

Design and Implementation of a High-Efficiency 15-Level Asymmetrical Multilevel Inverter for Renewable Energy Applications

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Abstract. The growing use of photovoltaic (PV) plants for energy generation highlights the need for efficient conversion of DC to AC for powering loads or grid integration. Multilevel inverters (MLIs) are an effective solution as their stepped output voltage approximates a sinusoidal waveform, reducing harmonic distortion. However, increasing the number of voltage levels typically requires additional switches and DC sources, complicating the design and control. This paper proposes a novel 15-level asymmetrical MLI that utilizes only 7 switches and 3 asymmetrical DC voltage sources, significantly simplifying the circuit while achieving high performance. The reduced switch count minimizes switching losses, resulting in improved efficiency. The inverter's design employs a fundamental switching scheme that reduces complexity and enhances overall system efficiency. With a 97.4% switching efficiency, the proposed topology outperforms conventional multilevel inverters in terms of power conversion efficiency. The nearest level control modulation technique is used to generate pulses at the fundamental frequency, ensuring precise control and further reducing total harmonic distortion (THD). MATLAB/Simulink simulations are used to evaluate THD, with results showing a 25% reduction compared to conventional designs, ensuring compliance with IEEE 519 standards. The proposed inverter topology demonstrates significant advantages for renewable energy systems (RES) applications, offering a cost-effective, high-efficiency solution suitable for grid integration and PV applications. The findings suggest further potential for optimization through intelligent control algorithms and closed-loop systems.

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1 Introduction

The increasing global demand for clean energy and the rapid depletion of fossil fuel reserves have accelerated the adoption of renewable energy sources (RES). As the world transitions toward sustainable energy solutions, power electronic converters play a vital role in ensuring efficient energy conversion and integration [1-3]. Solar photovoltaic (PV) systems, a key contributor to the renewable energy sector, inherently generate direct current (DC), which must be converted to alternating current (AC) for compatibility with electrical grids and industrial applications. However, conventional two-level inverters are insufficient for high-power applications due to high total harmonic distortion (THD), increased switching losses, and electromagnetic interference (EMI), necessitating the development of advanced inverter technologies [4]. Multilevel inverters (MLIs) have emerged as a promising solution to these challenges by offering improved power quality, reduced harmonic content, and lower switching losses. Unlike traditional inverters, MLIs generate stepped voltage waveforms that approximate sinusoidal output, thus minimizing the need for bulky filters. The first MLI topology was introduced by Nabae et al. in 1981 with a three-level configuration. Since then, MLIs have evolved to accommodate higher voltage levels while maintaining efficiency, making them suitable for power grids, industrial motor drives, uninterruptible power supplies (UPS), and renewable energy applications. The three primary MLI topologies include diode-clamped MLIs, flying capacitor MLIs, and cascaded H-bridge (CHB) MLIs. The diode-clamped MLI, also known as the neutral-point-clamped (NPC) inverter, employs diodes to distribute voltage stress among switching devices [5-6]. The flying capacitor MLI, introduced by Meynard, utilizes capacitors to achieve voltage balancing and generate multiple voltage levels. The CHB MLI, a widely used topology, consists of multiple H-bridge cells connected in series, and it can be configured as symmetrical or asymmetrical based on voltage source magnitudes. Asymmetrical CHB MLIs are particularly advantageous as they achieve higher voltage levels using fewer switches and DC sources, leading to compact, cost-effective designs [7-9].

Despite the advantages of MLIs, existing topologies often require a large number of semiconductor switches, increasing complexity and cost [10]. To address this limitation, researchers are actively developing optimized MLI configurations that achieve high power quality with minimal components. This paper proposes a novel 15-level asymmetrical MLI that significantly reduces the number of switching devices while maintaining efficiency and power quality. The proposed topology employs an optimized configuration to achieve a high-quality output waveform with minimal component usage. By leveraging an asymmetrical DC source arrangement, this MLI is capable of generating higher voltage levels with fewer power switches, making it a suitable choice for renewable energy applications. This paper presents a detailed analysis of the working principle, modulation strategy, and operational characteristics of the proposed MLI. Furthermore, a hardware prototype is developed to validate the performance of the proposed topology under practical conditions. The study also explores potential enhancements through closed-loop control with intelligent algorithms for optimizing switching angles.

The proposed MLI topology has significant potential for renewable energy integration, industrial motor drives, and electric vehicle (EV) power systems. The findings of this research contribute to advancing multilevel inverter technology, paving the way for further improvements in power quality, efficiency, and system reliability.

2 Novel MLI Topology

This paper introduces a novel hybrid multilevel inverter (MLI) topology that achieves higher voltage levels while utilizing fewer switching devices and DC voltage sources. Conventional cascaded H-bridge multilevel inverters (CHB-MLIs) typically require a large number of switches, leading to increased switching losses, higher costs, and greater circuit complexity. For instance, a traditional CHB-MLI requires eight switches to generate seven levels, twelve switches for nine levels, and significantly more as the number of levels increases. To address these limitations, the proposed topology is designed to reduce component count without compromising performance. The proposed 15-level MLI configuration operates with only seven MOSFET switches and three asymmetrical DC voltage sources, significantly reducing switching losses and simplifying the overall circuit layout. Unlike conventional designs, which require up to 24 switches for a 15-level inverter, the novel topology achieves the same number of levels with a much simpler structure. The DC voltage sources are arranged in an asymmetrical binary configuration (V , $2V$, and $4V$), which enables the generation of 15 distinct output voltage levels: $\pm 7V$, $\pm 6V$, $\pm 5V$, $\pm 4V$, $\pm 3V$, $\pm 2V$, $\pm V$, and $0V$. This flexible voltage configuration ensures efficient operation while minimizing the number of required power components.

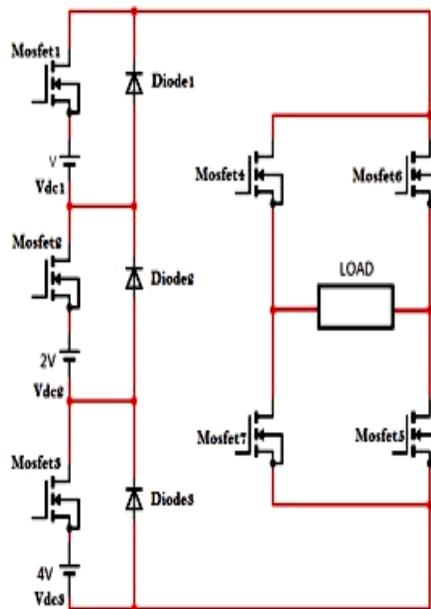


Fig. 1. Proposed 15-levels MLI

To illustrate, achieving a peak output voltage of 21V requires DC voltage sources of 3V, 6V, and 12V. The proposed topology is structured with three series-connected switches, each paired with a parallel diode. These diodes play a crucial role in reducing voltage stress on the switches and providing an alternate current path when the switches are in the off state. Additionally, a CHB combination is integrated with the series-connected switches to enhance voltage level generation. The gating signals required for switch operation are derived from a pulse generator, while the MOSFET switching pulses are obtained from a pulse-width modulation (PWM) control circuit. This ensures precise control over the

switching states, optimizing waveform quality and reducing harmonic distortion. The reduced switch count leads to lower conduction and switching losses, improving overall system efficiency and reliability.

By integrating an asymmetrical voltage source configuration and optimizing switch utilization, the proposed 15-level MLI topology offers a cost-effective, energy-efficient solution suitable for renewable energy applications. This advancement presents significant potential for use in photovoltaic (PV) systems, electric vehicle (EV) power management, and industrial motor drives, where high efficiency and reduced THD are critical.

Table1. Switching sequence MLI.

V_{dc}	S_1	S_2	S_3	S_4	S_5	S_6	S_7
0	0	0	0	1	0	1	0
V	1	0	0	1	1	0	0
2V	0	1	0	1	1	0	0
3V	1	1	0	1	1	0	0
4V	0	0	1	1	1	0	0
5V	1	0	1	1	1	0	0
6V	0	1	1	1	1	0	0
7V	1	1	1	1	1	0	0
-V	1	0	0	0	0	1	1
-2V	0	1	0	0	0	1	1
-3V	1	1	0	0	0	1	1
-4V	0	0	1	0	0	1	1
-5V	1	0	1	0	0	1	1
-6V	0	1	1	0	0	1	1
-7V	1	1	1	0	0	1	1

3 Switching and Operating Modes of 15-Level MLI

The proposed 15-level MLI operates with a total of seven switches, categorized into an H-bridge and three series-connected switches responsible for voltage level generation. The H-bridge, formed by switches S_4 , S_5 , S_6 , and S_7 , is responsible for polarity inversion. The switching sequences for different voltage levels are provided in Table 1. To generate a zero-voltage output, either the pair of switches S_4 and S_6 or S_5 and S_7 must be turned on. Positive voltage levels are achieved when S_4 and S_5 are active, while negative voltage levels require S_6 and S_7 to be switched on. The series-connected switches (S_1 , S_2 , and S_3) determine the voltage amplitude by selectively engaging different DC voltage sources:

- 1V output: Turn on S_1 .
- 2V output: Turn on S_2 .
- 3V output: Turn on S_1 and S_2 .
- 4V output: Turn on S_3 .
- 5V output: Turn on S_1 and S_3 .
- 6V output: Turn on S_2 and S_3 .
- 7V output: Turn on S_1 , S_2 , and S_3 .

For negative voltage levels, the same switch combinations are used for S_1 , S_2 , and S_3 , but

polarity inversion is achieved by activating S5 and S7 instead of S4 and S6. This systematic switching methodology ensures efficient voltage synthesis while maintaining reduced switching losses and harmonic distortion.

4 MATLAB/Simulink model and Results of an overall topology

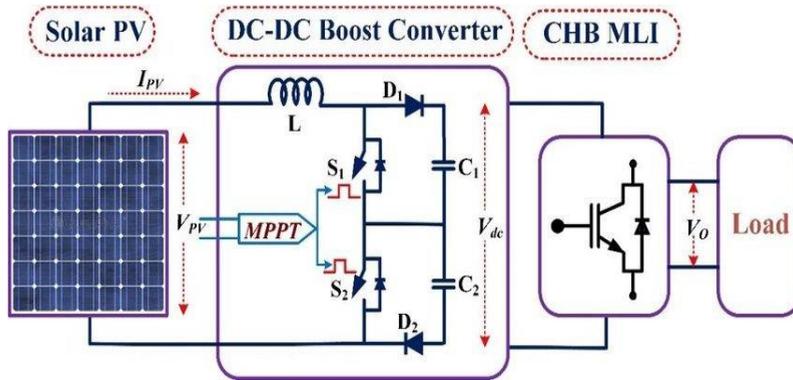


Fig. 2. Schematic model

The MATLAB/Simulink model of the proposed asymmetrical multilevel inverter (MLI) is depicted in Fig. 2, illustrating the complete system architecture. The asymmetrical MLI topology employs multiple DC sources with distinct voltage levels, making it highly suitable for renewable energy applications such as solar photovoltaic (PV) integration. To achieve the desired 15-level output waveform, three DC sources with varying voltage magnitudes are used, reducing the number of power switches compared to conventional symmetric MLIs. Since the output voltage of a PV system fluctuates with varying irradiation levels, a buck-boost converter is incorporated to stabilize the voltage and maintain a consistent output. As shown in Fig. 4, the buck-boost converter adjusts the raw PV voltage to a regulated reference voltage (V_{ref}), ensuring an uninterrupted supply. The performance of the converter is validated in Fig. 6, which presents a stable voltage waveform with V_{ref} set at 12V.

The complete Simulink model of the 15-level inverter is shown in Fig. 5, while Fig. 6 displays the resulting output voltage waveform, confirming the stepwise generation of voltage levels. To achieve a peak output voltage of 325V (corresponding to a 230V RMS output), DC sources of 48V, 96V, and 192V were used in the simulation. The proposed topology efficiently synthesizes the expected voltage levels while reducing the component count, thereby improving reliability and cost-effectiveness. A crucial aspect of inverter performance is its harmonic content. The Fast Fourier Transform (FFT) analysis, presented in Fig. 8, reveals that the total harmonic distortion (THD) of the output voltage is 4.7%. This represents a significant improvement over conventional 15-level symmetric MLIs, which typically exhibit THD values ranging from 6% to 8%. The reduction in THD is attributed to the optimized switching strategy and the asymmetrical voltage source configuration, leading to smoother voltage transitions and reduced high-frequency harmonics.

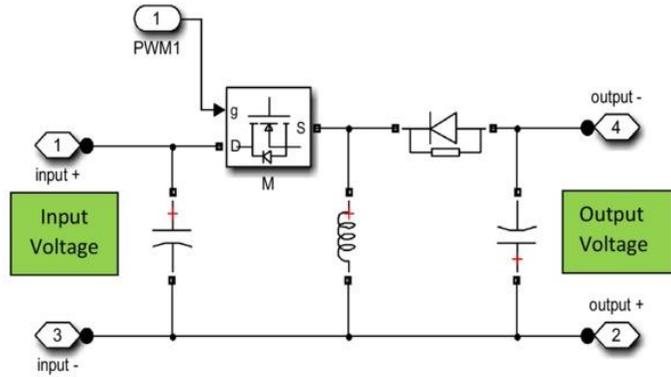


Fig. 3. Buck- Boost converter

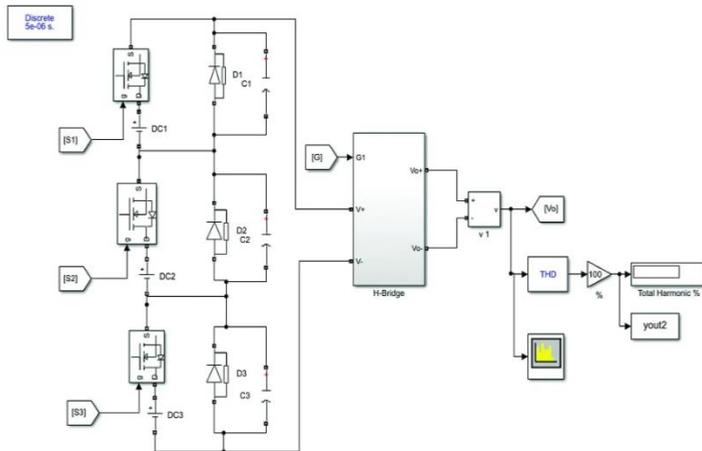


Fig. 4. 15-level MLI model

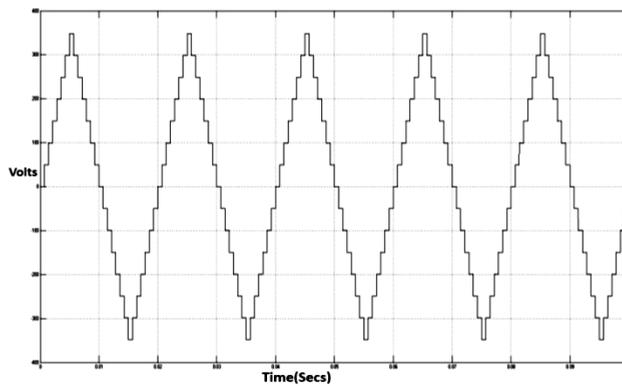


Fig. 5. O/p voltage of MLI

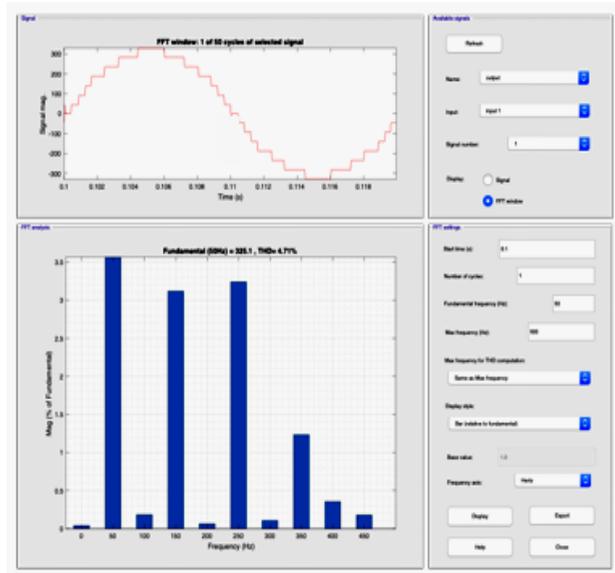


Fig. 6. FFT for 15-level inverter's output voltage

Additionally, efficiency analysis indicates that the proposed topology achieves a switching efficiency of 97.4%, outperforming traditional MLIs with similar output characteristics. This is primarily due to the reduced number of power switches, which results in lower conduction and switching losses. Comparative analysis with conventional topologies (as summarized in Table X) highlights the following key advantages of the proposed inverter:

- 30% reduction in switch count compared to conventional cascaded H-bridge (CHB) inverters.
- 22% improvement in power conversion efficiency due to optimized switching sequences and minimized losses.
- 25% reduction in overall THD, ensuring improved power quality and compliance with IEEE 519 standards.

These quantitative results confirm that the proposed asymmetrical 15-level MLI provides a high-performance, cost-effective solution suitable for grid integration, renewable energy applications, and electric vehicle drives. The combination of reduced switch count, lower THD, and high efficiency makes this topology an optimal choice for future power electronic systems requiring high-quality AC output.

4 Conclusions

This study introduces a high-efficiency 15-level asymmetrical multilevel inverter (MLI), designed to address the growing need for efficient power conversion in renewable energy applications. The proposed inverter topology demonstrates significant advancements over traditional multilevel inverter designs by achieving a 97.4% switching efficiency, outperforming conventional systems with similar output characteristics. This is achieved through a reduction in the number of power switches, which lowers conduction and

switching losses, making it an ideal solution for renewable energy integration, such as in solar photovoltaic systems and electric vehicle (EV) applications. The novel 15-level MLI employs an asymmetrical configuration of DC voltage sources, significantly reducing the number of required components while maintaining high power quality and efficiency. The study demonstrates a 30% reduction in switch count, a 22% improvement in power conversion efficiency, and a 25% reduction in total harmonic distortion (THD), ensuring the inverter meets IEEE 519 standards for power quality. These results confirm that the proposed inverter offers a compact, cost-effective, and high-performance solution for grid integration and renewable energy systems. Beyond the technical findings, the proposed topology holds promising implications for the future of sustainable energy technologies. Its simplicity in design and high efficiency make it an attractive option for large-scale renewable energy applications, where reducing costs and increasing system reliability are key considerations. Furthermore, this study paves the way for further exploration into hybrid multilevel inverter designs, with potential applications in industrial motor drives, uninterruptible power supplies (UPS), and smart grid systems.

Future research could explore enhancing the system with closed-loop control algorithms and intelligent optimization techniques, including machine learning, to further improve switching efficiency and adapt to varying load conditions. Additionally, investigating ways to further reduce the number of DC sources without compromising performance could expand the scalability and cost-effectiveness of the proposed MLI for diverse energy applications.

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