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Review Article

A Comprehensive Assessment on Modular Technologies, Multiple Inverters, and the Constraints of Standalone Photovoltaic Systems

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Abstract *- Recently, the use of modular technology, a wide range of inverters, and free-standing Photovoltaic (PV) systems has helped a lot in making MSPV more efficient, reliable, and safe to scale. Many engineers view MMCs as highly appropriate for major PV plants because they can be installed modularly, are galvanically isolated and have separate MPPT. With MMC inverters, both power quality and losses have improved when PV panels are connected to the grid. For a 5-level MMC inverter, the shared triangle saturation shared mode PWM method has both the least voltage THD and the lowest power losses in the inverter of the techniques that have been considered. Surprisingly, although modular technologies can help a lot, they can also cause problems in places with poor electricity connections. It is important to address concerns about stability when solar systems are linked to grids that have low short-circuit strength and inertia. This indicates that high-tech approaches to control and technology should be considered in these systems. PV or photovoltaics, offers one of the best chances to build renewable energy by turning light directly into electricity on the atomic level. Consequently, PV systems must be improved, taking into account the major role of this renewable power.*

Keywords *- Modularity technologies, Solar photovoltaic cells, Multilevel inverters, Power quality, Stability issues.*

1. Introduction

PV systems are adopting RDC MLIs more often, since they improve power quality, make systems more efficient and lead to fewer components and lower costs. Thanks to its high flexibility, reduced harmonics and good output voltage shape, this topology is increasingly popular in medium voltage and high-power applications. It is possible that coupling SC-based converters with DC-AC converters offers a smaller best, improved efficiency and has only ideal switching parts [1]. We should also point out that some RDC MLI layouts allow an increased output voltage, something useful for different applications. A boost-type MLI that uses a switched-capacitor will produce a 7-level output with a DC input/PV connection, giving three times as much AC load current. There is another option: have n sections repeated with level boosting, and the user can get 4n + 7 voltage levels where 2n + 3 are not enough. Overall, the main benefits of using MLIs in photovoltaic systems are: improved quality of electricity output, using fewer electronic components and greater efficiency [2]. Efforts in this research continue with the aim of achieving enhanced performance by using fewer switches, alleviating stress to electrical components and boosting voltage gain. Because of these changes, RDC MLIs may be easier to implement with renewable energy in the future, helping smaller, cheaper and more effective PV systems [3]. The main reasons for recent trends in multilayer inverters in photovoltaic systems are to increase power quality, reduce the number of required components and make them more efficient [4-6]. MLIs have recently evolved by using fewer devices, adding battery systems and developing advanced control strategies like model predictive control. Such improvements aim to make the system perform better and more efficiently at reduced costs and improved power quality [6]. Using high-power capacitors in PV systems has led to promising results for better energy storage and improved function [7, 8]. Research on made-in-Latin-America solutions that work well and are economical will be a key topic with the increase in worldwide PV installations. The potential of emerging modular technologies and how they may influence the photovoltaic industry has not been fully exploited. Theoretical literature tends to simplify the relationships between several inverters in one system, and it may cause confusion regarding the effectiveness and stability of the system. The actual limitations of a standalone photovoltaic system, e.g. weather conditions, maintenance problems, geographical limitations, etc., are scarcely researched. More complex interactions between two or more inverters in a single system can be explored in future studies, and more sophisticated predictive models can be developed. These results indicate that, though there has been extensive research on modular technologies, multiple inverters, and standalone photovoltaic systems, numerous gaps remain in our knowledge, especially in terms of methodology, theory, and practice. These gaps still require more research to fill so that we can improve our understanding in these areas.

1.1. Significant Benefits Associated with MV Multilevel Converters

In medium-to-high voltage applications, such as High-Voltage Direct Current (HVDC) transmission, MMCs are a new kind of power electronic converter. Enhanced dependability, reduced harmonic distortion, and power conversion efficiency are just a few of the factors that have made this sophisticated voltage source converter so popular [9, 10].

The following is a summary of an MMC's fundamental functions:

- The basic building blocks are called sub-modules, sometimes referred to as "arms" or "cells." Capacitors and power semiconductor devices (switches) are found in each sub-module. The converter's capacity to generate voltage levels is determined by the total number of sub-modules.
- Series connection: These submodules are linked in series to achieve the appropriate output voltage level. It is interesting to note that each sub-module has a voltage rating that is lower than the overall output voltage, improving voltage management and efficiency.
- Voltage synthesis: By regulating the switches in the submodules, the converter may generate varied voltage values between both the positive and negative connections, resulting in the ideal voltage output waveform.
- The control system uses Pulse Width Modulation (PWM) techniques to govern the switching of power semiconductor devices. In order to regulate the amplitude of every voltage level and appropriately shape the output voltage waveform, it modifies the period of the duty cycle of the PWM signals.
- Capacitor voltage balancing: Variations in loads or switching activities can cause voltage imbalances in capacitors while in operation. The control system keeps an eye on the capacitor voltages and makes any required adjustments to ensure stability and appropriate voltage distribution.
- Synchronization and Control: A complex control system is required to efficiently manage the MMC. It continuously checks factors such as output voltage, current, and capacitor voltage to ensure smooth and efficient performance. To maintain the necessary waveform integrity in multi-module MMCs, sub-module synchronization is required.

1.2. Traditional Multilevel Inverters

Compared to conventional two-level inverters, Multi-Level Inverters (MLIs) exhibit better harmonic performance and significantly higher power ratings, making them more attractive for high power and high voltage applications [11]. These inverters can output almost sinusoidal wave form voltage and switch once per fundamental period, dispensing with transformers in multipoles inverters for conventional utility interconnections and static var compensators. They also have more components, more switches and complicated gate pulse generation, all of which can lead to poorer efficiencies and higher costs (See Figure 1 and Table 1)

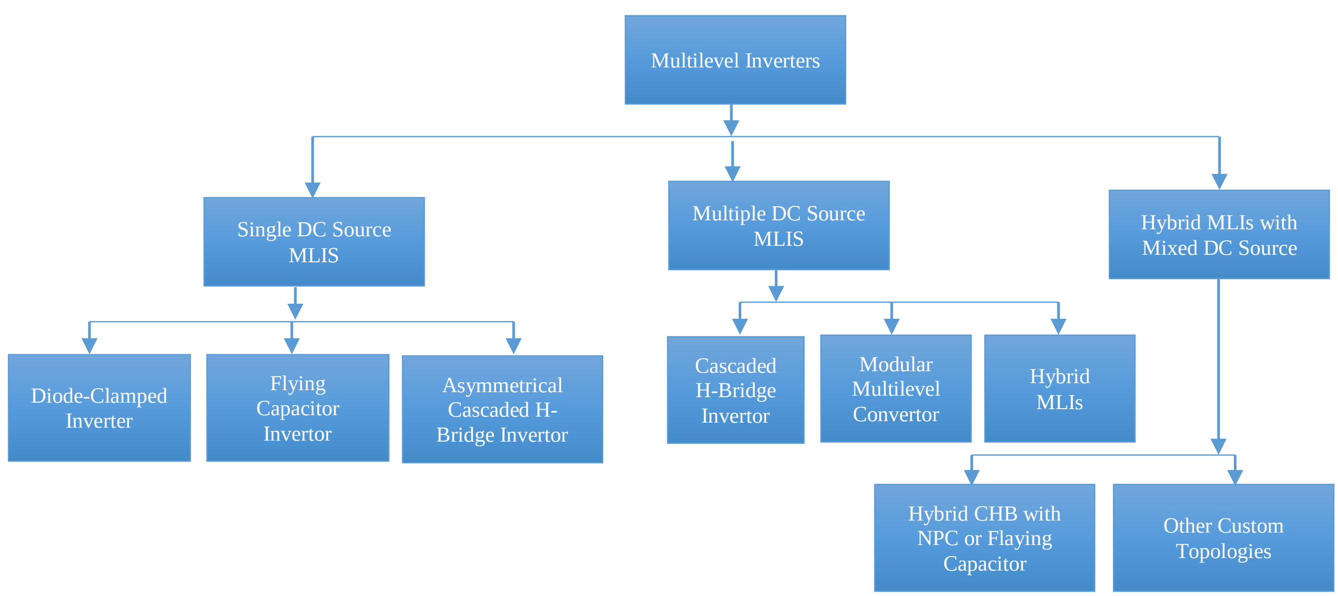


Fig. 1 Traditional multiple inverters [12]

Table 1. Limitations and merits of multiple-level and dual-level inverters

Multi-level inverter	Dual-level inverter
The output waveform exhibits low THD.	Maximum THD to Output waveform
Low-switching stress	Higher switching stress
High-voltage scope	Limitations of a higher voltage scope
Higher voltage levels	Did not enhance high voltages
Lower dv/dt	Higher dv/dt
Decreasing switching losses owing to lower	Higher switching losses due to the high switching frequency

Table 2. THD numbers for 2-level, 5-level cascaded, and 5-level NPC inverters

5-level NPC	5-level Cascaded	Dual-level	The concept of topology
Up-to 31.57	Up-to 29.65	Up-to 114.56	@ 1kHZ, Voltage THD%
Up-to 1.87	Up-to 0.43	Up-to 5.83	@ 1kHZ, Current THD%

1.3. Modular Technologies on Standalone PV Systems

Photovoltaic systems that operate on their own are constructed to deliver the power needed by particular DC or AC devices. Solar systems can use solar energy exclusively or also add wind, a generator powered by an engine or grid electricity to make them a photovoltaic-hybrid system. A simple way to use a stand-alone photovoltaic system is known as direct-coupling, where the DC power from a solar module or grid goes directly to a DC appliance [13]. As electrical storage is not needed for direct-coupled systems, the power is only delivered when there is sunlight (See Table 2). For this reason, these designs are commonly used in water pumps, ventilation fans and very small pumps found in solar water heating devices [14, 15]. A successful direct-coupled system depends on matching the load's impedance to the solar array's maximum power point. For certain loads like positive-displacement water pumps and others, a Maximum Power Point Tracker (MPPT) electronic converter is added between the array and its output to better utilize the array's maximum available energy [16]. Systems installed on the ground or roof require a mounting framework, and an inverter is required if the user wants AC power (See Figures 2 and 3). As batteries are often responsible for 40% of a stand-alone PV system's lifetime costs, they are generally chosen for energy storage in these kinds of installations.

1.4. Challenges of Future Prospects

Global improvements in different industries, as well as academic studies, have led to an increase in demand for high-energy efficiency converters. Because of their inherent benefits, MLIs are in high demand to play an important role in DC/AC process conversions that include both high-power and high-voltage techniques [18]. The ability to interact directly with intermediate voltage, a reduction in semiconductor devices, DC sources, and their associated gate driver circuits, as well as enhanced effectiveness, lower cost, and small size, are just a few of the key characteristics that have powered RSC-MLIs from an idea in theory to practical applications [19]. This literature study examines several topologies and modulation approaches, compares their performance metrics, and concludes that asymmetric multilevel inverters outperform symmetric MLIs with regard to positive aspects (Figure 4). The review study focused mostly on reduced switching multilevel inverter architectures [20]. This article provides a detailed explanation of modulation schemes for both higher and lower switching rates. This review aims to collect the majority of the necessary data for working in this sector, including information on selecting the best topology for a specific application, switching techniques, and control approaches. High performance and efficiency of modular technologies and multiple inverters have been reported in some studies, with lower values in others. Such contradictions can be explained by methodological, conditioning, or assumption differences in the studies. More research must be conducted in order to eliminate such contradictions and identify the variables that define the effectiveness and efficacy of such technologies. Original research on the creation of new modular technologies, as well as multiple inverters, is possible. This type of research would result in more efficient, reliable, and economical solutions to standalone photovoltaic systems.

2. Recent Advancement of Modular Technologies and Multiple Inverters

Stand-alone photovoltaic systems are intended to function independently of the electricity grid, and are often designed and sized to serve specific DC and/or AC electrical needs. These systems can be powered solely by a solar array or can also employ wind, an engine generator, or electricity from the grid as an auxiliary power source, resulting in a photovoltaic-hybrid system [23, 24]. The most basic sort of stand-alone photovoltaic power is a direct-coupled system, in which the DC output of a solar module or grid is directly linked to a DC load. Since direct-coupled systems do not require electrical energy storage (batteries), the load only runs when the sun is shining [25-27].

This makes these designs appropriate for typical uses like water pumps, ventilation fans, and tiny circulating pumps for solar-powered water heating systems (See Table 3). A key component of developing a successful direct-coupled system is matching the electrical load's impedance to the solar array's maximum power output [28]. For specific loads, such as positive-displacement pumps for water, an electronic DC-DC converter known as a Maximum Power Point Tracker (MPPT) is utilized between the array and the load to help better use the array's full power output [30]. A mounting framework is necessary for systems that are installed on the ground or roof, and an inverter is also needed if AC power is sought [31, 32]. Since batteries can make up as much as 40% of the total cost of a stand-alone PV system during its lifetime, they are frequently employed for energy storage in these systems (Figure 5).

2.1. Active Neutral Point Clamped (ANPC)

The working techniques of at least five levels of Active Neutral-Point-Clamped (ANPC) converters are revealed [34]. The maximum of five-level ANPC inverters may have upper and lower DC connections, a neutral point, a converter output, a number of switching devices, comprising lower and upper actively neutral clamps switching equipment, and in addition, one two-level cell linked to the output [35, 36]. Each two-level cell may contain a float capacitor and a reversible switch (See Figure 6 and Table 4). In some cases (See Figure 7 and Table 5), switches may be placed across the upper and lower DC links and the upper and lower active neutral clamp switching devices, while circuit breaking components may be linked between the neutral position and the lower and upper active neutral clamping switching devices. This method involves operating a five-level Active.

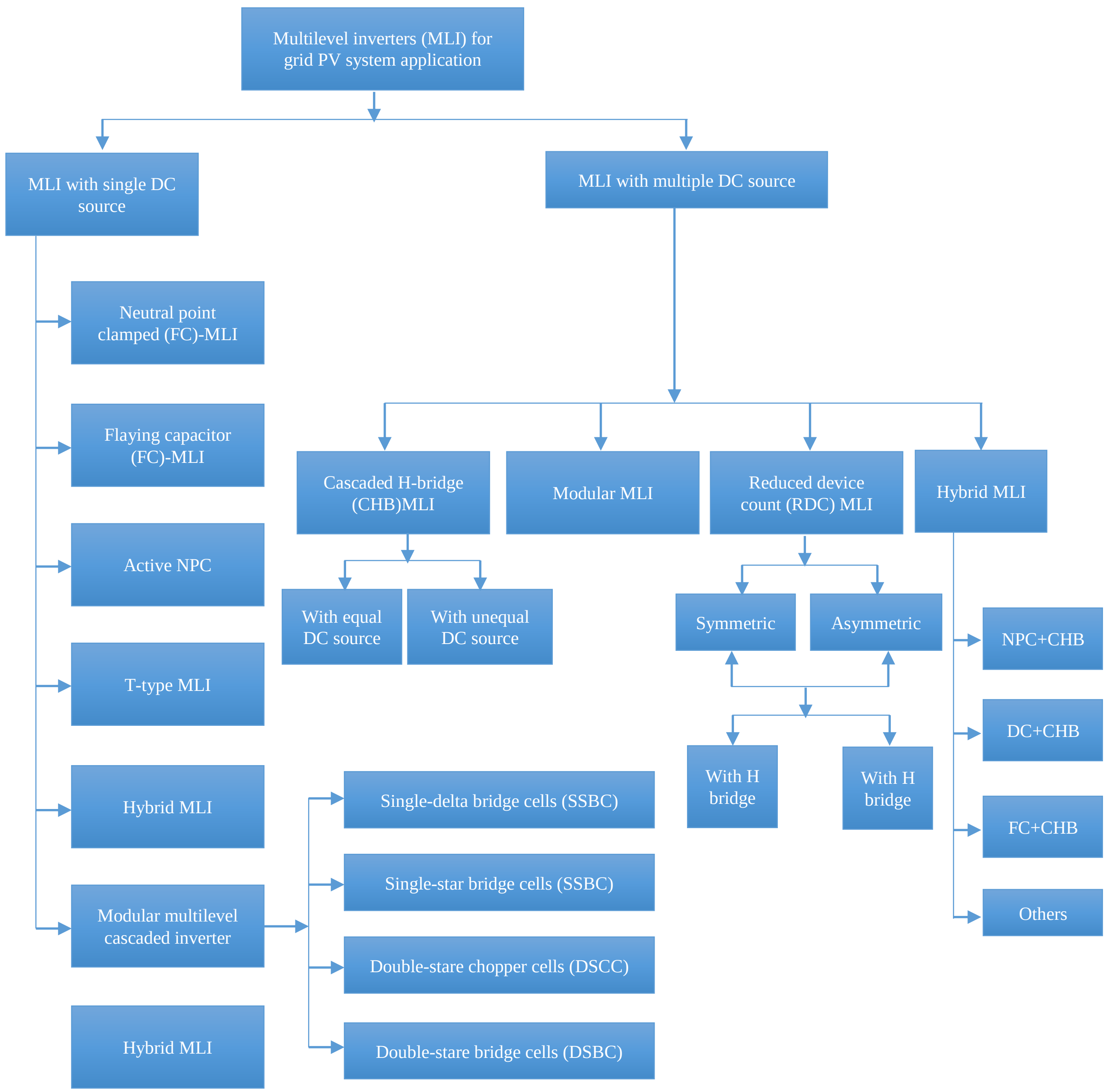


Fig. 2 MLI classification based on the number of DC sources employed [17]

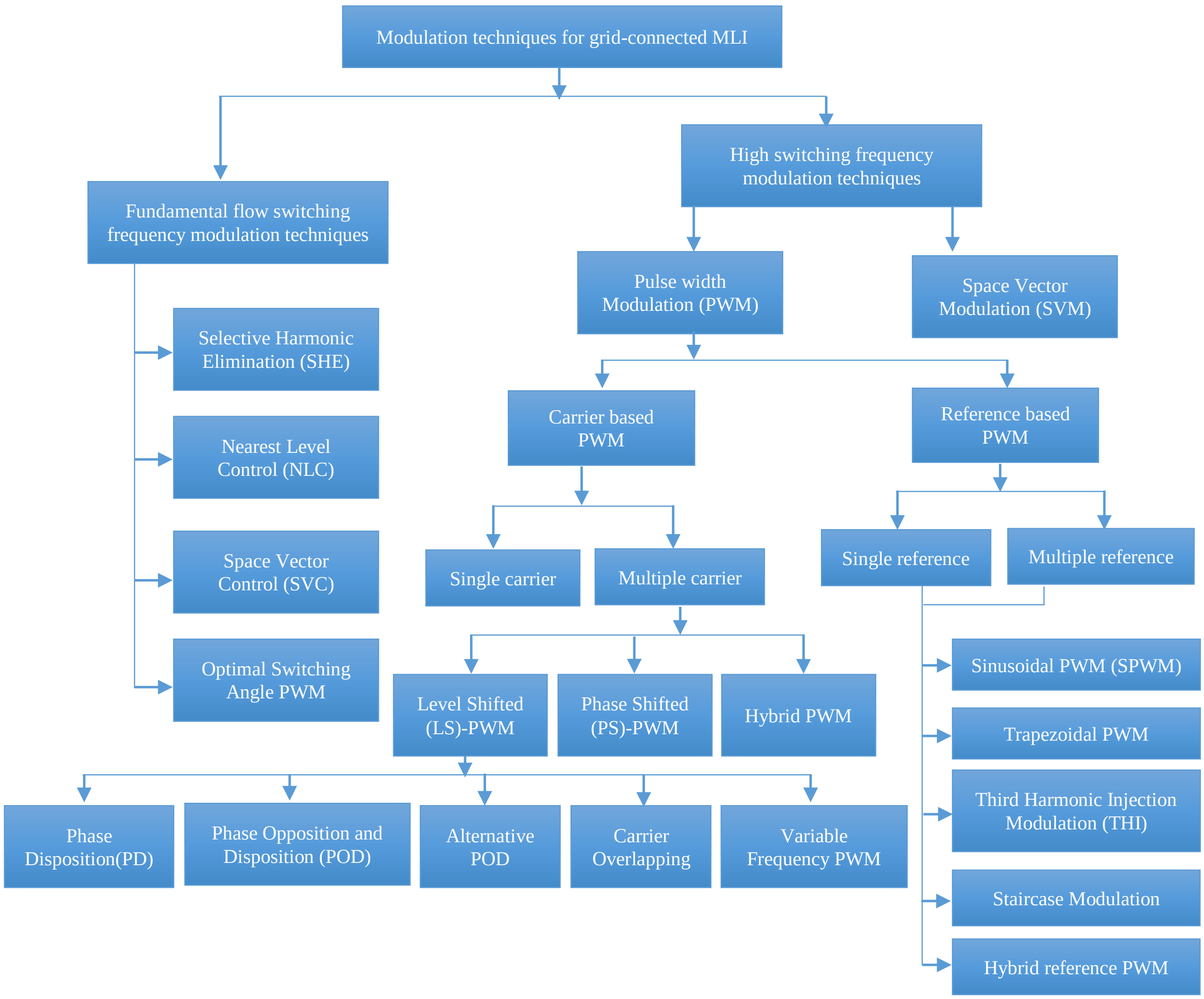


Fig. 3 Augmentation approaches for grid-connected MLIs [21]

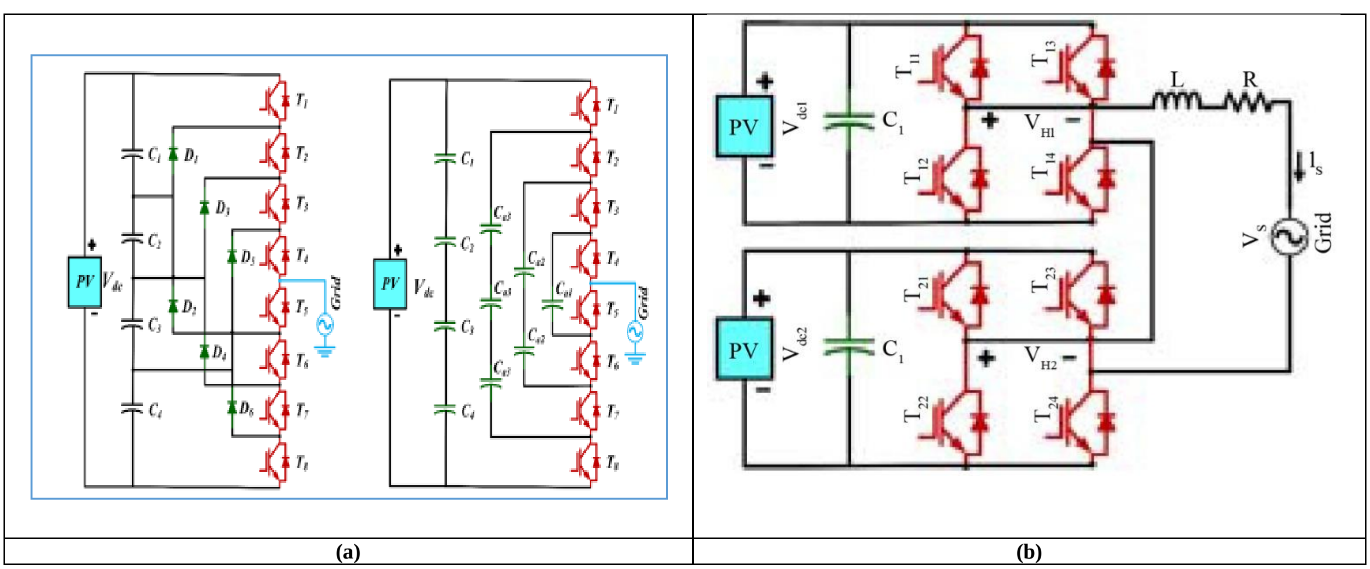
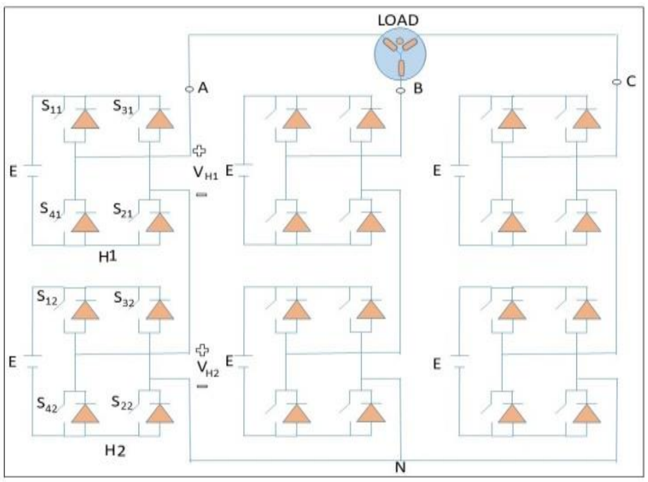


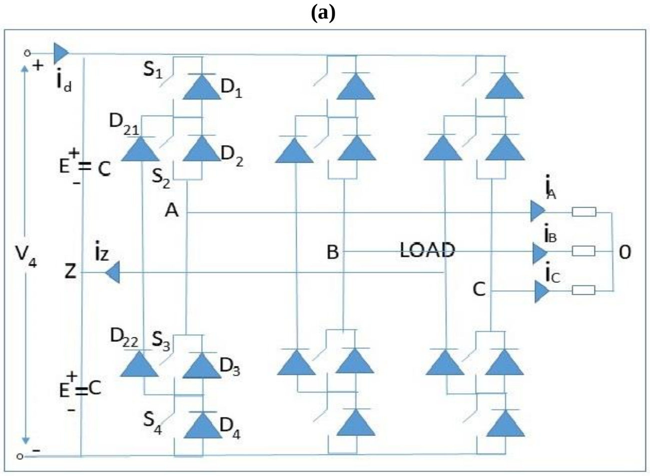
Fig. 4 Traditional MLI architectures [22]

Table 3. Comparing the characteristics of several multilevel inverter architectures [29]

The topological structure	H-bridge Cascaded	Capacitor-flying
Capacitors of the DC link	3*(n-1)	n-1
Clamping Diodes	3*(n-1)*(n-2)	0
Clamping capacitors	0	3*(n-1)*(n-2)/2
Voltage level	Very-small	Higher
Merits	Robust construction employs the fewest DC-link capacitors required (reduced voltage imbalance concerns).	Phase redundancy can be used to balance voltage across DC-link capacitors.
De-merits	As the number of levels increases, so do the clamping diodes.	Bulky and more expensive, with more complicated voltage balancing control algorithms.
Scope	STATCOM, Motor driving System	STATCOM, Motor driving System



(a)



(b)

Fig. 5 H-bridge inverter to five-level cascaded and H-bridge inverter to five-level cascaded and DC MLI of 3-level [33]

An Active Neutral-Point-Clamped (ANPC) converter with lower and upper DC sources, a neutral point located at a converter results in at least one two-level cell associated with the converter output, and a plurality of switching devices, including upper and lower engaged neutral clamp switching devices coupled to the neutral point, as well as other switching devices [37, 38]. The policy and regulation implications of the adoption and use of these technologies are not adequately discussed in the literature. Future research can focus on the impacts of different policy frameworks and regulations on the introduction and performance of standalone photovoltaic systems. Various sources give various opinions about the limitations of standalone photovoltaic systems. More research is required to shed a little more light on these contradictions and to give a far more detailed account of these restrictions.

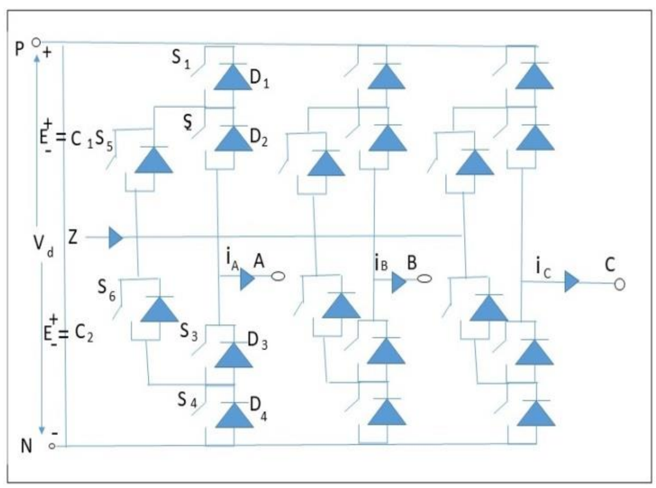


Fig. 6 Model of active-neutral point clamp MLI [39]

3. Reduced Device Count Topologies for Multiple-Level Inverters

People are interested in RDC MLI topologies because they supply good output voltage with a small number of devices [43]. These topologies are created to correct common problems in MLIs, such as a high number of devices connected, low lift and non-uniformity in DC voltage [36].

The reason RDC MLIs stand out in renewables is their flexibility and good generating power, especially for Photovoltaic (PV) systems (See Figure 8). Recent research has centered on new topologies of Novel MLIs that maintain or improve performance, while reducing the number of individual DC sources, power gate drivers, and/or power semiconductor devices [44, 45].

For instance, a single-phase asymmetric MLI that reduces the Total Standing Voltage (TSV) and number of devices has been presented, capable of generating 33 levels. Levels Dependent Source Concoction Multi-Level Inverter (LDSCMLI) uses a module to create a stepped DC link and relies on a traditional H-bridge to deliver the waveform for the AC output [46].

Table 4. MLI architectures are compared depending on the technical considerations [40]

	Inverter architecture				
	DC-MLI	**MLI-FC**	**MLI- CHB**	**MLI-DC**	**The Implementation Factor**
DC-ANPC Link Capacitors	Diodes clamping	Floating-capacitors	Isolated direct current sources	Clamping to diodes	Specific conditions.
Lower	Lower	Higher	Very higher	Lower	Modularity
Higher	Lower	Intermediate	Least (for transformer-free usage)	Lower	Complexity of conception and implementation.
Single	One DC input	One DC input	multiple or single DC input	One DC source	DC input requirement
Voltage Balancing Control is Active	Balancing voltage	Voltage configuration	voltage balancing and power-sharing	Balance voltage	Control-related issues
Simple	Challenges	Simple	Simple	Challenges	Fault-tolerance
Intermediate	High (>= 4-level) and Low (3-level)	High (>= 4 levels) and Medium (3 levels)	Transformer-less applications are quite low, transformer.	High (>=4-level) and Low (3-level)	Cost

Table 5. Performance comparisons between LSPWM and PSPWM systems [41]

Key aspects	PSPWM	LSPWM
The frequency at which devices switch	Similar across all devices.	Different
Does the gadget have the same conduction period?	Yes	No
Converter architecture	CHBC, FCMLC	Structure is independent.
THD (line-to-line voltage)	Good	Better
Nature capacitor voltage balance	Voltage balance was achieved.	Null
Control design	Simple	Complex

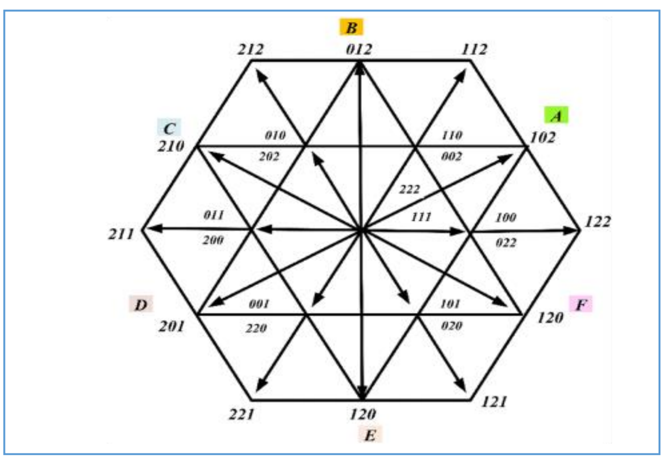


Fig. 7 SVM block diagram, the symbol 1 denotes positive states, 2 stands for negative states and 0 corresponds to zero states [42]

A couple of topologies have managed to boost voltage with fewer parts, like the Seven-Level Switched Capacitor Boost Inverter (7L-SCBI) that uses just eight switches and two capacitors to reach seven voltage stages and increases the input DC-link (See Figure 9) voltage by 1.5. Analogously, a modified seven-level H-bridge inverter with two DC supplies and six IGBTs has been built, and its output is managed by Aquila Optimizer (AO) [47, 48].

Such improvements prove that RDC MLIs can lead to huge reductions in the number of parts, expenses, and volume while sustaining or improving how well they function, unlike older designs [51, 52]. In essence, RDC MLI (See Figures 10(a) to 10(c)) topologies work well for many uses, especially when making energy-efficient and grid systems. Such topologies address major issues that most MLI systems encounter, such as cost-efficiency and a steady power supply, by reducing the components that are needed [53, 54]. As studies in this topic move ahead, we can predict new and better designs in RDC MLI (See Figures 11(a) to 11(c)), making power conversion for medium and high power applications less expensive, more space-efficient and improved [55].

This article explains how hybrid-switching and a closed loop are used to control a trinary asymmetric 27-level inverter when needed in a PV system. This diagram illustrates a two-loop control approach for a grid-connected PV system (See Figure 12). The internal loop ensures that the power factor stays at 100% and the external loop is in charge of setting the voltage for the main H-bridge [60-62]. Auxiliary H-bridge modules supply ceiling, floor and slope details for the right and left aligned timer approaches as explained. Steady operation is achieved when a zero-error signal is added to the closed-loop control system (See Figure 13). Equation-based balancing methods have been created to hold the flying capacitor voltage constant during any changes in power factor and load current values [63]. It is possible to detect the movement of the load's current with a zero-crossing detector (See Figure 14). At the start, the core controller gives the PWM its index for modulation, and the PWM then makes a multistep comparison signal. With sinusoidal PWM and HER, the PWM creates a baseline waveform that is not simple but has many steps [64]. Inputs to this subsystem are only the voltage levels from the inverter, so it can be used as a global modulator.

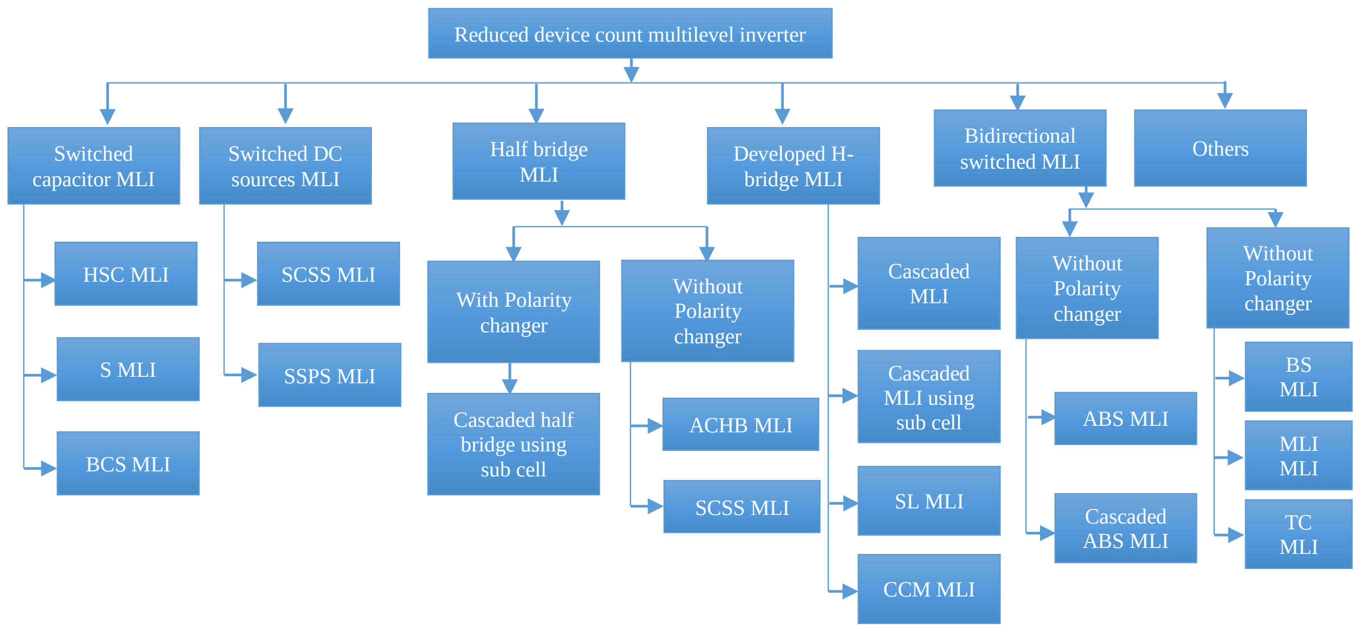


Fig. 8 MLI reduced the device count [49]

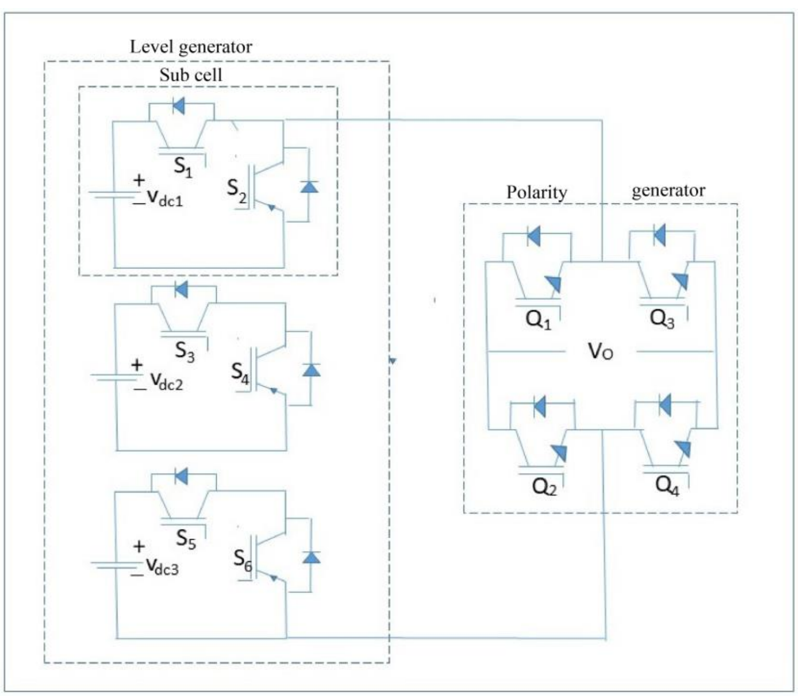
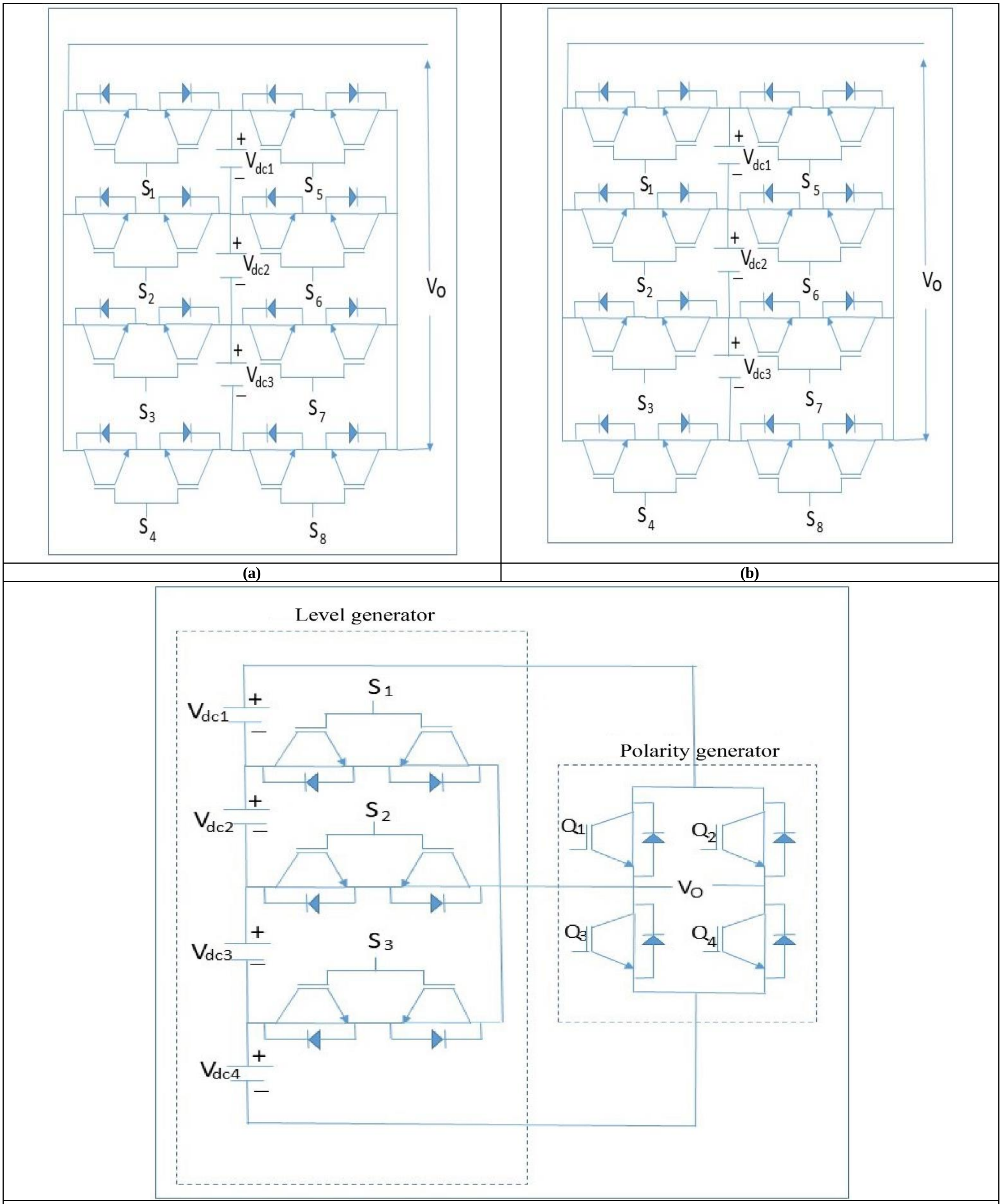


Fig. 9 Half-bridge MLI cascaded with sub-cells [50]



(a) **(b)**

(c)

Fig. 10 (a) Simplified half-bridge MLI with a cell that has reverse polarity, (b) A bidirectional asymmetric switch MLI with 13 levels, and (c) MLI with five transistor clamping levels [56].

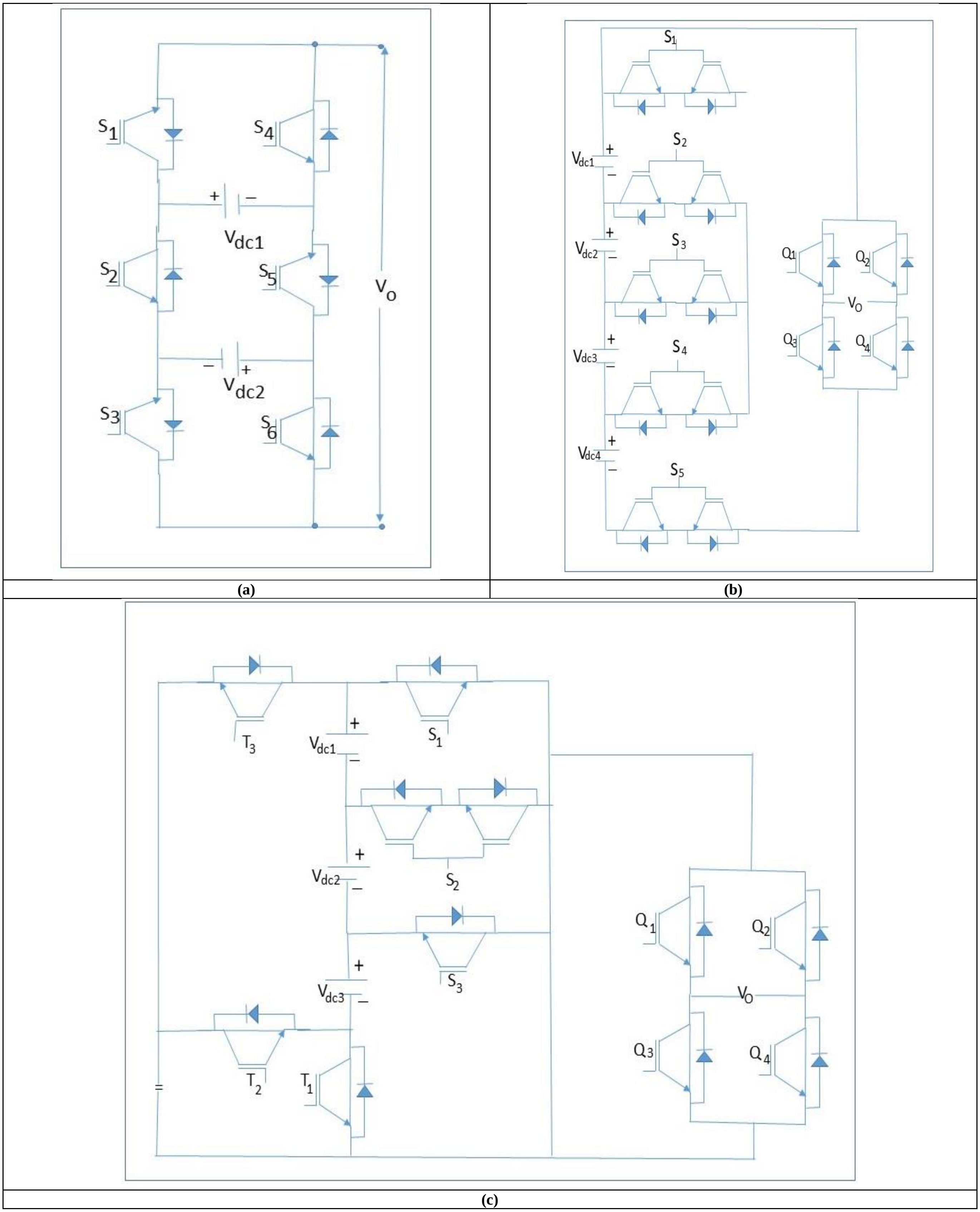


Fig. 11 (a) Inverter with many levels of modules, (b) SCSS MLI consists of five levels, and (c) A thirteen-level hybrid SCMLI [57].

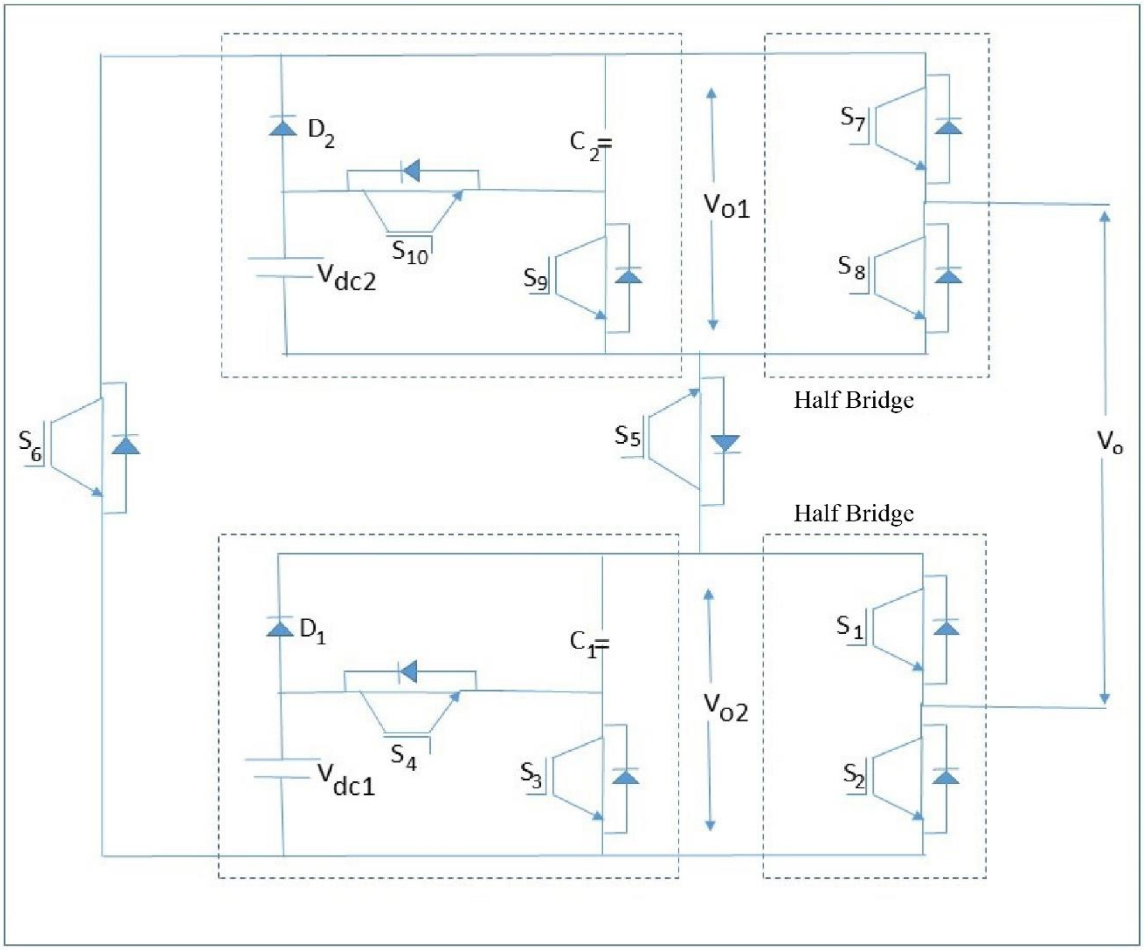


Fig. 12 A seventeen-level hybrid SMLI [58]

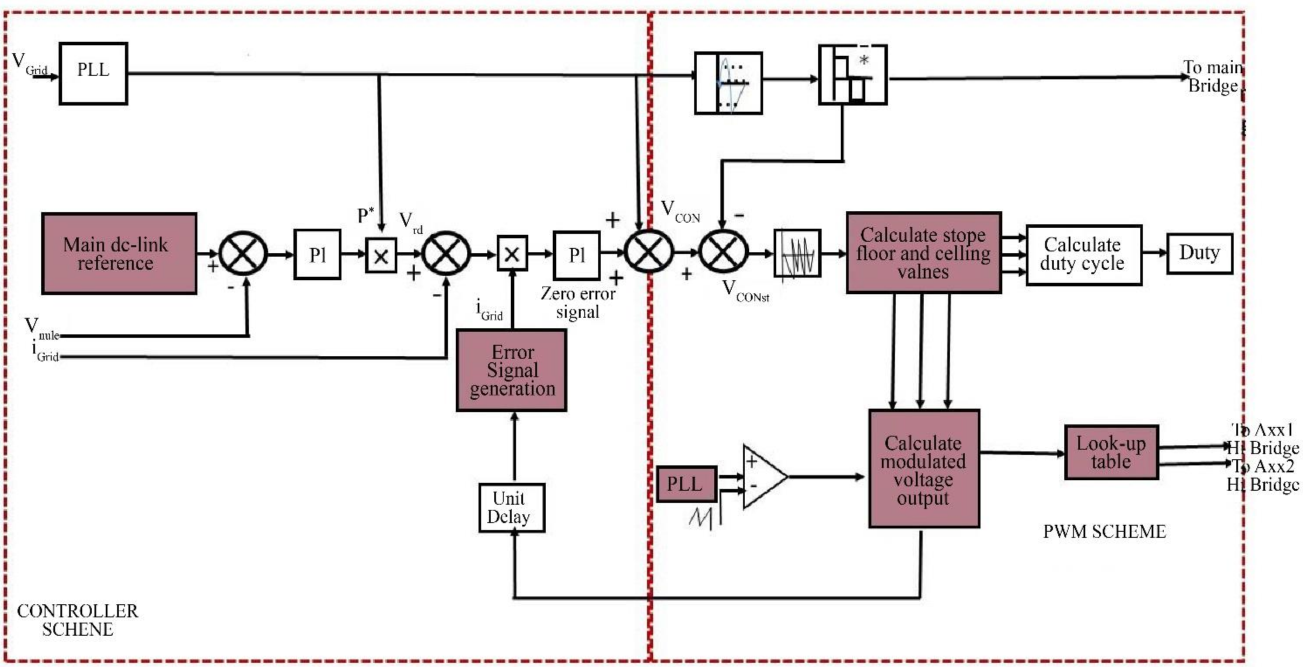


Fig. 13 A 27-level inverter uses hybrid Pulse-Width Modulation (PWM) and various control approaches [59]

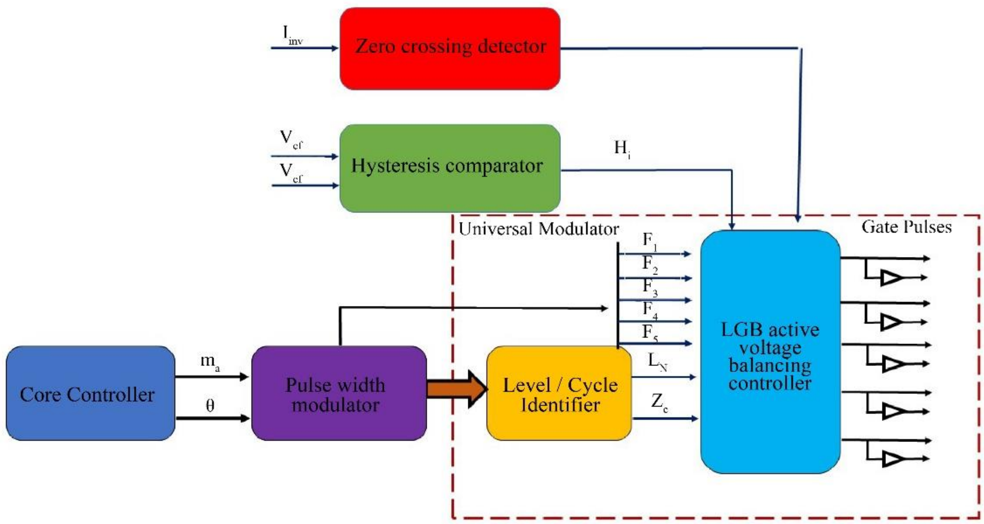


Fig. 14 Balancing FC active voltage with the LGB control infrastructure [65]

4. Techniques for Controlling Various Voltage Sources, Grid-Connected MLI

A special power transfer control system (See Figure 15) is described in the paper, which helps the CHB-MLI system in SECS to regulate capacitor charging under various environmental conditions [66, 67]. The technique Can investigate how to manage bidirectional power flow, which allows for separate control of each HBC and adjustable power drawn from the DC-links. Thanks to the panels being unevenly connected, a perfect balance is still reached using a DC-link capacitor [68, 69]. Sometimes, to inject sinusoidal current in phase with the grid, grid-connected cascaded MLIs depend on precise control systems that maintain the UPF (See Figure 16). Make sure all the PV-made electricity goes immediately into the grid with the DC-link voltage higher than the voltage the grid can handle [72, 73]. Similarly, the best method for the controller of cascaded MLIs is to maximize the power extracted from each solar array using separate control of the DC-link voltage [77]. A controller is required to maintain the system's stability when any of these external conditions change: the environment, radiation and wind [78]. The figure displays how the five-level Modular FC Multi-Level Converter (MFCMLC) manages the voltages at the electromagnetic-wave ports to control Vdcx1 and Vdcx2, which are the two reference dc-link voltages for the isolated HBCs. As each HBC allows separate regulation of the voltage and capacitors, MPPT is useful for both wind and solar systems [79]. In addition, the use of the MFCMLC with a control system and switching method that is good at handling imbalances in power that often appear between and among cells in a phase due to changes in the environment.

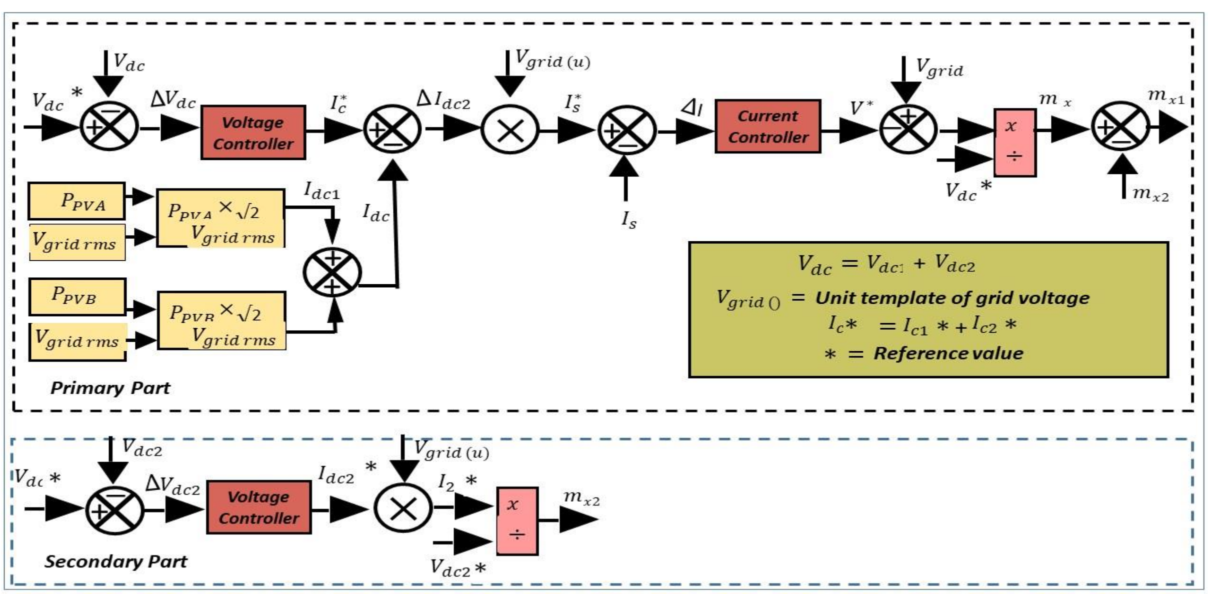


Fig. 15 CHB-ML control scheme [70]

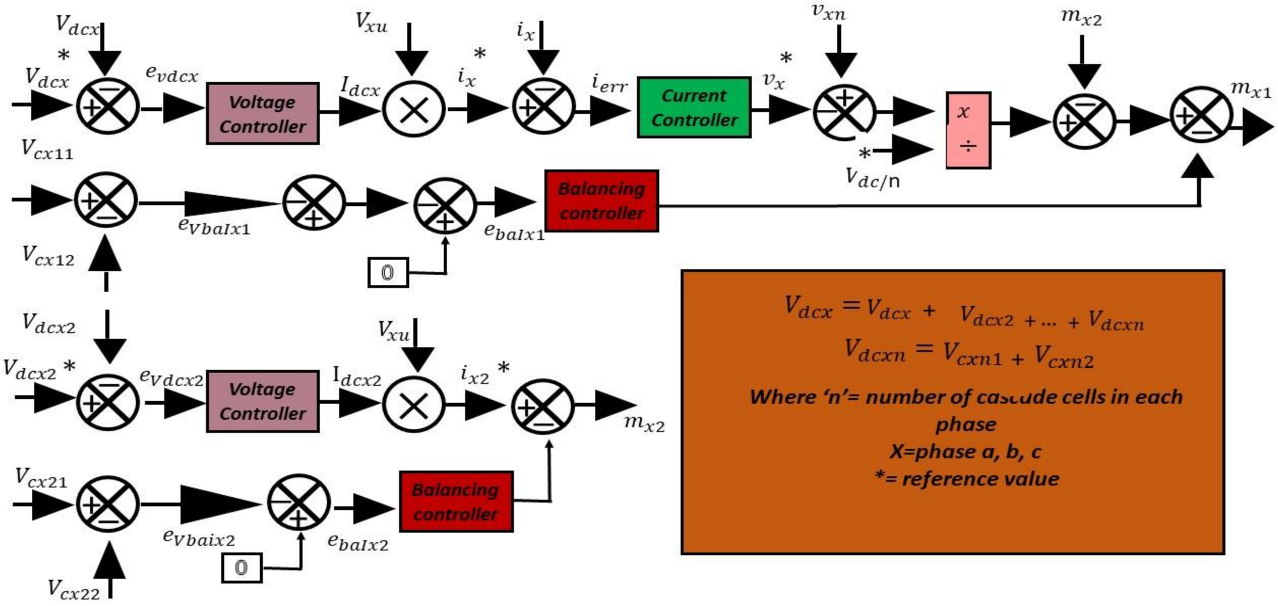


Fig. 16 MFCMLC control scheme [71]

Table 6. Detailed comparison of a multilayer inverter with fewer devices [80]

Summary	Unit Controlling	Software's	Parameters Determined	Scheme Modulation	Type MLIT	Author	References
The performance of these topologies was proven using simulation and prototype results.	Micro controller ATMEL 89C52	EMTDC/ PSCAD	----	Angle switching	MLI-CHB cells	Babaei, E (2010)	[81]
Its prototype hardware and simulation were used to assess the suggested topology.	Micro controller ATMEL 89C52	EMTDC/ PSCAD	THD, switching losses, conduction losses,	-----	Based MLI/ MLM	Ebrahimi, J et al. (2012)	[82]
Additionally, the simulation outcomes of this topology were contrasted with those of traditional topologies.	dSpace DS1103	Simulink/ MATLAB/	THD, switching losses, conduction losses,	SPWM/ PD	MLI/ SCSS	Gupta, K.K. etal (2014)	[83]
As a result, it became possible to remove the polarity changer, so there were less switching devices, less expense and simpler circuits.	Controller TMS320F28335 DSP	Simulink/ MATLAB/	THD	Harmonic elimination scheme	half-bridge inverter asymmetric cascaded	M,Ahmed et al. (2017)	[84]
A half-bridge	6013/ NI PCI	Simulink/	THD	POD (Phase	half-bridge	K.M,	[85]

inverter operating at 15 levels used PWM techniques that work in multiple carrier frequencies.		MATLAB/		opposite deposition), IPD (In phase deposition), APOD (Alternative POD),	inverter (cascaded)	Kotb, et al. (2016)	
A series connection of sub-multilevel inverters recommended using the RSB-MLI scheme.	Micro controller ATMEL 89C52	EMTDC/ PSCAD	Standing voltage, THD	Angle Switching	Bi directional switch/ ML	E, Babaei et al. (2007)	[86]
Approaches in the standard showed how to determine components and their voltage levels. The strategy was confirmed by results from simulations and experiments.	Micro controller ATMEL 89C52	PSCAD	output voltage/ THD	Frequency switching technique	half-bridge inverter (cascaded)	E, Babaei et al. (2007)	[87]

Table 7. Comparison of contemporary MLIs for PV systems with fewer devices

PV Configuration	Algorithm MPPT	Controller Systems	Modulation Scheme	Software's	MLI Configuration	References
Standalone	----	Micro controller PIC16F877A	PD, APOD, POD	Simulink/ MATLAB/	CHB Modified	[88]
Standalone	IC Incremental conductance	2560 Arduino Mega	PWM-PD PWM-SHE	Simulink/ MATLAB/	Reduced Switch H-Bridge-Based (RSHB)MLI with LDC	[89]
Standalone	------	Spartan 6 processor FPGA	NLM	Simulink/ MATLAB/	Multilevel inverter with dual source	[90]
Grid connected	------	STM32F407 DSP STMicroelectronics	PWM	--------	Double-mode with multilevel inverter	[91]
Grid connected	IC	dSPACE MicroLab Box	PWM	(R2009a) Simulink/ MATLAB/	Enhanced H-bridge multilevel inverter	[92]
Standalone	IC	Spartan FPGA	PWM	Simulink/ MATLAB/	Modified MLI H-bridge	[93]
Standalone	Fuzzy logic	3E-500FPGA Xilinx Spartan	PD/CPWM	Simulink/ MATLAB/	Cascaded sub-MLI H bridge	[94]
Standalone	Observe and Perturb (P &O)	dSPACE/1104 controller	PD/CPWM	Simulink/ MATLAB	CHB is integrated with a double-level circuit	[95]
Grid connected	IC	Controller/ DSP	PD/CPWM	Simulink/ MATLAB	(VLB)MLI Voltage Level Boost	[96]
Standalone	P/O	dSPACE/1104 controller	PD/CPWM	Simulink/ MATLAB	Micro multilevel inverter	[97]
Standalone	fuzzy logic	DSPIC/30F2010	SHE/PWM	Simulink/	Switched capacitor (MLI)	[98]

	control with GreyWolf optimization technique	controller		MATLAB		
Standalone	Fuzzy logic	------	Swarm optimization Anti-predatory particle	Simulink/ MATLAB	Switched capacitor (MLI)	[99]
Grid connected	hysteresis control with IC	---------	PWM	Simulink/ MATLAB	U-cells S-packed	[100]

Table 8. Key mechanisms to enhance the results by state-of-the-art techniques

References	State-of-the-Art Limitation	Modular/Multiple Inverter Approach	Improvement Area
[45]	Rigid, difficult to scale	Easy expansion, hot-swapping modules	Modularity and Scalability
[67]	Higher THD, more filtering needed	Low THD, stepped waveform	Power Quality
[78]	Centralized, limited by the weakest	Distributed, per-module optimization	MPPT Efficiency
[85]	System-wide shutdowns	Operation continues after faults.	Fault Tolerance
[90]	More components, higher losses	Fewer switches, lower cost	Component Count

5. Conclusion and Future Challenges

The review within this paper covers all the major points about classical multilevel inverters and various modulation techniques (See Tables 6 and 7). They are described with their pros and cons. The main focus of the current work is on multilevel inverters that need a lower number of devices. The framework in this work is built on the topology of how machines and fiber links are connected. Of late, many new topologies have been developed aiming to produce a larger number of output voltage levels with less need for power electronic devices. Particularly, SDCS-MLI topologies fit better for electric vehicles and renewable energy systems than MDCS-MLI structures. This means moving towards increased use of DC sources in magnetic levitation systems. Besides, topologies such as the Level Dependent Sources Concoction Multilevel Inverter, LDSCMLI, allows for producing different voltage levels using sizeable savings in components and control signals. Going forward, MLI researchers might focus on making RDC systems lighter, more efficient, and more tolerant of possible faults. Future research would also be wise to look at more SDCS-MLI designs, try out structures using different MLI types and find better control ways to increase performance and decrease stress on main components. Reliability should be improved, standby voltage should be lowered, and design modifications should consider certain applications, such as grid-connected systems or renewables integration. Modular design, distributed control and advanced inverter topologies allow standalone PV systems to be more efficient, reliable, and flexible than traditional solutions, especially when operating within the limits of real-world conditions.

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