

A Transformerless Photovoltaic Inverter With Dedicated MPPT For Grid Application

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Abstract The goal of lowering the size and expense of grid-connected solar systems has led to a recent surge in interest in transformerless grid-connected inverter advancements. However, achieving the maximum power from individual modules is a significant restriction in such systems. A modular transformerless grid-connected solar multilevel inverter that can accomplish each module's maximum power point (MPP) under various operating conditions is proposed in this study. There is flexibility to expand the number of inputs with fewer components thanks to the straightforward and modular architecture that is being given. For the suggested system, a single-phase synchronous reference frame PI (SRF-PI) controller has been developed and implemented, and the methodical process for doing so has been explained.

Keywords: Mppt, Transformerless Inverters, Photovoltaic, Grid Tied.

I. INTRODUCTION

In the pursuit of sustainable energy solutions, photovoltaic (PV) systems have become a fundamental aspect of renewable energy generation. The efficiency and effectiveness of these systems heavily rely on the performance of their inverters, which convert the direct current (DC) output of solar panels into the alternating current (AC) needed for grid compatibility. Traditional inverters have used transformers to provide electrical isolation and ensure safety. Nevertheless, transformerless inverters have emerged as a promising alternative, offering improved efficiency, reduced costs, and smaller physical footprints.

This report focuses on the innovative design and application of transformerless photovoltaic inverters, specifically emphasizing their role in grid-tied applications. A notable feature of these inverters is the integration of dedicated Maximum Power Point Tracking (MPPT) algorithms. MPPT plays a crucial role in optimizing the energy harvested from solar panels, ensuring that the system operates at its maximum potential under varying environmental conditions.

The report seeks to provide a comprehensive overview of transformerless PV inverters, delving into their operational principles, advantages, and the technical challenges they address. It also underscores the significance of MPPT in enhancing the overall efficiency of PV systems. By examining recent advancements and case studies, this report aims to illuminate the practical applications and future prospects of transformerless inverters in the renewable energy landscape. Through a thorough exploration of these topics, this seminar report aims to contribute to the understanding and advancement of solar energy technology, highlighting the transformative potential of transformerless photovoltaic inverters with dedicated MPPT in achieving a sustainable and efficient energy future. By delving into these topics, this seminar report aims to enhance understanding of transformerless photovoltaic inverters and their critical role in advancing solar energy technology. The insights provided will contribute to the broader goal of achieving a sustainable and efficient energy future, aligning with global efforts to mitigate climate change and promote renewable energy adoption.

II. TRADITIONAL INVERTER

In the realm of photovoltaic (PV) systems, traditional inverters, also known as transformer-based inverters, have long been the primary technology. These inverters play a crucial role in converting the direct current (DC) produced by solar panels into the alternating current (AC) required by the electrical grid and household appliances. A distinctive feature of traditional inverters is the incorporation of a transformer, which serves multiple essential functions: adjusting the voltage to align with grid requirements, providing galvanic isolation to prevent direct current injection into the AC grid for safety, and reducing electromagnetic interference (EMI) to produce cleaner AC output.

The electrical isolation capability of the transformer is a significant advantage as it enhances safety by preventing potential faults on the DC side from impacting the AC side, thereby reducing the risk of electric shock. Furthermore, traditional inverters are renowned for their durability and dependability, making them a trusted choice for a wide range of residential, commercial, and industrial applications. However, these inverters do have their drawbacks. The inclusion of a transformer introduces additional energy losses as energy is dissipated in the form of heat during the voltage transformation process, thereby decreasing overall efficiency. Additionally, transformers are bulky and heavy, resulting in larger and more cumbersome traditional inverters to install and handle. This added weight and size can also lead to increased shipping and installation costs. Moreover, the presence of a transformer raises the manufacturing cost, often making traditional inverters more expensive than their transformerless counterparts.

Heat generation is another concern as transformers produce heat, which may require additional cooling mechanisms, further complicating the system and increasing energy consumption. Traditional inverters also tend to be less efficient under partial load conditions, potentially leading to lower overall energy harvest from the PV system. Despite these disadvantages, traditional inverters remain widely used, particularly in applications where safety, reliability, and voltage matching are critical.

Their enduring presence in the market emphasizes their importance, even as newer, more efficient technologies like transformerless inverters continue to emerge. Understanding the advantages and limitations of traditional inverters is crucial for making informed decisions in the design and implementation of PV systems, balancing the need for safety and reliability with the pursuit of efficiency and cost-effectiveness.

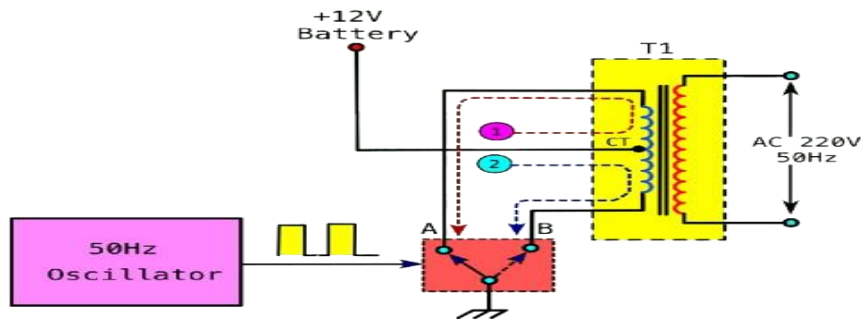


Fig.1. Basic single-phase Traditional inverter

The provided circuit diagram depicts a traditional inverter that converts direct current (DC) from a 12V battery into alternating current (AC). The primary components include a 50Hz oscillator, switching transistors, and a center-tapped transformer. The 50Hz oscillator generates a square wave signal that alternately switches the transistors on and off. When transistor A is activated, current flows from the battery through the upper half of the primary winding of the transformer, creating a magnetic field. Conversely, when transistor A turns off and transistor B turns on, current flows through the lower half of the primary winding, generating a magnetic field in the opposite direction. This alternating switching action induces an AC voltage in the secondary winding of the transformer, stepping up the voltage to the desired level, such as 220V AC at 50Hz. The role of the transformer is crucial as it provides voltage transformation and galvanic isolation, enhancing safety. Despite its effectiveness, this traditional inverter design has some disadvantages, including efficiency losses due to heat dissipation, bulkiness, and the need for robust cooling mechanisms. Nonetheless, it remains a reliable and straightforward solution for converting DC to AC, suitable for various applications where safety and voltage matching are essential.

III. TRANSFORMERLESS (PV) INVERTERS

Transformerless PV inverters have become popular in the solar energy industry due to their advantages and drawbacks. Their high efficiency, typically exceeding 97%, enables better energy conversion from solar panels to usable electricity. Additionally, they are lighter and more compact than transformer-based inverters, making installation and transportation easier and reducing costs. The absence of a transformer reduces manufacturing complexity and material expenses, resulting in a lower upfront cost.

However, transformerless inverters may pose safety risks due to the absence of galvanic isolation, operating at high voltages, and increasing the risk of electric shock. They may also be more prone to issues related to common mode noise,

affecting performance and potentially leading to system failures. Compatibility issues may arise with older solar panel systems, and using them in regions with strict electrical codes may require additional certifications or compliance checks, complicating the installation process. Careful consideration of safety, compatibility, and regulatory factors is essential for optimal performance and reliability.

One significant benefit of transformerless PV inverters is their ability to achieve higher energy yields, especially in variable or suboptimal sunlight conditions. Their simpler design allows for a quicker response time to changes in solar intensity, better tracking of the maximum power point of solar panels, and more effective capture and conversion of solar energy during partial shading conditions.

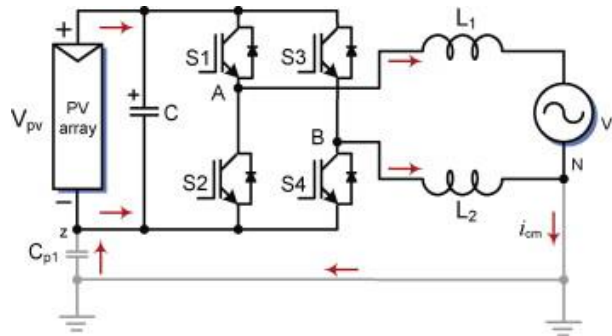


Fig.2 Basic single-phase transformerless PV inverter

Moreover, transformerless inverters typically have lower operational costs over their lifetime, requiring less maintenance and offering a longer operational lifespan. However, their lack of galvanic isolation may make them unsuitable for some applications, particularly in systems requiring a higher degree of safety or isolation from the grid. They can also be sensitive to grid disturbances and may require efficient cooling mechanisms to manage heat dissipation for optimal performance and reliability.

IV. PROPOSED CIRCUIT DIAGRAM

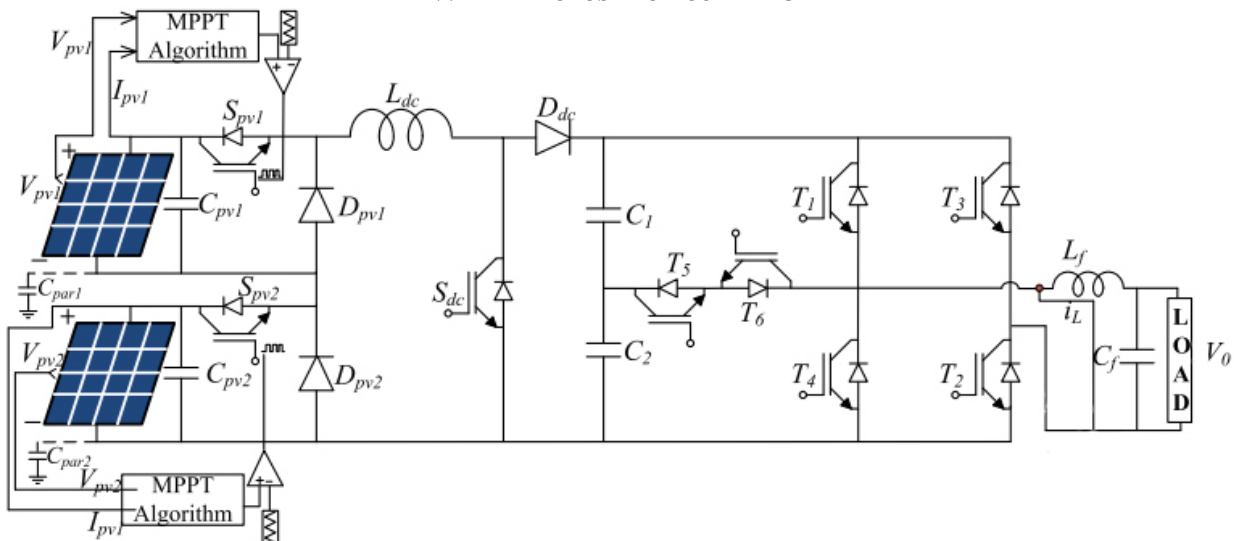


Fig.3. Schematic of the proposed configuration with mppt

The diagram illustrates a grid-tied power conversion system based on a dual photovoltaic (PV) array. This configuration includes essential components such as maximum power point tracking (MPPT) controllers, a DC-DC boost converter, and a DC-AC inverter, all working in harmony to effectively convert solar energy into usable AC power for grid or local load applications. Each stage of the system is meticulously designed to optimize energy conversion, ensuring maximum efficiency and stability during operation.

The system commences with two PV arrays, denoted as V_{pv1} and V_{pv2} , connected in parallel. Each PV array is responsible for capturing solar energy and converting it into direct current (DC) power. The parallel connection of the

arrays serves to boost the total power output, making it suitable for meeting higher energy demands. Each PV array is equipped with its own MPPT controller, continuously adjusting the operating conditions of the solar panels to extract the maximum possible power. By optimizing the duty cycle of switches (Spv1 and Spv2), the MPPT ensures that the solar panels operate at their most efficient point, considering factors such as sunlight intensity and temperature, which is crucial due to the significant impact of these environmental factors on the performance of PV panels.

Capacitors Cpv1 and Cpv2 are linked across the PV arrays to smooth the DC output by absorbing and releasing energy in response to fluctuations. Fluctuations in solar power generation due to changes in sunlight are buffered by the capacitors, stabilizing the voltage and ensuring consistent power delivery. Additionally, blocking diodes Dpv1 and Dpv2 are positioned between the PV arrays and the rest of the system to prevent reverse current flow, protecting the solar panels from potential damage in cases where current could flow back from the load or inverter toward the PV arrays, such as during faults or system shutdowns.

After the PV arrays' outputs go through the MPPT stage, they are combined at a shared DC bus, which serves as the central point for the convergence of DC power from both arrays. An inductor LdcL_{dc}Ldc is included at this point to filter the current and reduce high-frequency ripples resulting from the MPPT controllers' switching operations, which could otherwise negatively impact the system's efficiency and performance.

Following this, the system integrates a DC-DC boost converter, consisting of a switch SdcS_{dc}Sdc and a diode DdcD_{dc}Ddc, to elevate the voltage from the PV arrays to a level required for efficient DC-AC conversion or to meet specific grid/load voltage requirements. The boost converter works by periodically switching SdcS_{dc}Sdc on and off, storing energy in the inductor LdcL_{dc}Ldc during the "on" period and releasing this energy during the "off" period to boost the overall voltage. The output voltage is then stabilized in capacitors C1C_1C1 and C2C_2C2, preparing it for the inverter stage.

The DC-AC inverter is a critical component as it transforms the DC voltage from the boost converter into alternating current (AC), suitable for use by standard electrical appliances or feeding into the power grid. The inverter in the diagram is a full-bridge type, comprising six switches (T1T_1T1 through T6T_6T6) arranged in a three-phase configuration and controlled to generate an AC waveform. Typically, a control technique such as pulse-width modulation (PWM) is used to create a smooth sinusoidal AC output by rapidly switching the transistors on and off. This conversion is essential because most electrical loads and grids operate using AC power rather than DC.

Capacitors C1C_1C1 and C2C_2C2 connected to the DC link also play a vital role in ensuring smooth operation, stabilizing the voltage at the DC link to maintain the quality of the AC output. These capacitors act as a buffer to ensure a steady and consistent DC input to the inverter, minimizing the potential for power quality issues.

Following the inverter stage, the generated AC output is filtered through an LC filter comprising an inductor (LfL_fLf) and a capacitor (CfC_fCf) to remove or significantly reduce high-frequency harmonics introduced by the inverter's switching operation, ensuring a high-quality output with minimal distortion.

The output voltage V0V_0V0 represents the AC voltage supplied to the load. The load, which can be any electrical device, local grid, or other power-consuming application, receives this voltage. The system is created to guarantee stable and efficient power delivery to the load. By utilizing MPPT control, the boost converter, and the inverter, the system optimizes solar power conversion efficiency and ensures high-quality power is supplied to the load.

In brief, this robust and efficient system, consisting of a dual PV array with MPPT, boost conversion, and a full-bridge inverter, effectively converts solar energy into usable AC power. The system's flexibility and scalability are ensured by its modularity, with independent MPPT control for each PV array. The boost converter maintains the appropriate voltage level for AC conversion, while the inverter and LC filter guarantee a smooth and stable AC output. This design is suitable for both small-scale applications, such as residential solar installations, and larger grid-connected systems.

V. GRID CONNECTION OF A PHOTOVOLTAIC (PV) SYSTEM

Integrating solar energy into the power grid through a photovoltaic (PV) system using a multilevel inverter is a critical process. A multilevel inverter is responsible for converting the direct current (DC) power produced by the PV panels into alternating current (AC) that can be supplied to the grid. Utilizing multilevel inverters in PV systems provides various advantages, including enhanced power quality, reduced harmonic distortion, and increased efficiency when handling larger power capacities.

The process commences with the PV system itself, comprising solar panels that capture sunlight and transform it into DC power. Typically, multiple panels are connected in series or parallel to meet voltage and power requirements. To ensure optimal power extraction from the solar panels under changing environmental conditions, a Maximum Power Point Tracking (MPPT) system is employed. MPPT continuously adjusts the operating point of the PV panels to optimize power generation, especially considering varying sunlight intensity throughout the day.

The multilevel inverter, a power electronic device, is designed to convert the DC output from the PV panels into AC. Unlike traditional inverters that produce only two voltage levels (high and low), multilevel inverters can generate multiple voltage levels, resulting in smoother and more sinusoidal AC waveforms. This is particularly crucial for grid integration as it reduces Total Harmonic Distortion (THD) and ensures that the power quality meets grid standards. There are several types of multilevel inverters, including diode-clamped, flying capacitors, and cascaded H-bridge inverters. The cascaded H-bridge type is commonly used in PV systems due to its modular structure, ease of control, and scalability for higher-power applications.

Before the PV system can be connected to the grid, the output of the multilevel inverter must be synchronized with the grid's voltage and frequency. Synchronization guarantees that the inverter's AC output is in phase with the grid, meaning the voltage, frequency, and phase angle of the inverter's output match those of the grid. Typically, this is achieved using a phase-locked loop (PLL) in the inverter's control system, which continually monitors the grid parameters and adjusts the inverter's output accordingly. Synchronization is crucial because if the AC output is not aligned with the grid, it can lead to power quality issues, inefficiency, or even damage to the grid infrastructure.

Once synchronization is established, the multilevel inverter injects power into the grid. The inverter's control system manages the flow of both real (active) and reactive power. In grid-tied systems, the primary objective is to inject the maximum amount of active power generated by the PV system into the grid while minimizing reactive power to prevent voltage instability. The control system can also be designed to regulate the power factor, ensuring that the inverter contributes to maintaining a stable grid voltage. Advanced control methods such as droop control are used in larger systems to help stabilize the voltage and frequency without requiring direct communication with the grid operator.

In addition to power control, filtering is an essential aspect of grid-connected PV systems. Although multilevel inverters produce relatively smooth waveforms, additional filtering is typically required to eliminate any remaining high-frequency harmonics from the inverter's output. An LC filter, consisting of an inductor and a capacitor, is often used to smooth out the waveform and ensure that the power injected into the grid complies with grid codes regarding harmonic content. Ensuring low harmonic distortion is important for maintaining the overall power quality and protecting sensitive equipment connected to the grid.

Another critical aspect of grid connection is safety, particularly the prevention of islanding. Islanding occurs when the grid goes down, but the PV system continues to supply power, which can pose a safety risk to utility workers and damage grid equipment. Anti-islanding protection is built into the inverter to detect when the grid is offline and automatically disconnects the PV system from the grid. This ensures that the PV system only operates when it is safe and when the grid is available.

The actual connection of the PV system to the grid is usually done through a grid-tied relay or a circuit breaker, which physically connects and disconnects the system as needed. Before full-scale grid integration, the system undergoes several checks and testing to ensure it meets all safety, regulatory, and performance standards. The inverter must comply with local grid codes, which specify the required voltage levels, harmonic limits, anti-islanding protection, and synchronization capabilities. After passing these tests, the PV system can be officially connected to the grid.

Once connected, the multilevel inverter continues to monitor the grid conditions and adjusts the power output to match the grid requirements. It ensures that the PV system delivers clean, stable AC power to the grid while operating within the safety and performance parameters defined by grid operators. In many cases, the inverter is also equipped with communication systems that allow it to transmit operational data to the utility, ensuring that the system can respond to changes in grid demand or supply conditions.

In summary, the grid connection of a PV-based multilevel inverter involves several steps: designing the PV array and inverter system, synchronizing the inverter output with the grid, managing the power injection into the grid, filtering harmonics, implementing anti-islanding protection, and ensuring compliance with grid codes. The use of multilevel inverters in PV systems offers numerous advantages, such as improved power quality, scalability, and higher efficiency,

making them a popular choice for integrating renewable energy into the grid. By following the correct procedures and incorporating advanced control techniques, PV systems can effectively and safely contribute clean energy to the grid.

VI. CONCLUSION

This paper presents a proposal for a transformerless grid-connected photovoltaic multilevel inverter. The paper discusses the system configuration and provides a detailed design of the control scheme. The controller's effectiveness has been tested under load and source intermittencies, demonstrating its ability to achieve both individual maximum power point (MPP) realization and voltage regulation. The measured leakage current of the system is only 1mA, well below the limit specified in the German VDE 0126-1-1 standards. Additionally, the proposed converter has been validated for its application to grid-connected systems by confirming the common mode voltage. Furthermore, the PWM technique and controller architecture used inherently balance the capacitor voltages. The proposed method has been experimentally validated using a laboratory prototype. With an overall component count of 18, the system has fewer components compared to similar configurations reported in the literature. Moreover, the converter's efficiency has been found to be in the range of 89-95%.

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