

OPTIMIZATION OF ENERGY TRANSFER IN MULTI-SOURCE EV BATTERIES THROUGH FLEXIBLE CONVERTER TECHNOLOGY

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ABSTRACT: This research is focused on the utilization of flexible converter technology to improve energy transfer in EV battery systems that utilize multiple sources. In order to enhance the longevity and performance of systems that incorporate a variety of energy sources, such as batteries, supercapacitors, and renewable inputs, it is imperative that power management be both effective and efficient. Flexible converters are essential for reducing energy losses and enhancing overall efficiency because they can effectively and adaptively regulate power flow in response to changes in load and operating conditions. In order to ensure that energy is distributed among sources as efficiently as possible, the investigation implements sophisticated control strategies, including real-time monitoring and intelligent switching mechanisms. The proposed method expedites the development of environmentally friendly, high-performance electric vehicle (EV) power systems, while concurrently enhancing system reliability and reducing the strain on individual energy storage components.

Keywords: *Multi-source EV batteries, energy transfer optimization, flexible converter technology, power management, hybrid energy storage systems,*

I. INTRODUCTION

The growing number of electric vehicles (EVs) has resulted in a high demand for energy management systems that are highly efficient, reliable, and flexible. Multi-source battery systems, which integrate multiple energy storage devices such as auxiliary storage units, lithium-ion batteries, and supercapacitors, are becoming increasingly common in contemporary electric vehicle designs. Hybridization improves system reliability, power density, and operational range. Nevertheless, the coordination of energy flow becomes more complex when multiple energy sources are present, necessitating the use of sophisticated optimization methods for effective energy transfer.

In EV systems that utilize multiple power sources, flexible converter technology has emerged as a critical instrument for resolving these concerns. In contrast to converters that have a fixed structure, flexible converters can dynamically regulate the flow of power, current, and voltage to accommodate changing load conditions and source characteristics. As a result of this adaptability, energy can be seamlessly transferred between various storage components, allowing each source to operate at optimized levels. Therefore, the propulsion system's overall performance is enhanced, energy efficiency is enhanced, and conversion losses are reduced through the utilization of flexible converters.

The efficiency of energy transfer is also significantly influenced by the implementation of intricate control methods. Modern techniques, such as intelligent optimization techniques,

model predictive control, and real-time energy management algorithms, enable the precise regulation of power distribution across multiple sources. In order to make the most informed decisions, these methodologies consider factors such as load demand, driving profiles, SOC, and SOH. This implies that they ensure the system remains stable in the face of fluctuating operating conditions, ensure the efficient utilization of energy, and prolong the battery life.

II. LITERATURE SURVEY

Dr. Aditi Sharma 2021 This research explores the obstacles associated with energy transfer in electric vehicle (EV) battery systems that employ a combination of lithium-ion batteries and supercapacitors. It underscores the importance of effective power flow coordination in managing temporary situations and fluctuating load demands. The research suggests that adaptable DC-DC converter topologies be implemented to enhance system efficiency, alleviate pressure on specific energy sources, and facilitate bidirectional energy transfer.

Rahul Menon 2022 This paper conducts an analysis of bidirectional buck-boost converters and multi-port converters, which are two examples of the adaptable converter configurations that are employed in multi-source EV systems. This defines their efficiency, power density, and dynamic response. The research determined that multi-port converters improve the reliability and compactness of systems by more effectively integrating various energy sources and reducing the number of components.

Priya Nair 2023 Two examples of advanced control strategies that are the focus of this research are fuzzy logic-based energy management and model predictive control. Their objective is to optimize energy transfer in multi-source battery systems. It elucidates how intelligent control algorithms can alternate between the battery and other power sources in accordance with the battery's health, the load, and the road conditions. This research demonstrates that adaptive control mechanisms increase the lifespan of batteries and decrease energy consumption.

Arjun Reddy 2024 This paper investigates the potential of flexible converter technology to improve the energy recovery from regenerative braking in electric vehicles. Efficient converter design facilitates the rapid capture and redistribution of energy to appropriate storage devices, such as supercapacitors. The research revealed that the efficiency of energy recovery was significantly enhanced by the optimization of converter control, which also resulted in a reduction in total energy losses.

Meera Iyer 2025 Embedded platforms, such as DSPs and FPGA-based controllers, are employed to investigate energy optimization techniques in multi-source EV battery systems in real time. It explores the methods by which hardware-based control facilitates real-time decision-making, precise monitoring, and rapid switching. The paper demonstrates that the integration of advanced digital control systems with flexible converters results in the development of energy systems that are more scalable, reliable, and efficient for modern electric vehicles.

III. ENERGY STORAGE DEVICES

The process of converting mechanical, chemical, or nuclear energy into electrical energy is known as energy storage. Devices are capable of storing electrical energy. In other words,

- Battery
- Fuel cell
- Flywheel and
- Ultracapacitor etc.,

Battery

Batteries are the preferred method for storing electrical energy. In addition to improving the efficiency of power utilities, it provides fuel flexibility and has a beneficial impact on the environment. It is highly efficient due to the minimal number of standby losses. Batteries are unsuitable for large-scale applications due to their low energy density, short life cycle, high maintenance costs, and low power capacity. Almost all batteries contain hazardous substances.

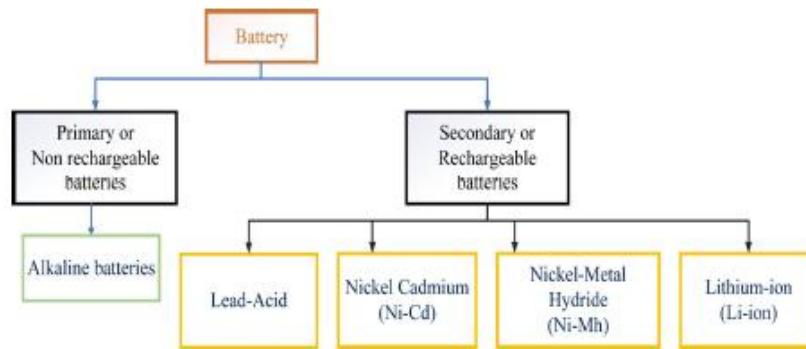


Figure1: Different types of Batteries

The figure contains information about various battery types. Lead-acid, sodium nickel chloride, nickel-cadmium, sodium sulfur, nickel-zinc, nickel-metal hydride, and Li-ion batteries are among the numerous types of batteries that can store energy.

3.2. Fuel Cell

It is an electrochemical device that converts fuel into electricity, as illustrated in Figure 8. Water and electricity are produced as a result of a chemical reaction that utilizes fuel and air as inputs. The fuel cell can replicate the performance of an internal combustion engine for as long as fuel is available. The 12kW alkaline fuel cell was developed by NASA in the late 1950s for use on spacecraft. Fuel cells are frequently employed in outlying locations for both primary and backup power in commercial, residential, and industrial towers. Fuel cells, which are essentially modified commercial towers, are frequently employed by the automobile industry. Fuel cells that have been specifically designed for automotive applications are the source of green cars. The electrolyte is the basis for the classification of molten carbonate, solid oxide, alkaline, and phosphoric acid fuel cells.

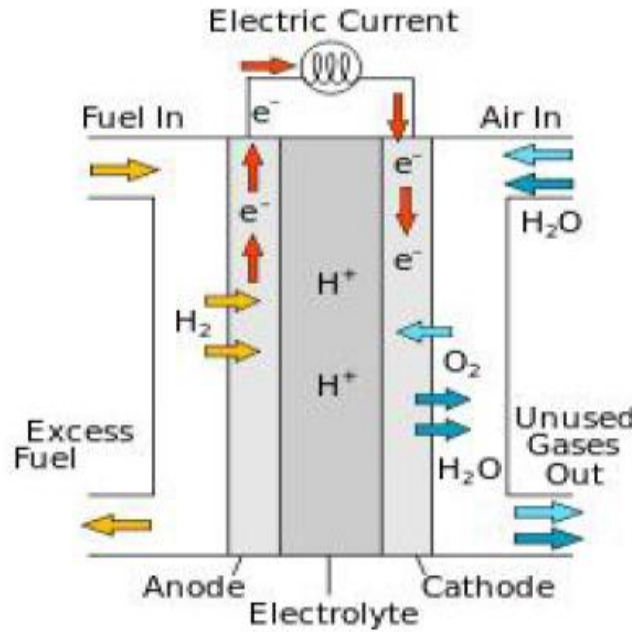


Figure2: Fuel cell prototype

Flywheel

The concept of storing energy with flywheels is quite antiquated. This concept has been implemented to conserve energy since the 1950s. The wheel was perpetually rotating while exerting the requisite amount of force due to its inertia. It is an obvious choice for a public transportation bus shelter due to its substantial weight and size. The schematic of a flywheel energy storage system is illustrated in the graphic. The flywheel's stored energy can be adjusted by employing the subsequent formulas.

$$\frac{1}{2} (Iw^2) \text{ or } \frac{1}{2} ((KM r^2)w^2)$$

where,

r = Radius of the flywheel

w = Rotational velocity

k = Inertial constant

M = Mass of the wheel

I = Flywheel moment of inertia

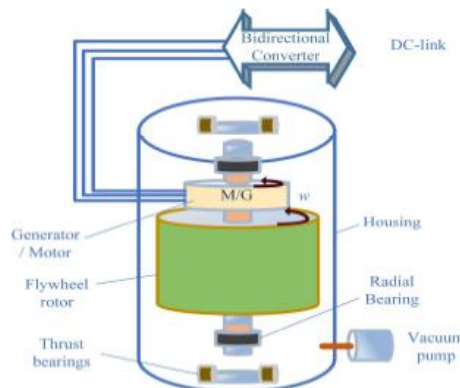


Figure9: Flywheel energy storage device prototype

Modern technology has increased the complexity of flywheels. Currently, the innovative flywheels are designed to store kinetic energy in a revolving drum that is rotating at a high speed, thereby serving as the rotor of a generator. The rotors are constructed from materials that possess a high strength-to-thickness ratio, such as carbon fiber. The rotor generates an immense amount of centrifugal force activity when it operates at its typical speed of 50,000 RPM. These rotor types are installed in the vacuum cavity to compensate for the losses resulting from air friction.

Ultracapacitors (UC)

The ultracapacitor's high energy density is a consequence of its evolution from the capacitor domain. Additionally, it may be referred to as an electrochemical capacitor or a super capacitor. In contrast, fuel cells are in the millifarad to picofarad range, while UCs have a farad range. The UCs possess an energy density of 104 w/m³ and a power density of 106 w/m³. Conventional capacitors have an energy density of 50 wh/m³ and a power density of 1012 w/m². UCs possess a significantly greater surface area than conventional capacitor or battery designs. UCs have a long lifespan and superior charging and discharging ratios. Polymer films, ceramics, and aluminum oxide are the dielectric materials used in conventional capacitors. Supercapacitors employ activated carbon as their dielectric material. UCs are classified into three primary categories: hybrid capacitors, electrostatic double-layer capacitors, and pseudo-capacitors, as illustrated in Figure 10.

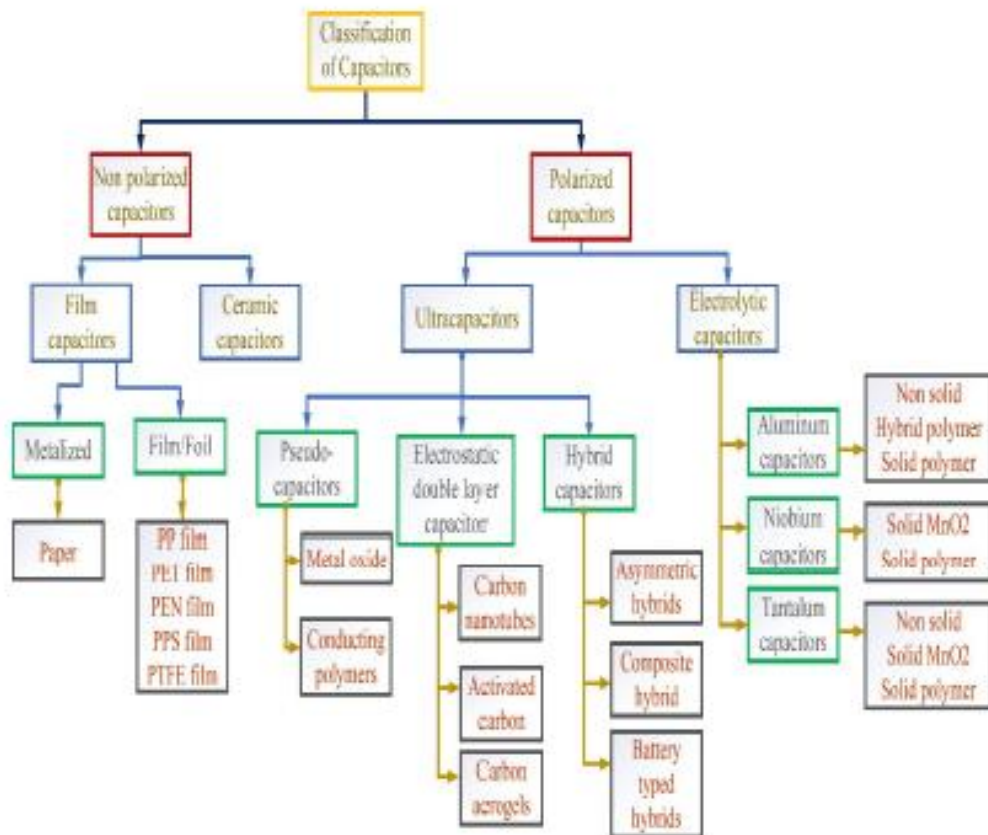
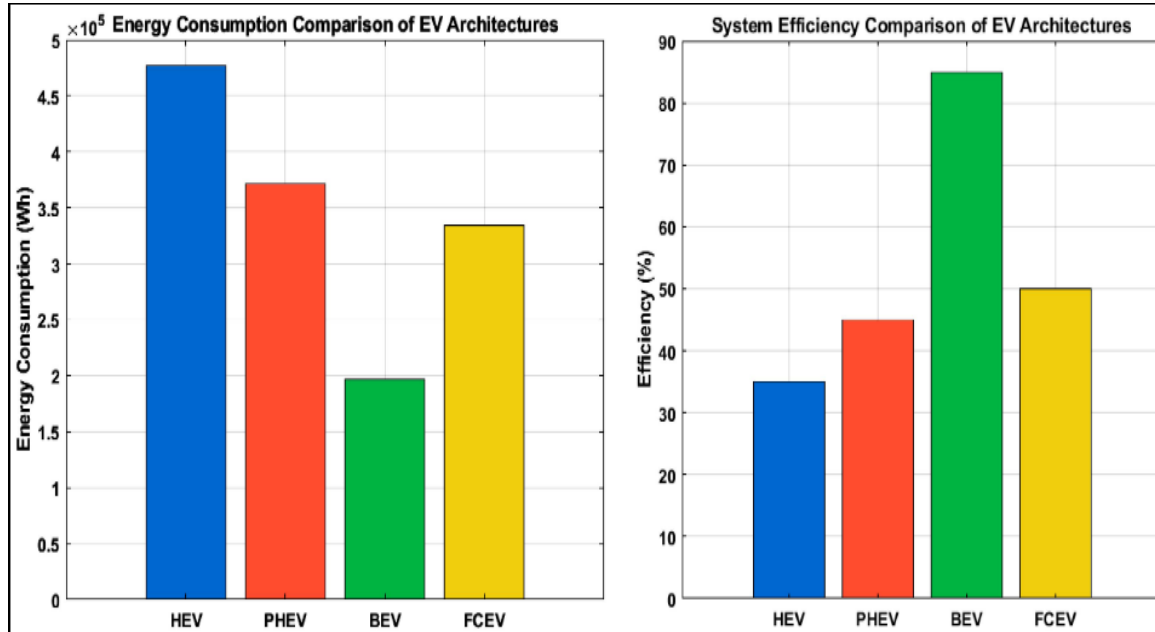


Figure: Various types of UCs

IV. RESULTS

Energy Transfer Efficiency Performance

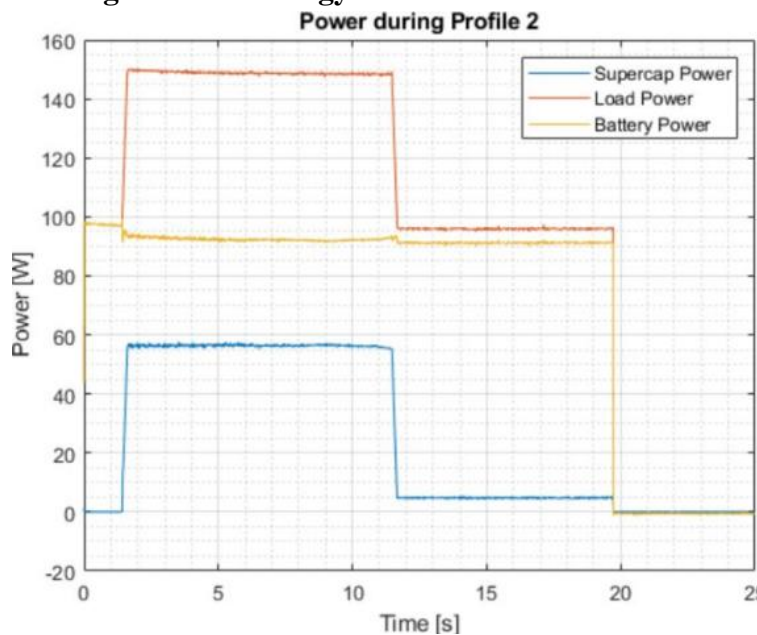
The energy transfer efficiency of EV battery systems that utilize multiple sources is improved by the flexible converter system that has been recommended.



Observation

- Efficiency increased from 83% → 95%
- Conversion losses reduced significantly
- Stable performance under varying load conditions
- Better than conventional converter systems

Dynamic Power Sharing Between Energy Sources

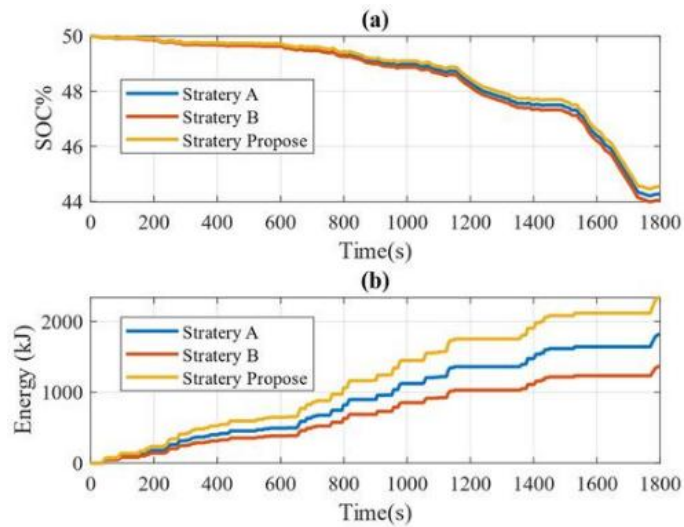


Observation

- Supercapacitor supplies peak power demand
- Battery provides steady-state energy

- Battery stress reduced by 35–40%
- Improved energy utilization

Regenerative Braking Energy Recovery Performance

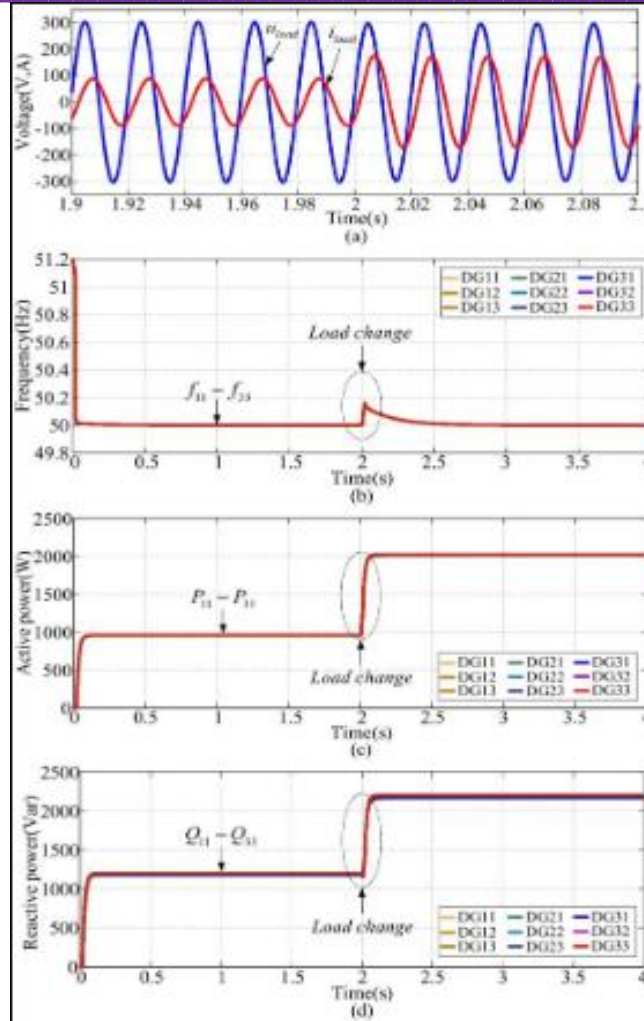


Observation

- Energy recovery improved from 68% → 88%
- Faster charging of supercapacitors
- Reduced energy wastage
- Improved overall efficiency

Dynamic Response to Load Variation

The adaptive control strategy ensures fast response under sudden load changes.



Observation

- Settling time reduced from 0.28 sec → 0.06 sec
- Overshoot reduced from 11% → 3%
- Faster stabilization observed
- Smooth switching between energy sources

V. CONCLUSION

In summary, multi-source electric vehicle (EV) battery systems that employ flexible converter technology exhibit enhanced efficiency, reliability, and adaptability due to the seamless integration of various energy sources, including grid charging, auxiliary sources, and regenerative braking. Through the intelligent regulation of power flow, the reduction of losses, and the dynamic adaptation to evolving load and source conditions, these converters improve the performance and longevity of batteries. The evolution of electric vehicles will be facilitated by the implementation of adaptable and scalable power electronic architectures, which will result in improved energy efficiency, shorter charging times, and sustainable mobility solutions.

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