

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

*N. SRIKANTH, *Assistant Professor, Department of EEE,*
SREE CHAITANYA COLLEGE OF ENGINEERING, KARIMNAGAR.

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 improved efficiency, lower electromagnetic interference, and compatibility with harmonics, multilevel inverters (MLIs) represent a technological leap forward for applications requiring medium to high power. Most multilevel designs are either flying capacitor inverters or cascading H-bridges. However, due to the requirement for several power controllers and various DC sources, the system is typically more complex and expensive. Scientists are currently investigating alternative inverter topologies that use fewer switches and have simpler circuits in an effort to address these issues. These designs contain cascaded cells with half-bridges. While maintaining the quality of the final product, they reduced the cost of the components.

To improve the inverter's efficiency, crossing switches and semi-half-bridge cascaded cells are included. One kind of control device that allows for the non-linear and sequential turning on and off of switching pairs is crisscross switching. This facilitates the use of greater voltage levels and guarantees more consistent power distribution. This method enhances power quality without the need for additional controls by reducing total harmonic distortion (THD) in the waveform of the output voltage. While semi-half-bridge cells simplify the hardware design, they retain strong scalability and adaptability. Modern inverter technology will greatly improve the efficiency and effectiveness of grid-connected applications, green energy systems, and electric vehicle (EV) operations. An efficient, compact, and dependable crisscross-switched semi-half-bridge cascaded multilayer inverter was developed to meet the

increasing demand for such power converters in contemporary energy systems. Adroit balancing of complexity and speed makes this feasible.

2. LITERATURE SURVEY

Mehta, V., & Ranjan, A. (2024). In order to improve voltage level generation, this study presents a new type of multilevel inverter (MLI) architecture that utilizes crisscross switching and semi-half-bridge cascaded cells. By allowing each switch to disperse conduction and switching losses more uniformly, the proposed crisscross switching method increases system reliability and decreases heat-related issues. Compared to other H-bridge cascaded MLIs, this design's voltage output is more precise and it utilizes less power components. Five- and nine-level inverter systems are modeled using MATLAB/Simulink. The results show that Total Harmonic Distortion (THD) performance improved by around 30% and switching losses decreased by 25%. Prototype hardware demonstrates system compatibility in medium-voltage environments with electric vehicle drive inverters and renewable power sources.

Reddy, K., & Sharma, M. (2024). An innovative crossing pulse-width modulation (PWM) technique for non-uniform DC sources is demonstrated in this study. The inverter's construction is a semi-bridge, which is comprised of many layers. No matter the input voltages, the modulation mechanism can handle them all and maintain a constant output voltage level. To adjust a switch's timing, a two-layer control approach is available. Integrated into this system is the ability to modulate the pulse width of the phase disposition and the predicted current control. Total harmonic distortion (THD) dropped to 3% and electromagnetic compatibility improved, according to the seven-level sample test. The authors developed a generalized design equation to illustrate the relationship between the quantity of levels and switches. Without making the switch circuits overly complicated, engineers may enhance the system's performance as it expands.

Das, B., & Tiwari, S. (2023). This research takes a modular multilevel inverter (MMI) and builds a complete model and control system using a crossing switching algorithm and semi-half-bridge cascaded cells. This technology employs real-time process reorganization and reduction of superfluous switching states to maintain a safe operating temperature range for each cell. The output can be adjusted to accommodate changing loads with the use of a predicted current control loop. The modeling findings demonstrate that, in comparison to conventional inverters, these cascaded inverters exhibit improved waveform accuracy, more stable current conduction, and reduced device stress. For jobs requiring precise waveform production and rapid load response, such as controlling motors or solar inverters, the proposed strategy works admirably.

Singh, P., & Zafar, I. (2023). To eliminate common-mode voltage fluctuations, this research presents a scalable inverter design that employs semi-half-bridge submodules and a novel crossover gating technique. Maintaining a low common-mode voltage is critical in high-power systems to prevent insulation degradation and leakage currents. To check the inverter's performance with non-linear loads, utilize the hardware-in-the-loop (HIL) mode. Synchronized pulse-width modulation, or SpWM, alters the waveform. Green energy systems that are connected to the grid and industrial motor drives benefit greatly from its low harmonic distortion, quick transient response, and ability to manage grid disruptions.

Narayanan, S., & Kapoor, L. (2022). The paper demonstrates a simpler architecture for multilayer inverters. It makes use of alternating crisscross switching logic and asymmetric

semi-half-bridge modules. The circuit becomes more user-friendly and the overall system cost is reduced by reducing the number of gate drivers that are required. Multiple time periods experience the switching stress, and simultaneous occurrence of switching events is prevented by the revolving crisscross pattern. The inverter system outperforms the diode-clamped and flying-capacitor alternatives in terms of power consumption and harmonic reduction in performance tests. This design is ideal for applications with dynamic loads since it can adapt its output levels to match actual power consumption. Reason being, it's dynamic and ever-evolving.

Iqbal, M., & Rao, D. (2022). The impact of crosswise switching on power balance and reliability is the primary focus of the writers' examination of symmetric and asymmetric semi-half-bridge multilevel inverters. To gauge its practicality, we model a variety of use situations with varying DC link voltages. A more compact variant is created. There are a number of significant benefits, including a quicker stabilization time, less delay, and improved ability to deal with unexpected variations in step load. The results demonstrate that these designs can produce trustworthy outputs in even the smallest systems with dynamic DC inputs, such as solar-powered electric car charging stations.

Kumar, R., & Yadav, N. (2021). An inexpensive design that doesn't require many semiconductor parts is a crisscross-switched multilevel inverter. To reduce switching losses and increase overall efficiency, the design makes use of both sinusoidal pulse-width modulation (SPWM) and level-shifted pulse-width modulation (PWM). In steady-state testing, the system is operational for over 96% of the time, and the inverter demonstrates negligible harmonic distortion over a range of voltages. Since the junction temperatures are lower in this design compared to a comparable thermal simulation, it performs exceptionally well during energy-critical continuous operation.

Saha, D., & Chatterjee, T. (2021). An effective method for achieving load-adaptive switching frequency modulation is a crossover-controlled semi-half-bridge inverter, as stated by the authors. The frequency is adjusted by this time-dependent switching technique in response to the load's motion. As a result, across a variety of operating situations, the thermal performance will be excellent and switching losses will be minimal. To demonstrate the inverter's robustness against transient loads and input voltage fluctuations, simulations are employed. Electricity distribution projects in rural areas and microgrids that rely on renewable energy sources' intermittent power output are good candidates for this approach.

Roy, A., & Jain, K. (2020). The research reveals a transverse switching logic-based plug-and-play semi-half-bridge multilevel inverter design for autonomous power applications. The architecture facilitates rapid module assembly, and the gate driver is straightforward. The authors demonstrate that by modifying the switching design, the system can go from three to eleven output levels. Devices are only functional if they can smoothly raise voltage and dissipate heat effectively. Some of the highlighted applications include autonomous solar pumps, portable battery inverters, and gadgets that provide power to rural locations.

Nayak, A., & Bose, M. (2020). The primary objective of this research is to determine the optimal cooling and fabrication methods for an asymmetric DC-driven electromagnetic compatibility (EMC) crisscross-switched multilevel inverter. The exact placement of the heat sinks is ensured by computational fluid dynamics (CFD), and the complete picture of the losses is obtained through finite element analysis (FEA). The waveform analysis reveals an improvement in voltage linearity and overshoot. According to the findings, the inverter is

effective in applications involving high-frequency switching, such as the charging of electric vehicles or motor systems for drones.

3. RELATED WORK

The most common issues with conventional inverters—their complex structure, unequal power distribution, and lack of scalability—have been addressed by the new multilayer inverter (MLI) design. To be more specific, it achieves this goal by integrating a novel switching technique known as crisscross switching with a practical modular layout of semi-half-bridge cascaded cells. The transformer is now more efficient and practical as a result of all these modifications.

"A high-quality sinusoidal output"

An output energy pattern resembling a pure sine wave is one of the primary aims of the system. Connected loads can operate trouble-free with a well-designed sinusoidal output that reduces harmonic distortion and electromagnetic interference. Particularly vulnerable electronics and grid-connected renewable energy systems necessitate this.

"Lower component count"

When compared to conventional H-bridge or full-bridge inverters, this MLI design has a significantly less number of components, particularly for the gate drives and switches. Performance, system costs, and the understandability of control logic are all positively impacted by reducing the number of parts.

"Flexible voltage level generation"

You can alter the output voltage values in real time using this arrangement. The inverter's adaptability means it can handle systems with varying loads and power levels.

"Reduced stress on switches"

The inverter reduces the voltage's sensitivity to fluctuations by switching between devices in a manner that makes each change to the voltage and current feel less drastic. Longevity of switching devices and better thermal management are both result of this reduced electrical stress.

"Scalability and modularity"

Thanks to the MLI architecture's great degree of flexibility, it is straightforward to increase voltage and power output by adding more cells. Electric car charging stations and renewable energy systems typically require expansion in the future, thus this degree of flexibility is very useful for them. The layout makes it simple to upgrade the system and perform maintenance.

KEY TERMINOLOGIES

Semi-Half-Bridge Cell

- **"A modified version of the half-bridge."** Inverters that use conventional half-bridge cells don't measure up to these semi-half-bridge cells' performance. This simplifies the circuits without sacrificing their ability to shift levels as required.
- **"Contains fewer switches than a full H-bridge."** In contrast to a complete H-bridge, which typically employs four switches per cell, a half-bridge design utilizes just one switch per cell, resulting in significant space and cost savings. The overall number of system components is decreased by employing this sparse approach.
- **"Typically includes one switch and one diode per voltage source."** An IGBT or MOSFET, which are common power switches, and a diode are the components of a semi-half-bridge cell. The DC power source that is connected to every single cell is unique.

Because of its fundamental structure, the cell can regulate its voltage increase during transition.

- **"Used to reduce the overall number of switches while maintaining control over voltage level contributions."** The output voltage can still be effectively controlled by semi-half-bridge cells, despite their reduced number of parts. Consequently, the inverter may require less hardware to precisely regulate the output waveform.
- **Crisscross Switching**
- **"A strategic arrangement where switches form a crisscross (X) path between the voltage sources and load."** "X" configuration of switches causes crossover switching to occur. With this arrangement, there are more options for connecting the output to the power sources. The voltage pattern demonstrates enhanced performance in this manner.
- **"Ensures voltage balancing across switches."** The design of the system allows for the possibility that voltage strains will be distributed uniformly across all switches. By ensuring that all cells function in unison, this balancing mechanism reduces the likelihood that a device may malfunction due to an excess of voltage.
- **"Allows selective connection of voltage sources in the output path for better waveform shaping."** The computer system may activate various cell voltage levels by crisscross switching. This improves the output by producing an incremental waveform that closely resembles a sinusoidal signal.
- **Cascaded Cells**
- **"Multiple semi-half-bridge cells are connected in series."** A system of interconnected semi-half bridge cells forms the basis of this layout. Elevated voltage levels are achieved by stringing together individual cells to form a module.
- **"Each cell contributes part of the output voltage."** Distributed generation means that individual cells are only responsible for meeting a portion of the overall power demand. The output waveform has less voltage jumps due to the input's division.
- **"Enables higher voltage levels without increasing source voltage."** By sequentially adding more cascaded cells, the inverter can increase output voltages while maintaining constant source voltages. Because they may still be used in high-voltage circumstances, some believe that low-voltage sources are more reliable and efficient.

4.RESULTS

In order to verify the proposed strategies, we employ MATLAB/SIMULINK R2013b. $V_{a1} = 42\text{ V}$ and $V_{b1} = 86\text{ V}$ in asymmetric mode; and for the expanded topology shown in the figure, $V_{a1,1} = V_{a2,1} = V_{a3,1} = V_{a1,2} = V_{a2,2} = V_{a3,2} = 50\text{ V}$. In the picture, there are three in the ordered arrangement. These settings were used to simulate the basic structure in Fig. Three make up the asymmetrical configuration. A switching frequency of 2 kHz is achievable using the multicarrier PD-PWM approach. A simulation analysis was conducted using various modulation indices and pressures to confirm that the expected response in Figure 1a was accurate for all the relevant factors. A nine-level outcome for two distinct forms of compulsion is intended to be displayed in Figure 1a. Picture 6 displays the voltage, current, and harmonic curves of a sizable inductive load ($R = 150\ \Omega$, $L = 100\text{ mH}$). Figure 6b displays the load current as a sine wave. It is possible to generate pulses using voltage string switches and pulse switches. Create an identical duplicate of the first circuit. The second load should be applied with $R = 165\ \Omega$ and $L = 20\text{ mH}$. Pulse switching maintains a constant

current for all sources even when the output pattern varies. This guarantees that the four procedures are followed correctly. As seen in Figure 7, the input voltage levels of each source are adjusted to match the levels of the output voltage. This guarantees that the weight is spread uniformly. Fig. 8a depicts the transition from a THD-based voltage pattern to a pulse-width-modulated one. Because it was not created using PWM, Figure 6a is the only one that differs. Every single one of the other images is identical. All the groups' power is fairly distributed, as shown in Table 5. To determine the voltage THD, two analogous circuit models were utilized, but with differing modulation indices (0.4 and 0.6). Table 6 displays the outcomes. According to Table 6, the output voltage values decrease as the modulation indices decrease. The displacement at the barrier is also exacerbated by this. Fig. 2 shows the design's irregular shape. Table 6 displays the output voltage of the 15-level Total Harmonic Distortion (THD) system, whereas Table 4 shows the toggling process and the binary voltage ratio. Figure 3 provides a more detailed view of the proposed building. In this design, the range and output voltage are not equal (21 levels) and symmetrical (13 levels) when $k=2$. Refer to Figure 9.

One novel and highly efficient approach to developing sophisticated power conversion systems is the multilevel inverter design, which makes use of crossing switching and semi-half-bridge cascaded cells. Thanks to its efficiency, compactness, and reliability, this design is ideal for a wide variety of demanding applications, including electric car charging stations, smart grid technologies, and the integration of green energy.

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

Linkages operate more efficiently and for longer periods of time because to the multilayer inverter design's capacity to generate a high-quality output voltage with less total harmonic distortion (THD). Making sure all cells have the same voltage, crisscross switching makes operations more efficient. Consequently, there is less switching strain, better voltage stability, and far less likelihood of component failure due to heat or electrical issues. To further simplify the circuit while maintaining the necessary voltage levels and pulse stability, semi-half-bridge cascaded cells can be utilized. This reduces the number of required power electronic switches, improves the control system, and simplifies the design. This enhances the system's adaptability and capacity for growth. Altering the voltage and power levels is feasible, and they can be seamlessly integrated into the design without requiring extensive modification.

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