The Causes and Thermal Management Strategies for Thermal Runaway of New Energy Vehicle Batteries

Ruishan Liu

College of New Energy, Xi'an Shiyou University, Xi'an, 710300, China

202314010209@stumail.xsyu.edu.cn

Abstract. This passage summarizes and analyzes the research on causes and thermal management strategies for thermal runaway of new energy vehicle batteries. Compared to traditional fuel vehicles, the new energy vehicles have superiority in the emission of gases and consumption of fuel. However the frequent thermal runway accidents of new energy vehicle batteries not only raise the worries of users and the market but also harm the safety of users' lives and property. The hidden danger is not conducive to the promotion of new energy vehicles. So it is urgent to optimize the performance of batteries. This passage surveys the thermal runaway mechanisms of new energy vehicle batteries mainly composed of lithium lon batteries. The mechanisms can be roughly divided into three aspects, electrical abuse, mechanical abuse, and thermal abuse. The writer gets conclusion that the lithium iron phosphate battery(LFP) more suitable for the high-temperature working condition by comparing the data. And this article focuses on the optimization of monitoring models based on different parameters and related sensor technology in thermal management strategies. Meanwhile, the writer made a review conducted on the research on cooling technology and compared the superiority of various cooling methods.

INTRODUCTION

Against the backdrop of global climate change, excessive greenhouse gas emissions, China's implementation of the dual carbon stra, and the energy shortage crisis, the energy consumption revolution is urgently needed. The trend of using renewable energy such as new energy to reduce the proportion of traditional fossil fuels is becoming increasingly evident. The exhaust emissions of fuel vehicles contain carbon dioxide, carbon monoxide, nitrogen and sulfur oxides, and particular matter. As a kind of greenhouse gas, carbon dioxide is the main reason for severe pollution of the atmospheric environment. Compared with fuel vehicles, new energy vehicles mostly use electric energy as a power source which not only has significant advantages in the emission of exhaust pollutants. At the same time, it is also conducive to the transformation of consumption from traditional energy to new energy and to cope with the energy crisis.

As the core energy storage component of new energy vehicles, the overall performance of batteries is closely related to new energy vehicles. For power batteries, the main factor affecting their safety and endurance is the battery temperature. Thermal runaway which proposes to new energy vehicle batteries means an accident in the working temperature of batteries can not be maintained in the normal range. And the heat that the batteries release will get rid of control. Thermal runaway is a phenomenon that may cause serious safety accidents. Excessive battery temperature will not only reduce the efficiency of the chemical reaction inside the batteries, increase the loss of the batteries but also lead to a dangerous accident of spontaneous combustion and explosion of the battery. All of them will raise the worries of the public for new energy vehicles. What worse is that the excessively low temperature will cause a series of performance problems for batteries such as insufficient power and reduced battery life. The main thermal runaway triggers include overcharge and overdischarge, collision acupuncture,high temperature conditions and other factors. There are some domestic and foreign literature which conducted research on the problem of thermal runaway in power batteries. Tan xiuwen conducted research on the characteristics of local small-area thermal runaway caused by short circuit between battery terminals and connecting pieces. By establishing a threedimenional lumped thermal runaway model of lithium-ion batteries, the inclined liquid cooling plate was proposed to solve the problem of heat accumulation in battery pole lug [1]; Sun wenhao et. analyzed the thermal runaway production characteristic of lithium-ion batteries, compared the thermal runaway gas production characteristics caused by different abuse situations,electrode materials,energy density and other factors.Meanwhile,he looked forward to the future multi-technolog collaborative battery gas production monitoring system[2];Yuan aote et. took impedance curvature as an early warning parameter for the original impedance data,which helped to find the correct minimum point and improve the simplicity and feasibility of the battery thermal management system algorithm[3].

To analyze the concept, mechanism and influencing factors of battery thermal runaway and to study relevant technologies for reducing ,monitoring thermal runaway,it can ensure the internal temperature of batteries is balanced and always in the normal operating temperature range.It is conducive approach to reduce the occurrence of new energy vehicle accidents,ensure people's life safety and to promote the promotion of new energy vehicles.

Firstly,this article described the temperature characteristics of new energy power batteries.And it studied the thermal runaway mechanism of batteries under various circumstance.The research progress of thermal management of lithium-ion batteries is summarized.The writer comb out the thermal runaway mechanism and thermal management technology of batteries at home and abroad,

NEW ENERGY VEHICLE BATTERIES

Temperature Characteristics of Power Batteries for New Energy Vehicles

Considering the stability and safety of automobile endurance, the power batteries currently used in domestic and foreign markets for new energy vehicles are mainly divided into two types: ternary lithium battery (NCM) and lithium iron phosphate (LFP) battery, both of which belong to lithium-ion battery [4].

When external operating conditions are at high temperatures, the thermal stability of lithium iron phosphate batteries is higher than that of ternary lithium iron phosphate batteries, with a lower probability of thermal runaway. This mainly depends on the thermal stability of the battery materials [5]. The critical decomposition temperature of the chemical materials in lithium iron phosphate batteries is between 400-700° ℃, approximately two to three times that of ternary lithium batteries. Therefore, when faced with ultra-high external temperatures, the probability of normal internal chemical reactions in lithium iron phosphate batteries is greater, and the structural stability of the battery is also higher than that of ternary lithium batteries, enabling better performance under extreme thermal conditions. When external operating conditions are at low temperatures, the adaptability of ternary lithium iron phosphate batteries is significantly higher than that of lithium iron phosphate batteries. At the same low temperature, such as-10° ℃, the working capability of lithium iron phosphate batteries may be completely lost, while the efficiency of ternary lithium batteries only decreases by 20%-30%. Studies have shown that this is related to the number of mobile lithium ions in the battery at low temperatures.

In summary, it can be seen that when the external temperature is too high, the challenge to a ternary lithium battery is greater, and the probability of spontaneous explosion caused by battery overheating is greater; while in the extreme low temperature condition, the adaptability of lithium iron phosphate battery is weaker, and it will face the problem of battery working efficiency.

Thermal Runaway Mechanism of New Energy Vehicle Power Battery

Thermal runaway refers to the chain reaction of heat accumulation in the battery of new energy vehicles during charging and discharging, triggered by mechanical abuse, thermal abuse, electrical abuse, and other causes, leading to uncontrollable intense exothermic reactions that can cause explosions, fires, and other hazardous accidents [6]. The triggers for battery thermal runaway are complex. Firstly, electrical abuse leads to battery thermal runaway. When a battery is overcharged, excess lithium ions deposit at the negative electrode instead of the positive electrode, inhibiting the normal movement of remaining lithium ions and increasing internal resistance. At the same time, lithium dendrites may form on the negative electrode. These dendrites not only react with internal materials such as electrolytes and binders, producing gas products, but also penetrate the lithium-ion battery separator, causing internal short circuits and excessive current, which leads to heat accumulation. When a battery is over-discharged, it increases the internal voltage, and lithium dendrites may form on the negative electrode, triggering internal chemical reactions that cause heat accumulation and thermal runaway.

Secondly, the analysis of thermal runaway caused by excessive heat abuse. When external conditions are at high temperatures or there is an external heat source, the risk of damage to the internal structure of the battery significantly increases. Chemical reactions occur between battery materials, and the resulting lithium dendrites may cause short circuits. The gas products increase internal pressure, indirectly leading to thermal runaway. The following figure shows a simulation experiment conducted by Yong-Un Na et al. on battery thermal runaway triggered by external high-temperature conditions. A 1000-watt heat source was added to the surface of the battery, and monitoring revealed that the voltage dropped sharply before thermal runaway occurred. At around 28 degrees Celsius, the battery temperature rose sharply [7].

Finally, the analysis of battery thermal runaway caused by mechanical abuse. Needle pricking, penetration, collision and other factors may lead to short circuit between battery electrodes or conductive materials infiltrate into the battery, resulting in short circuit between high and low potential parts, thus causing thermal runaway [8].

It is evident that the factors leading to thermal runaway in batteries are diverse. The primary triggers focus on the structural characteristics of electrode materials and the chemical reactions between battery materials, which result in heat accumulation and the production of flammable gases. When managing the thermal management of battery systems, it is essential to consider all factors comprehensively and summarize the data on the proportion of thermal runaway triggers to implement targeted preventive measures.

Thermal Management Strategy of New Energy Vehicles

Thermal Management Monitoring Technology for New Energy Vehicles

Effective monitoring and early warning of battery thermal runaway is one of the important steps in thermal management.

First, the monitoring of the normal operating state of power batteries mainly includes five aspects: charge state (SOC), health state (SOH), energy state (SOE), power state (SOP), and life state (SOL). The safety performance of new energy vehicle power batteries primarily depends on real-time monitoring of the charge state and health state. This mainly relies on the BMS system, where different working units play a crucial role in battery voltage balancing, temperature monitoring, and current sensing. The references[9] is based on sensor arrangement, model construction, and data analysis algorithms.

In addition, for the monitoring of thermal runaway risk in an abnormal battery state, the main parameters of sensors include electrical parameters, gas content and pressure parameters.

The technology for monitoring the electrical parameters of batteries is currently well-developed both domestically and internationally. This includes impedance sensing, current sensing, and voltage sensing [10]. In terms of monitoring and early warning through impedance sensing, Yuan Aotu et al. set the impedance spectrum range at 0.1-10kHz under different temperatures and SOC conditions to screen for characteristic impedance, selecting the real part of the impedance as an early warning feature for overcharging and deep discharging. Since the appearance of a minimum in characteristic impedance often indicates the formation of lithium dendrites, detecting this minimum in the real part of the impedance is crucial. To reduce algorithm complexity and improve monitoring accuracy, it is more practical to detect the curvature of the impedance. Through experiments, a density-based noise application space clustering algorithm (DBSCAN) was used for specific monitoring. The curvature value, neighborhood radius, and minimum number of points were calculated to construct a DBSCAN model for cluster analysis. It is evident that optimizing thermal management systems requires paying attention to the selection of monitoring data parameters. Experimental selection and validation of parameters are necessary, while also considering their impact on algorithms, sensor settings, and other factors. Regarding electrochemical impedance spectra, Zhang et al. summarized the latest methods for obtaining impedance spectra of lithium-ion batteries, including new methods to reduce the frequency range of measurements, primarily relying on time-domain methods such as Fourier transforms The Laplace transform is used to shorten the time to obtain data [11].

There are many studies on the direct monitoring of gas parameters of batteries or thermal runaway monitoring based on gas characterization, which is a well-developed method. It is a recognized reliable and rapid response detection method. Since the decomposition of SEI film accompanies the thermal runaway process of batteries, the main gas product is CO2、C2H4、O2; Hydrocarbon gases produced by the reaction of the negative electrode with the electrolyte; HF and H may be produced by the reaction of the binder2Gas [2]. Zhou Xin et al. found that H2And C2H4These two gases have a higher correlation with early warning, which mainly depends on their related chemical reactions in thermal runaway. As the product of the reaction, the timeliness and accuracy of early warning are closely related to the time when the corresponding chemical reaction occurs, the yield and state of the product [12].

Li et al. focused on ternary material pouch lithium-ion batteries, monitoring the gas production and battery surface temperature during overcharging, deep discharging, and puncture in thermal runaway processes. They used a dual-wavelength photometric and electrochemical detection method to determine the thermal runaway parameter [13] of lithium-ion batteries. Gas sensors used in new energy vehicle power batteries include electrochemical sensors, semiconductor sensors, chemical sensors, and non-dispersive infrared (NDIR) sensors. Luo et al. developed a method to monitor CO2The NIDR sensor is equipped with PMNT single crystal pyroelectric infrared detector, which effectively improves the monitoring accuracy [14] compared with traditional sensors. As a core component of thermal management monitoring system, the technological progress of the sensor can also have a positive impact on the overall development of the detection system.

It can be seen that by monitoring the composition of hydrogen and methane inside the battery, the thermal runaway situation of the battery can be more accurately understood.

When thermal runaway occurs inside a battery, it is often due to a short circuit between the positive and negative terminals. At this point, the current and voltage generated tend to become abnormal. Moreover, when a battery experiences thermal runaway, its temperature rises, leading to an increase in internal resistance. High-precision sensors are installed in the battery unit to monitor voltage, current, and resistance, accurately collecting real-time operational data, which is then wirelessly transmitted to the data processing center. By leveraging normal operating data from the battery, a machine-learning algorithm model is established to diagnose and predict thermal runaway.

Thermal Management and Temperature Control Technology of New Energy Vehicle Battery

First, focus on the differentiation of different battery modules. A battery pack consists of multiple battery modules, each with varying thermal characteristics due to factors such as position and usage conditions. Pay attention to the differences among these modules and apply different temperature control measures, such as fans, cooling tubes, and heating elements. Modular thermal management involves implementing appropriate temperature control measures for each battery unit, which is more targeted. Refined thermal management can ensure the efficiency of battery operation and enhance operational stability. Similarly, this will depend on the accuracy and timeliness of the thermal management systems monitoring.

Second, if the precursor of thermal runaway appears or thermal runaway has occurred, specific cooling measures are immediately required.

Currently, the main cooling methods include liquid cooling technology, air cooling technology, composite phase change material technology, and heat pipe technology. Liquid cooling technology, due to its high cooling efficiency, is suitable for high-power density battery packs, capable of more quickly and effectively reducing battery temperature, preventing overheating, and extending battery life. Although air cooling technology has lower cooling performance compared to liquid cooling, it offers the advantages of low cost and simple structure, making it suitable for battery systems with lower cooling requirements [15].

According to whether they consume power, cooling technologies can be divided into active and passive aspects. Active cooling technology mainly includes forced air convection cooling and liquid cooling systems [16]. Active cooling technology absorbs power to activate the car's cooling system. It uses the coolant medium in the cooling pipes to absorb the heat accumulated in the battery. To improve cooling efficiency, it is necessary to find cooling fluids with higher specific heat capacity that are more environmentally friendly. Passive cooling technology does not rely on additional power but uses phase-change materials to absorb heat. By converting heat into latent heat through the heat-absorbing material, it achieves the effect of heat absorption. From the above research, it is evident that the current two cooling technologies are closely related to materials. To advance the cooling technology of new energy vehicles, it is necessary to develop more efficient thermal storage materials.

At present, David et al. proposed the single-phase liquid immersion cooling technology. Compared with air cooling, immersion cooling makes the temperature of each module of the battery more uniform and reduces the temperature fluctuation between the highest and lowest temperature of the battery [17].

CONCLUSIONS

This paper reviews and summarizes the current research on the causes of thermal runaway in new energy vehicle batteries and specific thermal management strategies. The fundamental causes of thermal runaway can mainly be divided into internal short circuits, excessively high external operating temperatures, and overcharging or deep discharging. There are many specific accident reasons leading to these three causes, such as collisions, high temperatures, and compression. When managing the thermal environment of power batteries, attention is paid to the differentiation and refinement of different battery modules. Currently, the main technology for cooling power batteries involves using liquid cooling systems and phase change materials for heat dissipation. This study covers lithium-ion batteries and temperature control systems, which may contribute to future optimization of new energy vehicle batteries and the regulation of vehicle temperature control. It is hoped that this paper will help readers quickly understand the current research progress in power battery management systems both domestically and internationally, providing a reference for optimizing new energy vehicle batteries. This will accelerate the development of new energy vehicle batteries, thereby promoting the development of new energy vehicles and accelerating the global energy consumption revolution to address the energy crisis.

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