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Five-Level Switched H-9 with Reduced Capacitance Inverter without Boost Capacitor and Transformer

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Abstract - The utilisation of multilevel inverters that rely on switching capacitors without transformers is prevalent in both renewable and industrial energy systems. A transformer-less inverter that uses switching capacitors should primarily include features that reduce ripple current for efficiency and reliability and leakage current for safety. This brief proposes a new type of inverter for standalone photovoltaic systems that is single-stage, single-phase, five-level H-9 based. This H-9 inverter achieves the desired output voltage levels by means of nine switches. The built-in boost functionality is a result of combining the SC and SB units into one design. This design effectively decreases the leakage current by grounding the load terminal via the filter capacitor. In addition to being naturally balanced, the capacitors used in the switched-capacitor unit have very little ripple current. To do this, we demonstrate the practicality of using the modulation technique for control and empirically test the relevant results using a laboratory prototype of the converter that was recommended.

Key Words: Transformer less inverter, switched boost, switched capacitor, leakage current, ripple current, virtual ground**.**

1.INTRODUCTION

In comparison to inverters that rely on transformers, transformer-less multi-level inverters (MLIs) are more efficient, smaller, lighter, and cheaper. Reduced losses caused by transformers allow for a more efficient power system [1]. Grounding leakage current (iLG), input source ripple current (iripp), capacitor size, output voltage gain, and the number of power switches are some of the issues in transformer-less switched capacitor-based multi-level inverters. Minimising the iLG, iripp, and instantaneous power oscillations at twice the output frequency—which causes second-order ripples in the DC voltage or current—and reducing the size of the capacitors are the most important factors in achieving better efficiency and power density with regard to these challenges. When it comes to photovoltaic inverters, ripple can drastically lower the panels' conversion efficiency. For higher-level switching capacitor inverters, the best way to prevent iLG and iripp is to either incorporate a boost converter or add a quasi-resonant inductor in series with the source [1]. Even when the input DC voltage is low, the boost converters integrated into the system keep the input current from the DC power source constant, allowing the inverter to maintain a constant output voltage gain [2]. Nevertheless, there might be an extra decrease in output voltage due to the quasi-resonant inductor. Various methods have been proposed in the literature to address the problems of iLG, iripp, and capacitor size. Possible methods include creating a pulse width modulation (PWM) algorithm tailored to the converter, modifying the conventional H-bridge inverter to keep the common voltage (CMV) constant or zero, combining a switched capacitor unit with a switch boost (SB) cell in a single-stage arrangement, or using a virtual grounding technique.

The developed SCMLI uses a novel PWM-based approach to address the iLG issue [1, 3, 4]. The input iripp continues to be a problem in reference [1], which has a negative impact on the inverter's output power quality. In order to keep CMV constant, the AC and DC sides are isolated using a switching configuration during zero state periods of the output voltage (iLG is minimised, as described in references [5], [6]).

The output voltage gain of these inverters, however, is limited to one. Here, for single-stage conversion in neutral point clamped [2], [7] and Common ground-based MLI [8], [9], [10], it has been used to integrate the SB unit with a switched-capacitor unit controlled by constant switching frequency. Full dc-bus utilisation requires an extra number of components, which is a downside of these neutral point-clamped topologies [2], [7]. The comprehensive performance of transformer-less inverters is addressed in reference [8] by addressing iLG concerns with common grounding. When the output voltage is negative, however, the load voltage is entirely dependent on the switched capacitors that were charged

earlier.

Because the source is disconnected during the negative half cycle, the inverter's output voltage could experience a DC offset [5]. In order to solve the problems of iLG, iripp, and source disconnection, a common ground inverter based on flying type capacitors is used [9], [10]. Though the inverter's output might be negatively affected by the flying capacitor's self-balancing feature, which is achieved via a straightforward PWM technique [12]. However, in order to keep the voltage output level, all of these inverter topologies use huge capacitor sizes. Additionally, the iLG problem is mitigated in H-bridge type inverters [11] by connecting the grid terminals and source -ve terminals through active virtual capacitors, which are virtually grounded.

2. System Description

This may lead to a DC offset problem in the inverter's output voltage due to a source disconnection in a negative half cycle [5]. The flying type capacitor based common ground inverter is implemented to address the issue of i_{LG}, i_{ripp}, and source disconnection problem in [9], [10]. However, the self-balancing property of the flying capacitor, implemented through a simple PWM technique, may deteriorate the inverter's output [12]. Nonetheless, all these inverter topologies have large capacitor sizes that maintain the voltage output level. Moreover, the grid terminals and source -ve terminal are connected through the active virtual capacitors (virtually grounded) in the H-bridge type inverter [11], which alleviates the iLG issue of the inverter. Motivated by the above discussion, this brief proposes a single-stage dynamic boosting five-level inverter that minimizes both leakage and ripple currents by utilizing a small capacitor value. The integration of the boost converter feature ensures the continuous input source current and boosts the output voltage.

By continuous charging and discharging at any instant of level generation of the inverter, it minimizes the size and ripple current across the capacitor. The leakage current issue is alleviated by virtually grounding the load terminals bypassing the high-frequency component of current (i_{VG}) through the filter capacitor. Moreover, it achieves a zero offset in output voltage due to continuous symmetric charging and discharging operation in both cycles.

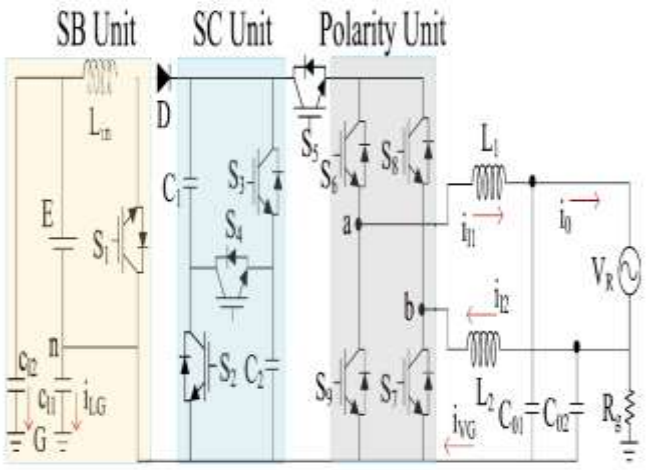


Fig. 1. Proposed five-level dynamic boosting-based transformer-less inverter.

3.Five-Stage Switched Boost Capacitor H-9 Without a Relay

The Reduced Capacitance H-9 Five-Level Switched Boost Capacitor Transformer-less Inverter is an advanced power converter that integrates switched-capacitor (SC) and switched-boost (SB) techniques. It eliminates bulky transformers and electrolytic capacitors, generating a five-level output while significantly reducing leakage currents in photovoltaic (PV) systems. [1]

3.1.Primary Principle

The inverter's core principle relies on the series-parallel conversion of internal capacitors to double the input voltage, synthesizing a step-up five-level AC output ($+2V_{dc}$, $+V_{dc}$, 0, $-V_{dc}$, $-2V_{dc}$). It accomplishes this through a modified H-9 configuration (nine power semiconductor switches) that incorporates a switched-boost network. By avoiding transformers, it prevents magnetic saturation and reduces overall system weight.

Operational Modes (Generating 5 Levels)

The inverter switches between different topological states within each switching cycle to charge the capacitors and synthesize the output voltage:

1. Level $+2V_{dc}$ (Maximum Boost): The input voltage source and switched capacitors are connected in series to the load, providing peak output voltage.
2. Level $+V_{dc}$: The switched capacitor is either bypassed or reconfigured to provide a lower step, producing half of the peak positive voltage.
3. Level 0: The load is short-circuited via the switches, dropping the output voltage to zero

while allowing the DC source to charge the capacitors.

4. Level -V_{dc}: The configuration operates in reverse, utilizing the negative states of the H-bridge with switched-capacitor contributions.
5. Level -2V_{dc}: The negative equivalent of the maximum boost state is applied to the load.

Key Operational Advantages

- Voltage Boosting without Transformers: The SC unit amplifies the DC input (e.g., V_{in} to $2V_{in}$), avoiding the need for a bulky, lossy intermediate DC-DC boost converter.
- Leakage Current Mitigation: Transformer less inverters are prone to dangerous leakage currents through parasitic capacitances. The H-9 topology virtually grounds the load terminal (usually through a filter capacitor), effectively clamping the common-mode voltage and mitigating ground leakage currents.
- Reduced Capacitance & Ripple: By actively utilizing advanced modulation techniques, the capacitance requirement is reduced. This allows for the use of reliable film capacitors rather than short-lived electrolytic capacitors.
- Inherent Voltage Balancing: The switched capacitors undergo intrinsic charging and discharging cycles, self-balancing their voltages without the need for complex, expensive voltage-balancing feedback sensors.

A transformer is a static electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. It is primarily used to increase (step-up) or decrease (step-down) alternating current (AC) voltage levels while maintaining the same frequency.

3.2. Concept of a Transformer-less Inverter

A transformer-less inverter is a power electronic converter that converts DC power into AC power without using a power-frequency isolation transformer between the DC source (such as a photovoltaic (PV) array or battery) and the AC load or utility grid.

Conventional grid-connected inverters use a transformer to:

- Provide galvanic isolation between the DC and AC sides.
- Step up or step down the voltage.
- Improve safety.

In contrast, transformer-less inverters eliminate the transformer, making the system lighter, smaller, less expensive, and more efficient.

Basic Concept

The main function of a transformer-less inverter is to convert DC electricity from a renewable energy source into sinusoidal AC electricity suitable for household loads or the utility grid without magnetic isolation.

Basic Block Diagram

Solar PV Array

4.Analysis Of Proposed Five-Level Dynamic Boost Inverter

The proposed five-level dynamic boosting type transformer less inverter. It comprises a DC source, a switch boost (SB) module, a switched capacitor (SC) unit, and a conventional H-bridge. The SB module requires a boost inductor (L_{in}), one power switch (S_1), and one diode (D), whereas the SC unit requires two capacitors (C_1 and C_2), three switches (S_2, S_3, and S_4). The integrated SB module enhances the output voltage gain over a wide range of inputs by charging the Lin from the DC source. Switches S_3 and S_5, along with capacitors C_1 and C_2, control the output voltage level, while switches S_6 to S_9 determine the output voltage polarity.

A. Modulation and Control Strategy

Fig. 2(a-d) illustrates the circuit configuration for each switching state for the +ve half cycle The PWM output voltage waveform the circuit's operating states during the interval $\theta_1-\theta_2$, In the switching strategy, $S_1 - S_3$ are operated with a constant duty cycle (D) at switching frequency (fsw) to boost and effectively maintain the average voltage across the capacitors (C_1 and C_2) and the charge the boost inductor (L_{in}).

4.1. Comparative Study of Proposed Five-Level Inverter

This section compares the proposed five-level inverter to the recently designed five-level transformer-less switched capacitor inverter topologies based on the component count, size of the capacitor, ripple current in capacitors, efficiency, size of input inductor, Nature of input current, Cost Function (C_F), and THD as listed in Table II. CF can be defined as the number of components per level for the converter. From Table II it is observed that [2], [5], [7], and [8] have a lower cost factor (C_F) than the

proposed inverter, but these inverters offer lower voltage gain.

Similar efficiency and peak capacitor ripple current as the proposed inverter is achieved in [2]. However, it suffers from a lower voltage gain and requires a higher number of switches. In [5] and [7], the inverter has a five-level output voltage with a lower switch count, but their capacitor sizes are significantly larger, and their efficiency is lower compared to the proposed topology. Furthermore, [5] has a discontinuous input current, and in [7], a large-size inductor is required. The topology in [8] has achieved the same efficiency and capacitor sizes as the proposed inverter but suffers from lower voltage gain with discontinuous input current. The inverters proposed

5.Simulation Results

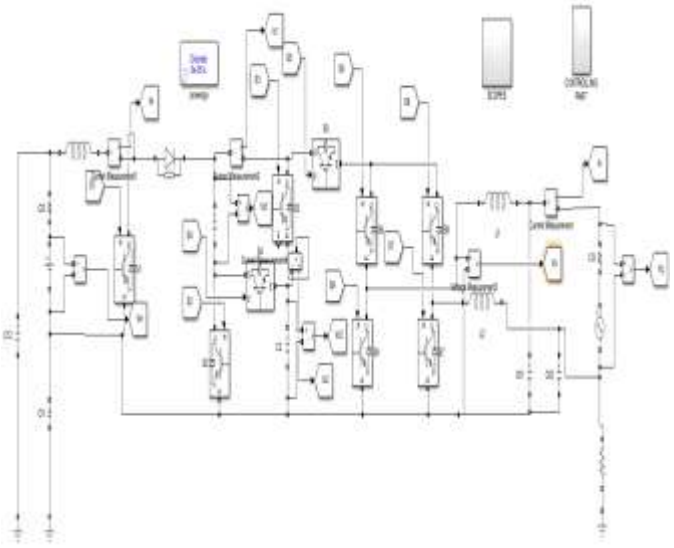


Fig.2.Simulation diagram

The Simulink model you shared represents a Reduced Capacitance H-9 Five-Level Switched Boost Capacitor Transformer-less Inverter for grid-connected photovoltaic (PV) applications. The circuit integrates a boost converter, switched-capacitor network, and five-level inverter into a single-stage topology. Its primary objective is to obtain a high AC output voltage from a low PV voltage while using fewer passive components and without a transformer.

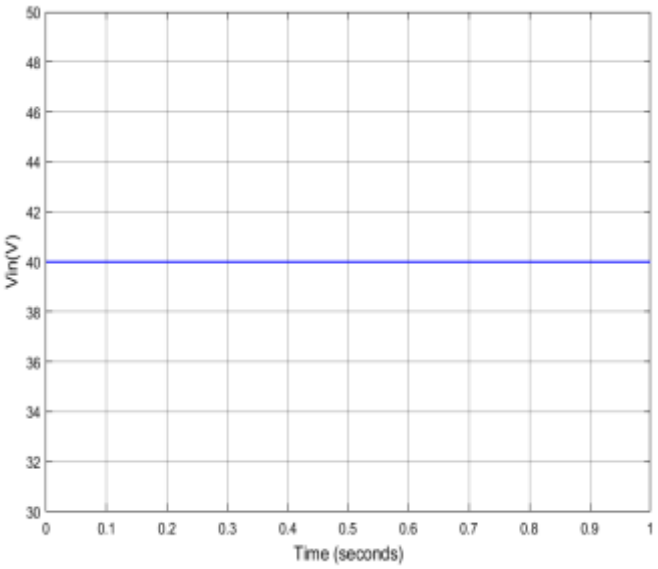


Fig.3 input voltage ((V_{in})) of the Reduced Capacitance H-9 Five-Level Switched Boost Capacitor Transformer-less Inverter

The graph shows the input voltage ((V_{in})) of the Reduced Capacitance H-9 Five-Level Switched Boost Capacitor Transformer-less Inverter. It indicates that the DC input voltage supplied by the PV source or DC source remains constant at 40 V throughout the simulation period from 0 to 1 second.

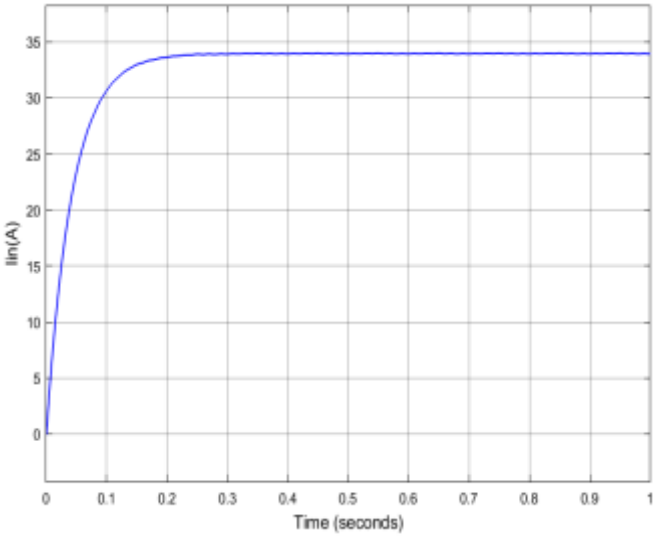


Fig.4.The figure shows the input current ((I{in})) of the Reduced Capacitance H-9 Five-Level Switched Boost Capacitor Transformer-less Inverter.

It illustrates how the input current changes from the instant the system is switched ON until it reaches a steady-state operating condition.

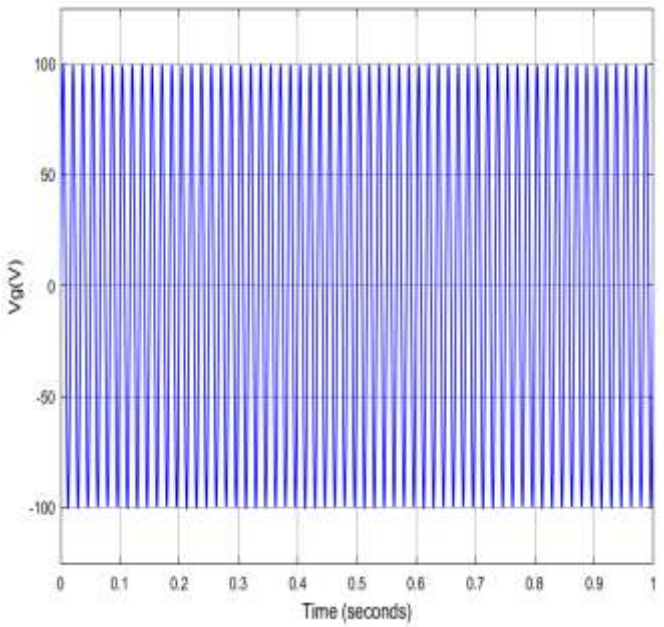


Fig.5.The waveform shown is the grid voltage ((V_g)) of the Reduced Capacitance H-9 Five-Level Switched Boost Capacitor Transformer-less Inverter.

It represents the AC voltage of the utility grid to which the inverter is synchronized. The graph demonstrates that the inverter is operating with a stable and sinusoidal grid voltage, which is essential for efficient and reliable grid-connected operation.

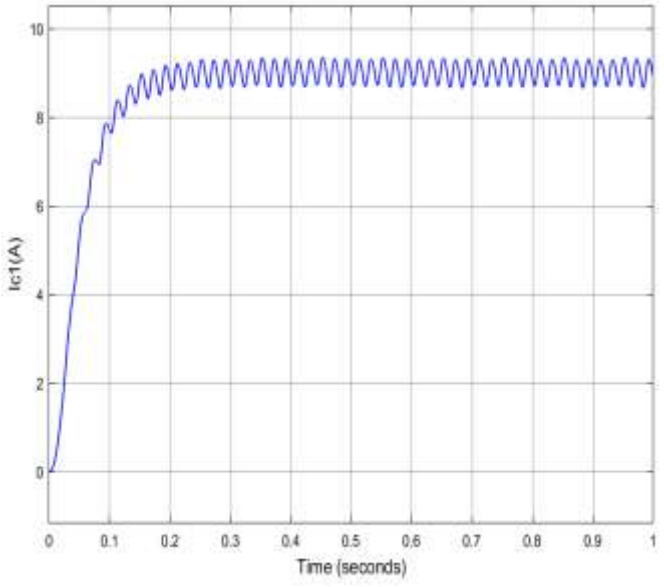


Fig.6.The figure shows the current through Capacitor-1 ((I{C1})) of the Reduced Capacitance H-9 Five-Level Switched Boost Capacitor Transformer less Inverter.

This waveform represents the charging and discharging current flowing through the switched capacitor (C_1), which plays a vital role in the voltage boosting process and five-level voltage generation.

6. CONCLUSIONS

The proposed Reduced Capacitance H-9 Five-Level Switched Boost Capacitor Transformer-less Inverter has strong potential for next-generation renewable energy applications. Future enhancements involving AI-based control, advanced MPPT techniques, wide-bandgap semiconductor devices, hybrid energy storage integration, smart grid support, and real-time hardware implementation can significantly improve its efficiency, reliability, and scalability. These developments will make the inverter highly suitable for grid-connected photovoltaic systems, electric vehicle charging stations, microgrids, and other modern power electronic applications.

This brief introduces a five-level dynamic boost-switched capacitor inverter, controlled using the sinusoidal PWM technique. With this, it is found that the size of the capacitor and its ripple current are reduced. The load terminal of this inverter is virtually grounded through a filter capacitor, effectively mitigating the leakage current to well below the safety limit. The inverter achieves a peak efficiency of 97.00% at 255 watts. It also exhibits low harmonic distortion (THD): 34.18% for the pole voltage and a significantly lower 1.29% for the resistive load. For the input voltage of 40 volts, the fundamental output voltage achieved is 154.54 volts

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