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SINUSOIDAL PWM-BASED CONTROL AND DEVELOPMENT OF A 7-LEVEL CHB MULTILEVEL INVERTER

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Abstract— The development of a 7-level Cascaded H-Bridge (CHB) multilevel inverter involves designing an advanced power electronics system capable of delivering high-quality, efficient AC power. This inverter topology comprises multiple H-bridge cells connected in series, each generating discrete voltage levels. By combining these levels, the inverter produces a stepped output waveform with improved quality, reduced harmonic distortion, and lower stress on switching components. The "7-level" designation indicates the inverter can generate seven distinct voltage levels, enhance control

Electronics, Pulse Width Modulation (PWM), Sinusoidal PWM (SPWM)	precision and resulting in a smoother AC waveform. Multilevel inverters are especially beneficial in applications that demand clean and stable power, such as sensitive electronic loads. Although LED lighting applications are not the primary focus of this study, the characteristics of multilevel inverters align well with the requirements of such systems, which typically demand low harmonic content and stable operation for optimal performance. Achieving this performance requires a solid understanding of power electronic design, modulation strategies such as Sinusoidal Pulse Width Modulation (SPWM), and system integration. The design process entails careful component selection, effective control implementation, and rigorous testing to ensure compliance with performance standards and operational reliability. This technical study focuses on the simulation, development, and evaluation of a 7-level CHB inverter using SPWM to assess its performance for general power conversion purposes.

I. Introduction

Multilevel inverters have emerged as a critical advancement in power electronics, particularly for applications requiring high-quality AC output with low harmonic distortion. Among the various topologies, the cascaded H-Bridge (CHB) multilevel inverter stands out due to its ability to produce a near-sinusoidal voltage waveform by synthesizing multiple voltage levels from several DC sources.

This architecture not only reduces the total harmonic distortion (THD) but also enhances power conversion efficiency and minimizes stress on components [1-2].

The significance of multilevel inverters has grown with the increasing adoption of technologies like electric vehicles, renewable energy systems, and smart grid integration [3-5]. Specifically, CHB inverters are favored for their modular design, which allows scalability and fault-tolerant operation. The use of advanced semiconductor devices such as Gallium Nitride (GaN) has further improved their performance by enabling higher switching frequencies and lower losses. Research shows that CHB inverters employing GaN switches can maintain THD below 5%, making them suitable for applications where power quality is crucial [2].

One such application is LED lighting, which demands a stable and distortion-free AC supply for optimal operation. Poor power quality can lead to flickering, reduced lifespan, and inconsistent illumination in LEDs. The refined output waveform of CHB inverters ensures smooth and efficient performance of LED systems, making them an ideal choice. Furthermore, improved power control and harmonic reduction significantly enhance the reliability of LED installations, especially under variable load conditions [6].

To achieve precise control over output waveforms, switching techniques such as Sinusoidal Pulse Width Modulation (SPWM) and Enhanced Pulse Width Modulation (EPWM) [7] are employed. SPWM, known for its simplicity, modulates the inverter’s output by comparing a reference sine wave with a carrier signal. This technique effectively reduces harmonic content and enables fine voltage control, which is critical for sensitive loads [8-9]. However, its adaptability under dynamic conditions is limited.

EPWM offers a more robust and flexible alternative by allowing dynamic adjustment of pulse widths and switching frequencies [7]. It integrates advanced control strategies capable of responding to real-time load changes, thus reducing THD more effectively than SPWM [6]. These techniques are particularly useful in 7-level CHB inverters, where multiple output voltage levels enable closer approximation to a sinusoidal waveform, further enhancing power quality.

The 7-level CHB inverter structure utilizes three H-Bridge cells per phase to produce seven distinct voltage levels. This configuration provides higher resolution in output voltage and contributes to better power quality with fewer components, resulting in reduced complexity, cost, and voltage stress [9]. The modular design also enables fault-tolerant operation, where a failed cell does not compromise the entire system [10]. This ensures reliability in mission-critical applications.

In summary, the integration of multilevel inverter technology especially the 7-level CHB inverter with advanced modulation strategies such as EPWM presents a compelling solution for high-performance power conversion in LED lighting systems. The synergy between improved output quality, control flexibility, and structural robustness makes CHB inverters an attractive research and application domain in modern power electronics.

II. Methodology

Figure 1 illustrates the flowchart for developing a 7-Level Cascaded H-Bridge (CHB) Multilevel Inverter, structured to ensure systematic progress. The process begins with a comprehensive literature review on CHB inverters, emphasizing design principles and switching techniques, particularly Sinusoidal Pulse Width Modulation (SPWM) and Enhanced Pulse Width Modulation (EPWM). Subsequently, 5-level and 7-level CHB inverter circuits are modeled and simulated using MATLAB Simulink to compare their performance under both switching methods. Key performance indicators such as efficiency, total harmonic distortion (THD), and switching losses are analyzed to identify the optimal configuration. Based on simulation results, a physical prototype of the 7-level CHB inverter is constructed using the most effective switching

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technique. The final phase involves implementing SPWM in the prototype, followed by performance testing to validate efficiency and waveform quality. This structured approach ensures the development of a reliable inverter that meets application requirements and provides a foundation for future advancements.

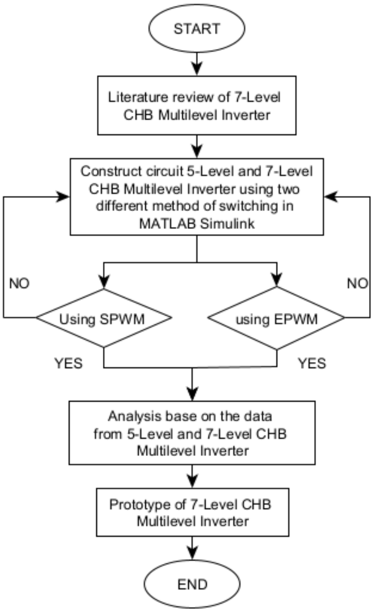

Figure 1: Flowchart for 7-Level Cascaded H-Bridge (CHB) Multilevel Inverter

A. CHB Multilevel Inverter

The block diagram in Figure 2 provides a visual representation of the primary system components and their interactions. It includes the DC input sources, H-bridge cells, control circuitry, and the output load. Each DC source is connected to a single-phase H-bridge inverter module, which is then integrated in series to generate a stepped AC output waveform.

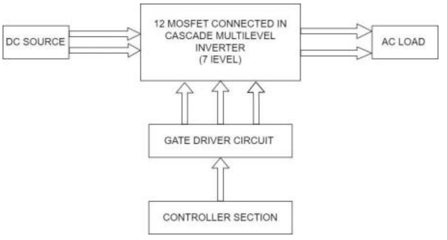

Figure 2: Primary system components

The operation of each H-bridge cell is independently controlled through gate driver circuits that respond to the Pulse Width Modulation (PWM) signals generated by the controller. These gate signals are crucial for switching the IGBT or MOSFET components in the H-bridge circuits, facilitating the synthesis of the multilevel output voltage.

The complete circuit design consists of three H-bridge modules, each powered by its own isolated DC supply. The switching devices within each module are driven according to the timing defined by the control algorithm, ensuring that the voltage levels produced are additive in nature.

The resultant output is a staircase waveform that approximates a sinusoidal AC voltage. This design effectively reduces total harmonic distortion (THD) and enhances the quality of the output power, making it suitable for applications requiring clean AC signals such as motor drives and renewable energy systems.

B. Switching Circuit

This section details the switching methods used in the Cascaded H-Bridge (CHB) Multilevel Inverter circuit as shown in Figure 3, focusing on Sinusoidal Pulse Width Modulation (SPWM) and Enhanced Pulse Width Modulation (EPWM). These techniques generate control signals for the CHB circuit to regulate switching behavior effectively.

The SPWM method as shown in Figure 4 generates switching signals by comparing a sinusoidal reference waveform with multiple high-frequency triangular carrier waveforms. When the sinusoidal reference surpasses the triangular waveform, the comparator outputs a HIGH signal; otherwise, it outputs a LOW signal. This technique ensures smooth modulation and precise control over the inverter's output voltage.

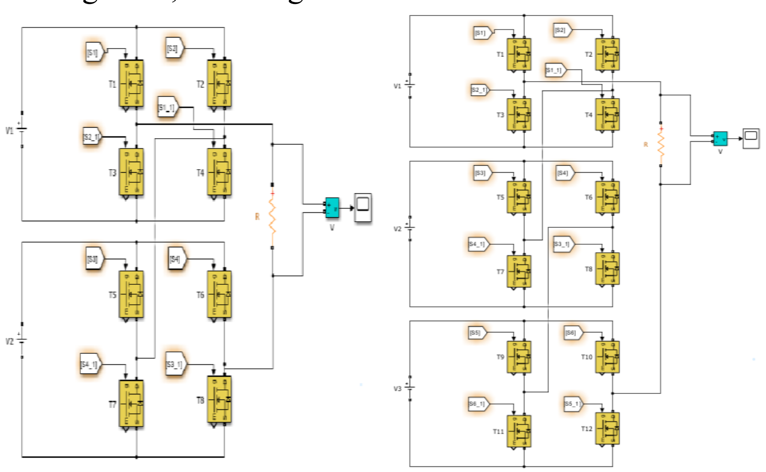

Figure 3: Cascaded H-Bridge (CHB) Multilevel Inverter circuit

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For the EPWM method as shown in Figure 5, gate signals are generated and processed to create complementary signals, ensuring synchronized operation of paired switches in the inverter. EPWM enhances modulation control, reduces switching losses, and improves waveform quality by dynamically adjusting pulse width and timing to minimize total harmonic distortion (THD).

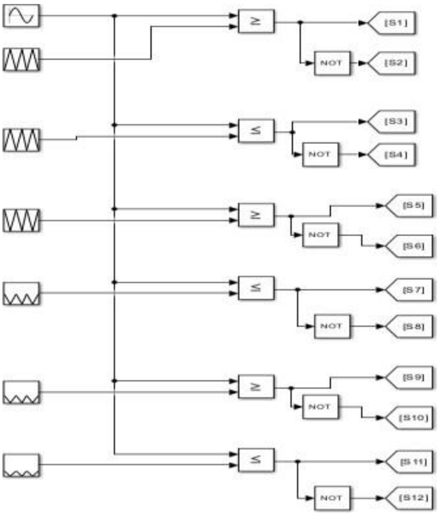


Figure 4: SPWM method

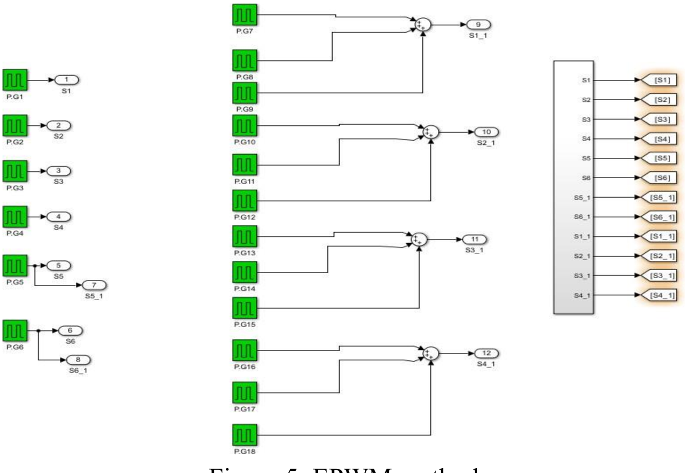


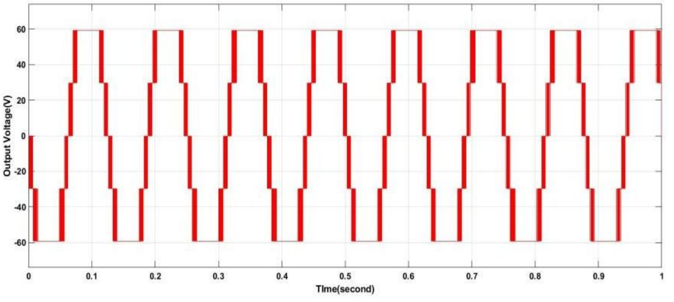
Figure 5: EPWM method

III. Results and Discussion

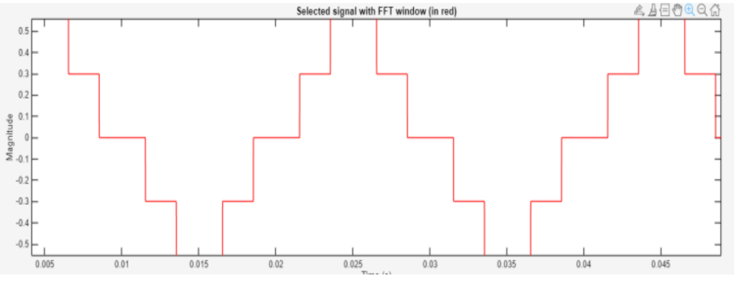
This section presents the analysis of the performance of 5-level and 7-level Cascaded H-Bridge (CHB) Multilevel Inverters, focusing on power quality and efficiency. The evaluation is conducted using MATLAB Simulink simulations, comparing the effects of Sinusoidal Pulse Width Modulation (SPWM) and Enhanced Pulse Width Modulation (EPWM) across different inverter configurations.

A. Performance of 5-level and 7-Level CHB Inverters

The 5-level CHB inverter using SPWM generates a stepped voltage waveform as shown in Figure 6 with noticeable harmonic distortion, resulting in a Total Harmonic Distortion (THD) of 106.70% as shown in Figure 7. The voltage transitions between discrete levels, leading to significant harmonic interference. In contrast, implementing EPWM in the same 5-level inverter reduces distortion substantially, achieving a THD of 30.17%, which enhances power quality and output stability.

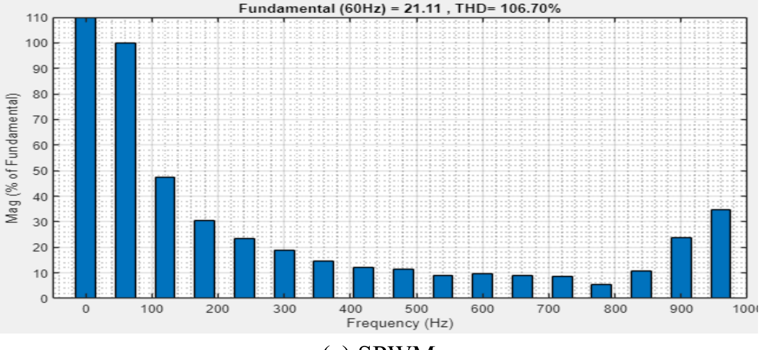


(a) SPWM

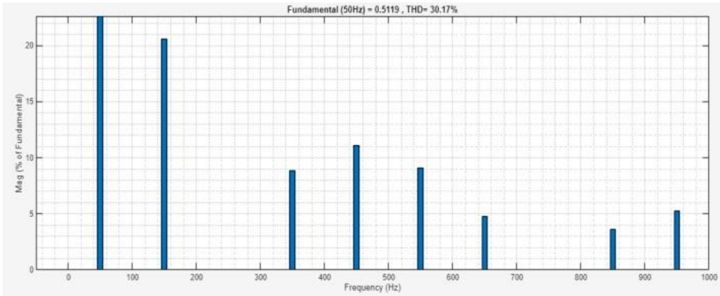


(b) EPWM

Figure 6: Output Voltage for 5 Level CHB



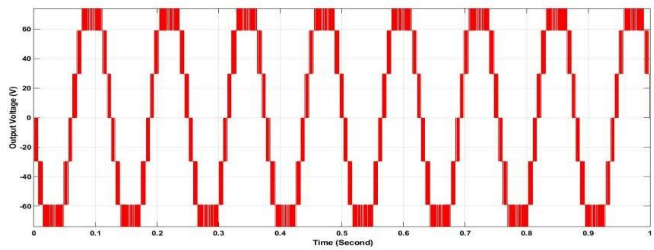
(a) SPWM



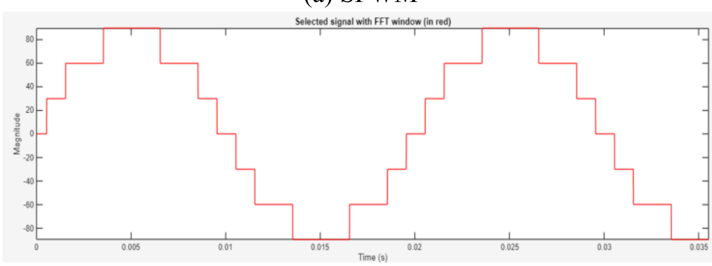
(b) EPWM

Figure 7: THD Value for 5 Level CHB

Similarly, for the 7-level CHB inverter, SPWM improves waveform characteristics over the 5-level version as in Figure 8, lowering THD to 86.54% as in Figure 9. The additional voltage levels allow finer voltage control, which smooths AC power delivery. However, the EPWM method further refines the output, reducing THD to just 14.22%, making it the most effective switching strategy. EPWM dynamically adjusts pulse timing and width, optimizing waveform integrity and minimizing energy losses, making it highly suitable for LED applications requiring flicker-free illumination.

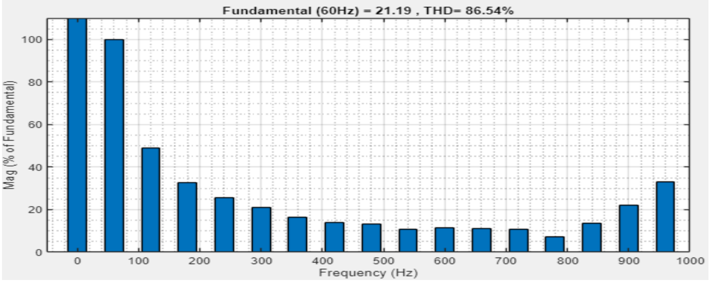


(a) SPWM

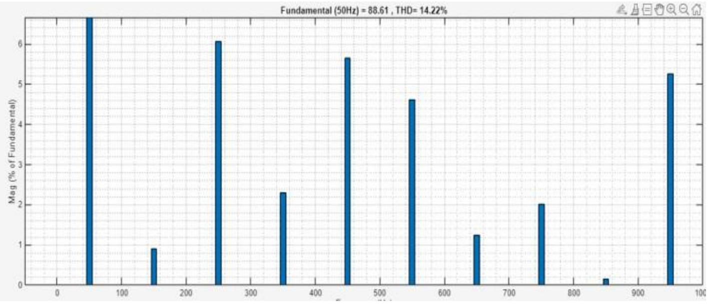


(b) EPWM

Figure 8: Output Voltage for 7 Level CHB



(a) SPWM



(b) EPWM

Figure 9: THD Value for 7 Level CHB

B. Comparison of Switching Methods for Different Levels

A comparative analysis between SPWM and EPWM across both 5-level and 7-level CHB inverters confirms the superior performance of EPWM. As shown in Table 1, the 7-level CHB inverter using EPWM offers the lowest THD, improved voltage stability, and enhanced waveform quality. This is the key factors in ensuring efficient power delivery for LED applications.

Table 1 Comparison between 5-level and 7-level CHB

Properties	SPWM		EPWM	
	5-level	7-level	5-level	7-level
Number of MOSFET	8	12	8	12
Number of Cascade	2	3	2	3
Voltage Output (V)	58.69	84	58.69	84
Number of Step Up	5	7	5	7
THD Value (%)	106.70	86.54	30.17	14.22

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IV. Conclusion

The development and analysis of the 7-Level Cascaded H-Bridge (CHB) Multilevel Inverter demonstrate its effectiveness in enhancing power quality for LED applications. Through MATLAB Simulink modeling and simulations, the inverter's performance was evaluated under different switching techniques, comparing 5-level and 7-level configurations. The results confirmed that increasing the number of voltage levels significantly reduces Total Harmonic Distortion (THD) and improves waveform quality.

Among the switching methods tested, Enhanced Pulse Width Modulation (EPWM) proved to be the most efficient, delivering superior power quality, lower harmonic distortion, and improved voltage stability. The 7-level CHB inverter with EPWM exhibited the lowest THD values, making it the optimal configuration for LED applications requiring stable and flicker-free operation.

These findings highlight the importance of multilevel inverters in power electronics, particularly in applications demanding high-quality AC power. The success of this project establishes a strong foundation for future improvements in inverter design, control strategies, and efficiency optimizations, paving the way for advanced implementations in LED lighting systems and beyond.

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