) systems has made the need for small, efficient, and affordable power conversion solutions even greater. This paper describes how to design and build a single-stage buck-boost transformerless inverter based on the H5 topology for use with grid-connected PV systems. The suggested system merges boosting voltage and changing DC to AC into one step. This method cuts down on the number of parts, makes the system easier to use, and lowers costs while making it more efficient. The H5 topology adds another switch to the conventional full-bridge inverter, allowing for effective disconnection of the PV array during freewheeling intervals. This feature greatly reduces leakage current, which is a big problem with inverter systems that don't use transformers. Also, the buck-boost feature makes sure that the output voltage stays stable even when the input conditions change because of changes in solar irradiance. Using MATLAB/Simulink, the system is modeled and simulated to test important performance metrics like output voltage quality, total harmonic distortion (THD), and the ability to stop leakage current. A hardware prototype is also made to make sure that the proposed design will work in the real world. The results show improved efficiency, reduced switching losses, and better power quality. A control strategy based on pulse-width modulation (PWM) is used along with grid synchronization to make sure that the system works reliably and stably. The suggested inverter topology works well for modern home and small-scale PV systems.

Index Terms—Photovoltaic (PV) system, Buck–Boost inverter, Transformerless inverter, H5 topology, Leakage current reduction, Pulse-width modulation (PWM), Grid-connected inverter, THD.

I. INTRODUCTION

As the need for renewable energy sources grows, more and more homes and businesses are using photovoltaic (PV) systems. Solar energy is one of the most popular renewable sources because it is plentiful, long-lasting, and good for the environment. But it's still hard to design PV systems that can turn the DC power that PV panels make into AC power that can be used.

Traditionally, PV systems use inverters that are based on transformers to keep people safe and provide galvanic isolation. These systems work well, but they have some problems, such as being bigger, heavier, more expensive, and less efficient because of transformer losses. Transformerless inverter topologies have gotten a lot of attention in the last few years to get around these problems. These topologies make systems work better and cost less overall, which makes them good for modern grid-connected PV applications.

The H5 topology has become a good choice for transformerless inverter setups because it has a simple design and better ability to reduce leakage current. The H5 inverter has an extra switch on top of the standard full-bridge design. This means that the PV array can be disconnected from the grid when it is not connected to anything else. This feature keeps the high efficiency while greatly lowering the leakage current. Also, traditional inverter systems usually need separate DC–DC converters to raise the PV voltage before inversion. This makes the system more complicated and expensive. To solve this problem, single-stage buck–boost inverter topologies have been created that combine voltage boosting and inversion into one unit. This method cuts down on the number of parts, makes the system more efficient, and makes it easier to design.

This paper talks about and shows how to use H5 topology to make a single-stage buck-boost transformerless inverter for grid-connected photovoltaic systems. The proposed system's goals are to improve power quality, cut down on leakage current, and make power conversion more efficient. We use MATLAB/Simulink simulation to look at how well the system works and then test it with a hardware prototype.

Section II talks about how the proposed system will be set up and how it will work. The control strategy is the subject of Section III. Section IV talks about the results of tests and simulations. Finally, Section V wraps up the paper.

TABLE I

COMPARISON OF SINGLE-STAGE BUCK-BOOST TRANSFORMERLESS INVERTERS

Topology	Gain	Components	Control	Eff.	Leakage	Use
H5	Limited	5 switches	Low-Med	Very High	Very Low	Rooftop
ZSI	High	2L, 2C, H-bridge	High	Med-High	Mod.	Grid PV
qZSI	High	2L, 2C, D, H-bridge	Med-High	High	Low	Renewable
SBI	Very High	L, C, switches	Medium	Medium	Mod.	Low PV
DBI	High	2 Boost + H-bridge	High	High	Low	Grid PV

II. PROPOSED TOPOLOGY

A. Circuit Description

This suggested topology offers an elegant solution to the problem by offering a compact, single-stage conversion topology that integrates the functionalities of both regulation and inverting processes. With a single-stage conversion process being carried out, there is no requirement for a dedicated DC-DC converter.

The circuit is modeled after the H5 inverter circuitry, which is a variation of the traditional full-bridge circuit by introducing one more switch to the DC side. The main components include a PV module with its parasitic capacitance, the inductor for energy storage, a diode as a supporting component, a capacitor on the DC link, and a five switch inverter. An output filter has also been included.

In this topology, switches S2 to S5 form the full-bridge inverter responsible for AC generation, while switch S1 is strategically placed on the DC side. The primary role of S1 is to isolate the PV array during specific switching intervals, particularly in freewheeling states. This operation helps in maintaining a nearly constant common-mode voltage, which in turn minimizes leakage current and enhances system safety.

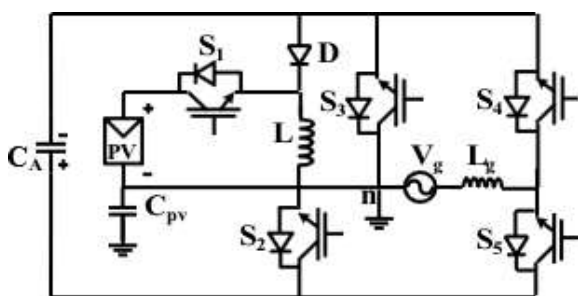


Fig. 1. Single-Stage Buck-Boost H5 Inverter Schematic

B. Operating Modes

Based on the input conditions and switching control, the proposed inverter can work in three different modes:

1) **Buck Mode Operation:** The converter runs in buck mode when the voltage from the PV cells is higher than what the DC-link needs. The duty ratio is regulated to step down the extra voltage.

2) **Boost Operation:** At low irradiance levels, when the PV voltage level is too low, the converter switches into boost

mode. Boost mode is characterized by the storage of energy in the inductor, which is then released to increase the DC-link voltage to the required value.

3) **Inversion Operation:** Once the DC-link voltage is stable, the inverter stage changes it into an AC wave that is in sync with the grid. This process makes sure that power is sent to the utility quickly.

To control the switching action, a unipolar sinusoidal pulse width modulation method is used. There is a dead time built into the switching process to stop any problems with shoot-through.

This system leads to better performance due to its smooth waveforms and low harmonics.

Furthermore, the proposed topology ensures continuous energy transfer, reduced switching stress on components, and enhanced efficiency, making it suitable for modern distributed PV generation systems.

III. SYSTEM ARCHITECTURE

The proposed single-stage buck-boost transformerless inverter based on H5 topology is shown in Fig. 2. Fig. 3 shows how the prototype was made in hardware.

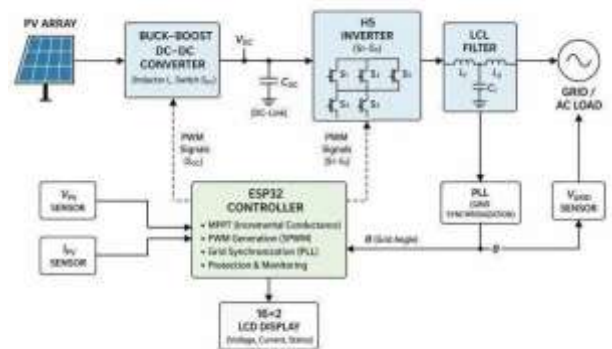


Fig. 2 Block diagram of the suggested H5 inverter system with a single stage buck-boost.

The system comprises of a photovoltaic (PV) panel, a single-stage buck boost DC-DC converter, an H5 inverter bridge, a filter and an ESP32-based control system.

The PV panel generates a varying DC supply according to the irradiation of the sun. The buck boost converter manages the voltage going in and maintains a steady DC link voltage utilizing an inductor and switch. This allows the system to work with low and high voltages of the PV panel.

The DC voltage thus controlled goes to the H5 inverter, where it is transformed from DC to AC with the help of five switches (S1 – S5). The H5 inverter has an extra switch that helps reduce leakage current by keeping the common-mode voltage steady.

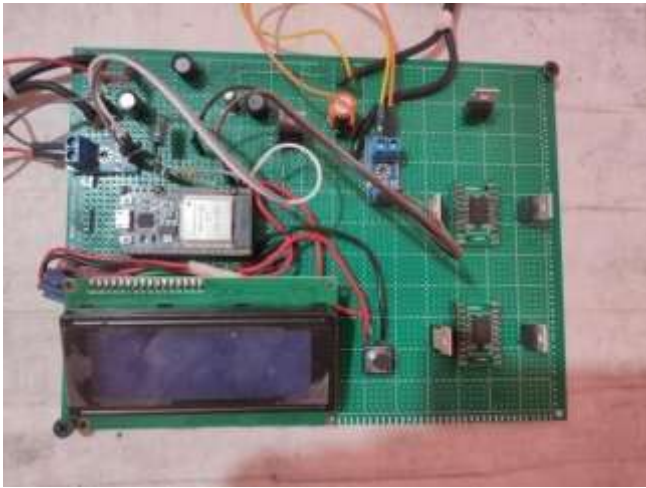


Fig. 3. Hardware implementation of the proposed inverter system.

The output section has an LCL filter that cuts down on harmonics and makes a clean sinusoidal output that can be connected to either the grid or the load..

The control system is implemented using an ESP32 microcontroller that implements various tasks such as the implementation of the MPPT algorithm using the incremental conductance technique, SPWM signal generation, and phase-locking using the PLL method. Closed-loop feedback from various sensors like PV voltage, current, and grid parameters are used for control purposes. Furthermore, a 16×2 LCD screen is used to provide feedback on system performance in terms of voltage, current, and status.

The suggested system combines the steps for converting DC to DC and DC to AC into one step. This cuts down on the number of parts and makes the system more efficient.

IV. SIMULATION RESULTS

In this paper, we have been able to conduct a simulation for the suggested one-stage buck boost converter less inverter system H5 in order to analyze the performance of the proposed inverter once it is integrated with the grid. The complete block diagram of the simulation has been presented in Figure 4 and comprises the PV source, controller, inverter switch circuitry, and output filter.

The controller uses a method called SPWM (Sinusoidal Pulse Width Modulation). SPWM compares a triangular wave with a sine wave to generate switching pulses for inverter switches. PLL is used to synchronize the inverter output with the grid voltage in frequency and phase.

Complete waveforms analysis consists of: (1) Grid voltage (V_g), (2) Grid current (I_g), (3) Inductor current (i_L), and (4) Auxiliary capacitor voltage (VCA). In this case, the inductor current shows that the energy transfer process is satisfactory in the buck and boost mode of operations. Also, the auxiliary capacitor voltage shows satisfactory operation in the range of voltages for the H5 system.

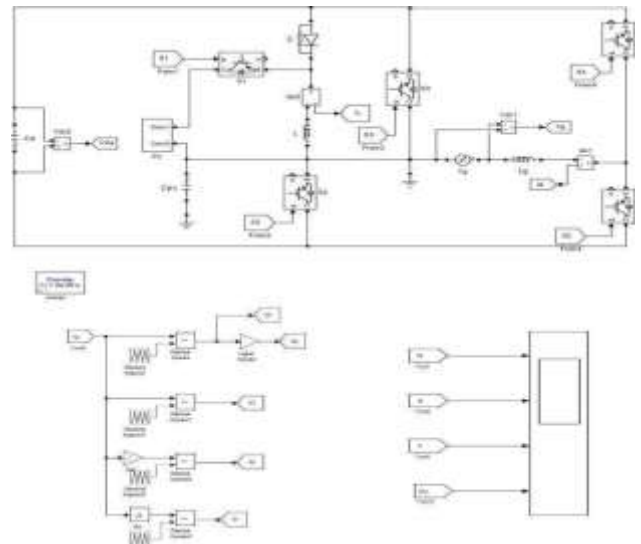


Fig. 4. MATLAB/Simulink model for the proposed inverter system using the H5 structure

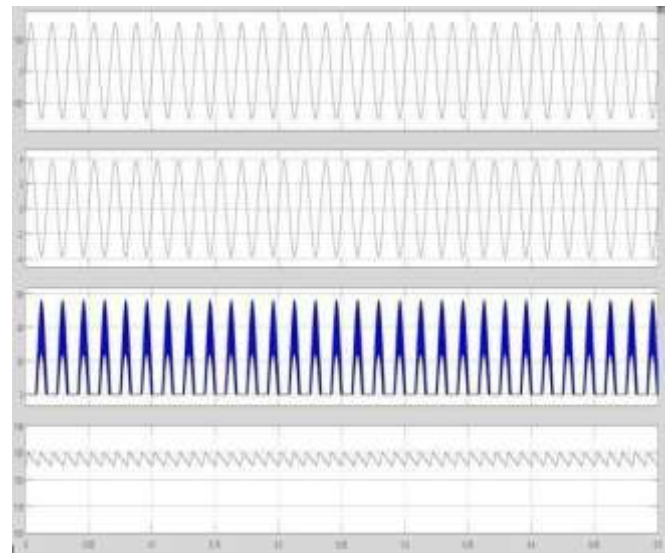


Fig. 5. Simulation results for the output voltage and current waveforms for the proposed inverter

The DC-link voltage remains stable under input variations due to the buck-boost feature. SPWM provides smooth switching and reduces harmonics, resulting in low THD. The H5 topology minimizes leakage current by maintaining nearly constant common-mode voltage.

The overall results of the simulation show that the proposed inverter topology works well, has good power quality, stops leakage current, and syncs up properly with the utility grid, making it a good choice for real-world PV applications.

V. CALCULATION

Efficiency Calculation WITH Transformer.

Given:

Input Voltage (V_{in}) = 6 V DC

Input Current (I_{in}) = 2 A

Output Voltage (V_{out}) = 12 V AC

Formula:

Efficiency (η) = $(P_{out} / P_{in}) \times 100$

Input Power:

$P_{in} = V_{in} \times I_{in} = 6 \times 2 = 12 \text{ W}$

Assumptions:

Output Current (I_{out}) = 0.8 A

Power Factor (pf) = 0.9

Transformer Efficiency = 85%

Inverter Output Power (before transformer):

$P_{inv} = 12 \times 0.8 \times 0.9 = 8.64 \text{ W}$

Final Output Power (after transformer):

$P_{out} = 0.85 \times 8.64 = 7.34 \text{ W}$

Efficiency:

$\eta = (7.34 / 12) \times 100 = 61.2\%$

Conclusion:

Efficiency with transformer is lower due to additional losses.

Efficiency Calculation WITHOUT Transformer using H5 topology.

Input Voltage (V_{in}) = 6 V DC

Input Current (I_{in}) = 2 A

Output Voltage (V_{out}) = 12 V AC

Formula:

Efficiency (η) = $(P_{out} / P_{in}) \times 100$

Input Power Calculation:

$P_{in} = V_{in} \times I_{in} = 6 \times 2 = 12 \text{ W}$

Output Power Calculation (assuming):

Output Current (I_{out}) = 0.8 A

Power Factor (pf) = 0.9

$P_{out} = V_{out} \times I_{out} \times pf = 12 \times 0.8 \times 0.9 = 8.64 \text{ W}$

Efficiency:

$\eta = (8.64 / 12) \times 100 = 72\%$

Conclusion:

The efficiency of the inverter is approximately 72%

VI. DISCUSSION

The simulation studies reveal that the proposed H5 single-stage buck-boost inverter exhibits efficient operation for different PV source input values without affecting the output voltage and current stability. Since this single-stage configuration combines both buck and boost functionalities, there is no necessity of including another DC-DC converter, leading to better performance and design of the inverter. The transformer-less approach has resulted in the downsizing of the proposed topology due to fewer components required for its implementation. The use of one more switch with the H5 topology results in isolation of the PV array during the freewheeling period, thus minimizing the risk of leakage current.

In conclusion, the proposed topology is an effective inverter for PV

applications, providing better output power quality.

VII. FUTURE SCOPE

Although the suggested single stage buck-boost transformerless inverter topology using H5 configuration shows an appreciable performance in efficiency, leakage current reduction, and reduced size and complexity, a number of areas for improvement may be identified.

For one thing, the present study is analyzed using MATLAB/Simulink and hardware. Further studies can explore the development of a full-size real-time working prototype using sophisticated controllers like DSPs or FPGAs. The advantages include fast control processes, increased accuracy, and improved performance in case of dynamic variations in the grid.

Another possible line of investigation is the use of more advanced control techniques. For example, AI-based Maximum Power Point Tracking (MPPT) algorithms and adaptive control methods can be used to achieve better efficiency in rapidly changing weather conditions compared to the classical incremental conductance approach.

Additionally, further research can be carried out to minimize total harmonic distortion (THD) by implementing advanced modulation techniques such as space vector PWM (SVPWM) or predictive control methods. This will enhance power quality and ensure better compliance with grid standards.

In addition, the design can further be extended into multi-level inverter structures for high power applications. This is because such an extension will result in low voltage stress to the switching components as well as improved waveform of the output voltage.

On the whole, the above advancements will immensely improve the inverter structure.

VIII. CONCLUSION

This paper explains the design and working of a buck-boost transformerless inverter using H5 topology for grid-connected solar systems.

The H5 topology allows both voltage boosting and conversion from DC to AC in a single stage, which makes the system simpler and more efficient.

From the results, the inverter gives a stable output voltage, low THD (less harmonics), proper synchronization with the grid, and power factor close to 1, which means efficient power transfer.

The H5 circuit also helps to reduce leakage current by keeping the common-mode voltage stable.

Overall, this inverter design is a good and reliable solution for modern solar PV systems, especially for small-scale grid-connected applications.

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