Power Quality Improvement through Multi-Level Cascaded H-Bridge Inverter Design

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Abstract - *The present study focuses on the design and performance evaluation of a 7-level cascaded H-Bridge multilevel inverter. Multilevel inverters are widely used in high-power and low total harmonic distortion (THD) applications, making them ideal for various energy distribution and control systems. In this work, a simulation model of a cascaded H-Bridge inverter is developed using MATLAB/SIMULINK. The simulation aims to assess the key performance metrics of the inverter, including output voltage waveform, total harmonic distortion, harmonic spectrum, and voltage stress across the power devices. The 7-level configuration enhances the quality of the output waveform by reducing harmonic distortion and improving voltage resolution. The simulation results demonstrate that this topology provides an efficient and reliable solution for power conversion in medium to high-power applications. Through this study, the potential of cascaded H-Bridge inverters in delivering high-quality power with reduced harmonic content is effectively illustrated.*

***Key Words*: Power quality, Smart grid, Renewable energy MATLAB Simulink, Multilevel inverter etc.**

1.INTRODUCTION

Renewable energy sources such as solar and wind are abundantly available and are rapidly becoming central to sustainable power generation worldwide. However, to ensure high reliability and improved power quality from these sources, innovative control strategies are essential. Among them, the use of multilevel inverter technologies has gained significant attention.

Solar and wind energy have seen exponential growth in recent years. Solar photovoltaic (PV) systems generate DC power, which must be converted to AC using inverters. A novel approach using multilevel inverters, specifically cascaded H-Bridge (CHB) inverters, is employed to reduce harmonic distortion and enhance output waveforms without the need for complex filters.

The proposed work focuses on connecting both wind and solar energy sources directly to the utility grid through a seven-level CHB inverter. Simulation studies conducted using MATLAB/Simulink demonstrate the effectiveness of this configuration in maintaining power quality and system reliability. As the demand for distributed generation grows, especially with renewable energy integration, there is a pressing need for advanced grid operation and management techniques.

Globally, installed capacities of solar and wind energy have reached impressive levels—India alone has achieved 42.8 GW of solar and 37.5 GW of wind power, while Sri Lanka has surpassed 100 MW and 367 MW respectively. Technologies such as CHB inverters are ideal for medium to high-power applications including motor drives, power conditioning, and reactive power compensation.

These inverters offer sinusoidal outputs, even without additional filters, and work effectively across resistive (R), inductive (RL), and capacitive (RLC) loads. However, challenges such as voltage balancing, circuit complexity, and the requirement for isolated DC sources at each level must be addressed for optimal performance.

2. Motivation

The review of multilevel inverter technology is driven by its growing importance in the future of renewable energy systems, especially in solar and standalone solar applications. Multilevel inverters are known for their ability to significantly reduce harmonic distortion, leading to cleaner and more stable power output. This makes them an ideal solution for improving power quality in renewable setups.

In particular, integrating multilevel inverter systems with solar energy in rural areas can ensure reliable and high-quality electricity supply. These systems not only enhance efficiency but also provide uninterrupted power, making them highly suitable for remote regions where consistent energy access is crucial.

3. H-Bridge Inverter

Traditional two- or three-level inverters are often unable to completely eliminate unwanted harmonics in the output waveform. To address this limitation, researchers are exploring the use of multilevel inverter architectures as a potential alternative to conventional pulse-width modulation (PWM) inverters.

In a typical multilevel inverter design, the total number of output phase voltage levels, denoted as *N*, corresponds to the number of individual cells or DC link voltages used. The total number of switching devices or converter connections in such a setup is calculated as $2N + 1$.

One of the key advantages of this structure is that the voltage across the DC link capacitor in each cell operates independently, allowing dynamic voltage variation based on the operating condition of that specific cell. Importantly, each circuit requires only a single DC power source, making the system more efficient and flexible.

The number of DC sources and output voltage levels is directly proportional to the number of H-bridge cells and their corresponding capacitors. Each H-bridge unit can output a positive, negative, or zero voltage. The final output voltage is obtained by summing the contributions from all H-bridge cells, resulting in a stepped waveform that closely approximates a pure sine wave with minimal harmonic distortion.

4. Literature Review

The growing demand for cleaner energy has driven significant research into multilevel inverter technologies, particularly cascaded H-bridge inverters. Comparative studies have shown that 7-level inverters produce considerably less harmonic distortion than their 5-level counterparts, making them more suitable for applications demanding high power quality. Simulation results confirm their efficiency, especially when paired with renewable sources like photovoltaic (PV) systems.

Recent studies have also addressed the challenge of non-sinusoidal source voltages and currents. By integrating intelligent control systems, these signals can be effectively converted into clean sinusoidal forms. This not only improves the total harmonic distortion (THD) but also reduces reactive power drawn from PV sources, enhancing the system's overall performance.

Simulations have further shown improvements in voltage stability at the point of common coupling (PCC), with some models reporting a 29.11% increase due to the inclusion of controllers. The integration of renewable energy into the grid is increasingly supported by modern power electronics, enabling more reliable and efficient hybrid systems.

MATLAB/Simulink has become a powerful tool in modeling various grid-connected loads (R, RL, RC, diode), studying THD impacts, and optimizing inverter design. The development of multilevel inverter topologies not only improves power quality but also reduces the number of switching components, thereby minimizing losses.

Techniques like switching angle optimization, space vector PWM, and carrier-based SPWM are being explored to further reduce THD. Solving the related nonlinear, transcendental equations often involves advanced methods such as the Newton-Raphson algorithm or evolutionary computation strategies.

With continuous innovations in control systems and power electronic design, multilevel inverters are becoming an essential component in modern energy systems—particularly in ensuring the quality, efficiency, and sustainability of renewable energy integration.

5. Simulation Model of seven level

A seven-level inverter configuration typically consists of three H-bridges, each equipped with four switches and its own dedicated DC supply. This system can be simulated using power system simulation platforms in MATLAB, where the circuit layout of the cascaded H-Bridge multilevel inverter is modeled in detail.

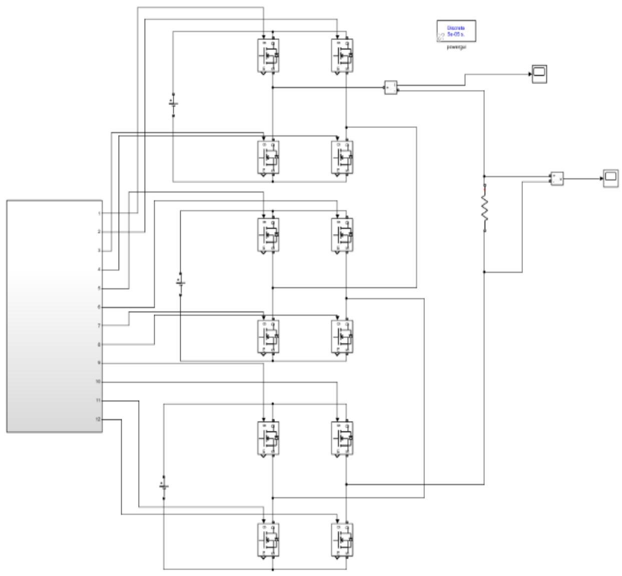

Fig-1: Single-Phase (CHB) Inverter with Seven Voltage Levels

In a single-phase cascaded H-Bridge inverter with multiple levels, three H-bridges are connected in series. Each H-bridge is powered by its own DC source, and these are combined to generate the desired voltage waveform. The total output voltage of the system is the sum of the individual contributions from each H-Bridge cell, resulting in a stepped waveform that closely approximates a pure sine wave. This configuration offers enhanced efficiency, reduced harmonic distortion, and improved power quality for various applications, including renewable energy systems.

6. Simulation Results of seven level

The performance of the seven-level cascaded H-Bridge inverter is thoroughly analyzed in MATLAB/SIMULINK, with a focus on the total number of switching operations and the harmonic distortion present in the output voltage. The simulation study investigates how the inverter performs under different load conditions—resistive (R), resistive-inductive (RL), and resistive-inductive-capacitive (RLC) loads.

The results provide insight into how the inverter maintains voltage stability and minimizes harmonic distortion across various load types. This analysis helps validate the effectiveness of the multilevel inverter design in delivering high-quality output voltage with reduced Total Harmonic Distortion (THD), making it suitable for integration into renewable energy systems and other sensitive power applications.

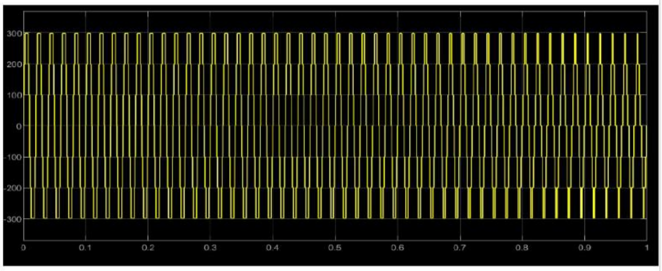

Fig- 2: Voltage Waveform of Resultant

6.1. THD% Of Seven-Level Inverter Load of R

The performance of the seven-level cascaded H-Bridge multilevel inverter with a purely resistive (R) load is illustrated in the corresponding simulation image. As shown in Figure 11, the inverter produces a stepped output voltage with a clear magnitude waveform. Figure 12 presents the Total Harmonic Distortion (THD) analysis, revealing a THD value of 16.69% at a fundamental frequency of 50 Hz. This result demonstrates a noticeable improvement in harmonic performance compared to a five-level inverter operating under the same R-load condition, highlighting the advantage of increasing voltage levels in enhancing power quality.

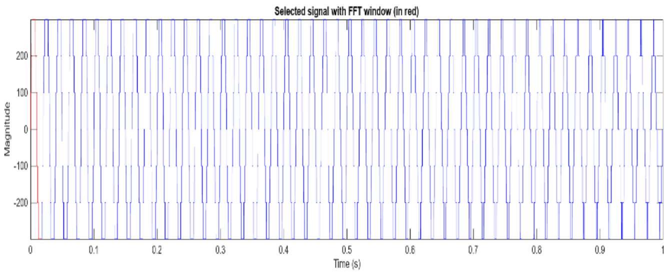

Fig-3: Voltage magnitude of a 7-stages of inverter for a load of R

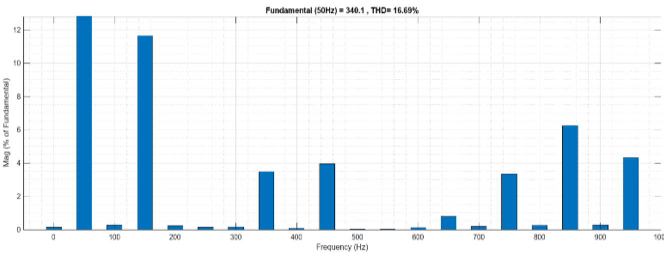

Fig-4: THD% of a 7-stages of inverters for load of R

6.2. THD% Of 7-Level Inverter RL-Load

This image illustrates the operation of the seven-level cascaded H-Bridge multilevel inverter under a resistive-inductive (RL) load condition. As shown in Figure 13, the inverter generates a stepped voltage waveform with a consistent magnitude. Figure 14 presents the Total Harmonic Distortion (THD) analysis, which reveals a THD value of 16.13% at a fundamental frequency of 50 Hz. This result demonstrates superior harmonic performance compared to that of a five-level inverter operating with an RL load, emphasizing the effectiveness of higher-level inverters in improving output waveform quality and overall efficiency.

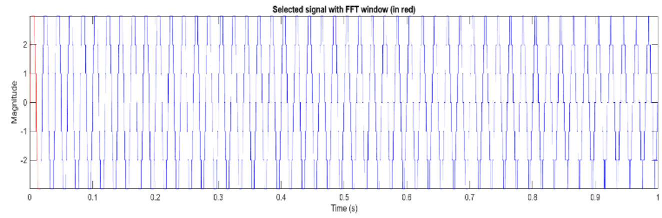

Fig-5: Voltage magnitude of 7-level inverter for load of RL

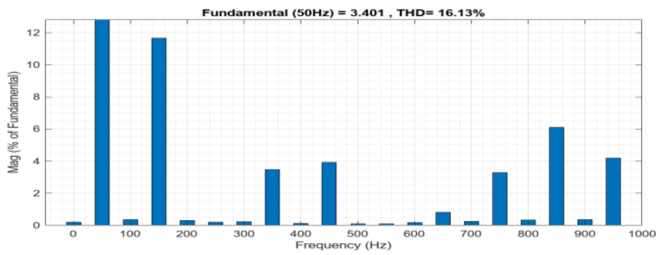

Fig-6: THD% of seven-level inverter for load of RL

6.3. THD% Of 7-Stages of Inverter Load of RLC

This graphic illustrates the performance of a seven-level cascaded H-Bridge multilevel inverter operating with a resistive-inductive-capacitive (RLC) load. Figure 15 displays the output voltage waveform, showing a well-defined stepped voltage magnitude. As shown in Figure 16, the Total Harmonic Distortion (THD) is recorded at 16.12% with a fundamental frequency of 50 Hz. Compared to a five-level inverter under similar RLC load conditions, the seven-level configuration delivers improved harmonic performance, confirming its effectiveness in enhancing power quality and waveform smoothness in complex load environments.

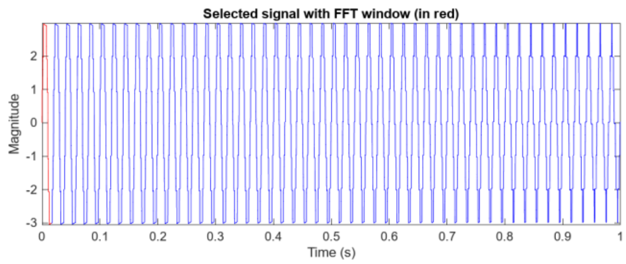

Fig-7: Voltage magnitude of 7-level inverterfor RLC-load

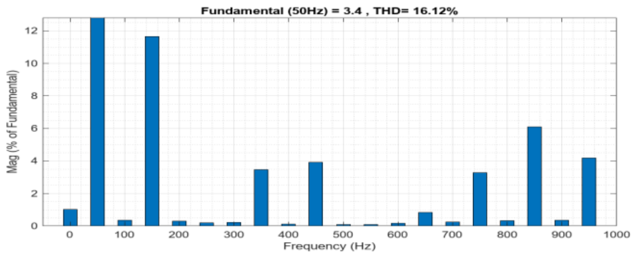

Fig-8: THD% of 7-stages of inverter for RLC-load

3. CONCLUSIONS

In this research, it has been observed that the seven-level cascaded H-Bridge inverter demonstrates superior efficiency and reliability compared to conventional lower-level inverter configurations. The primary advantage of the seven-level topology lies in its ability to significantly reduce Total Harmonic Distortion (THD), thereby delivering a smoother and more sinusoidal output voltage waveform. This is especially important in applications involving renewable energy sources such as solar and wind, where maintaining power quality is essential for both system performance and grid compliance.

Through detailed simulation studies conducted using MATLAB/SIMULINK, the seven-level inverter consistently showed better results across various types of loads, including resistive (R), resistive-inductive (RL), and resistive-inductive-capacitive (RLC). In each case, the THD levels were noticeably lower than those produced by five-level inverter systems, confirming the improved harmonic performance of the proposed topology.

Moreover, the modular structure of the cascaded H-Bridge design enhances the scalability and flexibility of the inverter, allowing it to be adapted for different power ratings and applications. It also simplifies maintenance and fault isolation, contributing to the overall reliability of the system.

The results of this research support the conclusion that the seven-level inverter is an effective solution for improving power quality, especially in grid-connected renewable energy systems. Its ability to reduce harmonic distortion, ensure better voltage regulation, and maintain high efficiency makes it a preferred choice for modern energy applications that demand clean and stable electrical power.

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