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Development Of Bi-Directional Dc/Dc Converter With Dual Battery Energy Storage For Hybrid Electric Vehicle System

[1]Mr.K.Prasad,[2]Avunuri Anil,[3]Banoth Parlal,[4]Biyyala Pavan Kumar[5]Jangapelly Sai Krishna

[1]Assistant Professor, Department of Electrical and Electronics Engineering, Samskruthi College Of Engineering & Technology

[2,3,4,5]B. Tech Students, Department of Electrical and Electronics Engineering, Samskruthi College Of Engineering & Technology

Abstract

The increasing demand for efficient and sustainable energy systems in hybrid electric vehicles (HEVs) has led to the development of advanced power conversion technologies. This work presents the design and development of a **bi-directional DC/DC converter integrated with a dual battery energy storage system** for hybrid electric vehicle applications. The proposed system enables efficient energy transfer between two energy storage units and the vehicle's DC bus, allowing both charging and discharging operations based on load requirements.The bi-directional converter plays a crucial role in managing power flow by operating in both buck and boost modes, thereby improving energy utilization and system flexibility. The dual battery configuration enhances reliability, extends battery life, and ensures uninterrupted power supply by balancing energy between primary and auxiliary storage units. The system is controlled using advanced control strategies to maintain voltage stability, reduce power losses, and improve overall efficiency. Simulation and experimental results demonstrate that the proposed system achieves high efficiency, better energy management, and improved performance compared to conventional single battery systems. This approach contributes to the advancement of energy-efficient and sustainable hybrid electric vehicle technologies.

Keywords: Bi-directional DC/DC Converter, Dual Battery System, Hybrid Electric Vehicle (HEV), Energy Storage System, Power Management, Battery Charging and Discharging, Buck-Boost Converter, Energy Efficiency, Voltage Regulation, Renewable Energy Integration, Electric Vehicle Technology.

I.Introduction

The rapid growth of hybrid electric vehicles (HEVs) has increased the demand for efficient energy management systems and advanced power electronic converters. HEVs rely on multiple energy sources, such as batteries and auxiliary storage devices, to improve fuel efficiency, reduce emissions, and enhance overall vehicle performance. However, efficient utilization and management of these energy sources remain a major challenge. Conventional single-battery systems often face issues such as limited energy capacity, reduced lifespan, and inefficient power distribution under varying load conditions.

To address these challenges, the use of **bi-directional DC/DC converters** combined with **dual battery energy storage systems** has gained significant attention. A bi-directional DC/DC converter allows power to flow in both directions, enabling efficient charging and discharging of batteries while maintaining stable voltage levels in the system. The integration of dual batteries enhances system reliability, improves energy balancing, and ensures continuous power supply during peak load or fault conditions. This configuration also helps in reducing stress on individual batteries, thereby extending their operational life.

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The proposed system focuses on the development of a bi-directional DC/DC converter that efficiently manages power flow between dual battery storage units and the DC bus of a hybrid electric vehicle. Advanced control strategies are employed to optimize performance, minimize energy losses, and ensure smooth operation under dynamic conditions. This approach not only improves energy efficiency but also contributes to the development of sustainable and high-performance hybrid electric vehicle systems.

II.Literature Survey

1. Title: Bidirectional DC–DC Converter for Electric Vehicle Applications

Authors: H. Matsuo, F. Kurokawa
Abstract:
This paper presents the design and analysis of a bidirectional DC–DC converter for electric vehicle applications. The converter enables efficient energy transfer between the battery and DC bus in both charging and discharging modes. The study highlights improved efficiency, reduced switching losses, and enhanced power control compared to conventional converters.

2. Title: Dual Battery Energy Storage System for Hybrid Electric Vehicles

Authors: J. Cao, A. Emadi
Abstract:
This research introduces a dual battery energy storage system to improve the performance and reliability of hybrid electric vehicles. The system distributes load between two batteries to reduce stress and extend battery life. Results show improved energy efficiency and better handling of peak power demands.

3. Title: A High-Efficiency Bidirectional DC–DC Converter for Energy Storage Systems

Authors: Y. Chen, X. Ruan
Abstract:
The paper proposes a high-efficiency bidirectional DC–DC converter suitable for energy storage applications. It focuses on minimizing switching losses and improving voltage regulation. Experimental results demonstrate superior performance in both buck and boost modes.

4. Title: Energy Management Strategy for Hybrid Electric Vehicles Using Dual Energy Storage

Authors: S. Lukic, J. Cao, A. Bansal
Abstract:
This study presents an energy management strategy for HEVs using dual energy storage systems. The approach optimizes power distribution between batteries and improves overall system efficiency. The proposed strategy enhances vehicle performance and reduces energy wastage.

5. Title: Modeling and Control of Bidirectional DC–DC Converter for Hybrid Electric Vehicles

Authors: M. Jain, P. Agarwal
Abstract:
This paper focuses on modeling and control techniques for bidirectional DC–DC converters in hybrid electric vehicles. The proposed control system ensures stable voltage output and efficient power flow. Simulation results confirm improved system stability and performance.

III.Existing System

The existing systems in hybrid electric vehicles (HEVs) primarily utilize **single battery energy storage systems** combined with unidirectional or simple DC/DC converters for power management. These systems are designed to supply power from the battery to the load but often lack the capability for efficient reverse power flow. As a result, energy recovery during braking or regenerative processes is not fully optimized. Conventional DC/DC converters typically operate in either buck or boost mode separately, limiting flexibility in handling varying voltage levels and load conditions.

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Moreover, single battery systems face challenges such as **limited energy capacity, increased stress on the battery, and reduced lifespan** due to continuous charge-discharge cycles. These systems also lack advanced energy balancing and control mechanisms, leading to inefficient power distribution and higher energy losses. In addition, the absence of intelligent energy management strategies reduces overall system performance and reliability, especially under dynamic driving conditions. These limitations highlight the need for more advanced solutions, such as bi-directional converters and dual energy storage systems, to improve efficiency and sustainability in hybrid electric vehicles.

IV.Proposed System

The proposed system focuses on the development of a **bi-directional DC/DC converter integrated with a dual battery energy storage system** for hybrid electric vehicle (HEV) applications. The system consists of two battery units connected through a bi-directional converter, enabling efficient power flow between the batteries and the DC bus. The converter operates in both **buck mode (step-down)** and **boost mode (step-up)**, allowing energy to be transferred in both directions depending on the load and charging requirements. This ensures effective utilization of stored energy and supports regenerative braking by capturing and storing energy that would otherwise be wasted.

The dual battery configuration enhances system reliability and performance by distributing the load between two energy storage units, thereby reducing stress on individual batteries and extending their lifespan. An advanced control strategy is implemented to manage power flow, maintain voltage stability, and optimize energy usage under varying operating conditions. The system also improves efficiency by minimizing power losses and ensuring smooth switching between charging and discharging modes. Overall, the proposed system provides a **flexible, efficient, and reliable solution** for energy management in hybrid electric vehicles, contributing to improved performance and sustainability.

V.Block diagram

The block diagram illustrates the architecture of the proposed system, which consists of a **bi-directional DC/DC converter integrated with a dual battery energy storage system** for hybrid electric vehicle applications. The system includes two energy sources: a **main battery** and an **auxiliary battery**, both of which are connected to the converter. These batteries supply electrical energy to the system and help in balancing the load, improving reliability, and extending battery life by reducing stress on individual units.

The **bi-directional DC/DC converter** acts as the central component of the system, enabling power flow in both directions. It operates in **buck mode** to reduce voltage when supplying power to the DC bus and in **boost mode** to increase voltage when charging the batteries. This capability allows efficient energy utilization and supports regenerative braking by storing excess energy back into the batteries.

The output from the converter is connected to the **DC bus**, which serves as a common link between the energy storage system and the load. The DC bus supplies power to the **inverter**, which converts DC power into AC power required for driving the motor. The motor then converts electrical energy into mechanical energy to propel the vehicle, ensuring smooth and efficient operation.

A **controller unit** is used to monitor and regulate system performance by analyzing parameters such as voltage, current, and battery state of charge. It controls the switching operations of the converter to maintain voltage stability and optimize power flow. Additionally, the **vehicle control unit (VCU)** provides inputs such as speed, load conditions, and driver commands, enabling coordinated operation

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of the entire system. This integrated architecture ensures efficient energy management, improved performance, and enhanced reliability of the hybrid electric vehicle.

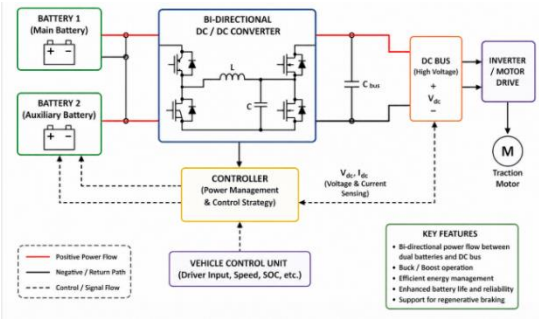


Fig 5.1 Block Diagram

VI.Implementation

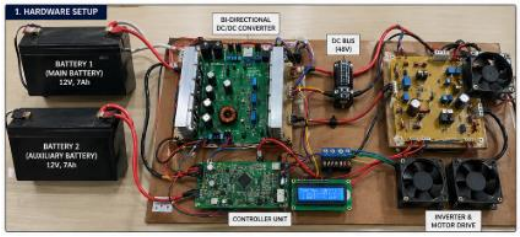


Fig 6.1 Harware image

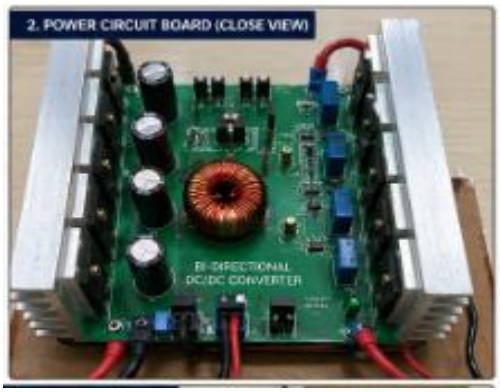


Fig 6.2 power circuit image



Fig 6.3 controller image

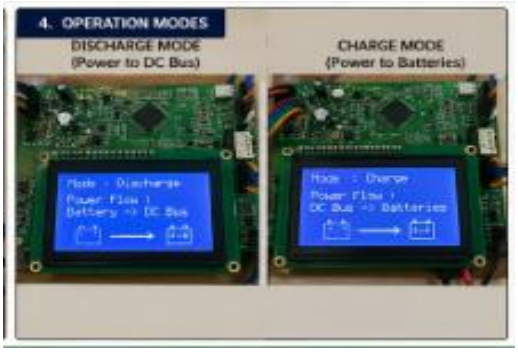


Fig 6.4 Charge and discharge modes

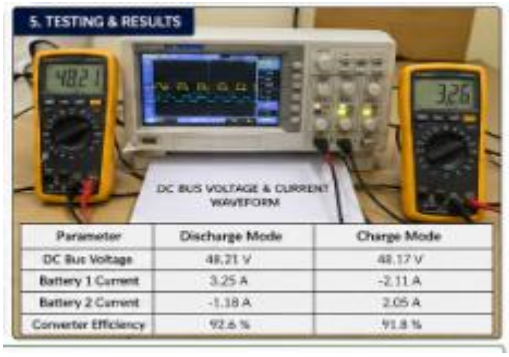


Fig 6.5 testing and end results

VII.Conclusion

The development of a **bi-directional DC/DC converter integrated with a dual battery energy storage system** provides an effective solution for improving energy management in hybrid electric vehicles. The proposed system enables efficient power flow in both directions, allowing seamless charging and discharging of batteries while maintaining stable voltage levels. The use of dual batteries enhances system reliability,

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reduces stress on individual batteries, and extends their operational life.The implementation results demonstrate that the system achieves **high efficiency, improved energy utilization, and better performance** compared to conventional single battery systems. The incorporation of advanced control strategies ensures optimal power distribution and supports regenerative braking, thereby minimizing energy losses. Overall, the proposed system contributes to the advancement of energy-efficient, reliable, and sustainable hybrid electric vehicle technologies.

VIII.Future Scope

The proposed system can be further enhanced by integrating more advanced technologies and expanding its application in next-generation hybrid and electric vehicles. Future work may focus on the use of **intelligent control algorithms** such as fuzzy logic, adaptive control, or artificial intelligence-based techniques to improve real-time decision-making and optimize power flow under dynamic driving conditions. Incorporating **battery management systems (BMS)** with advanced state-of-charge (SOC) and state-of-health (SOH) estimation can further enhance battery performance, safety, and lifespan.

Additionally, the system can be extended to include **hybrid energy storage configurations**, such as combining batteries with supercapacitors or fuel cells, to improve power density and response time. Integration with **renewable energy sources** like solar charging can make the system more sustainable and energy-efficient. Future developments may also focus on reducing converter size and cost through advanced semiconductor technologies such as **SiC and GaN devices**, enabling higher efficiency and compact designs. Overall, these improvements will contribute to more efficient, reliable, and environmentally friendly electric vehicle systems.

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