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ADVANCEMENTS IN ENERGY STORAGE SYSTEMS FOR ELECTRIC VEHICLES

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ABSTRACT

Electric vehicles (EVs) rely entirely on energy storage systems (ESS), making them the most critical components for storing and delivering electrical energy. ESS not only determines the driving range of EVs but also supports operations by providing the necessary peak power and energy capacity. Herein, this mini review discusses the technical principles, current developments and future prospects of each ESS including batteries, supercapacitors and fuel cells. Batteries, particularly lithium-ion dominate the market due to their high energy density and efficiency, although challenges remain such as safety and material availability. Hybridization of ESS provides a strategic advantage by combining the unique strengths of different storage technologies. By summarizing the interplay, this short review aims to quickly establish the strengths and limitations of each ESS, providing insights into their roles in optimizing EV performance.

KEYWORD

Electric vehicles, metal-air batteries, supercapacitors, fuel cells, hybridization

INTRODUCTION

The electric vehicles (EVs) market continues to experience significant growth. Despite that, there are several challenges that need to be addressed before EVs can completely replace ICE vehicles. The primary challenge lies in the energy storage systems (ESS). This presents several issues including limited range, long charging times and high costs. Currently, lithium-ion batteries (LIBs) stand out as the preferred commercial technology. However, the current state of LIBs has almost reached the limits which raises the question of further advancement (Kulova et al., 2020). Indeed, LIBs remain costly and the potential future shortage of lithium used in the production emphasize the necessity for developing batteries with improved cost-effectiveness and material availability (Diouf & Pode, 2015).

Addressing these significant challenges is important for the continued development of EVs. For this reason, this mini review discusses the potential of alternative ESS technologies and their hybridization to overcome the current barriers. By providing the technical principles, current developments and future prospects including batteries, supercapacitors and fuel cells, this short review aims to highlight pathways for optimizing EV performance. The insights can guide researchers in advancing the technology to meet future demands.

RECENT PROGRESS OF BATTERY ELECTRIC VEHICLE

Lead-acid battery appeared as the first rechargeable batteries with specific energy up to 40Wh/kg at the cell level (Liu et al., 2022). The initial development of lead-acid batteries marked a critical turning point in the integration of batteries into EV systems. Subsequently, researchers have worked on creating alternative batteries including nickel-metal hydride, lithium-ion, nickel-zinc and nickel-cadmium. The goal of continuous research is to improve the sustainability of batteries to meet the expectations of the rapidly growing EV market. Table 1 shows the key characteristics of a few well-known batteries and it appears that the majority of lithium-type batteries are expensive. There is a need for better batteries alternative that are safer, cheaper and higher capacity (Gao et al., 2022).

Table 1: Advantages and disadvantages of different battery types

Type	Advantage	Disadvantage
Pb–acid	Cost-effective, safe, recyclable, reliable	Limited cycle life, low energy density, toxic
Ni–Cd	Rapid charging, high discharge rate, good thermal stability	Toxic, prone to memory effect
Ni–MH	High energy density	Toxic, minor memory effect
Li–NMC	Customizable based on power requirements, high energy density	High cost, poor safety, degrade at high temperature
Li–LFP	High electrochemical performance, high safety profile, good thermal stability	Low cell voltage, poor conductivity, short lifespan
Li–LTO	Rapid charging, high discharge rate, good thermal stability	Low capacity, high cost, low cell voltage
Li–LMO	Low internal resistance, high power delivery, high energy density,	High cost, short lifespan
Li–NCA	High energy density, long cycle life	Poor safety, low voltage power

POTENTIAL OF METAL-AIR BATTERIES

In the ongoing research, MABs have gained more attention due to higher theoretical energy density. MABs integrate features from both traditional and fuel cell batteries, offering high energy efficiency surpassing that of LIBs by 5 to 30 times (Ahuja et al., 2021). Admittedly, rechargeable MABs are recognized as a promising solution for energy storage due to their affordability, high specific energy and power density as shown in Table 2 (Yaqoob et al., 2022).

Table 2: Comparison of different types of metal air batteries (Li & Dai, 2014; Zhang et al., 2016)

MABs	Cost per kg	Open circuit voltage (V)	Energy density (Wh/kg)	Type of cell
Fe–air	0.4	1.28	977	Secondary
Zn–air	1.85	1.65	1085	Secondary
Al–air	1.75	2.71	2791	Primary
Mg-air	2.75	3.09	2843	Primary
Na–air	1.7	2.27	1105	Secondary
K–air	20	2.48	935	Secondary
Li–air	68	2.96	3463	Secondary

SUPERCAPACITOR

Supercapacitor also known as ultracapacitor. It has similar structure to the electrochemical batteries, consist of two electrodes, electrolyte and separator. Both electrodes are immersed in the electrolyte and separated by a separator layer. The separator act as a membrane to ensure ion transfer and prevent direct connection between electrodes. There are several types of supercapacitors which are electric-double layer capacitors (EDLCs) and pseudocapacitors. Hybrid capacitor combines features from both EDLCs and pseudocapacitors.

FUEL CELLS

Fuel cells generate electricity using hydrogen as the primary fuel. It consists of anode, cathode and electrolyte. Hydrogen is considered as a clean and renewable energy supply compared to fossil fuel (Pramuanjaroenkij & Kakaç, 2023). Therefore, fuel cell electric vehicles (FCEVs) are considered as non-polluting transportation because it only produces pure water and heat as the byproducts (Selmi et al., 2022). The operations produce zero global warming gas emission. FCEVs have good characteristic including zero tailpipe emissions, high energy conversion efficiency and excellent dynamic feature (Wang et al., 2022). Toyota initiated the development of fuel cell system in 1992 and introduced the first generation Toyota Mirai in 2014 (Nonobe, 2016). It was the first

FCEV to be mass produced in Japan. Similarly, South Korea also has introduced the first hydrogen-powered vehicles, Hyundai Tucson in 2013 (Zhang et al., 2023). These initiatives align with global efforts to expand transportation options and reduce reliance on fossil fuels. Therefore, it can contribute to a more sustainable and environmentally friendly automotive industry.

HYBRIDIZATION

The combination between battery, supercapacitor and fuel cell is referred to the hybridization of ESS. The integration aims to take the advantages of each technology. As shown in Figure 1, fuel cell with battery is the most prominent hybridization that benefits from lower manufacturing costs and well-established industrial chain. This configuration improves overall efficiency by reducing high current impact during load transients and continuous high-load conditions (Gao et al., 2008). Notable EV models utilizing this hybridization include the Hyundai Nexo, Toyota Mirai and Honda Clarity (Zhao et al., 2022).

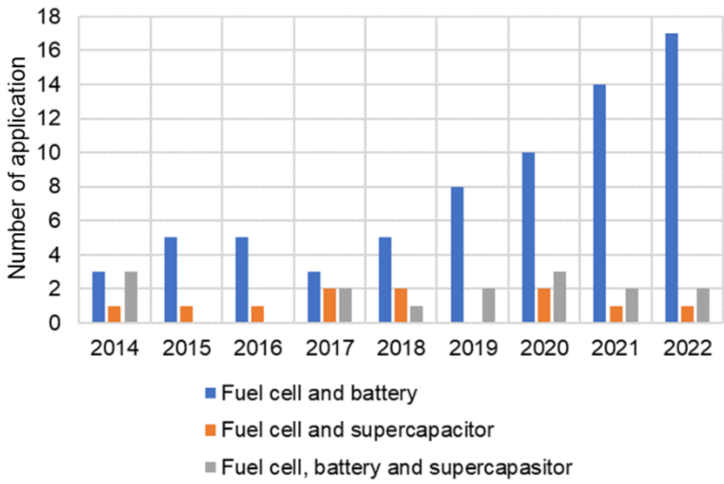

Figure 1: Distribution of hybridization (Zhao et al., 2022)

Additionally, the more complex hybridization involves integrating fuel cells with both batteries and supercapacitors. This configuration offers continuous energy supply and enhances dynamic response during transient working conditions. However, it comes with significant disadvantages which are complicated energy management strategies, high manufacturing costs and complex structural requirements. Currently, there are no specific EV models available that employ this type of hybridization.

CONCLUSION

The advancement of ESS is important to the transition to EVs. Currently, LIBs are the most popular technology that offer excellent energy density and efficiency, making them suitable for a variety of EV applications. However, their shortcomings in terms of cost, material availability and safety highlight the need for continuous improvements. This review underscores the significance of ESS in the development of EVs and emphasizes the necessity for ongoing innovation and hybridization. By advancing ESS technologies, we can enhance driving experience, maximize EV performance and significantly contribute to the shift towards more environmentally friendly transportation solutions.

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