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Enhancing Stability in Standalone Photovoltaic Systems using Transformerless Boost Inverter

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ABSTRACT: This study introduces a transformerless boost inverter tailored for standalone photovoltaic (PV) generation systems, featuring an integrated closed-loop control mechanism to improve performance and stability. The design combines a boost converter with a full-bridge inverter, where a single switch (S1) is employed for both boosting and inverting operations. The use of a non-polarized capacitor as the DC bus and the operation of inductor L1 in discontinuous conduction mode (DCM) contribute to a more compact design and extended component lifespan. Only two out of five switches operate at high frequency, reducing switching losses while maintaining output voltage regulation. A feedback-based control system dynamically adjusts the gain to modulate the reference sine wave amplitude, enabling accurate voltage control. The proposed approach is validated through both simulation and experimental results, demonstrating its effectiveness and reliability.

KEYWORDS: Transformerless Boost Inverter, Discontinuous Mode (DCM), photovoltaic generation systems, Closed loop control system.

I.INTRODUCTION

Photovoltaic (PV) systems have become increasingly popular as a clean and sustainable means of generating electricity by converting sunlight directly into electrical energy using solar modules. In order to make this DC power usable for standalone or grid-connected applications, an inverter is required to convert it into alternating current (AC). Traditionally, PV systems have relied on transformer-based inverters, which serve the purpose of voltage conversion, electrical isolation, and impedance matching. However, the inclusion of transformers adds considerable bulk, increases system cost, and introduces energy losses, thereby reducing overall efficiency.

To overcome these drawbacks, transformerless boost inverters have emerged as a more efficient alternative, particularly for standalone PV applications. By eliminating the transformer, these systems achieve a more compact, lightweight, and cost-effective design. In addition, they offer improved efficiency and higher power density. A transformerless boost inverter operates by stepping up the low-voltage DC output from the PV modules to a higher-voltage AC through high-frequency switching, typically using power semiconductor devices like MOSFETs or IGBTs. The energy conversion process is facilitated by inductors and capacitors, which are used for energy storage and transfer within the circuit.

The proposed inverter design offers several key advantages. One of the primary benefits is its ability to achieve high voltage gain without relying on transformers, thereby reducing the overall size and cost of the system. Additionally, the inverter features a simplified architecture with fewer power components, making it not only more cost-effective but also easier to control when compared to traditional two-stage inverter systems.

To regulate the output voltage, the design employs a monopolar sinusoidal pulse width modulation (SPWM) technique. This method enables precise voltage control by adjusting the duty cycle of the switching devices, ensuring efficient voltage boosting and compliance with output voltage specifications. Compared to other topologies—such as Z-source inverters, dual-boost inverters, double Cuk inverters, and buck-boost configurations—the proposed design offers a more straightforward structure, enhanced voltage gain, better integration, and simpler control dynamics.



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This innovative transformerless inverter topology demonstrates the potential for effective voltage boosting and regulation without relying on bulky transformers or complex circuitry. It holds promise for the development of compact, efficient, and economically viable inverter systems tailored to standalone PV applications. However, further research and experimental validation are essential to comprehensively assess the performance, efficiency, and long-term reliability of the proposed approach.

In this work, a boost converter is integrated to elevate the PV panel voltage prior to inversion, offering a simple, efficient, and low-component-count solution well-suited to standalone PV systems. The initial phase of the project focused on identifying the most appropriate inverter topology, achieved through an extensive review of existing literature. A low-loss design was then developed and validated through MATLAB simulations to verify the concept's feasibility. Upon successful simulation, a hardware prototype was constructed using the necessary electronic components and controllers. The system was subsequently tested under varying parameters to confirm its robustness and effectiveness in real-world conditions.

II. A TRANSFORMERLESS BOOST INVERTER WITH CLOSED LOOP

A transformerless boost inverter equipped with closed-loop control is proposed to improve the overall efficiency and stability of photovoltaic (PV) power systems. By integrating a boost converter with an inverter stage, this configuration eliminates the need for bulky and costly transformers, resulting in a more compact and economical design. The inclusion of a closed-loop feedback mechanism enables precise voltage regulation and enhances the dynamic response, making it well-suited for standalone PV applications.

This inverter topology is characterized by high voltage gain, minimized switching losses, and a simplified architecture, providing a reliable and efficient solution for converting solar-generated DC power into usable AC output. The circuit configuration includes five power switches (S1–S5), two energy storage elements (inductor L1 and capacitor C1), a load resistor (RO), a filter inductor (L2), a filter capacitor (C2), and a diode (D1). The body diodes of the switches are denoted DS1 through DS5. Notably, switch S1 serves a dual function, operating in both the boost and inverter stages, which reduces the overall switch count and improves integration.

During the boost operation, switches S3 and S5 are turned off. The input voltage (Uin) charges inductor L1 through diode D1 and switch S1, causing the inductor current (iL1) to increase linearly. Meanwhile, capacitor C1 charges inductor L2 and simultaneously supplies energy to the load resistor RO through switches S2 and S4. The switching actions of S1, S2, and S4 collectively manage the inverter's output. When S1 is on, inductor L1 discharges through the load, delivering power. Similarly, when S2 is engaged, the stored energy in L2 is transferred to RO. This integrated boost and inverter structure offers advantages including high gain, reduced device count, and compactness, all while maintaining efficient power delivery. Control is achieved using a monopolar sinusoidal pulse width modulation (SPWM) scheme, which allows accurate regulation of the output voltage.

The closed-loop control system continuously monitors the output voltage and dynamically adjusts the gain to maintain consistent performance. This real-time feedback is essential for maintaining reliable inverter operation, particularly in standalone PV systems where solar input may vary due to environmental factors. The control system's ability to adapt to changing conditions ensures stable voltage output under different load scenarios. Moreover, by maintaining tight control over the output voltage, the closed-loop mechanism enhances overall system efficiency, maximizing the effective use of the harvested solar energy.

III. SYSTEM ARCHITECTURE

Conventional systems typically combine a boost converter with a traditional full-bridge inverter and employ sinusoidal pulse width modulation (SPWM) to regulate and elevate the output voltage. While effective, this configuration often leads to increased complexity in both control and protection circuitry, requiring sophisticated mechanisms to ensure safe and stable operation. Furthermore, such systems tend to be more susceptible to voltage fluctuations and grid disturbances, which can compromise their stability and performance.

To address these challenges, this study proposes the development of a high-gain, high-efficiency inverter capable of delivering a constant output voltage for standalone photovoltaic (PV) applications. The proposed solution incorporates a proportional-integral (PI) controller that continuously monitors the load voltage and dynamically adjusts the duty cycle to maintain voltage stability under varying input and load conditions.

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Fig. 1 MATLAB simulated model of the proposed circuit with closed loop Fig.2 Modes of operation

IV.MODES OF OPERATION

The proposed inverter operates with the boost inductor functioning in discontinuous conduction mode (DCM). Each switching cycle consists of six distinct modes-three for the positive half-cycle and three for the negative half-cycle of the output voltage. Modes I, II, and III occur during the positive half, while Modes IV, V, and VI correspond to the negative half-cycle.

During the positive half-cycle, switches S1 and S2 alternate at high frequency, with S3 and S5 remaining off and S4 continuously conducting. The system transitions through the following modes:

- Mode I [to-t1]: At time to, switches S1, S2, S4, and diode D1 are turned on, while S3 and S5 remain off. The input DC voltage (Uin) charges inductor L1 via D1 and S1, causing a linear increase in the inductor current (iL1). Simultaneously, capacitor C1 transfers energy to inductor L2 and supplies power to the load resistor (RO) through switches S2 and S4.
- Mode II $[t_1-t_2]$: At time t_1 , switch S4 and diode DS3 are active, while S1, S2, S3, and S5 are turned off. In this phase, Uin and L1 charge capacitor C1 through D1 and DS4. Since the load current must remain continuous, inductor L2 continues supplying current to RO via DS3. The mode concludes when iL1 decreases linearly to zero.
- Mode III [t2-t3]: At time t2, only switch S4 remains on, with all other switches turned off. With iL1 now zero, the charging loop through L1 ceases. However, inductor L2 continues powering RO through the body diode DS3 until time t₃, marking the end of this mode.

The negative half-cycle of the output voltage follows a similar sequence:

- Mode IV [t4-ts]: At t4, switches S1, S3, and S5 are activated, while S2 and S4 are turned off. Uin charges inductor L1 through D1 and S1, causing iL1 to rise. At the same time, capacitor C1 transfers energy to inductor L2, powering RO through S3 and S5.
- Mode V [ts-ts]: At ts, switches S3 and S5 remain on, and all others are off. During this mode, Uin and L1 continue to charge capacitor C1 through D1 and DS4, while L2 supplies current to RO through S3 and DS4. This phase ends when iL1 reaches zero.
- Mode VI [t₆-t₇]: At t₆, with iL1 at zero, no further energy is drawn from Uin. However, inductor L2 continues • to deliver energy to the load through switches S3 and DS4 until time t_7 , concluding the switching cycle

Mode	S1/Ds1	S2/Ds2	S3/Ds3	S4/Ds4	s5/Ds5
Ι	1/0	1/0	0/0	1/0	0/0
II	0/0	0/0	0/1	1/1	0/1
III	0/0	0/0	0/1	1/0	0/0
IV	1/0	0/0	1/0	0/0	1/0
V	0/0	0/0	1/0	0/1	1/1
VI	0/0	0/0	1/0	0/1	1/0

Table 1 Switching sequence of inverter

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Fig. 4Waveforms at the Gate of switches S1 - S5

V. PROPOSED MODIFICATIONS AND HARDWARE IMPLEMENTATION

The modified inverter circuit incorporating closed-loop control was simulated using MATLAB to evaluate its effectiveness in improving stability in standalone photovoltaic (PV) systems. Building on the foundational design, this enhanced configuration integrates a feedback mechanism to dynamically regulate output voltage. Key components of the control system include a rectifier and an Analog-to-Digital Converter (ADC), which feeds data into a real-time Root Mean Square (RMS) computation module. This module is synchronized with a PWM generator that periodically resets it. The peak value of the resulting sine wave is compared to a predefined reference to determine the error, representing the deviation between the actual and desired output voltage. This error signal is then processed by a Proportional-Integral (PI) controller, which calculates a multiplication factor used to modulate the reference sine wave. This modulation adjusts the gain dynamically, thereby regulating the output voltage amplitude. By continuously updating the gain based on the error, the closed-loop control system maintains voltage stability even under variable solar input conditions. This real-time adjustment ensures a consistent AC output and enhances the overall reliability of the system. To validate the performance of the proposed closed-loop controlled boost inverter, a hardware prototype was developed. The core of the control system is built around the DSPIC30F2010 microcontroller from Microchip, chosen for its real-time processing capabilities. The prototype was subjected to thorough experimental testing using a photovoltaic panel and controlled input conditions. A VARTECH 3005B DC power supply was employed to simulate input voltage, while a resistive load was used at the output stage. Pulse-width modulation (PWM) signals were generated using a Toshiba TLP250H gate driver.

System performance and efficiency were measured using a Yokogawa WT1800 power analyzer and an Agilent Technologies DSO1052B oscilloscope. The experimental results confirmed the effectiveness of the closed-loop strategy, with the inverter maintaining stable output voltage and high efficiency under varying conditions.



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Fig. 5 Prototype Model

VI. RESULTS AND DISCUSSION

The simulation results obtained from the MATLAB/Simulink model clearly demonstrate the effectiveness of the proposed transformerless boost inverter with closed-loop control in improving the stability of standalone photovoltaic (PV) systems. The incorporation of a feedback mechanism ensures a consistent and reliable output voltage, even when the input conditions vary due to changes in solar irradiance. The system shows notable enhancements in voltage regulation, reduced ripple, and faster transient response. These outcomes confirm the theoretical advantages of the design, validating its ability to handle dynamic shifts in both PV input and load, thereby improving overall efficiency and performance.

The inverter showcased a strong capacity for maintaining output stability under varying DC input voltages, as verified through practical testing using a photovoltaic panel. During experimentation, the system responded swiftly to startup and voltage fluctuations, demonstrating high reliability and adaptability. The inverter's dynamic response improved significantly, with quick adjustments to load changes and minimal overshoot during transitions. One of the observed waveforms illustrates the inverter's voltage and current behavior across the load resistor (RO) during load variation—from light load to full load. This clearly indicates the system's ability to maintain stable performance under varying load conditions. Efficiency analysis revealed that the output voltage remained nearly constant at approximately 21V DC, even when the input voltage varied between 10V and 20V DC, aligning well with the desired reference value.

The closed-loop control system contributed substantially to this stability by dynamically adjusting output based on realtime feedback. Input voltage supplied via the PV panel was effectively regulated, resulting in a stable and reliable AC output. The combination of dynamic gain tuning and precision control helped maintain optimal performance, regardless of fluctuations in the input or load. Furthermore, modulation of the reference sine wave reduced harmonic distortion, leading to a cleaner output waveform. The integration of an ADC, RMS computation, and a PI controller allowed for precise measurement and control, significantly boosting overall system accuracy and reliability.



Fig. 6Vin, Vrms and Vm waveforms, Vout and Iout waveforms of the proposed inverter



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In the fig 6, it shows the Vin, Vrms and Vm voltages across the output inductor and the inverter's output voltage and the output inductor (L_2) current





Fig .7Plot of output voltage for variation in input voltage



VII.CONCLUSION

In conclusion, the implementation of closed-loop control mechanisms within the transformerless boost inverter circuit represents a significant enhancement for standalone photovoltaic systems. By integrating the closed loop control, the system achieves precise voltage regulation and stability despite fluctuations in the photovoltaic input. This closed-loop control mechanism enhances the stability and performance of the standalone PV system by continuously adjusting the gain and controlling the switches based on real-time measurements. The use of components like the PI controller, PWM generator, and running RMS calculation ensures that the system maintains a consistent output despite variations in the PV input.

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