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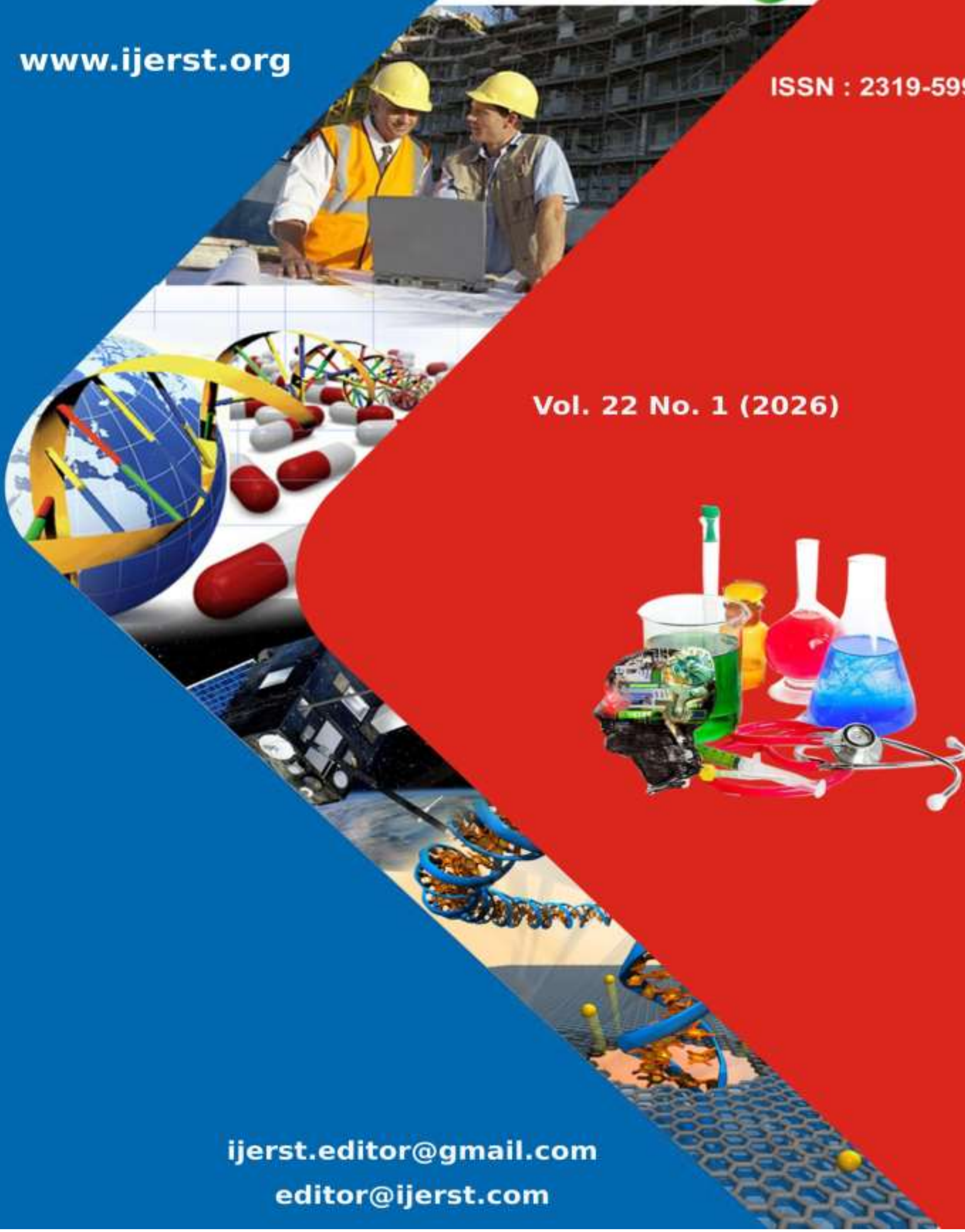

ijerst.editor@gmail.com

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Research

DESIGN AND PERFORMANCE ANALYSIS OF ANFIS-CONTROLLED BIDIRECTIONAL DC–DC CONVERTER FOR EV CHARGING

[1]L. SWARUPA RANI, [2] MRS.N. SUREKHA, [3]J. VARUN SAI RAM,[4]S. SIRIDI SRINIVAS
[2]Assoc.Prof & HoD, EEE Dept, RISE Krishna Sai Prakasam Group of Institutions, Ongole-523001, AP
[1,3,4,5]B. Tech final year students, EEE Dept, RISE Krishna Sai Prakasam Group of Institutions,Ongole-523001, AP
([1]lakkaswaruparani1715@gmail.com ; [2] surekhann2@gmail.com; [3] varunsairamjoolapalli2005@gmail.com; [4] srinivassunkesula2244@gmail.com)

ABSTRACT
The rapid growth of electric vehicles (EVs) has intensified the need for efficient and stable energy management systems capable of minimizing output fluctuations and improving overall performance. In EV applications, the energy storage unit—primarily composed of lithium-ion batteries and auxiliary storage elements such as supercapacitors—plays a critical role in ensuring reliable power delivery and regenerative energy utilization. However, conventional charging and control strategies often suffer from voltage instability and performance distortion under dynamic operating conditions.

This paper presents a dynamically designed bidirectional DC–DC converter integrated with a hybrid energy storage system for enhanced EV charging and discharging operations. An Adaptive Neuro-Fuzzy Inference System (ANFIS)-based intelligent control strategy is proposed to regulate power flow between the battery and supercapacitor while maintaining optimal state-of-charge conditions. The controller employs rule-based dynamic constraint management to improve energy distribution and reduce transient fluctuations.

Simulation results demonstrate that the proposed ANFIS-controlled system achieves improved voltage stability, reduced output distortion, and enhanced energy efficiency compared to conventional control approaches. The proposed framework contributes to improved endurance, reliability, and cost-effective operation of electric vehicle energy storage systems.

Keywords:ANFIS Controller, Bi directional DC-DC Converter, Super Capacitor/ Auxiliary Battery

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I INTRODUCTION

India's increasing energy demand and heavy dependence on imported petroleum products present significant economic and environmental challenges. Approximately 80% of the country's crude oil requirements are met through imports, making the economy vulnerable to global price fluctuations. Moreover, the combustion of fossil fuels contributes significantly to air pollution and greenhouse gas emissions. Therefore, reducing reliance on petroleum-based fuels and transitioning toward sustainable energy solutions has become essential.

Electric vehicles (EVs) have emerged as a promising alternative to conventional internal combustion engine vehicles due to their higher efficiency and zero tailpipe emissions. However, the performance of EVs strongly depends on their energy storage system. Lithium-ion batteries are widely adopted due to their relatively high energy density (around 90–100 Wh/kg for practical battery packs). Nevertheless, this value is significantly lower than the energy density of gasoline (approximately 12,000 Wh/kg), which limits driving range and increases battery cost.

To improve energy utilization and dynamic performance, hybrid energy storage systems combining lithium-ion batteries and supercapacitors are increasingly employed. Efficient power conversion through bidirectional DC–DC converters enable controlled charging, discharging, and regenerative braking operations. Furthermore, intelligent control strategies such as Adaptive Neuro-Fuzzy Inference System (ANFIS) can enhance voltage regulation, minimize fluctuations, and improve overall energy management in EV applications.

In addition to efficient energy storage, effective power management between the battery system and vehicle load is crucial for ensuring stable and reliable operation. Improper control strategies may lead to voltage fluctuations, increased stress on battery components, and reduced overall system efficiency. Therefore, the integration of intelligent control techniques with bidirectional power converters becomes essential to achieve optimized energy flow, improved dynamic response, and enhanced durability of the energy storage system. This motivates the development of advanced control-based EV charging frameworks.

II LITERATURE SURVEY

The development of electric vehicles (EVs) has led to extensive research in charging infrastructure, energy storage systems, and power management techniques. One major limitation of EV technology is the long charging time compared to conventional fuel refuelling. Depending on charger capacity, battery charging may require several hours, which affects vehicle usability and convenience. This has encouraged research into improved charging methods and efficient energy management systems.

Conventional conductive charging systems, though widely used, present challenges such as cable handling issues, safety risks in adverse weather conditions, and dependency on physical connectors. To address these limitations, researchers have investigated Wireless Power Transfer (WPT) systems for EV charging. Static wireless charging allows vehicles to charge while parked, whereas dynamic systems enable charging during motion. However, wireless systems often involve higher infrastructure cost and efficiency concerns.

Energy storage plays a crucial role in EV performance. Lithium-ion batteries are commonly used due to their relatively high energy density and efficiency. However, batteries alone suffer from limited power density and reduced lifespan under high dynamic load conditions. To overcome these issues, hybrid energy storage systems (HESS) combining batteries and ultra-capacitors have been proposed. Ultra-capacitors provide high power density and fast response, reducing stress on the battery and improving overall system reliability.

Recent studies also emphasize the need for intelligent control strategies to manage energy flow effectively. Advanced techniques such as fuzzy logic and ANFIS have been applied to handle nonlinear system behaviour and improve voltage stability. Therefore, integrating a bidirectional DC–DC converter with a hybrid energy storage system and intelligent control can significantly enhance EV charging performance and extend battery life.

III EXISTING SYSTEM

In conventional electric vehicle (EV) charging systems, a unidirectional DC–DC converter is typically used to regulate voltage between the power source and the battery. These systems mainly support charging operation and do not allow efficient bidirectional power flow for regenerative energy utilization.

Most existing EV systems rely only on lithium-ion batteries as the primary energy storage device. Although they offer good energy density, batteries experience high stress under sudden load variations, leading to reduced lifespan and performance degradation.

Traditional control methods such as PI or PID controllers are commonly used for voltage regulation. However, these controllers may not perform effectively under nonlinear and dynamic operating conditions of EV systems, resulting in voltage fluctuations and slower dynamic response. Additionally, the absence of hybrid energy storage limits the system's ability to handle high transient power demands efficiently.

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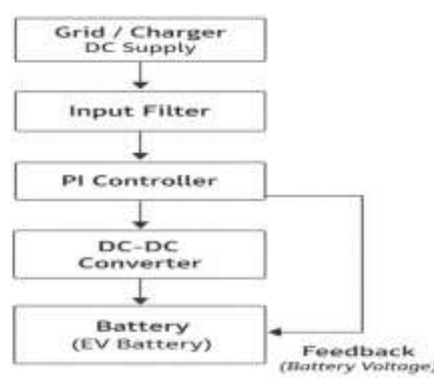

Fig.3.1 Electric Vehicle charging by using a unidirectional DC-DC converter and an PI controller

From the above fig.3.1 shows that the Electric vehicle charging by using a unidirectional DC-DC converter and a PI controller the above fig shows that the charging process which provides the DC supply this power passes through an input filter it uses that signal stability before to passing an PI controller. The PI controller regulating a desired output level from that energy levels delivered from the battery.

IV PROPOSED SYSTEM

To overcome the limitations of conventional EV charging systems, a bidirectional DC–DC converter integrated with a hybrid energy storage system (HESS) is proposed. Unlike traditional unidirectional converters, the proposed bidirectional topology enables controlled charging and discharging operations, allowing efficient power transfer between the energy storage unit and the load. This feature also supports regenerative braking, thereby improving overall energy utilization.

The hybrid energy storage system consists of a lithium-ion battery combined with a supercapacitor. The lithium-ion battery serves as the primary energy source due to its high energy density, while the supercapacitor compensates for sudden load variations owing to its high power density and rapid charge–discharge capability. This coordinated operation reduces battery stress, limits voltage fluctuations, and enhances the lifespan of the storage system.

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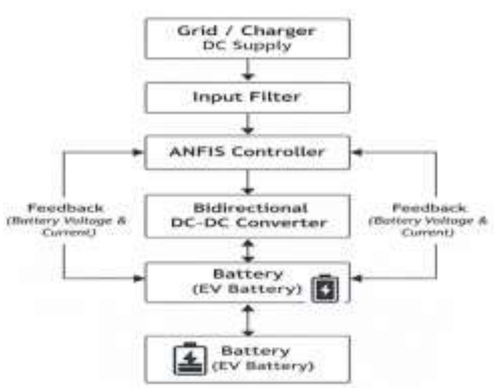

Fig.4.1 Electric Vehicle charging by using a bi-directional DC-DC converter and an ANFIS controller

From the above Fig.4.1. the bidirectional converter operates in two modes: buck mode during battery charging and boost mode during discharging. Proper control of switching devices ensures smooth transition between operating modes and stable DC-link voltage regulation.

To achieve intelligent energy management, an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller is implemented. The ANFIS controller dynamically regulates duty cycle based on system conditions, improving voltage stability and minimizing output distortions under nonlinear and varying load conditions.

The proposed system therefore enhances efficiency, improves dynamic response, and ensures reliable EV energy management compared to conventional control strategies.

Moreover, the proposed system enhances operational safety by ensuring controlled current flow during both charging and discharging modes. Overcurrent and voltage stress are minimized through intelligent regulation of the converter switching action. This improves system robustness and prevents sudden performance degradation under dynamic driving conditions. As a result, the proposed architecture offers improved reliability and stable operation of the EV power interface.

V CIRCUIT

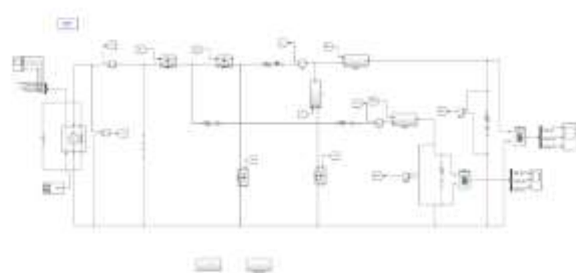

Fig.5.1. Electrical vehicle charging by using bi directional dc-dc converter and an ANFIS controller's simulation model.

From the above fig.5.1 it shows that the bi directional DC-DC Converter which is controlled by ANFIS controller in an ANFIS controller. The above figure shows the 2 batteries are connected. One is primary and another is auxiliary during normal conditions the motor/machine draws the power from the primary battery and during excess load the extra load draws from the auxiliary battery for fast switching operation for a dynamic response operation we are using MOSFET's. During breaking, the load act as source and the regenerative voltage will store in auxiliary battery for a continuous operation. For this we are using Bi-directional DC-DC converter for a power flow in both directions.

VI RESULTS

The proposed bidirectional DC–DC converter integrated with a hybrid energy storage system was simulated using MATLAB/Simulink to evaluate system performance under varying load conditions. The simulation model includes a lithium-ion battery, supercapacitor module, bidirectional converter topology, and ANFIS-based control strategy.

The system was evaluated during both charging (buck mode) and discharging (boost mode) operations. The DC-link voltage, battery current, supercapacitor current, and output voltage waveforms were observed to verify stability and dynamic response.

The results demonstrate that the ANFIS-controlled system maintains stable output voltage with reduced ripple under sudden load variations. Compared to conventional PI-based control, the proposed intelligent controller shows improved dynamic response and faster settling time. The hybrid energy storage configuration effectively distributes power between the battery and supercapacitor, thereby reducing peak stress on the battery.

During transient conditions, the supercapacitor responds quickly to supply high power demand, while the battery provides steady-state energy support. This coordinated operation improves overall system efficiency and minimizes voltage fluctuations. The system also demonstrated stable mode transition and improved voltage regulation under varying load conditions.

But in real time the super capacitors are very costly as compared to normal capacitors. So, it is not an economical solution; in order to solve this, we are using another battery source. Which we called it as auxiliary or secondary battery. Where the battery discharges during excess load conditions and charges during regenerative breaking of an EV's.

VII SIMULATION OUTPUTS

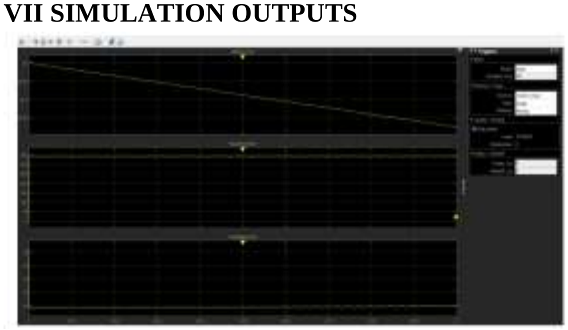

Fig.7.1. Characteristics of primary battery

From the above Fig7.1.it shows the characteristics of primary battery during normal condition the power flow form battery to motor or a machine.

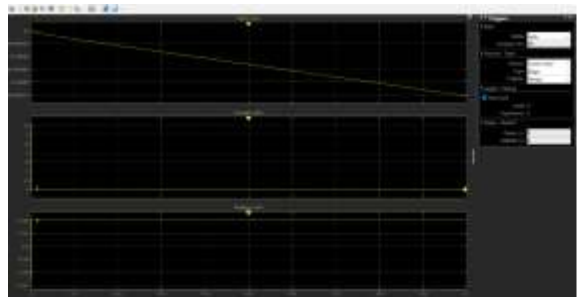

Fig.7.2. Characteristics of Auxiliary or Secondary battery

From the above Fig.7.2.it shows the characteristics of Auxiliary or Secondary battery during extra load condition the excess power drawn from the another battery the power flow from both batteries to motor or a machine.

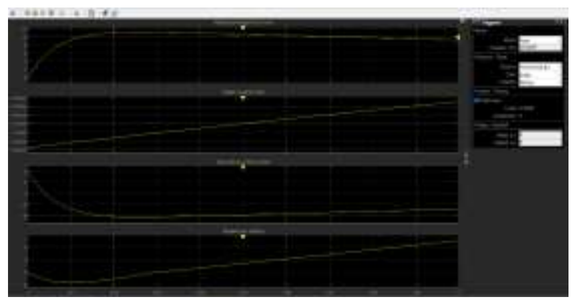

Fig.7.3. Characteristics of motor or a machine during Normal condition

From the above Fig.7.3.it shows the characteristics of a motor or a machine during running conditions. And the speed is going to increase gradually.

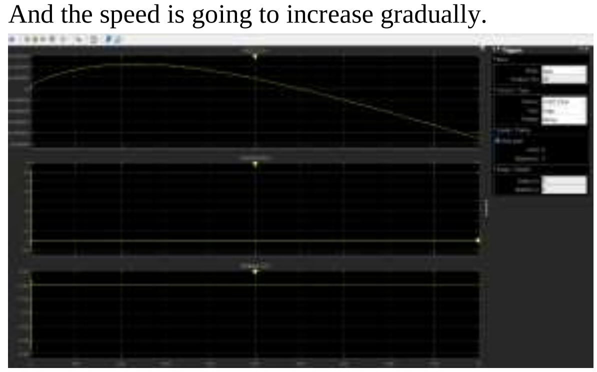

Fig.7.4. Characteristics of a auxiliary or Secondary battery during breaking condition

From the above Fig.7.4.it shows the characteristics of a auxiliary or Secondary battery during regenerative breaking. The battery is going to charge for some particular of period

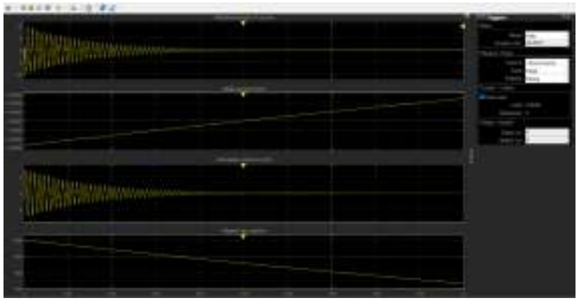

Fig.7.5. Characteristics of motor or a machine during breaking condition

From the above Fig7.5.it shows that the characteristics of a motor or a machine when breaks are applied. the speed is decreasing and due to regenerative breaking the current is increasing for particular time to charge the auxiliary battery

The simulation results confirm that the proposed system achieves enhanced voltage regulation, reduced output distortion, and improved energy management performance in electric vehicle applications.

VIII CONCLUSION:

Electric vehicles (EVs) are gaining significant attention due to their potential to reduce fossil fuel consumption and environmental pollution. The increasing demand for EVs requires efficient energy storage systems and advanced power management strategies to enhance performance, reliability, and driving range. Lithium-ion batteries play a major role in EV applications; however, their limitations in handling high transient loads necessitate improved energy management techniques.

In this work, a bidirectional DC–DC converter integrated with a hybrid energy storage system has been presented for electric vehicle applications. The proposed system combines battery and supercapacitor energy sources to improve power sharing and reduce stress on individual storage components. An ANFIS-based intelligent controller is implemented to regulate the converter operation and enhance voltage stability.

Simulation results demonstrate that the proposed ANFIS-controlled system provides smoother transitions, reduced output distortion, and improved dynamic response compared to conventional PI control. The system achieves high conversion efficiencies of approximately 97.25% in high-voltage regenerative buck mode, 95.32% in dual-source powering mode, 95.76% in boost mode, and 92.67% in buck mode. These results confirm the effectiveness of the proposed architecture for hybrid electric vehicle applications.

The proposed bidirectional converter system meets standard operating requirements and can be extended for practical EV implementations. Future work may include hardware realization of the system and further enhancement of the intelligent controller using advanced neural network-based optimization techniques.

Overall, the integration of intelligent control with bidirectional power conversion significantly enhances the

performance and efficiency of electric vehicle energy storage systems. The proposed approach contributes to improved system reliability, better energy utilization, and extended operational life, making it a promising solution for next-generation EV applications.

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