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A Versatile Non-Isolated Multiport Converter for Efficient Integration of Solar PV, Battery and Ultracapacitor in Electric Vehicles.

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Abstract

The DC-DC converter crucial in modern power electronic systems. They are extensively used in renewable energy integration, hybrid electric vehicles (HEVs) and portable electronic devices. For the electric vehicles (EVs) with a hybrid energy storage system (HESS) that includes both battery and ultracapacitor (UC) efficient power management is the key feature for improving system performance, reliability, and the lifespan of the storage units. This paper mainly focusses on improving how energy is managed in electric vehicles (EVs) by the help of hybrid energy storage system (HESS) that includes-ultra capacitor, solar photovoltaic (PV) and battery input. Hear to control the flow of power which from the sources to EV load, I design a versatile non isolated multiport converter for integration of solar PV, battery and ultracapacitor and getting a single output. This paper suggests a non-isolated multi-input, single-output multiport converter design. This architecture aims to offer flexibility in the power flow while adjusting to the changing load demands of EVs. The DC-DC converter manages varying power demands by selecting the most appropriate energy source and channeling power through the proper paths depending on whether high or low current are required. It also supports bidirectional power transfer, enabling sources in both directions. Moreover, the converter allows single-stage power conversion, thereby improving the overall efficiency of the system.

1. INTRODUCTION

The global surge in electric vehicle (EV) adoption will create a pressing need for reliable, intelligent, and efficient power management solutions. central to this challenge is the performance and durability of energy storage system, which play critical role in determining vehicle efficiency and overall user satisfaction. However, batteries-the primary energy storage devices in EVs-face several limitations. frequent charging and discharging cycles reduce their lifespan, while their ability to handle high peak current demands and response swiftly to sudden load variations remains limited. these shortcomings not only increasing maintenance costs but also compromise long term vehicle performance and reliability, thereby posing a barrier to the sustainable growth of electric mobility.

To address the limitations conventional energy storage, hybrid energy storage systems (HESS) have emerged as a practical and efficient solution. By combining the high energy density of batteries with the rapid charging and discharging ability of ultracapacitors, HESS achieves longer system life, improved energy efficiency, and faster transient response. In this work, a flexible non-isolated multiport DC-DC converter is proposed as an adaptable and effective power electronic interface for HESS in electric vehicle applications. The proposed converter dynamically manages power flow between the battery, ultracapacitor, and load, depending on real-time energy availability and demand. Its distinct current-handling pathways ensure that each storage device operates at its maximum potential.

Through a compact single-stage power conversion design, the system achieves reduced energy losses, improved dynamic response, and overall higher efficiency. In addition, the converter supports bidirectional power transfer across all ports, making it well-suited for advanced EV functionalities such as rapid acceleration, regenerative breaking, vehicle-to-grid (V2G) integration, and intelligent energy management strategies.

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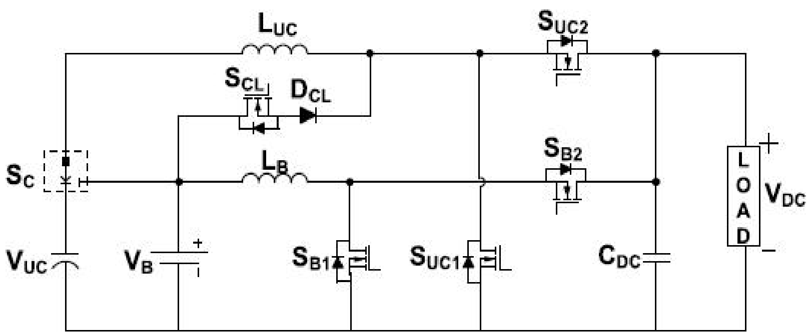
2. Experimental or Materials and Methods

2.1 Indication of problems

Electric vehicles that rely mainly on conventional battery-based energy storage systems face several limitations that effect efficiency and performance. One of the key issues is handling high peak current demands, especially during rapid acceleration or sudden changes in load. Such condition increases thermal stress on the batteries, accelerating wear and reducing its overall lifespan.in addition, batteries respond relatively slowly to fluctuating loads, making it difficult to maintain smooth and consistent performance across different driving condition. As a result, the durability, responsiveness, and reliability of the EV energy storage system can be significantly compromised.

2.2 Existing method

In the conventional design of electric vehicle (EV) power trains, the primary energy storage sources are typically the battery and the ultracapacitor. power is transferred from these sources to the load, usually the EV motor, through a multiport DC-DC converter. A central control unit manages this process, distributing power as needed while the converter regulates voltage and current. However, this method often requires multiple conversion stages, which increase's energy losses and lower overall system efficiency. In addition, high current ripple and limited adaptability to varying load demands can negative impact performance, even though the motor is able to draw the necessary power.



The limitation of the current system can be summarized as fallow the, First, poor efficiency results from higher conduction and switching losses caused by multiple conversion stages. Second excessive current ripple degrades power quality, causing unreliable and unstable motor drive operation. Thirdly inefficient power distribution further reduces system performance by limiting effective energy sharing between the battery and ultracapacitor. the increased circuit design complexity leads to the use of additional components, which in turn raises the overall coast, weight, and size of the system. Another significant challenge is the limited dynamic response, which restricts the system ability to quickly adapt to sudden load variation, such as during acceleration, deceleration, or cross-regulation adds further difficulty in achieving effective power sharing between the battery and the ultracapacitor, ultimately causing uneven energy distribution and lowering system reliability.

2.3 Proposed method

A non-isolated bidirectional multi-port DC-DC converter offers an effective solution for integrating both the battery and ultracapacitor into an electric vehicle powertrain. Unlike A non-isolated bidirectional multi -port DC-DC converter offer of a effective solution for integrating both the battery and ultracapacitor into an electric vehicle's powertrain, unlike traditional multi-stage configurations, this single-stage design creates direct power flow paths, which lowers conduction and management, its ability to quickly respond to sudden load variation makes it highly suitable for critical EV operation such as regenerative breaking rapid acceleration and other transient conditions by minimizing voltage and current ripple at the output the convert ensures a study supply of power to the motor improving driving smoothness and extending the lifespan of the energy storage units.

This design also enhance load isolation allowing the battery and ultra capacitor to meet their respective power demand independently without interference improved load regulation and reduced stress and components further increase system reliability the compact structures require fever components which simplifies control lower cost reduces weight and contributes to a more efficient overall system together these advantage make the proposed converter design a practical and efficient choice for modern EV application.

Block diagram

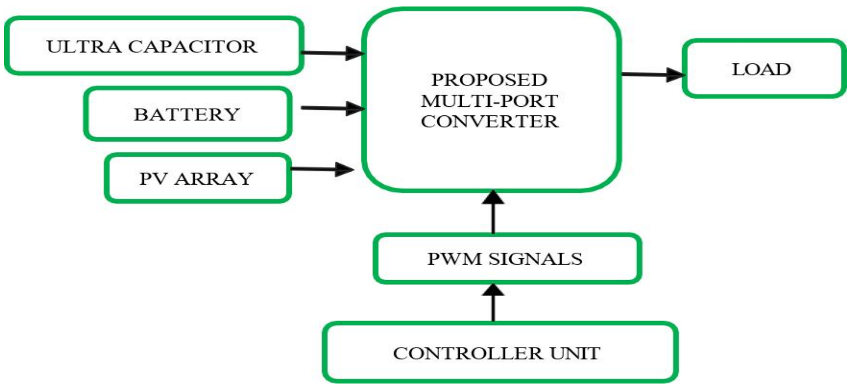


Fig 2. Block diagram

The proposed system uses a bidirectional DC-DC convert to integrate multiple input energy sources. Including an ultra-capacitor, a battery and a photo voltaic (PV) array its supplies well-regulated power to the load such as an electric vehicle (EV) motor or other high-power applications the design ensures that each energy source is utilized based on its own characteristics, which improves overall system performance, energy efficiency, and reliability.

Ultra-Capacitor (UC):

The ultra-capacitor acts as a fast-response energy buffer. It can supply and absorb high peak currents within very short time intervals.

Battery:

The battery is the main long-term energy storage unit, providing continuous and stable power to meet the system's base energy demand. It supplies energy during normal driving conditions and sustained operation

Photovoltaic (PV) Array:

The PV array adds a renewable and sustainable energy source to the system. By capturing solar energy, it can directly support the load demand or recharge ultra capacitor and battery based on their real time conditions.

Multi-Port Bidirectional Converter:

Serving as the main energy management hub, multi-port converter manages the power exchange between the PV array, battery, ultra capacitor and the load. Its single-stage, bidirectional design reduces energy loss while keeping it compact and cost-effective

PWM Control Signals:

Where the power switches in the multi-port converter are driven by the pulse width modulation (PWM) signal from the control uni. By adjusting duty cycle, these signals will control the energy transfer between multiple sources and the load.

Controller Unit:

Thies controller unit continuously tracks important operating parameters which are the input and output voltages, current, state of load and sources demands. Using this data, it adjusts the PWM signals to meet performance goals, including reducing ripple, ensuring voltage stability, and balancing energy use.

Load (EV Motor):

The load, represented by the electric vehicle traction motor, needs smooth, ripple-free, regulated DC power for reliable operation.

3. Results and Discussion

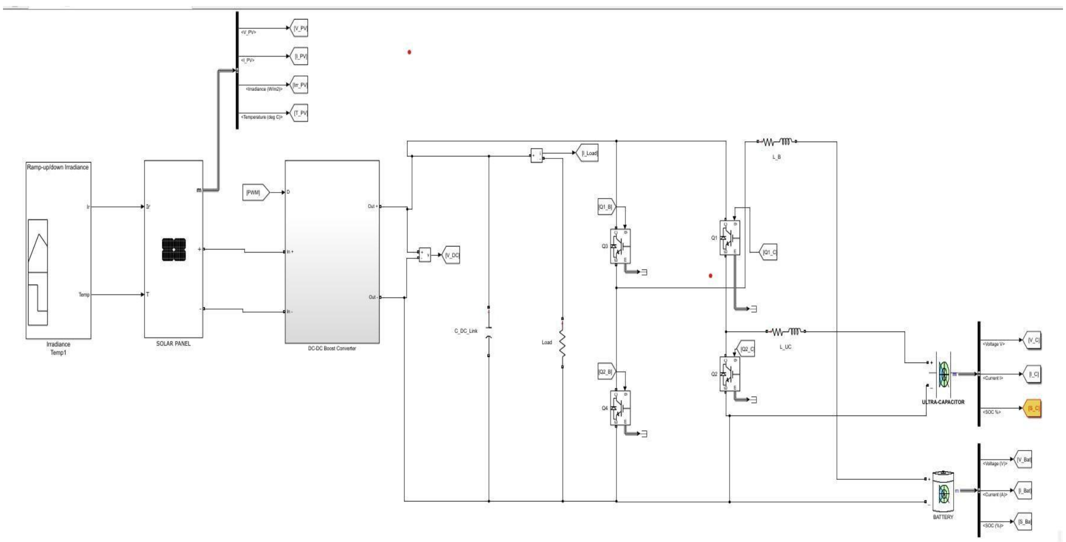


Fig 3. Simulink module

3.1 PV Array Voltage, Current, and Power Waveforms

Hear the voltage (Vpv), current (Ipv) and power (Ppv) waveforms of the PV array module illustrate how a system operates under various sunlight conditions. The photovoltaic array's output, which is dependent on temperature and sunlight levels, is indicated by the voltage. The current, which increases with stronger sunlight, indicates the amount of electricity being generated. Power, which reflects the quantity of energy the system generates, is calculated by multiplying voltage by current. By modifying the duty cycle in accordance with sunlight levels, the controller that employs maximum power point tracking, or MPPT, maximizes the system's ability to extract the more power from PV array.

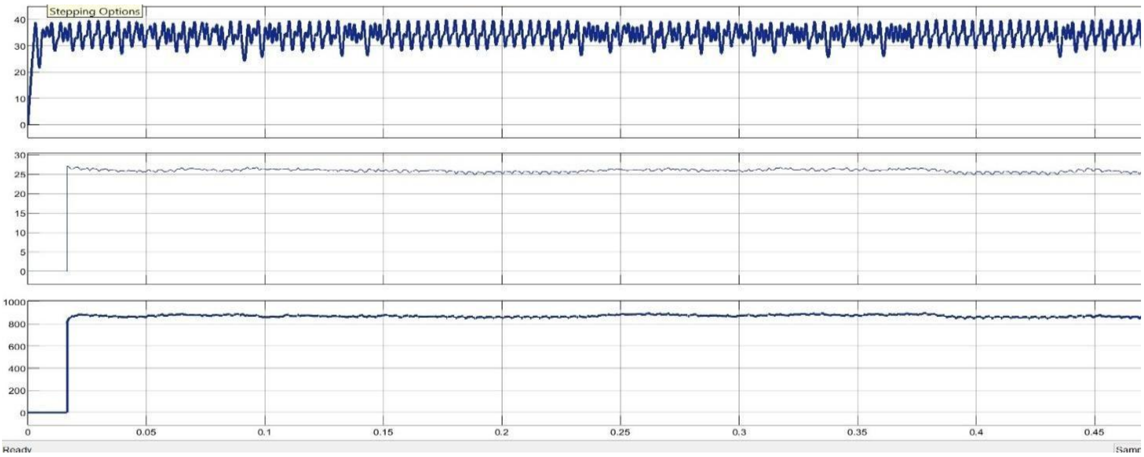


Fig 4. PV Array voltage, current and power waveforms

3.2 Battery Voltage, Current, and State of charge (SOC) Waveforms

The battery's voltage (Vbat), current (Ibat), and state of charge (SOC) waveforms to see how well it functions in the system. Whether the battery is charging or discharging will affect the voltage. Where depending on the requirements of the system, the current indicates whether the battery is receiving a charge or supplying power. SOC shows the battery's current level of fullness. Maintaining SOC helps shield the battery by avoiding deep discharge or overcharging. The battery supplies energy when solar power is low. The battery is charged when there is excess power.

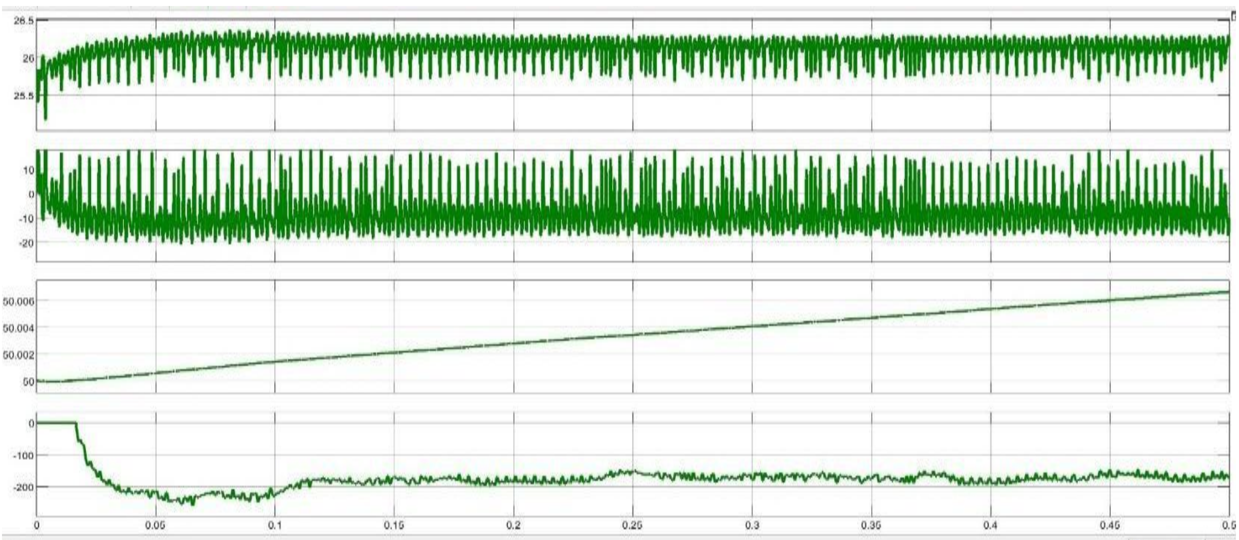


Fig 5. Battery voltage, current and state of charge waveforms

3.3 Ultra-capacitor Voltage and Current Waveforms

Hearing the displayed ultra-capacitor voltage (Vuc) and current (Iuc) waveforms aids in our comprehension of how the device behaves within the system. The voltage indicates the amount of charge it contains. When there are abrupt changes in load, the current indicates how quickly it charges or discharges. Ultra-capacitors help keep a steady power supply during abrupt load fluctuations and efficiently manage short-term power demands.

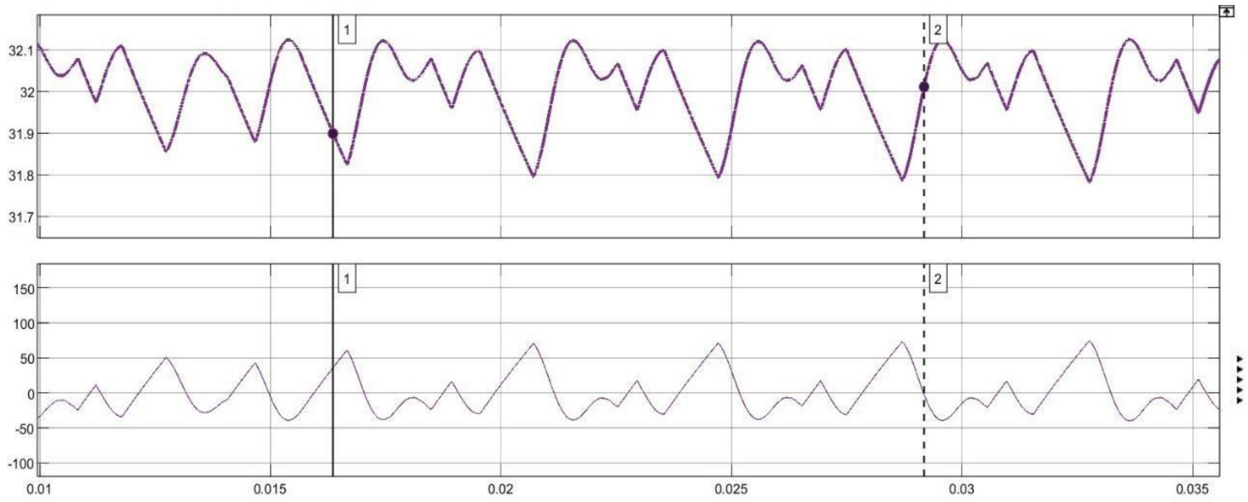


Fig 6. Ultracapacitor voltage and current waveforms

3.4 Load Voltage Waveforms

The output voltage applied to the motor load of an electric vehicle (EV) is known as the load voltage. where even the input sources, such as the battery, photovoltaic array, or ultra-capacitor, fluctuate the load voltage that will be essential for this voltage will stay constant. A stable voltage waveform shows that the power regulation is working correctly, even though slight variations in load demand can cause slight variations in voltage. Problems with energy storage or switching may cause abrupt voltage drops or spikes. PWM (Pulse Width Modulation) switching is used to maintain a constant voltage; this method aids in efficient output regulation

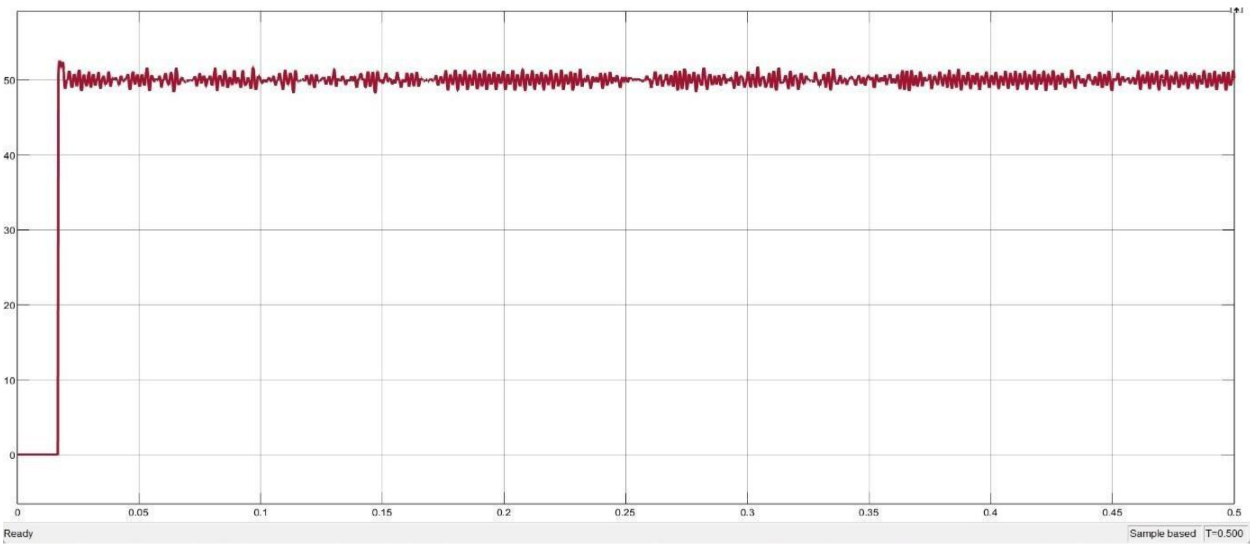


Fig 7. Load voltage waveform

4. Conclusion

Where the proposed multi-port converter is designed to integrate the both battery and ultra capacitor effectively, it well-suited for EV application. By coordinating the energy flow between these two storage devices, the system provides stable, balanced, and reliable power distribution to the traction motor under different operating conditions. When compared to traditional converter designs, the proposed one better reliability, faster response times, and lower power ripple. These factors contribute to smoother vehicle operation and better driving comfort. A major advantage is its ability to lessen battery stress during sudden load changes, by enabling the ultra- capacitor to manage high-power, short-duration demands, the converter lowers the cycling frequency and current stress on the battery. This guarantees the energy storage system's long-term durability and helps prolong the battery's lifespan.

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