COMPARISON OF BDISO CONVERTER AND DISO CONVERTER IN ELECTRIC VEHICLE APPLICATIONS

ELEKTRİKLİ ARAÇ UYGULAMALARINDA BDISO DÖNÜŞTÜRÜCÜ İLE DISO DÖNÜŞTÜRÜCÜNÜN KARŞILAŞTIRILMASI

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Özet

Yüksek verimli güç dönüşüm teknolojilerindeki gelişmeler ve fosil yakıtlara bağımlılığı azaltma ihtiyacı Elektrikli Araçlara (EA) olan ilgiyi artırarak kullanımını yaygınlaştırmaktadır. Gelişmiş kontrol stratejilerinin performansı önemli ölçüde artırdığı EA uygulamaları için detaylı araştırmalar yürütülmektedir. Bu doğrultuda, çift yönlü DC-DC dönüştürücüler EV uygulamalarında giderek daha önemli hale gelmektedir. Bu çalışmada, yüke verimli güç dağıtımı için birden fazla enerji kaynağını entegre etmek üzere tasarlanan Çift Yönlü Çift Giriş Tek Çıkış (BDISO) ve Çift Giriş Tek Çıkış (DISO) dönüştürücülerin yükseltme modu işlemleri karşılaştırılmaktadır. Öncelikle her iki dönüştürücü tipinin yapısı ve farklı çalışma topolojileri ele alınmıştır. Daha sonra detaylı çalışma prensipleri açıklanarak ilgili tasarım kriterleri belirlenmiş ve hesaplamalar bu kriterlere göre yapılmıştır. Giriş değerleri 24 V ve 12 V, çıkış gerilimi 48 V ve anahtarlama frekansı 20 kHz olan dönüştürücü tasarımlarının simülasyonları MATLAB/Simulink arayüzü kullanılarak gerçekleştirilmiştir. Son olarak iki topoloji tasarım, donanım, maliyet ve verimlilik açısından karşılaştırılmıştır. Ayrıca, bileşen sayısı, anahtarlama karmaşıklığı, güç kaybı, gerilim stresi, çıkış dalgalanması, dinamik tepki ve esneklik açısından analizler yapılmış ve sonuçlar karşılaştırmalı olarak sunulmuştur. Daha basit ve uygun maliyetli DISO dönüştürücülerin verimi %95 olarak bulunurken, daha gelişmiş esneklik ve enerji yönetimi sunan BDISO dönüştürücülerin verimi %97 olarak hesaplanmıştır. Bu doğrultuda, EA uygulamalarında BDISO dönüştürücülerin kullanılması verim açısından daha uygun bir seçim olacaktır.

Anahtar kelimeler: Elektrikli araç, DC-DC dönüştürücü, BDISO dönüştürücüler, DISO dönüştürücüler

Abstract

Developments in high-efficiency power conversion technologies and the need to reduce dependence on fossil fuels are increasing the interest in Electric Vehicles (EV) and making their use widespread. Detailed research is being conducted for EV applications where advanced control strategies significantly increase performance. Accordingly, bidirectional DC-DC converters are becoming increasingly important in EV applications. This paper compares the boost mode operations of Bidirectional Dual Input Single Output (BDISO) and Dual Input

Single Output (DISO) converters, which are designed to integrate multiple energy sources for efficient power distribution to the load. Firstly, the structure and different operating topologies of both converter types are discussed. Then, detailed working principles were explained and relevant design criteria were determined and calculations were made according to these criteria. Simulations of converter designs with input values of 24 V and 12 V, output voltage of 48 V and switching frequency of 20 kHz were performed using the MATLAB/Simulink interface. Finally, two topologies are compared in terms of design, hardware, cost and efficiency. Additionally, analyses were made in terms of component count, switching complexity, power loss, voltage stress, output ripple, dynamic response and flexibility and the results were presented comparatively. While the efficiency of the simpler and more cost-effective DISO converters is found to be 95%, the efficiency of the BDISO converters, which offer more advanced flexibility and energy management, is calculated as 97%. In this regard, the use of BDISO converters in EV applications would be a more appropriate choice in terms of efficiency.

Keywords: Electric vehicle, DC-DC converter, BDISO converters, DISO converters

1. INTRODUCTION

The increasing demand for efficient power conversion systems in electric vehicles (EVs) has led to extensive research on bidirectional DC-DC converters. These converters play a crucial role in integrating multiple low-voltage energy sources, such as photovoltaic (PV) panels and batteries, into a common DC bus with minimal component count, thereby improving overall system efficiency. Soft-switching techniques, combined with passive capacitor clamping, effectively mitigate voltage spikes across primary switches, ensuring reliable operation under bidirectional power flow conditions (Gunawardena et al., 2023).

Bidirectional DC-DC converters have been widely explored for EV applications, where advanced control strategies significantly enhance performance. Traditional Proportional-Integral (PI) control remains a common approach; however, intelligent techniques such as Fuzzy Logic and Neural Networks, when integrated with Wide Bandgap (WBG) semiconductor devices like Gallium Nitride (GaN) and Silicon Carbide (SiC), offer faster response times and reduced voltage overshoot, making them preferable for high-frequency applications (Martinez-Vera & Banuelos-Sanchez, 2024). Furthermore, high-frequency analog control methods have been proposed for Boundary Conduction Mode (BCM) boost converters, ensuring stable operation across varying input voltages and load conditions, particularly when GaN switches replace conventional silicon devices to minimize switching losses (Noruzi et al., 2020).

Beyond control advancements, novel methodologies have been introduced to derive Single-Input Dual-Output (SIDO) and Dual-Input Single-Output (DISO) DC-DC converters from standard Single-Input Single-Output (SISO) topologies. These approaches optimize component usage and reduce overall system cost while maintaining efficient power conversion (Chen et al., 2018). In EV applications, the need for robust bidirectional converters has driven the development of Passivity-Based Control (PBC) strategies, which enhance output regulation, dynamic stability, and robustness against disturbances (Abdolahi et al., 2024).

The integration of multi-input DC-DC converters within EV power systems facilitates efficient voltage regulation and energy management, often incorporating feedback mechanisms to ensure stable operation. Additionally, hybrid power architectures combining battery storage with auxiliary sources, such as dynamos, have been explored to improve backup reliability and efficiency (Elakya et al., 2020). Energy recovery during braking and transient operation is another critical challenge in battery-fed EVs, where a combination of bidirectional DC-DC converters and buck converters enhances overall efficiency, as validated through MATLAB/Simulink modeling (Rahman et al., 2015).

Advancements in power semiconductor technology have also contributed to improved converter performance. For instance, the adoption of enhanced trench-gate MOSFETs in 48V conversion systems for mild hybrid EVs allows for optimized switching characteristics, reducing thermal stress and improving system reliability (Musumeci et al., 2020). Additionally, high-voltage gain bidirectional converters leveraging switched-inductor and switched-capacitor techniques provide a wide voltage gain range while minimizing device voltage stress, offering an efficient solution for EV powertrain applications (Rezaii et al., 2022).

Several studies have proposed advanced resonant converters for EV fuel cell applications, aiming for high efficiency and reduced component size. For instance, a parallel-resonant LC converter incorporating high-frequency planar transformers effectively steps up voltage while ensuring galvanic isolation (Farhani et al., 2017). Similarly, hybrid energy storage systems combining fuel cells and ultra-capacitors have been modeled and simulated to demonstrate enhanced efficiency and transient response (Farhani et al., 2021).

To address the challenges associated with wide load variations, soft-switched synchronous buck converters employing coupled inductors have been designed for EV applications, achieving high efficiency while maintaining stable voltage regulation (Kumar et al., 2022). In addition, the implementation of PI-controlled bidirectional converters enables efficient energy transfer between ultra-capacitors and the DC bus, ensuring rapid response to load fluctuations (Amari et al., 2014). Advanced control methodologies, such as the super-twisting sliding mode controller, have further improved transient response and stability by minimizing chattering effects and reducing the number of adjustable gains (Boubzizi et al., 2018).

Recent developments in WBG semiconductor technology have also focused on the characterization of GaN High Electron Mobility Transistors (HEMTs) in high-frequency DC-DC converters. Experimental and simulation-based analyses of their switching behavior have demonstrated significant efficiency improvements over silicon-based counterparts (Mdanat et al., 2020). Moreover, Hardware-in-the-Loop (HIL) demonstrations of bidirectional DC-DC converters, integrating FPGA-based discrete PI controllers, have enabled rapid prototyping and validation of power management systems in EVs (Ali et al., 2022).

In addition to bidirectional architectures, multi-port DC-DC converters have been developed to support simultaneous charging of high-voltage and low-voltage EV batteries from a single DC source. By employing advanced pulse-width modulation (PWM) techniques, these converters achieve high efficiency while reducing device count and voltage stress (Tomar et al., 2021). Supercapacitor-based power regeneration systems have also been introduced, utilizing Lithium-Ion Capacitors (LICs) controlled by bidirectional DC-DC converters to enhance energy recovery, reduce battery stress, and extend overall battery lifespan (Sayed et al., 2021).

In the second part of the paper, the structure of BDISO and DISO DC-DC converters and different operating topologies are discussed. The detailed operating principles and equations of both converters are explained. Then, the relevant design criteria are determined and calculations are made according to these criteria. Finally, the circuit is simulated using MATLAB/Simulink and the relevant graphics are obtained. The third section of the paper compares DISO Boost DC-DC converters and BDISO Boost DC-DC converters. The differences are summarized in a table. Finally, the fourth section presents the conclusion of this study.

2. METHOD AND FINDINGS

2.1. Bidirectional Dual-Input Single-Output Dc-Dc Converter

Figure 1 depicts the BDISO configuration, which integrates a DC source and a battery as its dual input sources. The circuit's power components include MOSFETs (S1-S5) and a diode (D1). The BDISO converter operates in four distinct modes: bidirectional, Boost, Buck, and buck-boost. In this paper Boost mode of the BDISO converter will be analyzed (Abdolahi et al., 2024).

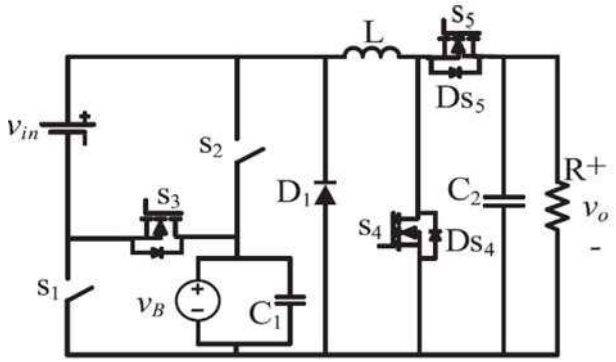


Fig. 1. Configuration of the proposed BDISO converter (Abdolahi et al., 2024)

Fig. 2 illustrates the boost state of the BDISO converter, where both V_{in} and V_B are combined as the input. In this case, switch S_3 remains conducting while S_4 operates in a switching state. The dynamic equations governing the boost state are given as follows:

$$\frac{di_L}{dt} = \frac{v_{in}}{L} - (1-D)\frac{v_o}{L}$$
$$\dot{v_0} = (1-D)\frac{i_L}{C} - \frac{v_0}{RC} \quad (1)$$

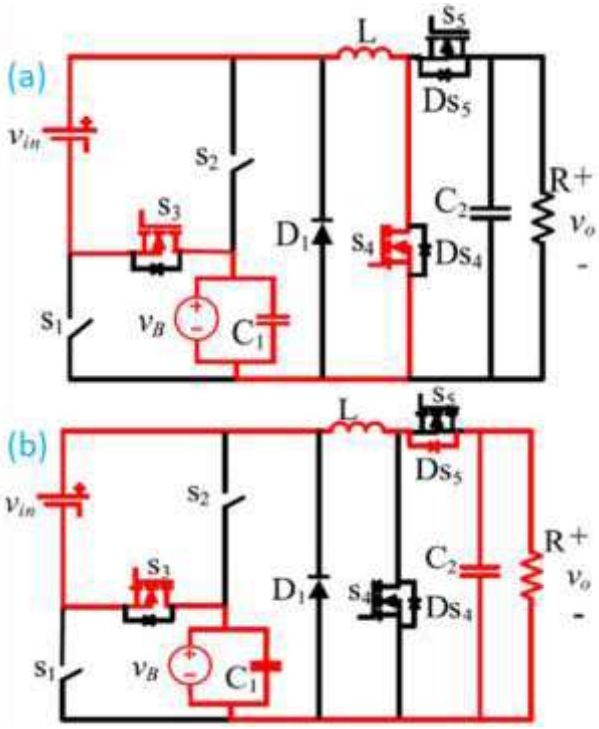


Fig. 2. Boost state of the BDISO converter. a) Switch S4 is in closed state, b) Switch S4 is in open state (Abdolahi et al., 2024)

The values of the C and L in the boost state are determined using the equations provided below.

$$L \geq \frac{(v_{in}+v_B)\times D}{f_{sw}\times \Delta i_L} \qquad (2)$$

$$C \geq \frac{D\times \delta I}{f_{sw}\times \Delta v} \qquad (3)$$

The following values have been obtained using the relevant equations. Table 1 includes the input and values to be used in the BDİSO converter simulation.

Table 1. Parameters of BDISO DC-DC converter

Quantity	Value
Input Voltage (V_{in})	24 V
Input battery voltage (V_B)	12 V
Output voltage (V_o)	48 V
Inductance (L)	2 mH
Load (R)	60 Ω
Capacitor (C_1)	1000 µF
Capacitor (C_2)	21 µF
Switching frequency (f_{sw})	20 kHz

Fig. 3 illustrates the Boost-mode BDISO converter in MATLAB/Simulink. A simulation was performed based on the calculated values, and the current and voltage waveforms were obtained. To operate the circuit in the simulation, switch S3 was short-circuited, while switch S4 was driven at 20 kHz with a duty cycle of 24.8%. Switches S1, S2, and S5 were kept in an open-circuit state.

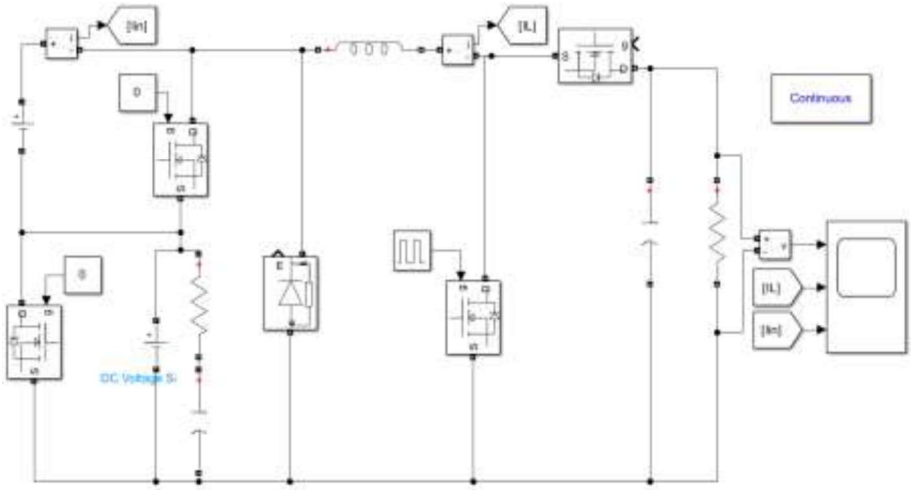


Fig. 3. Boost state of the BDISO converter in MATLAB/Simulink

In the MATLAB/Simulink model in Fig. 3, the input current and inductor current are connected to a scope block via a current measurement block. In this model, the input current and inductor current are connected to a scope block via a current measurement block. Additionally, to analyze the voltage drop across the resistive load, a voltage measurement block is utilized to observe the output voltage.

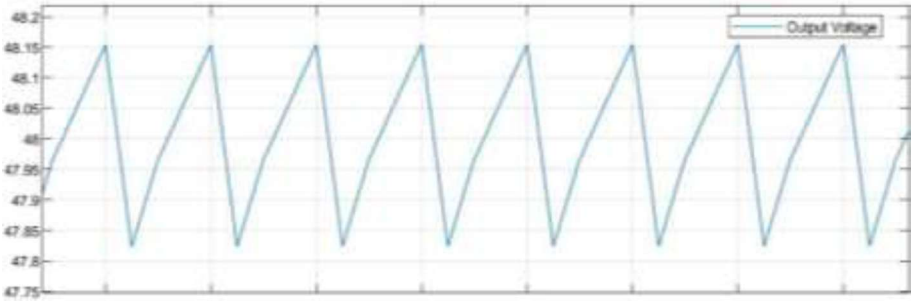


Fig. 4. Output voltage of BDISO in MATLAB/Simulink

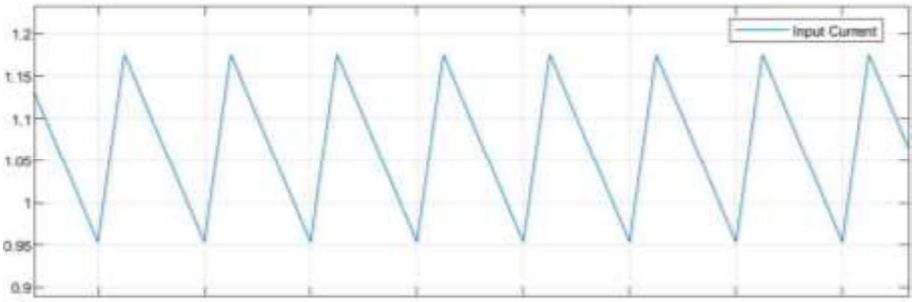


Fig. 5. Input current of BDISO in MATLAB/Simulink

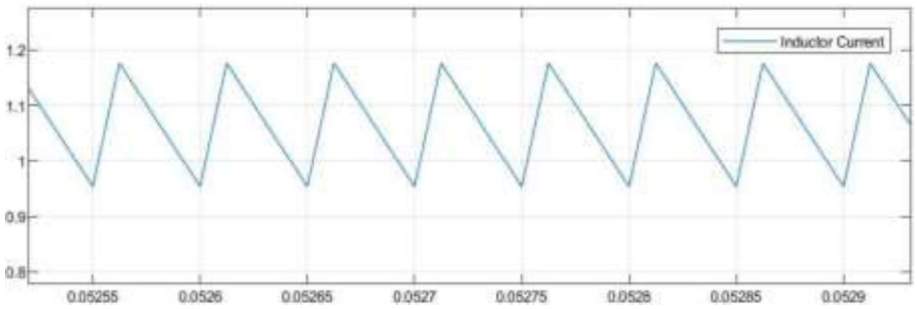


Fig. 6. Inductor current of BDISO in MATLAB/Simulink

The simulation results provide the obtained voltage and current values. It is observed that the system reaches steady-state at 20 ms. The output voltage is measured as 48 V, with variations ranging between 47.85 V and 48.15 V in Fig.4, resulting in a voltage deviation of ±0.15 V.

Regarding the current values is observed in Fig. 5 and Fig. 6. The input current exhibits a triangular waveform, fluctuating between 1.17 A and 0.95 A. Similarly, the inductor current follows the same trend as the input current, varying proportionally. The inductor current is also observed to range between 1.17 A and 0.95 A

2.2. Dual Input Single Output Dc-Dc Converter

The dual input single output (DISO) converter topologies are derived from traditional DC-DC converter topologies, and their basic structures and operating principles are similar to those of single input single output converter topologies. To obtain DISO converters from conventional DC-DC converters, additional components such as switches, diodes, inductors, and capacitors are used. Fig. 7 illustrate the schematic diagram of DISO converter.

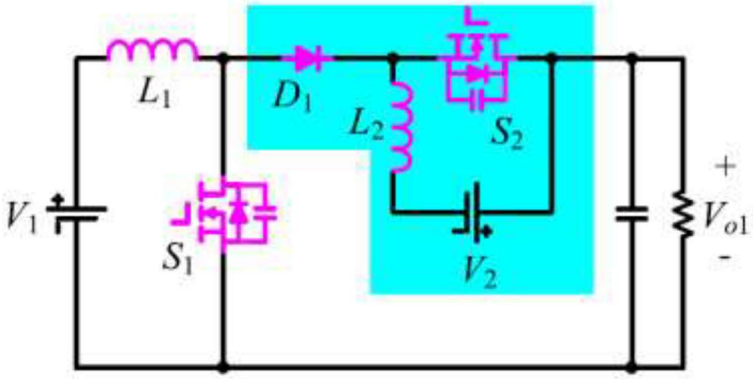


Fig. 7. Configuration of the proposed DISO converter (Chen et al., 2018)

The DC-DC converter shown in the circuit diagram is widely used in applications such as electric vehicles, energy storage systems, and renewable energy systems. The circuit consists of key components, including inductors L_1 and L_2, switches S_1 and S_2, a diode D_1, capacitors, and load resistance. The inductors store and transfer energy, ensuring smooth current flow, while the MOSFET or IGBT-based switches control energy transfer by rapidly turning ON/OFF at high frequencies. The diode D_1 prevents reverse current flow and regulates energy transfer. Capacitors serve to reduce voltage ripples and stabilize both the intermediate voltage V_2 and the output voltage V_{o1}. The circuit operates with two voltage sources V_1 and V_2, where V_1 acts as the primary input, and V_2 represents a secondary energy storage system such as a battery or supercapacitor.

Voltage gain of the DISO Boost converter can be calculated in Eqs. (4) and (5).

$$\frac{V_{01}}{V_1} \geq \frac{1}{1-D_{S1}} \quad (4)$$

$$\frac{V_{01}}{V_2} \geq \frac{1}{1-D_{S2}} \quad (5)$$

Inductor values of the converter calculated due to its maximum inductor current value. Eqs. (6) and (7) illustrate maximum inductor current.

$$I_{L1,max} = \frac{V_{01} I_{o,max}}{V1} \quad (6)$$

$$I_{L2,max} = I_{L1,max} \quad (7)$$

After calculating the current values, the inductor values can be determined using the following equations.

$$L_1 \geq \frac{V_1(1-D_{S1})T_S}{0.2I_{L1,max}} \quad (8)$$

$$L_2 \geq \frac{V_2(1-D_{S2})T_S}{0.2I_{L2,max}} \quad (9)$$

The following values have been obtained using the relevant equations. Table 2 includes the input and values to be used in the DISO converter simulation.

Table 2. Parameters of DISO DC-DC converter

Quantity	Value
Input Voltage (V_{in})	24 V
Input battery voltage (V_B)	12 V
Output voltage (V_o)	48 V
Inductance (L_1)	3 mH
Inductance (L_2)	1.41 mH
Load (R)	60 Ω
Capacitor (C)	100 µF
Switching frequency (f_{sw})	20 kHz

Fig. 8 illustrates the DISO converter in MATLAB/Simulink. A simulation was performed based on the calculated values, and the current and voltage waveforms were obtained. The duty cycle of the S_1 is %50 and S_2 is %23.65.

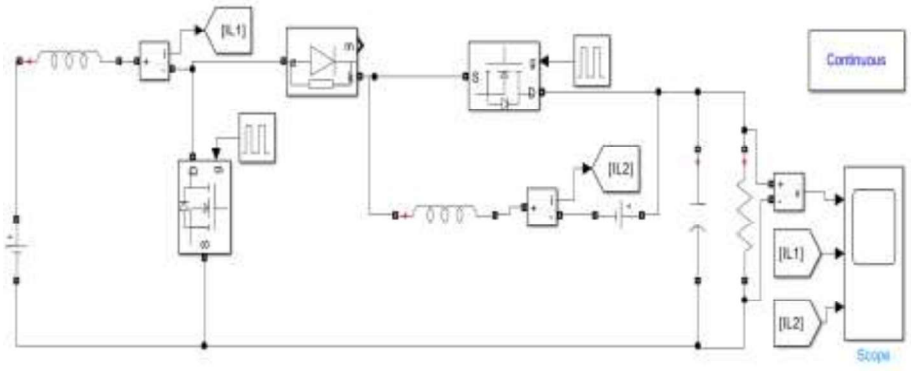


Fig. 8. DSIO DC-DC converter in MATLAB/Simulink

In this model, the input current and inductor current are connected to a scope block via a current measurement block. Additionally, to analyze the voltage drop across the resistive load, a voltage measurement block is utilized to observe the output voltage.



Fig. 9. Output voltage of DISO in MATLAB/Simulink

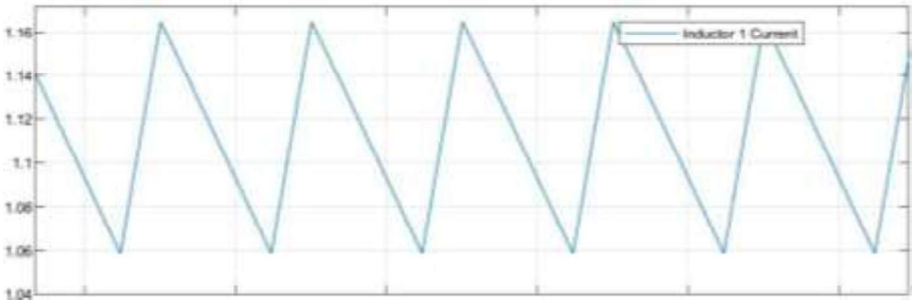


Fig. 10. Inductor 1 current of DISO in MATLAB/Simulink

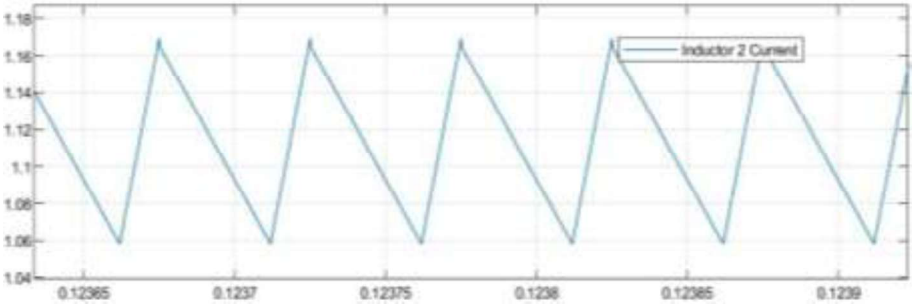


Fig. 11. Inductor 2 current of DISO in MATLAB/Simulink

The simulation results provide the obtained voltage and current values. It is observed that the system reaches steady-state at 50 ms. The output voltage is measured as 48 V, with variations ranging between 47.94 V and 48.06 V in Fig. 9, resulting in a voltage deviation of ±0.6 V.

Regarding the current values is observed in Fig. 10 and Fig. 11. When the S_2 switch is inactive, the current values through L_1 and L_2 are the same. Therefore, it is possible for these two graphs to resemble each other. Current range of L_1 and L_2 is between 1.16 and 1.06.

4. RESULT AND DISCUSSION

The main difference between the two circuit diagrams lies in their hardware and complexity. The circuit represents a DISO DC-DC converter, where two inductors L_1 and L_2 are used, and switching elements S_1 and S_2 regulate power transfer between the input voltage sources V_1 and V_2 and the output V_{01}. However, showcases a more complex multi-switch converter topology, incorporating additional switches S_3, S_4, S_5, diodes D_4, D_5, and capacitors C_1, C_2, allowing for more flexible power flow control. BDISO circuit appears to support multiple modes of operation, possibly improving efficiency and voltage regulation compared to the simpler DISO configuration in the first image. Detailed difference table can be seen in Table 3. BDISO converters achieve an efficiency of 97%, whereas DISO converters operate at 95% efficiency. Therefore, BDISO converters are a more suitable option in terms of efficiency (Abdolahi et al., 2024). DISO Converters use 6 components, BDISO converters use 10 components.

Table 3. Comparative analysis of DISO and BDISO converters

Comparison Criteria	DISO DC-DC Converter	BDISO DC-DC Converter
Topology Structure	Simpler structure with fewer components.	More complex with additional switches, diodes, and capacitors.
Number of Components	2 switches (S_1, S_2), 1 diode (D_1), 2 inductors (L_1, L_2), 1 capacitor (V_2).	5 switches (S_1, S_2, S_3, S_4, S_5), 2 diodes (D_4, D_5), 1 inductor (L), 2 capacitors (C_1, C_2).
Switching Complexity	Simpler control algorithm due to fewer switches.	More complex control algorithm requiring precise synchronization.
Power Loss	Lower switching and conduction losses due to fewer components.	Higher conduction and switching losses due to additional components.
Efficiency	High efficiency in low-power applications.	More efficient for high voltage and power levels.
Voltage Stress	Lower voltage stress on switches and diodes.	Higher voltage stress on some switches due to bidirectional operation.
Output Ripple	Higher ripple due to fewer capacitors and switches.	Lower output ripple due to additional capacitors and switches.
Dynamic Response	Faster response due to a simpler control structure.	Slower response due to a more complex control system.
Applications	Small-scale power management systems, low-power applications.	High-power energy management, electric vehicles, renewable energy systems.
Cost	Lower cost due to fewer components.	Higher cost due to additional components and complex control.
Flexibility	Limited power management, mainly dependent on two input sources.	More flexible power flow management due to bidirectional capability.

5. CONCLUSION

The study highlights the significance of bidirectional DC-DC converters in Electric Vehicle (EV) applications, particularly in integrating multiple energy sources for efficient power distribution. A comparative analysis of the Bidirectional Dual Input Single Output (BDISO) converter and the Dual Input Single Output (DISO) converter was conducted, focusing on their boost mode operations. Simulations performed in MATLAB/Simulink demonstrated the voltage conversion capabilities of both topologies under specified conditions. The results indicate that while BDISO converters offer enhanced flexibility and energy management, they require more complex control strategies and higher implementation costs. In contrast, DISO converters provide a simpler and cost-effective alternative but may have limitations in dynamic response and efficiency. Overall, the selection between these two topologies depends on the specific application requirements, considering factors such as design complexity, hardware constraints, cost, and efficiency.

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