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Review of Cascaded H-Bridge Multilevel Inverter with Solar

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Abstract— **The Cascaded H-Bridge (CHB) multilevel inverter has emerged as a pivotal technology in renewable energy applications, particularly in solar power systems, due to its efficient power conversion, modular structure, and ability to generate high-quality output voltages. This review examines the integration of CHB multilevel inverters in solar photovoltaic (PV) systems, focusing on recent advancements, benefits, challenges, and future potential. The CHB multilevel inverter's architecture is ideal for handling the fluctuating nature of solar energy, offering superior power quality and efficiency in medium to high-power applications. By utilizing multiple DC sources, CHB inverters can achieve enhanced voltage levels without the need for transformers, leading to a more compact and cost-effective solution for solar energy applications. This paper analyzes various modulation techniques, control strategies, and design optimizations for CHB inverters.**

Keywords*— *H-Bridge, Multilevel, Cascaded, Inverters, Solar.

I. INTRODUCTION

The growing global demand for renewable energy has accelerated the development of advanced power conversion technologies, with solar photovoltaic (PV) systems being at the forefront of sustainable energy generation [1]. Among the essential components of solar power systems, inverters play a critical role in converting the direct current (DC) output from solar panels into alternating current (AC), which can be utilized for household and industrial applications [2]. As the need for efficient and reliable power conversion increases, the Cascaded H-Bridge (CHB) multilevel inverter has gained significant attention due to its high efficiency, scalability, and ability to produce high-quality AC output. This technology is especially advantageous for solar applications where it can address power quality and efficiency issues while providing a robust platform for grid integration.

A CHB multilevel inverter consists of multiple H-bridge cells connected in series, allowing it to produce a stepped waveform that closely resembles a sinusoidal wave. This approach reduces the need for complex filtering and enables the inverter to operate at lower switching frequencies, minimizing switching losses. Furthermore, CHB inverters offer modularity, allowing for easy scalability by increasing the number of H-bridge cells to accommodate higher power levels [3]. This is particularly valuable in solar applications where the power generated can vary significantly based on sunlight conditions. By adding or removing H-bridge cells as needed, the CHB inverter can be adjusted to meet various power demands without compromising performance.

One of the most significant advantages of CHB inverters in solar PV systems is their ability to handle multiple DC sources independently. Each H-bridge cell within the inverter can be fed by a separate DC source, which is advantageous when working with solar panels. Given the variability of solar power generation, the CHB inverter can balance the output from different solar modules, enhancing the overall system's reliability and efficiency [4]. This flexibility also allows for easier integration with energy storage systems, enabling the CHB inverter to store excess energy and manage power fluctuations effectively.

Despite these advantages, the use of CHB inverters in solar applications presents several challenges, including the management of harmonics, thermal stability, and the complexity of control strategies [5]. Harmonics, for example, are a significant concern in power systems, as they can lead to overheating, interference with communication signals, and reduced equipment lifespan. In CHB inverters, harmonics are typically managed through various modulation techniques, such as sinusoidal pulse-width modulation (SPWM), selective harmonic elimination (SHE), and space vector modulation (SVM). Each technique has its benefits and limitations, and the choice of modulation strategy can significantly impact the inverter's performance and efficiency [6].

Control strategies for CHB inverters are another critical area of research, as they directly affect the inverter's ability to respond to changes in solar power generation and load demands. Advanced control methods, such as model predictive control (MPC) and neural network-based controllers, have been explored to improve the inverter's dynamic response and ensure stable operation under varying conditions [7]. However, these approaches require sophisticated algorithms and high computational power, which can be challenging to implement in real-time systems.

Thermal management is also a crucial aspect to consider in CHB inverters, especially in solar applications where the inverter may be exposed to high temperatures and harsh environmental conditions [8]. Effective cooling solutions and thermal management strategies are necessary to prevent overheating and ensure the longevity of the inverter components. The design of the inverter housing, the choice of materials, and the layout of the H-bridge cells all play a role in optimizing thermal performance [9].

Recent advancements in CHB inverter technology have focused on improving efficiency, reducing cost, and enhancing reliability. For instance, the development of new semiconductor materials, such as silicon carbide (SiC) and gallium nitride (GaN), has enabled CHB inverters to operate at higher voltages and temperatures, resulting in lower losses and greater efficiency. Additionally, innovations in inverter topology, such as hybrid CHB inverters that combine different types of power converters, have shown promise in optimizing performance for solar applications [10].

II. LITERATURE SURVEY

C. Buccella et al., [1] presented l -level cascaded H-bridge (CHB) inverters and proposes a new modulation method based on pulse active width modulation (PAWM), capable to minimize all harmonics with order $n<2l+1$ and to satisfy the European harmonic standards for medium-voltage-level applications EN 50 160 and CIGRE WG 36-05. A mathematical theorem and its proof are presented, stating the features of the procedure, which is an improvement of the selective harmonic elimination (SHE) PAWM.

C. Boonmee et al.,[2] established a novel control approach for two-cell cascaded H-bridge multilevel inverter grid-connected solar systems in this study. The purpose of this work was to enhance the performance of the system by developing the new control technique from conventional control techniques. This was done by monitoring the maximum power point injecting into the grid and preserving the unity power factor even when a solar string had little power. Both of these tasks were challenging, but they were ultimately successful. In addition, conventional methods of control were used as a foundation for the creation of this innovative method of control.

M. B. Satti et al., [3] It is stated here that a direct model predictive control (DMPC) has been developed for a unique H-Bridge multilevel inverter topology-based grid-connected photovoltaic system (GCPS). The DMPC offers various benefits over the usual control approaches, including optimality, the capacity to handle several control objectives at once, and the direct manipulation of semiconductor switches rather than the modulator. The primary control objectives of the GCPS are to derive the greatest amount of power from the photovoltaic (PV) system and to inject that power into the grid in a manner that causes the least amount of total harmonic distortion (THD) or comes as near as possible to achieving unity power factor.

T. Bertin et al., [4] Due to its modular multilevel structure, the solar Cascaded H-Bridge Multilevel Inverter (CHBMLI) is regarded in the photovoltaic (PV) area as an intriguing contender for a grid-tied converter. The elimination of passive components, flexibility, and local Maximum Power Point Tracking (MPPT), which guarantee maximum energy extraction, are this topology's key benefits. Nevertheless, demonstration units often run at low frequencies (less than 5 kHz) with a small number of PV panels because of the complexity of multi-level systems (between 3 and 5). In order to enhance the switching frequency (20 kHz) and the quantity of PV panels employed, this study suggests using distributed real-time hardware architecture with a comprehensive control system (up to 20). The hardware design is built on a fieldbus for real-time communication between a master controller and local controllers that are linked to each PV panel through a common insulated data bus. Modularity and scalability are benefits that this distributed system offers. To guarantee the independent management of each DC (Direct Current) voltage and the output grid current, an adjusted control system is proposed. Results from the experiments show that using 6 modules to achieve a 20 kHz frequency is possible using the given design.

S. Boontua et al., [5] For managing real power and reactive power (PQ) of a single-phase five-level H-bridge multilevel inverter for a PV grid-connected system (FHB-MLI for PVGCS) under poor irradiation conditions, the P&O MPPT control approach is utilized in this study. In this system, the maximum power is maintained for each module by using the maximum power point tracking (MPPT) method of Perturb and Observe (P&O). During uneven power irradiation from each PV, the suggested controller controls the actual dc-link voltage independently of one another and varies real power and reactive power with grid-current magnitude and power angle. A promising experiment and simulation utilizing the MATLAB/SIMULINK tool are used to validate the suggested technique. Results from simulations using a configuration of two PV modules, real power and reactive power processing under weak irradiation conditions, show that the overall system can function satisfactorily even under circumstances where the modules' irradiation varies while still injecting the maximum amount of power into the grid.

M. T. Islam et al., [6] A multilayer inverter is essential for converting dc electricity from various renewable energy sources into ac power. Many different strategies may be tested on an existing multilayer inverter in order to increase its effectiveness. The output voltage of the power inverter exhibits total harmonic distortion due to the modulation algorithm, modulation frequency, voltage drops between the switches, and modulation of the dc bus voltage, which causes overheating of devices and shortens their lifespan. The output voltage quality and total harmonic distortion are improved in this study with the help of a level-shifted pulse width modulation approach. In order to compare this innovative control strategy to the more traditional level-shifted pulse width modulation (LSPWM) with Phase Opposition Disposition (LSPWM-POD) approach, it is applied to an eleven-level conventional cascaded H-bridge multilevel inverter. The performance of the suggested LSPWM has been simulated for verification, and it was discovered that there are two optimum locations where the approach works well.

N. Mukundan et al. [7] for use in photovoltaic power conversion systems (PPCS) systems that are linked to distribution grids. At more levels, the power quality becomes better, and it's possible to achieve balanced active power sharing across the sources. The power flow is accomplished in both directions. By controlling the DC-DC converter using an incremental conductance (IC) method, the two-stage SPVS draws the most power possible from the solar panels. Together with the active power penetration into the grid, the system is developed with multi-functional goals including reactive power support and load harmonic reduction. With the MATLAB/Simulink platform, the system is modelled and simulated. A laboratory prototype is created, and test results are generated for result validation.

X. Pan et al.,[8] For large-scale photovoltaic (PV) systems, one of the most appropriate topologies is the cascaded H-bridge (CHB) multilevel inverter. Yet, when solar irradiation is unequal, a power mismatch issue is likely to occur. Voltage control is the main focus of current efforts to eliminate power mismatches, however this approach is inadequate for situations when there is a significant power imbalance. In order to solve this issue, a parallel control technique that eliminates power mismatch through power sharing across inverters is presented in this study. The power mismatch elimination approach can handle the majority of imbalance scenarios without voltage over modulation because it switches from circulating current management to voltage regulation. The efficiency of the suggested technique was verified by the simulation results.

B. Sharma et al., [9] In order to address the issue of different temperatures and irradiations that lead to partial shading and panel mismatch conditions in large-scale photovoltaic (PV) generation, this study presents a control scheme for a grid-connected cascaded H-bridge multilevel inverter (CHBMLI) based solar energy conversion system (SECS). Along with being practical in high-voltage systems, the main benefit of isolated dc connections in CHBMLI is sacrificed when used as a pulse-width modulated (PWM) converter to control uneven dc sources or loads because of changing power output or consumption, respectively. When SECS experiences the aforementioned power generation mismatch situations, the suggested control strategy has the capability of balancing the dc-link capacitors in each H-bridge cell of the CHBMLI used for this system. The proposed system is monitored and maintained in accordance with criteria for maximum and efficient energy conversion, grid-side voltage, and injected current quality. The mathematical model of CHBMLI as the PWM converter used for this application has also been defined by the modeling study of the converter. MATLAB simulation was used to analyze the system's performance, and the dSPACE-1104 was used to verify the results experimentally on a prototype model.

K. Wang et al.,[10] Large-scale grid-connected solar systems are a viable application for cascaded H-bridge (CHB) multilevel converters (megawatt to gigawatt). Unfortunately, the inter-module and inter-phase power balance cannot be guaranteed by the typical CHB multilevel converter, leading to unbalanced grid currents. Hence, a novel architecture with three-port DC-DC isolation converters based on interleaved-boost full-bridge LLC (IB-FBLLC) and CHB multilevel converters is suggested in this study. The inherent power imbalance problems may be totally resolved in this suggested topology by using a common dc bus made up of the low-voltage-side ports of three-port dc-dc converters based on the IB-FBLLC architecture. Also, a thorough discussion of the dc-dc converter design parameters is provided, taking into account the minimizing of input current ripple and optimization of switching frequency range. The efficacy and viability of the suggested topology and control techniques are amply supported by simulation results for the three-phase system and experimental findings for the single-phase system.

III. CHALLENGES

The use of Cascaded H-Bridge (CHB) multilevel inverters in solar applications, while beneficial, presents several challenges that must be addressed to optimize efficiency, reliability, and cost-effectiveness. Here are some of the primary challenges:

1. Harmonics and Power Quality

- **Challenge**: Harmonics are a common issue in multilevel inverters and can affect the quality of the output waveform, potentially leading to overheating, interference with nearby electronic equipment, and increased power losses. These effects can reduce the lifespan of connected equipment and degrade system performance.
- **Solution Approaches**: Harmonics can be managed through various modulation strategies, such as selective harmonic elimination (SHE) and space vector modulation (SVM). However, implementing these methods in real-time can require significant computational resources and may increase system complexity.

2. Control Complexity

- **Challenge**: The CHB inverter architecture requires sophisticated control strategies to manage multiple H-bridge cells and ensure stable operation under fluctuating solar generation. Traditional control methods may struggle to respond effectively to rapid changes in sunlight intensity and load demands, especially in grid-tied applications.
- **Solution Approaches**: Advanced control methods, like model predictive control (MPC) and artificial intelligence (AI)-based control, offer improved response times and adaptability. However, these approaches demand high processing power and can complicate system implementation and maintenance.

3. Thermal Management

- **Challenge**: In solar applications, inverters are often exposed to high temperatures and variable environmental conditions. The heat generated by multiple H-bridge cells can accumulate, causing thermal stress, affecting efficiency, and potentially leading to system failure if not managed well.
- **Solution Approaches**: Effective thermal management requires careful design of heat sinks, optimized layouts, and possibly liquid cooling systems. Although such methods can extend component lifespan, they add to the cost and complexity of the system.

4. Cost and Complexity of Modularity

- **Challenge**: While the modular structure of CHB inverters offers scalability, it also increases the number of components required, which can elevate manufacturing, installation, and maintenance costs. Additionally, each H-bridge cell needs its own DC source, which could be multiple solar modules or energy storage units, adding further complexity.
- **Solution Approaches**: Research into hybrid topologies and optimized designs aims to balance the modularity benefits with cost reduction. Standardizing components and incorporating higher-efficiency materials like silicon carbide (SiC) can also help manage costs.

5. Reliability and Fault Tolerance

- **Challenge**: With a large number of components, CHB inverters face a higher risk of faults, which can lead to disruptions in the power output. In solar systems, where continuous operation is ideal, even brief downtimes can significantly affect energy production and overall system profitability.
- **Solution Approaches**: Implementing fault-tolerant designs, redundancy, and real-time monitoring can enhance reliability but add complexity. Research into self-healing topologies and predictive maintenance could mitigate these challenges in the future.

IV. TOPOLOGIES WITH H-BRIDGE

MLDCL inverter with two input DC source is shown in Fig. 1. It consists of ‘n’ cascaded half-bridge units; each has a single dc source with two series switches. These cascaded units are considered the "level generation" part of the inverter which produces a stepped dc voltage waveform. The H-Bridge is used to change the output voltage polarity to generate a complete multi level ac waveform. Compared to the traditional MLIs, the MLDCL Contains less number of switches for the same output voltage Levels.

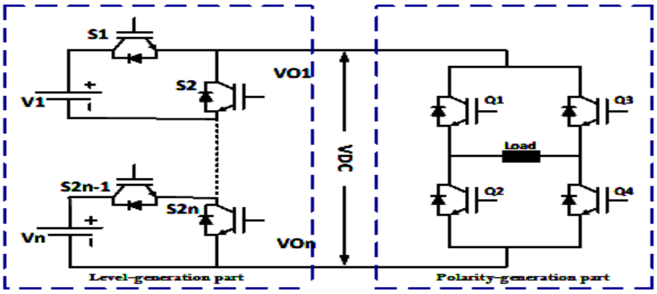

Figure 1: Circuit configuration of the MLDCL inverter

The advantage of this topology is that it operates with asymmetric source configuration. One application area in the low-power range (< 100 kW) is the permanent-magnet (PM) motor drives. A fast-switching semiconductor can be deployed for the leveler scheme such as Metal Oxide Semi-Conductor Field Effect Transistor (MOSFETs) while the polarity generation part can use Insulated-Gate Bipolar Transistor (IGBTs).

V. CONCLUSION

Cascaded H-Bridge (CHB) multilevel inverters hold significant potential for enhancing the efficiency, scalability, and reliability of solar power systems. Their modular architecture and ability to produce high-quality power output make them ideal for renewable energy applications, despite challenges in harmonic mitigation, control complexity, thermal management, and cost. Continued research into advanced control methods, semiconductor materials, and hybrid topologies will be essential to address these challenges and unlock the full potential of CHB inverters for solar applications. As these technologies evolve, CHB multilevel inverters are likely to play a vital role in advancing sustainable energy solutions and supporting the global transition to clean, renewable energy sources.

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