# P-I Controlled Transformerless Inverter for Solar PV Systems: A Python-Based Simulation

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**Abstract: This project presents the design and implementation of a Buck-Boost Transformer-less Inverter (BBTI) for grid-connected solar photovoltaic systems. Building upon existing research, this study introduces a novel control strategy utilizing a Proportional-Integral (PI) controller to enhance the inverter's performance. The PI controller effectively regulates output voltage and current, improving system stability and minimizing steady-state errors.**

**Implemented in Python, this project leverages extensive libraries for numerical computation and visualization, enabling real-time monitoring and adjustments. The simulation results demonstrate significant improvements in the dynamic response of the inverter, allowing it to adapt quickly to varying load conditions and optimize power delivery to the grid.**

**The enhanced control mechanism leads to a reduction in Total Harmonic Distortion (THD) and improved efficiency, validating the effectiveness of the proposed modifications. Overall, this project contributes to advancing the reliability and performance of transformer-less inverter technology in renewable energy applications.**

***Keywords**: Buck-Boost Converter; Python Simulation; Leakage Currents, PI Controller.*

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## I. INTRODUCTION

The increasing integration of renewable energy sources, particularly photovoltaic (PV) systems, into the power grid has necessitated the development of efficient power conversion systems. Among various power electronic converters, DC-DC converters play a critical role in regulating the output voltage of PV modules to match the requirements of downstream systems or grid interfaces. Among these, buck-boost converters offer the unique advantage of both stepping up and stepping down voltage levels, making them ideal for variable renewable energy sources, Traditional buck-boost converter topologies, while functional, often suffer from significant drawbacks including low efficiency, high ripple content, and poor dynamic response during grid-tied operations. In applications where energy must be injected into the grid with high-quality current and low total harmonic distortion (THD), these shortcomings become major challenges. To overcome these issues, this paper proposes a modified buck-boost converter topology tailored for grid-connected PV systems, which integrates an LCL filter and an advanced PI control strategy for grid current regulation. The topology supports bidirectional current flow, improves power quality, and minimizes the requirement for bulky passive filters by reducing harmonic distortion.

This study presents a complete simulation of the proposed converter using Python, an open-source programming platform. The simulation leverages libraries like NumPy, SciPy, Matplotlib, and Control Systems Toolbox to model the converter dynamics, implement the PI controller, and analyze system performance, particularly in terms of THD and voltage regulation.

## II. PYTHON LIBRARIES USED

Python has emerged as a powerful and flexible tool in the field of engineering simulations due to its open-source nature and a vast ecosystem of scientific libraries. In this work, Python was used for simulating the behavior of the proposed buck-boost converter circuit and analyzing the control strategies. Several essential libraries played a key role in modeling the system, running time-domain simulations, generating waveforms, and computing performance metrics such as Total Harmonic Distortion (THD). The following is an overview of the libraries utilized:

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➢ *NumPy (Numerical Python)*

NumPy is a fundamental package for scientific computing in Python. It provides support for large, multi-dimensional arrays and matrices, along with a collection of high-level mathematical functions. In this simulation, NumPy was used extensively to define time vectors, perform element-wise operations on waveforms, and store large sets of calculated data such as voltages, currents, and control signals.

➢ *SciPy (Scientific Python)*

SciPy builds upon NumPy and adds a wide range of modules for optimization, integration, interpolation, signal processing, and more. Specifically, the scipy.fft module was used to perform Fast Fourier Transform (FFT) on the simulated current waveform to evaluate the harmonic content and calculate the THD. This allowed for an accurate assessment of power quality.

➢ *Matplotlib*

Matplotlib is a 2D plotting library used for visualizing data in the form of graphs and charts. In this project, it was used to generate time-domain plots for key signals such as grid voltage, input inductor current, auxiliary capacitor voltage, and grid current. These visual outputs helped in understanding the dynamic performance of the converter under different control conditions.

➢ *Python-Control Library*

Although not used directly in the basic simulation, the Python Control Systems Library provides tools for system modeling and controller design, including transfer functions, PID tuning, and frequency response analysis. It is often used to validate control loop behavior before implementing it in time-domain code. In future extensions of this work, this library could be incorporated to fine-tune and analyze the PI controller

## III. PROPOSED BUCK-BOOST TRANSFORMERLESS INVERTER TOPOLOGY

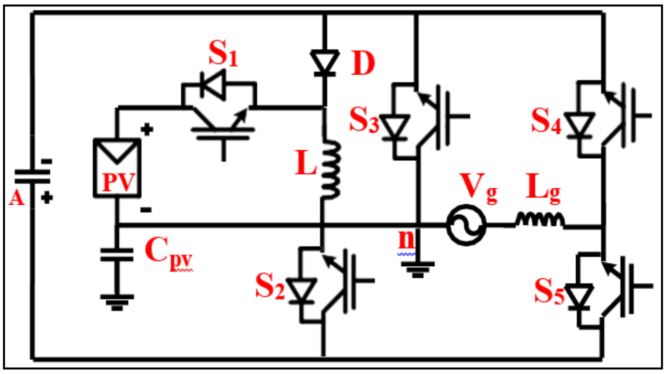


Fig 1 The Proposed Buck-Boost Transformer Less Inverter (BBTI) Topology.

➢ *Modes of Operation*

The operation of the proposed Buck-Boost Transformer less Inverter (BBTI) is divided into four distinct modes. These modes are based on the polarity of the grid voltage (positive or negative half-cycle) and the status of the switching devices. Each mode ensures efficient energy transfer, continuity in current flow, and reduced harmonic distortion.

- *Mode (a): Positive Half-Cycle – Powering Mode*

In this mode, the grid is in the positive half-cycle, and the inverter is actively supplying power to the grid. The switches S1, S3, and S5 are turned ON. The input inductor stores energy from the photovoltaic (PV) source through S1, while the auxiliary capacitor CA delivers energy to the grid via S3 and S5. This coordinated switching facilitates energy flow from both the PV source and the capacitor to the grid..

- *Mode (b): Positive Half-Cycle – Freewheeling Mode*

This mode also occurs during the positive half-cycle but represents a freewheeling state. Only S5 remains ON while all other switches are OFF. The inductor releases its stored energy to the auxiliary capacitor CA through diode D and the antiparallel diode of S2. Meanwhile, the current in the grid-side inductor continues to circulate through S5 and the antiparallel diode of S2, maintaining continuity in the grid current.

- *Mode (c): Negative Half-Cycle – Powering Mode*

When the grid enters the negative half-cycle, the inverter continues to feed power. Switches S1, S2, and S4 are turned ON in this mode. The auxiliary capacitor CA provides energy to the grid via S2 and S4, while the inductor again draws energy from the PV source through S1. The direction of current flow is reversed to match the polarity of the grid.

- *Mode (d): Negative Half-Cycle – Freewheeling Mode*

In this final mode, the system transitions to a freewheeling state during the negative half-cycle. Only switch S2 remains ON. The inductor delivers its stored energy to the auxiliary capacitor through D and the antiparallel diode of S5. At the same time, the grid inductor current continues circulating through S2 and the antiparallel diode of S5, ensuring a smooth and uninterrupted current path.

The detailed comparison of proposed BBTI topology with the existing buck-boost based transformer less inverter topologies is given in Table 1

Table 1 Conventional vs. Proposed Buck-Boost Converter

| **Parameter** | **Conventional** | **Proposed** |
|---|---|---|
| Efficiency | 70-85% | 90-95% |
| Voltage Stress | High | Reduced |
| Load & Line Regulation | Poor | Improved |
| Output Voltage Ripple | High | Low |
| Power Handling Capacity | Limited | High |

## IV. SIMULATION RESULTS OF THE GRID- CONNECTED BBTI TOPOLOGY

➤ *Simulation results*

The grid-connected BBTI system is simulated in Python for 300W power rating. The system parameters used for Python simulations are given in Table-II. 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 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 in Fig. 2.

Table 2 System Parameters for Simulation Studies

| | |
|---|---|
| Power rating | 300W |
| Switching frequency | 10kHz |
| Input voltage | 75V |
| Input inductor (L) | 115µH |
| Auxiliary capacitor (CA) | 50 µF |
| Output inductor (Lg) | 1mH |
| Filter capacitor (Cf) | 10 µF |
| DSP Controller | TMS320F28335 |

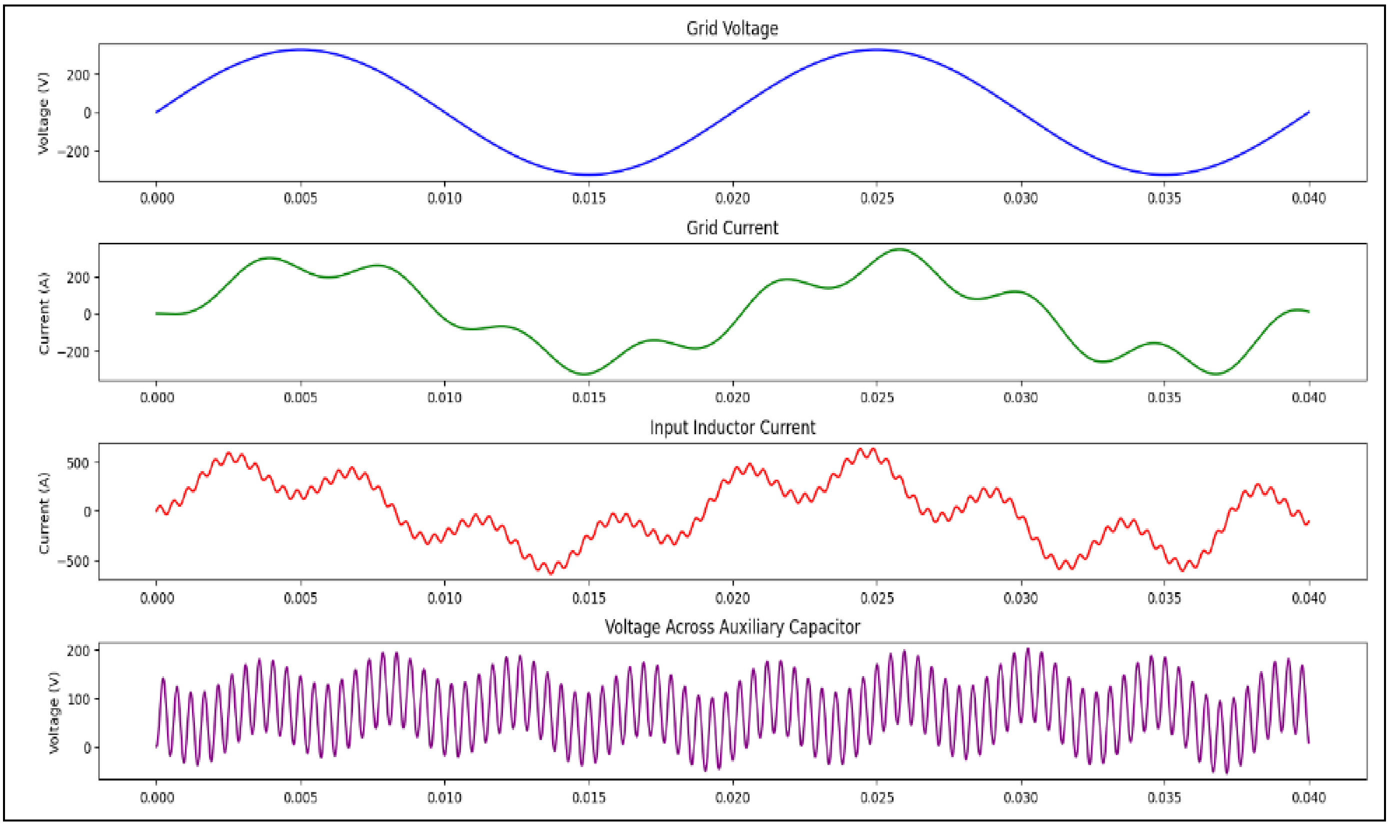


Fig 2 The Simulated Waveforms of the PV Fed Grid-Connected BBTI Topology; (a) the Grid Voltage ($V_g$); (b) Current through Grid ($I_g$); (c) Current through Input Inductor Current ($i_L$); (d) Voltage Across Auxiliary Capacitor ($V_{CA}$).

## V. CONCLUSION

This study demonstrated the effective simulation of a modified buck-boost converter for grid-connected applications. By using an auxiliary capacitor, LCL filter, and PI controller, the system achieved stable output with reduced harmonic distortion. The Python-based simulation confirmed the converter's ability to deliver clean, synchronized power to the grid. These results highlight the converter's potential for practical implementation in renewable energy systems. The BBTI was tested at the switching frequency of 10 kHz and it has been observed that the THD in current is 3.31% which is good.

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