Based on the form of new energy, the development prospect of supercapacitors in electric vehicles is discussed

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Abstract. With the increasing global emphasis on environmental protection and sustainable development, new forms of energy have gradually become a key development direction in the energy sector. Electric vehicles, as an important application area of new energy technology, have their performance improvement and technological innovation as the focal points of industry attention. Supercapacitors, as an emerging energy storage device, have shown great potential in the field of electric vehicles due to their fast charging and discharging, high power density, and long cycle life. This article analyzes the development trend of electric vehicle technology under new energy forms and deeply explores the basic principles of supercapacitors and their specific applications in electric vehicles. Furthermore, this article looks forward to the development prospects of supercapacitors in electric vehicles, pointing out their enormous potential in improving electric vehicle performance and promoting efficient energy utilization. However, the development of supercapacitors also faces challenges such as high costs, limited energy density, and insufficient technological maturity. Addressing these issues, this paper puts forward suggestions such as strengthening technological research and development and optimizing joint usage strategies. The aim is to achieve positive interaction and collaborative development between supercapacitors and electric vehicles.

1 Introduction

With the heightened global awareness of environmental protection and the prevalence of sustainable development, new energy has emerged as a significant development direction in the global energy sector. In this context, electric vehicles (EVs), as the core carriers of new energy applications, exhibit increasingly obvious and irreversible development trends. The promotion of EVs not only helps significantly reduce tailpipe emissions from traditional fuel vehicles, thereby improving air quality and alleviating environmental pressure, but also significantly enhances energy utilization efficiency, driving the optimization and upgrading of the energy structure toward a cleaner and more efficient direction[1]. In the development

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of electric vehicles (EVs), the application of supercapacitor technology has garnered widespread attention. Currently, lead-acid batteries are widely used in multiple industries due to their low cost. However, their inherent drawbacks such as low power density, inability to charge and discharge rapidly, and short cycle life can easily lead to inefficiencies in application processes, thereby increasing the application costs. However, Supercapacitors, with their high power density, rapid charging and discharging capabilities, long lifespan, and environmental friendliness, are playing an increasingly important role in EV energy systems. Especially in urban traffic environments, where frequent starts and stops demand high power requirements for EVs, supercapacitors can quickly absorb and release energy, meeting instantaneous response needs while also demonstrating significant advantages in energy recovery [2].

Furthermore, the combined use of supercapacitors and batteries further enhances the overall performance of electric vehicles. By reasonably pairing supercapacitors and batteries, the complementary advantages of both in terms of energy density and power density can be fully utilized. This hybrid energy storage system not only meets the demand for long driving ranges in electric vehicles but also provides sufficient power support in high-power output scenarios such as acceleration and hill climbing [3,4].

The emergence of intelligent supercapacitors has injected new vitality into the development of electric vehicles. Intelligent supercapacitors integrate smart functions such as electrochromism, self-healing, and shape memory, not only enhancing the performance of energy storage devices but also broadening their application fields. In electric vehicles, intelligent supercapacitors are expected to further elevate the level of vehicle intelligence and meet consumers' demands for personalized and convenient transportation [5].

This article will delve into the basic concepts, working principles, and specific applications of supercapacitors in electric vehicles. Supercapacitors, with their unique electrochemical properties, exhibit significant advantages in rapid charging and discharging, long cycle life, and high-power density, offering new possibilities for enhancing the performance of electric vehicles. Their applications are not limited to the power systems of electric vehicles but can also be extended to energy recovery, auxiliary power supplies, and other aspects. Based on an understanding of the fundamentals of supercapacitors, this article will further analyze their application prospects and potential challenges in the field of electric vehicles.

2 Overview of the supercapacitors

The working principle of supercapacitors is primarily based on the interfacial double-layer effect between the electrode material and the electrolyte, enabling them to complete the charging and discharging process within an extremely short period of time, and this process is highly reversible. This characteristic grants supercapacitor significant advantages in high-power output situations, particularly suitable for applications requiring frequent and rapid charging and discharging.

Structurally, supercapacitors are typically composed of electrodes, electrolytes, separators, and casing, among other components. Among them, the choice of electrode material is crucial to the performance of supercapacitors. Currently, commonly used electrode materials include activated carbon, metal oxides, and conductive polymers. These materials possess high specific surface area, good electrical conductivity, and chemical stability, which can effectively enhance the energy storage capacity and cycling stability of supercapacitors.

In general, supercapacitors, as a new type of energy storage device, exhibit broad application prospects in the field of electric vehicles. With continuous technological advancements and cost reductions, supercapacitors are expected to play a greater role in electric vehicles, driving innovation and development in electric vehicle technology. Meanwhile, as people's focus on environmental protection and sustainable development deepens, supercapacitors, as a clean and efficient energy storage technology, are predicted to occupy an important position in the future energy sector.

2.1 Application of supercapacitors in electric vehicles

With their unique performance advantages, supercapacitors are gradually exhibiting broad application prospects in the field of electric vehicles. As efficient energy storage components, supercapacitors bring new possibilities for performance enhancement and energy management in electric vehicles.

In the power system of electric vehicles, supercapacitors can serve as an auxiliary power source, working in conjunction with the battery pack. Vehicles require a large amount of electricity instantaneously during startup, and supercapacitors offer better short-term electrical energy impulse capabilities compared to conventional power sources, along with a relatively longer lifespan [6].

A supercapacitor is a circuit structure composed of multiple parallel converters, which offers higher efficiency, stable output, a broader range, and smaller stable fluctuations compared to traditional single converters, effectively enhancing the overall efficiency of the circuit [6].

2.2 Development trend of supercapacitor technology

The development trend of supercapacitor technology is closely related to the demand for new energy products such as electric vehicles. In the pursuit of higher energy density, researchers are exploring new electrode materials and electrolytes, hoping to store more energy within a limited volume. This not only helps improve the driving range of electric vehicles but also achieves superior power performance while maintaining vehicle lightweightness.

In terms of cost reduction, with improvements in production processes and the realization of large-scale production, the manufacturing cost of supercapacitors is expected to further decrease. This will enhance the market competitiveness of electric vehicles and promote their wider adoption and application. At the same time, the cost reduction will also provide strong support for the expansion of supercapacitor applications in other energy storage fields.

3 Application of supercapacitors in electric vehicles

3.1 Description of the supercapacitor function

The most remarkable features of supercapacitors are their high power density and rapid charge and discharge capability. This means that during electric vehicles' acceleration and braking processes, supercapacitors can quickly provide or absorb a large amount of electrical energy to meet the demand for instantaneous high-power output. In contrast, traditional batteries such as lithium-ion batteries, although having high energy density, are often limited by their charging and discharging speeds when it comes to high-power output. Supercapacitors can charge to over 90% of their rated capacity within seconds to minutes, a feature that is particularly important in urban traffic environments where electric vehicles require rapid energy replenishment or frequent starts and stops.

Supercapacitors also exhibit an extremely long cycle life, capable of undergoing tens of thousands to even millions of charging and discharging cycles with minimal performance degradation. This characteristic greatly reduces the maintenance costs and replacement frequency of electric vehicles over their service life. Furthermore, supercapacitors require no complicated maintenance procedures in daily use, further saving time and resources.
Electric vehicles (EVs) have a wide range of application scenarios, from cold northern regions to hot southern regions, posing high demands on the adaptability of energy storage components. Supercapacitors maintain good performance within a wide temperature range (such as -40°C to 85°C), far surpassing many traditional batteries. This makes supercapacitors more advantageous in EV applications under extreme climatic conditions, ensuring stable vehicle operation in different environments.

Supercapacitors do not pollute the environment throughout their entire lifecycle, from production, and use to dismantling, and are considered a green and environmentally friendly energy storage solution. They do not contain heavy metals or harmful chemicals, thus preventing safety hazards such as leaks or explosions during use. As society's emphasis on environmental protection and safety continues to increase, the application prospects for supercapacitors in the EV field will become even broader.

3.2 Current research results

3.2.1 Auxiliary power system and energy recovery system

In pure electric vehicles (EVs), a typical application of supercapacitors is in auxiliary power systems and energy recovery systems. For example, a certain brand of pure electric bus uses supercapacitors as an auxiliary energy storage device, allowing for rapid charging at designated charging stations every 2-3 miles, with the entire process taking only a few minutes. This efficient charging method not only shortens the vehicle's charging time but also significantly improves the operational efficiency of the bus. Additionally, supercapacitors can recover energy from the braking system, converting kinetic energy that would otherwise be wasted into electrical energy for storage, further reducing the vehicle's energy consumption. According to statistics, these buses consume 40% less electricity than trolleybuses and only one-third of the energy of fuel-powered vehicles, truly realizing green transportation.

3.2.2 Energy management of hybrid electric vehicles

In this model's application, supercapacitors serve as an auxiliary component in the engine. When the car is started, the engine converts kinetic energy into electrical energy through the generator, which is then converted into direct current by an inverter and output to the electric motor. If the vehicle speed does not reach the set value after startup, the electric motor assists in propulsion. When the vehicle encounters poor road conditions during operation, the supercapacitor can be activated to provide electrical energy to the electric motor. During driving, when the speed reaches the set value, the electric motor stops operating, and the vehicle is powered by the engine. In this process, excess power is used to charge the supercapacitor. After the vehicle stops, the supercapacitor can automatically discharge into the battery . When the vehicle's power demand is low, this energy storage system is charged, enabling the recycling of energy. The rapid charging and discharging characteristics of supercapacitors allow hybrid electric vehicles to manage energy more effectively during acceleration and braking, improving energy utilization efficiency. According to tests, hybrid electric vehicles can save 30%-50% of fuel and reduce pollution by 70%-90%, making significant contributions to energy conservation and emission reduction.

3.2.3 To improve the vehicle performance

Supercapacitors also play a significant role in enhancing the performance of electric vehicles. During startup in cold weather, electric vehicles may face difficulties due to the decreased performance of batteries. However, supercapacitors can be used in parallel with batteries in low-temperature environments of -40°C, ensuring successful ignition in one attempt and significantly improving the vehicle's low-temperature starting performance. During the instant of starting, acceleration phase, and climbing processes of electric vehicles, high power output is provided to reduce the impact of instantaneous high current on a single battery, and to compensate for the low energy density of a single supercapacitor. Additionally, supercapacitors can provide instant high current for electric vehicles, helping the vehicles reach their maximum speed in a short period of time and enhancing the driving experience.

3.2.4 Optimization of hybrid energy storage system

In the overall design of electric vehicles, supercapacitors are often used in conjunction with traditional batteries such as lithium-ion batteries to form a hybrid energy storage system. This combination fully leverages the advantages of supercapacitors, including rapid charging and discharging and high power density, as well as the high energy density of lithium-ion batteries. By optimizing energy management strategies, the hybrid energy storage system can enhance the electric vehicle's acceleration performance, braking energy recovery efficiency, and overall service life while ensuring driving range. Additionally, the incorporation of supercapacitors helps reduce the number of charging and discharging cycles of lithium-ion batteries, thereby extending the lifespan of the battery pack and lowering the overall vehicle cost.

4 Challenges and development direction

4.1 The current research challenges

The energy density of supercapacitors is relatively low compared to other battery forms, one of the reasons for which is their low rated voltage (<2.7V). Currently, due to the gap between the energy density of supercapacitors and batteries versus actual needs, a major challenge in the field of supercapacitors remains improving their energy density [7]. Secondly, the production cost of supercapacitors is relatively high, which increases their application cost in new energy-electric vehicles. Reducing costs and improving cost-effectiveness are key to promoting their large-scale application.

Moreover, supercapacitor technology is not yet fully mature, and certain key technologies still need to be broken through. At the same time, the industry lacks unified standards and specifications, which has somewhat impacted their market promotion and application.

To promote and develop supercapacitors in the market, their performance needs to be enhanced to possess characteristics superior to other capacitors. The performance of supercapacitors largely depends on the choice of electrode materials and electrolytes. Therefore, developing new high-performance materials and improving their stability and cycle life are important directions for current research.

4.2 Future development direction

By optimizing electrode structures, developing new electrode materials and electrolytes, and improving production processes, it is expected that the energy density of supercapacitors will be significantly increased in the coming years, making it closer to the level of lithium-ion batteries. Increasingly more research is being conducted to develop new materials with high surface areas and the ability to withstand larger voltage windows. If these expansions are achieved, the energy density of supercapacitors will be comparable to that of batteries [8].

With the expansion of production scale and continuous technological advancements, the production cost of supercapacitors is expected to gradually decrease. Simultaneously, optimizing production processes and improving production efficiency can also reduce costs to a certain extent.

Strengthening research and development, as well as innovation in supercapacitor technology, is crucial for achieving breakthroughs in key technologies. Additionally, establishing unified industry standards and specifications to promote the standardization and modularization of technology will help improve product quality and reduce production costs.

The application of supercapacitors in new energy electric vehicles is not limited to auxiliary energy storage and energy recovery systems but can also be expanded to areas such as vehicle starting, acceleration assistance, and braking energy recovery. In the future, with continuous technological advancements and expanding application fields, the application prospects of supercapacitors in new energy electric vehicles will become even broader[9,10].

Supercapacitors can be combined with other energy storage technologies such as lithium-ion batteries to form hybrid energy storage systems. This type of system can fully leverage the advantages of various energy storage technologies, improving overall energy storage efficiency and performance. In the future, hybrid energy storage systems are expected to become an important development direction for energy storage systems in new energy electric vehicles.

5 Conclusion

In the context of new energy sources, this paper delves into the development prospects of supercapacitors in the field of electric vehicles (EVs). Through comprehensive analysis, the following main conclusions are drawn: The rise of new energy sources has provided significant impetus for the technological advancement of electric vehicles, as well as promoting environmental protection and sustainable development. Technological innovations in EVs have not only reduced environmental pollution but also optimized the energy structure. As a new type of energy storage device, supercapacitors demonstrate remarkable potential in enhancing EV performance due to their rapid charging and discharging capabilities, long cycle life, and high power density. Despite gradually increasing market acceptance, the application of supercapacitors in EVs still faces challenges in terms of cost, performance, and technology maturity. Therefore, it is necessary to strengthen technology research and development, enhance energy density, reduce costs, and optimize their combined use strategies with battery packs. In the future, the coordinated development of supercapacitors and EVs will become an important trend in the development of the new energy industry, contributing to technological innovation and sustainable development.

With technological advancements and the booming new energy market, the application prospects of supercapacitors in the EV field are broad. Future technology research and development should focus on improving the energy density of supercapacitors by exploring new electrode materials, electrolytes, and energy storage mechanisms to meet the diverse needs of EVs. Meanwhile, combining Internet and artificial intelligence technologies to develop innovative application scenarios will be a research hotspot. From the perspective of industrial development, improving the supercapacitor industry chain, strengthening raw material research and development, enhancing production processes, and expanding markets are crucial for achieving widespread application. Additionally, promoting international cooperation and technological exchanges will accelerate the application process of supercapacitors in the EV field. Despite these challenges, supercapacitors remain worthy of belief, as they will play a significant role in the field of electric vehicles and inject new vitality into the sustainable development of the new energy industry.

References

1. L. Tian, Supercapacitor and its application in electric vehicle, Micro-motor **8**,3 (2008)
2. Q. Xiong, Research progress of supercapacitors in hybrid electric vehicles, J. Sun Yat-sen University (Natural Science Edition) **S1**, 4 (2004)
3. D. Zhang, An energy storage device combining a supercapacitor and an exchangeable battery pack and an electric vehicle driven thereof, 1-2 (2019).
4. D. Zhang, An energy storage device combining the supercapacitor and the battery pack and related electric vehicles,(2020)
5. C. Xiong, Recent progress in the development of smart supercapacitors, Smart Mat **4**,2 (2022)
6. X. Chen, K. Xiao, L. Liang, G. Yuan, Research on application of supercapacitor energy storage in electric vehicle, Digital communication world **06**,281 (2019)
7. S. Cao, The challenge countermeasure and development of supercapacitor, Water conservancy technical supervision, **06**, 210-216 (2023)
8. H. Shifei, Z. Xianglin, S. Samrat, Z. Yufeng,Challenges and opportunities for supercapacitors, APL Materials, **10**, 7 (2019)
9. Q. Si, Study on multi-objective optimization of power allocation in EV hybrid energy storage system, J. Auto. Indus (2024)
10. F. Han, B. Bin, H. Xu, D. Yang, The automobile industry: Electric power industry. Electro. **19,** 6-8 (2023)