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NEURAL NETWORK BASED HYBRID MPPT ALGORITHMS FOR BIDIRECTIONAL DC CONVERTER

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Abstract—

Electric vehicles (EVs), which operate on battery power, have significantly reduced carbon emissions in the transportation sector. The batteries can be charged either from the electrical grid or, preferably, from hybrid renewable energy sources such as photovoltaic (PV) systems, fuel cells, and supercapacitors. To ensure smooth power flow and stable operation of these hybrid sources, bidirectional DC–DC converters are essential, as they regulate the DC-bus voltage at both the load and input terminals where the PV and battery are connected.

In this paper, a performance analysis of a dual-switch bidirectional DC–DC converter is presented. The proposed converter is capable of efficient buck–boost operation across a wide range of voltage levels. Considering the environmental variability affecting PV systems, a hybrid Maximum Power Point Tracking (MPPT) algorithm integrated with neural network-based tuning is developed to extract maximum power under fluctuating irradiance conditions. The proposed control strategy enhances the overall efficiency of the converter. The system's performance is validated using MATLAB/Simulink simulations.

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Keywords—

Renewable Generation System, Bi-Directional DC Converters (BDDC), Electric Vehicles, Neural Network (NN), Hybrid Battery Storage System (HBSS), Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

The transformation of the Traditional Power Grid System (TPGS) into a hybrid system, driven by the integration of Renewable Generation Systems (RGS) and their associated power conversion units, has increased the demand for high-rating converters, both DC–DC and DC–AC/DC↔AC types. On the generation side, the green energy transition is advancing rapidly, with nearly 40% of total electricity now derived from renewable sources. However, on the demand side, DC-based applications are still in the adaptation phase, aiming to further reduce the overall carbon footprint.

These DC applications rely on Bidirectional DC–DC Converters (BDDCs), which can reverse the direction of power flow and adjust voltage levels as required. Renewable energy systems also depend on DC battery storage to bridge environmental and supply inconsistencies, thereby improving system reliability. The BDDCs play a critical role in charging and discharging these batteries. Beyond energy storage, they are widely utilized in Electric Vehicles (EVs). In EV technology, BDDCs serve dual functions: (1) managing the charging and discharging cycles of the Hybrid Battery Storage System (HBSS), and (2) regulating voltage levels during start-up, running, and braking modes. With the increasing electrification of automotive systems, power demands for start–stop operations in EVs and Hybrid Electric Vehicles (HEVs) have risen significantly [1]. During ignition and braking, the BDDC frequently transitions between buck and boost modes, necessitating converters with high switching frequency, precision control, and superior efficiency. Such converters are crucial for the global adoption of EVs across all segments—low-, medium-, and high-voltage vehicles [2].

For instance, in a Low-Voltage Electric Vehicle (LV-EV), a current of 200 A distributed through a 12-V bus requires thick copper conductors, increasing cost and conduction losses, thereby reducing system efficiency. A 48-V power architecture effectively mitigates these issues, and a BDDC is employed to manage the 12 V ↔ 48 V conversion, ensuring seamless voltage coordination under various operating conditions [3]. Table 1 illustrates this case study, highlighting the performance benefits of such a configuration.

TABLE I. 12-48 V SYSTEM A CASE STUDY IN EV

<table>
<tr><td>12 V system</td><td rowspan="5">12 V BUS</td><td rowspan="2">DC↔DC
48 V</td><td>48 V system</td></tr>
<tr><td>Power Train Control
-Engine Management
-Transmisson Control</td><td>- 48V Accumulator
-Electric AC Compressor
-Cooling Fan
-Electric Heating
-Rear Window Heater
-Air Blower
-Vaccum Pump
-Water pump
-Fuel Pump
-Electric power steering
-Roll stabilization
-Audio Amplifier
-Exterior Light</td></tr>
<tr><td>Chasis Control
-Brake System
-Suspension System</td><td colspan="2" rowspan="3">Infortainment System
-Instrumentation
-Navigation
-Radio/Display
-Communication
-Video</td></tr>
<tr><td>Safety System
-Passenger Safety
-Driver Assistance</td></tr>
<tr><td>Body Control
-Access System</td></tr>
</table>

Therefore, the development of efficient Bidirectional DC–DC Converter (BDDC) topologies has become a crucial research focus aimed at enhancing the utilization of renewable energy resources [4]. This paper presents a BDDC topology integrated with a solar energy system for effective DC battery charging. A dual-switch BDDC is designed and evaluated under both constant and variable irradiance conditions.

Although extensive research has been conducted in this area, the novelty of the proposed work lies in the converter's ability to operate efficiently across a wide voltage range at both the input and output terminals. Additionally, the controller employs a Neural Network (NN)-based tuning algorithm to generate the gate pulses for the switches, ensuring optimal dynamic response and stability. The system's performance is validated through simulations in both buck and boost modes, demonstrating effective charging and discharging of the battery.

Bidirectional DC-DC Converter Topologies

Considering the wide diversity of electric vehicle (EV) configurations, the Bidirectional DC–DC Converter (BDDC) must possess a high voltage conversion range to ensure effective voltage matching between the Hybrid Battery Storage System (HBSS) and the vehicle's DC bus, in accordance with the varying environmental conditions of the Renewable Generation System (RGS) [5]. For compact EV designs, a high power density BDDC is essential to minimize installation space. Due to the high switching frequency operation of BDDCs in EVs, it is also critical to minimize electromagnetic interference (EMI) within the powertrain system. Furthermore, the input and output sides of the converter should share a common ground to ensure stable operation and prevent potential EMI-induced issues [6]. To mitigate damage caused by large current ripples in the HBSS, the power-source-side current of the BDDC should remain continuous, thereby enhancing the durability and lifespan of the storage system [7]. In high-power EV applications, elevated voltage and current stresses can reduce the overall reliability of the converter. Therefore, the BDDC should be designed to minimize voltage and current stresses across the switching devices to prevent possible damage due to high transient conditions [8], [9]. Additionally, achieving high conversion efficiency is crucial to minimize heat generation and energy losses in semiconductor devices [10]. However, incorporating all these desirable characteristics into a single BDDC topology is impractical. Consequently, numerous topological variations have been proposed in the literature to achieve specific performance objectives [11]. Existing BDDC configurations are broadly classified into two categories: non-isolated and isolated types. The non-isolated BDDC employs an impedance network consisting of inductors, capacitors, and switches to achieve direct DC–DC conversion [12]. In contrast, the isolated BDDC introduces a transformer between the DC–DC stages to enable DC↔AC↔DC conversion, where a high voltage conversion ratio can be obtained by appropriately adjusting the transformer turns ratio [13], [14].

The classification detail classification of BDDC is shown in Fig. 1.

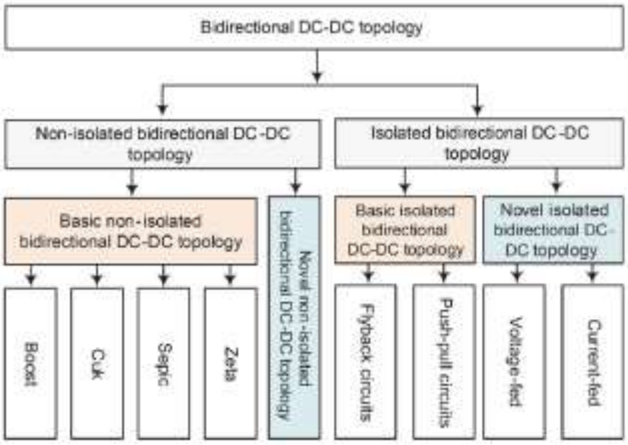

Fig. 1. Classification of BDDC topologies.

This paper presents a novel Bidirectional DC–DC Converter (BDDC) topology featuring a dual-switch configuration, capable of achieving wide-range voltage conversion with high voltage gain. The key innovation of the proposed topology lies in its integration of a Neural Network (NN)-based tuning mechanism for the PID controller, enabling the generation of precise gate pulses for the power semiconductor switches. The proposed converter demonstrates smooth bidirectional operation between boost and buck modes, achieving high conversion gain and superior efficiency compared to conventional designs.

II. Proposed Work

This paper proposes a bidirectional DC–DC converter (BDDC) capable of efficiently charging and discharging batteries connected at both the input and output terminals. The input-side battery is energized by a photovoltaic (PV) source, while the output terminal of the BDDC is linked to an electric vehicle (EV) battery. The schematic configuration of the proposed system is illustrated in Figure 2. The developed converter effectively monitors and regulates the battery states on both ends, ensuring a stable DC bus voltage at the EV terminal under varying input voltage and load conditions. On the PV side, the impact of irradiance fluctuations is examined. Comparative results are also provided for the scenario in which the PV-side battery is disconnected, allowing the PV output to feed the BDDC directly. The PV subsystem comprises a PV array integrated with a Maximum Power Point Tracking (MPPT) controller. The Incremental Conductance (IncCond) algorithm is implemented to precisely track the maximum voltage and current of the PV system, ensuring optimal energy extraction.

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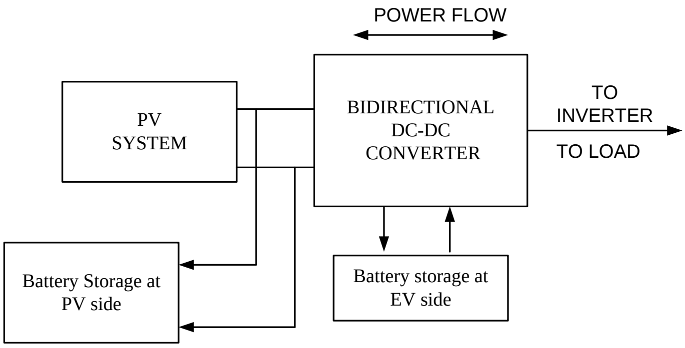

Fig. 2. Schematic of proposed BDDC topologies.

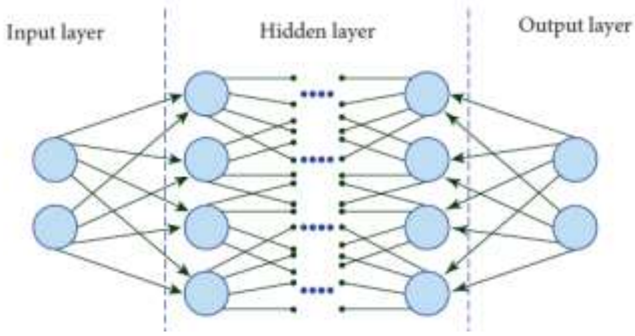

Fig. 3. Neural topology.

III. SIMULATION RESULTS

The simulation results for the proposed system were obtained using MATLAB/Simulink software. The Bidirectional DC–DC Converter (BDDC) operates in dual modes—boost and buck—to accommodate variations in solar irradiance and changes in electric vehicle (EV) power demand during ignition and braking conditions. During ignition, a high voltage is required to start the vehicle, whereas during braking, the generated power is fed back to the system. Thus, the bidirectional operation of the converter enables simultaneous charging and discharging of the batteries.The proposed BDDC is powered by the PV source, as illustrated in Figure 4. The two switching devices, denoted as S_1 and S_2, control the boost↔buck transitions, ensuring efficient energy flow management under dynamic operating conditions.

The performance of the proposed Bidirectional DC–DC Converter (BDDC) is analyzed under both constant and variable solar irradiance conditions. A photovoltaic (PV) module with a maximum voltage of 30.7 V and a maximum current of 8.15 A is considered, corresponding to an overall operating voltage range of 70–200 V. The design parameters of the proposed BDDC are summarized in Table 2.

TABLE II. BDDC DESIGN PARAMETERS

Parameters	Values
F	50Hz
Fs	10 KHz
D1	0.4
D2	0.6
C1	1000 μF
C2	100 μF
R1	0.01
R2	0.1
L1	20mH
Proportional gain	1.5
Integral gain	25

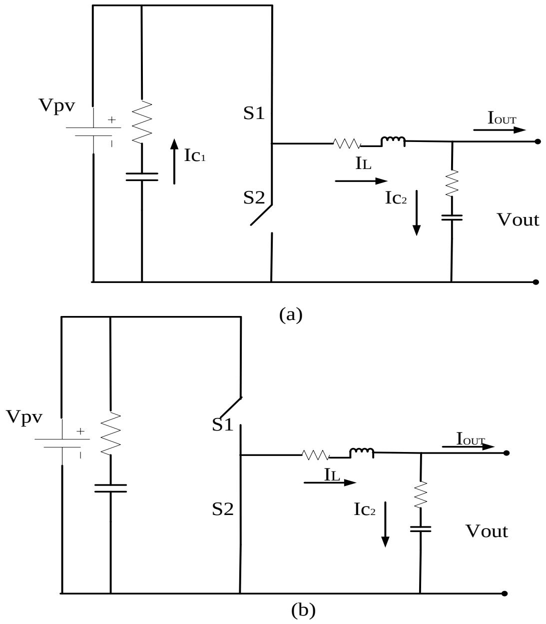

Fig. 4. Single line diagram of proposed BDDC topologies.

A. Boost operation with constant Irradiations

To evaluate the performance of the proposed Bidirectional DC–DC Converter (BDDC) in boost mode, the solar irradiance is maintained at a constant level of 1000 W/m². Under these conditions, the PV array generates approximately 9000 W at an input voltage of 70 V. This voltage is supplied to the BDDC, which effectively boosts it to 200 V, as illustrated in Figure 5. The corresponding switching behavior of the converter under this operating condition is presented in Figure 6.

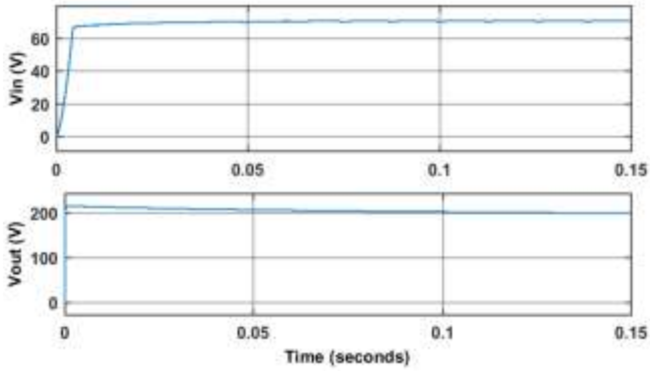

Fig. 5. Input/Output voltage under boost mode with constant irradiations.

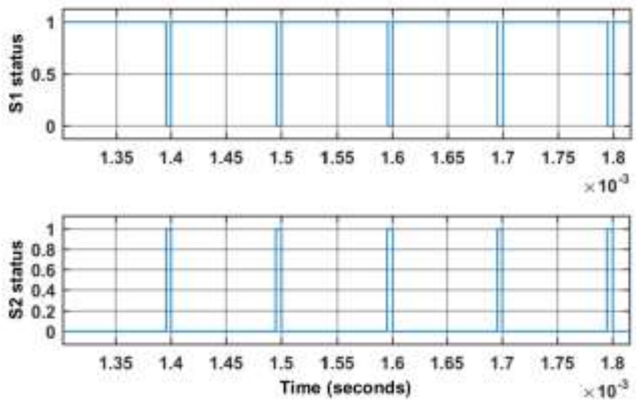

Fig. 6. Switch status under boost mode.

B. Buck operation with constant Irradiations

In buck mode, the current flow reverses direction, transferring power from the EV battery back to the PV system. This operating condition occurs during braking or when the battery is overcharged, ensuring that the voltage levels at both terminals remain within the predefined limits. In this mode, the solar irradiance is also maintained at a constant value.The corresponding input and output voltages under this condition are illustrated in Figure 7, while the associated current waveforms are shown in Figure 8.

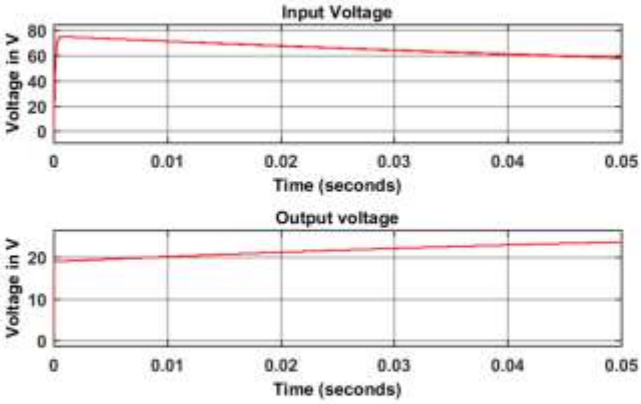

Fig. 7. Input/output voltage under buck mode with constant irradiance.

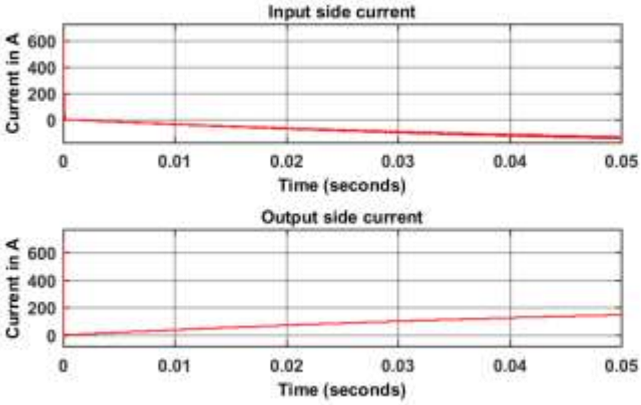

Fig. 8. Input/output current for buck mode with constant irradiance.

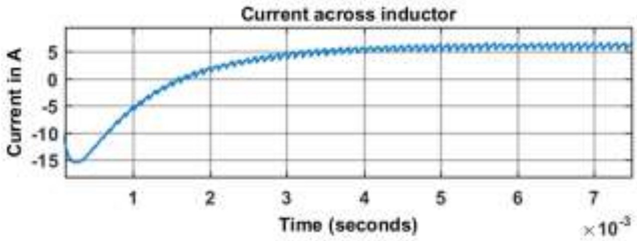

Fig. 9. Inductor current for buck mode.

As observed from Figure 8, the input-side current (i_1) flows in the reverse direction, demonstrating the bidirectional capability of the proposed BDDC. Under this mode, the input voltage of 70 V is stepped down to 25 V. The inductor current behavior during this operation is depicted in Figure 9.

C. Boost/Buck operation with Variable Irradiations

The designed system is further analyzed under variable solar irradiance conditions in boost mode operation. The irradiance level is varied from 1000 W/m² to 600 W/m², as illustrated in the graph shown in Figure 10. The corresponding switching status of the converter under these varying conditions is presented in Figure 11.

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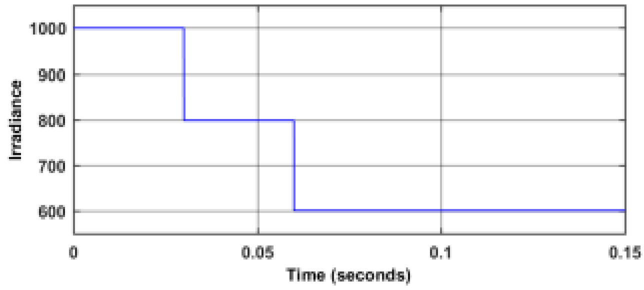

Fig. 10. Variable irradiance graph.

The input and output voltages of the proposed system in boost mode under variable irradiance conditions are illustrated in Figure 12. In buck mode, the input voltage of 150 V is stepped down to 20 V, as shown in Figure 13. From both figures, it can be observed that although the solar irradiance varies, the terminal voltages of the Bidirectional DC–DC Converter (BDDC) remain stable, demonstrating effective voltage regulation capability. The corresponding inductor current waveform under these operating conditions is presented in Figure 14.

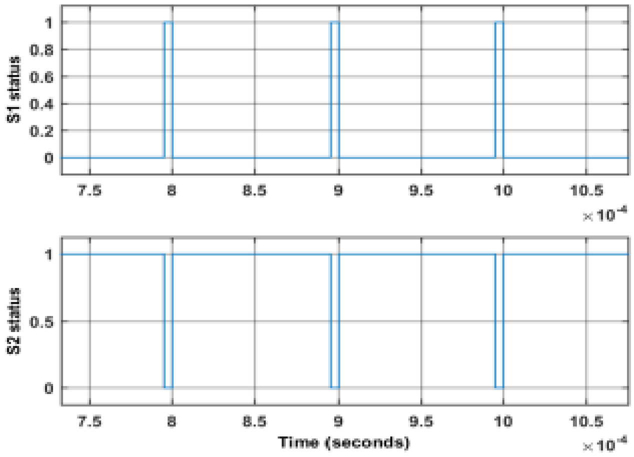

Fig. 11. Switch status under the condition of variable irradiance with buck mode.

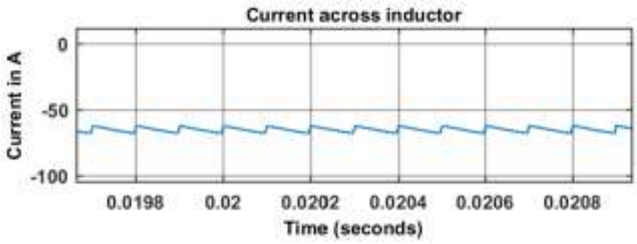

Fig. 12. Inductor current for variable irradiance.

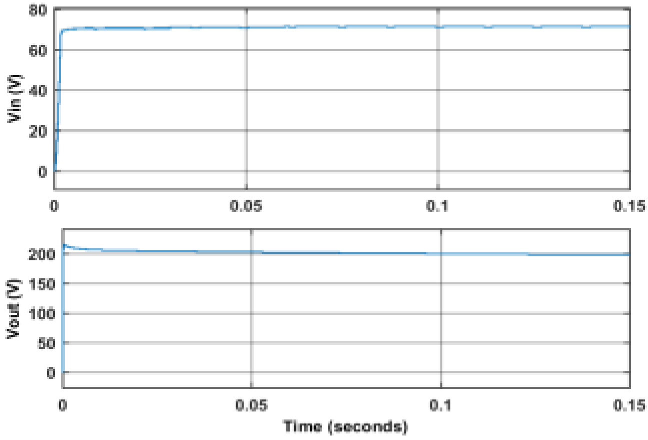

Fig. 13. Input/Output voltage under boost mode with variable irradiations.

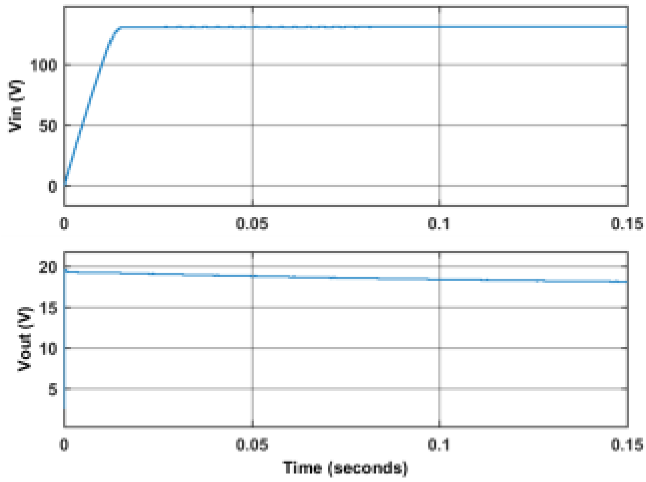

Fig. 14. Input/Output voltage under buck mode with variable irradiations.

IV. Simulation Results

With the growing adoption of green energy systems, the use of DC battery systems and corresponding bidirectional DC–DC converters (BDDCs) has become increasingly significant. This paper presents an application of a BDDC in an electric vehicle (EV) system. In the proposed configuration, the input-side battery of the converter is charged using solar power, while the output-side battery supplies energy to the EV. Since solar irradiance is inherently variable, an Incremental Conductance MPPT algorithm is employed to track the maximum power point of the PV system. To enhance the tracking accuracy and achieve faster dynamic response, a Neural Network (NN) is integrated with the MPPT algorithm. The proposed BDDC is tested under both constant and varying irradiance conditions for bidirectional boost↔buck operation. The simulation results confirm that the output voltage remains stable despite irradiance fluctuations, demonstrating smooth bidirectional operation. The results obtained over a wide voltage range validate the versatility and robustness of the proposed converter design in fulfilling the performance requirements of electric vehicle applications.

References

[1] Dusmez, S., Hasanzadeh, A., & Khaligh, A. (2014, June). *Loss analysis of non-isolated bidirectional DC/DC converters for hybrid energy storage system in EVs.* In 2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE) (pp. 543–549). IEEE.

[2] Ye, Z., & Rajagopalan, S. (2016). *Bidirectional DC/DC converter topology comparison and design.* In Power Supply Design Seminar (Vol. 17).

[3] Georgious, R., Garcia, J., Navarro-Rodriguez, A., & Garcia, P. (2018). *A study on the control design of nonisolated converter configurations for hybrid energy storage systems.* IEEE Transactions on Industry Applications, 54(5), 4660–4671.

[4] Karbozov, A., & Ibanez, F. M. (2019, November). *Optimal design methodology for high-power interleaved bidirectional buck–boost converters for supercapacitors in vehicular applications.* In 2019 8th International Conference on Renewable Energy Research and Applications (ICRERA) (pp. 152–157). IEEE.

[5] Yahyazadeh, S., Khaleghi, M., Farzamkia, S., & Khoshkbar-Sadigh, A. (2020, February). *A new structure of bidirectional DC–DC converter for electric vehicle applications.* In 2020 11th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC) (pp. 1–6). IEEE.

[6] Pellitteri, F., Miceli, R., Schettino, G., Viola, F., & Schirone, L. (2020). *Design and realization of a bidirectional full-bridge converter with improved modulation strategies.* Electronics, 9(5), 724.

[7] Wang, J., Wang, B., Zhang, L., Wang, J., Shchurov, N. I., & Malozyomov, B. V. (2022). *Review of bidirectional DC–DC converter topologies for hybrid energy storage system of new energy vehicles.* Green Energy and Intelligent Transportation, 1(2), 100010.

[8] Yi, W., Ma, H., Peng, S., Liu, D., Ali, Z. M., Dampage, U., & ajjiah, A. (2022). *Analysis and implementation of multi-port bidirectional converter for hybrid energy systems.* Energy Reports, 8, 1538–1549.

[9] Abbasian, S., & Farsijani, M. (2022). *A single-switch high step-up zero-current switching DC–DC converter based on three-winding coupled inductor and voltage multiplier cells with quasi-resonant operation.* International Journal of Circuit Theory and Applications, 50(12), 4419–4433.

[10] Al-Obaidi, N. A., Abbas, R. A., & Khazaal, H. F. (2022, May). *A review of non-isolated bidirectional DC–DC converters for hybrid energy storage systems.* In 2022 5th International Conference on Engineering Technology and its Applications (IICETA) (pp. 248–253). IEEE.

[11] Chmielewski, A., Piórkowski, P., Bogdziński, K., & Możaryn, J. (2023). *Application of a bidirectional DC/DC converter to control the power distribution in the battery–ultracapacitor system.* Energies, 16(9), 3687.

[12] Sutikno, T., Aprilianto, R. A., & Purnama, H. S. (2023). *Application of non-isolated bidirectional DC–DC converters for renewable and sustainable energy systems: a review.* Clean Energy, 7(2), 293–311.

[13] Tank, S. B., Manavar, K., & Adroja, N. (2015). *Non-isolated bi-directional DC–DC converters for plug-in hybrid electric vehicle charge station application.* In Proc. of Emerging Trends in Computer & Electrical Engineering (ETCEE 2015) (pp. 13–14).

[14] Mumtaz, F., Yahaya, N. Z., Meraj, S. T., Singh, B., Kannan, R., & Ibrahim, O. (2021). *Review on non-isolated DC–DC converters and their control techniques for renewable energy applications.* Ain Shams Engineering Journal, 12(4), 3747–3763.