Research on Transportation Risk Assessment Method of Lithium-ion Battery Energy Storage System

Yibin Zhao*, Wenji Fan, Shihui Tian

Research Institute of Highway Ministry of Transport, Beijing, China

*yb.zhao@rioh.cn

Abstract. China's lithium-ion battery industry has developed rapidly and has become the world's largest producer of lithium-ion batteries. The energy storage system with lithium-ion battery as the main component belongs to dangerous goods in road transportation, but there is no effective method for evaluating the transportation risk of lithium-ion battery energy storage system. This paper studies the safety of lithium-ion battery energy storage system in highway transportation, focusing on five aspects, including natural environmental factors, energy storage system parameters, road traffic conditions, emergency rescue conditions, and safety management measures. Based on the analytic hierarchy process (AHP), a risk assessment method for the transportation of lithium-ion battery energy storage system is proposed. The risk assessment is carried out for the actual transportation cases from Guangxi Province to Xinjiang Province in China, and the corresponding measures and suggestions are put forward.

Keywords: Road Transportation, Energy Storage System, Risk Assessment.

1 Introduction

With the rapid transformation and upgrading of the global energy structure, more and more lithium-ion battery energy storage systems (hereinafter referred to as "energy storage systems") are used in wind power and photovoltaic power plants, integrated light storage and charging stations in service areas, household emergency power and other scenarios, and the output of energy storage lithium batteries has surged. In 2024, China's output of energy storage lithium-ion batteries reached 260Gwh, an increase of 40.5% year on year. As China's energy storage system manufacturing enterprises are mostly distributed in Fujian, Guangdong, Anhui and other eastern coastal and southwest regions, while the provinces with large installed capacity of energy storage system are mainly Xinjiang, Inner Mongolia, Qinghai and other northwest regions, with obvious uneven distribution of production and sales and large demand for long-distance transportation, the transportation volume of energy storage system also increases rapidly.

The thermal runaway of lithium-ion batteries may occur under high temperature, extrusion, collision and other conditions, while the energy storage system generally contains thousands of lithium-ion batteries, and the risk of thermal runaway is super-

A. Mallik et al. (eds.), *Proceedings of the 2025 6th International Conference on Management Science and Engineering Management (ICMSEM 2025)*, Atlantis Highlights in Economics, Business and Management 4,
https://doi.org/10.2991/978-94-6463-845-5_54

imposed and amplified. In addition, since the lithium-ion battery can generate oxygen itself in the event of thermal runaway, even if a large amount of water is used to extinguish the open fire, it is very easy to re ignite. At present, there is no effective emergency treatment method. In January 2025, a truck loaded with energy storage system in Taiwan Province overturned and ignited spontaneously. After more than 9 hours of extinguishing, the vehicle fire ignited again. At present, the research on the safety risk of thermal runaway of energy storage system mainly focuses on the modeling of thermal runaway behavior of energy storage system [1][2], and does not involve the transportation scenario of energy storage system. Although some research results have studied the safety risks of some dangerous goods transportation based on historical data, they also do not involve the targeted research on the energy storage system [3][4]. Therefore, it is necessary to study the evaluation method of transportation risk of energy storage system, and provide reference for the safety management of long-distance transportation of energy storage system.

2 Analysis of Risk Factors

2.1 Natural Environmental Factors

The weather of the transportation section of the energy storage system has a certain impact on the transportation risk. Extreme high temperature weather may increase the activity of lithium-ion battery in energy storage system, which is more prone to thermal runaway. In addition, strong rainfall and snowfall may also cause the energy storage system transport vehicle to roll over, increasing the possibility that the lithium-ion battery of the energy storage system is damaged and out of control.

2.2 Parameters of Energy Storage System

The parameters of the energy storage system will also directly affect the transportation safety risk. The larger the rated capacity of the energy storage system, the higher the SOC of the charge, and the more energy it carries during transportation. In the process of thermal runaway of the energy storage system, the electric energy carried by itself will be converted into heat energy, causing continuous fire and even explosion. In addition, different energy storage systems with different specifications have different ways of loading and fixing during transportation, which also affects the risk of sliding of the energy storage system to a certain extent.

2.3 Road Traffic Conditions

The road condition and traffic volume of the energy storage system transport vehicle route are important factors affecting the occurrence of road traffic accidents. In general, the more active vehicles, the higher the proportion of bridge section and tunnel section, and the greater the probability of accidents, the more likely the transport vehicles of the energy storage system are to have collision, rollover, and other traffic accidents, and the greater the risk of transportation. In addition, the longer the transportation vehicle of energy storage system travels in a single day, the driver is more prone to fatigue driving, thus increasing the probability of traffic accidents.

2.4 Emergency Rescue Conditions

Once a fire occurs in the energy storage system due to out of control heat, a large amount of water needs to be used for cooling. Therefore, the transportation accidents of the energy storage system need to rely on the local fire department for professional rescue, and the distance of emergency rescue has become a key factor affecting the rescue efficiency. In addition, the bridge, tunnel and other sections of the highway are more difficult to evacuate and more likely to cause serious casualties than the general sections.

2.5 Safety Management Measures

In China, small energy storage systems can be transported by dangerous goods transport vehicles. Besides the driver, the vehicles also need to be equipped with escorts. Large energy storage systems (with a total weight of more than 49 tons) can only be transported by large cargo transport vehicles. At present, escorts are not required. In addition, some energy storage system transport vehicles will be equipped with temperature, smoke sensing and other alarm devices in the cargo compartment, which can alert the driver at the first time in case of thermal runaway of the energy storage system. Therefore, the personnel, vehicles, intelligent monitoring and other safety management elements of the energy storage system transportation also have a direct impact on the transportation risk.

3 Risk Assessment Model

Since the risk assessment model we proposed contains multiple indicators, it is necessary to clarify the contribution of different indicators to the overall transportation risk. Constructing a transportation risk assessment model for energy storage systems using Analytic Hierarchy Process (AHP), which is a commonly used method for risk assessment of dangerous goods transportation [5-7]. The transportation risk assessment of energy storage system mainly includes the following steps: first, build the model framework, determine the main levels of the model and the assessment indicators included in each level; Secondly, the importance matrix is constructed according to the contribution of each indicator to the upper level indicator; Third, calculate the weight of each indicator in each level and analyze the rationality of indicator weight; Finally, according to the actual situation of the transportation route of the energy storage system evaluated, the corresponding evaluation indicator is assigned, the risk value R of the energy storage system transportation is calculated, and the risk level is divided by certain criteria.

3.1 Model Structure and Included Indicators

The risk assessment model for energy storage system transportation includes multiple levels. R represents the overall risk of energy storage system transportation, and the five main indicators (R1-R5) in the next level directly affect the overall risk R. The bottom 14 evaluation indicators (I1-I14) correspond to the five indicators R1-R5 according to their types (see Fig. 1).

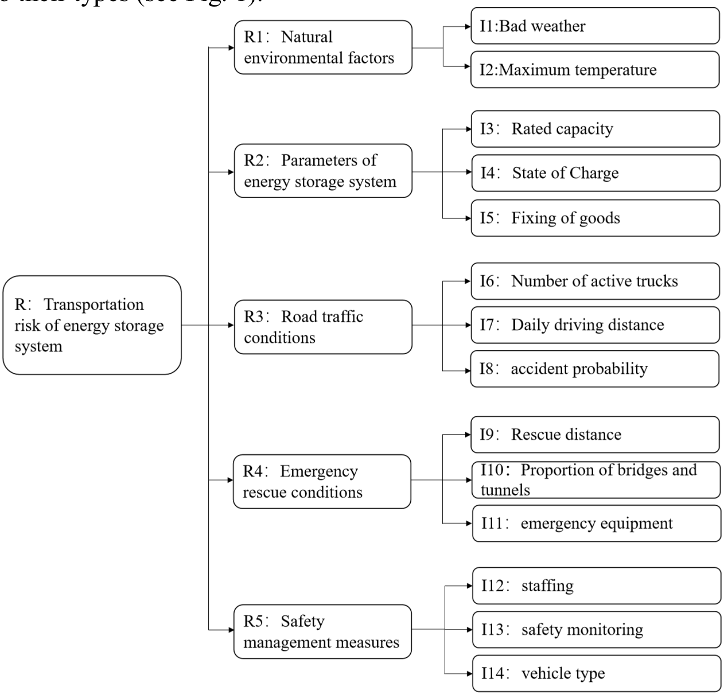

Fig. 1. Model hierarchy and indicators.

3.2 Construct Importance Matrices

Starting from the five main indicators (R1~R5) of the model, construct an importance matrix between different indicators at the same level based on Table 1.

Table 1. Value basis for importance matrix.

The value of k_{ij}	Relative importance of i and j
$k_{ij}=1$	Indicator i and indicator j have the same importance
$k_{ij}=3$	Indicator i is slightly more important than indicator j
$k_{ij}=5$	Indicator i is more important than indicator j
$k_{ij}=7$	Indicator i is much more important than indicator j
$k_{ij}=2,4,6,8$	The relative importance is between the above
Reciprocal value	$k_{ji}=1/k_{ij}$

Calculate the importance matrix of indicators R1~R5 relative to the overall risk R (see Table 2).

Table 2. Importance matrix of R.

R	R1	R2	R3	R4	R5
R1	1	1/7	1/5	1/5	1/5
R2	7	1	2	5	4
R3	5	1/2	1	3	1
R4	5	1/5	1/3	1	1/2
R5	5	1/4	1	2	1

Similarly, calculate the importance matrix of indicators I3~I6 relative to risk R2 (see Table 3).

Table 3. Importance matrix of R2.

R2	I3	I4	I5
I3	1	1/7	1/5
I4	7	1	2
I5	5	1/4	1

The calculation method for the remaining importance matrices is similar.

3.3 Indicator Weight Calculation and Consistency Test

According to the actual situation, assign values to the lowest level indicators I1~I14 according to the principles in Table 4.

Table 4. Principle of indicator assignment.

Severity of risk	Low risk	Moderate risk	High risk	Extremely high risk
Indicator assignment	5	10	15	20

Then use formulas (1) and (2) to check the consistency.

$$CI=(\lambda max-N)/(N-1) \tag{1}$$

$$CR=CI/RI \tag{2}$$

In the formula, λmax is the largest eigenvalue of the importance matrix, N is the order of the matrix, RI is a random variable.If the consistency test value CR<0.1, the indicator weight is considered reasonable. See Table 5 for all indicator weights and test results.

Table 5. Calculation and test results of indicator weights.

Previous level indicator	Indicators	Weights	Test results
R	R1	0.041	CI=0.061 CR=0.054
	R2	0.453	
	R3	0.219	
	R4	0.110	
	R5	0.177	
R1	I1	0.333	-
	I2	0.667	
R2	I3	0.556	CI=0.027 CR=0.052
	I4	0.354	
	I5	0.090	
R3	I6	0.182	CI=0.027 CR=0.052
	I7	0.703	
	I8	0.115	
R4	I9	0.709	CI=0.043 CR=0.082
	I10	0.214	
	I11	0.077	
R5	I12	0.633	CI=0.019 CR=0.037
	I13	0.260	
	I14	0.106	

Calculate the risk values of indicators R1-R5 and the overall risk value R, and determine the safety risk level according to the criteria in Table 6.

Table 6. Risk level determination criteria.

Risk level	Risk value range	Degree of risk
I	R<12	Low risk
II	12≤R<14	Moderate risk
III	14≤R<16	High risk
IV	R>16	Extremely high risk

4 Instance Test

Taking a transportation route of energy storage system from Guangxi Province to Xinjiang Province in China as an example, the transportation risks of energy storage system in each section passing through five provinces (numbered P1~P5) were evaluated. The overall risk value and second level risk value of transportation passing through the five provinces are shown in Table 7.

Table 7. Calculation results of transportation risks for energy storage systems.

Province	Risk level	R	R1	R2	R3	R4	R5
P1	I	11.63	1.00	2.65	2.00	1.08	3.00
P2	I	10.92	1.67	2.65	1.12	1.29	3.00
P3	II	12.22	2.00	2.65	1.89	2.00	3.00
P4	II	14.36	2.67	2.65	3.11	3.20	3.00
P5	III	15.08	4.00	2.65	3.41	3.42	3.00

From the evaluation results, the transportation of energy storage systems through Guizhou Province and Guangxi Province is considered low-risk, while passing through Sichuan Province and Gansu Province is considered medium risk, and passing through Xinjiang Province is considered high-risk. The main reasons for the high risk of energy storage system transportation passing through Xinjiang Province are natural environmental factors R1, road traffic conditions R3, and emergency rescue conditions R4. Specifically, the extreme high temperatures, long-distance transportation, and long emergency rescue distances in Xinjiang have increased transportation risks.

5 Suggestions

The transportation department may consider equipping fire trucks and fire brigades on highways to facilitate the rescue of energy storage system transport vehicles that have accidents on nearby roads in some long-distance transportation channels. In addition, corresponding emergency plans should be developed for transportation vehicles of energy storage systems passing through bridges, tunnels, and other difficult sections for personnel evacuation, regularly carry out drills through simulated accidents, evaluate and improve the effectiveness of the emergency plan in simulated accident scenarios, and further improve the level of emergency rescue by allowing emergency rescue personnel to participate in drills.

In the future, we can carry out targeted research on the safety technical conditions of energy storage system transportation, clarify the standardized process of energy storage system safety transportation, further unify the differences in transportation safety management in different provinces, and effectively improve the overall safe operation level of the industry.

6 Conclusions

This article analyzes the factors that affect the transportation safety of energy storage systems, constructs a multi-level risk assessment model for energy storage system transportation, and selects typical transportation cases from Guangxi to Xinjiang in China for risk assessment, proposing corresponding safety management measures and suggestions. In reality, transportation departments can conduct risk assessments on the main transportation routes of energy storage systems within their jurisdiction, determine corresponding risk levels, and guide energy storage system transportation vehicles to choose transportation routes reasonably. At the same time, energy storage system transportation companies can also use the evaluation results to provide safety reminders to drivers who are about to pass through high-risk road sections, reducing the risk of transportation accidents.

References

1. Qi, C., Zhu, Y., Gao, F.: Mathematical model for thermalbehavior of lithium ion battery pack under overcharge. International Journal of Heat and Mass Transfer 124, 552–563 (2018).
2. Feng, X., Liu, L., Ouyang, M.: A 3D thermal runawaypropagation model for a large fommat lithium ion battery module. Energy 115, 194-208 (2016).
3. Quddus, N., Yu, M., Tamim, N.: Risk assessment of class 3 (PG I & III) hazardous materialsin transportation. Process Safety Progress 37(3), 376-381 (2018).
4. Shen, X., Yan, Y., Li, X.: Analysis on tank truck accidents involved in roadhazardous materials transportation in china. Traffic injury prevention 15(7), 175-184 (2014).
5. Li, S., Wu, Y., Bai, X.: Research on risk assessment of road dangerous goods transportation based on AHP and entropy weight method. Journal of Chongqing Jiaotong University 20(02), 43-50 (2020).
6. Wang, L., Jin, C., Li, C.: Comprehensive Evaluation on Safety Management of Road DangerousGoods Transportation Enterprises Based on Multi-level Gray Relational Analysis. Conference Series: Earth and Environmental Science 526(1), (2020).
7. Zhang, Y., Lv, S., Wang, W.: Safety evaluation of hazardous chemical road transportation based on AHP and grey clustering. Safety 41(03), 54–60 (2020).