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Non-Isolated Interleaved Bidirectional DC-DC Converter for Electric Vehicles : A Review

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Abstract—Power conversion plays a significant part in the functioning of electric vehicle systems. During the design process of the electric vehicle, careful consideration was given to the implementation of a multiple energy power management system in order to optimise power consumption efficiency. Addition of battery and capacitor provides the quick acceleration and deceleration like normal IC engine. The efficient DC-DC power conversion was obtained by different converters. Every converter had different specifications and applications. The optimized power transmission was depending on selection of converter. The ripple was produce by achieving high power conversion system. The efficient power management system is obtained by selection of converter with ripple reduction.

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Keywords-DC-DC Converter, Types, Ripple Current, Voltage Regulation, Efficiency

I. INTRODUCTION

Air pollution is one of the important factor for universal health and environmental concerns. Transportation sector is the main reason for the air pollution, among all the sectors like industrial process, Agriculture, waste treatment and biomass burning etc. Especially on-road vehicle transportation contributed 97% of pollution when compared to the other transport like railways, water ways and airways. This phenomenon might be attributed to the rise in vehicular use. To mitigate pollution and alleviate fuel expenses, there is a growing impetus for both developed and emerging nations to transition from internal combustion engines to electric vehicles inside metropolitan areas. Electric vehicles (EVs) are known for their reduced environmental impact compared to internal combustion engine (ICE) vehicles. Unlike ICE vehicles, EVs do not emit pollutants during operation, resulting in a significant reduction in pollution. An electric vehicle (EV) is a mode of transportation that utilises a battery to store electrical energy, which is then used to power an electric motor. It does not run by fuel. The ICE is replaced by the Electric motor. So the pollution emitted by the transportation sector will be reduced.

Figure 1 depicts the fundamental constituents of an electric vehicle. The components involved in an electric vehicle system include an electric motor, battery, electric power control unit, and on-board charger. The conversion of battery power to kinetic force for the operation of an electric vehicle requires many essential components. The Electric Power Control Unit (EPCU) is used for the regulation and management of electric power inside Electric Vehicles (EVs). The system is comprised of an inverter, a voltage control unit, and a DC-DC converter. The significance of DC-DC converters in the provision of electrical power for vehicles cannot be overstated. This paper presents a comprehensive examination of DC converters, including an analysis of several converter types and an exploration of their operational phases.
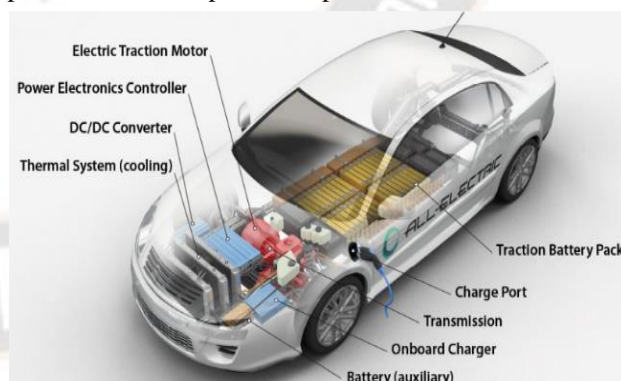

Figure 1. Electric Vehicle System [1]

II. UNIFIED CONTROLLER RIPPLE REDUCTION METHODOLOGY

The high-efficiency converter will generate ripple inside the conversion system. In order to prevent the modelling of a high power unified converter, a potential solution is suggested. The Switch mode is seen to activate the buck operation and boost operation in accordance with the direction of the current flow, as shown in Figure 2. In this study, a unified logic architecture is presented as a solution for both buck and boost operations [24].
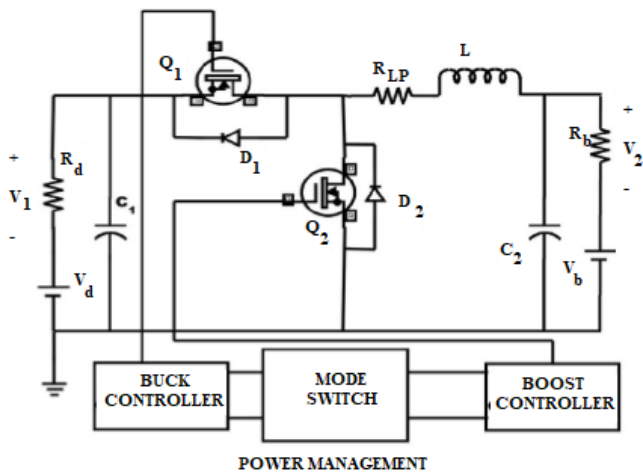
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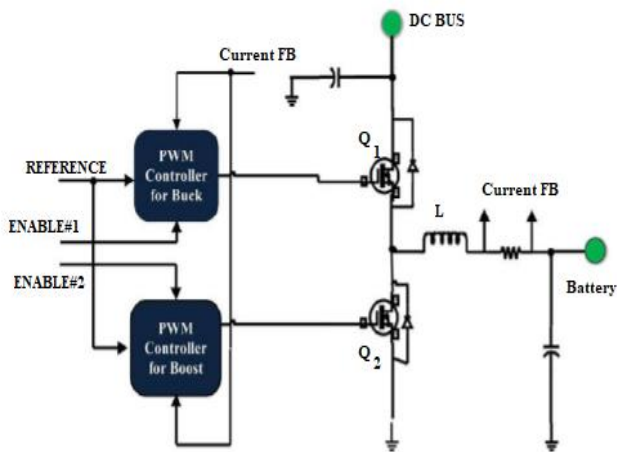Figure 2 Unified controller schematic diagram.

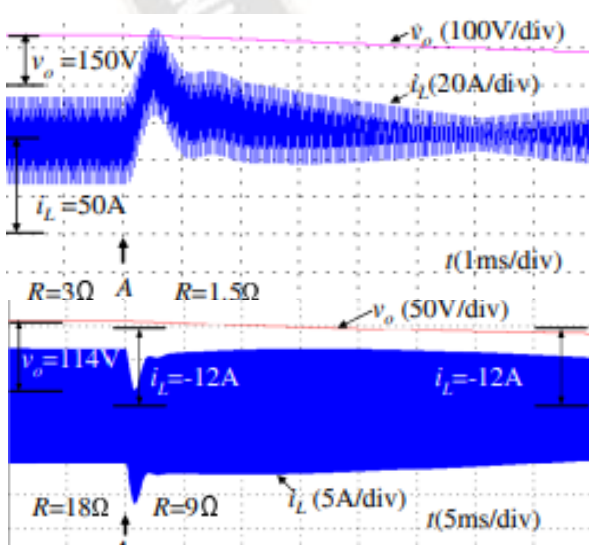Figure 3 Unified controller switching diagram

Figure 4 Buck and Boost load step up simulation result

The Fig.3 Shows the unified control switching Diagram. Signal used here helps to choose buck or boost operation.

III. SYMMETRICAL MULTILEVEL DC-DC BOOST CONVERTER RIPPLE REDUCTION METHODOLOGY

The decrease of ripple is accomplished by interconnecting two multilevel converters in a differential configuration, with opposing directions [23]. The design reduces switch stress, provides a high voltage gain, and reduces capacitor input-current and voltage ripple.

The Symmetrical DC converter with ripple mitigation is shown in Figure 5. Dual multilevel boost converters are employed. Power switch (S1), inductor (L1), three capacitors (C1, C2, and C3), and three diodes (D1, D2, and D3) make up the converter's top. The first floating output comes from capacitors C1, C2, and C3.
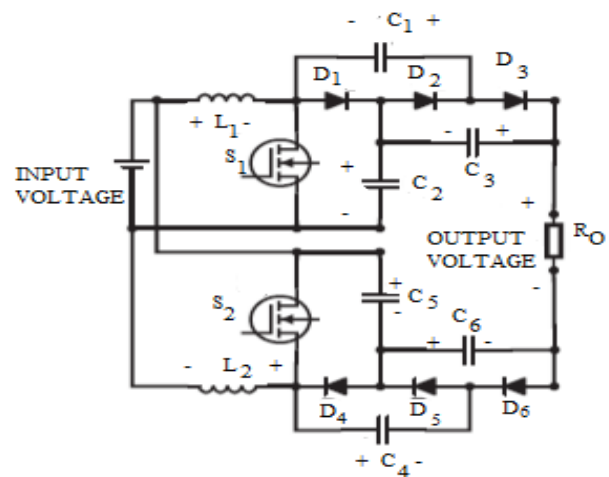

Figure 5. Symmetrical dc-dc converter with ripple reduction.

The bottom of the converter has a power switch (S2), an inductor (L2), three capacitors (C4, C5, and C6), and three diodes (D4, D5, and D6), mirroring the top. Capacitors C5 and C6 add a floating output. The load is differently coupled to the upper and lower floating outputs.

A. Output voltage ripple:

In upper and lower converter capacitors, 180 degree phase shifted switches of S1 and S2. the ripple voltage reduce the duty cycle 50% which is shown in Fig.6.
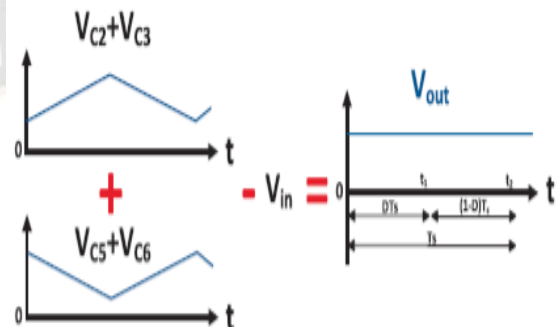

Figure 6 Complementary switches reduce output voltage ripple.

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IV. DC-DC CONVERTERS FOR EV

DC-DC converters convert DC voltage using electrical circuits. Here, incoming energy is stored and utilised at the output to various degrees [2]. The storage devices include inductors, transformers (which rely on magnetic fields), and capacitors (which rely on electric fields). In the field of electric vehicles (EVs), the DC-DC converter may be categorised into two types: unidirectional converter and bidirectional converter [3]. Typically, a unidirectional converter facilitates the passage of electricity from the input to the output in a singular direction. A bi-directional converter has the capability to facilitate electricity flow in both directions. For motoring and Regenerative Braking process of electric vehicle, Bidirectional Converter is preferred. It gives uninterruptable power supply. Bi-directional converter is classified into many types which is shown in Fig.7. [4].
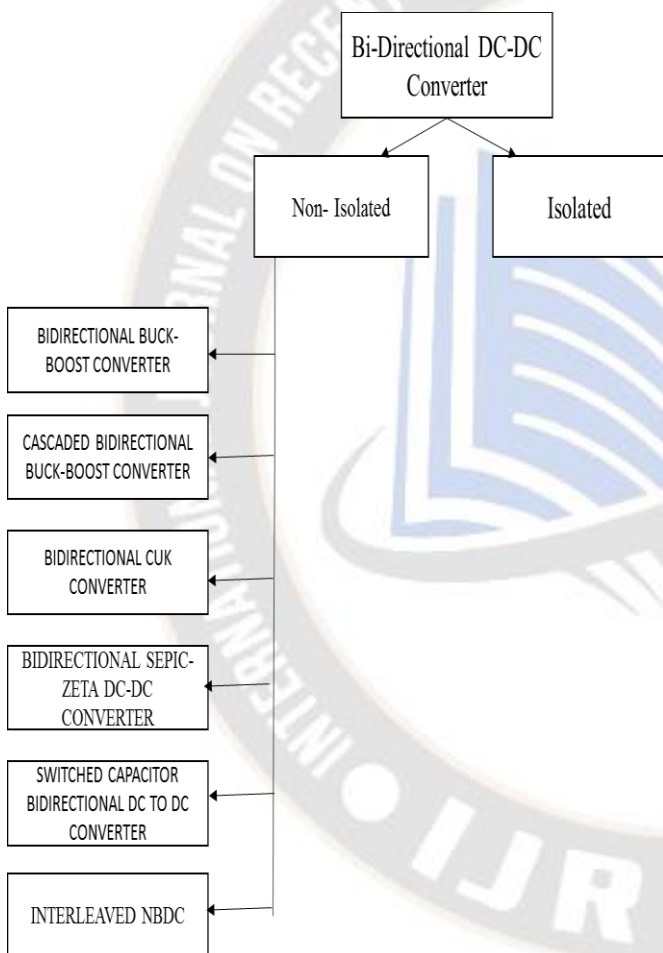

Figure 7. Classification of Bi-Directional DC-DC converter

The isolated converter effectively partitions the input and output by using a division of two distinct sections, so impeding the passage of current from the input side to the output side. This isolation is accomplished by the use of a transformer [5], and each circuit is equipped with its own dedicated ground or common reference.

While isolation does provide a secure means of achieving compilation, the inclusion of a transformer in the circuit introduces complexity, increased weight, and higher switching loss.

The power conversion efficiency is comparatively lower in the isolated converter as compared to the non-isolated converter [6]. To avoid these drawbacks, non-isolated converter is always preferred in electric vehicle. The non-isolated converter is a circuit where current flow from input to output side. It has common ground [7]. The advantages of non-isolated converter is less in weight, simple circuit, less expensive, and switching loss is also reduced by providing direct path for input to output. Depends on the output voltage levels, this is further classified into single phase, single phase with auxiliary circuitry and interleaved.

A. Topologies of NBDC

NBDC is a type of converter which does not contain any transformer to separate the source and load. Hence, it is used in lower power applications and gives more efficient. It can be easy control. This section gives information about performance of each type and comparison analysis between the types of Non-Isolated Bidirectional DC-DC converter.

V. BIDIRECTIONAL BUCK-BOOST CONVERTER

Figure 8 depicts the Bidirectional Buck-Boost Converter, which is similar to the Bidirectional DC-DC converter.
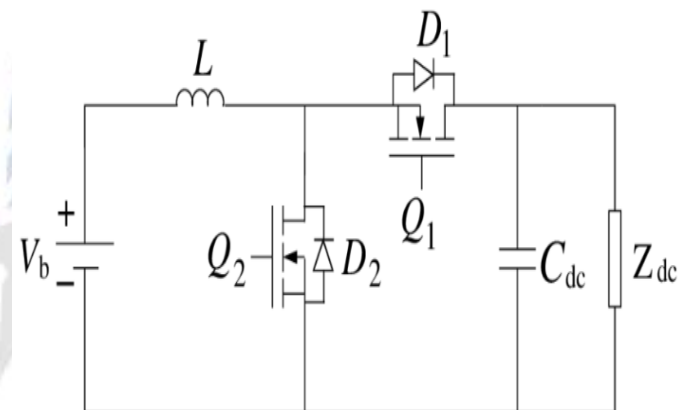

Figure 8. Bidirectional Buck-Boost Converter [8]

This circuit uses metal-oxide-semiconductor field-effect transistors (MOSFETs) for two switches, Q1 and Q2, and two diodes, D1 and D2. Anti-parallel switches and diodes allow bidirectional current flow in the circuit. Conductivity depends on duty cycle. Buck mode operates with Q2 conducting and Q1 non-conducting.

In Boost mode, Q1 conduct and Q2 will not conduct.

Due to this structure, the negative current produced from the inductor (L) convert to electrical energy with help of mechanical energy in the load, and stored in the filter capacitor (c).

With this bidirectional switches it acts as rectifier which increases the efficiency of the converter [9] mainly for low and medium power applications.

VI. CASCADED BIDIRECTIONAL BUCK-BOOST CONVERTER

The circuit design of the Cascaded bidirectional buck-boost converter is seen in Figure 9. This Four quadrant Operation

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operates as both Buck Mode and Boost Mode. But using more switches results in high Switching losses.
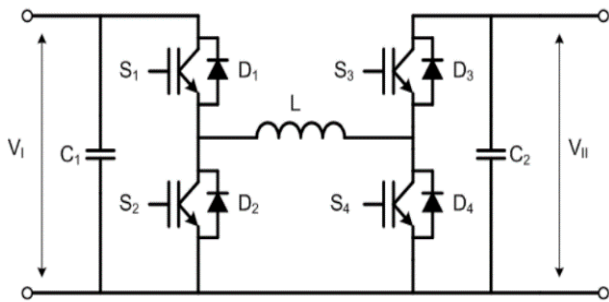

Figure 9 Cascaded Bidirectional Buck-Boost Converter

It provides a different method to change the input AC to output DC with two switches [10]. The CBBC gives regulated output voltage [11], quality power factor for input current [12]. The main advantage of CBBC is gives continuous conduction mode for current circulating in inductor, it is useful dc load.

Fig.10. Inductor current with RPWM and output capacitor current with FPWM

TABLE.1 COMPARISON OF CONVERTERS

Terms	Bidirectional BBC	Cascaded bidirectional BBC	Bidirectional CC	Bidirectional sepic-zeta dc-dc converter	Switched capacitor bidirectional dc to dc converter	Interleaved NBDC	2-phase interleaved NBDC
VH/VL	1/(1-D)	1/(1-D)	(-D)/(1-D)	D/(1-D)	2	1/(1-D)	2/(1-D)
Inductors	1	1	2	2	0	2	2
Capacitors	2	2	3	3	3	2	2
Switches	2	4	4	2	4	4	4
Characteristics	1.Few elements, 2.Input current discontinuity	1.Higher voltage gain 2.Reduce current stress	1.Continuous Iin/Io 2. Couples inductors to eliminate Iin waves	1. Output voltage positive 2. Reduce current ripple via auxiliary branch.	1.Low weight/size (inductor-absence) 2. Constant input	1. Low frequency-current ripple switching 2. Smaller EMI filter needed	1.Increased voltage conversion ratio 2. Reduce switch voltage stress and current ripple
Applications	Photo Voltaic system [25], UPS[26]	Electric vehicle [27], Smart grid[28]	Battery storage system [29].	Distributed power systems. [26]	diversified sources of energy	Distributed energy storages [31], high power applications [30].	High power applications [30], Electric vehicle [31].

VII. BIDIRECTIONAL CUK CONVERTER

Figure 11 depicts the circuit diagram of the Bidirectional Cuk Converter. The user provides a numerical reference [13].

In the Forward Condition, Q1 functions as the controlling switch, while Q2 is in the off state. Additionally, the circuit includes another diode, which is connected to Q2 and serves as the primary diode.

In the Reverse Condition, Q2 functions as the controlling switch, while Q1 is in the off state and the circuit diode is connected to Q1.

This converter output has less ripple content when compared to all other converters. It has applications in energy storage system which interconnects with circuits and provides high frequency operation [14].
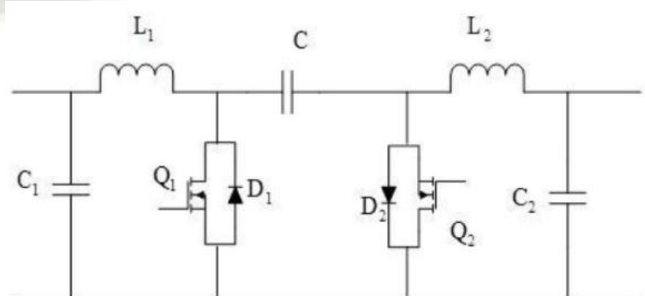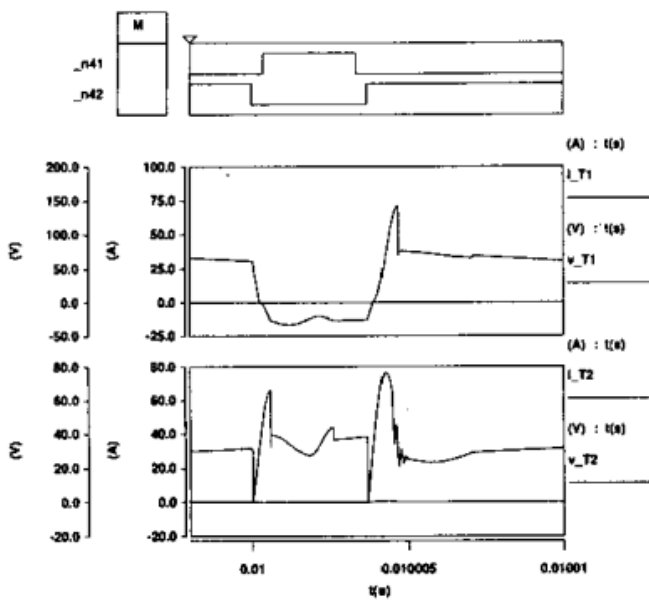

Figure 11.Bidirectional Cuk Converter

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Figure 12.ZVS Switch simulation waveforms from computer simulation (i_{L2}=-18A)

The fundamental schematic design of the SEPIC-ZETA converter is shown in Figure 13 [15]. The converter in question is equipped with a dual-source configuration, with two inductors and three capacitance components. The device has the capability to function in either SEPIC mode or ZETA mode, with a reduced amount of components [16].
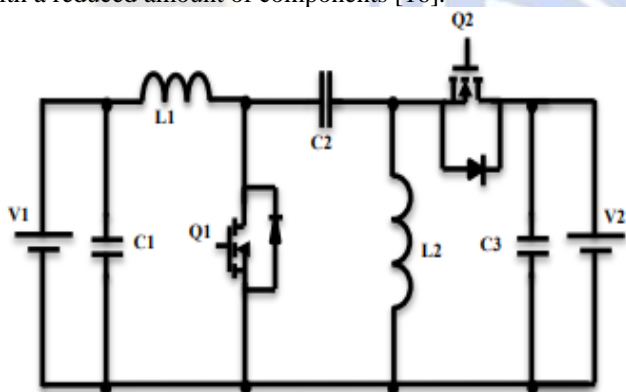

Figure 13. Bidirectional SEPIC-ZETA Converter

It provide simpler circuits but the high ripple value of the output and voltage fluctuations. To avoid this snubber circuit is used and also it operates both forward and reverse directions [17]. This reduces the circulating current in the inductor without any methods. This decrease the conduction and switching losses.

VIII. A BIDIRECTIONAL DC TO DC CONVERTER WITH SWITCHED CAPACITOR

The concept of switched capacitor refers to a technique often used in electronic circuits for the purpose of simulating and manipulating analogue signals. Figure 15 [18] displays this schematic representation of a bidirectional DC-DC converter. The high voltage side and the low voltage side, which are each

outfitted with four power semiconductors, are the two separate sides of the system. To adjust the energy levels on both the high and low sides, the system uses different paths for the capacitors' charging and discharging operations [19]. This converter is mostly used for the integration of a super capacitor with a high voltage system. The use of a solitary capacitor results in decreased efficiency, as shown by a study conducted by researchers [20].
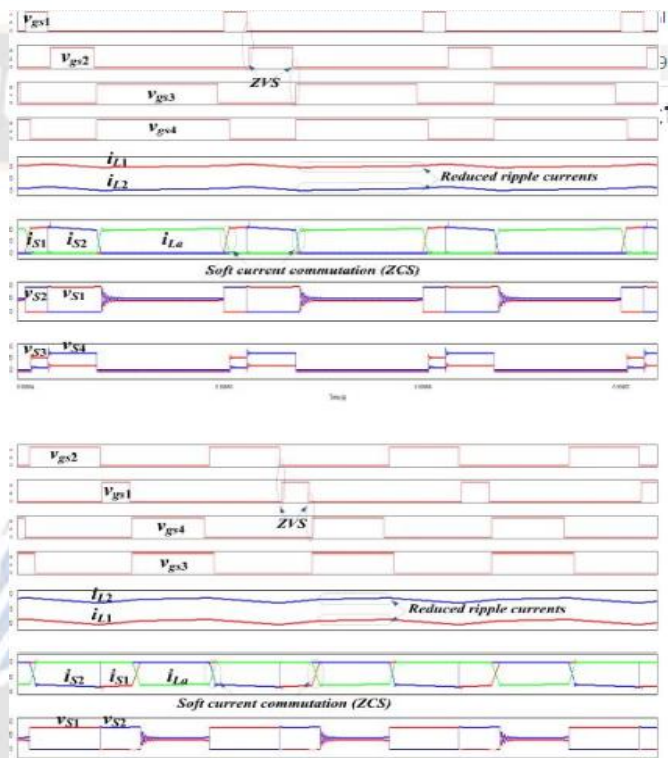

Figure 14 Simulation result SEPIC step-down and ZETA step-up operations
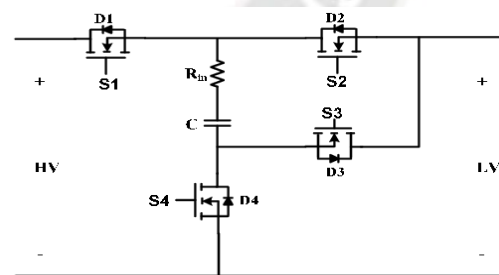

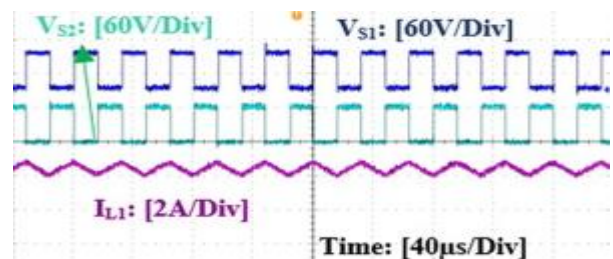
Figure 15 Switched Capacitor Bidirectional DC-DC Converter

Figure 16 Switched Capacitor Bidirectional DC-DC Converter current simulation result

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The use of soft switching techniques enhances the efficiency of the converter. The user has provided a reference to support their statement.

IX. INTERLEAVED NBDC

NBDC provide high voltage gain compare to conventional dc dc converter. NBDC is used to integrate EMS, PV, battery and electric motor with proper sequence. Avoid current and voltage stress produced in the system.
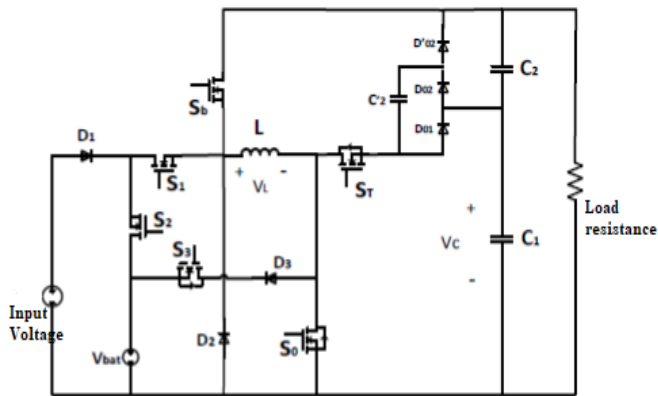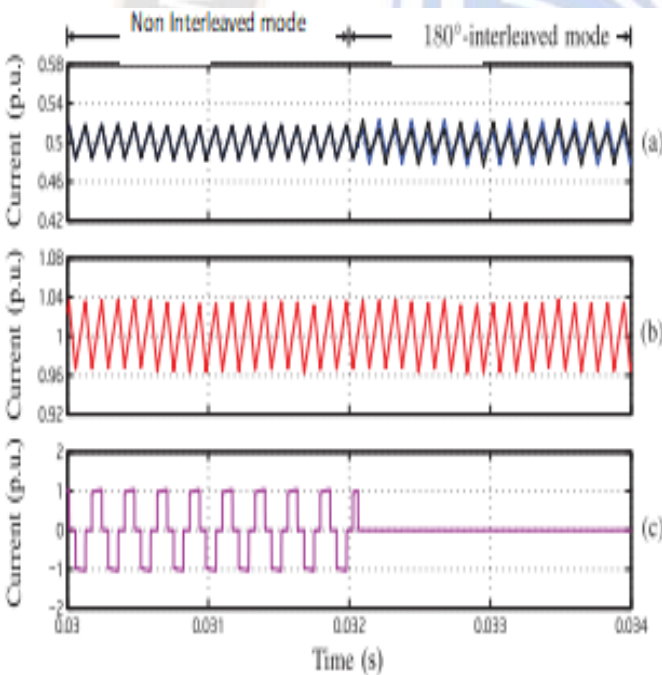

Figure 17.NBDC with 2 input and 2 output

Figure 18.Simulation results for Proposed NBDC a)Unit output current b) Total output current c) Total neutral point current

X. 2-PHASE INTERLEAVED NBDC

The achievement of rapid acceleration and deceleration is facilitated by the use of an interleaved bidirectional DC-DC converter. This architecture has a minimal number of components and good efficiency over a broad range of loads, making it a suitable option for applications requiring high power and high current levels.
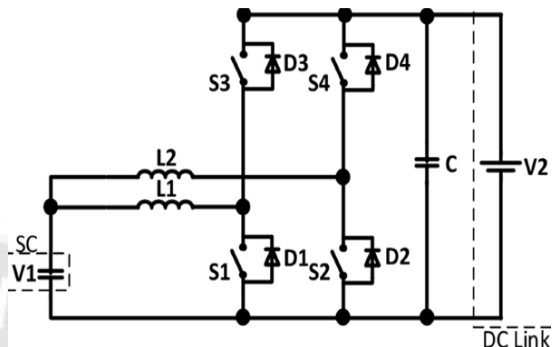

Figure 19. Two-phase bidirectional DC-DC converter with interleaving

XI. CONCLUSION

Different converters were compared with different operating conditions. Every converter had different specifications and applications. Ripple reduction methodology also consider when design high efficient power converter. The design of high efficient multiple power management system is obtained by interleaved Bi Directional DC-DC converter. With the help of this converter, we can integrate renewable energy sources with battery and capacitor.

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