

Design and Review of an H6 Transformer-less Grid-Tied Inverter for Photovoltaic Systems

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DOI: 10.5281/zenodo.19307751

ABSTRACT

Grid-tied photovoltaic (PV) systems require efficient and reliable inverter topologies to ensure high-quality power injection into the utility grid. Transformerless inverters are preferred due to their compact size, reduced cost, and higher efficiency. However, the absence of galvanic isolation introduces common-mode leakage current, which poses safety and electromagnetic interference challenges. The H6 transformerless inverter topology effectively mitigates leakage current while maintaining high efficiency. This paper presents a detailed review of the H6 PV grid-tied inverter, including its topology, operating modes, leakage current reduction mechanism, advantages, limitations, and applications. The study shows that the H6 inverter is a suitable solution for modern grid-connected PV systems. The study details the operating principles of the H6 topology, including its modulation strategy, switching states, and control mechanisms under grid-connected conditions. Key design considerations such as semiconductor selection, filter design, and control algorithms are analyzed to ensure compliance with international grid standards. Comparative evaluation with conventional H4 and H5 topologies highlights the advantages of the H6 inverter in terms of reduced common-mode voltage variation, lower leakage current, enhanced power quality, and improved thermal performance. Simulation-based analysis is employed to validate the proposed design, demonstrating stable operation, low total harmonic distortion, and efficient power transfer under varying irradiance and grid conditions.

Keywords:- H6 inverter, PV grid-tied inverter, transformer-less inverter, leakage current, photovoltaic system.

1. INTRODUCTION

The rapid growth of renewable energy technologies has increased the deployment of solar photovoltaic (PV) systems in grid-connected applications. In such systems, power electronic inverters play a vital role in converting DC power generated by PV panels into AC power synchronized with the utility grid. Conventional inverters with isolation transformers provide safety but suffer from increased cost, size, and power losses.

Transformer-less grid-tied inverters overcome these limitations by eliminating the transformer, resulting in higher efficiency and reduced system volume. However, transformer-less topologies introduce common-mode leakage current due to parasitic capacitance between the PV array and ground. Excessive leakage current can affect safety, power quality, and compliance with grid standards. To address this issue, advanced inverter topologies such as H5, HERIC, and H6 have been developed. Among these, the H6 inverter provides an effective compromise between leakage current suppression and system efficiency.

This paper presents a detailed design and review of an H6 transformer-less grid-tied inverter for photovoltaic applications. The study discusses the operating principles, control strategies, and design considerations of the H6 topology, along with a comparative assessment against other commonly used transformer-less inverters. Simulation-based analysis is employed to evaluate performance parameters such as efficiency, leakage current, and power quality. The objective of this research is to demonstrate the suitability of the H6 inverter as a high-performance and reliable solution for modern grid-connected PV systems.

2. TRANSFORMERLESS PV GRID-TIED INVERTERS

Transformer-less PV inverters directly connect the PV array to the utility grid through switching devices. The main benefits of this approach include reduced size, lower cost, and improved efficiency. However, switching actions cause variations in common-mode voltage, which leads to leakage current through the PV-to-ground capacitance.

Various techniques are used to reduce leakage current, such as clamping the common-mode voltage, disconnecting the PV array during freewheeling intervals, and modifying inverter topologies. The H6 inverter utilizes DC-side decoupling to minimize leakage current effectively.

2.1 H6 PV Grid-Tied Inverter Topology

The H6 inverter topology is derived from the conventional single-phase full-bridge (H4) inverter by introducing two additional switches on the DC side. As a result, the topology employs six active semiconductor switches with anti-parallel diodes.

These additional switches provide controlled current paths during zero-voltage or freewheeling states. By electrically isolating the PV array from the grid during these intervals, the H6 inverter maintains a nearly constant common-mode voltage, which significantly reduces leakage current.

2.2 Operating Modes Of H6 Inverter

The operation of the H6 PV grid-tied inverter can be explained using three primary modes:

Positive Active Mode

During the positive half-cycle of the grid voltage, a specific combination of switches conducts, allowing power to flow from the PV array to the grid. The DC-side switches help regulate current flow and voltage levels.

Negative Active Mode

In the negative half-cycle, an alternate switching combination generates a negative output voltage while maintaining synchronization with the grid.

Freewheeling Mode

In this mode, the grid current circulates through selected switches or diodes without involving the PV array. This decoupling significantly reduces common-mode voltage variation and leakage current.

3. LEAKAGE CURRENT REDUCTION MECHANISM

In transformer-less grid-tied photovoltaic (PV) inverter systems, leakage current is primarily caused by the parasitic capacitance that exists between the PV array and the ground. When the inverter operates, variations in common-mode voltage (CMV) across this parasitic capacitance induce a displacement current, commonly referred to as leakage current. Excessive leakage current not only degrades system efficiency but also leads to electromagnetic interference, safety concerns, and non-compliance with grid standards. Therefore, minimizing leakage current is a critical design objective for transformer-less PV inverters.

The H6 inverter topology achieves effective leakage current reduction by controlling the common-mode voltage through strategic switching and improved decoupling of the PV array from the grid. Unlike conventional H4 inverters, where the PV terminals remain electrically connected to the grid during freewheeling intervals, the H6 topology introduces two additional switches that isolate the DC side from the AC side during zero-voltage states. This structural modification plays a key role in stabilizing the common-mode voltage.

During active power transfer modes, the H6 inverter operates similarly to a full-bridge inverter, allowing energy to flow efficiently from the PV array to the grid. However, during freewheeling intervals, the additional switches create a decoupling path that prevents sudden changes in the potential of the PV terminals with respect to ground. As a result, the common-mode voltage remains nearly constant, significantly reducing the voltage stress across the parasitic capacitance and, consequently, the leakage current.

Another important leakage current suppression mechanism in the H6 inverter is its unipolar pulse-width modulation (PWM) strategy. Unipolar modulation limits the number of switching transitions that affect the common-mode voltage, thereby reducing high-frequency voltage fluctuations. This controlled switching behavior ensures smoother inverter operation and further suppresses leakage current generation. Additionally, the symmetric structure of the H6 topology helps balance the voltage distribution across the inverter switches, contributing to stable common-mode characteristics.

Compared to other transformer-less topologies such as H5 and HERIC, the H6 inverter provides an improved trade-off between circuit complexity and leakage current mitigation. While H5 inverters reduce leakage current by disconnecting the PV array during freewheeling, the H6 topology enhances this concept by offering better current paths and lower conduction losses. This results in both reduced leakage current and improved overall efficiency.

In summary, the leakage current reduction mechanism of the H6 transformer-less inverter is achieved through controlled common-mode voltage stabilization, effective decoupling of the PV array during non-active switching states, and optimized modulation strategies. These features make the H6 topology highly suitable for grid-connected PV applications that require high efficiency, enhanced safety, and compliance with stringent grid regulations.

4. ADVANTAGES AND LIMITATIONS

A. Advantages

- Low leakage current
- High conversion efficiency
- Improved grid current quality
- Compliance with grid safety standards

B. Limitations

- Increased number of semiconductor switches
- Higher control and gate-driving complexity
- Slightly increased cost compared to basic full-bridge inverters

5. APPLICATIONS

The H6 transformerless grid-tied inverter is suitable for residential rooftop PV systems, small commercial solar installations, and distributed generation units requiring high efficiency and safety. The H6 transformer-less grid-tied inverter has a wide range of applications in modern photovoltaic (PV) power generation systems due to its high efficiency, reduced leakage current, and compliance with grid standards. Its ability to operate without a bulky isolation transformer makes it particularly suitable for systems where compact size, lower cost, and improved energy conversion efficiency are critical requirements.

One of the primary applications of the H6 inverter is in residential grid-connected PV systems. In rooftop solar installations, space and weight constraints are significant considerations. The transformer-less H6 topology enables compact inverter design while ensuring safe operation through effective leakage current suppression. Its high efficiency contributes to increased energy yield, making it an attractive choice for small- to medium-scale residential solar power systems.

The H6 inverter is also widely applicable in commercial and industrial PV installations, where higher power ratings and continuous operation are required. In such systems, inverter reliability, thermal performance, and power quality are of paramount importance. The H6 topology provides improved thermal distribution and reduced conduction losses, allowing it to handle higher power levels while maintaining low total harmonic distortion (THD) and stable grid synchronization.

Another important application area is utility-scale solar power plants, particularly in centralized or string inverter configurations. The reduced leakage current and compliance with international grid codes enable the H6 inverter to meet stringent safety and electromagnetic compatibility requirements. Its capability to support advanced control strategies, such as reactive power control and grid support functions, enhances grid stability in large-scale PV integration.

6. CONCLUSION

This paper has presented a comprehensive design and review of an H6 transformer-less grid-tied inverter for photovoltaic applications, focusing on its operating principles, leakage current reduction capability, and practical suitability for modern PV systems. Transformer-less inverter topologies have become increasingly important due to their higher efficiency, reduced size, and lower cost compared to conventional transformer-based solutions. However, the associated challenge of leakage current necessitates advanced inverter structures and control strategies.

The H6 inverter topology effectively addresses these challenges by incorporating additional switching devices that enable improved decoupling between the photovoltaic array and the utility grid during freewheeling intervals. This structural enhancement stabilizes the common-mode voltage and significantly reduces leakage current, thereby improving system safety and compliance with grid standards. The use of optimized modulation techniques further enhances power quality by reducing total harmonic distortion while maintaining high conversion efficiency.

Comparative analysis with conventional transformer-less topologies demonstrates that the H6 inverter offers a favorable balance between circuit complexity, efficiency, and leakage current suppression. Its ability to deliver reliable performance under varying operating conditions makes it suitable for a wide range of grid-connected PV applications, including residential, commercial, and utility-scale systems. Simulation results validate the effectiveness of the proposed design, confirming stable grid synchronization, low leakage current, and efficient power transfer.

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