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Solar Power Enhancement Using Switched-Capacitor Based Seven-Level Inverter

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Abstract

This research paper presents a seven-level inverter for photovoltaic grid integration that requires only six power semiconductor devices. The system utilizes a DC-DC boost converter coupled with a transformer to establish two voltage sources with a 2:1 relationship, feeding a cascaded topology that combines a capacitor selection stage and a full-bridge conversion unit. Seven voltage levels are produced (Vdc, 2Vdc/3, Vdc/3, 0, -Vdc/3, -2Vdc/3, -Vdc), resulting in improved harmonic characteristics and reduced electromagnetic emissions. In this design only one switch operates at high-frequency at any moment, decreasing switching losses and boosting efficiency. Voltage balancing across DC-link capacitors occurs inherently through the circuit's voltage relationships, eliminating the need for additional control mechanisms. Hardware prototypes were constructed and tested, with experimental findings confirming the viability of this approach. Measurements reveal a total harmonic distortion of 3.6%. Traditional diode-clamped and flying-capacitor topologies demand twelve switches for comparable voltage levels, while cascaded H-bridge designs need eight switches—the proposed circuit achieves similar results with fewer components. Benefits include reduced conduction losses, simplified circuitry, and higher power density. The multilevel output reduces filter inductor size relative to two-level designs. Operation remains stable across different solar irradiation levels while regulating DC-link voltages. Incorporating maximum power point tracking and model predictive control techniques in future iterations could optimize energy harvest and grid synchronization

Keywords: Seven Level Inverter, DC-DC Boost converter, Voltage Balancing, Cascaded Topology, Low THD**.**

1. Introduction

The global energy landscape is undergoing a significant transformation driven by growing environmental concerns and the accelerating depletion of conventional fossil fuel resources. The combustion of coal, oil, and natural gas has contributed substantially to greenhouse gas emissions, intensifying climate change and compelling a worldwide shift toward cleaner, sustainable energy alternatives. Among the various renewable energy technologies currently being explored, solar photovoltaic systems have emerged as particularly promising candidates due to their abundant availability, modular scalability, and continuously declining installation costs. Small-capacity distributed solar generation systems are increasingly being adopted in residential and light commercial applications, offering the combined benefits of reduced electricity expenditure and lower environmental impact.

In grid-connected solar power applications, the DC output of the photovoltaic array must be accurately converted into utility-synchronized AC power through a two-stage power conversion interface consisting of a DC-DC boost converter and a DC-AC inverter. Since solar arrays typically produce low terminal voltages, the boost converter is essential for stepping up the voltage to levels compatible with the inverter's DC bus. Power losses occurring across both conversion stages, whether from device conduction resistance or high-frequency switching transitions, directly diminish the usable energy yield, making efficiency a paramount design consideration. Multilevel inverter technology has been widely adopted to address the harmonic distortion, switching stress, and filter size limitations associated with conventional two-level inverters, as the stepped output voltage waveform reduces per-switching voltage changes and improves overall power quality.

This paper proposes a novel solar power generation system comprising an integrated DC-DC power converter and a new seven-level inverter requiring only six power electronic switches. The DC-DC converter employs a boost converter with a 2:1 turns-ratio transformer to generate two inherently voltage-balanced DC sources, eliminating complex active balancing circuits. The inverter cascades a capacitor selection circuit with a full-bridge converter, ensuring only one switch operates at high frequency at any given moment, substantially reducing switching losses. A prototype was experimentally validated, demonstrating seven-level output voltage, sinusoidal grid current at unity power factor, 3.6% total harmonic distortion, on RL load.

2. Literature Review

Multilevel inverter topologies have been extensively investigated for renewable energy applications due to their superior harmonic performance, reduced switching stress, and improved power conversion efficiency compared to conventional two-level inverters. Three fundamental topologies dominate the existing literature: diode-clamped, flying-capacitor, and cascaded H-bridge inverters.

In Diode-clamped configuration, intermediate voltage levels are generated using clamping diodes on a shared DC bus. While offering reasonable harmonic performance, the diode count and capacitor voltage balancing complexity grow significantly with increasing output levels, reducing practical reliability. Flying-capacitor inverters substitute floating capacitors for clamping diodes, providing switching redundancy but requiring active balancing control and substantially more capacitors as levels increase, raising system size and cost.

In Flying-capacitor configuration, the need for clamping diodes is eliminated, by using capacitors to generate intermediate voltage levels. However, this topology requires a significant number of capacitors, and active control is often required to maintain voltage balance across these capacitors. As the number of levels increases, the control strategy becomes increasingly complicated, and the system size expands considerably.

Cascaded H-bridge configurations are widely favoured in photovoltaic applications since independent DC sources can be naturally obtained from separate PV module groups, offering modularity and scalability.

However, conventional seven-level implementations require eight to twelve switches, leading to higher losses, increased gate drive complexity, and greater hardware cost.

Various reduced-switch topologies have been proposed to address these limitations, including level-polarity partitioned structures and modular multilevel configurations. Nevertheless, these approaches typically compensate for lower switch counts through additional passive components, complex capacitor balancing schemes, or simultaneous high-frequency operation of multiple switches, limiting practical efficiency improvements. Hence, a need remains for a seven-level inverter that minimizes active switch count, restricts high-frequency switching to a single device at any instant, and achieves inherent voltage balance without dedicated balancing circuits. This work proposes a six-switch seven-level inverter using two capacitors maintained at a natural 2:1 voltage ratio via a transformer-based DC-DC converter, achieving improved efficiency, simplified control, and high waveform quality for grid-connected solar applications.

3. Components & Methodology

a. Proposed Topology

The proposed seven-level inverter topology employs a switched capacitor selection circuit cascaded with a conventional full-bridge power converter. Two DC capacitors, C1 and C2, maintained at voltage levels of Vdc/3 and 2Vdc/3 respectively through a 2:1 transformer-based DC-DC converter, form the core of this arrangement. The capacitor selection circuit controls the individual or series discharge of these two capacitors through strategic switching of SS1 and SS2, generating three distinct DC voltage levels at its output. The full-bridge converter subsequently inverts these levels to produce the complete seven-level AC waveform. A key advantage of this topology is that capacitor voltages are balanced automatically through the transformer charging mechanism, eliminating dedicated balancing circuits and considerably simplifying overall control implementation.

b. Components

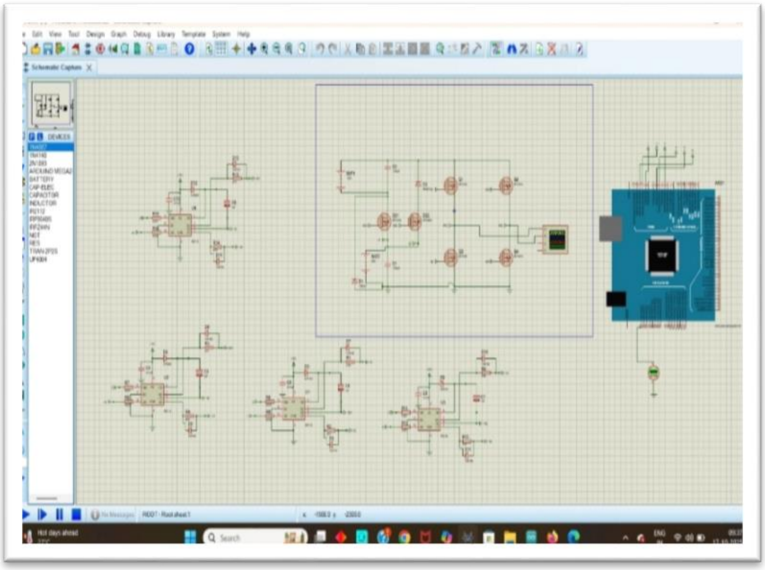
The proposed solar power generation system utilises carefully selected components to ensure reliable seven-level output generation within practical voltage and current ratings.

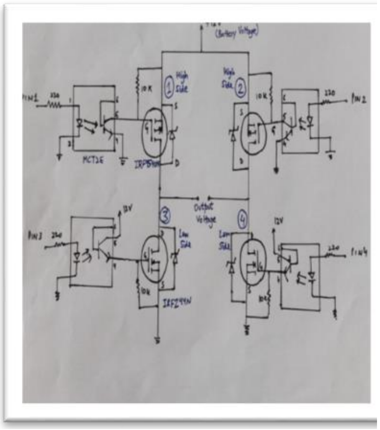
A 12V solar panel serves as the primary input energy source, converting sunlight into DC electrical energy. The panel output directly feeds the DC-DC converter stage, making the system suitable for small-capacity residential solar power generation applications. The input supply voltage is 12V DC derived from the solar panel. The system controller is based on the ATmega2535 microcontroller, which generates the necessary PWM switching signals and manages the overall control logic for both the DC-DC converter and the seven-level inverter stages.

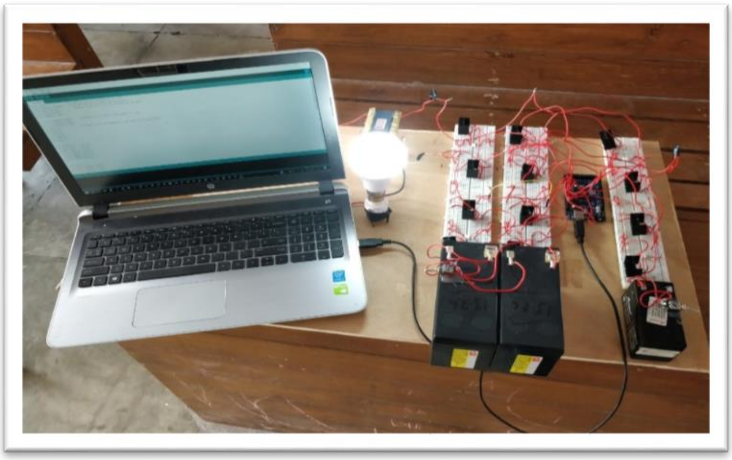
The power electronic switches, primarily used throughout the circuit are N-type enhancement mode MOSFETs rated at 55V and 25A. These devices offer low on-state resistance and fast switching characteristics suitable for the operating frequency requirements. A complementary gate driver with a 42V boost, incorporating a trapping pulse generator with isolated output, is used to drive the MOSFET gates reliably while preventing shoot-through conditions. On the DC side, capacitors rated at 100μF and 35V are used within the capacitor selection circuit to store and supply the required voltage levels. On the AC output side, capacitors rated at 0.1μF and 440V AC are employed for filtering purposes.

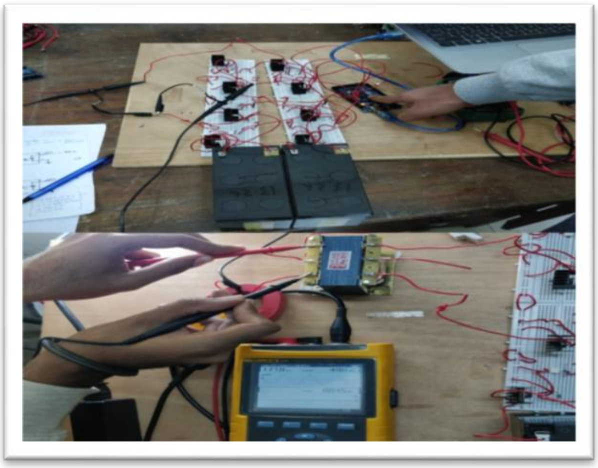
The transformer operates with a 12V primary input and 220V secondary output, stepping up the inverter output to utility-compatible voltage levels. Since the transformer is non-standard, combined with the inherent 0.7V forward voltage drop across each conducting MOSFET, switching losses accumulate within the conversion stages. These device-level losses are ultimately reflected across the output, contributing to minor voltage fluctuations observed in the final AC output waveform.

c. Software & Hardware Configuration





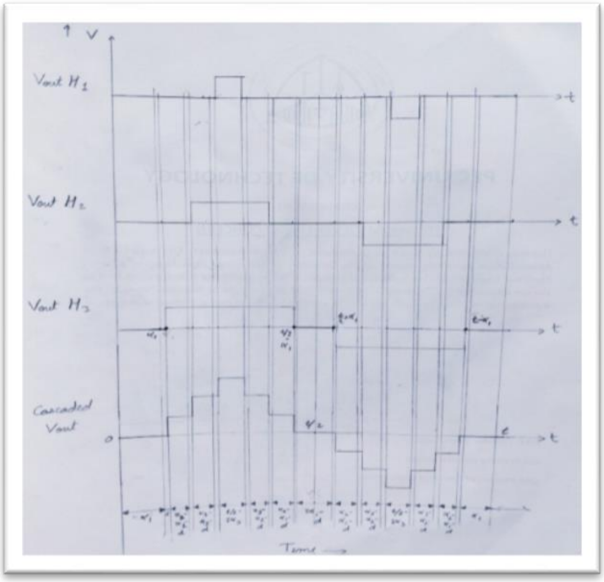


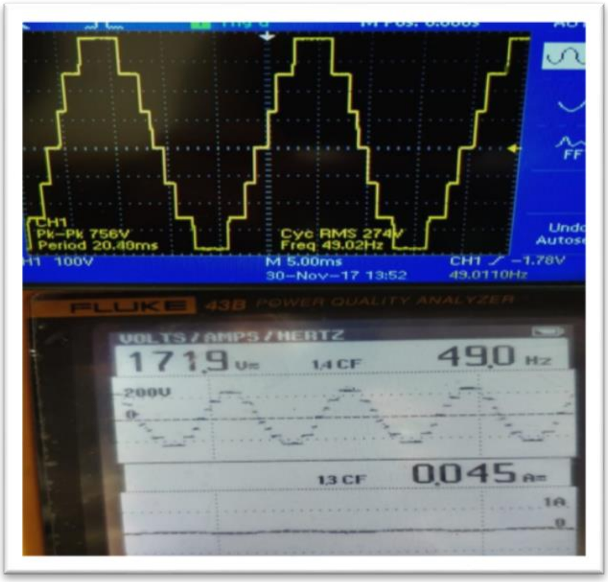


4. Results

The proposed solar power generation system was experimentally validated through a 500W prototype using a ATmega2535 controller, tested on a single-phase 220V, 60Hz utility supply because of losses consider it in between 160-180v. The seven-level inverter successfully generated seven distinct output voltage levels comprising Vdc, 2Vdc/3, Vdc/3, 0, -Vdc/3, -2Vdc/3, and -Vdc through coordinated operation of the capacitor selection circuit and full-bridge power converter. During the positive half cycle, individual and series discharge of capacitors C1 and C2 produced the positive voltage steps, while the full-bridge converter inverted these levels during the negative half cycle. Each switching transition produced a voltage change of only Vdc/3, significantly reducing switching stress and output current ripple.

The output current was sinusoidal and in phase with the utility voltage, achieving total harmonic distortion of 3.6%. Capacitors C1 and C2 were naturally maintained at 120V and 60V respectively, preserving the 2:1 voltage ratio without active balancing.





5. Discussion

The experimental results confirm that the proposed solar power generation system successfully addresses the key limitations associated with conventional multilevel inverter topologies. The generation of seven distinct voltage levels through only six power electronic switches represents a meaningful advancement over existing designs, which typically require eight to twelve switches for equivalent output performance. This reduction in active device count directly translates into lower hardware cost, reduced gate drive complexity, and simplified circuit implementation.

A particularly significant finding is that only one power electronic switch operates at high frequency at any given instant throughout all switching modes. This characteristic fundamentally differs from many previously reported reduced-switch topologies where multiple devices switch simultaneously at high frequency, accumulating switching losses that degrade overall efficiency. By confining high-frequency operation to a single device, the proposed system achieves lower switching power dissipation while maintaining clean seven-level output waveform quality.

The measured total harmonic distortion of 3.6% demonstrates that the stepped output voltage waveform closely approximates a sinusoidal profile, meeting standard grid interconnection requirements without demanding an oversized filter inductor. The smaller voltage step of Vdc/3 per switching transition, compared to the full DC bus voltage change in two-level inverters, directly contributes to this improved harmonic performance and reduces filter component size.

The natural maintenance of the 2:1 capacitor voltage ratio through the transformer-based DC-DC converter eliminates the need for dedicated active balancing circuits, considerably simplifying the overall control architecture. Collectively, these results validate the practical viability and efficiency advantages of the proposed seven-level solar power generation system for residential grid-connected applications.

6. Conclusion

This paper presented a novel solar power generation system comprising a transformer-based DC-DC converter and a six-switch seven-level inverter for residential grid-connected applications. By restricting high-frequency switching to a single device at any instant and naturally maintaining the 2:1 capacitor voltage ratio through the transformer-based converter, the system achieves reduced switching losses and simplified control without requiring dedicated balancing circuits. The dual-loop control strategy ensures accurate sinusoidal current injection at unity power factor while protecting MPPT performance from capacitor ripple interference. Experimental validation on a prototype confirmed seven-level output generation, 3.6% total harmonic distortion, unity power factor, and reliable maximum power point tracking, collectively demonstrating that the proposed system delivers a practical, efficient, and simplified solution for small-capacity solar power generation suitable for widespread residential deployment.

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