

Impact of DC-DC Converters for Photovoltaic Systems: A Comprehensive Study

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Abstract- In recent years, researchers have drawn significant attention to the use of sources of sustainable energy. The power generated by photovoltaic (PV) sources is still inadequate, and the corresponding costs are still substantial. Therefore, efforts are still being made to enhance the PV converter and controller to increase the effectiveness and affordability of power extraction. Non-isolated DC-DC converters received special attention during the process of extraction of electric power from PV. The abundance of non-isolated elevated-performance DC-DC boost converters interconnected with PV sources has made it crucial to analyze and categorize them thoroughly. The energy acquired from a solar panel is increased using different MPPT techniques. This work investigates and evaluates the critical characteristics of stand-alone and grid-interfaced DC-DC converters. The non-isolated high boosts DC-DC converters are categorized into multiple classifications and reviewed based on recommended and generalized configurations in this study. To provide a basis for comparing new configurations or selecting the best converter for a given application, the characteristics of each structure and control scheme are presented alongside their usual applications.

Keywords: DC-DC Converter, MPPT, High Voltage Gain, Photovoltaic, Converter topologies

Nomenclature

ANFIS	Adaptive neuro-fuzzy inference system	QBC	Quadratic boost converter
ANN	Artificial neural network	QRHGHE	Quasi-resonant high-gain high-efficiency
BO	Butterfly algorithm	QZS	Quasi Z-source
CBC	Cascaded boost converter	RC	Ripple correlation
CI	Couple inductor	RCC	Ripple correlation control
CIBuBoC	Couple inductor buck-boost converter	RES	Renewable energy source
CS	Couple switch	RMPP	Rated maximum power point
ESC	Energy storage cell	SC	Switch capacitor
ESCB	Extended switch capacitor-based	SCEVG	Switched capacitor-based non-isolated enhanced voltage gain
FLC	Fuzzy logic control	SCDS	SC-based dual switch

FSC	Fractional short circuit	SEPIC	Single-ended primary inductor converter
FOCV	Fractional open-circuit voltage		
GMPP	Global maximum power point	SMC	Sliding mode control
GWO	Grey wolf optimization	S-SCZS	Symmetrical switch capacitor bases Z source
HC	Hill climbing	TBC	Three-level boost converter
HVG	High voltage gain	VDC	Voltage doubler circuit
IC	Incremental conductance	VG	Voltage gain
ICBC	Integrated cascaded boost converter	VMC	Voltage multiplier cell
I_{MPP}	Current at MPP (A)	V_{MPP}	Voltage at MPP (V)
INR	Incremental resistance	V_{oc}	Open-circuit voltage (V)
I_{sc}	Short-circuit current (A)	V_{ss}	Voltage across the switch
MMCC	Multilevel modular capacitor clamped	WCCI	Winding cross couple inductor
MPPT	Maximum power point tracking	ZCS	Zero current switching
NOC	Number of components	ZSCBC	Z-source switch capacitor-based converter
OCC	One cycle control	ZVS	Zero voltage switching
PSO	Particle swarm optimization		
PV	Photovoltaic		
P&O	Perturb and observe		

1. Introduction

In the past few years, there has been a dramatic increase in interest in solar energy because of its abundant resource reserves, widespread distribution, and lack of pollution. Furthermore, distributed photovoltaic (PV) power production is a significant area for study and application [1]. Given that the sun irradiance and the cell's accessible temperature are the two climatic factors that determine how much power a PV source can deliver. These variables change based on the state of the atmosphere and are not constant. PV modeling, maximum power point tracking (MPPT) methods, high-rise DC-DC converter construction, duty cycle management, and efficiency enhancement have all been studied in the field of solar energy [2]. Continuous power supply variation is the primary problem with solar power generation. Therefore, MPPT must be used with power electronic converters [3]. Owing to the sporadic behavior of solar energy, storage components like batteries should be installed to give the load a steady and constant power supply [4]. Additionally, a DC-DC converter with substantial voltage gain is required to scale up the voltage at the output for particular uses due to the constraints of PV energy sources, which possess a low output voltage that ranges from approximately 12 to 60 V [5].

Depending on their specific requirements, many converters that convert DC to DC are now used to control the input voltage. Converters are broadly categorized into two

ways: isolated and non-isolated. Isolated converters have galvanic isolation because they use a transformer that splits the output and input components of the converters [6].

Because it has a distinct ground, it cannot exert any input influence on the converter's output side. Various factors, including the converter configuration, might cause the converter's output value to have a negative or positive polarity. Isolated converters have significant disadvantages, including inductance leakage, saturation in the core, heat impact, elevated voltage spikes on switches, and considerable size, which makes them more expensive than non-isolated converters. Because there is no galvanic barrier spanning the input and output sides of a non-isolated converter architecture, fluctuations on the side of the input immediately impact the electrical output end of the converters. Compared to the isolated topology, their component density is lower [7]. However, they have some minor difficulties that must be handled, such as an extreme duty cycle proportion, inadequate voltage transformation ratio, and extra circuitry for optimal functioning. Each sort of converter arrangement has its benefits and drawbacks. The application requirements drive the selection. A comparison analysis with other recently issued papers on DC-DC converters was conducted to verify the impact of this manuscript. A synopsis of non-isolated standard DC-DC converters is narrated in [8]. These papers also discussed using traditional DC-DC converters in renewable energy sources (RES). They also include the constraints and current

advancements of traditional DC-DC converters. None of these papers have combined the standalone with grid-interfaced DC-DC converter topologies.

To raise the transformation ratio, the configuration of [9] employs m units of VMCs and n levels of the diode-capacitor cells. Nevertheless, the practical lifespan of the RES is shortened by fluctuation in input current generated by the primary switch and source being linked in series. Recently, several investigators have designed and modified the usual boost converter design to yield a considerable voltage enhancement with increased dependability and efficacy [10]–[12]. Various buck-boost designs with output that is either positive (P/O) or negative (N/O) have been established in recent years. In [13], a P/O buck-boost converter with an arrangement of buck and KY converters that runs in CCM is presented. This converter's conversion ratio is insufficient for scaling up an input voltage, limiting its applicability. Article [14] describes a single-stacked buck-boost topology using only one switch. Inevitably, it receives inconsistent input, which is a drawback when drawing a steady current, which is a better choice for RES. In other words, for improved power supervision, a continuous low-pulsed input current is necessary since MPPT requires a low ripple input current [15]. In [16], a transformerless buck-boost with a squared times transformation ratio of a regular buck-boost converter is put forward by integrating an extra switching structure into the standard converter. This converter necessitates the use of two floating switches. The paper [17] converter features a wide variety of transformation ratios and a constant input current, making it suited for RES and simplifying the design of the input filter. The typical buck-boost converter can convert voltage in steps up and down; however, its disrupted input current limits its capacity to perform optimal MPPT without huge decoupling capacitors. Although Cuk and SEPIC conversions have ongoing input currents and can perform the up and down of voltage, their enormous input current disturbances still hinder MPPT performance since the solar system varies mainly around its MPP.

The SEPIC converter and the typical boost converter can be utilized to enhance the electrical voltage of the RES. SEPIC has the potential to produce a quasi-resonant (QR) action between its middle parameters via a resonant tank within the switch's turn-on phase. As a result, the soft-switching operation can acquire the power switch without auxiliary parts, improving the converter's efficiency in contrast to the boost-based configuration. In [18], the voltage enhancement is somewhat increased by substituting a couple of inductors (CI) with the SEPIC's middle inductor. This converter employs a fundamental passive clamp circuitry (diode and capacitor) to recycle the CI's leakage energy. [19] suggests another SEPIC-based high-rise converter that uses a couple of CIs. Despite achieving an ultrahigh voltage enhancement, this converter issues from high pulsed feed current, potential stress, and significant switching and backward rebound power dissipations. The increase in voltage of the SEPIC converters described in [20] is significantly boosted by using voltage multipliers (VMs) in the manner of a voltage rectification on the other end of the

CI. Nonetheless, employing numerous components is the fundamental disadvantage of this conversion. We need a VM with a CI in the circuit's intermediate stage to attain a high gain in voltage ratio without needing big duty cycles. Using a VM and a CI within the circuit's intermediary stage allows us to achieve an elevated gain in voltage ratio despite requiring large duty cycles. Furthermore, the leaky inductor generates the zero current switching (ZCS) situation at the turn-off phase for all diodes, eliminating the diode-reversed recovery loss of power.

The z-source (ZS) and quasi-z-source (qZS) systems were recently paired with voltage-enhancing methods to offer elevated step-up conversions. ZS and qZS topologies were initially recommended to address shoot-through and constrained voltage output difficulties in classic current and voltage-fed inverters and attain buck-boost voltage enhancement [21]. As a result, the idea of boosting via ZS and qZS systems was applied to DC-DC converters. The functioning states of the standard ZS DC-DC converter were investigated in [22]. In [23], the diode at the output was substituted with an inductor to decrease the output voltage fluctuation significantly. However, replacing an inductor for the output diode reduces the resulting voltage gain compared to the regular ZS circuit. The SC scheme has been incorporated into the standard ZS network, proposing an innovative SC-interfaced ZS (SCZS) network [24]. In contrast to typical ZS converters, the resultant diode and capacitor are linked to the SCZS network in an alternative manner. As a result of this procedure, three new SCZS converters are produced. The suggested converters significantly boost voltage gain and reduce potential semiconductor device strains when compared to usual ZS converters.

A DC-DC converter must be appropriately designed and analyzed to address the drawbacks of series-connected PV panels. Fig. 1 shows the typical grid-tied PV system. PV arrays are often mounted on the roof of a home in a PV grid-tied system. For grid-tied power usage, full-bridge inverters run at approximately 375–400V [25] and half-bridge at approximately 760V [26]. Such voltage gain cannot be achieved using the traditional boost structure. Otherwise, the power semiconductor component will be under excessive duty ratio and potential stress. Because of this, numerous scientists have recently created and altered the usual boost topology to produce a high-voltage gain that is more dependable and efficient [27]–[29]. PV panels are typically connected in series as a conventional way to handle the DC bus voltage needed for inverters connected to the grid. To increase voltage and current, series-parallel PV panel combinations are not a practical option due to their high cost and considerable space constraints [30]. Therefore, to generate high-voltage outputs, it is necessary to use a converter with a high-voltage conversion ratio.

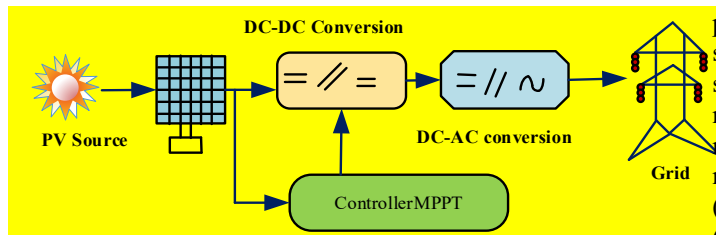


Fig. 1. Typical grid-tied PV system

The literature contains numerous examples of traditional and progressive MPPT approaches, all of which depend on regulating the boost converter's output voltage and its duty cycle [31]–[33]. The most often-used aspect of solar power output is enhancing its reliability, and scholars have been involved in developing many sophisticated MPPT systems. The existing FOCV and FSC approaches are the most complex to apply out of all the standard techniques [34]. Nevertheless, these methods are limited to low power uses due to their imprecise MPP tracking. Additional traditional MPPT methods, like perturb and observe (P&O) [35], hill climbing (HC) [36], incremental conductance (IC) [37], adjustable IC, ripple correlation (RC) [38], and incremental resistance (INR) [39], are suitable for both high- and low-power applications that require greater MPP tracking precision.

The functioning point in this P&O fluctuates around the MPP, which the proportional-integral (PI) controller can manage. The primary disadvantage of this strategy is that it cannot follow the MPP under various environmental circumstances, resulting in power loss during a perturbation. An IC strategy is used to follow the MPP with quick changes in ecological variables while avoiding the challenges of P&O. Additionally, compared to P&O, there are far fewer fluctuations around the MPP in IC. However, the main flaw with IC technology is its difficulty in application.

The HC approach is comparable to the P&O MPPT technique in tracking MPP [40]. Since voltage is used as the control variable in this instance, increasing PV voltage will increase PV power when the point of operation is on the left flank of the MPP. The voltage is increased to decrease power if the point of operation is found on the right part of the MPP. As long as the MPP is attained, this process will continue. An adjustable IC MPPT method is used to track the quick variations in irradiance and get the highest voltage for PV, almost equivalent to the V_{oc} of PV [41]. In a PV system, the converter's switching states cause fluctuation in the current and voltage. Consequently, ripple power is produced by the PV array [42]. A solar PV system's power output is controlled and extracted via RC control utilizing PV power ripples. The mutual interactions between the time derivatives of the current and voltage elements in the RC result in a zero-power gradient. As a result, the PV system's point of operation approaches the actual MPP.

Many authors have focused on evolving MPPT strategies to solve the issues with standard MPPT methodologies. Evolutionary algorithms are characterized by their capacity to handle nonlinear situations, expand the search field, and

produce understandable results. All biological algorithms and soft computing techniques are applied to maximize the PV system's nonlinear behavior. Recently, artificial neural network (ANN) [43], fuzzy logic control (FLC) [44] adaptive neuro-fuzzy inference system (ANFIS) [45], and various nature-inspired MPPTs such as particle swarm optimization (PSO) [46], cuckoo search (CS) [47], gray wolf optimization (GWO) [48], butterfly optimization (BO) [49] and more evolutionary algorithms have been incorporated. In [50], the steady-state instabilities at the MPP under dynamic radiation conditions are lessened by using the ANN technique. The ANN is trained using either the PV current and voltage, the temperatures and radiation from the sun, or any combination of the two sets of data. When the system consists of numerous layers, the main disadvantage of the ANN approach is that it necessitates a large amount of data. The most often used method for tracking MPP is the fuzzy MPPT approach, which solves nonlinear problems without requiring the computation of mathematical equations.

In contrast to ANN systems, it functions for exact and sloppy input functions. The FLC has two disadvantages: once the rules are set, they cannot be changed, and the user's knowledge is the only factor used to determine the membership function. To overcome the fuzzy approach's drawbacks, the MPP is tracked using an AFLC-based MPPT mechanism [51]. The MPPT algorithm is essential when utilizing a DC-DC converter in a PV system. It facilitates effective energy harvesting, optimizes the converter's performance, and guarantees that energy is stored and used efficiently. Several MPPT approaches that necessitate PV-fed high-gain DC-DC converters are provided to ensure the best possible performance from a solar source described in [52].

This work examines the recently developed design of many non-isolated configurations with a high conversion ratio. Furthermore, a collation and an analysis of the functioning of the various modified topologies are provided. The article is configured as follows: Section 1 briefly describes the typical DC-DC converter, inverter, and various MPPT algorithms used to detect optimum PV power. The detailed categorization of high-step-up converters suitable for PV systems is enfolded in Section 2. Section 3 provides the comparative analysis on which the researcher can design an appropriate converter for the PV system. A succinct description and a comparative study of the grid-tied DC-to-DC converter topologies are enclosed in section 4. The issues and challenges and the last thoughts for the entire work are contained in Sections 5 and 6.

2. Progression of PV-fed DC-DC Converter

A DC-DC non-isolated converter is used in PV systems that convert voltages from 12 to 60 volts to a fixed voltage at the load side. Due to the significant output demand from low input voltage, a large-step-up converter is needed. When the voltage level is equal to the grid level, traditional DC-DC converters are limited in raising the voltage to higher levels. The configurations of converters in renewable energy

systems have been examined in several papers [53], [54]. In addition, numerous studies have been conducted using a variety of novel topologies created by modifying the traditional DC-DC converter circuit [55], [56]. These have excellent efficiency and reliability and can raise voltage levels. DC-DC converters have been modified in several types to fulfill the requirement of the desired load, extracting the optimum output from the renewable source. A description of the several elevated gain DC-DC converters is given in Table 1.

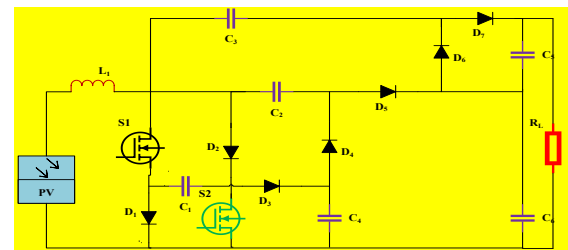
2.1.1 Characterization of boost converter

The load-side voltage value in the majority of PV applications is required to be higher than the PV voltage at the output. Under these circumstances, an MPPT controller incorporates a boost converter. With these, the voltage may be raised to extremely elevated levels while still being highly reliable and efficient. The boost converter circuit's modified structure can be classified into four distinct designs. They are high gain low power, high gain high power, and low gain low power. Among all of them, high gain low power is mostly used in PV systems. Various modifications are being compelled to enhance the gain of the converter which has already been listed above. Among all of these topologies quadratic structure is one of the most commonly used structures with PV. The equation for quadratics, which is interestingly competent in providing a remarkably larger gain at a smaller duty ratio, can be used to raise the voltage level in the quadratic boost design.

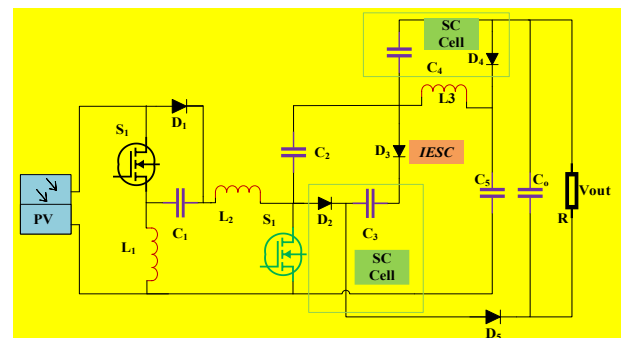
In [57], a quadratic boost converter includes single and double voltage lifting cells to enhance performance. To continuously upgrade the performance of the quadratic topology, various modifications have been carried out by many researchers [58]–[61]. When the duty cycle exceeds 0.70, the voltage transformation of the QBC increases. By raising the value of the numerator in the voltage gain equation, the VM-coupled QBC is developed to boost voltage gain. A modified version of the VM coupled CBC and VM-QBC is presented to increase the VM-QBC's performance, which is narrated in [62]. ICBC comprises an SC-based sub-converter that produces the second output tumbled with an inductor-employed sub-converter that makes the first output [63]. It should be emphasized that these hybrid converters are discrete component-based designs that offer significant power output at highly high efficacy. However, a compound approach for an integrated energy management unit is still a relatively new design idea.

This article describes many high step-up-derived-derived enhance-gain DC-DC converters utilizing the SI and SC ideas [64], [65]. These converters are limited to operating at a particular duty ratio, which results in a limited circuit efficiency with more voltage stress. There is a report of a

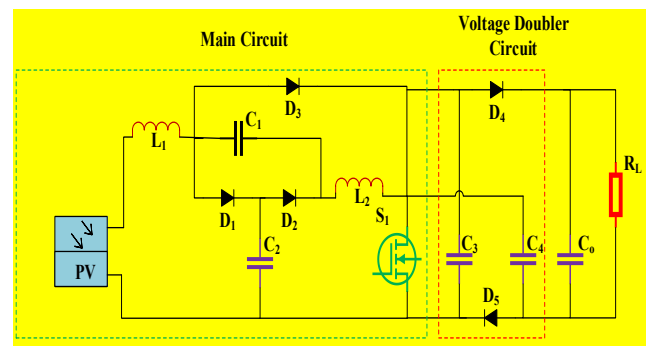
quadratic flying capacitor-based step-up converter [66]. Despite the converter using 11 components to create a gain, the switches are under more voltage and current stress. There is a reported SI-based HVG converter with soft switching [67]. Although soft switching lowers switching loss, switch conduction loss is more significant due to higher current stress on the switch. More switches are used in the converter [68] with a higher voltage gain, which also has a fluctuating source current and no shared ground connection. Arguably, the most intriguing topology is an MC, which has easy control and less current stress on switches [69]. However, a sizable electrolytic capacitor bank must be employed to attain high effectiveness, increasing the overall converter size. A diagram of some recently developed high-gain boost converter is depicted in Fig. 2.



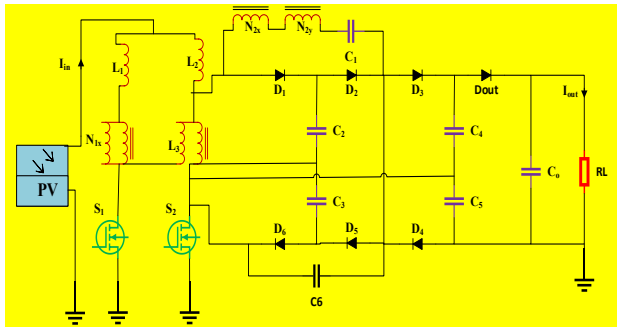
(a)



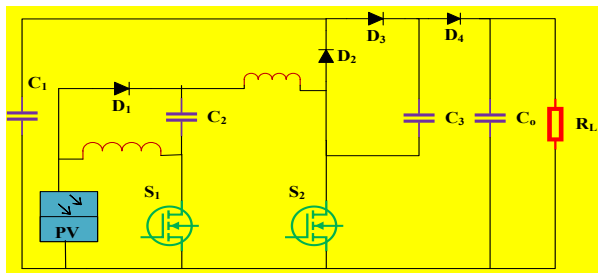
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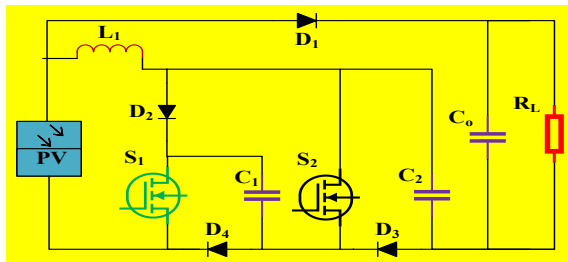
(c)



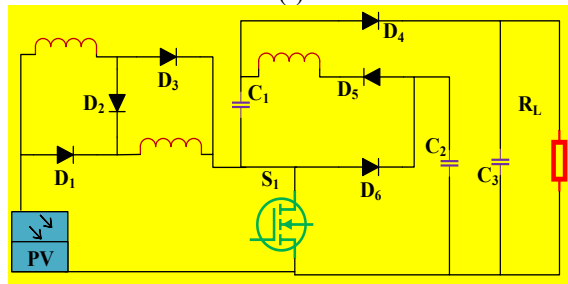
(d)



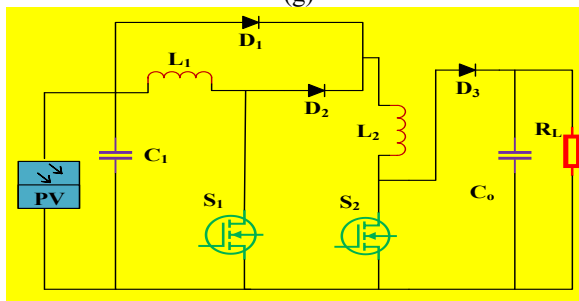
(e)



(f)



(g)



(h)

Fig. 2. Topological schematic of various high gain boost converters, (a) SCVEG converter [70], (b) Step-up converter with SC and ESC [71], (c) Non-inverting converter [30], (d) VMC and CI-based DC-DC converter [65], (e) SC-based

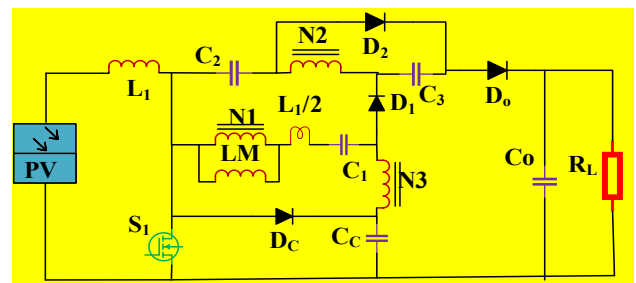
Converter [74], (f) SCDS Converter [75], (g) SI and VDC based step-up converter [67], and (h) High step-up converter [50].

2.1.2 SEPIC converter

The SEPIC converter can be utilized in addition to the ordinary step-up converter to raise the RES voltage level. One of SEPIC's distinctive properties is the ability to generate a quasi-resonant (QR) action between the middle parameters during the switch's turn-on mode to generate a QR action. As a result, compared to boost-based converters, the soft-switching function can acquire the power switch without needing additional parts, improving the converter's efficiency.

Various improved SEPIC converter DC-DC topologies incorporating CI and additional voltage-enhancing techniques have recently been shown. The voltage gain has somewhat increased [76] by using the middle inductor of the SEPIC in place of a CI. This topology uses a simple passive clamping circuit to recycle the CI's leakage energy (diode and capacitor). There is a suggestion [77] for an additional step-up converter based on SEPIC that uses two sets of CI.

Despite achieving an ultrahigh voltage transformation ratio, this converter experiences severe voltage stress, input current oscillation, and high switching and reverse recovery losses. The voltage enhancement is significantly boosted in the SEPIC topology suggested [78] by utilizing VMs on the CI's secondary side like a voltage rectifier. However, these converters' primary flaw is the excessive component utilization. Many researchers have suggested several topologies of SEPIC converters to overcome the problems of low gain, high voltage stress, minimal ripple contamination, and less voltage stress across semiconductor devices [79], [80]. The topological view of some HG SEPIC converters is below in Fig. 3.



(a)

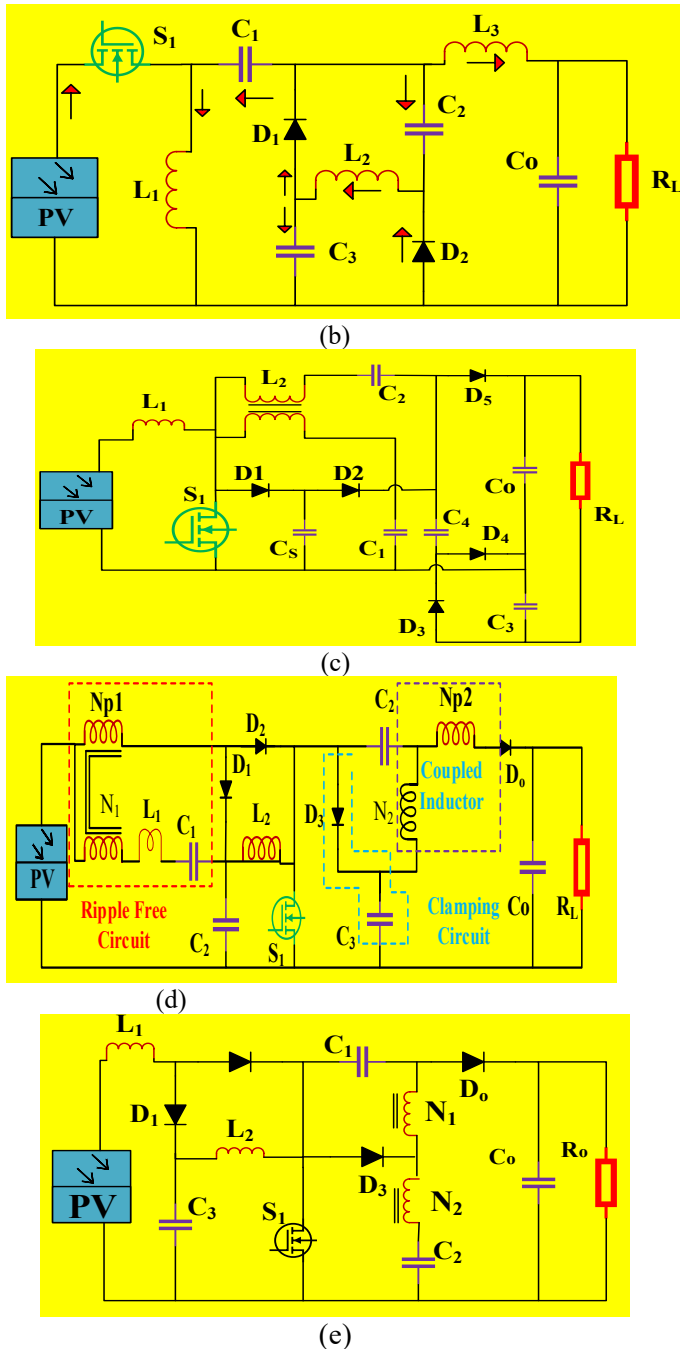


Fig. 3. Topological schematic of various high gain SEPIC converters, (a) Trans inverse SEPIC [81], (b) QRHGHE-SEPIC [76], (c) High-efficiency DC-DC converter [15], (d) Tapped inductor SEPIC [20], (e) SEPIC converter with zero input current ripple [77], and (f) Quadratic SEPIC [102].

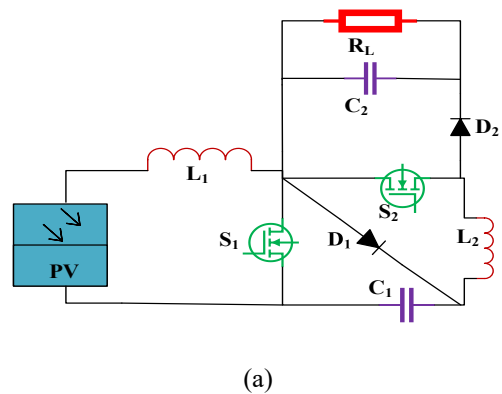
2.1.3 Buck-Boost converter

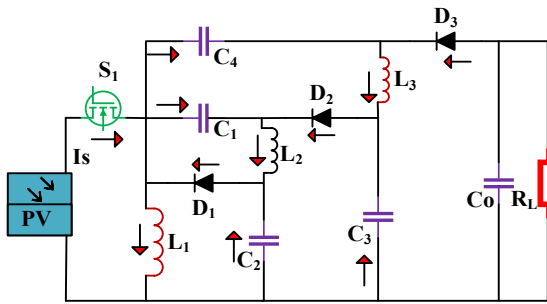
DC-DC Buck-boost converters are another essential element of PE applications, such as renewable energy and electric cars, because they have tunable output voltage and an extensive range of voltages. While a standard buck-boost converter has high efficacy, its intermittent input current makes it unsuitable for energy sources such as FCs or PVs

[82]. The output voltage can be increased or decreased using traditional buck-boost converters with a single switch, such as Cuk, SEPIC, and ZETA, but their voltage gain is constrained, and their switches are subject to high voltage stress. These converters need to raise the duty cycle to boost the voltage gain. As a result, efficiency drastically decreases in actual use [83]. Therefore, providing a new buck-boost circuit with improved features is vital. Researchers have put forth several buck-boost converter designs to address the problem above.

A solitary-switch converter is suggested in [84]. Its input current is irregular, and its voltage gain is modest, even at large duty cycles. In [85], a buck-boost converter built using the ZETA topology is demonstrated, even if this converter's current input issue remains unresolved. Researchers have discovered superior properties in quadratic converters that can achieve more considerable voltage increases. A converter with quadratic gain in voltage and constant input current has been suggested in [86]. However, because the output voltage in this converter is inverted, the output diode must withstand a more significant potential stress than the produced voltage. Though the ripple voltage is almost equivalent to zero, in [87], the output is still inverted.

The problem of inversion has been overcome in another research. However, in buck mode, the voltage gain is considerably high, and a more significant voltage stress than the output voltage may be applied to one of the switches. Switches under high voltage stress experience increased conduction and switching loss, which lowers converter efficiency. Researchers have developed a converter with relatively low potential stress on switches to address this issue [88]–[93]. On the other hand, this converter has numerous parts, which might lead to decreased efficiency and increased size and cost. The reader might get some structural idea of various buck-boost converters from Fig. 4.





(b)

Boost Converter	SEPIC Converter	Buck Boost Converter	Z-Source-based step-up Converter	CUK Converter
QBC[61] CBC[9] ICBC[64] TBC[112] Multilevel SC technology[64] VMC[7] VDC[67] Coupled inductor-based converter (Basic type, Active clamp type, snubber-assistant active clamp, Three winding coupled inductor, Three winding with charge pump) [113] SC integrated converter[28] Three-state switching cell-based converter[114] SC and SI-based converter[115] Converter with flying capacitor[66] Switch photovoltaic DC-DC converter[53] CI and SC-based converter[75] WCCI[26] MMCCC[116] Dual couple switch[117] SI double inductor[5] Voltage lift technique (Elementary lift cell, Basic switch inductor cell, self-lift cell, Double lift cell)	Quasi resonant SEPIC[76] Trans Inverse[81] Clamp mode couple[20] Boost SEPIC[77] SEPIC Flyback[118]	Triple port DC-DC buck-boost [88] CI Buck-Boost[90] Semi-quadratic buck-boost[76] Switch capacitor-based buck-boost[119]	Z-source with capacitor[24] Hybrid Z source[99] Quasi Z source[100] Z network SC[101]	Cuk SEPIC[18] Boost Cuk Converter[103] SI-Based Cuk[104]



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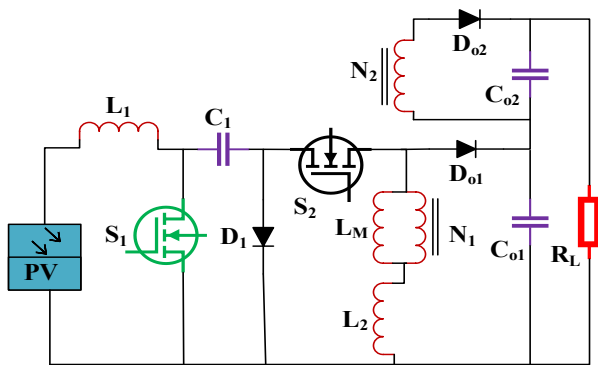
Table 1. Commonly used high gain of DC DC Converter

Table 2. Key performance parameters to model DC-DC converter

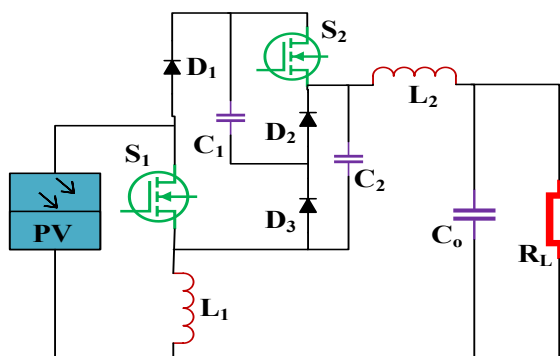
Referenc es	NOC					Voltage stress on switch	Input- output voltage	Voltage stress on diode	effici ency (%)	Switc hing freque ncy	Voltage gain	Teste d powe r	Switchi ng tech	Input current ripple	Reverse recovery loss	Common ground	Limitation
	s	D	C	CI	L												
[106]	2	4	4	2	0	$\frac{1}{1+N+D}$ $\frac{1-D}{1+N+D}$	25-400V	$\frac{1+N}{1+N+D}$	94.4 %	50kHz Z	$\frac{1+N+D}{(1+D)^2}$	400W	NA	Continu ous and less		YES	High conduction loss
[65]	2	7	7	2	0	$\frac{1}{2N+2}$	32-800V	$\frac{2}{2N+2}$	96.7 %	118kHz Z	$\frac{2N+2}{1-D}$	400W	ZCS	Continu ous and less	mitigated	No	CCM only
[107]	2	6	6	2	0	$\frac{V_o}{2N+4}$	(20-30) V-400V	$\frac{2N}{2N+4}$	95.8 %	40kHz Z	$\frac{2N+4}{1-D}$	200W	ZCS	Continu ous and less		No	No common ground
[108]	2	5	4	2		$\frac{V_o}{3N+1}$	40V- 400V	$\frac{2NV_o}{3N+1}$	97%	50kHz Z	$\frac{3N+1}{1+D}$	400W	ZCS	Continu ous and less	mitigated	YES	DCM analysis is not performed
[11]	2	7	6		1	$\frac{V_o}{5}$	48V- 800V	$\frac{2V_o}{5}$	95.5 %	50kHz Z	$\frac{5}{1-2D}$	500W	NA	Continu ous and less	mitigated	YES	The switching technique is missing

[24]	1	4	6		3	$\frac{1}{3-2D}$	33V-400V	$\frac{1}{3-2D}$	91.25 %	100kHz Z	$\frac{3-2D}{1-2D}$	400W	NA	Continuous and less	NA	YES	The switching technique is missing
[60]	2	4	4		2	$\frac{1}{1-D}$ $\frac{2-D}{(1-D)^2}$	12V-80V	$\frac{2}{(1-D)^2}$	90%	10kHz Z	$\frac{3-D}{(1-D)^2}$	150W		Continuous and less	NA	YES	The switching technique is missing
[59]	2	4	4		2	$\frac{1}{(1-D)^2}$ $\frac{1}{(1-D)^2}$	48V-650V	NA	97.3 %	50kHz Z	$\frac{2}{(1-D)^2}$	500W		Continuous and less	NA	YES	The switching technique is missing
[32]	2	5	5	1	1	$\frac{(1-D)}{(3+2n-D)(3+n-D)}$ $\frac{1}{3+2n-D(3+n-D)}$	20V-400V	$\frac{n(2-D)V_o}{3+2n-D(3+n-D)}$	94%	50kHz Z	$\frac{3+2n-D(3+n-D)}{(1-D)^2}$	150W		High	NA	YES	The switching technique is missing
[26]	1	3	4	1	1	$\frac{N-1}{2N-1}$	20V-200V	$\frac{N}{2N-1}$	96.04 %	50kHz Z	$\frac{2N-1}{(1-D)(N-1)}$	200W	ZVS ZCS	Continuous and less	mitigated	YES	DCM analysis is not included
[76]	1	4	5	1	1	$\frac{V_o}{(2+n+nD)}$	10V-200V	$\frac{(1+n)V_o}{2+n+ND}$	97.3 %	60kHz Z	$\frac{2+n+nD}{(1-D)}$	160W	ZCS ZVS	Low	mitigated	YES	DCM analysis is not conducted
[74]	2	4	4	0	2	$\frac{V_o}{4}, \frac{V_o}{2}$	32V-400V	$\frac{V_o}{2}$	96.5 %	100kHz Z	$\frac{4}{1-D}$	200W	NA	Low	mitigated	YES	Switching technique is not given

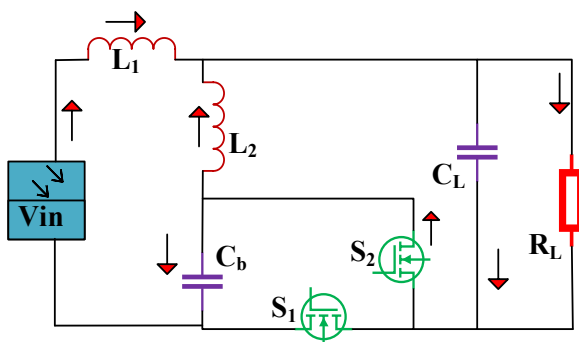
[105]	1	6	7	0	2	$\frac{V_o}{3}$	12V-96V at 0.3 duty ratio	$\frac{V_o}{3}$	95.4 %	50kHz Z	$\frac{6}{1-D}$	200W		Low	NA	YES	Reverse recovery analysis is not carried out
[109]	2	4	3	2	0	$\frac{V_o}{(1+2n)}$	15V-120V	$\frac{2nV_o}{(1+2n)}$	94.7 %	100kHz Z	$\frac{1+2n}{(1-D)}$	1kW	ZCS	Low	NA	YES	Reverse recovery analysis is not carried out
[110]	3	2				$V_{s1} = V_{s1} = V_e + V_c(m)$	40V-400V	$V_{ds} = V_e + V_c(m) - V_o$	97.6 %	100kHz Z	$\frac{2}{3} - \frac{2}{3}D$ $\frac{3}{(1-D)}$	200W	ZCS ZVS	NA	NA	YES	Reverse recovery analysis is not carried out
[5]	2	7	3	0	2	$V_{s1} = V_{s1} = \frac{V_o - V_g}{2}$	40V-200V	$V_o - V_g$	93%	50kHz Z	$\frac{3-D}{1-3D}$	200W		Continuous	NA	Yes	CCM analysis is conducted only
[81]	1S	4D	5C	0CI	1L	$\frac{(1+N_{s1}-N_{s2})V_g}{2+N_{s1}(2-D)-N_{s1}(1+D)}$	20V-250V	$\frac{(1-N_{s1})V_g}{2+N_{s1}(2-D)-N_{s1}(1+D)}$	94.4 %	55kHz Z	$\frac{V(2+N_{s1}(2-D)-N_{s1}(1+D))}{(1-N_{s1})(1-D)}$	200W	ZCS+QR	Continuous	Very low	Yes	Applicable small-scale RE application



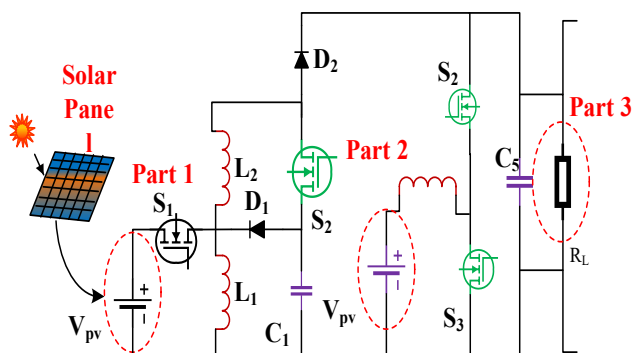
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(d)



(e)



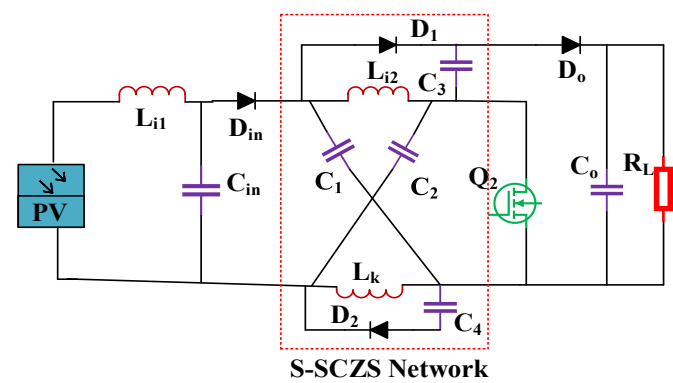
(f)

Fig. 4. (a) A high gain Buck Boost [92], (b) A quadratic Buck-Boost [91], (c) CIBuBoC Converter [90], (d) ESCB Converter [83], (e) Inherently non-pulsating Converter [89], and (f) Non-Isolated High-Gain [88].

2.1.4 Z-source converters

Unlike other converters, a ZS converter controls and moves electrical energy between an electrical source and a load. In contrast to a conventional one, it is made with special impedance networks that provide certain benefits, such as voltage buck and boost abilities. ZS converters are crucial for applications that are delicate to power quality because they can reduce input current distortions and oscillations. Substantial step-up converters have recently been produced by integrating specific voltage-boosting strategies with the qZS and ZS circuits. To obtain a buck-boost voltage augmentation and address the problems with a limited output voltage of conventional current and voltage-fed inverters, ZS and qZS topologies were first developed [94], [95]. As a result, boosting via ZS and qZS connections was expanded to include DC-DC converters. The traditional ZS DC-DC converter's operating states were examined in [96].

In contrast to the traditional ZS converter in [97], an upgraded ZS converter can produce fewer voltage strains on the switching components and ZS's capacitors. The voltage transformation was identical to that of the traditional ZS converter. The structure of the CZS network can be either symmetric or asymmetric, as stated in [98], with the asymmetric network having two possible variants. Furthermore, in contrast to traditional ZS converters, the SCZS network is connected to the capacitor and diode at the output side in several ways. This particular design can potentially significantly boost voltage gain while lowering voltage pressures on semiconductor components. Fig. 5 shows some schematic views of the ZS converter.



(a)

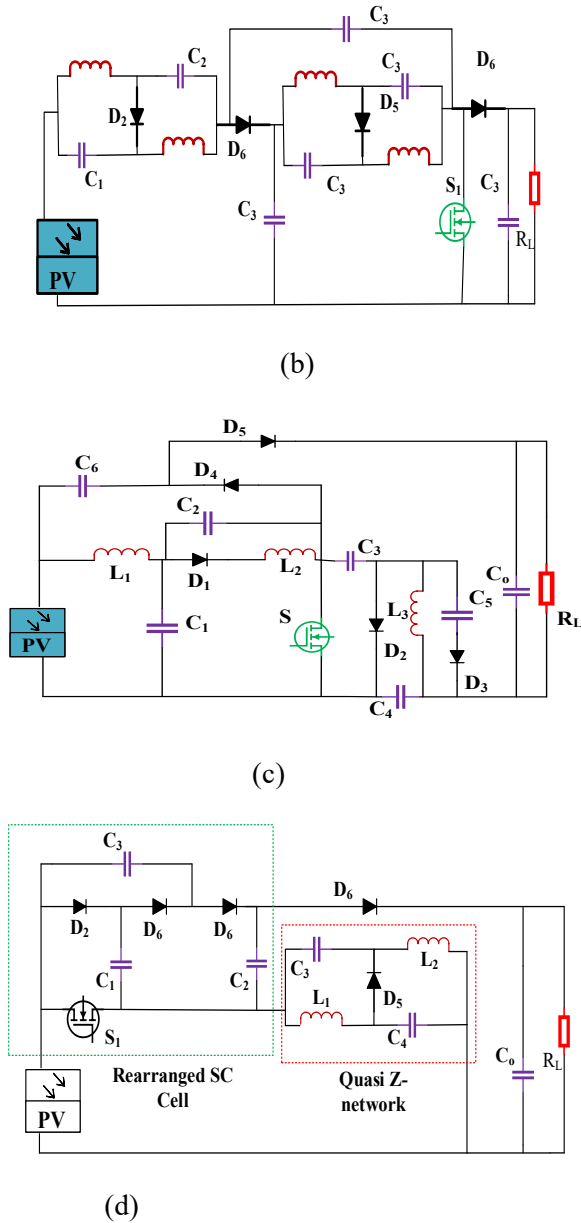


Fig. 5. (a) S-SCZS Converter [24], (b) Hybrid Z source Converter [99], (c) QZS converter [100], and (d) ZSCBC converter [101].

2.1.5 Cuk converter

There are many procedures and factors to consider when developing and analyzing a Cuk converter for a solar power application. The Cuk converter is a form of DC-DC converter that is appropriate for RES, such as solar panels, because it can effectively regulate the output voltage while managing changes in input voltage. Most of the substantial DC-DC converters with static gain suggested in the literature have an intriguing layout for a two-stage construction with an inverter for the voltage source as the output stage [102]. Some topologies that utilize high static yield output current sources have been developed, although they only function as

step-up converters. Since the current at the output cannot be driven to the grid when the grid's voltage is lower than the solar module's voltage, these configurations cannot be used as an emerging structure, producing a current distorted near the zero crossing. As a result, the DC-DC converter needs an output that can step up and down and have a substantial static gain action to be implemented in an unfolding structure.

A step-up-down architecture with output and input current sources characterizes the traditional Cuk DC-DC converter. Although the switch voltage of a conventional Cuk converter is equal to the combined magnitude of the voltages at the input and output, the step-up static gain may not be sufficient to power a low-voltage PV module. These two issues are addressed using the switched-inductor approach with the traditional Cuk converter. They were switching out the conventional Cuk converter's input switch and inductor for two input inductors (L_1 , L_2) and two switches (S_1 , S_2). The SEPIC-based converter wiring diagram is given in Fig. 6.

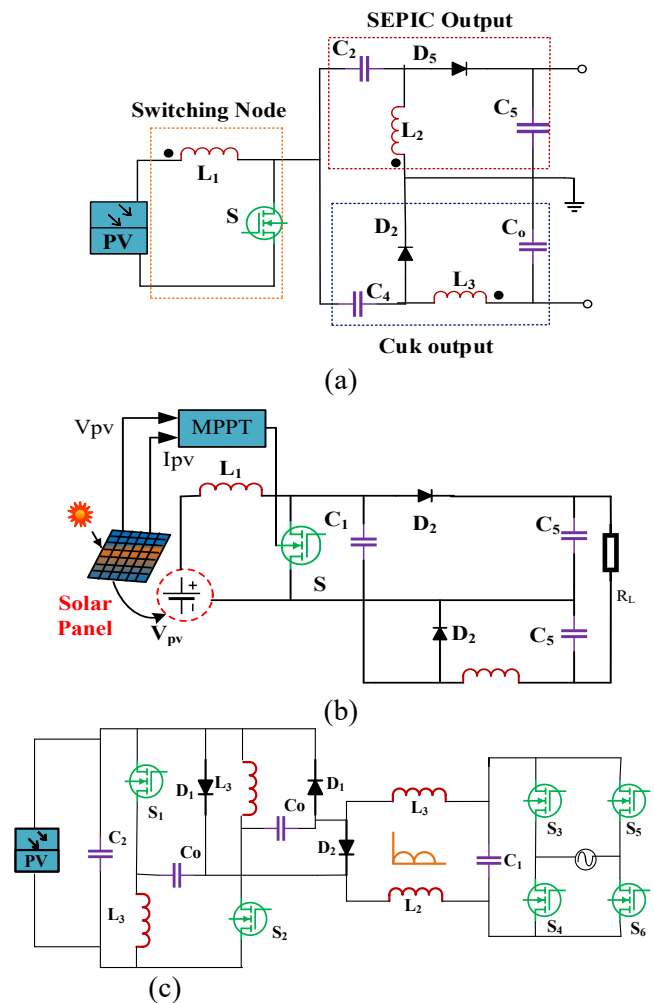


Fig. 6. (a) CUK SEPIC converter [18], (b) Boost-Cuk Converter [103], and (c) SI Cuk module [104]

3. Comparative Research and Conflict

In this article, we have chosen eighteen recently developed works from traditional DC-DC conversion strategies to accomplish the comparison investigation. Each strategy has benefits as well as drawbacks based on specific criteria. Some approaches, for instance, have minimal gain in voltage and excellent efficiency but high ripple in input current. Some approaches feature high efficiency but at an extreme duty ratio. Some can operate at low duty and with little potential stress, but the hardware complexity and associated costs are prohibitively expensive. Problems with diode reverse recovery and converter effectiveness are also significant. Before selecting a suitable converter topology for further implementation, the researcher should ensure the key performance parameters of that topology. A comparison of different topologies for various performance parameters is tabulated in Appendix A. Parameters such as HVD, VSS, NOC, efficiency, etc., which contribute to certifying the outperformance of topologies, have been considered to create the comparative table. This table will give the reader a comprehensive idea regarding the most highlighting features of any converter. Six criteria have been selected for comparison in this manuscript. Potential stress-spanning semiconductors (V_{ss}), input and output voltage ratio (V_G), switching frequency (F_s), power management capacity, efficiency, and number of components (NOC) are all considered. The numerical values in each category are split into different segments. Table 3 shows a detailed comparison of the seventeen methods. V_{ss} is classified as slight, moderate, significant, and very large for approximately less than one-fifth, one-fourth, one-third, and half of the output voltage, respectively.

NOC is categorized as very high, high, medium, and low with ranges of (>17), (16 to 17), (12 to 15), and (<12), respectively. Efficiency is categorized as extremely high, high, medium, and low for percentages of ($>97\%$), (94% to 97%), (92% to 93%), and ($<92\%$), respectively. Regarding the voltage gain (>19), (15 to 19), (11 to 14), and (<11) are characterized as extremely high, high, medium, and low. Switching frequency plays a critical role, as higher frequencies allow the use of more minor passive elements but can lead to increased switching losses, resulting in decreased efficiency. Thus, a converter with a lower switching frequency is considered well-performing. Frequencies beyond 100kHz are deemed as very high. The range between 100kHz and 50kHz is classified as high, while 50kHz to 10kHz is considered moderate. Frequencies below 10kHz fall into the low category. Evaluating the converter's power handling capacity follows the criteria of voltage gain and efficiency measurements on the graph. Converters

capable of handling power above 400kW are considered well-performing, while those between 400kW and 200kW are rated good. Ranges of 150kW to 100kW are categorized as moderate, and those below 100kW are labeled low.

A radar chart is initialized to simplify the comparison, whereas the performance is evaluated based on six essential criteria. Fig. 7 shows a radar chart depicting the previously outlined nineteen DC-DC topologies. The radar chart outlines are standardized using a rating system from 1 (minimum) to 4 (maximum), with the lower end indicating the method's inadequacy and the higher end representing its effectiveness. For NOC and switching frequency, 'very high' and 'low' values denote the lowest and highest points on the scale. Similarly, for V_{ss} , the highest and lowest points correspond to low and high values. In the context of efficiency, voltage gain, and power, an extremely high rating represents the maximum contour, while a low rating indicates the minimum contour on the radar chart diagram. The entire area of each converter's rating indicates its performance assessment on the radar graph, where a larger contoured area signifies better performance than a smaller one. Users can select their preferred approaches by observing the blue-filled region and performance classification suitable for their desired application.

4. Issues and Challenges Designing PV-fed DC-DC Converters

DC-DC converters are crucial parts of solar power systems to adjust the energy produced by PV panels to fulfill the needs of the load or energy storage system.

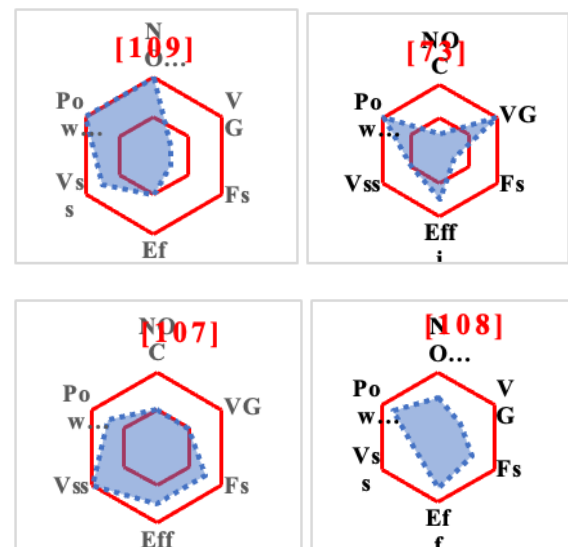
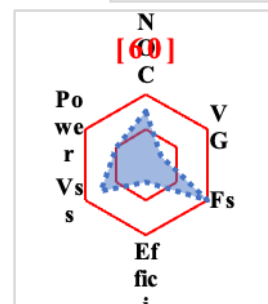
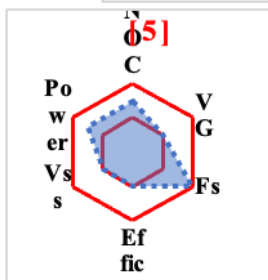
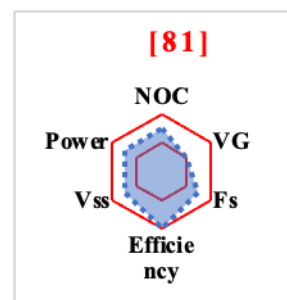
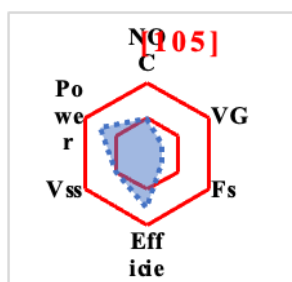
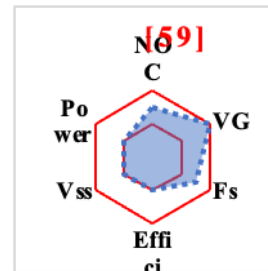
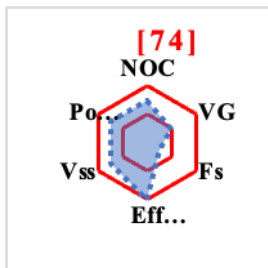
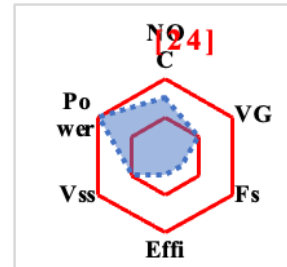
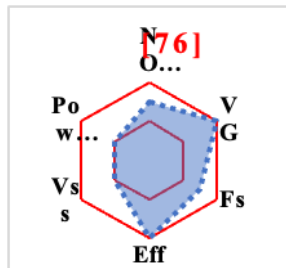
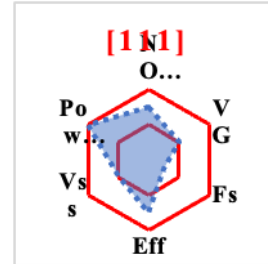
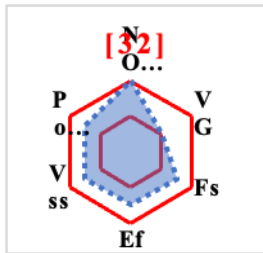
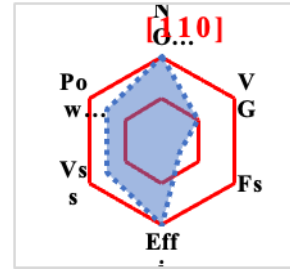
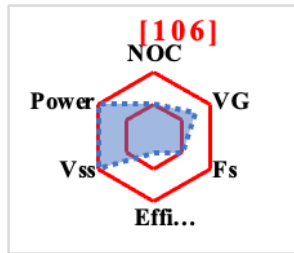


Table 3. Comparison of Performance Parameters

Reference No	Publication year	Converter type	Efficiency	V_{ss}	F_s	Voltage gain	power	NOC
[109]	2014	Boost with n stages of diode-capacitor inductor	Low	Low	Moderate	Very high	Moderate	high
[73]	2020	CI and VMC interfaced interleaved boost	High	Moderate	Very high	Very high	Very high	Very high
[107]	2021		Medium	Very low	Moderate	Medium	Very high	Very high
[108]	2020	Interleaved asymmetric VMC	Very high	Medium	Moderate	Medium	Very high	High
[106]	2021	Two winding CI and VMC	Medium	Low	Moderate	Medium	Very high	Medium
[32]	2021	CI with the magnetic core structure	High	High	Very high	Medium	Good	Low
[76]	2021	QRHGHE-SEPIC Converter	Very high	Medium	Moderate	Very high	Good	Medium
[74]	2021	Active switch network interfaced boost	High	High	Very high	Medium	Good	Medium
[105]	2021	SL, SC connected modified VMC	High	Medium	Moderate	Low	Good	High
[5]	2021	SL-DS boost	Medium	Medium	Moderate	Low	Good	Medium
[110]	2022	CI-VMC-SC/SL-based boost	Very high	High	High	Medium	Good	Low
[111]	2022	MICC with NRSS	Very high	Medium	Very high	Medium	Good	Medium
[24]	2022	ZS with SC converter	Low	Low	Moderate	Medium	Good	Medium
[59]	2022	Two stages converter with CI and VMC	Medium	Low	Moderate	Very high	Good	High
[81]	2023	SEPIC based trans-inverse	Medium	Medium	Moderate	Medium	Good	Medium
[60]	2023	QBS with SC cell	Low	Low	Low	Low	Good	Medium
[9]	2023	VM-QBC configured converter	Very high	Low	Moderate	High	Very high	Medium
[11]	2023	SCEVG) DC-DC converter is	Medium	Very low	Moderate	High	Very High	High



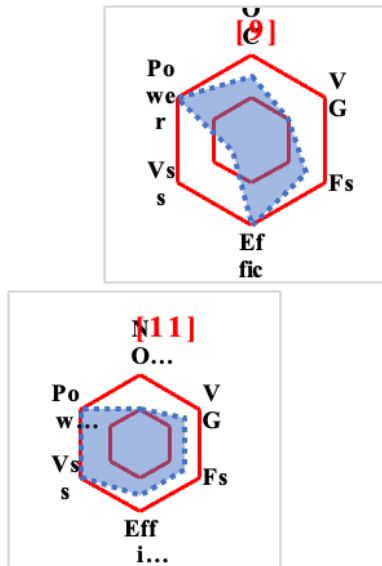


Fig. 7. Radar graph showcasing the different DC-DC circuits' performance

However, they also deal with several problems and difficulties, such as providing stable output that responds to variable input voltage and current. PV panels produce electricity in response to temperature and sunshine intensity, among other variables. Maintaining a steady DC output can be difficult due to this fluctuating input current and voltage fluctuation, mainly if the power source is unstable. Since losses throughout the conversion process lower the overall energy yield, efficiency is another crucial issue. Maintaining high efficiency under various operating situations is complex; efficiency usually drops under partial loads.

DC-DC converters frequently require algorithms for MPPT to continuously adapt their functioning point to the highest peak power of the PV array to maximize the electrical power output of PV panels. It can be difficult to implement MPPT efficiently since precise sensing and control algorithms are needed. System stability and dependability depend on the converter attaining acceptable steady-state and transient execution, where it can withstand variations in input or load. Without experiencing extreme voltage or current spikes, the converter ought to be able to react to changes fast. Due to the operation of DC-DC converter switches, they can cause electromagnetic interference that can disrupt connections between other electronic devices.

EMI mitigation is necessary to adhere to the regulation. Components such as inductors, capacitors, and semiconductors may experience stress due to the high-frequency switching of DC-DC converters. Proper choice of components and heat management is crucial to guarantee greater durability and dependability. It is important to ensure

the converter can interact with the utility grid securely and effectively in grid-tied systems. Handling synchronization, grid code, and anti-islanding security issues is necessary.

Power electronics and photovoltaic technology development and research must continue to address these problems and obstacles. Improvements in materials science, element design, algorithms for control, and integration of systems are continuously enhancing PV-fed DC-DC converter performance and dependability.

5. Recommendation and Subsequent Studies

Each of the strategies presented in Table 3 demonstrated supremacy in various categories. There is no single structure that outperforms the other configuration across every aspect. Table 4 classified the converters into 04 (four) groups based on weighted scaling and the blue-filled region of the radar graph. Group A's design outperforms the other three categories based on the overall weighted effectiveness. [11,76,81] Topologies outperform Group A's other 02 (two) solutions across all criteria. The [11] circuit outperforms the other two techniques based on performance. [81] would be a better choice amongst these three configurations because of its lower V_{ss} than the other two.

As described in Section 2, typical converters have numerous limitations. The researchers attempted to improve the common shortcomings in several ways.

Table-4 Classification of converters based on performance

Groups	No. of Paper	References	Score
A	5	[76, 81,11, 107, 110]	16 and above
B	6	[106, 108, 9,74, 111]	15
C	3	[5, 109, 105]	14
D	3	[24, 60, 73]	13 and below

Nevertheless, the VMC approaches enhanced performance on one or two parameters but did not improve performance across the board. Section 3's comparative analysis and radar chart graphic describe the outcomes of the chosen conventional converter design. It should be noted that every single one has specific limitations and constraints. Additionally, a few applications need high efficiency and straightforward procedures.

Integrate the practical MPPT approach to guarantee that the converter works at the ideal point for extracting optimum power from the solar panels, particularly under variable

climatic conditions. Choose components of excellent quality that are qualified for the high current and voltage requirements. It reduces switching losses, ensures low-resistance elements, eliminates parasitic elements, and uses advanced control strategies for lowering power dissipation to optimize the converter's design for high efficiency.

6. Conclusion

This review paper aims to study the performance of non-isolated DC-DC topologies with PV sources. The applications and several benefits of various PV-fed converter topologies are discussed here, and a comprehensive review of PV-fed converters is provided to aid researchers in selecting the optimal converter for an understudied field. A critical element that can be summed up is that varied converter topologies provide optimal operating qualities. At its best, the buck converter is supposed to be utilized with a load impedance that is less than but near the RMPP. The boost converter's poor tracking performance in low radiation conditions is adverse. Instead, it must be utilized with a load impedance bigger than but still within range of RMPP at the weakest conditions. The only converters evaluated as able to achieve optimal functioning irrespective of the load values are the buck-boost, SEPIC, and CUK designs.

The Buck and Boost configurations are the most effective for a particular cost. Nevertheless, they experience tracking issues in related load, radiation, and temperature scenarios. Furthermore, because they can track maximum power values due to their operations being independent of temperature and radiation, the Buck-Boost, SEPIC, and CUK converter circuits are suitable for MPPT implementation. Furthermore, the primary Buck and Boost configurations are the most effective for a particular cost.

Disadvantage of the SEPIC and CUK circuits is that they have higher reactive component values. On the other hand, their primary drawback could be their high cost even when they work efficiently. Converter and control systems' efficiency and cost-effectiveness are still being worked on, and a commercially feasible response to the growing concern over environmental issues is being sought. As technology for power electronics develops further, solar power generation aiding power electronics will expand exponentially over the next ten years.

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Author Contributions

All authors were responsible for the conceptualization, validation, resources, data curation, software development, and project administration. They jointly contributed to the methodology, formal analysis, investigation, original draft preparation, review and editing, visualization, supervision, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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