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Key Technologies for New Energy Vehicles Aimed at Improving Energy Efficiency

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Abstract:
With the rapid development of new energy cars, the problem that the battery life is generally short due to poor energy consumption control has come to light. Nowadays, researchers have conducted studies and achieved results in areas such as electronic control, motors, batteries, and tires. This essay discusses the energy management strategies for new energy vehicles in terms of body design, power system, and battery optimization. The energy consumption can be reduced by using bionic design to reduce the wind resistance coefficient, using lightweight materials, optimizing the transmission and motor to enhance energy efficiency, and improving the energy recovery and battery management systems. Thus, the endurance mileage can be improved. In addition, fuel cell technology offers new solutions for energy consumption management in the future. Through these strategies, the new energy vehicles will have better performance of energy consumption, which meets the sustainable development goals. This paper will provide reference significance for automobile designers and engineers in terms of reducing energy consumption.

Keywords: New energy vehicles; energy consumption management; body design; motor transmission; battery

1. Introduction

As global energy consumption continues to rise nowadays, environmental pollution has become increasingly severe. To meet the environmental protection goals, it is acknowledged that using new energy vehicles instead of traditional fuel vehicles is an effective method [1]. New energy vehicles have reduced the reliance of transportation on petroleum, thereby decreasing the emissions of harmful compounds and greenhouse gases. Moreover, due to their large demand for charging, new energy vehicles have promoted the development of renewable energy sources such as solar and wind power. It facilitates the implementation of more renewable energy power generation projects, which is significant for improving the global energy landscape.

The development of the new energy vehicle market is rapid. Some governments have made a series of subsidy policies to promote sales. However, in most underdeveloped and cold regions, fuel vehicles still account for the majority of sales. This is due to the problems of short endurance mileage and poor long-distance reliability of new energy vehicles.

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The problems are particularly serious in underdeveloped regions because of the lack of supporting facilities [2]. The construction of supporting facilities such as charging stations requires a large amount of human, material, and financial resources, which cannot be solved in the short term. Therefore, strengthening energy management and improving the energy efficiency of electric vehicles to increase the endurance mileage is a better solution. Moreover, this method fundamentally reduces energy consumption and is more in line with the sustainable development goals.

Nowadays, researchers in various fields have started to upgrade the energy consumption management system from aspects such as vehicle body design, power system, and battery optimization. In the field of vehicle body design, the current research achievements mainly focus on the following aspects. First, optimizing the body contour by adjusting the body shape based on aerodynamic principles to reduce air resistance. Second, designing additional devices such as spoilers and side skirts to reduce turbulence and further lower wind resistance. Third, using lightweight materials to reduce the vehicle body weight and thereby lower energy consumption [3]. In terms of power system optimization, the research mainly involves the following points. First, equipping a transmission similar to that of traditional fuel vehicles enables the motor to operate in the optimal energy consumption range and thus reduce energy consumption [1]. Second, choosing the appropriate motor according to different working conditions. It is also in order to avoid the motor operating in the high energy consumption range [4]. Third, optimizing the energy recovery system to convert the excess kinetic energy back into electrical energy and store it in the battery [5]. In the aspect of battery optimization, the research includes adopting more efficient fuel cells to improve the system and improving the battery management system based on the existing power battery [6][7]. This article will discuss the above aspects, analyze the problems faced by current new energy vehicles, and propose corresponding solutions.

2. Optimization of Vehicle Body Design

2.1 Structural Design

For fuel vehicles, since the engine has an requirements of intake, there are intake grilles designed at the front of the vehicle. The purpose is to ensure a certain intake volume to ensure the normal operation of the engine. However, for new energy vehicles (taking pure electric vehicles as an example), there is no intake requirement. The front is a fully enclosed structure. The traditional solution would only significantly increase the vehicle‘s wind resistance coefficient, resulting in energy loss and increased energy consumption.

Bionic design can be adopted to imitate the shape of the boxfish found in the ocean. It helps to achieve similar excellent fluid dynamics performance and stability at high speeds. Automakers such as DaimlerChrysler are attempting to apply the design of the boxfish to their vehicles. But related research is still limited. Harun Chowdhury’s experiment established a boxfish model using CATIA software, and then designed multiple models using the trial-and-error method. After Computational Fluid Dynamics analysis and optimization, one model was retained for wind tunnel testing. The experimental datashow that the wind resistance coefficient of the boxfish is only 0.24. The prototype vehicle designed based on the shape of the boxfish has a wind resistance coefficient of only 0.28, which is much lower than the 0.56 of traditional fuel vehicles represented by Holden cars. The design significantly reduces the energy loss caused by resistance during high-speed driving [8].

In addition, some additional devices can be designed, such as spoilers and side skirts. Spoilers are typically installed at the front, rear, or top of the car. Their main function is to change the direction of air flow, thereby reducing the air resistance and lift. It can enhance the vehicle‘s stability and reduce energy consumption at high speeds. For example, the rear spoiler can effectively sort out the airflow at the rear of the vehicle, avoiding the generation of vortices. It is particularly beneficial for high-speed vehicles, as it can significantly reduce resistance and increase downforce, ensuring the handling stability of the vehicle at high speeds. Side skirts are installed on both sides of the vehicle, close to the ground. Their main function is to control the airflow on both sides of the vehicle. They reduce the amount of air flowing under the vehicle, thereby suppressing the increase in air resistance caused by turbulence [3].

2.2 Selection of Vehicle Body Materials

In addition to reducing the wind resistance coefficient of the vehicle, using lightweight materials to lower the overall vehicle weight is also a solution to reduce energy consumption. Moreover, the use of lightweight materials can also optimize the dynamic performance of the vehicle, making the vehicle more responsive and having higher limits. Currently, widely used lightweight materials include carbon fiber, aluminum alloy, high-strength steel, magnesium alloy, and engineering plastics, etc. For example, the front and rear bumpers of the vehicle are made of engineering plastic. This operation is based on multiple considerations. First, the bumper is a large component, and using engineering plastic can significantly reduce the weight. Second, the bumper is a vulnerable part, which can reduce maintenance costs when replacing it. Third, this soft material of engineering plastic can reduce the harm to pedestrians to a certain extent in a frontal collision with pedestrians. After the vehicle has been lightened in weight, the power system does not need to output excessive power to drive the heavy vehicle body. The load on the motor is reduced when the motor frequently starts and stops in urban sections. The utilization rate of electrical energy is increased, and energy consumption is reduced. After the vehicle‘s curb weight is reduced, the rolling resistance of tires also decreases. It reduces the energy consumption caused by tire rolling resistance during high-speed cruising [3].

3. Optimization of the Power System

3.1 Optimization of Transmission

Most traditional fuel vehicles are equipped with multi-speed transmissions. Due to the limited output torque and speed range of engine, the transmission is needed to adjust the transmission ratio to match the engine‘s characteristics. However, since the motor has a wide speed range and can output the maximum torque at 0 rpm, it generally does not need a transmission. Nevertheless, this approach prevents the motor from operating in the most energy-efficient optimal speed range as much as the engine does.

A two-speed automatic mechanical transmission specially optimized for electric motors is designed. It can switch between two sets of gears with different transmission ratios according to the requirements of speed and torque. Compared to a single-speed electric motor, it has better speed-torque characteristics. The experiment used an improved particle swarm optimization (PSO) algorithm to optimize the transmission ratios of the transmission, in order to minimize the energy consumption of the entire vehicle under the New European Driving Cycle (NEDC) conditions. This algorithm improves the optimization accuracy and convergence speed by using nonlinear learning factors. The experiment also compared the motor efficiency under different gears and considered the extent of the accelerator pedal based on the shifting rules of motor efficiency and economy. Then, the optimal shifting points can be selected. For example, when the pedal extent is 10%, the shift can be made at 29.39 km/h. When the pedal amplitude is 90%, it indicates that the driver needs the vehicle to accelerate urgently. The shifting point should be delayed to 34.06 km/h. The experiment shows that this transmission is stable, reliable and quick. With this transmission, the acceleration time from 0 to 100 kilometers per hour is reduced by 17.7%, while the energy consumption is also decreased by 1.8% [1].

Furthermore, electric vehicles can reduce energy consumption through a four-speed dual-motor system, which adjusts the torque distribution between the front and rear and the transmission system [2]. This provides a solution for optimizing energy consumption in performance electric vehicles.

3.2 Optimization of Motor

The size of the motor is generally positively correlated with its maximum power and the optimal power range. If the driving conditions of an electric vehicle closely match the optimal power range, the energy consumption can be effectively controlled. The experiments conducted by Jamshid Mavlonov et al. used the backward modeling method to construct an energy consumption assessment model for electric vehicles. Then they analyzed the impact of the efficiency graph and size of the motor on energy consumption through simulation experiments. Their experiments selected three commercial motors (BMW i3 EM, Kia Soul EM, and YASA 400 EM) for simulation. The power of motors was also scaled up or down to make the maximum power points consistent with those of the target vehicle. The results of experiments showed that the efficiency graph of the motor had an impact on energy consumption of approximately 8% to 10%, while the size of the motor had an impact of approximately 2% to 11%. When both the efficiency graph and the size of the motor were considered, the overall difference in energy consumption was approximately 10% to 21%. These results indicate that the energy consumption of electric vehicles can be reduced by optimizing the efficiency graph of the motor and selecting the appropriate motor size. This experiment also suggests that designers can choose appropriate motors by predicting the usage scenarios of target customers [4]. For example, small-power motors can be used in small vehicles mainly for urban commuting, because it can ensure that the daily conditions closely match their optimal power range. While in vehicles mainly for high-speed cruising or aimed at performance, large-power motors can be installed to avoid abnormal energy consumption caused by motor overload, such as overtaking at high speeds. If the usage scenarios of target customers cannot be predicted, different motor options can be provided for consumers to choose.

3.3 Optimization of Energy Recovery

When the accelerator pedal of a fuel vehicle is released, there is a distinct engine braking effect. Similarly, when the accelerator pedal of an electric vehicle is released,

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there is also a significant deceleration effect. This is due to the electromagnetic induction phenomenon caused by the tires driving the coils to cut the magnetic field lines. This phenomenon can be used to recover the kinetic energy of the vehicle into electrical energy, which helps to increase the endurance mileage of electric vehicles and reduce energy consumption.

Energy recovery efficiency is related to the motor, electronic control system, and battery. The power generation of the motor is directly proportional to the rotational speed. The higher the rotational speed, the greater the power generation. Therefore, the performance of the motor directly affects the energy recovery efficiency. Currently, most pure electric vehicles made in China use permanent magnet synchronous motors, while a few high-performance pure electric vehicles use AC asynchronous motors. The maximum rotational speed of AC asynchronous motors is generally higher than that of permanent magnet synchronous motors. Therefore, the motor with a higher rotational speed has a higher theoretical limit of energy recovery efficiency. The electronic control system mainly lies in how the energy recovery system reasonably allocates the braking force. If the motor characteristic parameters are the same, the reasonable allocation of braking force is an important factor affecting the recovery efficiency. Due to the maximum charging power of the battery and the working limit of the power conversion unit, the kinetic energy recovery efficiency cannot reach 100%. And part of the braking force will be wasted. Therefore, it is necessary to make decisions through the controller to optimize the proportion and distribution of braking force recovery. The battery is the energy storage component of pure electric vehicles. Its material properties directly affect the energy recovery efficiency. Currently, ternary lithium and lithium iron phosphate are the mainstream battery materials. Ternary lithium has a higher energy density and charge-discharge efficiency. Therefore, under the same conditions, the maximum charge-discharge power and theoretical energy recovery efficiency of ternary lithium are higher.

Optimizing the energy recovery efficiency can also be carried out from these three aspects. According to the specific requirements of the vehicle, motors with higher speed and higher efficiency can be chosen, such as an AC asynchronous motor, to improve the energy recovery efficiency. In terms of batteries, researchers can continue to research and develop high-performance battery materials. For instance, optimizing the material system of lithium iron phosphate can increase its energy density and charging-discharging efficiency. For the electrical control system, researchers can design the front and rear axle braking force distribution corresponding to different braking intensities (mild, moderate, emergency braking). Mandani-type fuzzy controller with three inputs (braking intensity, vehicle speed and state of charge) can be used. It can output the braking force distribution ratio coefficient corresponding to the degree of motor participation in braking under the three braking conditions. The constraints of the motor and battery can also be considered, so redistributing the front and rear axle braking force can make it more in line with the actual situation. The stability of the vehicle during braking and the energy recovery efficiency can also be ensured. When the vehicle is in coasting or mild braking, try to let the motor participate in braking as much as possible; when in moderate braking, mechanical braking and electric braking work simultaneously, and the braking force is distributed according to the braking intensity; when in emergency braking, only mechanical braking works. Through optimized control strategies, the energy efficiency improves a lot. Under the NEDC driving condition, the energy consumption per 100 kilometers was reduced from 13.62 kW/h to 11.71 kW/h, representing an optimization rate of 14%; under the FTP75 driving condition, the energy consumption per 100 kilometers is optimized from 12.99 kW/h to 9.95 kW/h, an optimization amplitude of 23.4% [9].

4. Optimization of Battery

4.1 Fuel Cell

Fuel cells can directly convert the chemical energy in hydrogen and methanol into electrical energy. It has features such as high energy efficiency, fast charging speed, and strong adaptability. They have great potential. The type of representative is the proton exchange membrane fuel cell

By combining different energy storage systems such as fuel cells, batteries and supercapacitors to form a hybrid power system, the flexibility and efficiency of energy management can be improved. This hybrid system can better meet the energy demands under various driving conditions, as well as reduce the burden on a single energy system [6].

The energy management strategies for fuel cells can be mainly classified into three categories: rule-based strategies, optimization-based strategies, and learning-based strategies.

Rule-based strategies manage energy distribution through simple rule sets (such as „if-then-else“), which has features such as low computational complexity and fast response speed. These strategies are easy to implement and suitable for online applications, but they are usually based on empirical rules. It means rule-based strategies have limited optimization effects, and are difficult to adapt to complex driving conditions. For example, fuzzy logic control enhances the robustness and adaptability of the system through fuzzy rules, while the equal efficiency energy consumption minimization strategy (ECMS) optimizes energy distribution by minimizing the instantaneous cost function. However, the optimization effects of these strategies are usually not as good as those of optimization-based and learning-based strategies. Nevertheless, rule-based strategies still have significant value in practical applications, especially in scenarios requiring rapid response and low computational resources.

Optimization-based strategies achieve global optimization of energy flow through mathematical models and optimization algorithms, significantly improving the energy utilization efficiency of the system. These strategies include global optimization methods (such as global extremum search and linear programming) and real-time optimization methods (such as quadratic programming and dynamic programming). Global optimization strategies search for optimal solutions through complex mathematical models and algorithms. However, they have high computational complexity and are difficult to apply in real time. Real-time optimization strategies simplify models and algorithms to make rapid energy management decisions, which is suitable for dynamic driving conditions. For example, dynamic programming methods optimize energy distribution in stages, significantly improving the overall efficiency of the system. Although optimization-based strategies can theoretically achieve global optimal solutions, they still face challenges in computational complexity and real-time performance in practical applications.

Learning-based strategies utilize big data and machine learning algorithms to achieve adaptive control, which means they can dynamically adjust energy management strategies according to changes in driving conditions. These strategies include reinforcement learning, supervised learning, and unsupervised learning methods. Reinforcement learning optimizes energy distribution through trial-and-error learning. It can adapt to complex driving environments and improve the flexibility and robustness of the system. For example, the Q-learning algorithm dynamically adjusts energy distribution strategies, significantly reducing hydrogen consumption and extending battery life. Although learning-based strategies have significant advantages in adaptability and robustness, they require a large amount of data and complex computational resources. Future research directions include further optimizing learning algorithms to improve their computational efficiency and adaptability to better meet practical application requirements [10].

4.2 Battery Management System

Apart from fuel cells, the battery management system can be optimized without affecting the existing structure and chemical composition of the batteries. Through the optimized battery management system, energy losses during battery charging and discharging can be reduced. This method can enhance charging and discharging efficiency and optimize energy consumption. The battery management system is a complex system combining software and hardware, used to monitor and manage the operating status of the batteries. It ensures the safe, efficient and reliable operation of the batteries. The system receives battery information collected by sensors, monitors and analyzes the working status of the batteries in real time in order to avoid overcharging, over discharging and overheating. The battery management system also collaborates with the vehicle's central control unit for data coordination, coordinating the charging and discharging operations of the batteries to achieve the optimal allocation of vehicle energy. However, the existing battery management systems still have some drawbacks, such as low intelligence level and inability to respond quickly to changes in driving methods, resulting in low work efficiency. Additionally, the design concept of the existing battery management systems is relatively outdated and requires updating to adapt to the development of new energy vehicles [11].

To address the issues of low intelligence level of the battery management system and outdated design concept, a hybrid reinforcement learning model can be used to optimize the model. A hybrid reinforcement learning (RL) model based on deep Q-learning (DQL) and active-critic learning can be used to optimize the charging and discharging process of lithium-ion batteries. This model combines the advantages of the two technologies, learning the optimal control strategy through interaction with the battery system, thereby improving battery efficiency and performance. The Proximal Policy Optimization (PPO) algorithm is used to train the DRL agent, enabling it to dynamically adjust the charging and discharging strategies based on the battery's status of health (SOH) and state of charge (SOC). Finally, through simulation and experiments, it is proved that the hybrid RL model can effectively adapt to changes in battery states. It works well to optimize charging and discharging strategies and reduce energy losses. Experimental results show that the optimized strategy can more effectively utilize power resources, reduce unnecessary energy consumption and improve the energy efficiency of electric vehicles [7].

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5. Conclusion

This paper analyzes the energy consumption management strategies of new energy vehicles in terms of body design, power system, and battery optimization. it also demonstrates how to enhance energy efficiency and increase endurance mileage. The research indicates that through biomimetic design, lightweight materials, transmission and motor optimization, energy recovery, and improvements in battery management systems, the energy consumption of new energy vehicles can be significantly reduced. Additionally, the development and application of fuel cell technology can provide new ideas for the energy consumption management of future new energy vehicles. These energy consumption optimization strategies are of great significance to automakers and policymakers in optimizing the endurance mileage of new energy vehicles.

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