A Thermal Runaway Risk Warning Scheme for Power Batteries

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ABSTRACT

With the rapid development of electric vehicles, the safety issues caused by overheating of power batteries are increasing, and even affecting the users' lives. Based on this, the state has issued relevant policies requiring measures to inform users before power batteries thermal runaway occur. In this paper, a set of early warning scheme for thermal runaway of power batteries based on DCF is designed. The core of this scheme is the monitoring algorithm of DCF integrated power batteries system, which combines the relevant information of DCF to actively push early warning information to vehicle users and restrict related activities within a certain period of time. In addition, a maintenance manual is generated for risky vehicles for maintenance personnel to use, so as to reduce the risk of thermal runaway caused by power batteries in the above way.

Keywords: power batteries; thermal runaway; monitoring algorithm; warning information

1. INTRODUCTION

In the face of increasingly severe energy security and environmental crises, countries around the world are taking measures to reduce energy consumption and reduce the emission of harmful pollutants[1]. The development of new energy vehicles, represented by electric cars, have become a trend. With the continuous development of new energy vehicles, there have been more and more reports of related fire incidents[2]. Among them, the fire problem caused by power battery burning car is more prominent. According to research, in August 2020, the big data Alliance of New Energy countries released the Safety Supervision report on the National Supervision platform of New Energy vehicles, which showed that a total of 67 cars were burned from January to August 2019[3]. Inquire by recalling the official website, it can be seen that from early 2021 until now, almost 30,000 vehicles (all electric vehicles) have been recalled due to the risk of power batteries thermal runaway[4]. As users have higher and higher requirement for high mileage, it is inevitable to enhance the maximum driving range of electric vehicles by improving the energy density of power batteries[5-7]. However, the increase in energy density will lead to a significant rise in thermal energy of lithium batteries[8-11]. When it exceeds the maximum heat dissipation efficiency of electric vehicles, the working temperature of power batteries will continue to rise, ultimately resulting in the risk of thermal runaway[12]. At the same time, collision, extrusion, overcharging and other factors may also lead to a thermal chain reaction of lithium battery in a very short event[13-14], further developing into thermal runaway, smoke emission, fire, and even explosion accidents causing injuries or fatalities.

In order to reduce the occurrence of thermal runaway incidents in power batteries, research on the safety performance of power batteries has become an important direction[15-17]. Overall, the current research mainly focuses on two aspects: Firstly, improving the manufacturing process of power batteries by enhancing materials and improving the manufacturing process of separators to enhance the safety of power batteries[18-19]. Secondly, introducing a thermal runaway warning mechanism[20-23]. The corresponding characteristic gas will be produced at different stages of thermal runaway of power batteries. Through the power batteries management system and sensor real-time collection of relevant information, including internal resistance SOC and other parameters as the basis for thermal runaway prevention scheme.

Due to the relatively mature technology of batteries and limited room for improvement, most companies adopt a thermal runaway warning scheme to reduce related risks [24-26]. The thermal runaway warning scheme and implementation strategy have become particularly crucial. Most enterprises integrate the algorithm into the power batteries management system and give an early warning to the user by only taking some parameter changes of SOC (vehicle display or IP) [27-31]. However, this approach often leads to false alarms due to the simplicity of the algorithm and users may not receive timely warnings when they are not near the vehicle. Based on this, this paper designs an early warning scheme based on DCF. This DCF

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forms a set of remote thermal runaway early warning scheme by collecting real-time data related to power batteries and combining with other real vehicle data. The scheme can not only monitor and push the relevant thermal runaway risk vehicle information to users in real time, but also generate maintenance manuals for related risk vehicles combined with database to guide maintenance personnel to maintain related risk vehicles. Furthermore, a novel self-discharge warning algorithm is integrated for DCF, which uses the trend of ΔSOC over time to issue warnings. This set of thermal runaway warning scheme can well reduce the potential risks of various automobile company due to thermal runaway and improve user satisfaction.

2. OVERALL SCHEME DESIGN

The architecture of the thermal runaway early warning system of power batteries is shown in Figure 1. DCF receives the relevant vehicle data collected and automatically selects high-risk vehicles through the early warning algorithm and pushes thermal runaway messages. The main functions of each component are as follows:

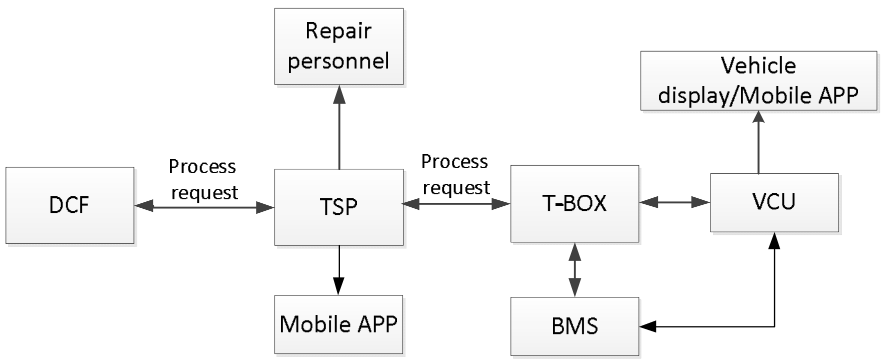

Figure 1.Thermal runaway warning monitoring architecture

DCF: Collect power batteries and other related data for high-risk vehicle analysis; push news about the risk of thermal runaway.

T-BOX: Responsible for collecting and uploading relevant data of the power batteries to the TSP; responsible for real-time storage of local power batteries management system and vehicle-related data.

TSP: Data service forwarding as a bridge between T-BOX and DCF.

Vehicle display /APP: Responsible for the early warning of the risk of thermal runaway.

3. SYSTEM FUNCTIONAL LOGIC

The functional logic of the thermal runaway early warning system of the power batteries is shown in Figure 2 and Figure 3. DCF identifies risky vehicles through algorithms and automatically generates a list of early warning frame numbers. At the same time, according to the related vehicle failure, the fault push information and maintenance manual are automatically generated through the large database. DCF will check the status of the faulty vehicle. If the faulty vehicle is online, the fault information will be pushed to the vehicle. If the faulty vehicle is not online, it will wait for the vehicle to come online and push the fault message again. The TSP platform is responsible for sending vehicle fault alarm messages to the vehicle networking terminal (T-BOX) of the whole vehicle. T-BOX forwards the fault alarm information to the BMS through the vehicle communication network. BMS stores and receives fault information and feeds back the results of the received information to DCF through T-BOX. If DCF fails to receive the feedback of the warning push notification from T-BOX within a certain period of time, it will wait for the vehicle to come online again before pushing it again.

In addition, after receiving the warning message, BMS will determine the state of the vehicle (driving or stationary).When the vehicle is running, send the power batteries system level fault 1 to the vehicle controller VCU, VCU performs fault handling measures and displays them to the user through the vehicle display / mobile APP; If the vehicle is in a stationary state, it sends power batteries system level 2 fault to the VCU, and the VCU executes fault handling measures such as disconnecting the high voltage and reminds the user through the vehicle display/mobile APP.

When the vehicle is at the risk of thermal runaway, the user needs to go to the maintenance station or contact the maintenance personnel before the vehicle can be restored. The maintenance personnel read the fault codes of the relevant early warning information through the diagnostic instrument, and download the maintenance instruction manual of the relevant faulty vehicles in DCF to complete the maintenance of the related vehicles. After the maintenance personnel have completed the maintenance, they also need to clear the fault code through the relevant equipment and feedback the maintenance records of the vehicle to the big data platform. Big data platform carries out a new round of monitoring according to the vehicle maintenance record data.

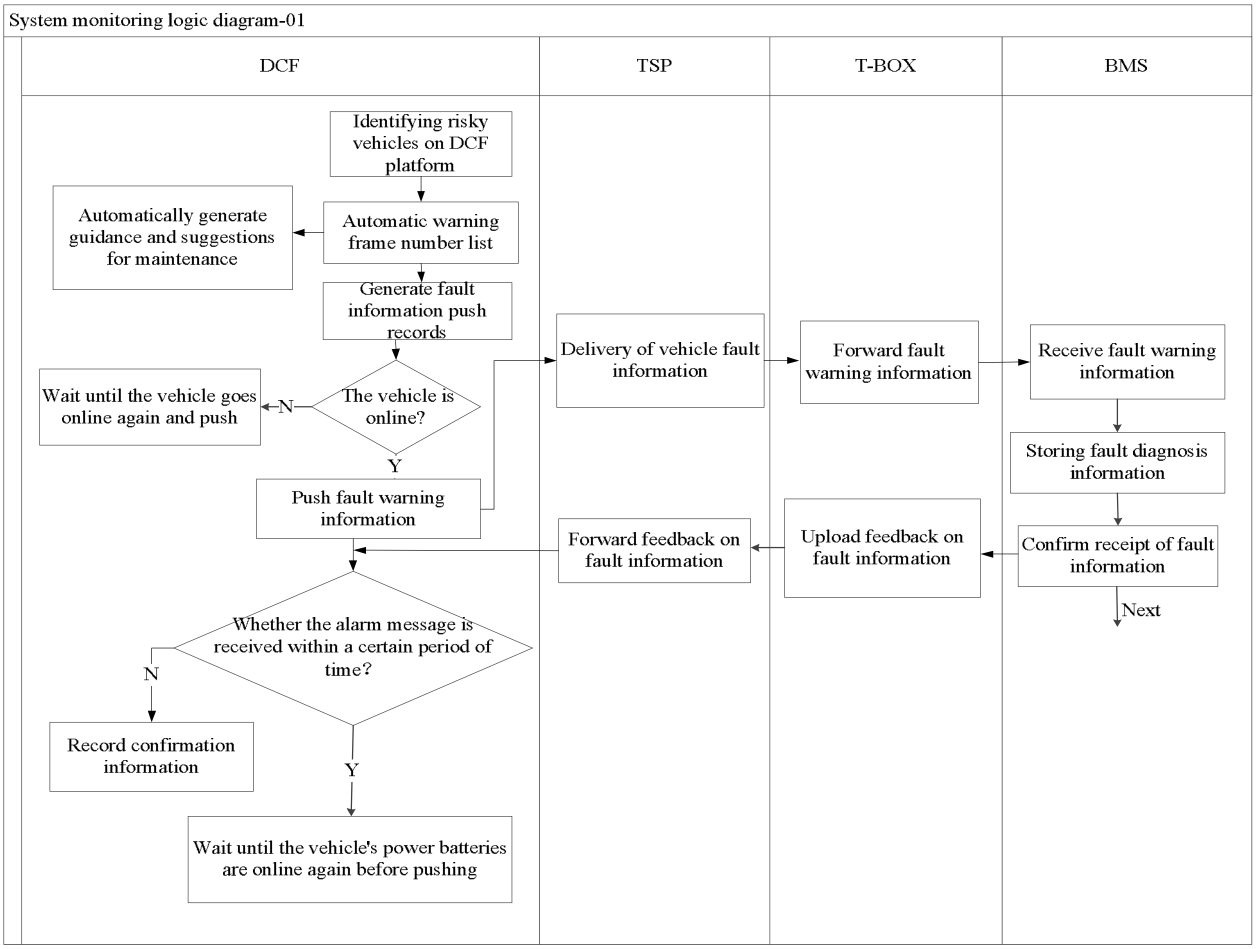

Figure 2. The system monitoring logic diagram-01

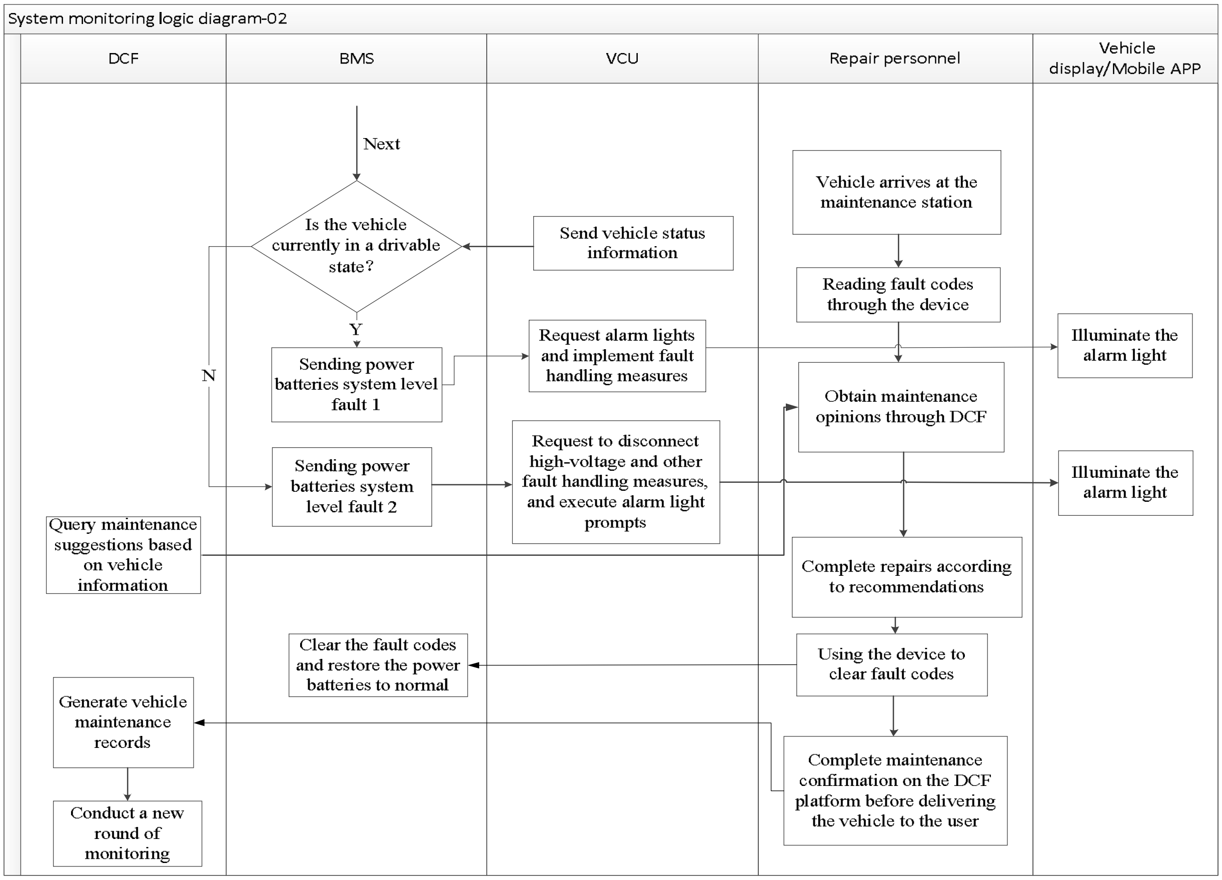

Figure 3. The system monitoring logic diagram-02

4. ALGORITHM DESIGN FOR THERMAL RUNAWAY RISK MONITORING SYSTEM

The core of thermal runaway risk monitoring is algorithm design. By screening different monomers, this algorithm shows the changing trend of Δ SOC which meets the conditions in the last month, and gives an early warning of the abnormal self-discharge of soft short circuit

(1) Principles of data screening:

a. The time difference between the first data record obtained through T-BOX after vehicle power-on and the last recorded time of the previous event is greater than 2 hours.

b. The difference between the first data record obtained through T-BOX after vehicle power-on and the last recorded mileage of the previous event is less than 0.2 km.

c. The difference between the first real-time SOC value obtained through T-BOX after vehicle power-on and the last recorded SOC value of the previous event is less than 0.5%.

d. The total voltage at the time of the first data obtained through T-BOX after vehicle power-on is greater than 120V, and the total current is less than 5A.

(2) Algorithm calculation rules:

a. DCF obtains relevant data from the vehicle through T-BOX, including time, cell voltage, unit number, SOC, mileage, vehicle speed, total current, total voltage, charging status, etc.

b. Count the charging status of the last time the vehicle was uploaded through T-BOX.

c. $\Delta SOC_i = SOC_i - AVG(SOC_i)$, i is the cell number.

d. According to the whole packet capacity, the abnormal and display anomalies are judged and displayed in four SOC intervals of 10-40,30-60,50-80,70-100. the number of SOC intervals and the starting and ending values of SOC intervals should be set to later adjustable.

(3) Principle of judgment:

Determination of the decreasing trend at time t:

a. Calculate the sum of ΔSOCi(t-a, t) for cell i from t-a to t.

b. Calculate the sum of ΔSOCi(t-a-b, t-b) for cell i from t-a-b to t-b, where a > b > 0.

If SUM(ΔSOCi(t-a, t)) - SUM(ΔSOCi(t-a-b, t-b)) < -3%, then the ΔSOC of cell i shows a decreasing trend.

There are three types of abnormal warning:

a. ΔSOC self-deviation (ΔSOC at time t - average value of ΔSOC in the previous week) decreases by more than 5%; calculate the rate of decrease: ΔSOC decrease value at time t / time interval for calculating ΔSOC at time t.

b. Continuous decrease in ΔSOC of a single cell, with three consecutive decreases greater than 2% within 14 days; calculate the rate of decrease: decrease value for three consecutive decreases / time interval for three consecutive decreases.

c. Outlier in ΔSOC of a single cell: ΔSOC of the single cell is less than -18%.

Through the above algorithm rules, theΔSOC decline rate of the relevant early warning vehicles is taken as the criterion for determining the risk grade (the greater the decline rate, the higher the risk coefficient).

The early warning vehicle graphics displayed by DCF should also include the parameters shown in Table 1, and the points corresponding to abnormal conditions should be highlighted.

Table 1. Displays the main parameters of the alerted vehicles.

Serial number	Display mode	Graphic format	X-axis	Y-axis	Filtering criteria
1	ΔSOC changes over time	Scatter plot	Real time	ΔSOC	Power batteries cell ID
2	ΔSOC module distribution	Scatter plot	Cell ID	ΔSOC	Collection time points
3	ΔSOC descent rate sorting	List	—	—	Alert types、vehicle models、VIN、dates, etc

5. Experimental verification

5.1 Indicator verification - risk identification

The early warning of power batteries thermal runaway needs to be able to automatically identify risky vehicles within a certain period of time, and be able to download risky vehicle data through DCF,Table 2 shows the simulated thermal runaway risk fault data of a vehicle at different time periods downloaded through the vehicle terminal, and Table 3 shows that DCF can obtain the risk fault information at different time points in Table 2 within a certain period of time (time deviation is less than 6s) . Through the analysis of the data in the table, the test results are consistent with the original design.

Table 2. Early warning information of power batteries for real vehicle simulation.

VIN	Effective value	Time
LS6A3E034MB3xxxx	22	2022-08-09 13:00:02
LS6A3E034MB3xxxx	22	2022-08-11 13:40:47
LS6A3E034MB3xxxx	22	2022-08-11 14:06:10
LS6A3E034MB3xxxx	22	2022-08-11 14:20:47
LS6A3E034MB3xxxx	22	2022-08-11 14:50:33
LS6A3E034MB3xxxx	22	2022-08-12 10:00:02

Table 3. Obtain risk vehicle information through DCF.

VIN	Application	Cell ID	Vehicle type	Risk level	Abnormal location	Trigger time	Exception name
LS6A3E034 MB3xxxx	Test Car	001	SCH004XX	4	Chongqing	2022-08-09 13:00:04	Temperature difference alarm
LS6A3E034 MB3xxxx	Test Car	001	SCH004XX	4	Chongqing	2022-08-11 13:40:50	Battery high temperature alarm
LS6A3E034 MB3xxxx	Test Car	001	SCH004XX	7	Chongqing	2022-08-11 14:06:14	Overvoltage alarm
LS6A3E034 MB3xxxx	Test Car	001	SCH004XX	7	Chongqing	2022-08-11 14:20:51	Insulation alarm
LS6A3E034 MB3xxxx	Test Car	001	SCH004XX	7	Chongqing	2022-08-11 14:50:35	DC-DC status alarm
LS6A3E034 MB3xxxx	Test Car	001	SCH004XX	4	Chongqing	2022-08-12 10:00:05	Under voltage alarm

5.2 Indicator verification - risk push

After the vehicle has a thermal runaway warning risk, the DCF can push the relevant vehicle information to the relevant personnel in a certain way. Table 4 shows that after part of the thermal runaway risk failure occurs, the maintenance personnel can obtain the risk vehicle information in some way. Through the analysis of the data in the table, the test results are consistent with the original design.

Table 4. Maintenance personnel receive vehicle information about the risk of thermal runaway.

Risk level	Exception name	Abnormal location	Abnormal time	Pressure difference	Maximum voltage unit number	Minimum voltage unit number	VIN	Processing Tip
low	Temperature difference alarm	Chongqing	2022-08-09 13:00:04	0.0041	28	32	LS6A3 E034 MB3xx xx	check the abnormal temperature of the vehicle battery
high	Overvoltage alarm	Chongqing	2022-08-11 14:06:14	0.0023	15	37	LS6A3 E034 MB3xx xx	The vehicle is in danger of overvoltage, please handle it
high	Insulation alarm	Chongqing	2022-08-11 14:50:35	0.003	21	69	LS6A3 E034 MB3xx xx	The vehicle is at high risk of getting out of control. Please deal with it

5.3 Indicator verification - user prompt

When a vehicle encounters a thermal runaway risk, the user can receive timely warning messages of different levels. Different strategies are implemented based on different warnings. For a level 4 fault, power limit measures are taken, while for a level 7 fault, a direct prompt for high-power system failure is given, requiring the user to stop the vehicle (as shown in Figure 4).

Level 4 fault prompt

Level 7 fault prompt

Figure 4.Thermal runaway risk vehicle reminder message

6. CONCLUSION

As a core component of a vehicle, the power battery's research on thermal runaway has become particularly important. It is the main cause of vehicle fires and poses a threat to the safety of occupants. Based on this, the government has issued relevant regulations and policies, requiring automakers to monitor abnormal conditions of the power batteries in the vehicles they sell [32]. The thermal runaway early warning scheme designed in this paper integrates the abnormal algorithm of soft short circuit self discharge of power batteries into DCF.DCF combined with the real-time data of the whole vehicle can accurately and timely warn and maintain the related risky vehicles, effectively avoid the risk of thermal runaway of vehicles, and at the same time avoid the negative effects caused by thermal runaway, and improve the quality of vehicles.

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