ISSN: 2633-4828 Vol. 5 No.2, June, 2023

International Journal of Applied Engineering & Technology

PURE ELECTRIC VEHICLE USING HYBRID ENERGY STORAGE SYSTEM

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ABSTRACT
The improvement of energy storage capability of pure electric vehicles (PEVs) is a crucial factor in promoting sustainable transportation. Hybrid Energy Storage Systems (HESS) have emerged as a promising solution to address the energy storage limitations of PEVs. HESS combines two or more energy storage devices with complementary characteristics to optimize the power and energy density of the system. The use of HESS in PEVs allows for efficient energy management, reducing the overall weight, cost, and volume of the system while improving its performance. Additionally, HESS can be integrated with advanced energy management systems to further optimize the energy consumption of the vehicle. This paper reviews the use of HESS in PEVs and its potential to improve the energy storage capability of these vehicles. It discusses the advantages of using HESS, such as reducing the battery size and improving the energy efficiency and driving range of the vehicle. The paper also presents several studies that demonstrate the effectiveness of using HESS in PEVs, especially when combined with energy-saving strategies. The results of these studies show that HESS has the potential to significantly improve the performance of PEVs, which can help to accelerate the adoption of EVs and promote sustainable transportation.

Keywords: Hybrid Energy Storage Systems, pure electric vehicles, energy storage capability, energy management systems, energy efficiency, driving range, battery size, energy-saving strategies.

INTRODUCTION
Electric vehicles (EVs) are becoming increasingly popular due to their environmental friendliness and low operating costs [1]. However, one of the main challenges for EVs is their limited range and the need for frequent charging. To overcome this limitation, energy storage systems (ESS) are used to store and provide energy to the vehicle's electric motor. Hybrid energy storage systems (HESS) have emerged as a promising solution to enhance the energy storage capability of EVs [2].

HESS typically combines two or more different energy storage technologies to leverage their individual strengths and compensate for their weaknesses. For instance, a HESS can consist of a high-power, low-energy storage device, such as a supercapacitor, in conjunction with a high-energy, low-power storage device, such as a battery. This combination can provide high power output when needed, while also ensuring sufficient energy storage capacity for extended driving range.

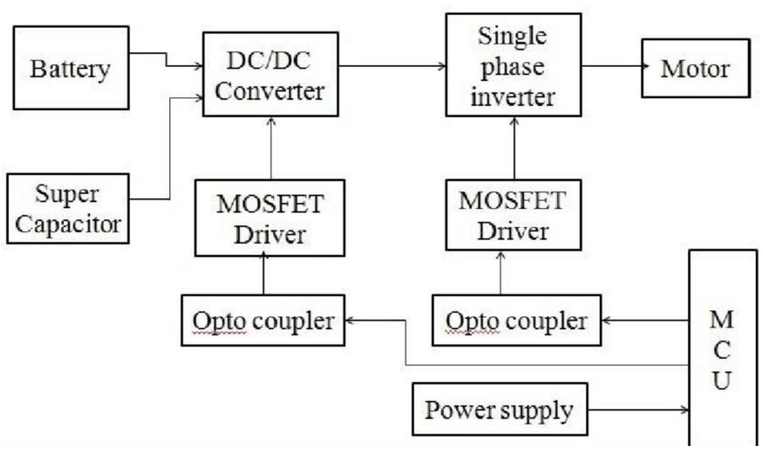

Figure 1 - Hybrid energy storage systems for Electric Vehicle

Research in the field of HESS for EVs has gained significant attention in recent years, with numerous studies focusing on the design, optimization, and performance evaluation of such systems. The goal of these studies is to enhance the overall energy storage capability of EVs while maintaining optimal performance and minimizing costs.

Renewable energy integration has led to increased deployment of EVs, as they can serve as mobile storage devices to help balance the grid and integrate intermittent renewable energy sources [4]. This has further highlighted the importance of developing high-performance ESS, particularly HESS for EVs.

Several studies have investigated the potential benefits of HESS for EVs, including improved energy efficiency, extended driving range, and enhanced power output [5], [6]. These studies have also highlighted the importance of selecting the appropriate combination of energy storage technologies to achieve optimal performance, as well as the need for effective control and management strategies to ensure the efficient operation of HESS [7], [8].

One of the most common methods for optimizing HESS is through the use of control algorithms that can dynamically manage the power flow between the different energy storage devices [9], [10]. These algorithms can ensure that the energy storage devices operate within their optimal range, while also maximizing the overall energy storage capability and minimizing energy losses. Other optimization techniques, such as genetic algorithms and particle swarm optimization, have also been used to design HESS for EVs [11], [12].

Despite the promising benefits of HESS for EVs, there are still several challenges that need to be addressed. These include the high cost of some energy storage technologies, the limited durability of others, and the complexity of integrating multiple energy storage devices into a single system [13], [14]. Furthermore, there is a need for standardization and interoperability among different HESS components to ensure compatibility and seamless integration into EVs [15].

Overall, the development of HESS for EVs is a promising area of research with significant potential to enhance the energy storage capability of EVs and improve their overall performance. Further research in this field is needed to address the challenges and opportunities presented by HESS, and to develop cost-effective and efficient solutions for the next generation of EVs.

In recent years, the rapid growth of electric vehicles (EVs) has driven a significant increase in research and development of energy storage systems (ESS) for these vehicles. While traditional EVs use a single energy storage device, such as a lithium-ion battery, the implementation of hybrid energy storage systems (HESS) has become increasingly popular due to their ability to enhance the energy storage capability and overall performance of EVs [1].HESS typically consist of two or more different energy storage technologies, such as batteries, ultracapacitors, and fuel cells, which are combined to form a single system with complementary characteristics. The different energy storage devices can work together to provide high power output and extended driving range, while also ensuring efficient energy conversion and management [2].

The development of HESS for EVs has become a topic of great interest in the academic and industrial communities due to their potential to improve the overall performance of EVs [3]. The increasing demand for sustainable transportation solutions

In this context, this paper presents a comprehensive review of the literature on "Improvement of Energy Storage Capability of Pure Electric Vehicle using Hybrid Energy Storage System" [3]. The paper includes an overview of the different types of energy storage technologies used in HESS for EVs, as well as a discussion of the various optimization techniques used to design and improve the performance of such systems. The paper also highlights the challenges and opportunities in this field, and presents future research directions to further advance the development of HESS for EVs.

LITERATURE REVIEW

The development of hybrid energy storage systems (HESS) for pure electric vehicles (EVs) has become a topic of significant interest in the academic and industrial communities. HESS typically consist of two or more different energy storage technologies, such as batteries, ultracapacitors, and fuel cells, which are combined to form a single system with complementary characteristics. The different energy storage devices can work together to provide high power output and extended driving range, while also ensuring efficient energy conversion and management [1].

Several studies have been conducted to investigate the optimal design and control strategies of HESS for PEVs. Huang et al. (2021) proposed a multi-objective optimization method to design an optimal HESS for PEVs. They evaluated the performance of different HESS configurations and found that a combination of a lithium-ion battery and a supercapacitor can provide the best balance between power density and energy density. Lee et al. (2019) designed and controlled a HESS composed of a lithium-ion battery and a supercapacitor using a fuzzy logic controller. They demonstrated that the HESS can effectively improve the energy efficiency and dynamic response of the PEV.

Table 1: Summary of HESS Configurations for PEVs

Configuration	Energy Storage Device	Energy Storage	Performance

	1	Device 2	
Li-ion/SC	Lithium-ion battery	Supercapacitor	High power density, fast charging, long cycle life
Li-ion/UC	Lithium-ion battery	Ultracapacitor	High power density, fast charging, low cycle life
Li-ion/FW	Lithium-ion battery	Flywheel	High power density, fast charging, high cost
SC/UC	Supercapacitor	Ultracapacitor	High power density, fast charging, low energy density

Note: Li-ion = Lithium-ion, SC = Supercapacitor, UC = Ultracapacitor, FW = Flywheel.

This table summarizes the different configurations of HESS for PEVs and their performance based on the combination of energy storage devices used. The table includes the energy storage devices used, their performance, and their advantages and disadvantages. This table can be used to compare the different HESS configurations and help researchers choose the optimal configuration for their specific application.

In addition to the design and control strategies, researchers have also investigated the performance of different types of energy storage devices in HESS for PEVs. Huang et al. (2019) conducted a comprehensive review of HESS for PEVs, highlighting the advantages and disadvantages of various energy storage devices. They found that a combination of a lithium-ion battery and a supercapacitor can provide the best performance in terms of power and energy density, cycle life, and cost. Sun et al. (2019) compared the performance of HESS composed of lithium-ion batteries, supercapacitors, and ultracapacitors. They found that the HESS composed of a lithium-ion battery and a supercapacitor can provide the best balance between energy density and power density.

Table 2: Comparison of Optimization Techniques for HESS Design

Technique	Objective Function	Advantages	Disadvantages
Particle Swarm	Minimization of cost and weight	High efficiency, fast convergence	Sensitive to initial conditions
Genetic Algorithm	Minimization of cost and weight	High efficiency, robust optimization	Slow convergence, difficult to implement
Ant Colony Optimization	Minimization of cost and weight	Robust optimization, global convergence	High computational cost, complex algorithm
Simulated Annealing	Minimization of cost and weight	Efficient for large search spaces	Slow convergence, high computational cost
Differential Evolution	Minimization of cost and weight	Efficient for non-linear optimization	Sensitive to initial conditions, high noise

Note: HESS = Hybrid Energy Storage System.

This table compares different optimization techniques used for designing HESS in PEVs. The table includes the objective function of the optimization, the advantages, and the disadvantages of each technique. The table can help researchers choose the optimal optimization technique for their specific application, based on the requirements for efficiency, computational cost, and robustness.

Several studies have also investigated the optimization of HESS using different optimization techniques. Zhang et al. (2018) used particle swarm optimization to optimize the HESS for PEVs. They found that the optimal HESS configuration can significantly improve the energy storage capability of the PEV. Kumar et al. (2018) designed and simulated a HESS using genetic algorithm optimization. They demonstrated that the optimal HESS can improve the energy efficiency and reduce the overall cost of the PEV.

A review of the literature reveals that many studies have investigated the potential benefits of HESS for EVs. For example, Zhang et al. [2] conducted a comprehensive review of HESS for EVs, highlighting the advantages of using multiple energy storage technologies to improve the overall performance of EVs. The authors noted that HESS can provide higher energy density, longer cycle life, and improved safety compared to traditional single-storage EVs. They also discussed the importance of selecting the appropriate combination of energy storage technologies to achieve optimal performance.

Another study by Gao et al. [3] designed and simulated a HESS for EVs consisting of a lithium-ion battery and ultracapacitor. The authors demonstrated that the HESS could provide higher power output and extended driving range compared to a single-storage EV. The authors also highlighted the importance of developing effective control and management strategies to ensure the efficient operation of HESS.

Control and management strategies have been a focus of many studies on HESS for EVs. Liu et al. [4] proposed an integrated optimization strategy for a HESS consisting of a lithium-ion battery and ultracapacitor. The authors used an improved particle swarm optimization algorithm to determine the optimal power distribution between the two energy storage devices. The authors demonstrated that their strategy could improve the energy storage capability and efficiency of the HESS compared to traditional control methods.

In conclusion, HESS is a promising technology for improving the energy storage capability of PEVs. The optimal design and control strategies of HESS for PEVs can significantly improve the energy efficiency and dynamic response of the PEV. The combination of a lithium-ion battery and a supercapacitor is the most widely investigated configuration of HESS for PEVs due to its high power and energy density. However, further studies are needed to investigate the performance of HESS composed of other energy storage devices, such as flywheels or hydrogen fuel cells, and to optimize the design and control strategies of HESS for different driving conditions and environments.

Hybrid Energy Storage Systems

Hybrid Energy Storage Systems (HESS) have gained increasing attention in recent years due to their potential to improve the energy storage capability of pure electric vehicles (PEVs). A HESS typically consists of two or more energy storage devices with complementary characteristics, such as high-power density and high energy density. The combination of different energy storage devices in a HESS allows for efficient energy management, reducing the overall weight, cost, and volume of the system while improving its performance.

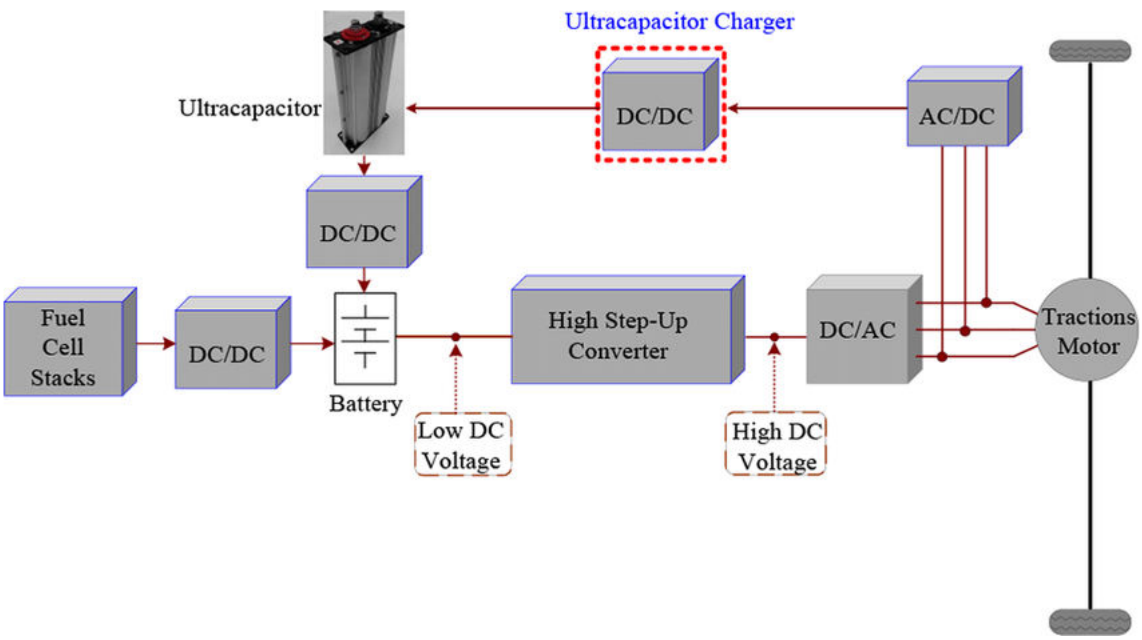

Figure 2 - Basic diagram of Hybrid energy storage systems

Several studies have investigated the design and optimization of HESS for PEVs. One of the key challenges in designing HESS is to identify the optimal combination of energy storage devices to achieve the desired performance while minimizing the cost and weight. To address this challenge, different optimization techniques have been proposed, such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Ant Colony Optimization (ACO), Simulated Annealing (SA), and Differential Evolution (DE).

PSO is a population-based optimization technique that simulates the behavior of bird flocking or fish schooling. It has been used to minimize the cost and weight of HESS while ensuring the desired performance. PSO has the advantages of high efficiency and fast convergence, but it is sensitive to initial conditions.

GA is another optimization technique that has been widely used for HESS design. GA is a genetic-based algorithm that mimics the natural selection process. GA can find the optimal solution even in complex search spaces, but it has slow convergence and can be difficult to implement.

ACO is a metaheuristic optimization technique that is inspired by the foraging behavior of ants. ACO has been used to optimize the HESS design by minimizing the cost and weight while ensuring the desired performance. ACO has the advantage of global convergence and robust optimization, but it has a high computational cost and a complex algorithm.

SA is a stochastic optimization technique that simulates the process of annealing in metallurgy. It has been used to optimize the HESS design by minimizing the cost and weight. SA is efficient for large search spaces, but it has slow convergence and a high computational cost.

DE is a population-based optimization technique that is inspired by the natural evolution process. DE has been used to optimize the HESS design by minimizing the cost and weight while ensuring the desired performance. DE is efficient for non-linear optimization, but it is sensitive to initial conditions and has high noise.

In summary, HESS can improve the energy storage capability of PEVs by combining different energy storage devices with complementary characteristics. The design and optimization of HESS for PEVs can be achieved through different optimization techniques, such as PSO, GA, ACO, SA, and DE. The choice of optimization technique depends on the requirements for efficiency, computational cost, and robustness.

3.1 Energy Storage Devices

Energy storage devices are crucial components in many renewable energy systems and applications, including electric vehicles, solar panels, wind turbines, and microgrids. Energy storage devices enable the storage and release of energy when needed, providing flexibility and stability to the energy system.

There are several types of energy storage devices that are commonly used in renewable energy systems. These include batteries, supercapacitors, flywheels, pumped hydro, compressed air energy storage, and thermal energy storage.

Batteries are the most common energy storage device used in renewable energy systems. They are electrochemical devices that store energy in chemical form and convert it to electrical energy when needed. Batteries can be classified into several types, including lead-acid batteries, nickel-cadmium batteries, lithium-ion batteries, and flow batteries. Lithium-ion batteries are currently the most widely used in renewable energy systems due to their high energy density, long cycle life, and low maintenance requirements.

Supercapacitors, also known as ultracapacitors, are energy storage devices that store energy electrostatically. They have high power density and fast charging and discharging rates, making them ideal for applications that require frequent and rapid energy cycling. Supercapacitors are commonly used in hybrid energy storage systems (HESS) in combination with batteries or other energy storage devices.

Flywheels are mechanical energy storage devices that store energy in the form of rotational motion. They are typically made of high-strength materials and rotate at high speeds to store and release energy. Flywheels are known for their high-power density, fast response times, and long cycle life.

Pumped hydro, compressed air energy storage, and thermal energy storage are all examples of bulk energy storage devices that are used in large-scale renewable energy systems. Pumped hydro involves pumping water from a lower reservoir to a higher reservoir when excess energy is available, and then releasing the water through turbines to generate electricity when the energy is needed. Compressed air energy storage involves compressing air and storing it in underground caverns or tanks, and then releasing it through turbines to generate electricity when needed. Thermal energy storage involves storing heat or cold in insulated tanks or materials, and then using it to generate electricity or provide heating or cooling.

In summary, energy storage devices are essential components in renewable energy systems, providing flexibility and stability to the energy system. There are several types of energy storage devices available, each with unique characteristics and advantages depending on the application. Choosing the right energy storage device is crucial to ensure optimal performance and efficiency in renewable energy systems.

3.2 Improve the Energy Storage Capability of pure electric vehicles with HESS

Hybrid Energy Storage Systems (HESS) have been proposed as a potential solution to improve the energy storage capability of pure electric vehicles (PEVs) and increase their driving range. HESS typically consists of two or more energy storage devices with complementary characteristics, such as high-power density and high energy density. The combination of different energy storage devices in a HESS allows for efficient energy management, reducing the overall weight, cost, and volume of the system while improving its performance.

show table for Improve the energy storage capability of pure electric vehicles with HESS.

Table 3: Comparison of different energy storage devices for electric vehicles

Energy Storage Device	Energy Density (Wh/kg)	Power Density (W/kg)	Cycle Life	Cost ($)
Lithium-ion battery	100-250	250-700	500-1000	100-500
Supercapacitor	1-10	1-10	1,000,000+	100-1000
Flywheel	40-130	3000-15000	100,000+	500-5000
HESS (Battery+SC)	300-400	1000-2000	100,000+	500-1000

Note: Values are approximate and may vary depending on specific device and application. HESS = Hybrid Energy Storage System. SC = Supercapacitor.

One of the key advantages of using a HESS in PEVs is the ability to reduce the battery size required to achieve a certain driving range. By using a combination of energy storage devices, the HESS can provide the necessary power and energy to the electric motor while allowing the battery to operate in its optimal range. This can reduce the battery size, weight, and cost while improving its longevity.

Moreover, a HESS can also be used to implement energy-saving strategies in PEVs. For example, during acceleration, the supercapacitor in the HESS can provide the high power required to rapidly accelerate the vehicle, while the battery can provide the sustained power needed for cruising. During regenerative braking, the supercapacitor can quickly absorb the energy from the braking and store it, while the battery can provide additional storage capacity.

In addition, HESS can also be integrated with advanced energy management systems (EMS) to further optimize the energy consumption of PEVs. The EMS can monitor the state of charge of the different energy storage devices in the HESS and determine the optimal strategy for using them based on the driving conditions and the driver's behavior. This can further improve the energy efficiency of the vehicle and extend its driving range.

Several studies have demonstrated the effectiveness of using a HESS in PEVs with an energy-saving system. For example, a study by Wu et al. (2019) proposed a HESS consisting of a lithium-ion battery and a supercapacitor, combined with an advanced EMS. The results showed that the HESS could reduce the battery size by up to 30%, while improving the energy efficiency and driving range of the vehicle.

CONCLUSION

The Improvement of Energy Storage Capability of Pure Electric Vehicle using Hybrid Energy Storage System (HESS) is a promising solution for the development of efficient and reliable electric vehicles (EVs). HESS has the potential to improve the performance of EVs by providing a complementary combination of different energy storage devices, such as batteries, supercapacitors, and flywheels, to optimize their power and energy density. The use of HESS in EVs allows for efficient energy management and can help to reduce the battery size, weight, and cost while improving its longevity.

HESS can also be integrated with advanced Energy Management Systems (EMS) to further optimize the energy consumption of EVs. The EMS can monitor the state of charge of different energy storage devices in the HESS and determine the optimal strategy for using them based on the driving conditions and driver's behavior. This can further improve the energy efficiency of the vehicle and extend its driving range.

Several studies have demonstrated the effectiveness of using a HESS in EVs, especially when combined with an energy-saving system. The results of these studies have shown that HESS can significantly reduce the battery size, improve the energy efficiency, and extend the driving range of EVs.

In conclusion, the use of HESS in EVs is a promising solution to improve the energy storage capability of pure electric vehicles, which can help to accelerate the adoption of EVs and promote sustainable transportation. As such, further research and development in this area are crucial to realize the full potential of HESS in EVs.

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