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Review and comparative analysis on dc-dc converters used in electric vehicle applications

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Abstract: This paper is reported with different kinds of DC-DC converters such as sepic, boost and bidirectional converters. Integrating the boost, sepic, bidirectional DC-DC converters enables to identify the suitable converter for renewable energy applications with accurate power rating. The performance of non-isolated converter is assessed on the basis of these review. The solar PV conversion efficiency is low, so the converter is used to step-up/step down the voltage levels. This paper attempts to perform by examing efficiency of DC-DC converters and the voltage and current stress on the switches. A detailed review is carried out on basic PV and fuel cell based electric vehicles.

Keywords: Fuel cells, Solar PV, Boost, Sepic and Bi-directional converters, Electric vehicles.

1. INTRODUCTION

The power generated through the photo voltaic (PV) panels remains intermittent and random in nature. To maintain continuous supply from PV panels DC-DC converters are required. These converters are classified as isolated and non-isolated converters. According to the configuration of converter topologies isolated converters has two configurations full and half bridge topologies [1-5]. In addition, the half-bridge converter needs a centre-tapped transformer, which results in a complex structure, and the full-bridge converters are require a higher number of semiconductor devices and cost of the converter also increased [6-9]. In order to reduce the voltage stress caused by the leakage inductance, a DC-DC converter with an active clamp circuit is used [10]. The leakage inductance utilized in dual active bridge and the phase-shift full-bridge to achieve the soft-switching, and stored energies in leakage inductance are transmitted to the load [11-13].

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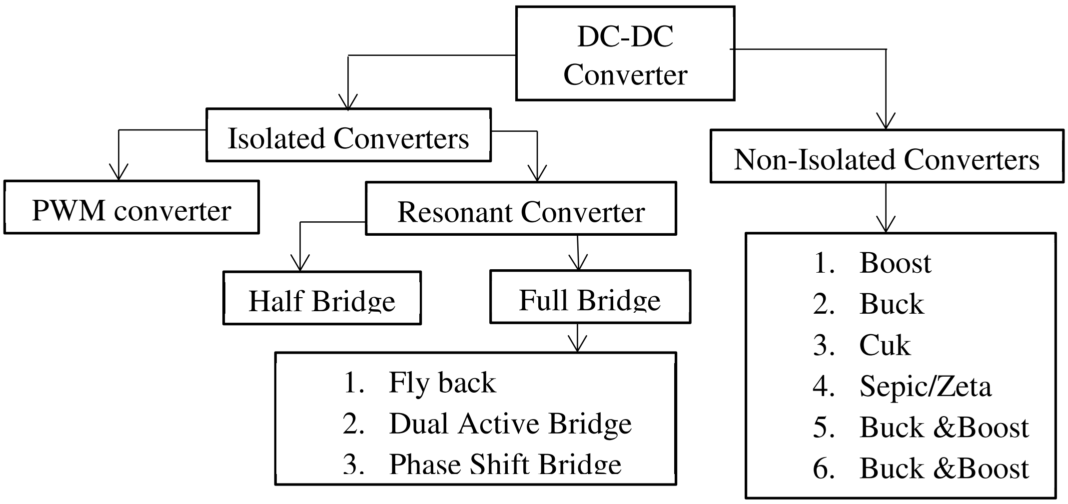

Figure. 1 Classification of DC-DC Converter

2.Non-Isolated DC-DC Converters

This topology is widely used for the application of Uninterruptible Power Supplies (UPS) and Hybrid Electric Vehicle (HEV). The design of the circuit itself helps to charging and discharging the battery bank. The above figure 1 shows the Non-isolated DC-DC converters. Bidirectional converter delivers a large voltage assortment in two operating conditions since it operates under a Zero Voltage Switching (ZVS) condition. The benefit of the BDC is as follows. 1) In both boost and buck mode the BDC attains high static voltage gain. 2) If we want to oprate the converter as a bidirectional condition three active switches are required. 3) To design these converters less number of passive elements are required. 4) The switching and conduction losses is reduced by using voltage clamping circuit, ZVS and synchronous rectification.

2.1 BOOST CONVERTER

The conventional boost converters used for medium and low power applications. The input current of the converter is non-pulsating and structure is simple. The simple boost converters are used for low and medium power levels. Electromagnetic interface is the major drawback of the basic converter. These converters have non-pulsating input current and simple structure. The conventional switched inductor boost converter (SIBC) having more switching losses at the main switches and the switching diodes having more conduction losses. The converter having the advantages are soft switching, low duty loss and high voltage gain. The converter conduction losses reduced by adding the auxiliary switches [1]. The interleaved coupled inductor boost converter needs a single active soft switching module to achieve the soft switching property. These converters share the input and output currents and also reduce the ripple currents [2]. For extensive range of input voltage, load current variations and switching frequency the ZVZCS provides soft commutation to the main switches [3]. If the number of capacitors and diodes increases higher voltage gain is attained but the cost of the converter becomes increases. By increasing the number of diodes and capacitors a high gain can be attained [4]. The boost converter can’t track maximum power point at low irradiation condition. High voltage-gain and low-cost boost converter topologies are

- Coupled inductor with boost converter
- Switched capacitor with boost converter
- Coupled inductor with boost converter and switched capacitor
- Switched capacitor with inductor and boost converter [5].

TABLE-1

Reference	Switching frequency In kHz	Input Voltage In volts	Number of switches	Number of capacitors	Number of inductors	Output Voltage In volts	Efficiency In (%)
[1]	100	30	4	2	3	200	94.76
[2]	50	100	3	1	3	250	95.12
[3]	100	50	4	1	4	120	98.2
[4]	24	30	1	3	2	300	92.9

2.2 Coupled inductor with boost converter

To obtain higher gain of the voltage and realizing continuous input current the coupled boost converter having extra diodes. The coupled inductor with boost converter as shown in fig.2 reversal coupled inductor T-source boost converter, coupled inductor Y- source boost converter, coupled inductor T- source boost converter topologies are analyzed. Based on the high efficiency and voltage gain the coupled inductor Y-source boost converter is better than the quasi-Y-source boost converter [6]. The circuit cost and volume is reduced when the two input inductors are coupling each other. Yie-Tone Chen proposed a converter with two main switches and one active soft switching module to attain soft switching property [7]. Because of coupled inductor leakage inductace, high voltage spike occurs at the main switch. The coupled inductor with cascaded boost converter gives higher voltage gain and efficiency [8].

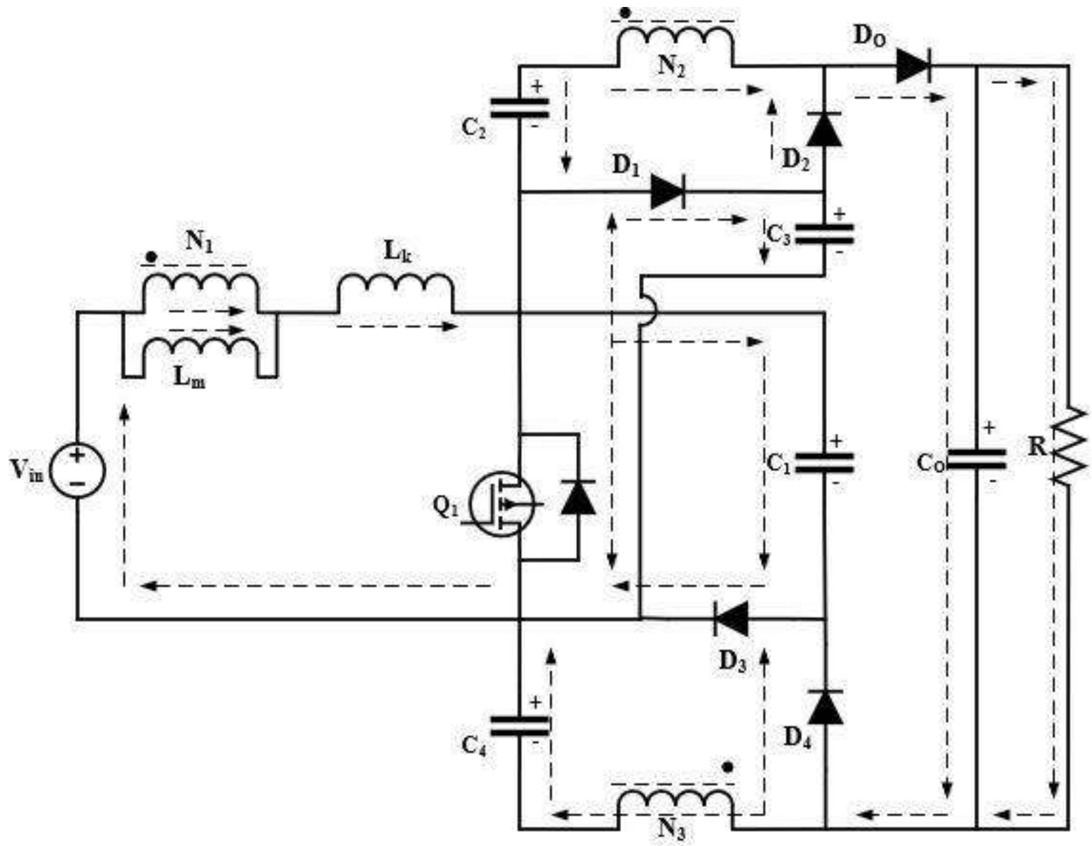

Figure. 2 Coupled inductor with boost converter [9].

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To form a hybrid multiplier cell in coupled inductor the secondary windings are used. In addition to maximizing the voltage gain, and minimizes the voltage stress on the converter the coupled inductor type converter is preferred [9].

2.3 Switched capacitor with boost converter

To enhance the regulation of output voltage Robert stala proposed a converter. Fig. 3 shows the switched capacitor type boost converter. By increasing the voltage ratio, the inrush current problem occurs in the circuit. Based on the inrush current the circuit parameters needs to be designed [10].

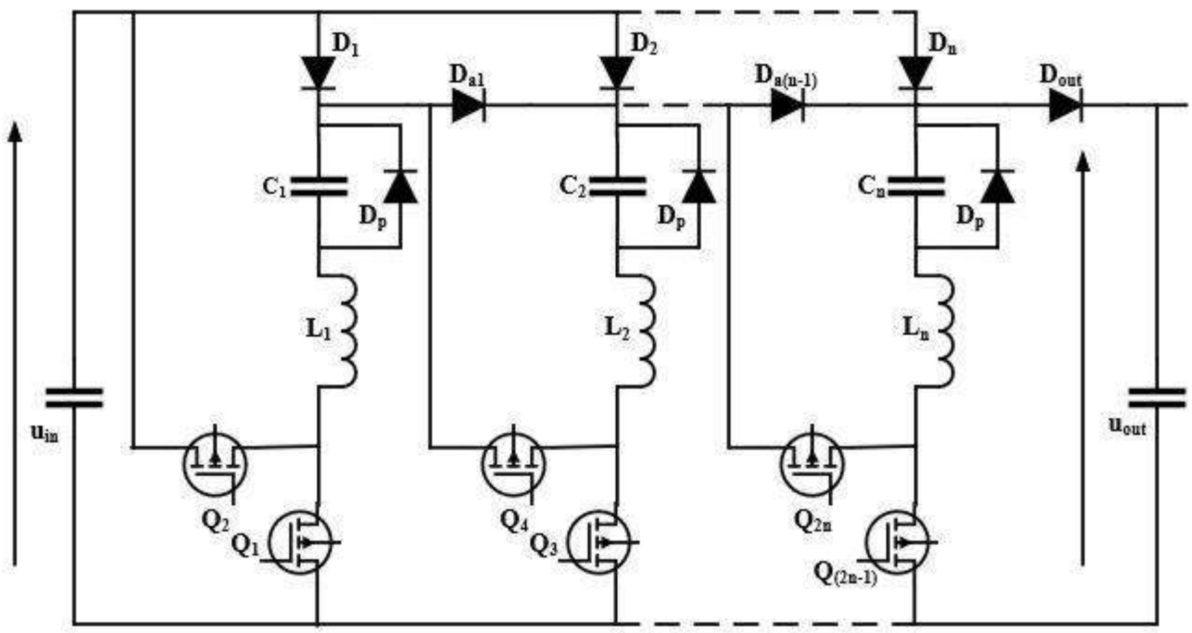

Figure.3 Switched capacitor type boost converter [10]

The two capacitors are connected in parallel to the single dc source to form a switched capacitor cell. The advantages are high efficiency less complexity and appropriate boosting property. To reach a greater number of output voltage levels with extended configuration two switched capacitor cells are connected. [11]. Minh-khai Nguyen proposed a converter with small duty cycle with high voltage gain. The converter decreases the conduction loss on the switches and decrease the voltage stress. The converter gives 200V output voltage with the 25-50V input voltage and operating power 200W [12]

2.4 Coupled inductor with boost converter and switched capacitor

The voltage stress on the main switches reduced by using low voltage rated transistors. The structure of the converter easily extended for high voltage gain. Fig. 4 shows the coupled inductor with boost converter and switched capacitor. In the converter soft switching condition achieved by utilizing leakage inductance with the help of diodes. To improve the efficiency small on state resistance with low voltage rated MOSFETs can be chosen. With the same duty ratio and the same input voltage the voltage stress on the main switches are less [13].

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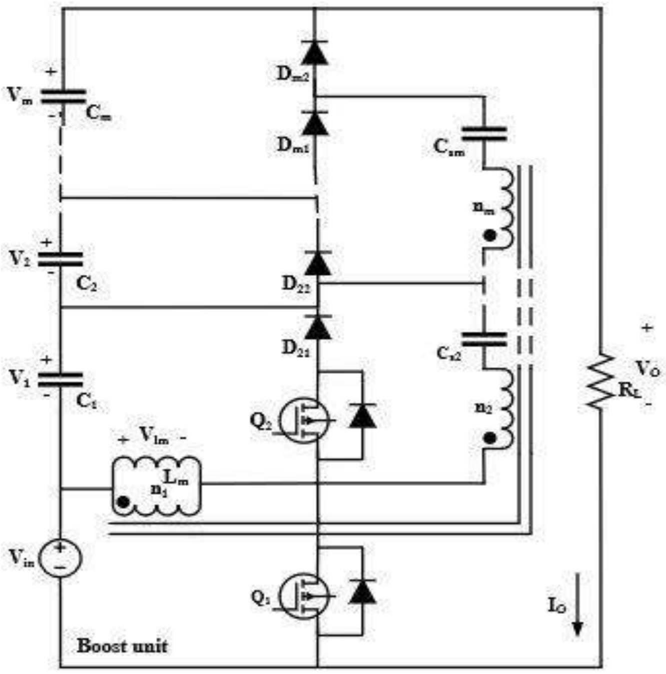

Figure. 4 Coupled inductor with boost converter and switched capacitor

To eliminate the hard-switching phenomenon diodes are ZCS turned on/off and transistors are ZVS turned on. The voltage stress on the converter diodes and transistors equal to the input voltage, remains low. The resonance tank consists of two small capacitor and one inductor. The converter output characteristics, voltage-gain curves are analyzed [14].

2.5 Switched capacitor with inductor and boost converter

The combination of conventional switched boost network through the switched capacitor or switched inductor cell have maximum voltage gain, The voltage stress on the switches and diodes. Fig. 5 shows the switched capacitor with inductor and boost converter circuit. The switched capacitor with inductor having the advantage of expandability. By adding three diodes and one inductor the extra cell can be easily cascaded. Compared to other boost converters switched capacitor converter gives low duty ratio with more voltage gain [15].

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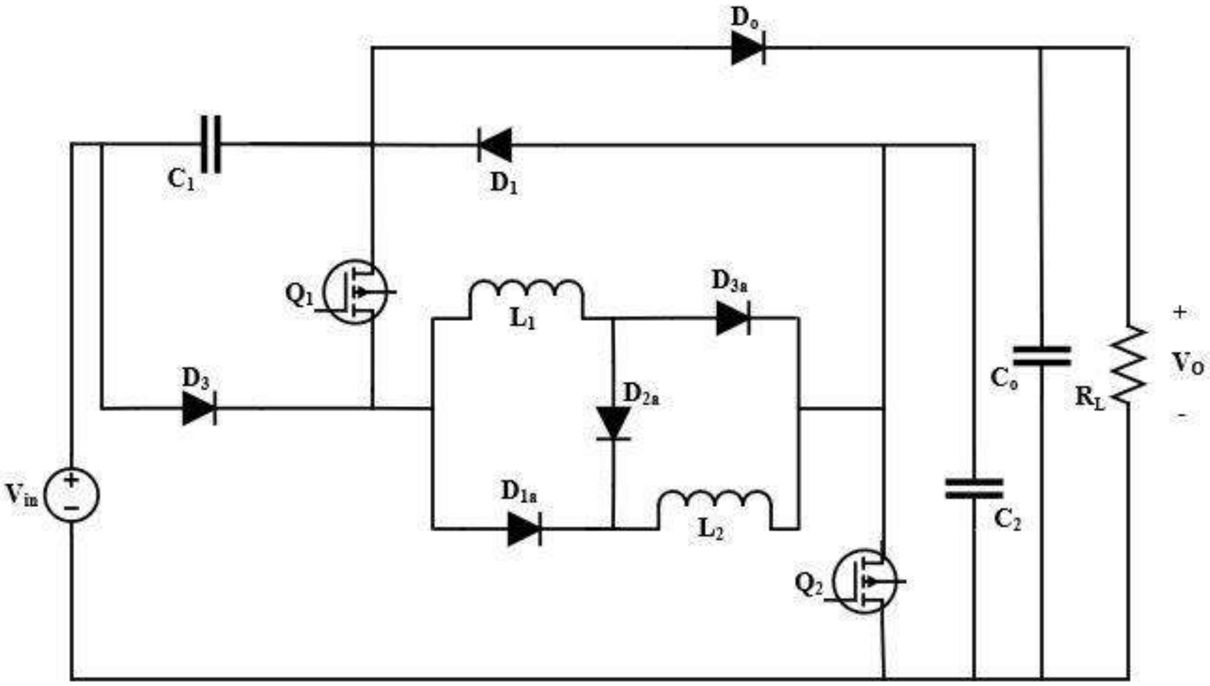

Figure. 5 switched capacitor with inductor and boost converter

The coupled inductor leakage inductance is used to the load. The switched capacitor having inrush current problem due to the leak inductance of the coupled inductor restrained the inrush current [16].

PV system performance is also influenced by selection of the converter. If the panel resistance is equal or below the load resistance then boost converter track maximum power point. By reducing the stress on switches, the converter efficiency increases. The input ripple current of buck-boost, buck and zeta converters are greater than that of cuk, zeta and SEPIC converters [17].

The leakage inductance reduces the voltage gain of the coupled inductor DC-DC converter. Coupled inductor with voltage multiplier cell is used to increase the voltage gain of the converter. The voltage stress on the switch is reduced by using high gain cell. If high gain cell increases the voltage conversion ratio increases [18]. The combination of self-lift Cuk and boost converter reduces the voltage stress of the diodes and switches [19].

3. Buck converter

Although the modified series-capacitor (SC) high conversion ratio (HCR) DC-DC buck converter having extra capacitor to eliminate the start-up voltage stress on the switches. Compared with conventional SC buck converter the input capacitance of these converter is 0.5 V_{in} [20]. Based on the size of MOSFETs the parasitic capacitance and on resistances are changed. The efficiency of the buck converter reduced by switching and conduction losses. Gate split technique is used to adjusts the switching and conduction losses [21]. To minimize the output voltage ripples of the buck converter the resolution of the analog to digital converter have to be increased [22]. Yi Liu et all proposed a dc-dc buck converter to limit the current and voltage ripples [23].

4. Sepic Converter

The maximum power point tracking of the PV system is achieved by the single ended primary inductor (SEPIC) converter with fuzzy logic controller. Fig. 6 shows the SEPIC converter circuit. Even though the input signal is not smooth the output signal is smooth [24].

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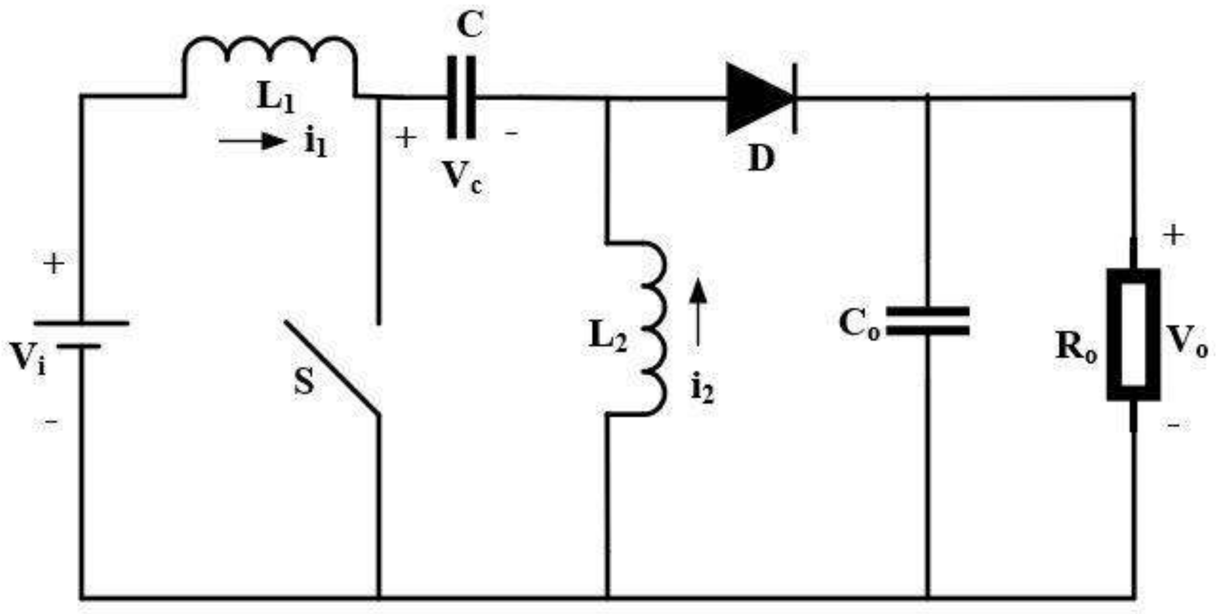

Figure. 6 SEPIC converter

Emilio Mamarelis proposed a converter, designing a sliding mode controller for PV applications with maximum power point technique [25]

5. NON-ISOLATED BI-DIRECTIONAL CONVERTER

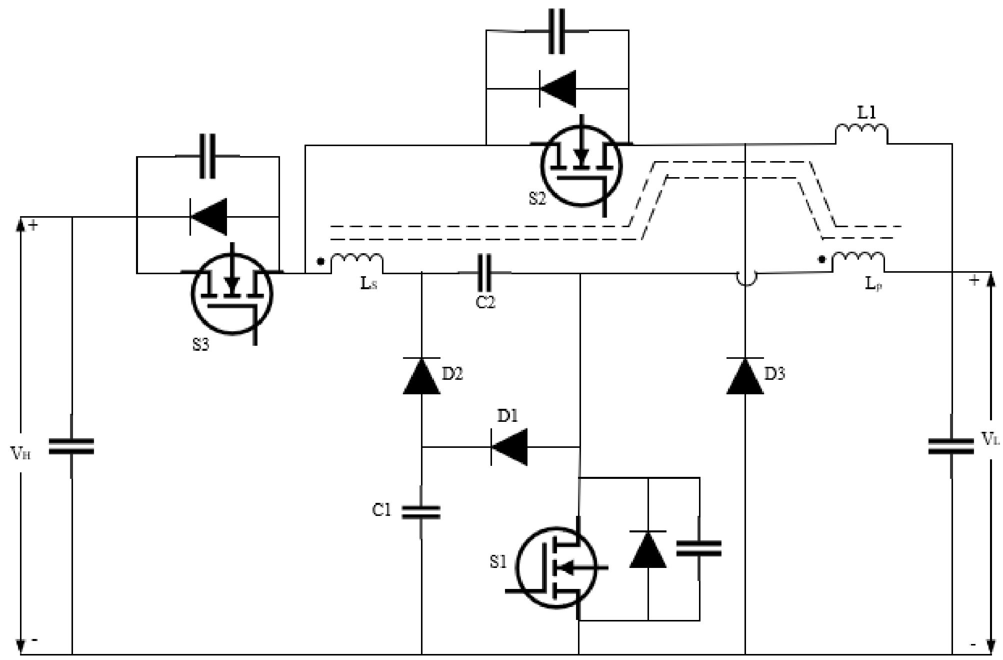

Figure. 7 ZVS Non-Isolated Bi-directional Converter [26]

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Table 2. Efficiency of the Non-isolated bidirectional converter with different output power

Output Power in Watts	Efficiency in %	
	Buck Mode	Boost Mode
50	87.5	92.5
100	90.5	95.5
150	92	96
200	93	96.5

Fig. 7 shows the ZVS non-isolated Bi-directional converter. A Switched-Capacitor (SC) BDC with a high step-up/step-down static voltage gain is conferred for EV with a hybrid energy source scheme. Also the presented converter has the benefits of being a simple circuit, a lesser number of components, an extensive voltage-gain limit, a squat voltage stress, and a common ground. Furthermore, the efficiency of the converter is raised since the synchronous rectifiers permit ZVS turn-on and turn-off deprived of needing any additional hardware [26].

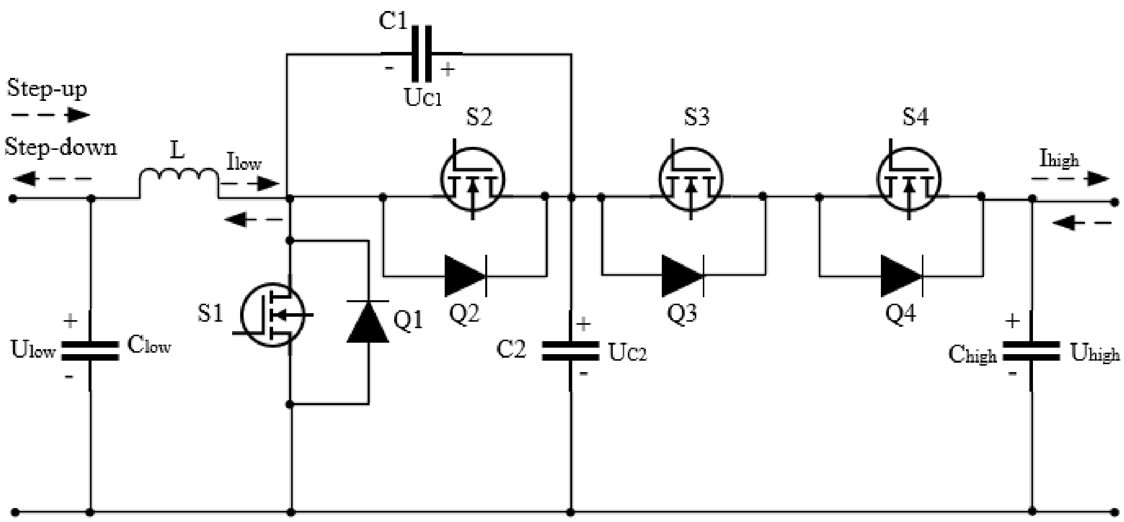

Figure. 8 Switched – Capacitor BDC [27]

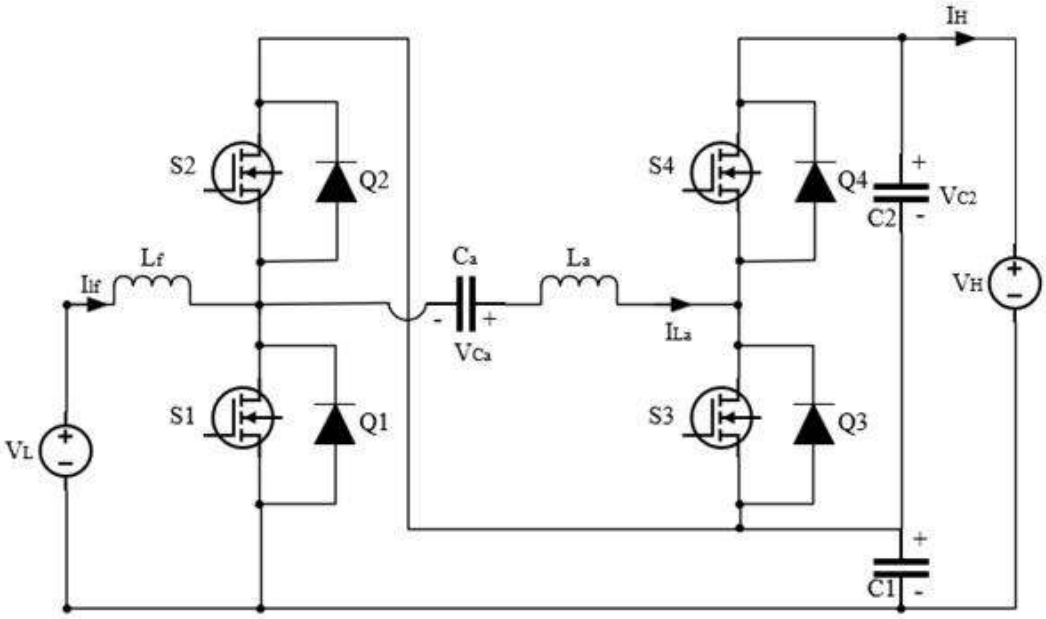

Figure. 9 Proposes high step-up soft switched bidirectional dc-dc converter [28]

Fig. 8 shows the switched capacitor BDC. The passive component size and stress current is decreased by applying interleaving scheme. A two-phase interleaved type of the high step up converter is depicted in Fig. 9.

TABLE 3. ANALYSIS OF THE DC-DC CONVERTERS

Parameter	**Converter in [29]**	**Converter in [30]**	**Converter in [31]**	**Converter in [32]**	**Converter in [33]**
Voltage stress on MOSFETs	$\frac{V_0}{1+2N-ND}$	$\frac{V_0}{1+ND}$	$\frac{V_0}{2(1+N)}$	$\frac{V_0}{1+N}$	$\frac{V_0}{2}$
Soft switching of MOSFETs	ZVS	Hard switching	ZVS	Hard switching	ZVS
Number of MOSFETs	2	1	2	1	2
Voltage stress on output diode	$\frac{NV_0}{1+2N-ND}$	$\frac{NV_0}{1+ND}$	$\frac{V_0}{2}$	$\frac{NV_0}{1+N}$	$\frac{V_0}{2}$
Soft switching of diodes	ZCS	Hard switching	Hard switching	Hard switching	ZCS
Diodes	3	2	4	3	2
Number of magnetic components	1	1	1	1	2
Voltage gain	$\frac{1+2N-ND}{1-D}$	$\frac{1+ND}{1-D}$	$\frac{2(1+N)}{1-D}$	$\frac{1+N}{1-D}$	$\frac{2}{1-D}$

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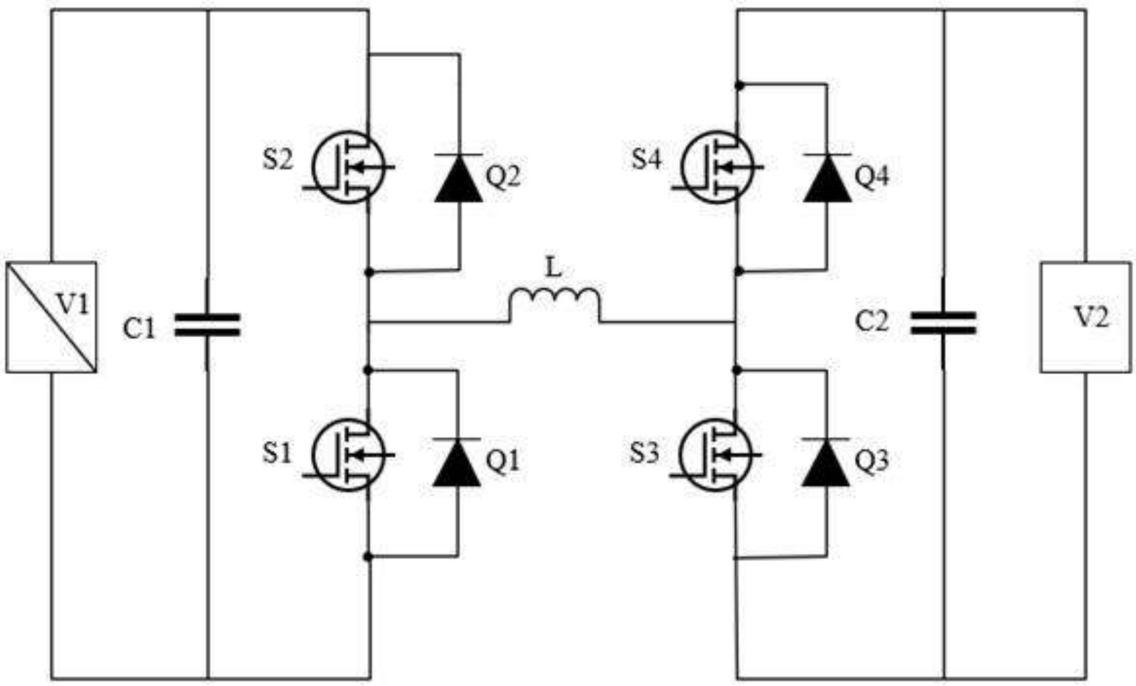

Figure. 10 CBB-IIM [34]

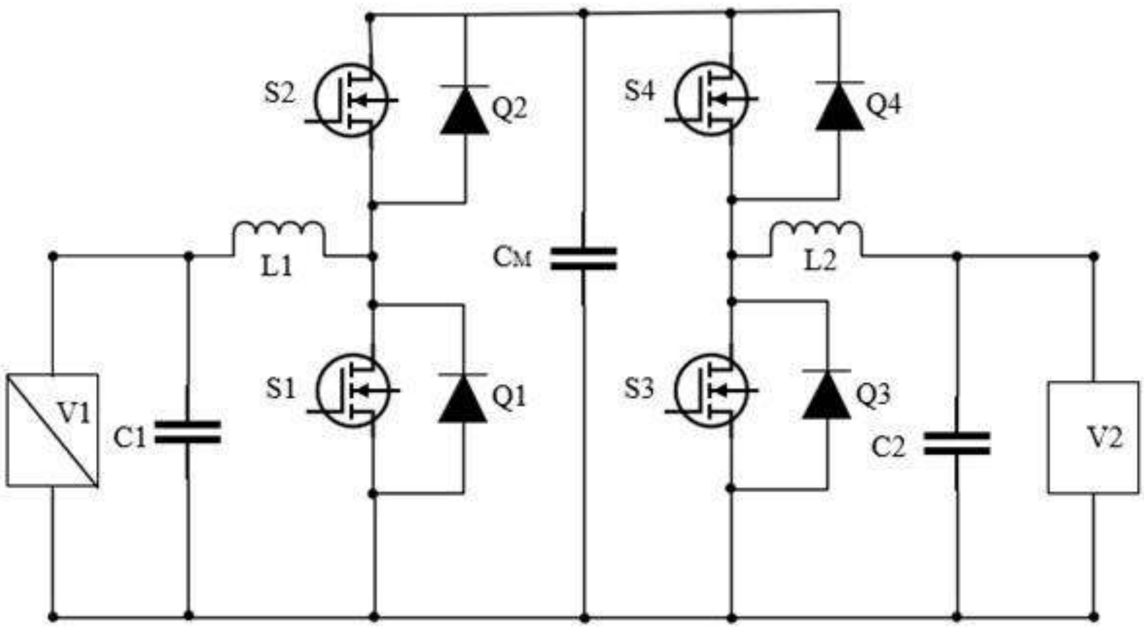

Figure. 11 CBB-CIM [34]

A dc–dc converter with Multi-Input and Multi-Output (MIMO) competence is valuable for EV/HEVs which uses numerous input sources or needs numerous auxiliary outputs. Multiple input decisions are desirable to unite two sources such as an ultra-capacitor and a battery pack consolidation [35]–[37]. In heavy HV such as fleet trucks, several auxiliary outputs will need dissimilar output voltage range [38], [39]. Nowadays, the mechanical engine belt compressor for Air Conditioning (AC) structures is swapped by an electrically compelled compressor to decrease emissions and improve gas mileage. The compressor motor is compelled by a high voltage (220–400 V) at 3–5-kW power necessities [40], [41]. The circuit of CBB-IIM as shown in Fig. 10. The usage of CBB-CIM and CBB-IIM topologies with several inputs and/or several outputs is evaluated in the subsequent. The CBB-CIM topology with auxiliary outputs associated to Vout1 and Vout2 is exposed in Fig. 11.

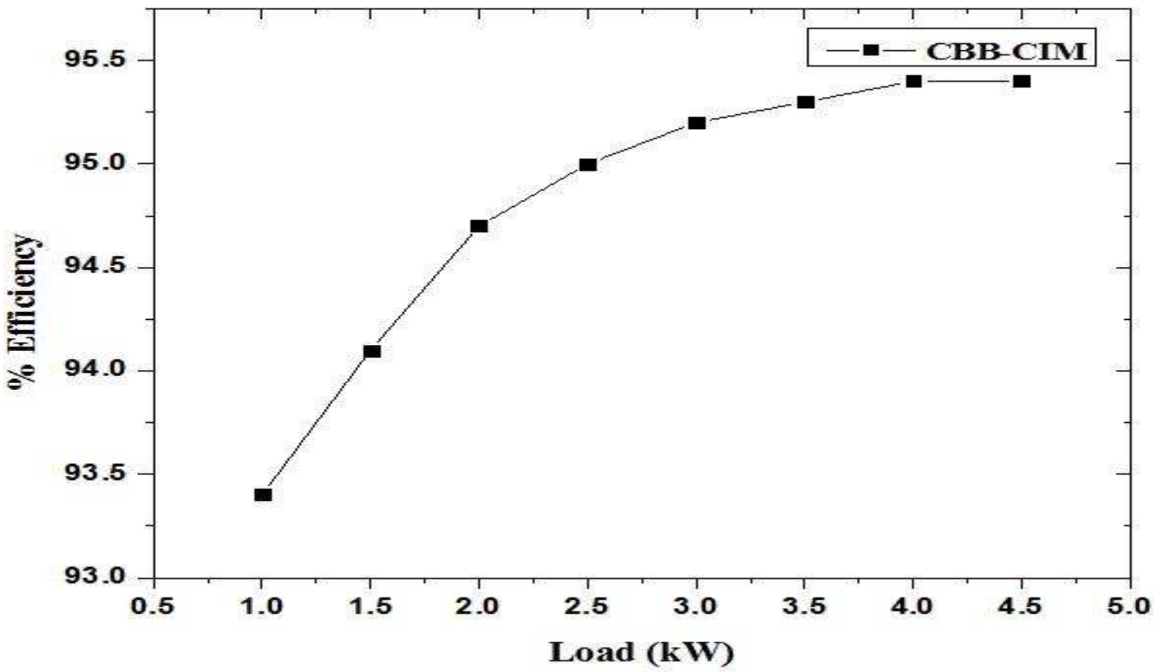

Figure. 12 Efficiency with load variation of the CBB-CIM topology for the multiple input case

For an EV charging station, multi-input and multi-output instance, CBB-CIM provides better enactment as the input-side and output-side reins are sovereign. Fig. 12 shows the efficiency with load variation of the CBB-CIM topology. System controller elasticity and consistency are enhanced with CBB-CIM.

6. CONCLUSION

This paper proposes different kinds of FC based non-isolated DC-DC converters. Each converter has its own importance for the required applications. By using the coupled inductor with ZVS operation, the stress on the semiconductor devices reduces. By using the suitable DC-DC converter between the source and dc bus the efficiency of the system increases. The voltage stress on the capacitors and power semiconductor devices are reduces with the help of bidirectional interleaved switched capacitor type DC-DC converter. By using the interleaved converter, current ripples at the low voltage side is less. The voltage stress on the diodes, power switches and conduction losses are reduced in the coupled inductors and switched capacitor technique. The life time of the fuel cell increases by using the parallel input, series output DC-DC boost converter because the ripple current at the input is low and the voltage stress on the switches are 50% of the output voltage.

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IOP Conf. Series: Materials Science and Engineering **623** (2019) 012005 doi:10.1088/1757-899X/623/1/012005

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