Advanced Thermal Management System of Power Battery for New Energy Vehicles

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Abstract. Enhancing the performance of electric vehicles (EVs) necessitates a strategic approach to managing the power battery system, with a pivotal focus on the Battery Thermal Management System (BTMS). Proper functioning and longevity of BTMS are critical for ensuring the safety and operational efficiency of EVs. The crux of battery safety lies in managing heat and temperature; an inability to adequately dissipate heat can lead to excessive temperatures, precipitating rapid degradation of battery performance, diminished lifespan, and potentially triggering thermal runaway—a severe risk to both personal and property safety. This paper delves into the current developmental status and research advancements in the thermal management systems of power batteries for new energy vehicles. It presents a comprehensive design of the BTMS, examining its distinctive features. Building on this analysis, the paper proposes optimization strategies for the BTMS's control mechanisms. This research contributes significantly to the field of battery thermal management, offering insights that are pivotal for the advancement of thermal regulation technologies in electric vehicles.

Keywords: Thermal management; battery; new energy vehicles.

1. Introduction

Nowadays, with the progress and development of the industrial level, a large amount of oil has been extracted, oil resources are becoming more and more scarce, and the energy problem is gradually highlighted. On the other hand, as China's economic development level increases, private car ownership increases, people's travel modes change, a large number of traditional fuel car exhaust emissions on the pollution of nature is becoming severe, resource-saving and environmental health problems are becoming more and more serious. Therefore, to solve the mutual trouble of global humankind: energy crisis and environmental degradation, the development of new energy vehicles undoubtedly has great practical value.

At this stage, global non-renewable resources are gradually strained, and the automobile industry is gradually changing from the fuel trend to the electric trend to seek a cleaner and environmentally friendly energy supply solution. As a new generation of energy storage solutions, lithium-ion batteries have good performance such as zero-emission and recyclability [1]. In recent years, China has been attaching great importance to the development of new energy vehicle BTMS, but also actively in the corresponding technology to continue to innovate, and in the country specifically set up special research on electric vehicles [2]. In today's era, China has been in the leading position in the field of automotive, research institutions and automobile manufacturers in various countries are focusing on the innovation and development of the thermal management system of the power battery of new energy vehicles and have achieved certain results [3]. At present, the more complete power BTMS in China has the lithium-ion power battery pack developed by Suzhou Xingheng Electric Power Company, and the system developed by Beijing University of Aeronautics and Astronautics can collect the current, voltage, and other data and other functions.

As one of the key components of the vehicle, the thermal management system of the power battery is mainly responsible for managing the working status of the battery system, as well as evaluating the internal battery [4]. In recent years, China has paid special consideration to the independent study and exploitation of new resource vehicles and hopes to advance the rapid progress of the electric vehicle

industry based on this, but also the research and growth of new energy vehicles are included in the national major scientific and technological innovation and industrial engineering construction projects and puts forward a lot of relevant preferential policies. At present, many well-known domestic automobile companies have joined in the production of electric vehicles, such as BYD, FAW Pentium, and other small cars, in addition to some city buses have gradually become electric vehicles. Various universities have also joined hands with enterprises to carry out the research and development of thermal management systems of power batteries, and all these technical achievements will promote the development of China's new energy automobile field to a certain extent.

To reduce energy consumption, many foreign countries are also gradually and actively developing electric vehicle technology, and the energy battery thermal management system is an important research and development project. Comparatively speaking, foreign technology in power batteries is slightly ahead of domestic. In some foreign schools and organizations, the information management system of lithium-ion power batteries has been studied in depth, while in some automobile companies, the research and development of BTMS is more detailed. In recent years, many well-known car manufacturers have been based on different types of batteries to carry out a lot of research and development, and the new energy vehicles on the relevant test achieved better results, but also to ensure its feasibility.

Nevertheless, in numerous significant sides such as security and reliability, range, finance control, etc., new energy vehicles are still constrained by the technical level of electronic control, batteries, power systems, etc., and there is an obvious gap with traditional fuel vehicles, and it is urgent to solve the problem of thermal management of power batteries. The power battery of an electric vehicle is its key part, so the protection of the power battery is crucial. To maximize the role of lithium battery packs and extend the service life of the battery, reasonable battery thermal management must be carried out. This paper carries out a series of studies on the power system and thermal management system of electric vehicles, as well as their overall design, and analyzes the optimization of the control strategy of the thermal management system of power batteries.

2. Power System and BTMS

2.1. Classification of Power Systems

Power battery systems, usually a combination of a single or many battery packs plus a BTMS, can power an electric automobile. According to the power and various requirements of passenger car vehicles, power batteries are categorized into power batteries for pure electric PEVs, power batteries for plug-in hybrid PHEVs, power batteries for plug-in fuel cell hybrid PFCVs, power batteries for hybrid HEVs, etc. [5].

The total battery energy of pure electric PEVs is generally between 20 kWh and 100 kWh, and the main power source of the vehicle is the battery, which has a large power battery energy. Plug-in hybrid PHEV power battery range needs to reach pure electric 50 km, the total battery energy is generally between 4 and 15 kWh, with the battery as the auxiliary power source of the vehicle. Hybrid HEV power cell battery total energy is generally less than 2 kWh, the battery is mainly responsible for ensuring that the engine works in economy mode, further reducing fuel consumption.

2.2. Functional Definition of the Power System

The power battery system mainly contains a thermal management system, pre-charging circuit, power battery case, high-voltage electric safety system, battery management unit (BMS), DC contactor and control circuit, ground protection and detection unit (current sensor, voltage sensor, and temperature sensor).

The core functional components of the power battery system design are a battery management system, voltage sensors, current sensors, temperature sensors, 108 strings of battery modules, main switch with fuse, 2 main contactors, 1 pre-charging resistor, 1 charger relay, charger high voltage

electrical interface, charger low-voltage electrical interface, vehicle high voltage electrical interface and vehicle low-voltage electrical interface, and 1 charger fuse, etc. [6].

The functional design of the power battery system includes battery system self-test function, system detection function, total voltage detection, total current detection, temperature detection (module), import/export temperature detection, system diagnosis, insulation detection, power prediction, and SOC estimation, discharge equalization function, charging management, overvoltage/under voltage protection, overcurrent protection, contactor and pre-charge logic control, high-voltage interlocking circuits, and communication with VMS.

2.3. The Need for a BTMS

The mutual conversion between electric energy and battery chemical energy is the essence of charging and discharging of vehicle power battery, which is accomplished through the chemical reaction of active materials inside the battery. As the chemical reaction is very sensitive to the difference in temperature, different temperatures have great differences in the rate of the battery reaction, the performance of side reactions, etc. These differences directly affect the performance of the battery. Since the chemical reaction inside the battery is mainly between the electrolyte and the active material, when the temperature is too low, the electrolyte viscosity inside the battery increases, and the movement rate of the conductive ions decreases, which leads to a significant decrease in the performance of the battery's numerous usage characteristics such as charging and discharging capacity, output power, and discharge voltage plateau [7]. Not only that, the low-temperature environment is more likely to lead to the formation of lithium crystals, which can cause an internal short circuit of the battery, critically influencing the age of the battery, and even impacting the user security [8].

When the temperature rises, and the flow rate of the electrolyte increases, the chemical reaction rate of the battery is accelerated, and the above performance will be improved, which can effectively delay the battery’s life and enhance operational safety. Nonetheless, if reaching a high temperature, not only will the performance of the battery in all aspects no longer improve, but it will even decline. Therefore, the maximum temperature of the battery system must be effectively controlled. In addition, different batteries are located in different positions in the car, and the degree of heat dissipation is not the same, resulting in the internal temperature of each battery is not the same. Excessive internal temperature difference is extremely unfavorable to the performance of the battery system, so the control of internal temperature must also be ensured.

To realize the above goals, a scientific and effective BTMS is indispensable. Nowadays, domestic and international research work on BTMS mainly focuses on establishing a more accurate battery thermal model and exploring more effective battery cooling methods.

2.4. Research Status of BTMS

With the development of the new energy automobile industry, domestic and foreign companies are increasing the demand for lithium power batteries, and at the same time, their performance requirements are also improving, some car companies and laboratories to improve the range and constantly improve the energy density of lithium batteries at the same time need to pay more attention to the study of the use of lithium batteries safety. Therefore, it is necessary to establish a battery mechanistic model to analyze the heat generation and dissipation of the battery from the principle level, to optimize the structure of the BTMS (BTMS), to realize the temperature control of the battery pack in the working state, to inhibit the control and alarm in the thermal runaway state, to slow down the propagation rate of the heat in the thermal runaway condition, to improve the heat dissipation capability of the system, and to introduce a highly efficient and useful BTMS [9-11].

BTMS for electric vehicles can effectively cope with problems related to thermal runaway of the battery so that the safety performance and life of the battery can reach a corresponding safe use standard. BYD's DM-i plug-in hybrid architecture is designed with a new intelligent thermal management system [12,13], which realizes a split cooling strategy, controlling the flow rate ratio

between the cylinder block and the cylinder head through a combination of an electronic thermostat and a paraffin thermostat, and actively controlling the flow rate of the coolant to control the system's thermal demand using an electronic water pump. Various new energy vehicle companies are constantly developing newer and more optimized BTMSs to continuously improve the performance and driving experience of new energy vehicles.

2.5. Battery Thermal Characterization

Electrochemical heat generation within lithium batteries is a complex process that is influenced by factors such as current rate, operating temperature, and cell chemistry. Many scholars have studied the heat generation problem from monomer to module. However, it is still necessary to study the deep electrochemical reactions in electrochemical modules. The heat associated with lithium battery electrochemical reactions is generated by three main factors: ohmic losses (due to ionic motion), activation kinetics, and substance transport concentration. All of the heat generated results in lower voltage and higher temperature.

2.6. Design of Thermal Management System for Power Battery

The process of driving a new energy vehicle is the process of discharging the power battery. When the temperature of the battery itself is too high due to the discharge caused by driving the car, the software design of the MCU master control unit receives the temperature signal and controls the speed of the fan to complete the cooling of the battery, so that the temperature is kept in a constant state and can work normally, to achieve the purpose of delaying the life of the battery. The Power Battery Intelligent Management System has three actuating components: a temperature sensor, a motor drive module, and a fan. Air-cooled, liquid-cooled, and phase-change-cooled are the three ways of power battery heat dissipation. Air-cooled heat dissipation consumes fewer resources compared with the other two ways of heat dissipation, has less influence on the structural design of the whole vehicle, and has lower design requirements for the battery. Because the rated voltage and operating voltage range of the entire system must match the heat sink control unit and motor selected in the design, and to ensure that the battery cooling system can operate stably, it is necessary to determine the specifications of the heat sink battery that meets the requirements according to the number of batteries and the motor's operating voltage level.

Generally speaking, electric new energy vehicles have a complete cooling system for battery cooling, battery internal signal acquisition, fan (motor) control, communication modules constitute the entire power BTMS, the main controller for the DSP, through the acquisition of internal battery signals to determine the state of the battery pack and then make the appropriate processing. The collection of temperature is mainly used for the over-temperature protection of the battery pack, the data collected by the DSP is adjusted and the speed of the motor is controlled through PID control, and finally, the information is processed and sent to the monitoring system for monitoring and feedback.

2.7. Problems with Thermal Management Systems

2.7.1 Inaccurate temperature control

The battery system of new energy vehicles is crucial to vehicle performance, and the temperature of the battery has an important impact on its performance and life, so it needs to control the temperature precisely. However, the current thermal management system of new energy vehicles still has technical difficulties in temperature control. Batteries that are either too hot or too cold can negatively impact performance, so real-time temperature monitoring and control are required. However, existing temperature sensing technologies are limited and do not provide sufficient accuracy and stability, which can lead to imprecise temperature control and impact battery life and performance. In addition, uneven temperature distribution among battery components is also a problem, which may lead to overheating of some components and overcooling of some components,

directly affecting the performance of the whole battery module. At present, some thermal management systems for new energy vehicles still fail to effectively solve this problem.

2.7.2 Energy waste

Currently, the thermal management system of new energy vehicles suffers from energy waste, which can lead to unnecessary energy consumption and reduce the range and overall efficiency of the vehicle. The heat generated by some systems is not effectively recovered or reutilized, but instead is discharged into the environment, which is not only a waste of energy but also a burden on the environment. Therefore, there is a need to study more effective heat recovery technologies to reduce heat emissions.

In addition, the heating and cooling system of the battery may also produce energy waste. Conventional methods consume large amounts of energy and reduce the energy utilization efficiency of the battery. Therefore, research into more energy-efficient heating and cooling technologies is needed to reduce energy waste. The key lies in improving energy management and utilization efficiency, including optimizing the design of thermal management systems, improving heat recovery technologies, and introducing efficient heating and cooling methods. Reducing energy waste can improve the range and overall energy efficiency of new energy vehicles, making them more competitive.

3. Power BTMS Control Strategy Optimization Ideas

To further improve the control strategy of the thermal management system of new energy vehicle batteries, it can start from the following aspects: establishing a more accurate battery model, optimizing the battery state estimation algorithm, establishing an intelligent battery management system, and formulating a targeted control strategy. In this process, it is necessary to comprehensively consider many factors, such as battery characteristics and vehicle use, and use a variety of control means for co-optimization to further improve the control performance and stability of the system.

3.1. Modeling More Accurate Batteries

Introducing more battery performance parameters and applying more advanced modeling methods can establish a more accurate battery model, which is of extraordinary importance for optimizing the control strategy of the battery management system of new energy vehicles and improving the new energy motor cars' performance and reliability.

First, people can introduce more battery performance parameters. Battery performance is affected by many factors, including material, structure, temperature, current, voltage, charging and discharging state, and health state. To build a more accurate battery model, people need to consider these factors and incorporate them into the model. For example, by performing experimental measurements at different temperatures, currents, voltages, and charging/discharging states, people can obtain data on the performance parameters of the battery and build a multi-factor battery model based on these data to accurately characterize the performance of the battery and thus improve the control accuracy of the battery management system.

Second, people can apply more advanced modeling methods. Traditional battery models are usually based on the equivalent circuit model of the battery, which is easy to use but may not accurately describe the complex performance of the battery. With the development of science and technology, some new modeling methods have emerged, such as electrochemical models, neural network models, and particle filtering models. These models can more accurately describe the electrochemical processes, dynamic performance, and nonlinear performance of the battery, thus improving the accuracy of the battery model. For example, the electrochemical model can accurately describe the electrochemical reaction process of the battery, the neural network model can adaptively learn and predict the dynamic performance of the battery, and the particle filtering model can effectively deal with the uncertainty in the state of the battery and the nonlinear performance problem.

By applying these advanced modeling methods, people can better understand and optimize the performance of batteries, and thus improve the performance and reliability of new energy vehicles.

3.2. Optimizing the Battery State Estimation Algorithm

To optimize the battery state estimation algorithm, it is first necessary to establish a high-precision model that accurately reflects the complex electrochemical properties of the battery and considers the multi-physical field coupling effect of the battery. For this purpose, it is necessary to establish a thermodynamic model, an electrical model, and a mechanical model of the battery, and to ensure that these models can be coupled with each other to accurately describe the changes in the battery's parameters, such as voltage, temperature, SOC, etc., under different operating conditions. Based on this model, advanced filtering algorithms can be employed to estimate the SOC of the battery. This high-capacity electrochemical physics model can predict the state of the battery more accurately in real-time than a simple equivalent circuit model.

Based on complex electrochemical models, improved algorithms such as extended Kalman filtering, and particle filtering can be used to optimize the parameter estimation of the battery state. For example, the Kalman filter family of algorithms is effective in reducing the root-mean-square estimation error of the system, but it also places higher demands on the accuracy of the modeling. These filtering algorithms can deal with the nonlinearities of the battery model and incorporate multiple variables such as current, voltage, temperature, etc. to accommodate the model noise and make the estimation algorithms for parameters such as SOC more robust. In addition, mapping relationships for battery state estimation can be established with the help of advanced deep learning and neural network algorithms through big data-driven model training, to realize accurate prediction of battery state.

3.3. Establish an Intelligent Battery Management System

To build an intelligent battery management system, people need to employ advanced data analytics and machine learning technologies. These technologies will help us intelligently predict and diagnose the state and performance of the battery. People also need to introduce advanced control algorithms and strategies to optimize the battery charging and discharging control strategies and to achieve adaptive and optimal control of the battery management system.

First, people can build a big data platform for battery management systems, utilizing advanced data analysis and machine learning technologies. By collecting a variety of information such as battery operation data, environmental parameters, and user behavior, people can build a platform that contains rich data. This data is then mined and analyzed using data analytics and machine learning techniques to extract features and patterns related to battery performance and health status. By applying these data analysis and machine learning methods, people can achieve intelligent prediction and diagnosis of battery status and performance and provide intelligent decision support for battery management systems.

Second, people can introduce advanced control algorithms and strategies to optimize the performance of the battery management system. By utilizing intelligent algorithms and advanced control theories, people can develop control algorithms and strategies suitable for battery management systems. For example, people can use model predictive control algorithms to optimize the charging and discharging control strategy in real-time according to the characteristics and operating state of the battery, to maximize the charging efficiency and prolong the service life of the battery. At the same time, people can also apply reinforcement learning and optimization algorithms to dynamically adjust the control strategy according to the real-time state of the battery and the environmental conditions, to realize the adaptive and optimized control of the battery management system and improve the performance and reliability of the system.

3.4. Develop Targeted Control Strategies

Developing targeted control strategies is one of the important methods to optimize the battery management system of new energy vehicles. The core objective of the battery management system is to ensure the safe operation of the battery and to extend the service life of the battery. To achieve this goal, control strategies need to be adjusted according to the real-time state of the battery (e.g., voltage, current, temperature, health, etc.). As an example, when the current is too high, the current can be limited to avoid overheating the battery; when the battery temperature is too high, the cooling system can be activated to reduce the temperature; when the battery health condition is declining, the charging and discharging frequency can be lowered to prolong the battery's service life. All these control strategies need to be based on real-time monitoring of the battery status and adjusted according to the changes in the battery status.

Analyzing driving behavior can help develop more targeted control strategies because the driving behavior of new energy vehicles directly affects battery usage. For example, when driving behavior is stable, such as when driving on highways, an efficient charging strategy can be used to improve battery usage. This means that the energy of the battery can be utilized more fully to meet the needs of the vehicle. However, when driving behavior is highly variable, such as in urban traffic, a protective charging and discharging strategy can be used to protect the battery. This means that the charging and discharging rate of the battery can be limited to minimize energy consumption and reduce the load on the battery, thereby extending its life. By analyzing driving behavior and developing appropriate control strategies, the performance and reliability of the battery can be maximized.

4. Conclusion

Lithium-ion batteries, as the prime energy source for electric vehicles, have a decisive influence on their performance. Reasonable thermal management planning can not only advance the performance of charging and discharging Li-ion batteries but also extend their use age and guarantee the safety performance of electric vehicles. As new energy vehicles occupy the automobile market, research on technologies related to battery management systems has also made some progress. After studying a lot of literature on battery power systems and thermal management, this paper investigates the development status and research progress of thermal management system of power batteries for new energy vehicles and focuses on proposing ideas and methods for optimizing the control strategy of the thermal management system by analyzing the design characteristics of the thermal management system of power battery. The domestic and international research status and development process of the thermal management system of the power battery of new energy vehicles are described, and the overall design of the BTMS is carried out, its characteristics are analyzed, and then the optimization of the control strategy for the thermal management system of the power battery is proposed according to the analysis. Due to the limitation of time and the author's scientific research ability, there are still some deficiencies in this topic, and the relevant conclusions are not proved by experimental data, and the thermal management of the whole vehicle including the thermal management system of the electric motor should be further researched to do a good job in the study of heat dissipation and temperature change.

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