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CRISSCROSS-SWITCHED MULTILEVEL INVERTER USING CASCADED SEMI-HALF-BRIDGE ARCHITECTURE

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ABSTRACT: This research presents a novel multilevel inverter (MLI) architecture that utilizes a crisscross switching structure with semi-half-bridge cascaded cells. This layout optimizes the power components, reduces switching losses, and boosts the quality of the output waveform. By linking semi-half-bridge units in a flexible manner, this design reduces the amount of active switches and DC sources needed by conventional cascaded H-bridge inverters. The power quality is improved by crisscross switching because it lowers harmonic distortion in the output voltage and changes the voltage levels across cells. In addition to lowering EMI, this approach simplifies the use of gate drivers. We model and simulate the system with MATLAB/Simulink and do a Total Harmonic Distortion (THD) study to ensure the proposed method works. Medium to high power applications, such as electric propulsion, smart grid integration, and renewable energy systems, are well-suited to the architecture.

Keywords: Multilevel inverter (MLI), crisscross switching, semi-half-bridge cells, cascaded inverter, harmonic reduction, THD minimization.

1. INTRODUCTION

Due to their superior efficiency, less electromagnetic interference, and compatibility with harmonics, multilevel inverters (MLIs) have emerged as a crucial technology for medium- to high-power applications. The two most prevalent kinds of multilevel architectures are rising capacitor inverters and clashed H-bridges. However, due to the requirement for numerous power switches and independent DC sources, the system is typically more intricate and costly. Currently, researchers are exploring alternative inverter topologies that have fewer switches and simpler circuitry as potential solutions to these issues. Cascaded cells with semi-half bridges are one kind of such design. They reduced component overhead without sacrificing product quality.

The efficiency of inverters is greatly enhanced by combining crossing switching with semi-half-bridge cascaded cells. A form of control known as crisscross switching allows for the ordered and non-linear activation of switching pairs. This paves the way for more uniform power distribution and greater voltage levels. By further reducing total harmonic distortion (THD) in the output voltage pattern, this approach improves power quality without increasing the number of switches. Along with simplifying the hardware architecture, the semi-half-bridge cells retain the advantages of being able to grow and change. This state-of-the-art inverter design is ideal for electric vehicle (EV) operations, renewable energy systems, and grid-connected applications that prioritize speed and cost-effectiveness. An emerging need in modern energy networks for compact, dependable, and efficient power conversion systems has led to the proposal of a crisscross-switched semi-half-bridge cascaded multilevel inverter. It achieves this by deftly balancing complexity with speed.

2. LITERATURE SURVEY

Mehta, V., & Ranjan, A. (2024). Improved voltage level production is achieved in this study through the deployment of a novel multilevel inverter (MLI) design utilizing crisscross switching and semi-half-bridge cascaded cells. In addition to improving the system's reliability, the proposed crisscross switching method reduces heat problems by allowing each switch to share conduction and switching losses more equitably. Compared to conventional H-bridge cascaded MLIs, this design makes less usage of power devices while maintaining a fine-grained voltage output. The writers simulate 5-level and 9-level inverter systems in MATLAB/Simulink. Switching losses are 25% reduced and THD performance is almost 30% better, according to the data. In medium-voltage applications, hardware prototypes demonstrate the system's potential for electric vehicle drive inverters and the integration of renewable energy sources.

Reddy, K., & Sharma, M. (2024). This research introduces a novel crisscross pulse-width modulation (PWM) method developed for non-uniform DC sources. The construction is a multilayer inverter with a semi-bridge design. The modulation technique may manage input voltages that aren't equal while also ensuring that the output voltage level remains constant regardless of the sources. Use of a two-layer control system allows for the fine-tuning of switch timing. Predictive current control and phase disposition pulse width modulation are combined in this system. The results of the seven-level sample test reveal an improvement in electromagnetic compatibility and a decrease in total harmonic distortion (THD) to below 3%. In order to establish a relationship between the quantity of levels and the quantity of switches, the authors developed a generalized design equation. Without over-designing the switch circuits, engineers can improve the system's performance as it increases.

Das, B., & Tiwari, S. (2023). This study develops a comprehensive model and control system for a modular multilevel inverter (MMI) using semi-half-bridge cascaded cells that have been enhanced with a crisscross switching algorithm. For each cell to remain within safe operating temperatures, this technique dynamically reorders switching processes and restricts redundant switching states. Adapting the output to changing loads is made possible via a predictive current control loop. Simulation results demonstrate reduced device stress, more steady current flow, and improved waveform integrity when contrasted with conventional cascaded inverters. Solar inverter and motor control applications that require rapid load adaptation and high-quality wave production are ideal for the proposed construction.

Singh, P., & Zafar, I. (2023). This study proposes a scalable inverter architecture that minimizes common-mode voltage fluctuations through the use of semi-half-bridge submodules and an innovative crossing gating technique. This reduction in common-mode voltage is essential in high-power systems for preventing insulation degradation and leakage currents. The inverter's performance with non-linear loads can be evaluated in a hardware-in-the-loop (HIL) environment. Synced pulse-width modulation (SPWM) is used to control the pulses. Due to its low harmonic production, rapid transient recovery, and ability to withstand grid disturbances, it is optimal for usage in grid-connected green energy systems and industrial motor drives.

Narayanan, S., & Kapoor, L. (2022). This research presents a simpler multilevel inverter layout using asymmetric semi-half-bridge modules with alternating crisscross switching logic. The circuit becomes simpler and the system's cost goes down by reducing the number of gate drivers needed. The alternating crisscross construction restricts the simultaneous occurrence of switching events, and the switching stress is distributed over multiple time periods. The inverter system outperforms the diode-clamped and flying-capacitor alternatives in terms of power loss and harmonic reduction, according to the performance metrics. The architecture is suitable for applications with dynamic loads because it can adjust output levels in response to actual power demands. The reason behind this is that it's modifiable.

Iqbal, M., & Rao, D. (2022). Examining symmetric and asymmetric semi-half-bridge multilevel inverters, the authors zero in on the effects of crisscross switching on power balance and reliability. Test scenarios with fluctuating DC link voltages are simulated to determine its real-world performance. A scaled-down model is constructed. The system settles down more quickly, has less overshoot, and is better able to withstand abrupt changes in step-load, among other important results. Even in small systems with variable DC inputs, such as solar-powered EV charging stations, the study demonstrates that these designs can maintain steady outputs.

Kumar, R., & Yadav, N. (2021). Due to its low cost and little semiconductor component usage, a crisscross-switched multilevel inverter architecture is recommended. In order to maximize efficiency and minimize switch heat, the design incorporates both level-shifted pulse-width modulation (PWM) and sinusoidal pulse-width modulation (SPWM). At various voltage levels, the inverter exhibits negligible harmonic distortion, and the system is operational for over 96% of the time in steady-state investigations. In energy-critical continuous operation, the design excels due to reduced junction temperatures in a comparative thermal simulation.

Saha, D., & Chatterjee, T. (2021). One of the most effective ways to implement load-adaptive switching frequency modulation, according to the authors, is using a crossover-controlled semi-half-bridge inverter. In order to provide optimal thermal behavior and switching loss across a variety of operating conditions, this time-variant switching approach dynamically adjusts the frequency in response to the load's motion. In order to demonstrate the inverter's capability to manage rapid variations in load and input voltage, simulations are employed. The approach is most effective for microgrids and rural electrification systems that draw power intermittently from renewable sources.

Roy, A., & Jain, K. (2020). The research presents a transverse switching logic-based plug-and-play semi-half-bridge multilevel inverter design for standalone power applications. The gate driver is simple, and the layout promotes rapid modular assembly. The authors demonstrate that the system may be extended from three to eleven levels of outputs by employing the identical switching architecture. The units should have an appropriate amount of heat exchange, and consistent voltage steps can be set up, according to practical application. Portable battery inverters, standalone solar pumps, and gadgets that provide power to remote places are some of the featured uses.

Nayak, A., & Bose, M. (2020). Finding the optimal cooling and fabrication method for an asymmetric DC-driven electromagnetic compatibility (EMC) crisscross-switched multilevel inverter is the primary objective of this work. Using computational fluid dynamics (CFD), it verifies the optimal placement of heat sinks, and FEA provides a comprehensive study of the loss. Voltage linearity and overshoot are both improved according to the waveform analysis. According to the findings, the inverter is effective in applications involving high-frequency switching, such as electric vehicle charging and drone motor systems.

3. RELATED WORK

The novel multilayer inverter (MLI) design aims to address the primary issues with conventional inverters, including their complex construction, uneven voltage distribution, and restricted expansion potential. To be more precise, it achieves this by integrating a novel switching technique known as crisscross switching with a practical modular arrangement of semi-half-bridge cascaded cells. The inverter is now more practical and efficient thanks to all of these upgrades.

"A high-quality sinusoidal output"

The generation of an output voltage with characteristics similar to those of a pure sine wave is one of the primary objectives of the system. The smooth operation of linked loads, as well as the reduction of harmonic distortion and electromagnetic interference, are all benefits of a well-designed sinusoidal output. Connected renewable energy systems to the grid or fragile electronics are prime examples of why this is crucial.

"Lower component count"

There are far fewer components, particularly switches and gate drivers, in this MLI design compared to conventional H-bridge or full-bridge inverters. Simplified control logic, lower system cost, and improved performance are all results of reducing the number of parts.

"Flexible voltage level generation"

The layout allows for real-time adjustment of the output voltage levels. The inverter's adaptability allows it to meet the demands of systems with varying loads and voltage levels.

"Reduced stress on switches"

The inverter increases voltage balance and decreases the effect of each switch on current and voltage by crisscross switching between devices. In addition to improving thermal management in general, this reduced electrical stress also increases the lifespan of switching devices.

"Scalability and modularity"

The MLI architecture is quite adaptable, so it's simple to incorporate additional cells to boost the voltage and power output. Renewable energy systems and electric vehicle charging stations, which frequently require expansion in the future, benefit greatly from this degree of adaptability. The design facilitates system updates and basic maintenance.

KEY TERMINOLOGIES

Semi-Half-Bridge Cell

- **"A modified version of the half-bridge."** These semi-half-bridge cells are an improvement above the standard half-bridge cells used in inverters. The purpose of this is to simplify the circuits while allowing them to convert voltages as required.
- **"Contains fewer switches than a full H-bridge."** Compared to a full H-bridge, which typically includes four switches, the half-bridge structure requires just one switch per cell, resulting in reduced space and expense. This spare approach reduces the overall amount of system components.
- **"Typically includes one switch and one diode per voltage source."** A diode and a power switch (often an IGBT or MOSFET) are the components of a semi-half-bridge cell. Each cell is connected to a different DC voltage source. Because of its fundamental form, the cell is able to add voltage in a regulated manner during transition.
- **"Used to reduce the overall number of switches while maintaining control over voltage level contributions."** The number of components in semi-half-bridge cells is reduced, but they nevertheless manage to control the output voltage well. As a result, the inverter may maintain precise control over the output waveform with minimal hardware.
- **Crisscross Switching**
- **"A strategic arrangement where switches form a crisscross (X) path between the voltage sources and load."** Having the switches arranged in a "X" pattern is known as crossing switching. More flexible connection lines between the voltage sources and the output are made feasible by this configuration. The voltage waveform becomes more efficient as a result.
- **"Ensures voltage balancing across switches."** Voltage stresses might be distributed uniformly across all switches in this configuration according to the design. By reducing the likelihood of a device breaking due to an excess of voltage, this balancing mechanism ensures that all cells function in the same manner.

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- **"Allows selective connection of voltage sources in the output path for better waveform shaping."** Crisscross switching allows the control system to activate various cell voltage levels. This chosen activation enhances the output quality by producing a stepped waveform that mimics a sinusoidal signal.
- **Cascaded Cells**
- **"Multiple semi-half-bridge cells are connected in series."** This design is comprised of a network of connections between semi-half-bridge cells. The voltage values are increased by connecting each cell in series to form a module.
- **"Each cell contributes part of the output voltage."** Each cell contributes a fraction of the total power required, rather than relying on a single source to produce the entire output. The output waveform exhibits lower voltage steps as a result of this contribution split.
- **"Enables higher voltage levels without increasing source voltage."** The inverter can increase the output voltages while maintaining the individual source voltages constant by stacking more cascaded cells on top of each other. You can still utilize low-voltage sources in high-voltage applications; this makes them more efficient and safer.

4.RESULTS

To assess the proposed layouts, we employ MATLAB/SIMULINK R2013b. The simulation parameters: (Va1 = Va2 = Vb1 = Vb2 = 75 V) under symmetrical mode (Va1 = 42 V; Va2 = Vb1 = Vb2 = 86 V) under asymmetrical mode for the basic topology seen in Fig. 1b (Va1,1 = Va2,1 = Va3,1 = Va1,2 = Va2,2 = Va3,2 = 50 V) for extended topology depicted in Fig. 3 under symmetrical mode and also for the same seen in Fig. 3 (Va1,1 = 30 V, Va2,1 = Va3,1 = 60 V, Va1,2 = 30 V, Va2,2 = Va3,2 = 60 V) under asymmetrical mode. The 2 kHz switching frequency is obtained using the multicarrier PD-PWM approach. To ensure the accuracy of the projected response in Figure 1a for various modulation indices and loads when all factors were included, a simulation analysis was conducted. For two distinct forms of coercion, Figure 1a is prepared to display a nine-level outcome. You may observe the patterns of voltage, current, and harmonics with a large inductive load (R = 150 ©, L = 100 mH) using Image 6. A sine wave representing the load current is displayed in Figure 6b. Pulse generation is accomplished by utilizing voltage string switches and pulse swaps. Create an identical second circuit to the first. The second load should have R = 165 Ω and L = 20 mH. Despite the cyclical nature of the output pattern, pulse switching guarantees a constant current flow to each source. This ensures that the four processes are executed methodically. To ensure the load is distributed appropriately, each source adjusts its input according to the levels of the output voltage, as seen in Figure 7. Figure 8a shows the switching from a voltage pattern and total harmonic distortion (THD) to pulse width modulation (PWM). Figure 6a, which was created without PWM, and the two photos are identical but for that. The equitable distribution of power among all groups is illustrated in Table 5. Table 6 shows the results of running two identical circuit design models with different modulation indices (0.4 and 0.6) to determine the voltage THD. According to Table 6, the output voltage values decrease with decreasing modulation indices. Furthermore, this exacerbates the distortion at the barrier. After modeling the design's asymmetrical mode in Fig. 1b using a binary voltage ratio and the switching order in Table 4, the 15-level THD output voltage is displayed in Table 6. An improved depiction of the intended structure can be seen in Figure 3. At k=2, the output voltage and spectrum of this configuration are symmetrical (13 levels) and unequal (21 levels). Just look at Figure 9.

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Table 5 Power delivered by each source

Output power	Input power delivered by sources based on the PWM without circulation				Input power delivered by sources based on the PWM with circulation			
	V_{a1}	V_{a2}	V_{b1}	V_{b2}	V_{a1}	V_{a2}	V_{b1}	V_{b2}
271 W	86.02 W	80.77 W	67.77 W	40.684 W	68.81 W	68.81 W	68.81 W	68.81 W

Table 6 Proposed topology under different operating modes

MLI structure	Ratio of source voltage magnitudes	m_i	Voltage THD Magnitude (% of fundamental)	No. of voltage levels at the output, m
proposed topology	1:1	1	13.44	9
	1:1	0.6	24.21	7
	1:1	0.4	38.6	5
	1:2	1	7.8	15
extended topology	1:1	1	8.57	13
	1:2	1	5.67	21

5. CONCLUSION

Lastly, a unique and highly effective approach to developing sophisticated power conversion systems is the multilevel inverter design, which employs crisscross switching and semi-half-bridge cascaded cells. Renewable energy integration, smart grid technologies, and electric vehicle charging stations are just a few examples of the demanding uses that benefit greatly from this design's emphasis on efficiency, compactness, and dependability.

Improved performance and longer life for linked loads are the results of multilevel inverter design's ability to produce high-quality output voltage with minimal total harmonic distortion (THD). By ensuring a uniform voltage distribution across all cells, the crisscross switching technique further enhances operating performance. This result in improved voltage balance, reduced switching stress, and significantly reduced component failure due to excessive heat or electricity.

Furthermore, the circuit can be simplified without sacrificing the necessary voltage levels or pulse quality by employing semi-half-bridge cascaded cells. Along with improving the control mechanism and reducing the number of power electronic switches needed, this simplifies the structure, making the system more versatile and expandable in the long run. Alterations to the voltage and power levels are possible; however they can be easily implemented into the design without requiring extensive overhauls.

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