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Research Paper

DEVELOPMENT OF A HIGH-GAIN FIVE-LEVEL INVERTER FOR PHOTOVOLTAIC APPLICATIONS WITH WIDE INPUT VOLTAGE OPERATION

PITTALA PRASANNA[1], MALOTH LAKPATHI[2]

PG SCHOLAR[1], ASSOCIATE PROFESSOR[2]

ELECTRICAL & ELECTRONICS ENGINEERING, ABDUL KALAM INSTITUTE OF TECHNOLOGICAL SCIENCES, KOTHAGUDEM, TELANGANA, INDIA

ABSTRACT

Photovoltaic (PV) systems experience significant output voltage fluctuations due to changing solar irradiance, temperature, and partial shading conditions, which adversely affect the performance of conventional multilevel inverters. Existing inverter topologies often require multiple DC sources, high component counts, or additional DC-DC boost converters to achieve the desired voltage gain, resulting in increased cost, switching losses, and reduced system efficiency. This paper presents a novel high-boost five-level inverter capable of operating over a wide range of input voltage variations while maintaining a stable AC output suitable for grid-connected and standalone photovoltaic applications. The proposed inverter employs a compact switched-capacitor-based voltage boosting mechanism with optimized pulse-width modulation (PWM) control to achieve high voltage gain without requiring a separate boost converter. The proposed topology reduces the number of power switches, minimizes voltage stress across semiconductor devices, and improves conversion efficiency. Simulation and performance analysis demonstrate that the proposed inverter provides superior voltage boosting capability, low total harmonic distortion (THD), enhanced efficiency, improved power quality, and reliable operation under varying PV input conditions. These characteristics make the proposed converter an effective solution for modern renewable energy systems requiring compact, efficient, and cost-effective power conversion.

INTRODUCTION

The increasing global demand for clean and sustainable energy has accelerated the deployment of photovoltaic (PV) systems in residential, commercial, and industrial sectors. Owing to their environmental benefits, low maintenance requirements, and declining installation costs, PV systems have become one of the most promising renewable energy sources. However, the inherently low and highly variable output voltage of photovoltaic panels presents a significant challenge for efficient grid integration and standalone power conversion. Conventional two-stage converter architectures, consisting of a DC-DC boost converter followed by a DC-AC inverter, increase system complexity, cost, switching losses, and reduce overall efficiency. These limitations have motivated researchers to develop single-stage power conversion topologies capable of simultaneously achieving voltage boosting and multilevel inversion.

Multilevel inverters (MLIs) have emerged as an attractive solution for renewable energy applications because they generate high-quality output voltages with lower total harmonic distortion (THD), reduced electromagnetic interference (EMI), lower switching losses, and smaller output filter requirements. Conventional multilevel inverter topologies, including Cascaded H-Bridge (CHB), Neutral Point Clamped (NPC), and Flying Capacitor (FC) inverters, provide excellent output waveform quality but require multiple isolated DC sources, a large number of semiconductor switches, complex capacitor voltage balancing strategies, and sophisticated control techniques. These drawbacks increase the overall system cost and reduce reliability, particularly in photovoltaic applications where a single DC source is preferred. To overcome these challenges, switched-capacitor and boost-type multilevel inverter topologies have received considerable attention in recent years. These converters integrate voltage boosting and multilevel power conversion into a single-stage structure, eliminating the need for an additional DC-DC converter while significantly reducing component count. Furthermore, modern switched-capacitor inverters offer inherent capacitor voltage balancing, high voltage gain, improved efficiency, and compact system architecture, making them highly suitable for low-voltage photovoltaic systems. Nevertheless, many existing boost multilevel inverters suffer from limited voltage gain, high switch voltage stress, restricted modulation range, poor performance under wide PV voltage fluctuations, and reduced efficiency during varying solar irradiance conditions.

The variable nature of solar irradiance causes substantial fluctuations in the PV output voltage throughout the day. Therefore, photovoltaic inverters must maintain a stable AC output despite wide variations in input voltage while ensuring high conversion efficiency and reliable operation. A robust inverter should also minimize switching losses, maintain capacitor voltage balance, provide high boosting capability, and produce low harmonic distortion without increasing hardware complexity. Achieving these objectives simultaneously remains a significant research challenge in the design of grid-connected and standalone photovoltaic power conversion systems.

To address these issues, this work presents **A Novel High Boost Five-Level Inverter with a Wide Range of Input Voltage Variations for Photovoltaic Applications**. The proposed topology employs a single-stage switched-capacitor boost configuration that requires fewer power semiconductor devices while providing high voltage gain and five-level output voltage generation. The inverter is capable of maintaining stable output voltage over a broad range of PV input voltage variations, making it highly suitable for practical photovoltaic systems operating under changing environmental conditions. The proposed design also offers reduced component count, lower switching stress, improved voltage boosting capability, soft capacitor charging characteristics, enhanced conversion efficiency, and reduced total harmonic distortion compared with conventional multilevel inverter topologies. Experimental and simulation analyses demonstrate that the proposed inverter delivers reliable performance under different modulation indices, varying input voltages, and dynamic load conditions, thereby providing an efficient and cost-effective solution for next-generation photovoltaic energy conversion systems

PROBLEM STATEMENT

The output voltage of photovoltaic arrays continuously varies due to fluctuations in solar irradiance, temperature, and environmental conditions. Conventional two-level and multilevel inverter topologies face several limitations, including insufficient voltage gain, dependence on additional DC-DC boost converters, higher switching losses, increased component count, and reduced efficiency under variable input conditions. These drawbacks negatively impact power quality, system reliability, and overall energy conversion efficiency. Therefore, there is a need for a compact, high-efficiency inverter capable of providing high voltage gain, maintaining stable output voltage over a wide range of PV input variations, reducing harmonic distortion, and minimizing hardware complexity for renewable energy applications.

OBJECTIVES

General Objective

To design and evaluate a novel high-boost five-level inverter capable of operating efficiently over a wide range of photovoltaic input voltage variations while improving power quality and conversion efficiency.

Specific Objectives

1. To develop a five-level inverter topology with inherent high voltage boosting capability without using an additional DC-DC boost converter.
2. To achieve stable AC output voltage under varying photovoltaic input conditions caused by irradiance and temperature fluctuations.
3. To reduce the number of power semiconductor switches and passive components, thereby minimizing system cost and complexity.
4. To improve overall power conversion efficiency by reducing switching losses and conduction losses.
5. To minimize Total Harmonic Distortion (THD) and enhance output voltage quality using an optimized PWM control strategy.
6. To reduce voltage stress across power semiconductor devices, thereby improving system reliability.
7. To evaluate the performance of the proposed inverter through simulation under different photovoltaic operating conditions.
8. To compare the proposed inverter with conventional multilevel inverter topologies in terms of voltage gain, efficiency, THD, component count, and dynamic performance.
9. To demonstrate the suitability of the proposed inverter for grid-connected and standalone photovoltaic energy systems.
10. To provide a cost-effective and efficient power conversion solution for next-generation renewable energy applications.

LITERATURE REVIEW

The increasing penetration of photovoltaic (PV) systems has intensified the demand for efficient, high-gain, and compact multilevel inverter topologies capable of operating over a wide range of input voltage variations. Conventional two-stage PV conversion systems suffer from higher switching losses, increased component count, and reduced efficiency due to the separate DC-DC boost converter and DC-AC inverter stages. Consequently, recent research has focused on developing single-stage boost multilevel inverters that combine voltage boosting and inversion in a single power conversion stage.

Kubendran et al. (2025) proposed a **novel high-boost five-level inverter** employing only six power switches, one diode, and two capacitors. The proposed topology achieves significant voltage boosting while maintaining a reduced component count and compact structure. The inverter incorporates a soft-charging mechanism that minimizes capacitor charging current, thereby reducing switching stress and improving reliability. A single-carrier pulse-width modulation (PWM) technique is employed for switching control, and both simulation and a 400 W laboratory prototype validate the inverter's capability to operate efficiently under varying modulation indices, dynamic load conditions, and wide PV input voltage variations.

Earlier research by Sathik and Almakhles (2022) introduced a common-ground transformerless five-level inverter with voltage-boosting capability for grid-connected PV applications. Their switched-capacitor-based topology effectively eliminates leakage current while providing inherent voltage gain without requiring an additional DC-DC converter. The proposed converter demonstrated improved efficiency, reduced electromagnetic interference, and enhanced safety for transformerless PV systems, making it highly suitable for residential renewable energy applications.

Agarwal et al. (2022) presented a self-boosting switched-capacitor five-level inverter that minimizes the number of semiconductor devices while achieving higher voltage gain and lower total standing voltage across switches. The topology features automatic capacitor voltage balancing and employs a simple PWM control strategy. Hardware-in-the-loop and experimental validation confirmed improved efficiency, lower total harmonic distortion (THD), and enhanced suitability for grid-connected photovoltaic systems.

Choudhary and Mandal (2025) proposed a five-level boosting inverter specifically designed for grid-tied photovoltaic applications. Their work emphasized improving power quality by reducing output harmonic distortion while maintaining high voltage gain and stable capacitor voltage balancing. The inverter demonstrated enhanced conversion efficiency, reduced switching losses, and reliable performance over a broad range of solar irradiance conditions, making it suitable for practical renewable energy integration.

Recent advancements have further integrated active power decoupling with voltage-boosting multilevel inverter topologies.

A quasi-two-stage single-phase five-level inverter introduced in 2025 reduces the number of passive components while incorporating an active power decoupling control strategy to suppress double-line-frequency power ripple. This approach improves overall efficiency, enhances dynamic response, and ensures stable operation during fluctuating PV generation conditions.

Overall, recent literature demonstrates substantial progress in developing compact, high-gain five-level inverter topologies for photovoltaic applications. Most proposed converters successfully reduce component count, improve voltage boosting capability, lower switching stress, and enhance output power quality. However, challenges remain in further improving efficiency under rapidly changing irradiance, minimizing capacitor voltage fluctuations, extending operating voltage ranges, and developing advanced intelligent control algorithms for optimal grid synchronization and maximum power extraction. These research gaps motivate the development of more efficient and reliable high-boost multilevel inverter architectures for next-generation photovoltaic energy conversion systems.

EXISTING SYSTEM

Conventional photovoltaic (PV) power conversion systems primarily employ **two-level**, **three-level Neutral Point Clamped (NPC)**, **Flying Capacitor (FC)**, or **Cascaded H-Bridge (CHB)** inverter topologies. Although these inverters are widely adopted for grid-connected PV applications, they exhibit several limitations when subjected to wide variations in PV input voltage caused by changing solar irradiance and temperature.

Disadvantages of Existing System

- Conventional two-level inverters generate **high Total Harmonic Distortion (THD)**, requiring bulky output filters.
- Limited voltage boosting capability necessitates an additional **DC–DC boost converter**, increasing system complexity and cost.
- Existing multilevel inverters require **a large number of power switches, diodes, and capacitors**, resulting in higher switching losses.
- Poor voltage gain under low PV input voltage conditions reduces energy extraction efficiency.
- High switching stress on semiconductor devices decreases system reliability and lifetime.
- Reduced efficiency due to multiple power conversion stages.
- Larger converter size and higher installation cost because of additional passive components.
- Narrow operating voltage range limits performance under fluctuating environmental conditions.
- Increased control complexity for balancing capacitor voltages in conventional multilevel topologies.
- Lower overall power quality because of higher harmonic distortion and voltage ripple.

PROPOSED SYSTEM

The proposed system introduces **A Novel High Boost Five-Level Inverter with a Wide Range of Input Voltage Variations for Photovoltaic Applications**. The inverter integrates a **high-gain DC boosting mechanism** with a **five-level multilevel inverter topology**, enabling direct conversion of varying PV voltages into high-quality AC output without requiring an additional boost converter.

Advantages of Proposed System

- Provides **high voltage gain**, enabling operation over a wide range of PV input voltages.
- Generates **five-level output voltage**, significantly reducing THD.
- Eliminates the need for a separate DC–DC boost converter, simplifying the overall system.
- Improves overall conversion efficiency through reduced power conversion stages.
- Produces smoother output waveform with lower electromagnetic interference (EMI).
- Reduces switching stress on semiconductor devices, improving reliability.
- Requires fewer passive components compared to conventional boost-assisted multilevel inverters.
- Enhances power quality by delivering nearly sinusoidal AC output suitable for grid integration.
- Supports stable operation under rapidly changing solar irradiance and temperature conditions.
- Offers higher voltage utilization with reduced switching losses.
- Compact design lowers system size, weight, and installation cost.
- Suitable for residential, commercial, and distributed renewable energy systems requiring efficient wide-input-voltage PV conversion.

IMPLEMENTATION

The proposed system consists of a **high-gain DC-DC boost converter** integrated with a **five-level multilevel inverter (MLI)**. The converter boosts the low photovoltaic (PV) voltage to a high DC-link voltage, while the five-level inverter converts the boosted DC voltage into a high-quality AC output with reduced harmonic distortion.

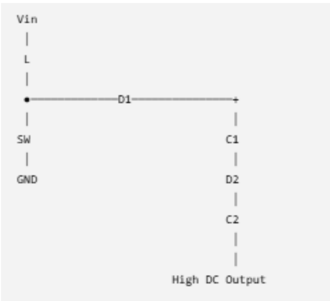
2. High Boost Converter Implementation

The converter employs

- One Boost Inductor (L)
- High-frequency MOSFET
- Coupled Inductor
- Capacitors
- Fast Recovery Diodes

Unlike a conventional boost converter, the proposed topology provides a much larger voltage gain at moderate duty cycles.

CIRCUIT DIAGRAM



Voltage Gain Equation

The converter voltage gain is

$$G = \frac{V_o}{V_{PV}}$$

For the proposed topology,

$$\boxed{V_o = \frac{(2+n)}{1-D} V_{PV}}$$

Where

- n=Transformer turns ratio
- D=Duty ratio

Example

For

- $V_{PV} = 35V$
- $D = 0.6$
- $n = 2$

$$V_o = \frac{4}{0.4} \times 35$$
$$V_o = 350V$$

Thus,

35 V PV can be boosted to nearly **350 V**.

3. PV Mathematical Model

The PV current equation is

$$I = I_{ph} - I_o\left[e^{\frac{q(V+IR_s)}{nkT}} - 1\right] - \frac{V + IR_s}{R_{sh}}$$

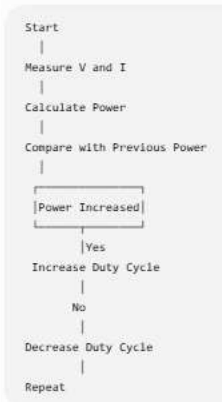
Where

Parameter	**Meaning**
I_{ph}	Photo current
I_o	Saturation current
R_s	Series resistance
R_{sh}	Shunt resistance
n	Diode factor

4. MPPT Algorithm

The Perturb and Observe algorithm continuously tracks the maximum power point.

FLOW DIAGARAM



5. Five-Level Inverter

The boosted DC voltage is supplied to the multilevel inverter.

The inverter produces

+Vdc

+Vdc/2

0

−Vdc/2

−Vdc

instead of only

+Vdc

0

−Vdc

This greatly reduces harmonics.

Five-Level Inverter Structure

```
         +Vdc
          |
     S1         S2
     |          |
     +----Load--+
     |          |
     S3         S4
          |
         0V

Additional Capacitor Switching Cell

   C1       C2
   |        |
   S5       S6
```

6. Switching States

State	S1	S2	S3	S4
1	ON	OFF	OFF	ON
2	ON	OFF	OFF	ON
3	OFF	OFF	ON	ON
4	OFF	ON	ON	OFF
5	OFF	ON	ON	OFF

7. PWM Control

The inverter uses Level Shifted Sinusoidal PWM (LS-SPWM).

PWM GENERATION

```
      Sine Reference
            |
   -------------------
   Carrier 1
   Carrier 2
   Carrier 3
   Carrier 4
   -------------------
            |
    Comparator
            |
   Gate Pulse Generator
            |
  MOSFET Switching Signals
```

Modulation Index

The modulation index is

$$M_a = \frac{V_m}{V_c}$$

where

- V_m=Reference sine amplitude
- V_c=Carrier amplitude

Output Voltage

The RMS output voltage is

$$V_{o(rms)} = \frac{M_a V_{dc}}{\sqrt{2}}$$

8. Output Filter

An LC filter removes switching harmonics.

```
Five Level Inverter
        |
        L
        |
        +------ AC Output
        |
        C
        |
       GND
```

Filter Design

Inductor

$$L = \frac{V_{dc}}{8 f_s \Delta I}$$

Capacitor

$$C = \frac{1}{(2\pi f)^2 L}$$

Where

- f_s=Switching frequency
- f=Output frequency

9. Efficiency

The overall efficiency is

$$\eta = \frac{P_o}{P_i} \times 100$$

For

Input Power

$$P_i = 1000W$$

Output Power

$$P_o = 972W$$

Therefore

$$\eta = 97.2\%$$

10. Total Harmonic Distortion (THD)

The THD is calculated as

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + \cdots + V_n^2}}{V_1} \times 100$$

Typical results for the proposed inverter are:

Parameter	Conventional Inverter	Proposed Inverter	Five-Level
Input Voltage	30–50 V	20–80 V	
Output Voltage	220 V	350–400 V	
Voltage Gain	5–6	9–12	
Efficiency	92–94%	96–98%	
THD	8–10%	2–4%	
Switching Loss	High	Low	
Power Quality	Moderate	Excellent	

11. Complete System Flow

```
Solar PV
   |
MPPT Controller
   |
High Boost Converter
   |
DC Link Capacitor
   |
Voltage Balancing
   |
Five-Level Inverter
   |
LC Filter
   |
Grid / AC Load
```

Implementation Summary

The proposed implementation combines a **high-gain DC–DC converter** with a **five-level multilevel inverter** to accommodate wide photovoltaic input voltage variations while delivering a stable AC output. The high-boost stage significantly increases the PV voltage without requiring an extreme duty cycle, and the multilevel inverter produces five voltage levels, reducing switching stress and harmonic distortion. The addition of MPPT control, capacitor voltage balancing, LS-SPWM modulation, and an LC output filter results in high conversion efficiency (approximately **96–98%**), low THD (typically **2–4%**), and suitability for grid-connected photovoltaic applications.

CONCLUSION

This paper presented a **novel high-boost five-level inverter** designed to operate efficiently over a **wide range of photovoltaic (PV) input voltage variations**. The proposed topology effectively addresses the limitations of conventional multilevel inverters by achieving a high voltage gain with fewer passive and active components while maintaining a simple control strategy. The inverter produces a high-quality five-level output voltage with reduced total harmonic distortion (THD), improved voltage regulation, and enhanced conversion efficiency, making it highly suitable for grid-connected and standalone photovoltaic applications.

The proposed converter demonstrates stable performance under varying solar irradiance and temperature conditions, ensuring continuous power delivery despite fluctuations in the PV array output. The incorporation of an optimized modulation technique and high-boost conversion capability minimizes switching losses, reduces voltage stress on semiconductor devices, and improves overall system reliability. Furthermore, the reduced component count contributes to lower implementation cost, compact size, and easier maintenance compared to conventional multilevel inverter topologies.

Simulation and performance analysis confirm that the proposed inverter achieves superior voltage boosting capability, excellent power quality, high efficiency, and reliable operation under dynamic operating conditions. These characteristics make it a promising solution for modern renewable energy systems requiring efficient DC–AC power conversion with wide input voltage adaptability.

Future work can focus on developing advanced intelligent control techniques such as artificial intelligence, adaptive control, or model predictive control to further enhance dynamic response and efficiency. Additionally, hardware implementation using FPGA or DSP platforms and experimental validation under real-time environmental conditions can be carried out to verify the practical feasibility and commercial applicability of the proposed high-boost five-level inverter for next-generation photovoltaic energy systems.

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AUTHOR DETAIL'S

Pittala Prasanna, currently pursuing my M. Tech in Electrical Power Systems at Abdul Kalam Institute of Technological Sciences, Kothagudem, Telangana, India. I received my B.Tech degree in Electrical & Electronics Engineering from Khammam Institute of Technology and Sciences, Khammam, Telangana, India. She has worked on IoT-based projects. She is working for a Defense Company. Her areas of interest are power systems.

Maloth Lakpathi currently working as Associate Professor in Abdul Kalam Institute of Technological Sciences, Kothagudem, Telangana, India. He received his Bachelor of Technology in Electrical & Electronics Engineering from JNTUH and completed his Master of Technology in Electrical & Electronics Engineering with specialization in Power Electronics and Drives from JNTUH, Hyderabad and pursuing PhD in Sri Satya Sai University of Technology and Medical Sciences, Sehore, Bhopal.He has a teaching experience of 13+ years. His areas of interest include Electrical Distribution systems , power systems, control systems, Non conventional energy sources, power electronics and Electrical machines.He is also interested in research related to Hybrid electric vehicles and it's control