PREVENT+

Understand PaRticlE VENTing and Arcing for Safer Batteries Plus

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Projektbeschreibung

Die Elektromobilität und Li-Ionen basierende Batterietechnologie hat in den letzten Jahren große Fortschritte gemacht. Die Hersteller haben es geschafft, die Energiedichte der Li-Ionen Zellen auf über 300 Wh/kg zu erhöhen. Damit ergeben sich positive Effekte: Senkung der Materialkosten und des Ressourcenverbrauchs, günstige Elektrofahrzeuge mit hoher Reichweite für die Kunden. Es entstehen auch neue Herausforderungen. In einem worst-case Fehlerfall wird die gespeicherte Energie als exotherme chemische Reaktion (Thermal Runaway) freigesetzt.
In Experimenten wurde beobachtet, dass die neuen Zellgenerationen heftiger reagieren und bei der Reaktion zusammen mit dem entstehenden Gas auch hohe Mengen an Partikeln ausstoßen. Diese Partikel können die Isolation im Batteriesystem beeinträchtigen und zur Bildung von Lichtbögen beitragen. Lichtbögen habe einen sehr zerstörerischen Einfluss und können spontan unkontrollierbare Batteriebrände verursachen.
Im Projekt wird der Einfluss der Gas-Partikel-Strömung auf die Sicherheit der Batterie quantifiziert. Es wird festgestellt, mit welchen Mechanismen die Gas-Partikel-Strömung die Entstehung von Lichtbogen begünstigt. Zu untersuchende Mechanismen sind:

• Partikelausgasung: Thermische/abrasive Beschädigung elektrischer Isolatoren, Verringerung der Durchschlagsspannung
• Partikelablagerung: Überbrückung elektrisch isolierender Luftspalte, Erhöhung der Kriechströme
• Partikelaufladung: Aufladung durch Triboelektrizität, Ladungstrennung, spontane Entladung

Die Ergebnisse des Projektes sind

• Simulationsframework für Partikelbeladene Ausgasung im Batteriesystem
• Neue Prüfstände und Testmethoden zur Charakterisierung der Partikelausgasung
• Neue Bewertung der Isolationskoordination und der Sicherheitskonzepte
• Leitfaden für Konstrukteure, wie kann die Sicherheit auch mit den Hochenergiedichten Zellen gewahrt werden

Abstract

In the recent years both, the electromobility and the Li-ion battery technology showed impressive progress. The cell manufacturer achieved an increase of the energy density of mass-produced cells above 300 Wh/kg. Thus, making possible

lower material cost as less raw-material usage for the manufacturer and cheaper electric vehicles with higher range for the consumer.
With higher energy density new safety challenges arise. In the worst-case failure of a cell (the Thermal Runaway) the stored energy is released in an exothermic reaction. In recent Thermal Runaway experiments with newer cell generations a more intense reaction and the release of high amounts of gas and particles was observed. The particles may influence the insulation inside the battery-pack and could start electric arcing. Electric arcs have very destructive effects and can spontaneously cause uncontrollable battery fires.
The goal of this project is to quantify the safety consequences of gas-particle release. We will research mechanism of ignition of electric arcing by particles. Such mechanisms are
• Particle-venting: thermal/abrasive damage to electric insulators, reduction of breakdown voltage in an air-gap
• Particle-deposition: shorting of electrically insulating air-gaps, electric breakdown along particle covered surface of insulators
• Particle-charging: effects of triboelectricity, charge separation and discharge in the particle flow
The results of the project are
• Simulation framework for particle-gas flow inside a battery pack
• New testing methods and test stands to characterize particle-venting
• Review of insulation coordination and safety concepts for battery packs
• Guideline for the engineers in how to maintain safety in battery packs which utilize cells with high energy density

Endberichtkurzfassung

The funded project Prevent+ focused on battery safety, specifically on the worst-case failure of a cell— thermal runaway —during which the stored energy is released through an exothermic reaction. During thermal runaway, newer generations of Li-ion cells exhibit intense reactions and release large amounts of gas and particles. The goal of the project was to quantify the safety consequences of particle release.

Virtual Vehicle and Green Testing Lab developed and utilized test rigs to quantify insulation failure and to visualize material ejection from the cells. Safety experiments revealed that the released material can easily cause sparks and arcing between unprotected wiring, even at voltages as low as 48 V. It was found that ejected electrolyte causes electrical creepage and sparks on wetted PTFE insulator surfaces between electrodes at 400 V. Ejected copper flakes and particles triggered arcing in air gaps as large as 10 mm [1]. Deposited particles also caused insulation failure on unprotected PCBs.

To further understand the failure mechanisms, the consortium developed CFD tools to simulate particulate venting, taking into account the triboelectrification effect. Advanced simulations were conducted for two industrial use cases to analyze gas-particle venting and triboelectric charging during fault scenarios in battery systems. The objective was to better understand particle behavior during outgassing events and how this can lead to electrical discharges.

The simulations yielded practical recommendations for improving safety in battery module design, including optimal venting channel configurations to prevent particle deposits, guidance on necessary insulation at critical locations, and insights into minimizing the risk of electric discharge. Specifically, the results indicated that particles can quickly accumulate charge upon contact with boundaries, depending on particle size, velocity, and restitution coefficient. The simulations also showed that heat loss from the walls significantly affects the electric field distribution within the vent channel. Most importantly, regions

with a high solid volume fraction are critical with respect to arcing, due to charge accumulation and elevated triboelectric voltages.

The developed simulation framework is intended to support future design efforts by reducing the need for costly physical testing and minimizing the risk of arcing events. These outcomes contribute directly to safer and more efficient battery systems in automotive applications [2–3].

Overall, it is strongly recommended to ensure proper insulation and protection of voltage-carrying components so that a single-cell thermal runaway event does not result in arcing or secondary failures within the battery pack.

[1] T. Ledinski, A. W. Golubkov, O. Schweighofer, and S. Erker, “Arcing in Li-Ion Batteries,” Batteries , vol. 9, no. 11, Art. no. 11, Nov. 2023, doi: 10.3390/batteries9110540 .

[2] J. Abraham, M. Gruber, A. Kospach, M-S. Salehi and S. Radl, A Compressible Two-Fluid Model for the Simulation of Triboelectrification, conference paper to be presented at the Conference on Modelling Fluid Flow CMFF’25, Budapest, 2025

[3] J. Abraham, M-S Salehi, A. Kospach, S. Radl, 2023. “Towards rigorous simulation of thermal runaway of Lithium-Ion-Batteries: the effect of particle flow and triboelectrification”, 4th Aspherix and CFDEM Conference, Linz: 29

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