Grenze International Journal of Engineering and Technology, January Issue

A Survey on High-Frequency Operable AFE-RDC-MLI Topologies

Hareesh A[1], Adhipa K R[2], Vishnu P Madhanmohan[3] and Jayanand B[4]
[1]Government Industrial Training Institute, Thiruvambady, Kozhikode, Kerala, India.
Email: harielayur@gmail.com
[2]Research Scholar, Department of Electrical and Electronics Engineering, Government Engineering College, Thrissur, Kerala, India
Email: adhipakpmr@gectcr.ac.in
[3]Department of Electrical and Electronics Department, Christ College of Engineering Irinjalakuda, Thrissur, Kerala, India
Email: vishnumadhanmohan@cce.edu.in
[4]Electrical & Electronics Engineering Department, SCMS School of Engineering and Technology, Karukutty, Affiliated to APJ Abdul Kalam Technological University, Kerala, India.
Email: jayanandb@gmail.com

Abstract— **This paper presents a comprehensive review of active front-end (AFE)-based reduced device count (RDC) multilevel inverter (MLI) topologies that offer high dynamic performance, compact size, and improved power quality. These topologies, featuring an AFE converter followed by a synchronized H-bridge, operate at high switching frequencies, producing high-quality output voltage waveforms with reduced total harmonic distortion (THD). Suitable for renewable energy, motor drive, and grid-connected applications, AFE-RDC-MLIs leverage advanced control strategies and benefit from the integration of wide-band-gap (WBG) devices, which can significantly enhance topology performance. This survey provides an in-depth analysis of high-frequency operable AFE-RDC-MLI topologies and highlights their applications.**

Index Terms— **active front end, multilevel inverters, reduced device count, wide-band-gap (WBG) devices.**

I. Introduction

DC-AC inverters play a crucial role in power electronics, permitting efficient power conversion in applications such as electric drives, electric vehicles, and renewable energy integration. However, conventional inverters face limitations such as high power ratings, dv/dt stress, output voltage distortion, and electromagnetic interference. Multilevel inverters (MLIs) have been developed as a solution, offering improved power quality, efficiency, and reliability. Despite their advantages, classical MLI topologies, such as the Neutral Point Clamped (NPC) [1], Flying Capacitor (FC) [2], and Cascaded H-bridge (CHB) [3], require a large number of semiconductor devices and passive components, increasing the system complexity. RDC-MLI topologies have been developed to address this challenge, aiming to enhance the output voltage levels, power quality, and system efficiency while reducing the component count and cost.
The AFE-RDC-MLI topology, comprising an AFE converter and synchronized H-bridge, has gained significant attention owing to its enhanced dynamic performance, compact size, and improved power quality.

Grenze ID: 01.GIJET.12.1.37

These topologies exhibit several key attributes. These include improved waveform quality with superior THD values, enhanced reliability owing to reduced shoot-through risk, high dynamic performance, applicability of advanced control strategies, simplified closed-loop control, and fast dynamic response owing to high switching frequency operation. In most these type configurations, The AFE converter acts as a pseudo-dc-link, generating a fully rectified sinusoidal multilevel waveform, whereas the H-bridge inverted to a multilevel sinusoidal output waveform at the power frequency resulting in a two-stage operation. Because the AFE converter operates at high switching frequencies, replacing silicon-controlled devices with WBG devices, such as silicon carbide (SiC) or gallium nitride (GaN), can significantly enhance the topology performance. This survey focuses on H-bridge-based two-stage AFE- RDC-MLI topologies. Most of these topologies are referred to in the single-phase form, the majority of them can be converted to three-phase configurations, with some familiar three-phase structures also being explored.

II. Classification of AFE-RDC-MLI Topologies

The classifications of AFE-RDC-MLI topologies that employ various dc-to-dc converters are listed as follows.

- Boost converter-based MLI topologies,
- Buck converter-based MLI topologies,
- Buck-boost converter-based MLI topologies (isolated/non-isolated),
- Fly-back converter-based MLI topologies,
- Z-source inverter-based MLI topologies,
- Current-fed switched inverter (CFSI) based MLI topologies.

A comparative analysis of the AFE-RDC-MLI topologies based on the device count, AFE converter types, and applications is provided in Table I.

A. Boost converter-based MLI topologies

The work of Geoffrey R. Walker et al. presented a non-isolated per-panel DC-to-DC converter in [4], as shown in Fig.1. The topology employs a DC-to-DC boost converter as the AFE converter, generating a completely rectified output waveform across the capacitor (C). The H-bridge topology then inverts this waveform to produce a sinusoidal output voltage. Designed for renewable energy applications, this single-phase topology utilizes a series-connected photovoltaic (PV) cell array as the dc-source voltage. By linking PV cells in series, a high dc-source voltage is achieved, enabling the "converter-per-panel" approach. This configuration eliminates the need for separate DC-to-AC grid-connected inverters, thereby reducing costs and efficiency losses.

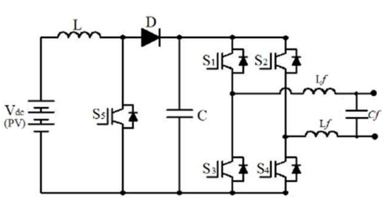

Fig.1

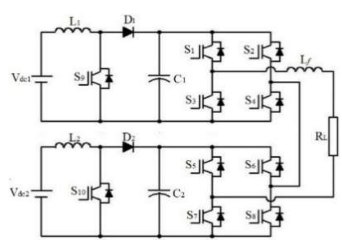

Fig.2

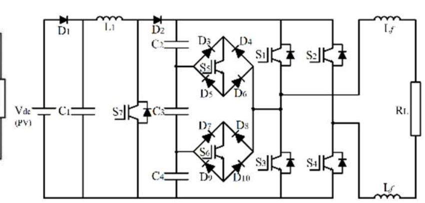

Fig.3

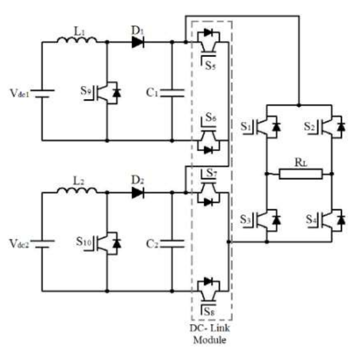

Fig.4

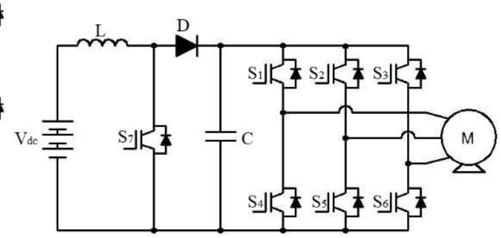

Fig.5

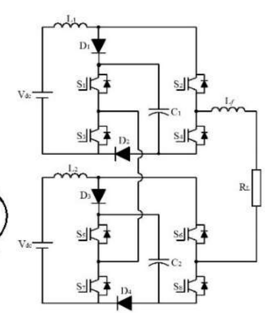

Fig.6

Figure 1. Non-isolated per-panel DC-to-DC converters connected to a DC-to-AC inverter,
Figure 2. Conventional two-stage cascaded H-bridge (CHB) boost-five-level inverter (CHB-BFLI),
Figure 3. Single-phase seven-level grid-connected inverter for photovoltaic (PV) systems,
Figure 4. Single-phase seven-level BDCL CMLI,
Figure 5. Three-phase PWM inverter with a DC-to-DC boost converter,
Figure 6. Single-stage qCHB-FLBI.

R. Uthirasamy et al. introduced a two-stage CHB-BFLI topology [5], as shown in Fig.2. Each H-bridge circuit utilizes a DC-to-DC boost converter to serve as a voltage-building circuit and regulate the dc-link voltage. K. H. Law et al. proposed a three-phase, five-level cascaded inverter with a boost converter topology for static synchronous compensators (STATCOM) [6].

This architecture enables the closed-loop regulation of both current and voltage, thereby meeting reactive power (VAR) requirements under varying load conditions. Additionally, the authors introduced a novel multilevel selective harmonic elimination pulse-width modulation (SHE-PWM) control approach achieved by adjusting the dc-source voltage levels.

Nasrudin A. Rahim et al. proposed a single-phase seven-level grid-connected inverter for PV systems, as depicted in Fig.3. [7]. References [8]–[11] introduced an alternative topology utilized to develop a five-level inverter comprising a conventional single-phase H-bridge inverter for polarity generation and a level generation section.

This section features two bidirectional switches and a capacitor voltage divider circuit. Notably, this design reduces the number of semiconductor devices and passive components required compared with traditional inverter topologies. Additionally, a novel PWM modulation technique was introduced, employing three reference signals and a carrier signal to generate PWM switching signals, facilitating direct power transfer from the PV array to the grid.

Ramasami Uthirasamy et al. proposed a single-phase seven-level boost DC-link cascaded multilevel inverter (BDCL-CMLI) topology, as shown in Fig. 4. [12] This architecture reduces the voltage stress across the inverter switches compared to the traditional CMLI and two-level H-bridge inverter configurations.

The multicarrier pulse-width modulation control logic switches the DC-link and boosts the output AC-power. With fewer DC-sources and switches required, the system is more cost effective. Topological verification confirmed the suitability of the proposed structure for power converters in UPS and drive applications. The number of levels in a BDCL-CMLI configuration can be determined using the formula $N_{level} = 2(m+1)s - 1$, where *'m'* represents the number of H-bridge inverters and *'s'* denotes the number of DC-sources. Additionally, the number of switches required can be calculated using the expression $NSwitch = 2s + 4m + n$, where *'n'* signifies the number of boost chopper units.

The BDCL-CMLI configuration reduces the on-state power loss by 29.17% compared that with of traditional boost MLIs. However, the primary limitation of the design is that the DC- bus voltage (fuel-cell stack output voltage) varies with load fluctuations.

Miaosen Shen et al. proposed a three-phase PWM inverter with a dc-dc boost converter [13], shown in Fig.5. Traditional three-phase PWM inverters used in electric vehicles face challenges owing to the wide voltage range and low output of the fuel cell stack, which stress the switching devices and limit the motor's constant power speed ratio (CPSR). The boost converter of the proposed design steps up the DC-voltage when the required output voltage exceeds the fuel cell voltage, alleviating these issues.

Minh-Khai Nguyen et al. [14] introduced a novel single-stage quasi-CHB five-level boost inverter (qCHB-FLBI) configuration, as shown in Fig. 6. The converter features two DC-sources, two quasi-boost inverter (qBI) modules, and a series-connected inductance filter with a resistive load. Each qBI module comprises one capacitor, one boost inductor, four switches, and two diodes.

The key benefits of this topology are its five-level output voltage, reduced number of passive components, and shoot-through immunity. A simple PID controller ensures a constant capacitor voltage with an excellent transient response and disturbance rejection. The authors also presented a circuit analysis and PWM control strategy for the proposed system.

B. Buck converter-based MLI topologies

Zaohong Yang et al. [15] proposed a single-phase switch-mode DC-to-AC inverter using a buck converter topology shown in Fig.7. This design provides a robust output voltage regulation despite significant supply and load impedance variations, exhibiting a fast dynamic response. The output voltage of the inverter remained stable even with substantial input voltage and output current fluctuations, reducing the distortion around the zero-crossing point.

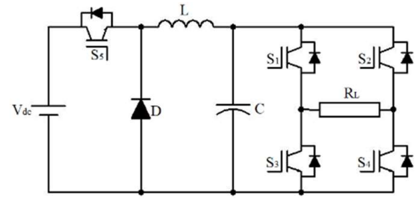

Figure 7. Single-phase switch-mode DC-to-AC inverter using a buck converter

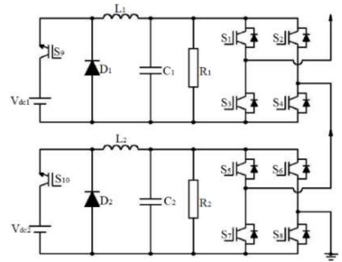

Figure 8. Single phase switch-mode DC-to-AC inverter using the buck converter.

Law Kah Haw et al. [16] proposed a single-phase five-level inverter with cascaded H-bridges for transformerless STATCOM applications, as shown in Fig.8. The system employs a multilevel selective harmonic elimination (MSHE) PWM control algorithm that performs effectively under varying loads and produces a higher quality output voltage.

C. Buck-Boost Converter-Based MLI Topologies

The performance of a three-phase single-stage buck-boost inverter (BBI) architecture was evaluated in Fig. 9, based on the work by Eltaib Abdeen et al. [17].

The proposed architecture, based on a three-phase full-bridge inverter, adds only one inductor and one switch to increase the input voltage. This design offers several benefits, including a reduced semiconductor power switch count and simplified control implementation. Notably, this topology minimizes passive element usage while providing voltage step-up and grid-feeding capabilities.

Tang et al. [18] proposed an active buck-boost full-bridge inverter (ABI) topology, shown in Fig.10. This topology optimizes the design by using a single inductor for both output voltage halves. The ABI can operate in the buck-boost mode, leveraging two equivalent circuits to produce a bipolar output voltage through two sub-topologies. A modified switching technique is described in [19]. The front-end H-bridge, which operates at a power frequency, controls the polarity via switches S1-S4. The inverter was designed to operate in boost mode. However, if it operates in the buck mode, the inductor current increases, resulting in higher conduction losses.

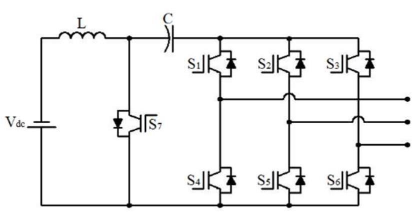

Fig.9

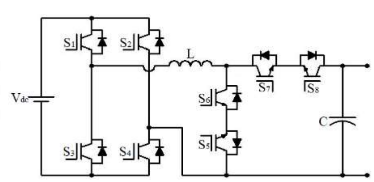

Fig.10

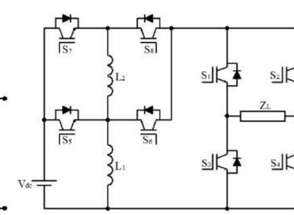

Fig.11

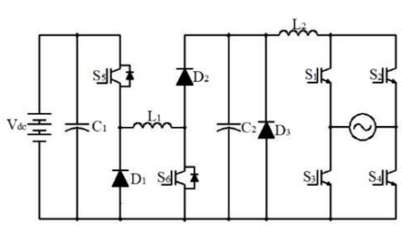

Fig.12

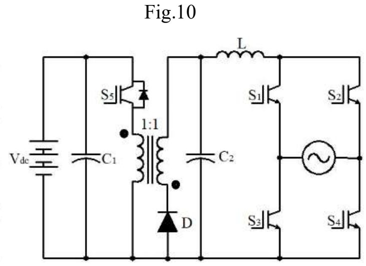

Fig.13

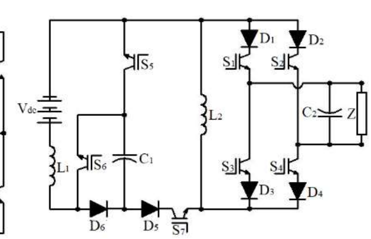

Fig.14

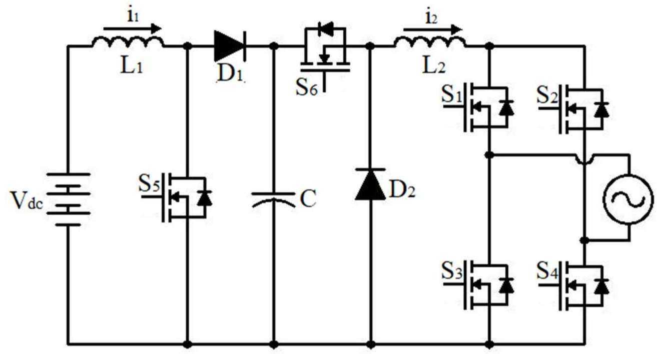

Fig.15

Figure 9. Three-phase single-stage buck–boost inverter (BBI) topology,
Figure 10. ABI topology,
Figure 11. Five-level buck-boost MLI,
Figure 12. Two-stage nonisolated buck–boost inverter,
Figure 13. Two-stage isolated buck-boost inverter,
Figure 14. Buck-boost inverter,
Figure 15. quad-modal BBI

Wang Liqiao et al. proposed a novel buck-boost MLI topology, well-suited for applications with wide DC-link voltage fluctuations, such as renewable energy generation. The high inductor values of the topology enable operation as a current source inverter (CSI). The inverter's converter section of the inverter consists of two parallel buck-boost converters with inductors. As shown in Fig.11, a five-level structure is achieved with four converter-side switches and four power-frequency switches on the polarity generator side, allowing both single-phase and three-phase configurations.

Inverters are categorized as isolated or nonisolated based on the electrical separation between the input and output stages. Saha et al. [20] proposed a buck-boost inverter architecture. A two-stage isolated buck-boost inverter suitable for grid-connected PV systems was presented in [21] and is illustrated in Fig.12. In contrast, a two-stage non-isolated architecture, although simple, has limitations in terms of DC-voltage fluctuation range and voltage conversion ratio.

A two-stage isolated buck-boost inverter design utilizing a fly-back transformer provides electrical separation from the utility grid [20]. As shown in Figs.12 and 13, the second stage operates as a power-source inverter with a half-wave rectifier at the power frequency. The high-frequency transformer-based isolation topology enables power extraction from renewable energy sources with low DC-source voltages while ensuring utility safety. Isolated inverter topologies are particularly suitable for systems with significant DC-source voltage fluctuations, which are often achieved using line-frequency or high-frequency transformers on the AC output side.

Futabiki et al. [22] proposed a transformerless inverter design that extended the DC-input operation range using a buck-boost converter. This was achieved by adding a charging loop to the energy storage capacitor, as shown in Fig.14. The inverter can maintain a satisfactory output despite significant DC-source voltage deviations from near-zero to above the output voltage. However, this design requires additional switching components and complex operations, which increases its cost.

Zhao et al. [23] proposed a quad-modal buck-boost inverter (BBI) that utilizes four distinct circuits to generate the desired voltage in each mode. The simplest quad-mode BBI topology, shown in Fig.15, features a cascaded connection of boost and buck converters. Grid current shaping is achieved by controlling the buck inductor (L2) current, whereas current unfolding is performed by the H-bridge inverter. The H-bridge switches operate at the power frequency, with the S1-S4 and S2-S3 pairs controlling the bipolar grid current. In the buck mode, S5 is OFF, and S6 receives high-frequency PWM pulses. In boost mode, S6 is ON, and S5 receives the PWM pulses. This results in distinct buck and boost mode equivalent circuits for the negative and positive half-cycles of the grid current.

D. Fly-back converter-based MLI topologies

Seong-hye Kim et al. [24] proposed a cascaded H-bridge MLI architecture with a front-end unified converter, as shown in Fig.16.

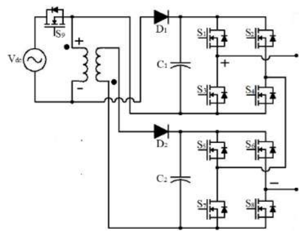

Fig.16

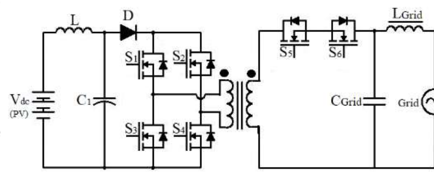

Fig.17

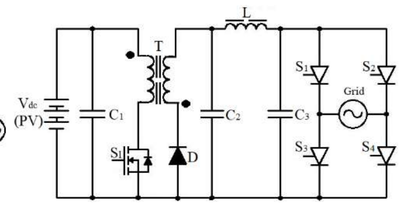

Fig.18

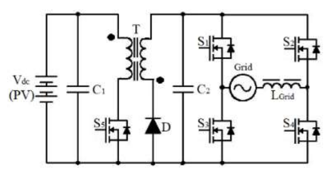

Fig.19

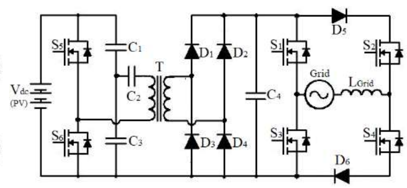

Fig.20

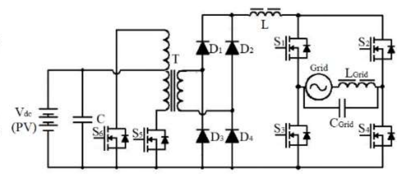

Fig.21

Figure 16. Cascaded H-bridge MLI employing a front-end unified converter,
Figure 17. Dual two-transistor fly-back-type inverter,
Figure 18. Fly-back DC-to-DC converter with an unfolding DC-to-AC inverter,
Figure 19. Fly-back DC-to-DC converter with PWM DC-to-AC inverter,
Figure 20. Series-resonant DC-to-DC converter with bang-bang DC-to-AC inverter,
Figure 21. Soladin 120 commercial inverter topology.

The converter integrates a buck-boost and fly-back converter into a single DC-to-DC converter, comprising a single DC-voltage source, one transformer, and two H-bridge cells. The top capacitor (C1) is charged via a buck-boost circuit, whereas the lower capacitor (C2) is charged by a fly-back-operated circuit, utilizing the high-frequency transformer in place of the buck-boost inductor. This topology enables the synthesis of five output voltage levels using a single independent DC-voltage source.

The inverter topologies shown in Figs. 17 and 18 are designed to connect PV modules to a single-phase grid. A 160-W buck-boost converter is shown in Fig.17. [25] Similarly, S. Mekhilef et al. [26] proposed a fly-back DC-to-DC converter combined with a line-frequency unfolding inverter, as shown in Fig.18. A similar 100-W inverter architecture was reported in [27], with the grid filter relocated from the DC-link to the grid side. The line-frequency inverter utilizes thyristors, which require a current at the gate terminal for switching, posing a challenge.

The inverter in Fig.19 consists of a 100-W fly-back DC-to-DC-converter cascaded with a PWM DC-to-AC inverter. The output stage was implemented using a four-switch configuration operating at a high frequency [28]. M. Meinhardt et al. [29] proposed a 110-W series-resonant DC-to-DC converter with a high-frequency inverter topology, as shown in Fig.20. This topology features a series resonant converter, which is notable for being one of the earliest resonant converter implementations.

The grid-facing inverter was modified with two additional diodes to prevent rectifier operation and eliminate the inrush current during grid connection. A 250-W system with similar characteristics was described in [30]. Based on the structure in Fig.21, S. B. Kjaer proposed a "plug-and-play" inverter design [31], commercialized as the Mastervolt Soladin 120, which features a dual-stage topology without built-in power decoupling. The inverter operates at 90 W nominal input power (20-40V) and utilizes PV modules as the DC-source, with a 2 × 1000 mF, 50V capacitor serving as an energy buffer.

E. Z-source inverter-based MLI topologies

To overcome the limitations of traditional voltage source inverters (VSIs) and current source inverters (CSIs), a single-stage Z-source inverter (ZSI) was introduced [32]–[34]. The ZSI achieves voltage boosting by introducing a shoot-through zero state, during which two switches in the same leg or all switches are turned on simultaneously. The traditional six active switching states remain unchanged, whereas zero states are partially or fully replaced by shoot-through states to achieve the desired voltage boost [35]. However, ZSIs have limitations, including high-voltage stress, low boost factors, and large inrush currents. Recent modifications [36]–[40] have addressed these issues. Fig.23 illustrates a single-stage, three-phase ZSI topology, which uniquely enables the buck-boost operation in one stage. Although Z-source concepts have been applied in some MLIs for improved gain and EMI compatibility, their full potential remains untapped. Researchers have explored modular multilevel inverters to expand the Z-source viability. The switched inductor (SL) concept [41] has been integrated into traditional Z-source networks, yielding a novel SL Z-source architecture [42] with an enhanced boosting gain and reduced component stress.

M. R. Banaei et al. proposed a novel RDC-MLI topology [43], comprising a cascaded basic unit with a single Z-source, DC- voltage source, and H-bridge inverter. This design reduces the number of power semiconductor switches compared with

traditional MLIs. As shown in Fig.24, the topology enables the output voltage amplitude to exceed the DC-source voltage summation through the impedance network shoot-through state control, enhancing the reliability against short circuits. The proposed inverter significantly reduces the THD of the injected voltage. Leveraging the shoot-through and voltage-boost capabilities of the Z-source inverter, the design integrates a dynamic voltage restorer (DVR) circuit.

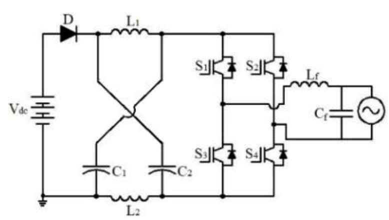

Fig.22

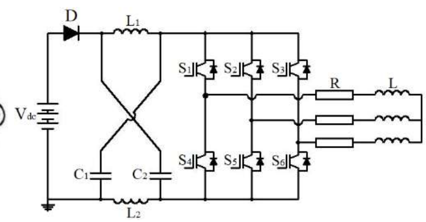

Fig 23

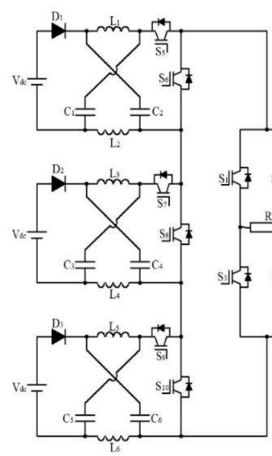

Fig.24

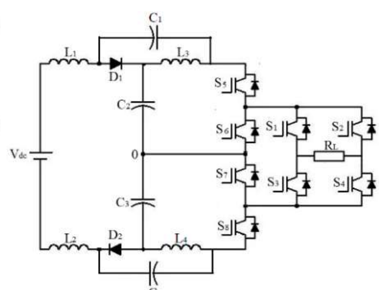

Fig.25

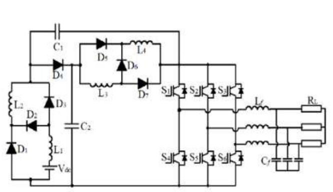

Fig.26

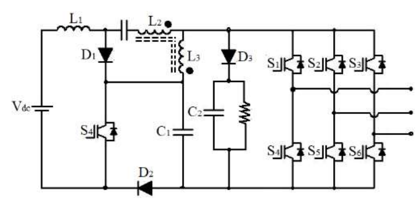

Fig.27

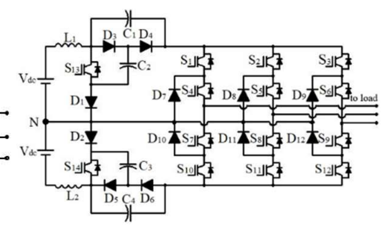

Fig.28

Figure 22. Schematic of ZSI,
Figure 23. Classical ZSI,
Figure 24. Seven-level MLI-based Z-source,
Figure 25. Hybrid quasi-Z-source network-MLI (qZSN),
Figure 26. Current-switched inductor quasi-Z-source inverter (cSL-qZSI),
Figure 27. Extended QMCAIS for hybrid output,
Figure 28. A switched-capacitor-based quasi-switched boost neutral-point-clamped single-stage MLI

Anh-Vu Ho et al. proposed a novel hybrid quasi-Z-source network MLI (qZS-NMI) architecture for solar systems [44], as illustrated in Fig. 25. The design combines an impedance source network with a high-frequency three-level switching unit and a low-frequency single-phase inverter. An effective modulation strategy based on phase-shifted disposition (PSD) scheme regulates the shoot-through states for both boost and buck output voltage states. The proposed topology reduces the number of circuit components, operates reliably, and provides a constant input current. The updated modulation method seamlessly integrates upper-shoot-through (UST) and lower shoot-through (LST) states using classic sine modulation, enabling straight forward implementation.

M. K. Nguyen et al. [45] and Abualkasim Bakeer et al. [46] proposed the continuous input current switched inductor quasi-Z-source inverter (cSL-qZSI) and modified topology switched inductor quasi-Z-source inverter (MTSL-QZSI), respectively. The MTSL-QZSI topology, depicted in Fig. 26, replaces the middle diode (D6) with a bootstrap capacitor in the second switched cell, thereby reducing the component count. This design provides a continuous input current, common-mode connection, and increased conversion efficiency owing to the use of a capacitor instead of a diode. The benefits include a larger boost factor, lower output filter size, and enhanced performance compared to the traditional cSL-qZSI.

Avneet Kumar et al. presented a high-gain. quasi-mutually coupled active impedance source (QMCAIS) converter topology [46], as shown in Fig.27. This design utilizes an autotransformer concept to enhance the effective number of turns and reduce the component count. The coupled inductor network stores energy proportional to the turns ratio, thereby achieving a high boost factor. The proposed converter attains a maximum gain across a wide duty cycle range, reducing the conduction loss and improving the output voltage profile. Compared to SL-Y source converters, it offers lower component utilization, a constant input current, and a reduced input current ripple, thereby minimizing battery stress.

T. Ajaykumar et al. proposed a switched-capacitor-based quasi-switched boost neutral-point-clamped single-stage MLI [47], as shown in Fig.28. This topology converts low-level DC-voltage from renewable sources to AC-output-voltage in a single step, achieving a high voltage gain with reduced voltage stress on the switches, diodes, and capacitors. The proposed inverter offers a larger boost factor, fewer passive components, and lower voltage stress than existing impedance-source MLIs. Additionally, it requires lower-rated components in the Z-network, and capacitor voltage stress decreases as the number of switched-capacitor cells increases.

F. Current-Fed Switched Inverter-Based MLI Topologies

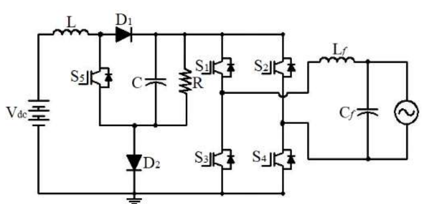

Fig.29

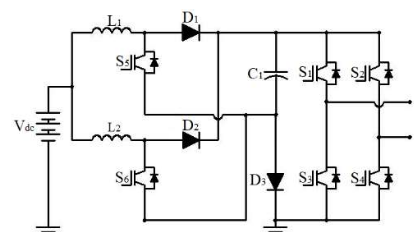

Fig.30

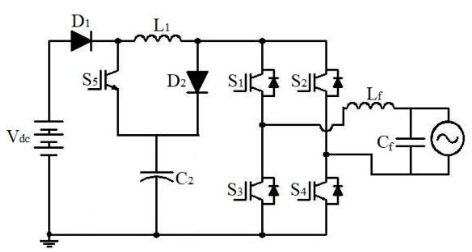

Fig.31

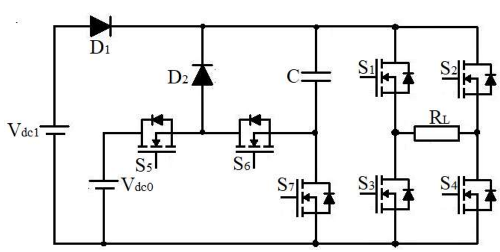

Fig.32

Figure 29. Current-fed switched inverter (CFSI),
Figure 30. Interleaved CFSI (ICFSI),
Figure 31. Current-fed switched inverter (CFSI),
Figure 32. Seven level-switched-capacitor MLI (SCMLI).

Anil Gambhir et al. presented a study on current-fed switching inverter (CFSI) [48], as depicted in Fig.29. CFSI offers single-stage conversion, inherent shoot-through protection, and buck-boost capabilities. However, impedance source inverters (ISIs) often operate at higher DC-link voltages, increasing voltage stress on capacitors and switches. To mitigate this, a novel pulse-width modulation (PWM) method for active front-end based ISI (AFE-ISI) is proposed, enabling large AC-gain while reducing voltage stress. This approach combines benefits of boost-VSI and ISIs, reducing inductor current ripple, AC-output voltage THD, and enhancing efficiency. Although it increases RMS current of switch S5 and diode D2, the proposed PWM technique improves overall performance.

As illustrated in Fig.30, Sonam Acharya et al. suggested a unique interleaved topology for a current-fed switching inverter (CFSI) (ICFSI) [49]. CFSI is a high-gain inverter architecture that is well-suited to applications with low input DC source voltage, such as rooftop solar cells. It is ideal for low-power stand-alone inverter applications because of the high step-up ratio between the AC-output and DC-input, as well as the inherent shoot-through protection. A PWM technique for driving this interleaved topology has also been proposed.

Soumya Shubhra Nag et al. put forward a high-boost inverter construction in line with a current-fed DC-to-DC converter architecture [50]. CFSI topology, shown in Fig.31, operates in the two boost and buck modes, offering enhanced EMI noise resilience. By incorporating a shoot-through interval, the converter achieves high gain. This paper details the CFSI circuit design, steady-state-characteristics, PWM switching mechanism, and modulation index constraint. A comparative analysis with traditional boost VSI, switched boost inverter (SBI), and-ZSI highlights the advantages and limitations of CFSI.

S. Raghu-Raman et al. proposed a switched capacitor MLI (SC-MLI) topology [51] for high-frequency AC-power distribution systems, as shown in Fig.32. The topology is well-suited for applications involving asymmetric DC- voltage sources, such as renewable energy farms, AC-micro-grids, and electric vehicles. The seven-level SCMLI topology inherently solves capacitor voltage balancing issues, with levels corresponding to input voltages.

TABLE I: COMPARISON OF ACTIVE FRONT END (AFE)-REDUCED DEVICE COUNT (RDC)-MULTILEVEL INVERTER (MLI) TOPOLOGIES

Fig. No.	Ref.	Topology	Switches	Diode (D)	Inductor (L)	Capacitor (C)	Transformer	DC-source	AFE-converter	Switching frequency	1Ph/3Ph	Polarity generation	Efficiency η (%)	Output THD (Vo)	RDC topology	Applications
1	Geoffrey R. Walker et.al. [4]	Non-isolated dc-to-dc boost converter based dc–ac inverter	5	1	1	1	0	1	Boost	–	1	H-bridge	94	–	Yes	Renewable Energy
2	R. Uthirasamy et al. [5]	Two-stage cascaded H-bridge (CHB) boost-five-level inverter (CHB-BFLI)	10	2	2	2	0	2	Boost	–	1	Cascaded H-Bridge	–	–	Yes	–
3	Nasrudin A.Rahim et al. [7]	Single-phase seven-level grid-connected inverter for photo-voltaic (PV) systems	7	10	1	4	0	1	Boost	–	1	H-bridge	–	3.90 %	Yes	Grid-connected inverter for photo-voltaic (PV) systems
4	Ramasami Uthirasamy et al. [12]	Boost dc-link cascaded multilevel inverter (BDCL CMLI)	10	2	2	2	0	2	Boost	–	1	H-bridge	–	4.16 %	Yes	UPS and AC-Drive
5	Miaosen Shen	Three-phase PWM	7	1	1	1	0	1	Boost	–	3	Three-arm-	–	–	Yes	Hybrid electric

	et al. [13]	inverter with a dc-to-dc boost converter										bridge				and fuel cell vehicles
6	Minh-Khai Nguyen et al. [14]	Single-stage qCHB-FLBI	8	4	2	2	0	2	qCHB Z-Source	–	1	H-bridge	–	–	Yes	–
7	Zaohong Yang et.al [15]	Switch-mode dc-to-ac inverter using the bidirectional buck converter	5	1	1	1	0	1	Buck	50	1	H-bridge	–	2.40 %	Yes	–
8	Law Kah Haw et al. [16]	Single-phase five-level inverter using two cascaded H-bridges configuration	10	2	2	2	0	2	Buck	1.6	1	H-bridge	97	23.45 %	Yes	Power system, STATCOM
9	Eltaib Abdeen et al. [17]	Three-phase single-stage buck-boost Inverter (BBI)	7	0	1	1	0	1	Buck-Boost	10	3	Three-arm-bridge	–	–	Yes	AC grid application
10	Tang et al. [18]	Active buck– boost full bridge inverter (ABI)	8	0	1	1	0	1	Buck-Boost	20	1	H-bridge	96.40	–	Yes	AC grid application
11	Wang Liqiao et. al.	Five-level buck-boost inverter	8	0	2	0	0	1	Buck-Boost	24	1	H-bridge	–	22.65 %	Yes	Renewable Energy generation
12	Saha and Sundarsingh [20]	Two-stage nonisolated buck-boost inverter	6	3	2	2	0	1	Buck-Boost	36	1	H-bridge	–	–	Yes	PV(Small DG system),
13	[20]	Two-stage isolated buck-boost inverter	5	1	1	2	0	1	Buck-Boost	36	1	H-bridge	–	–	Yes	PV Grid connected only
14	Funabiki et al. [22]	Buck-boost inverter	7	6	2	1	0	1	Buck-Boost	5.2 - 17	1	H-bridge	–	–	Yes	Standalone (wind, PV)
15	Z. Zhao et al. [23]	quad-modal BBI	6	2	2	1	0	1	Cascaded Buck Boost	–	1	H-bridge	98.50	–	Yes	Grid connected application
16	Seong-hye Kim et.al. [24]	Cascaded H-bridge MLI employing a front -end unified converter	9	2	0	2	1	1	Buck-Boost & Fly-back	20	1	Cascaded H-Bridge	–	–	Yes	–
17	-	Dual two-transistor fly back-type inverter	6	1	1	1	1	1	Fly-back	–	1	H-bridge	–	–	Yes	PV grid application

18	S. Mekhilef et.al. [26]	Fly-back dc-to-dc converter together with a line-frequency dc-to-ac unfolding inverter	5	1	1	3	1	1	Fly-back	–	1	H-bridge	–	–	Yes	PV grid application
19	[28]	Fly-back dc-to-dc converter with PWM dc-to-ac inverter	5	1	0	2	1	1	Fly-back	–	1	H-bridge	–	–	Yes	PV grid application
20	M. Meinhardt. et.al. [29]	Series-resonant dc-to-dc converter with bang-bang dc-ac inverter	6	6	0	3	1	1	Series-Resonant	–	1	H-bridge	–	–	Yes	PV grid application
21	S. B. Kjaer [31]	Soladin 120commercial inverter (“plug-and-play” inverter)	6	4	1	1	1	1	Fly-back	–	1	H-bridge	–	–	Yes	PV grid application
22	[32]-[34].	Z-Source Inverter (ZSI)	4	1	2	2	0	1	Z-Source	–	1	H-bridge	–	–	Yes	–
23	-	Classical Z-source inverter	6	1	2	2	0	1	Z-Source	–	3	Three-arm bridge	–	–	Yes	–
24	M.R. Banaei et.al. [43]	Seven-level multilevel inverter-based Z-source	10	3	6	6	0	3	Z-Source	–	3	H-bridge	–	24.27 %	Yes	Power system-Power quality-DVR
25	Anh-Vu Ho et.al [44]	Hybrid quasi- Z-source network multilevel inverter (qZSN)	8	2	4	4	0	1	qZSI	5	1	H-bridge	97	–	Yes	Renewable energy system-PV, fuel cell
26	M. K.Nguyen et.al. [45]	Current switched inductor quasi Z-Source Inverter (cSL-qZSI)	6	7	4	2	0	1	qZSI		3	–	–	–	Yes	–
27	Avneet Kumar et.al [46]	Extended QMCAIS for hybrid outputs	7	3	2	2	1	1	Quasi Mutually coupled active Z-Source converter	20	3	Three-arm-bridge	94	–	Yes	Standalone AC applications
28	T. Ajaykumar et.al. [47]	Switched-capacitor-based quasi-switched boost neutral-point-	14	12	2	4	0	2	Quasi Switched boost NPC	5	3	–	90.89	–	Yes	Renewable

		clamped single-stage multilevel inverter													
29	Anil Gambhir et.al. [48]	Current-fed Switched Inverter(CFSI)	5	2	1	1	0	1	Impedace Source Inverter (ISI)	75 SiC	1	H-bridge	90.20	3.45 %	Yes	–
30	SonamAcharya et.al. [49]	Interleaved CFSI (ICFSI)	6	3	2	1	0	1	Interleaved Topology CFSI	25-100	1	H-bridge	93.50	2.78 %	Yes	Standalone rooftop PV
31	Soumya Shubhra Nag et al. [50]	Current-Fed Switched Inverter) CFSI	5	2	1	1	0	1	CFSI		1	H-bridge	–	–	Yes	Renewable energy-farm based AC micro-grid
32	S. Raghu Raman, et al. [51]	Seven level-switched-capacitor multilevel inverter (SCMLI)	7	2	0	1	0	2	Switched Capacitor		1	H-bridge	–	–	Yes	Electric vehicle

III. Conclusions

This paper presents a comprehensive study of various high-frequency operable AFE-RDC-MLI topologies with H-bridge configurations. These application-oriented multilevel inverters are designed primarily from traditional topologies or their hybrids, significantly reducing device counts and gate drivers. Moreover, the DC-bus voltage can be significantly reduced to achieve the same performance as traditional configurations. The presence of a DC-to-DC converter as the front-end converter enables these topologies to generate improved voltage and current waveforms with reduced THD and exhibit high dynamic performance. Advanced control strategies developed for DC-to-DC converters can be directly applied to these types of topologies, thereby enhancing system flexibility. Since the AFE converter operates at high switching frequencies, replacing silicon-controlled devices with WBG devices, such as silicon carbide (SiC) or gallium nitride (GaN), can significantly enhance topology performance. WBG devices are particularly well-suited for high-frequency switching operations, offering several key advantages when integrated into existing topologies.

References

[1] X. Yuan and I. Barbi, "Fundamentals of a new diode clamping multilevel inverter,"IEEE Transactions on power electronics, vol. 15, no. 4, pp. 711–718, 2000.

[2] M. F. Escalante, J.-C. Vannier, and A. Arzande, "Flying capacitor multilevel inverters and dtc motor drive applications,"IEEE Transactions on Industrial Electronics, vol. 49, no. 4, pp. 809–815, 2002.

[3] L. Tolbert, F. Z. Peng, T. Cunnyngham, and J. N. Chiasson, "Charge balance control schemes for cascade multilevel converter in hybrid electric vehicles," IEEE transactions on industrial electronics, vol. 49, no. 5, pp. 1058–1064, 2002.

[4] G. R. Walker and P. C. Sernia, "Cascaded dc-dc converter connection of photovoltaic modules," IEEE transactions on power electronics, vol. 19, no. 4, pp. 1130–1139, 2004.

[5] V. K. C. R. Uthirasamy, U. S. Ragupathy and C. Megha, "Experimentation of boost chopper interfaced cascaded multilevel inverter topology for photo voltaic applications," Int. Rev. Electr. Eng., vol. 9, no. 1, p. 16–25, 2014.

[6] A. Mora, J. Juliet, A. Santander, and P. Lezana, "Dead-time and semiconductor voltage drop compensation for cascaded h-bridge converters," IEEE Transactions on industrial electronics, vol. 63, no. 12, pp. 7833–7842, 2016.

[7] N. A. Rahim, K. Chaniago, and J. Selvaraj, "Single-phase seven-level gridconnected inverter for photovoltaic system," IEEE transactions on industrial electronics, vol. 58, no. 6, pp. 2435–2443, 2010.

[8] V. Agelidis, D. Baker, W. Lawrance, and C. Nayar, "A multilevel pwm inverter topology for photovoltaic applications," in ISIE'97 Proceeding of the IEEE International Symposium on Industrial Electronics, vol. 2. IEEE, 1997, pp. 589–594.

[9] S.-J. Park, F.-S. Kang, M. H. Lee, and C.-U. Kim, "A new single-phase fivelevel pwm inverter employing a deadbeat control scheme," IEEE Transactions on power electronics, vol. 18, no. 3, pp. 831–843, 2003.

[10] J. Selvaraj and N. A. Rahim, "Multilevel inverter for grid-connected pv system employing digital pi controller," IEEE transactions on industrial electronics, vol. 56, no. 1, pp. 149–158, 2008.

[11] N. A. Rahim and J. Selvaraj, “Multistring five-level inverter with novel pwm control scheme for pv application,” IEEE transactions on industrial electronics, vol. 57, no. 6, pp. 2111–2123, 2009.
[12] R. Uthirasamy, U. S. Ragupathy, and V. Kumar Chinnaiyan, “Structure of boost dc-link cascaded multilevel inverter for uninterrupted power supply applications,” IET Power Electronics, vol. 8, no. 11, pp. 2085–2096, 2015.
[13] M. Shen, A. Joseph, J. Wang, F. Z. Peng, and D. J. Adams, “Comparison of traditional inverters and z-source inverter for fuel cell vehicles,” IEEE Transactions on power electronics, vol. 22, no. 4, pp. 1453–1463, 2007.
[14] M.-K. Nguyen and T.-T. Tran, “Quasi cascaded h-bridge five-level boost inverter,” IEEE Transactions on industrial electronics, vol. 64, no. 11, pp. 8525– 8533, 2017.
[15] Z. Yang, “Bidirectional dc-to-ac inverter with improved performance,” IEEE Transactions on Aerospace and Electronic Systems, vol. 35, no. 2, pp. 533–542, 1999.
[16] L. K. Haw, M. S. Dahidah, and H. A. Almurib, “She–pwm cascaded multilevel inverter with adjustable dc voltage levels control for statcom applications,” IEEE Transactions on Power Electronics, vol. 29, no. 12, pp. 6433–6444, 2014.
[17] E. Abdeen, M. A. Gaafar, and M. Orabi, “Performance analysis for single-stage buck-boost inverter,” in 2019 International Conference on Innovative Trends in Computer Engineering (ITCE). IEEE, 2019, pp. 587–592.
[18] Y. Tang, X. Dong, and Y. He, “Active buck–boost inverter,” IEEE Transactions on Industrial Electronics, vol. 61, no. 9, pp. 4691–4697, 2013.
[19] Y. Tang, F. Xu, Y. Bai, and Y. He, “Comparative analysis of two modulation strategies for an active buck–boost inverter,” IEEE Transactions on Power Electronics, vol. 31, no. 11, pp. 7963–7971, 2015.
[20] S. Saha and V. Sundarsingh, “Novel grid-connected photovoltaic inverter,” IEE proceedings. Generation, transmission and distribution, vol. 143, 1996.
[21] Y. Xue, L. Chang, S. B. Kjaer, J. Bordonau, and T. Shimizu, “Topologies of single-phase inverters for small distributed power generators: an overview,” IEEE transactions on Power Electronics, vol. 19, no. 5, pp. 1305–1314, 2004.
[22] S. Funabiki, T. Tanaka, and T. Nishi, “A new buck-boost-operation-based sinusoidal inverter circuit,” in 2002 IEEE 33rd Annual IEEE Power Electronics Specialists Conference. Proceedings (Cat. No. 02CH37289), vol. 4. IEEE, 2002, pp. 1624–1629.
[23] Z. Zhao, M. Xu, Q. Chen, J.-S. Lai, and Y. Cho, “Derivation, analysis, and implementation of a boost–buck converter-based high-efficiency pv inverter,” IEEE Transactions on Power Electronics, vol. 27, no. 3, pp. 1304–1313, 2011.
[24] S.-h. Kim, H.-T. Kim, J.-s. Park, and F.-s. Kang, “Unification of buck-boost and flyback converter for driving cascaded h-bridge multilevel inverter with single independent dc voltage source,” in Journal of international Conference on Electrical Machines and Systems, vol. 2, no. 2. Journal of International Conference on Electrical Machines and Systems, 2013, pp. 190–196.
[25] M. Nagao and K. Harada, “Power flow of photovoltaic system using buck-boost pwm power inverter,” in Proceedings of Second International Conference on Power Electronics and Drive Systems, vol. 1. IEEE, 1997, pp. 144–149.
[26] S. Mekhilef, N. Rahim, and A. Omar, “A new solar energy conversion scheme implemented using grid-tied single phase inverter,” in 2000 TENCON Proceedings. Intelligent Systems and Technologies for the New Millennium (Cat. No. 00CH37119), vol. 3. IEEE, 2000, pp. 524–527.
[27] E. Achille, T. Martire, C. Glaize, and C. Joubert, “Optimized dc-ac boost converters for modular photovoltaic grid-connected generators,” in 2004 IEEE International Symposium on Industrial Electronics, vol. 2. IEEE, 2004, pp. 1005–1010.
[28] D. C. Martins and R. Demonti, “Grid connected pv system using two energy processing stages,” in Conference Record of the Twenty-Ninth IEEE Photovoltaic Specialists Conference, 2002. IEEE, 2002, pp. 1649–1652.
[29] M. Meinhardt, T. O’Donnell, H. Schneider, J. Flannery, C. Mathuna, P. Zacharias, and T. Krieger, “Miniaturised" low profile" module integrated converter for photovoltaic applications with integrated magnetic components,” in APEC’99. Fourteenth Annual Applied Power Electronics Conference and Exposition. 1999 Conference Proceedings (Cat. No. 99CH36285), vol. 1. IEEE, 1999, pp. 305–311.
[30] A. Lohner, T. Meyer, and A. Nagel, “A new panel-integratable inverter concept for grid-connected photovoltaic systems,” in Proceedings of IEEE International Symposium on Industrial Electronics, vol. 2. IEEE, 1996, pp. 827–831.
[31] S. B. Kjar, Design and control of an inverter for photovoltaic applications. Institut for Energiteknik, Aalborg Universitet, 2005.
[32] F. Z. Peng, “Z-source inverter,” IEEE Transactions on industry applications, vol. 39, no. 2, pp. 504–510, 2003.
[33] F. Z. Peng, X. Yuan, X. Fang, and Z. Qian, “Z-source inverter for adjustable speed drives,” IEEE power electronics letters, vol. 1, no. 2, pp. 33–35, 2003.
[34] Y. Huang, M. Shen, F. Z. Peng, and J. Wang, “z-source inverter for residential photovoltaic systems,” IEEE transactions on power electronics, vol. 21, no. 6, pp. 1776–1782, 2006.
[35] T. Bulo, B. Sahan, C. Noding, and P. Zacharias, “Comparison of three-phase inverter topologies for grid-connected photovoltaic systems,” in Proc. 22nd Eur. Photovolt. Sol. Energy Conf. Exhib., Milan, Italy, 2007.
[36] F. Gao, P. C. Loh, D. Li, and F. Blaabjerg, “Asymmetrical and symmetrical embedded z-source inverters,” IET power electronics, vol. 4, no. 2, pp. 181–193, 2011.
[37] R. Strzelecki, M. Adamowicz, N. Strzelecka, and W. Bury, “New type t-source inverter,” in 2009 Compatibility and Power Electronics. IEEE, 2009, pp. 191–195.
[38] M. Adamowicz and N. Strzelecka, “T-source inverter,” Electrical Review, vol. 85, no. 10, pp. 1–6, 2009.

[39] W. Qian, F. Z. Peng, and H. Cha, "Trans-z-source inverters," IEEE transactions on power electronics, vol. 26, no. 12, pp. 3453–3463, 2011.
[40] R. Strzelecki and M. Adamowicz, "Boost-buck inverters with cascaded qz-type impedance networks," Electrical Review, vol. 86, no. 2, pp. 370–375, 2010.
[41] M. Zhu, K. Yu, and F. L. Luo, "Switched inductor z-source inverter," IEEE Transactions on Power Electronics, vol. 25, no. 8, pp. 2150–2158, 2010.
[42] M.-K. Nguyen, Y.-C. Lim, and G.-B. Cho, "Switched-inductor quasi-z-source inverter," IEEE Transactions on Power Electronics, vol. 26, no. 11, pp. 3183–3191, 2011.
[43] M. Banaei, A. Dehghanzadeh, E. Salary, H. Khounjahan, and R. Alizadeh, "Zsource-based multilevel inverter with reduction of switches," IET power electronics, vol. 5, no. 3, pp. 385–392, 2012.
[44] A.-V. Ho and T.-W. Chun, "A buck-boost multilevel inverter for pv systems in smart cities," in International Conference on Industrial Networks and Intelligent Systems. Springer, 2017, pp. 295–306.
[45] M.-K. Nguyen, Y.-C. Lim, and J.-H. Choi, "Two switched-inductor quasi-zsource inverters," IET Power Electronics, vol. 5, no. 7, pp. 1017–1025, 2012.
[46] A. Kumar, S. Kamal, M. Raghuram, D. Deepankar, S. K. Singh, and X. Xiong, "High gain quasi-mutually coupled active impedance source converter utilizing reduced components count," IEEE Transactions on Industry Applications, vol. 55, no. 6, pp. 6376–6388, 2019.
[47] T. Ajaykumar and N. R. Patne, "Switched-capacitor-based neutral-point-clamped quasi-switched boost multilevel inverter," Arabian Journal for Science and Engineering, vol. 45, no. 3, pp. 1765–1775, 2020.
[48] A. Gambhir, S. K. Mishra, and A. Joshi, "A modified pwm scheme to improve performance of a single-phase active-front-end impedance source inverter," IEEE Transactions on Industry Applications, vol. 55, no. 1, pp. 928–942, 2018.
[49] S. Acharya and S. K. Mishra, "Interleaved current-fed switched inverter," IEEE Transactions on Power Electronics, vol. 35, no. 7, pp. 7015–7030, 2019.
[50] S. S. Nag and S. Mishra, "Current-fed switched inverter," IEEE Transactions on Industrial Electronics, vol. 61, no. 9, pp. 4680–4690, 2013.
[51] S. R. Raman, K. W. E. Cheng, and Y. Ye, "Multi-input switched-capacitor multilevel inverter for high-frequency ac power distribution," IEEE Transactions on Power Electronics, vol. 33, no. 7, pp. 5937–5948, 2017.

	HAREESH A received the Bachelor of Technology Degree in Electrical and Electronics Engineering from Government Engineering College, Idukki, Kerala, India in 2008, and Master of Technology in Electrical Engineering specialized in Power Systems from Government Engineering College, Thrissur, Kerala, India in 2011. Ph.D. Degree in Electrical Engineering from Government Engineering College, Thrissur, affiliated to A. P. J. Abdul Kalam Technological University, Kerala, India 2024. He is currently working in Government Industrial Training Institute, Theruvambady, Kerala. His research interest includes Power Electronics, Drives, Multilevel Inverters, Power Quality and Power Systems.
	ADHIPA K R was born in Kerala, India, in 1995. She received the B.Tech. degree in Electrical and Electronics Engineering from the University of Calicut, Kerala, India, in 2016, and the M.Tech. degree in Power Systems from Government Engineering College, Thrissur, Kerala, India, in 2019. She is currently working as an Assistant Professor in the Department of Electrical and Electronics Engineering at Thejus Engineering College, Kerala, India. She is also pursuing her Ph.D. in Power Electronics at APJ Abdul Kalam Technological University, Kerala, India. Her research interests include power electronic converters and motor control.
	VISHNU P MADHANMOHAN He received his B.Tech. degree in Electrical and Electronics Engineering from Calicut University, India, in 2009, and his M.Tech. degree in Power Electronics Engineering from Visvesvaraya Technological University, Belagavi, India, in 2012. He obtained his Ph.D. from APJ Abdul Kalam Technological University in 2022. He is currently serving as an Assistant Professor in the Department of Electrical and Electronics Engineering at Christ College of Engineering, Irinjalakuda. His research focuses on analyzing the causes and effects of partial shading in solar photovoltaic systems. His broader research interests include the integration and efficient utilization of renewable energy sources.
	JAYANAND B is currently a Professor at the Department of Electrical and Electronics Engineering in SCMS School of Engineering and Technology, Karukutty, Kerala, India. He received Bachelor of Technology Degree from Government Engineering College, Thrissur in 1987 and Master of Technology from IIT Madras in 1989. He received PhD from IIT Madras in 1998. His teaching career has spanned through Govt. Engineering Colleges at Kannur, Thrissur, Kozhikode and Idukki. He had received Career Award for Young Teachers of AICTE in the year 2000. He had also functioned as Chairman, Board of Electrical Engineering streams of Calicut University and Kerala Technological University, Kerala, India. He had also associated with consultancy projects for Industries. His Fields of interest include: Power Electronics, Drives, Neural Network applications to Power Electronics, FACTS, Real Time DSP Implementations.