Transformer Less Non-Isolated High Gain DC/DC Converters for Solar Photovoltaic System Applications

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A R T I C L E I N F O

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A B S T R A C T

This work offers a thorough analysis that focuses on the features DC Voltage Lifting Techniques of Single-phase Transformer less Converters for PV Applications. The high boost approaches are categorized as multistage/level structures, switched capacitor (SC), voltage multiplier (VM), voltage lift (VL), switched inductor (SL), and magnetic coupling (MC) in the article. The pros and cons of each category and applications are covered in length in the article. Comparisons are also made between the quantity of passive and active (APC) components, voltage gain, voltage stress, switching frequency, efficiency, and power rating. the entire conversation's main essay is on non-isolated high DC gain approaches, even if coupling inductors are discussed Regarding a non-isolated converter. Evaluation of high boosting approaches, not the discussion of DC/DC converters, is the paper's main contribution. When the generated voltage is low, there are several applications, this enables the emergence of novel concepts additionally, improved power converters that aid in the provision of highly efficient and adaptable power converters. This study also summarizes a number of DC/DC converter applications and control methods.

1. INTRODUCTION

Energy-intensive technology solutions that are also affordable and effective are urgently needed in this quickly industrializing world due to the surge in energy consumption. Renewable energy sources (RES) are assuming greater significance as we anticipate future concerns like climate change. interest is currently shown in photovoltaics (PVs) and Fuel cells (FC) as the RES industry has grown. Due to its reliability, dependability, and lack of emissions, PV energy is most important energy sources and will become dominant power generating source by 2040 [1,2]. systems that use solar energy and are linked to the grid are developing in many continents and nations, including the US, Japan, and Europe, where they are employed in household applications [3]. but the PV panel's generating voltage is quite low but some applications require high DC voltage. Number of Modules can be connected in series to provide a greater DC voltage from a PV panel [4], however, this strategy has not been favored for applications requiring low power It reduces stability and resolves shading issues brought by the cloud, neighboring buildings, and plants. [5,6]. Photovoltaic (PV) panels are suggested to be coupled in parallel wherever possible for more dependable and effective functioning to minimize the effects of faulty panels [7]. One low-power panel can connect to the grid in some applications, like the microinverter, but the voltage must be significantly increased. For grid-linked PV electricity systems, cascaded H-bridge multilevel inverters and other multilevel designs used to maximize the PV supply capacity and take advantage of the switch voltage blocking capabilities [8,9]. The use of another technique to increase voltage gain

Voltage divider circuits, although the output voltage and efficiency are low [10]. To boost the conversion rate of voltage ratio, multiple PV panels may be connected in series, or voltage divider networks can be used. However, a DC/DC converter may be employed alternative because it is a dependable option, especially for applications that require minimal power, and it can offer a regulated voltage [11]. To control the direct current (DC) interface among the electricity supply and a DC/AC grid inverter, which the traditional step-up chopper must be dependable and extremely efficient in a 220 V AC grid-dependent energy system, a 12-48 V generated by the PV systems needs to increase to 380 V DC to operate the full-bridge inverter.

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With only a few parts, the standard Step-up Chopper is employed to increase supply voltage with necessary greater magnitude for the practical limit demanded from the load. Inductor is used to store the energy in one instance then released in addition with the supply voltage will produce higher voltage. For leading PF applications, the boost converter is highly well-liked. Additionally, it is utilized in DC motor drives, battery power systems, consumer electronics, power amplifiers, automatic control applications, and power factor correction circuits. The typical boost converter has to perform at a very higher duty factor in order to get high output voltage, however it will decrease the converter's efficiency and renders it useless [12].

By substantial conduction & switching losses caused by extremely high duty cycle, high voltage and current rated MOSFETs that have elevated ON-state resistance (RDS(ON)) are needed [13]. Additionally, it constrains the converter to work with low switching rates and brief off times. A significant diode reverse-recovery current results in an extremely brief off time, which raises the EMI level [14]. Because lower switching rates result in increased ripple current, the voltage that comes out is more receptive to duty cycle variations hence passive element sizes will be very big. Making a compensatory alteration in the load side is challenging when the duty cycle is high because there is very little room for control. Additionally, the typical boost converter has a higher MOSFET (RDS(ON)) [15] when PWM is used in converter with high power MOSFET as power switch. The main shortcomings of traditional high voltage gain choppers are their increased cost, smaller efficiency, and larger passive parts. In order to address the aforementioned issues, an architecture that might give traditional boost DC/DC converters greater dynamic stability, accuracy, higher efficiency, and greater density of power is required. The converter should additionally have minimum ripple, cheap cost, wide bandwidth, lower electromagnetic noise as well as rapid response to abrupt changes [16].

For a variety of power applications, there will always be a need for step-up voltage choppers that are dependable, effective, lightweight, and tiny in size. chopper output voltage can be effectively greatly boosted using a variety of voltage enhancing approaches. A wide variety of distinctive topologies are produced by combing and permuting a variety of voltage boosting techniques using various switching configurations and switching cells. This study offers a comprehensive analysis and categorization of high-boosting DC/DC power converter techniques. The overall structure, the boosting mechanism, connections, the circuit structures, the conspicuous features, and the benefits and drawbacks are defined, illustrated, and explored. Section-2 categorizes high step-up methods. in Section-3 Quadratic boost, interleaved, symmetric, non-symmetric, and cascaded multistage/multilevel converters are discussed. Sections-(4-6) discuss SC, VM, & VL techniques respectively. Section-7 discusses SL techniques, Section-8 examines MC techniques, and finally Section-9 comes to a finish at its conclusion.

2. HIGH STEP-UP TECHNIQUES

A steep ascent. VM, SL, VL, and converters with multistage/level (ML) designs are the main subcategories of high voltage gain choppers. charge pumps (CPs) are another name for switched capacitors. Depending on the application, these offer pros and cons as far as of cost, complexity, quantity of power, dependability & efficiency. In Figure 1, these classifications are displayed. The SC, VL, and SL are only a few of the families that are specifically related to one well-known approach. Some subfamilies are added to some other families, for instance, to the multi-stage family, which includes cascaded, interleaved, and multilevel subfamilies.

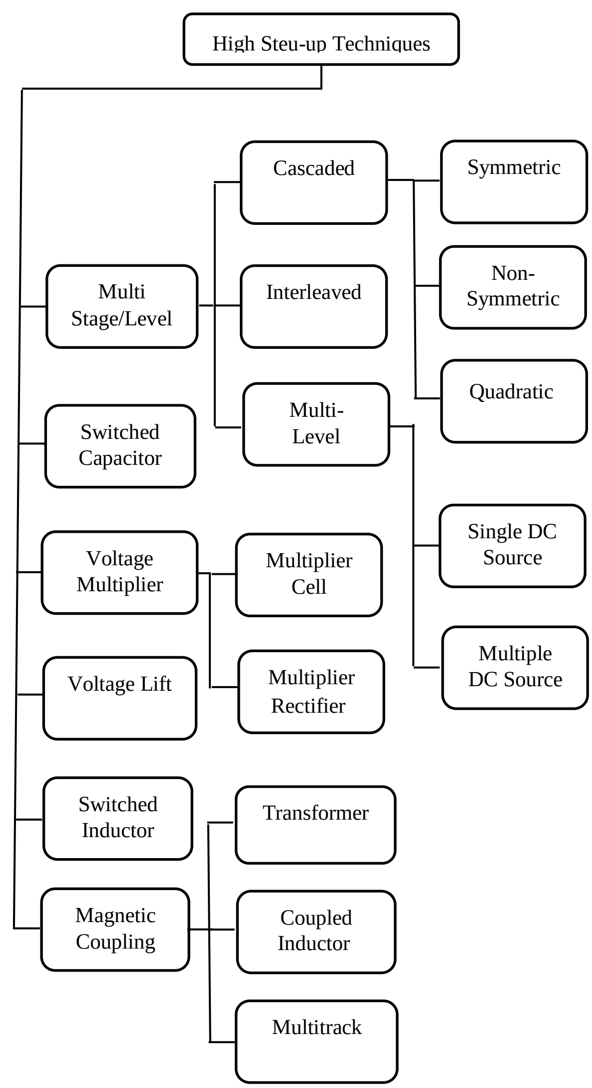

Fig. 1. DC voltage boost approaches.

3. MULTISTAGE/LEVEL STRUCTURES

Connecting several stages of a converter is a type of simplest ways to boost voltage. One way to do this is to combine symmetric/non-symmetric converters using numerous higher DC step-up approaches. Depending on the architecture being employed, the voltage gains rises linearly. Such topologies could be broadly divided into three categories: cascaded, interleaved, and multilevel.

3.1. Cascaded Topology

3.1.1. Symmetric and Non-Symmetric Converters

In the typical cascaded converter configuration shown in Figures 2 (a, b), there are 2 or greater than 2 symmetrical/non-symmetrical converters which employ 2 or greater than 2 controlled switching components [17–18]. and one switching component [19–20] can be coupled in common configuration of cascaded converters.

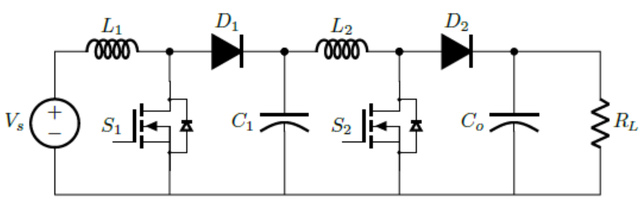

Fig. 2(a). Symmetric cascaded step-up chopper.

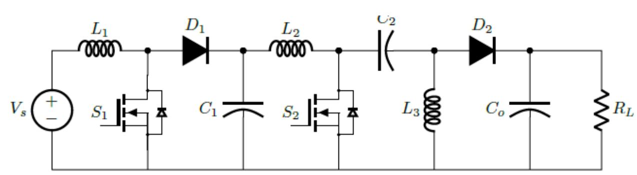

Fig. 2(b). Non-symmetric cascaded chopper.

Figure-3a illustrates how the first stage of the cascade's the switch under low stress caused by potential difference allows for high frequency operation. The second stage [21,22] runs at a low frequency, which lowers switching losses [18]. A cascaded circuit, on the other hand, includes two sets of power devices, which increases its complexity and cost [23]. Additionally, both power devices must be synchronized to avoid problems with circuit stability brought on by the beat frequency [24,25]. An additional method for reducing the overall losses brought on the use of active switches, as demonstrated by Figure-3b, is to employ n-stage cascaded step-up chopper that operates with a single MOSFET. They also have a straightforward control circuitry. [27] presents a comparison of the boost and zeta converters.

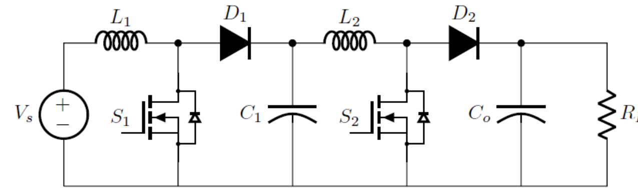

Fig. 3(a). Cascaded Double Boost Copper.

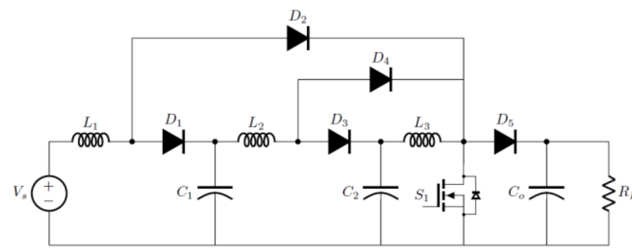

Fig. 3(b). Cascaded N-Stage Step-up Chopper.

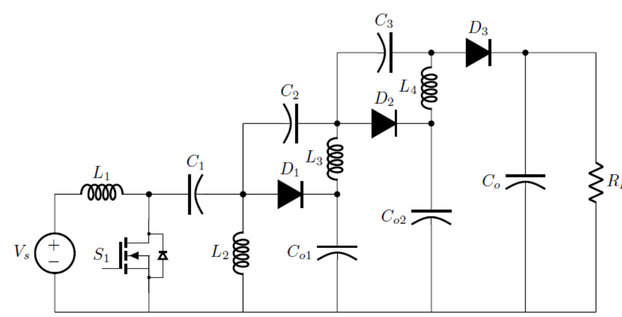

Fig. 3(c). SEPIC Based on Buck-Boost Chopper.

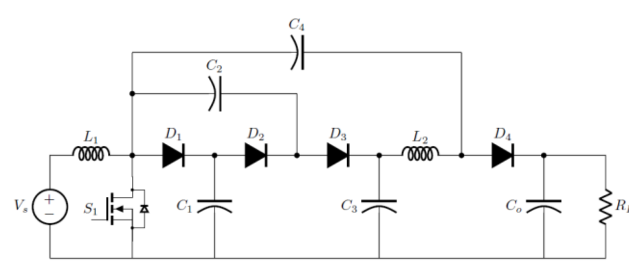

Fig. 3(d). Double Boost SEPIC chopper

Figure-3c depicts a single switch step-up chopper using buck/boost method and the latest SEPIC technology [28]. It has a larger voltage conversion ratio than SEPIC and buck/boost converters. Consequently, the power switch is not under excessive potential pressure, and the input current is constant. Figure 3d illustrates the presentation of an integrating doubled boost as well as SEPIC converter (IDBS) in [29]. At a low duty cycle, it can achieve a high DC gain. The ability of this combo converter to provide high voltage conversion ratio and low current-input ripple is one of its advantages. The following information concerning these cascading boost converters is summarized in Table 1: Component count and voltage gain.

Table 1. Cascaded Boost Methods Comparative Analysis

Topology		Number of Components					Voltage Gain in CCM (M)
		Passive			Active		
Tech.	Converter	L	C	L||	S	D	
Symmetric Converter	Converter shown in Figure 3a [20, 21]	Two	Two	Zero	Two	Two	$\frac{1}{(1-D)2}$
	Converter shown in Figure 3b [26]	Three	Three	Zero	One	Five	$\frac{1}{(1-D)\,n}$
Non-symmetric Converter	Converter shown in Figure 3c [28]	Four	Six	Zero	One	Three	$\frac{3D}{1-D}$
	Converter shown in Figure 3d, [29]	Two	Five	Zero	One	Four	$\frac{2+D}{1-D}$

3.1.2. Quadratic Boost Converters (QBC)

Figure-4 shows typical configuration of a QBCs, it consists of a single switch, 3 diodes, and 4 passive components. At a modest duty cycle [20,30], a quadratic converter Figure-4 can achieve a significant high DC gain, however, fundamental disadvantage of such converters resides in the fact that the stress power switch caused by the output voltage. As a result, effectiveness is diminished. Due to its limited voltage gain, the traditional quadratic boost converter was inappropriate for exceptional applications.

A modified VL cell-equipped QBC is shown in Figure-5a [31], it has large output voltage gain. Additionally, it alleviates the problem with conventional quadratic boost converters, that puts the power switch under electrical stress. several quadratic boosts converters & modified QBCs with quadratic boost functions has developed in literature [34–52] to block the prevailing restrictions in conventional boost converters. Presented in [38] is a quadratic following boost converter (QFBC). At a modest duty cycle, it could increase up the voltage gain thanks to its dual switches, 3 capacitors, 3 diodes, and a pair of inductors construction. A bootstrap network is incorporated into modified QFBC (MQFBC) introduced [39] to enhance the standard boost converter. In Figure-5b, a QBC with linked inductor is used to provide an elevated gain in voltage with reduced voltage stress [40,41]. However, the linked inductor's leaking inductance places a considerable voltage demand on the power switch. Circuits with passive clamping is used to lessen the higher stresses caused by potential difference. The Figure 5c SEPIC and quadratic boost converter topologies, which are described in [42], without needing a high duty ratio, raise the voltage ratio of conversion. This converter uses a QBC, that has an excellent voltage conversion ability, SEPIC converter can lessen ripple in source current. Both of these well-known DC/DC converters are used.

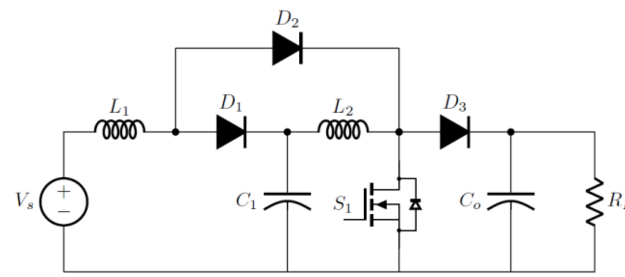

Fig. 4. QBC Topology.

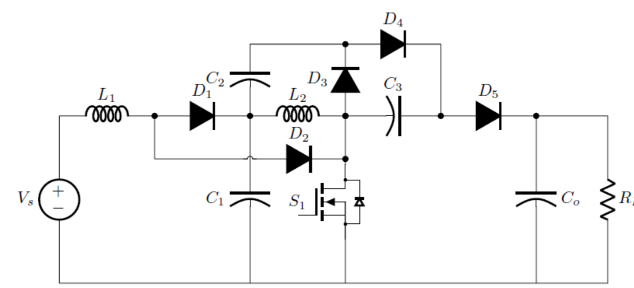

Fig. 5(a). QBC based on VL Cascaded topology

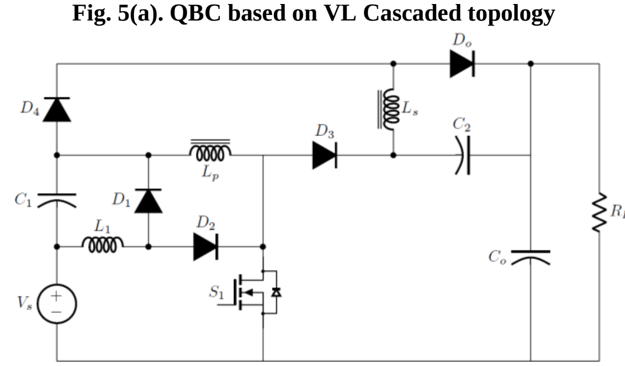

Fig. 5(b). QBC based on linked Inductor Cascaded topology.

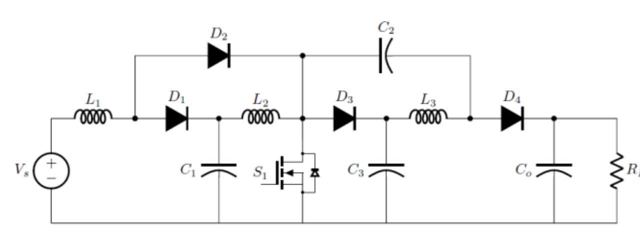

Fig. 5(c). QBC and SEPIC Converters Cascaded topology.

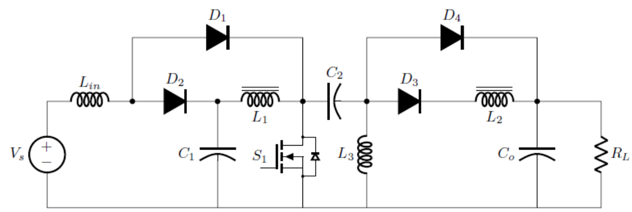

Fig. 5(d). QBC-SEPIC based on SC and linked Inductor.

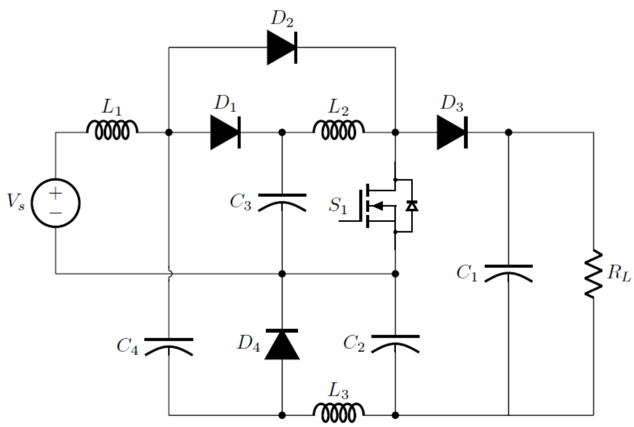

Fig. 5(e). QBC and C' uk Converter Type-I Cascaded topology

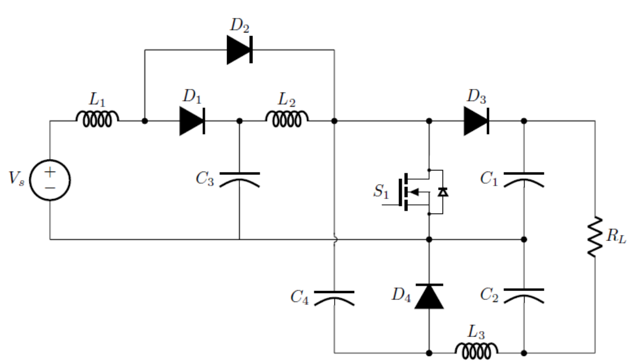

Fig. 5(f). QBC and C' uk Converter Type-II Cascaded topology

It is suggested in [43] to boost the voltage gain using Figure 5d illustrates the switched-coupled inductor-based quadratic SEPIC. For High voltage amplification along with efficacy are required a zeta converter and a QBC are suggested [44]. Zeta converter and QBC both have low input and output current ripples. An increased step-up voltage must be attained by combines a C' uk converter and a QBC [45]. Figure-5 (e), (f) illustrates two different configurations.

The hybrid QBC type I arrangement in Figure-5e has a lower electrical pressure compared to converter's output voltage. The hybrid QBC type II design in Figure-5f has a greater voltage conversion ratio in comparison to hybrid type QBC I arrangement. In [46], a new QBC is developed that has low inductor currents and can boost voltage just as effectively as a traditional QBC. Additionally, the switch is under low electric pressure & non-pulsating input current. This converter's primary flaw is the use of 2 no. of switches. Typically, voltage multiplier connections plus a quadratic boost converter make up a HSBC. In [47], a linked inductor with a wider voltage doubler cell and a quadratic boost converter are used to produce a large voltage gain. When using same duty cycle as conventional QBC, QBC a in comparison to cell produces an output voltage that is significantly greater [48]. Regarding the components count and voltage gain, Table 2 provides further information regarding quadratic boost converters.

Table 2. QBC Topologies Comparative Analysis

Topology	Number of Components					Voltage Gain in CCM (M)
	Passive			Active		
	L	C	L||	S	D	
Converter shown in Figure 4 [22]	Two	Two	Zero	One	Three	$\frac{1}{(1-D)^2}$
Converter shown in Figure 5a [33]	Two	Four	Zero	One	Five	$\frac{2}{(1-D)^2}$
Converter shown in Figure 5b [40]	One	Three	One	One	Five	$\frac{1+N-D}{(1-D)^2}$
Converter shown in Figure 5c [42]	Three	Four	Zero	One	Four	$\frac{1+D-D^2}{(1-D)^2}$
Converter shown in Figure 5d [43]	One	Three	One	One	Four	$\frac{D(N+1)}{(1-D)2}$
Converter shown in Figure 5e [45]	Three	Four	Zero	One	Four	$\frac{1+(1-D)D}{(1-D)^2}$
Converter shown in Figure 5f [45]	Three	Four	Zero	One	Four	$\frac{1+D}{(1-D)^2}$

3.2 Interleaved Converters

According to Figure-6, an interspersed High gain chopper uses voltage multiplication modules connecting the resultant voltage of a diode, the input voltage of switch and active/ passive clamp circuits to provide a high DC gain. However, low current conversion ratio enhances electricity density and decreases current ripple. The literature [53–62] contains a variety of interleaved DC/DC converters using various approaches.

Because the interlaced arrangement is used at the input end in Figure-7a, interlaced converter with VMC suggested in [53] can lowers the input current ripple while enhancing power rating. voltage multiplier cell also causes an increase in voltage gain increases at the resultant. By conjecting a voltage VMM up of SC & linked inductors, as shown in

Figure-7b, a traditional IBC produces high voltage gain [54,55]. Additionally, it increases power transfer and reduces ripples in input current. The interleaved quadratic high gain chopper, as shown in Figure 7c, has been presented as a way to maximize voltage gain by combining two QBC designs. A VL capacitor being used to get the desired voltage gain [56].

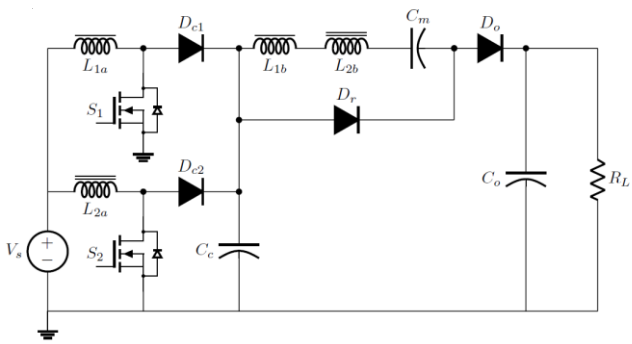

Fig. 6. Interleaved Converter topology.

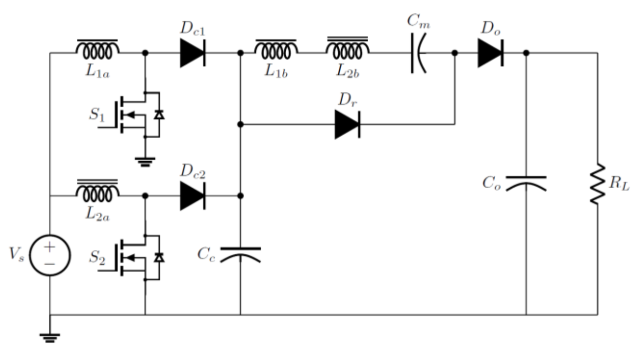

Fig. 7(a). VMC and CI Interleaved Converters.

A single capacitor snubber interleaved step-up chopper is shown in [57]. To get higher voltages, a Winding Crossed Coupled Inductor (WCCI) with three winding CIs has introduced in [58]. The second segment has the 3-rd. winding, while the first phase has two windings. Either an active/passive clamp employed to reuse the lost energy and reduce spikes in voltage brought on Using the leaking inductance [59]. The suggested converter in [60] combines three approaches with a braided high gain step-up chopper.

A non-isolated high gain step-up chopper with lower electrical pressure on power switches been suggested in [61] in order to boost the voltage gain without the use of linked inductor. 2 no. of interleaved improved step-up KY converters are proposed converter in Figure 7d consists of. Comparatively speaking, the voltage conversion ratio more compared to SEPIC, C'uk, ZETA, and interleaved boost converters. Due to the low electrical pressure on semiconductor devices and the consequently low $RDS_{(ON)}$ and low conduction loss, the proposed converter's effectiveness is boosted. [62] makes the suggestion of a voltage multiplier and linked inductor together.

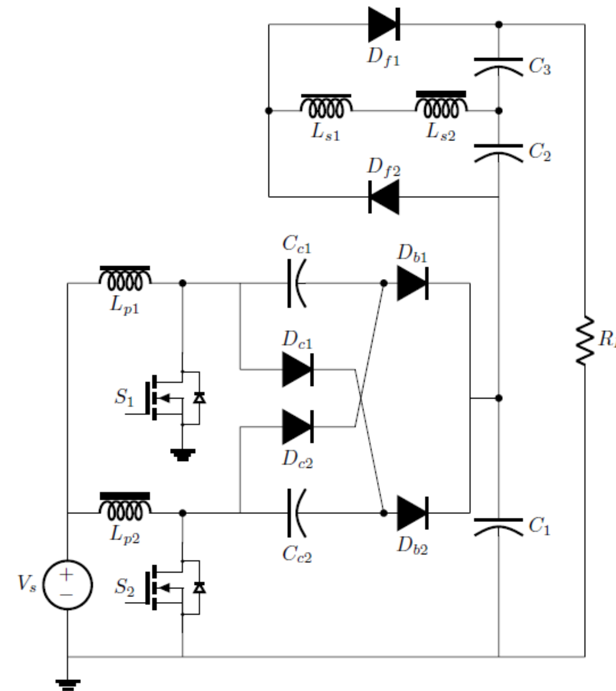

Fig. 7(b). VMC based on SC and CI Interleaved Converters.

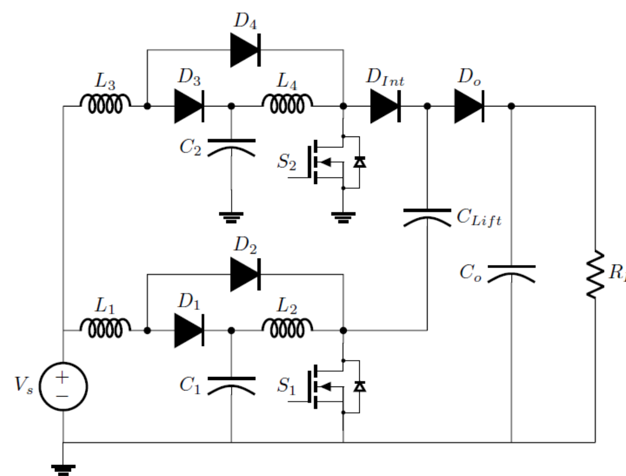

Fig. 7(c). QBC based Interleaved Converters.

The suggested converter utilizes an input-side interleaved boosting converter, which results in a low input current ripple. Two connected inductors with a VM are used to produce extreme step-up DC gain. Additionally, it can solve the diode's issue with reverse recovery current and recycles leaking energy. Finally, by using MOSFETs having a low on-state impedance that are rated for low voltage that can lower conduction loss, the efficiency of a suggested topology can be raised. More information of the interleaved boost converter, including component count and voltage gain, is compiled in Table 3.

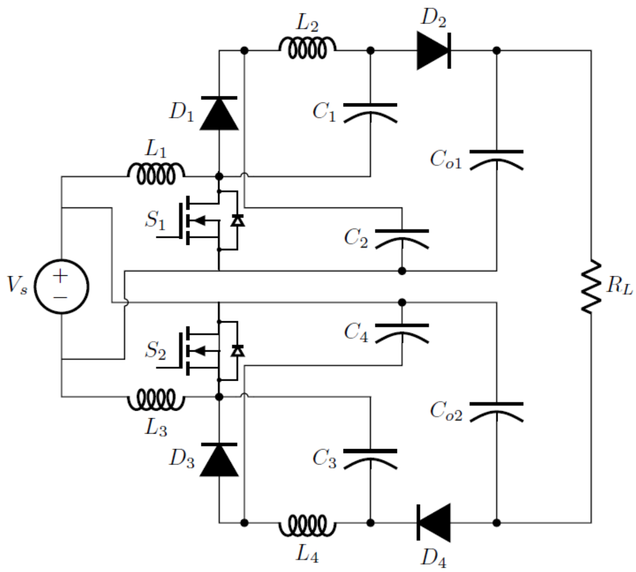

Fig. 7(d). IMSKY Converters.

Table 3. Interleaved Boost Topologies Comparative Analysis

Topology	Number of Components					Voltage Gain in CCM (M)
	Passive			Active		
	L	C	L||	S	D	
Figure 7a, Linked Inductor and VMC Interleaved [53]	Zero	Three	Two	Two	Four	$\frac{2N+1}{1-D}$
Figure 7b, SC & Coupled Inductor Interleaved with VMC [54]	Zero	Five	Two	Two	Six	$\frac{2N+2}{1-D}$
Interleaved QBC Figure 7c [56]	Four	Four	Zero	Two	Six	$\frac{2}{(1-D)2}$
Figure 7d [61] depicts two interleaved improved step-up KY converters.	Four	Six	Zero	Two	Four	$\frac{1+3D}{1-D}$

3.3. Multilevel Converters

In order to achieve appropriate cost, dimension, and weight goals while regulating high-temperature operation, a MLBC in reducing or nearly eliminating the inductors [63]. MLBC can be divided into two classes based on the number of DC sources, both a single and several DC sources. Most traction motors and electric or fuel cell-powered vehicles use single source multilevel systems. In contrast, flexible alternative power sources require several DC source multilevel converters using cascaded topologies [16]. Multilevel converters frequently use switch capacitor designs. A crucial module for raising the voltage level is the Module with clapped capacitors for multilayer converters in Figure 8b, which has three switches and one capacitor [64–66]. Figure 8a illustrates how [67] uses 2 no. of capacitors & 4 no. of switches to get quadruple input voltage. By series connecting, PV modules can raise its voltage level as a result, a chopper must be used for every solar power module if you want to preserve the controlled voltage. Higher safety/protection, reduced cost, lower maintenance, and higher reliability are all benefits of this connection [68]. The Modular Multilevel Converter (MMC) is a common name for this converter [69–71].

Table 4. Multilevel Boost Topologies Comparative Analysis.

Topology		Number of Components					Voltage Gain in CCM (M)
		Passive			Active		
Tech.	Converter	L	C	L||	S	D	
Single Input	MMCCC Figure 8a [64]	Zero	Five	Zero	Thirteen	Zero	$\frac{(1+N)NV_{in}}{2}$
	6X SC Figure 8b [67]	Zero	Six	Zero	Twelve	Zero	$\frac{\left(1+\frac{N}{2}\right)NV_{in}}{2}$
Multiple Input	Cascaded chopper [68]	One	One	Zero	One	One	-

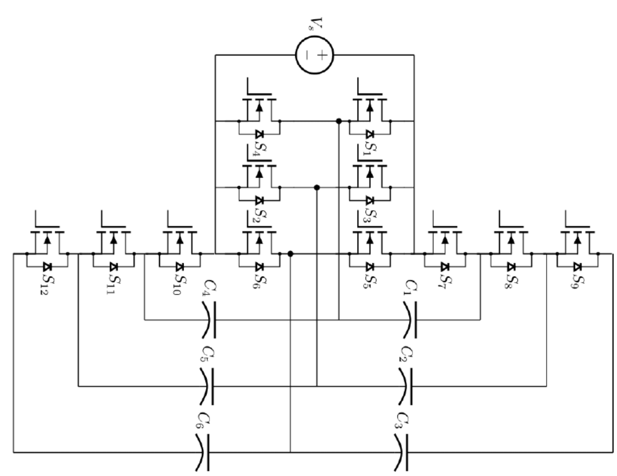

Fig. 8(a). 6X SC Topology.

Table 4 provides an overview of information about multilayer boost converters, including component numbers and voltage gains. Although the MMC has a modular structure, a high-power density, and a high level of reliability, it also has high levels of voltage and current and excellent efficiency. The basic multi-stage/level includes drawbacks, complicated control structure with numerous components. Everything will be fairly huge, bulky, and heavy. This method is applicable to space technology, and HVDC transmission.

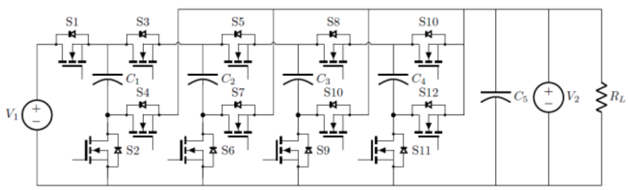

Fig. 8(b). MMCCC topology.

4. SWITCHED CAPACITOR STRUCTURE

SC-based topologies are frequently employed in low power applications, particularly systems constrained in terms of size that require large power densities [72]. The foundation of SCs is the charge pump (CP), it refers to quantity of capacitors employed in SC cells to achieve large DC gain [73–76]. There are no inductive components in it; it just consists of capacitors, MOSFETs, and diodes. They have properties that enable monolithic integration, low EMI levels, and reduced volume [77]. The input and output voltage polarities can be the identical or different based on the non-inverting/inverting cell terms [78]. As depicted in Figure 9, it is inserted into traditional high gain choppers (like Zeta, SEPIC, and C'uk converters) to create an innovative structure. It consists of 2 no. of capacitors and 3 no. of diodes. The new converters' operation is described by the voltage divider circuit. The capacitors (C1 & C2) get charged in series polarity when the diodes (D1 & D2) are in OFF state. The capacitors (C1 & C2) are charged in parallel while the diodes (D1 & D2) are in the ON state. The employment of non-inverting/inverting SC can be seen in a variety of high gain choppers in Figures 9 (a-e). Zeta converters for SC cells are shown in Figures 9a and 9b, respectively. In its development, a non-inverting & reverting SC cell was used in place of the standard Zeta converter's outlet capacitor, outlet inductor, and outlet diode. greater DC gain attained by a typical Zeta converter due to the additional components. The power switch is also under less voltage stress. Figure-9c shows SEPIC converter built around non-inverted Switched capacitor cell it is used as output diode in place of traditional SEPIC converter. It increases the voltage conversion ratio and lowers the electrical pressure upon MOSFET compared to traditional SEPIC converter. An inverting SC cell C' uk converter is shown in Figure 9d. It is created by replacing the output diode, output inductor, and capacitor of a regular C'uk converter with an inverted SC cell. Figure 9e shows a circuit that is similar to Figure 9d, except the output side now also includes a voltage doubler cell. Since there is less voltage stress and higher DC gain in the previous circuit. Inductors are also present on both sides of the C' uk converter, allowing continuous current to flow in both directions. A high-efficient, large DC gain chopper with minimal voltage stresses developed [79] by combining switching capacitor & coupled inductor. For an extremely higher DC gain, additional windings are not required. Additionally, Leakage electricity can be used again by a passive clamp circuit, reducing efficiency while preventing voltage spikes at the switch. Compared to other converter, the primary switch experiences less voltage stress and retains its stability across the whole duty cycle range.

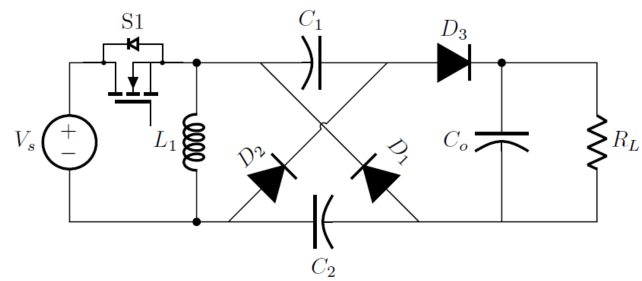

Fig. 9(a). Zeta Converter based on Non-inverting SC Cell Topology.

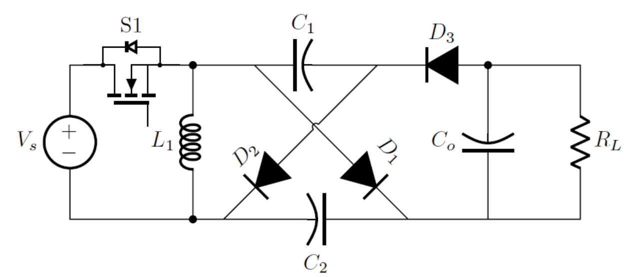

Fig. 9(b). Inverting SC Cell topology.

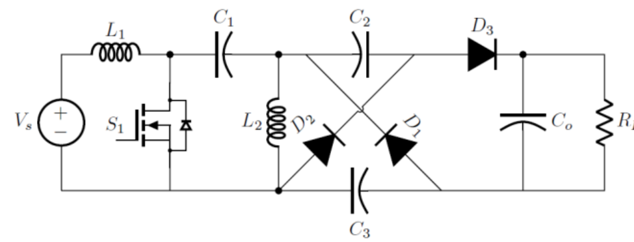

Fig. 9(c). SEPIC Converter based on Non-inverting SC Cell Topology.

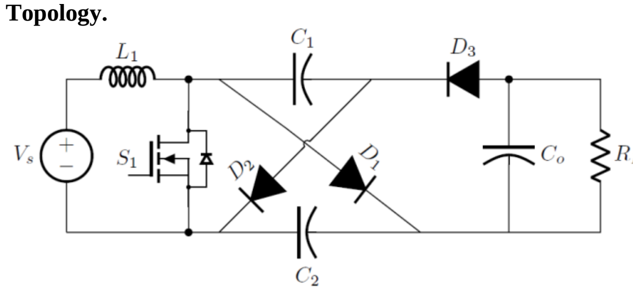

Fig. 9(d). C´ uk Converter based on Inverting SC Cell Topology.

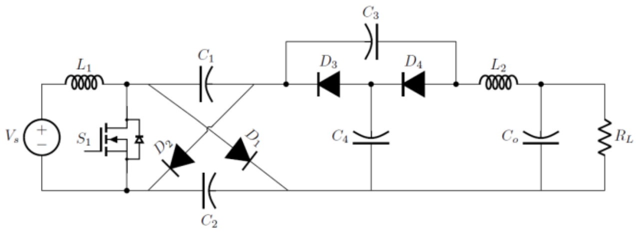

Fig. 9(e). C´ uk Converter with Voltage Doubler based on Inverting SC Cell Topology.

There are five no. of widely used methods based on SC, VD, Ladder, Dickson, Makowski or Fibonacci, and Series-Parallel. The output voltage of the VD SC is double the the input voltage and two-phase system with complementarily operating ON and OFF switching devices [80]. Two groups of capacitors make up the ladder SC. Due to the varying voltage gain generated, the lower ladder's capacitor has modifying input voltage [80]. You can use the Dickson SC as a voltage multiplier. Instead of active switches, the Dickson SC charges pumps using diodes. To drive the switching devices, two pulse strings with the A proper phase shift is frequently required, operating at tens of kilohertz or higher. The Makowski SC, which is sometimes referred to as Fibonacci because its DC gain would increase in accordance with the Fibonacci number, is another SC-based technology. The Makowski SC, however, uses fewer components to achieve significant voltage gain [16]. Techniques' ranges for regulating voltage have been constrained, and the circuit's voltage gains have been predetermined. In order to get higher DC voltage, gain and wider voltage restrictions, in this design, one of the five active switches will be replaced with a single inductor. SC [81]. Non-isolated high gain choppers have been developed employing Dickson SC methods and interleaving to boost the voltage gain of step-up chopper [82]. The Dickson SC approach gives this suggested converter the advantage of a better voltage conversion ratio. By including a tiny resonant inductor into the Dickson SC method, they may reduce large current spikes [83,84]. Due to interleaving operation, it can also improve power density and decrease input current ripple.

In regard to component count, voltage gain, stress caused by voltage on the MOSFET voltage pressure in the diodes connected on output side, input and output voltage, frequency of switching and energy rating, duty cycle, efficiency, the characteristic of each chopper. utilizing the SC method is summarized at Table 5. Despite its compact size and low-cost, high-quality, lightweight circuits, SC may give converters a rapid dynamic as well as elevated power density response. Complex modulating and sensitivity to a capacitor's Equivalent Series Resistance (ESR) are two drawbacks of SC's principles. All of this will result in unstable output voltage. This method can be applied to high gain DC/DC applications, mobile displays, automotive applications, and energy harvesting.

Table 5. SC Topologies Comparative Analysis

Topology	**Number of Components**					**Voltage Gain in CCM (*M*)**
	Passive			**Active**		
	L	**C**	**L||**	**S**	**D**	
Converter shown in Figure 9a [78]	One	Three	Zero	One	Three	$\frac{1+D}{(1-D)}$
Converter shown in Figure 9b [78]	One	Three	Zero	One	Three	$\frac{2-D}{(1-D)}$
Converter shown in Figure 9c [78]	Two	Four	Zero	One	Three	$\frac{2-D}{(1-D)}$
Converter shown in Figure 9d [78]	One	Three	One	One	Three	$\frac{2}{(1-D)}$
Converter shown in Figure 9e [78]	Two	Five	Zero	One	Four	$\frac{2+D}{(1-D)}$

5. VOLTAGE MULTIPLIER

Diodes and capacitors are used in voltage multiplier circuits to produce high output-side DC voltage. Thus, effective, affordable, and straightforward design. VM cell and VM Rectifiers (VMR) are the two main categories into which voltage multipliers can be divided. To lessen the voltage load on the primary switch, VMC might be installed after it, as depicted in Figures 10a and b. The VMC also has other benefits, like a greater gain and enhanced efficiency. VMR installed at the transformer's or coupled inductor's output stage. However, rectifying the pulsing DC or AC voltage is beneficial. It serves as VM in the interim [16]. Figure 10c depicts the general configuration of the VMR.

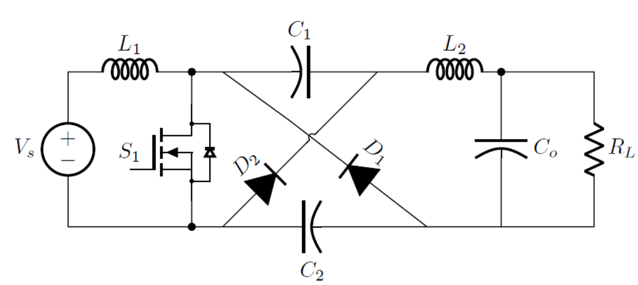

Fig. 10 (a). VMC structure.

Since the source voltage is multiplied in high voltage requirement applications, numerous structures with VMC/VMR become well-known. Because the large capacitors are not needed, it is also inexpensive, small, and lightweight even though it's working on a high frequency [85]. As seen in Figures 11a, b, Certain VMCs are referred by the term switched-diode-capacitors. VMCs since they only include diodes and capacitors within [86]. Due to the need to use certain VMC inductors in order to achieve a higher gain Zero current switching (ZCS) technology can be used by the electrical switch [78]. A high gain non-isolated chopper is provided by the modified VMC and modified conventional boost converter [87].

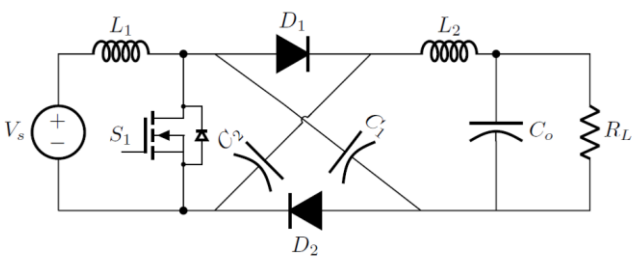

Fig. 10 (b). VMC structure.

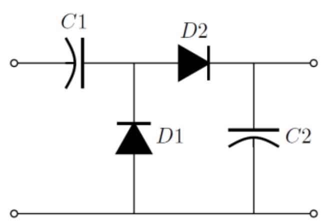

Fig. 10(c). VMR structure.

A linked inductor with a VMC is used to introduce a high DC gain SEPIC converter-based chopper in [88]. These converter's features include enhanced efficiency, large DC gain, and minimal input-current ripple. It combines SEPIC converter with two voltage boosting methods. A unique, customized single switch SEPIC is the cornerstone for high step-up chopper that is presented by [89]. A linked inductor and VMR can be added to get high voltage. Continuous current mode operation, zero current switching (ZCS), and minimal loss are benefits of the SEPIC. Consequently, the MOSFETs voltage spike is small. Half-wave [90] or full-wave voltage [91] multipliers with diodes and capacitors are available in a wide variety of designs. Figure-11c displays Greinacher Voltage-Doubler-Rectifier (G-VDR), It is widely applications of transformer-based or multiple-stage choppers having modular series output at the output stage [92]. The output voltage is the same as the value of the capacitor voltage, and the increased voltage stress on the diodes that causes the VMR deficit.

Comparable to the G-VMR in function but created in a separate year, the Cockcroft-Walton (CW) is a VMC that is renowned for its cascading structure [93]. Because voltage pressure on the output capacitor equals the output voltage divided by two, full-bride voltage doubler rectifiers are frequently utilized in a variety of choppers [94, 95]. Since the VMR is occasionally referred to as it is possible to use a voltage-regulated triple rectifier applied in a variety of ultra-step-up choppers. The VMR can be utilized in isolated structures and structures with multiple layers of output [96]. Despite having characteristics like a cell-based structure, a simple topology, and high voltage capability, voltage multipliers can be included into a variety of converters. The voltage multiplier has other drawbacks as well, such excessive voltage stress on parts. For applications requiring high voltage, this needs many cells. Applications for this approach include physics (plasma research, particle accelerators), high power laser, and medical (X-ray, laser). Table 6 summarizes further information about the voltage multiplier-based chopper component quantity and voltage gain.

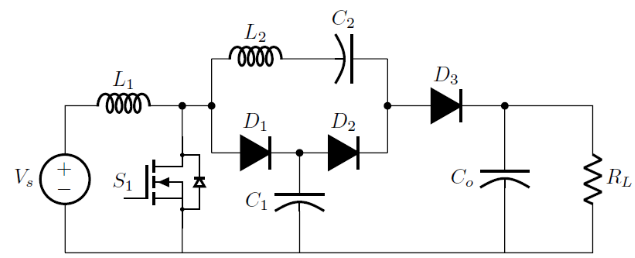

Fig. 11(a). Step-up chopper with VMC M = 1.

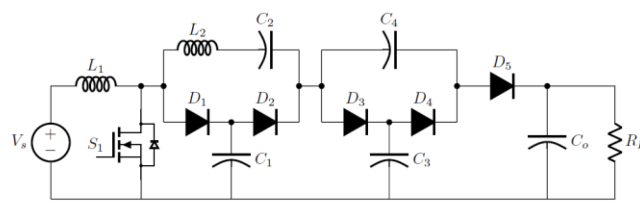

Fig. 11(b). Step-up chopper with VMC M = 2.

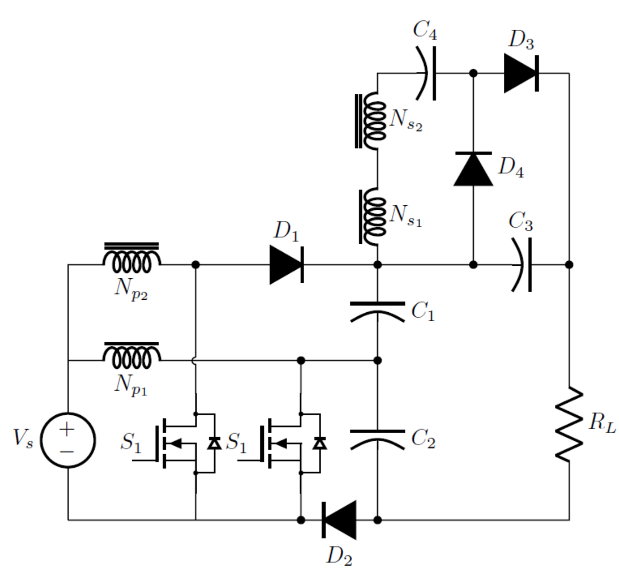

Fig. 11(c). I-Parallel O-Series Step-up chopper with dual Coupled Inductor and VMR.

Table 6. VM Topologies Comparative Analysis.

Topology		Number of Components					Voltage Gain in CCM (M)
		Passive			Active		
Tech.	**Converter**	**L**	**C**	**L||**	**S**	**D**	
VMC	Converter shown in Figure 11a [87]	Two	Three	Zero	One	Three	$\frac{M + 11}{(1 - D)}$
VMC	Converter shown in Figure 11b [87]	Two	Five	Zero	One	Five	$\frac{M + 11}{(1 - D)}$
VMR	Converter shown in Figure 11c [92]	Zero	Four	Two	Two	Four	$\frac{2(N + 1)}{(1 - D)}$

6. VOLTAGE LIFT (VL)

Parasitic components limit the resultant voltage and reduce the transmission efficacy of DC-to-DC converters. An excellent opportunity to enhance circuit characteristics is offered by the voltage raise technique. Figure 12 illustrates the voltage lift's fundamental structure. The Luo converter, first presented in [97,98], is a well-known converter that makes use of the VL approach. The output voltage increases when a capacitor charges to a particular voltage and reaches that level.

By re-applying the approach as illustrated in Figure 13a [99-101], Depending on how many capacitors are in the circuit, the voltage that is produced can be increased further, tripled, and quadrupled. excellent power density, excellent efficiency, and affordability of this topology are its key benefits. Additionally, the outcome voltage ripple is barely there for higher voltage applications. every VL approach is applied by different converters in the literature, including the C'uk, SEPIC, and Zeta converters [102,103]. The voltage multiplier and voltage life technique-based N-Stage quadratic boost converter (NQBC-VLVM) is introduced in [37]. The NQBC-VLVM's input inductor can be switched out for the VL method Increase the voltage to current ratio. of conversion with a low duty cycle. its advantages are that the voltage gain can be doubled by two, and every main switch is subjected to electrical pressure This only makes up half of enhanced efficiency by increasing the output voltage.

In [104,105], a QBC with a VD and VL method is introduced. This converter uses the VL approach to raise voltage gain four times, as seen in Figure 13b. Additionally, it can cut electrical pressure on every switch until the output of the voltage is halved and twice the voltage gains by utilizing a VDC. To get high DC gain, the QBC based on fundamental VL method is suggested in [106]. The DC gain of this suggested topology would be exponentially raised, depending on the quantity of inductors. As a result, the double lifted circuit in the gain in voltage of Figure-13c is 8 no. of times greater than the supply voltage, while the triple lift circuit in with respect to input voltage, Figure 13d's roughly 16 times greater voltage gain. On the other hand, efficiency falls off as the number of inductors rises.

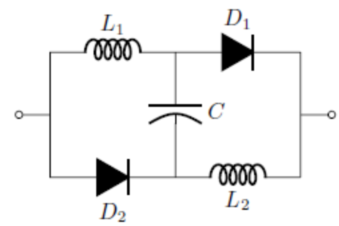

Fig. 12. Voltage Lift (VL) Cell.

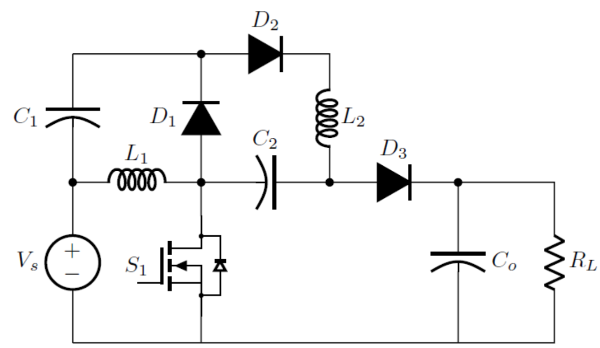

Fig. 13(a). Boost Converter based VL technique.

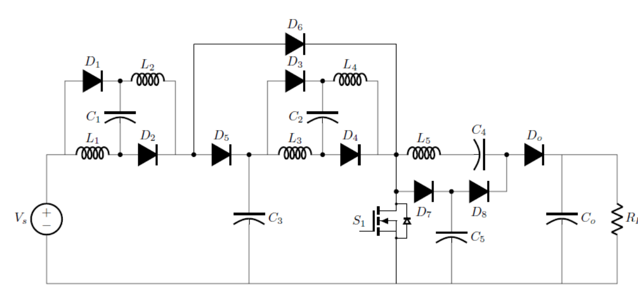

Fig. 13(b). QBC based on Voltage Doubler and VL technique.

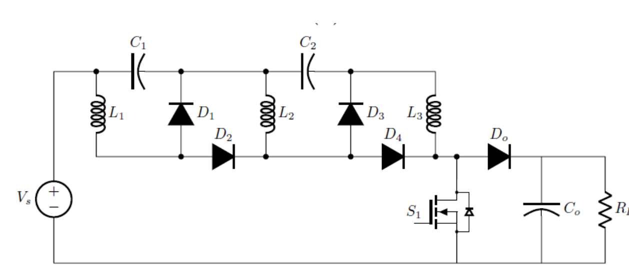

Fig. 13(c). QBC based on elementary VL (Double Lift) technique.

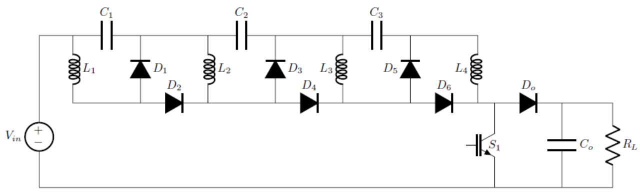

Fig. 13(d). QBC based on elementary VL (Triple Lift) technique.

On the basis of the double VL method, as in [107], a cascaded boost converter is suggested. This converter's every subsequent stage's input voltage is derived from the initial stage's output, allowing it to operate at low duty cycles while still achieving low voltage pressure on MOSFET & higher DC gain. More information on the step-up chopper based on the VL technique, including the number of component and voltage gain, is summarized in Table 7.

Table 7. VL Topologies Comparative Analysis

Topology	Number of Components					Voltage Gain in CCM (M)
	Passive			Active		
	L	C	L||	S	D	
Converter shown in Figure 13a [99]	Two	Three	Zero	One	Three	$\frac{1+D}{1-D}$
Converter shown in Figure 13b [104]	Five	Six	Zero	One	Nine	$\frac{8}{(1-D)^2}$
Converter shown in Figure 13c [106]	Three	Three	Zero	One	Five	$\frac{1}{(1-D)^3}$
Converter shown in Figure 13d [106]	Four	Four	Zero	One	Seven	$\frac{1}{(1-D)^4}$

7. SWITCHED INDUCTOR (SL)

Figure 14 presents an illustration of the fundamental SL cell. Magnetizing components are electrically parallel charging and series dissipation, which is how this cell functions. The first instance of this kind of procedure appeared in [86]. A traditional boost converter to switched inductor circuit replaces a hybrid boost converter with an input inductor. As a result, it offers a larger voltage gain than a typical step-up chopper.

Due to the fact that these two inductors have the same inductance, one inductor can be created by combining them, which enables Dimensions and weight of the converter be reduced. The output diode a main VL cell and a tiny resonant inductor have recently been added was swapped out to create a step-up chopper with high DC gain [108]. The primary advantages of this converter are its straightforward design and great efficiency. Self-lift SL cells are produced via incorporating every basic VL cell into every SL cell, and the extra self-lift SL cell is made by including an additional capacitors and diodes [109]. As a result, employing (So) instead of (Do) for the primary SL cell.

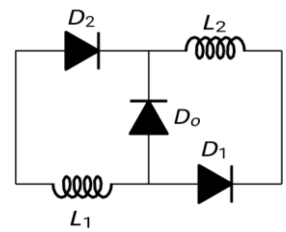

Fig. 14. SL Cell structure.

A transformer-less high gain step-up chopper with high voltage gain has been suggested inside [110] and is based on SL and SC approaches. Additionally, it can lessen the voltage stress on MOSFET, however because there are two switches, the price will go up. Another architecture, another architecture that can offer a high DC gain one switch step-up chopper combined structure of SL&SC was given in [111] and is shown in Figure 15a. This converter has the benefits of only requiring one switch under low voltage stress, with achieving high DC gain without use of a linked inductor

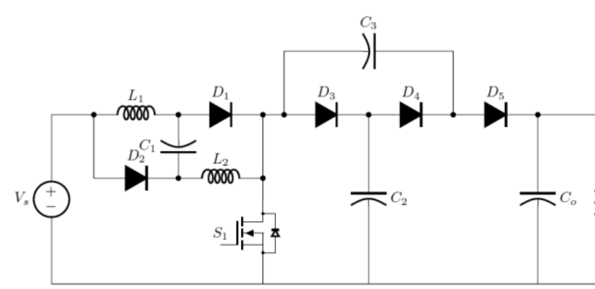

Fig. 15(a). High DC gain chopper designed with SC&SL Techniques.

Figures 15 b, c illustrates the introduction of the XY step-up chopper family in [112]. The simultaneous use of one or more large step-up approaches, which include a single inductor, SL, VL-SL, and modified MVL-SL, is done by these individuals, among other high step-up approaches. When compared to the standard converter, this family may produce higher output voltage. With just one switch, it may deliver negative output voltage. It is appropriate for large step-up applications including higher voltage automotive applications & solar multilayer inverter systems. A SI and VMC utilized in Figure 15d to generate a large DC gain [113]. These are accomplished by creating an N-level chopper with 2 switches, 2 inductors, 2 diodes, and 2 N-1 capacitors. However, the number of output levels effects this converter's voltage gain.

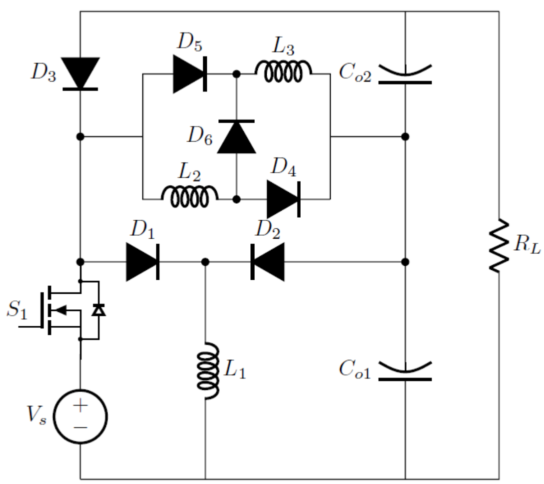

Fig. 15(b). XY Converter (L-SL) Techniques.

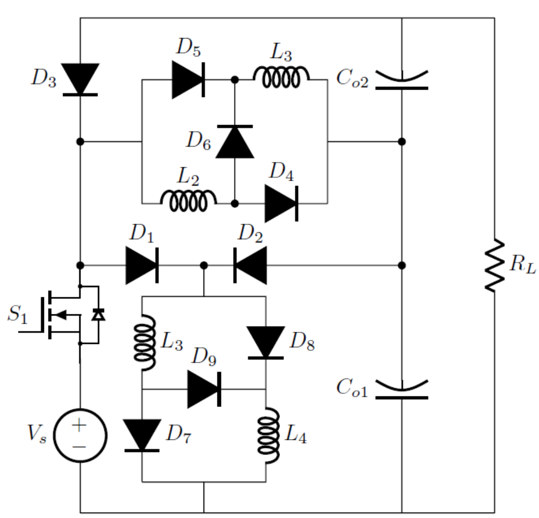

Fig. 15(c). XY Converter (SL-SL) Techniques.

With regard to voltage gain & number of components, Table 8 presents further information about the high gain converters based on the SL approach. High power applications do not call for this type of converter. High gain DC/DC applications and midrange choppers can both make advantage of the SL approach.

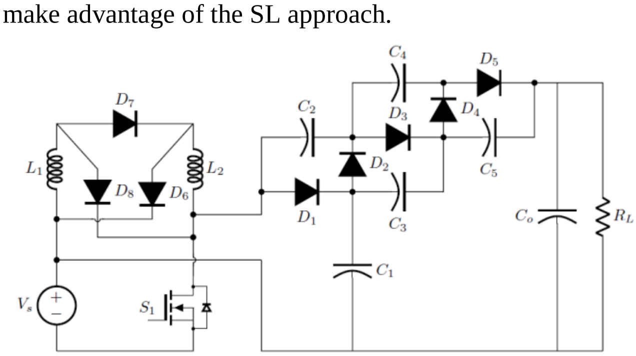

Fig. 15(d). N-level boost Converter with SL and VM.

Table 8. SL Topologies Comparative Analysis

Topology	Number of Components					VoltageGain in CCM (M)
	Passive			Active		
	L	C	L||	S	D	
Converter shown in Figure 15a [111]	Two	Four	Zero	One	Five	$\frac{4}{(1-D)}$
Converter shown in Figure 15b [112]	Three	Two	Zero	One	Six	$\frac{(D^2-3D)}{(1-D)^2}$
Converter shown in Figure 15c [112]	Four	Two	Zero	One	Nine	$\frac{-4D}{(1-D)^2}$
Converter shown in Figure 15d [113]	Two	Five	Zero	One	Eight	$\frac{(N-1)+(N+}{(1-D)}$

8. MAGNETIC COUPLING

Magnetic coupling, which is utilized in both non-isolated/isolated choppers, serves as one among the most often used voltage raising techniques. The unique quality of magnetic link is the capacity to boost output voltage by varying the duty cycle from windings next to the switch [114]. However, the magnetic link has some issues, namely leakage inductance [115]. It may be broadly divided into topologies for transformers, coupled inductors, and multi-track systems.

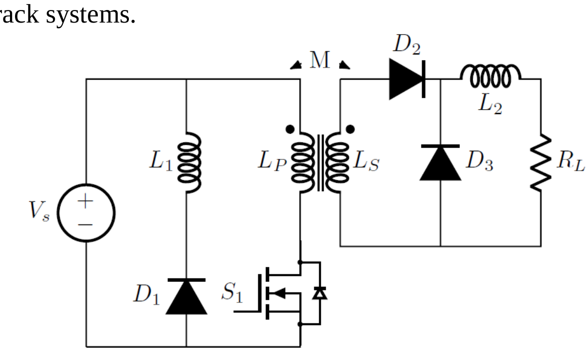

Fig. 16. Transformer-Based Converter.

8.1. Transformer

A medium/high frequency transformer is necessary for an electrically isolated chopper, as depicted in Figure-16. Many isolated high DC gain converters, including full/half-bridge converters, forward converters, push-pull converters, and flyback converters, make use of such a device. Isolated DC/DC converters have improved traditional boost converter performance for various applications over the past ten years [116-122].

8.2. Coupled Inductor

Many applications don't need isolation, therefore linked inductor circuits may benefit from transformer couplings without separation to boost the voltage in choppers [123-132].

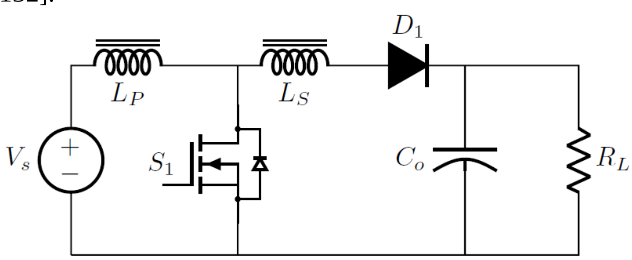

Fig. 17. Coupled Inductor (CI) Circuit.

Table 9. Coupled Inductor Topologies Comparative Analysis

Topology	Number of Components					Voltage Gain in CCM (*M*)
	Passive			Active		
	L	C	L‖	S	D	
Converter shown in Figure 18a [124]	Zero	Four	One	One	Three	$\frac{2+N}{1-D}$
Converter shown in figure 18b [125]	Zero	Four	One	One	Four	$\frac{1+N+ND}{1-D}$
Converter shown in Figure 18c [133]	One	Three	One	One	Three	$\frac{2+N}{1-D}$
Converter shown in Figure 18d [135]	Zero	Five	Three	One	Five	$\frac{3+2N_2+N_3}{1-D}$

A traditional configuration for step-up converter with CI is shown in Figure 17. The clamp capacitors and diodes are employed to restore the energy lost that is recycled either directly or via a secondary winding into the load, with the secondary winding serving as a voltage source [123]. Additionally, a snubber circuit, as seen in Figure 18a, which can be used to boost effectiveness and absorb the electricity of the leakage inductance. Figure 18b illustrates the applying a linked inductor along with a charge pump with SL_VMC in [125] to provide a greater voltage gain, which is useful for distributed generating systems. Figure 18c depicts a non-isolated high gain chopper that is introduced in [133] and has a linked inductor that continuously integrates input current. There are 3 no. of diodes, 3 no. of capacitors, and 1 no. of inductor in it. Additionally, the linked inductor used for achieve higher DC gain and less ripples due to an inductor's series link to the input, a rise on input current. The main switch's voltage stress is lessened by the clamp circuit. Low $RDS_{(ON)}$ can be attained as a result, which lowers conduction losses. As a result, whenever the switch is activated with no current will flow, the switching loss is reduced. [134] makes a proposal for one switch higher voltage gain & high-efficiency chopper. The intermediate capacitors are charged through the connected inductor in parallel and discharged in series to provide the voltage gain. A high DC gain step-up chopper using two Cockcroft-Walton and three winding linked inductors was suggested in [135], as seen in Figure 18d. study in high DC gain converters is the impedance (Z-) source. By employing a low duty cycle, it can increase voltage gain [136–140].

Table 9 highlights some information about the coupled inductor step-up converter in terms of voltage boost and component number.

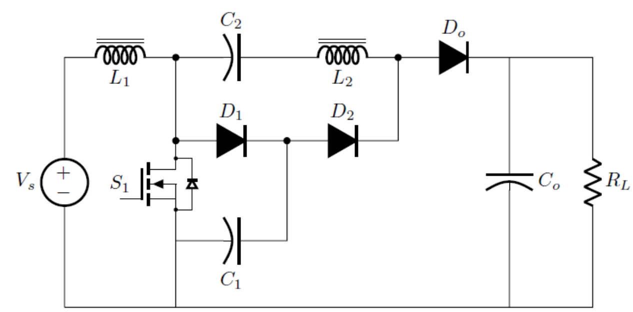

Fig. 18(a). Boost Converter based CI structure.

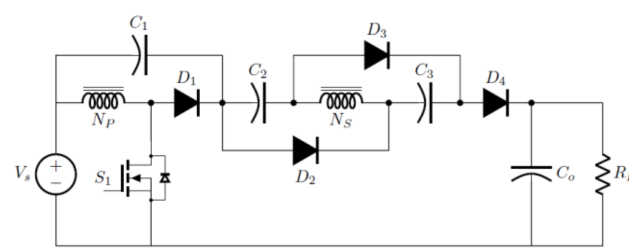

Fig. 18(b). Two Capacitors and one CI structure.

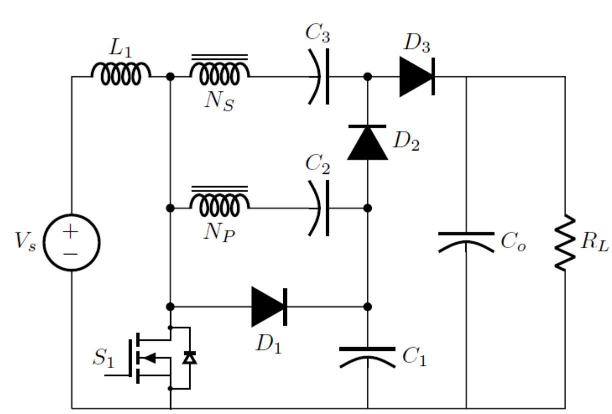

Fig. 18(c). Coupled Inductor structures.

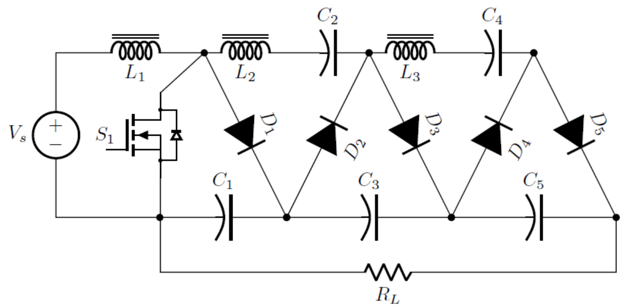

Fig. 18(d). 3-winding Coupled Inductor structure.

8.3. Multi-Track Structure

One can distinguish between a Single and multi-stage step-up chopper. A one-stage structure could accomplish several tasks in a one stage; as a result, it has a simple control and is not a complex circuit. Single-stage structures, however, are unable to operate throughout a broad variety of operations with excellent performance. The performance of a multi-stage structure is improved since each stage can carry out one or more tasks. In comparison, this structure has a large number of parts and is more complex. In the literature [141–144], a SC, SL, and magnetically coupled circuits are included in the fundamental an illustration of the multi-stage designs in block form, which is regarded as one of the key solutions. Voltage regulation is accomplished using switching inductor circuits, but their size, high conversion efficiency performance, and power density are all constrained. In order to provide balance efficiency, switched capacitor circuits are used; nevertheless, they are unable to regulate voltage. greater voltage conversion ratios, galvanic isolation, and gentle switching are all features offered by magnetic circuits; however, they are unable to maintain high performance throughout a variety of operations. In order to offer a high performance, [145] proposed cascaded two-stage topologies for low power applications. The initial stage is inductor-free, soft-switching, SC voltage divider, a large power density, and [146] all of these characteristics.

A buck converter serves as the second phase that can supply regulated bus voltage because it's as compared to the voltage divider, the density of power is lower. Magnetic circuits are integrated with a variety of high voltage approaches in multi-Track. [147] proposes multi-track power conversion using SC and magnetism. It incorporates a hybrid magnetic/capacitor switching arrangement construction that divides the conversion of an extensive voltage range to lower ranges, distributes power over several tracks, integrates the isolation & regulation stages on a functional level.

Due to the magnetic coupling's adjustable turn ratios, it offers certain appealing qualities including great increase capacities with freedom and flexibility of design. To further aid reduce conducting loss and achieve high efficiency during soft switched operations, a switch can be added to the converter' lower-voltage side. However, converters using MC have several drawbacks, such as a negative impact of leaked inductance, resulting in a large voltage spike. These converters are also regarded as big due to the magnetic components that are incorporated into their construction. This method can be applied to applications requiring high power/voltage DC supplies, high voltage systems.

9. CONCLUSIONS

The fundamental shortcomings of power conversion systems are addressed by the introduction of power electronics converters that has high boosting ratio. great boost converters that are not separated are preferred because of their low cost, great efficiency, and simplicity. For some non-isolated converter types, this assertion is not true. This study evaluates, describes, and categorizes the benefits and drawbacks of numerous cutting-edge step-up converters using techniques for increasing the voltage. The study divides the high boost approaches into SI, VM, VL, SC, multistage/multilevel & MC. The pros and drawbacks of cost, complexity, density of power, dependability, and efficiency are covered in detail for each area in this study.

In addition, in addition, Tables 1 through 9 of this study examine the quantity of active as well as passive components, voltage gain and stress, switching rate, efficiency, overall power rating. Instead of focusing on DC/DC converters, this paper focuses on large DC gain conversion techniques, which will encourage the development of fresh concepts and novel power conversion devices that will contribute to the development of highly effective and flexible strength converters for a range of applications. where the voltage at the transmitting end is very low, like photovoltaic systems. Any high DC gain converter faces substantial difficulties in achieving significant voltage gain and reducing rippling current because of the high switching rates. Additionally, because a high RDS(ON) and voltage rating of switches are not necessary, by reducing the stress caused by voltage upon the electrical switch, the cost and losses in conduction of the electrical device can be kept low. As a result, using soft switching and addressing the output diode reverse recovery issue reduce switching losses and reverse recovery losses.

The topology could be combined with one or two DC/DC converters, such as Boost, C'uk, SEPIC, Zeta, and QBC, based on one or more techniques, such as SC, SL, VL, and Voltage Doubler Cell. This would enable the use of both the boosting technique and the DC/DC converter's features in a one-stage conversion system. With the help of the QBC, which is based on the VDC and Voltage Lift (VL) approach, DC voltage gain can be increased by eight times without having to run the device at an incredibly high duty cycle. Additionally, the VDC can increase DC gain by a factor of two, and voltage stress across MOSFET could be cut in half. In order to account for conduction losses, it needs a reduced voltage rating and RDS(ON) power switch. Therefore, by decreasing switching, the reverse recovery current issue can be solved using Schottky rectifiers, increasing efficiency. Another architecture uses a linked inductor, 2 no. of capacitors, and a high gain chopper to boost the voltage gain without operating at excessively large duty cycles and turns ratios. Additionally, A passive clamp circuitry recycles the power that comes from the paired inductor's leaked inductance, which could reduce the electrical stress on the MOSFET. As a result, it lowers the conduction losses and makes low resistance RDS(ON) possible. Ultimately, important DC/DC converter properties are a high DC-to-DC conversion ratio, inexpensiveness, high efficiency, and a substantial power density. The overall structure and rules for the forthcoming generation of non-isolated large gain choppers are clarified in this study.

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