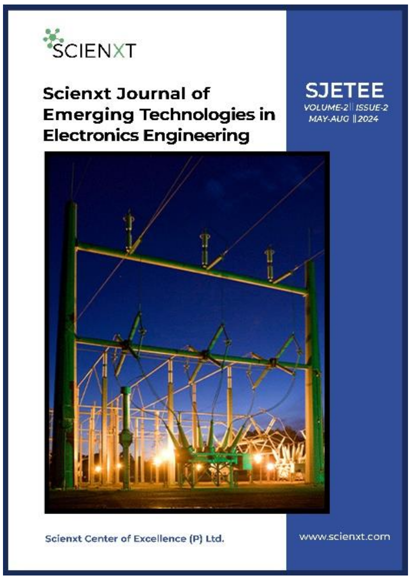

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Enhancing electric vehicle battery reliability: failure recognition, testing, and life prediction

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Abstract:

With the pressing need to mitigate vehicle emissions and the escalating demand for fossil fuels, automotive manufacturers worldwide are exploring alternative avenues to introduce new car models that can captivate the market. Electric Vehicles (EVs) have emerged as a promising solution to leverage current global concerns regarding fossil fuel prices and environmental impact. Given the pivotal role of car batteries in the overall performance of EVs, numerous researchers are dedicated to enhancing this crucial component. This paper delves into the reliability of EV batteries, encompassing aspects such as failure recognition, testing methodologies, and life prediction techniques. By addressing these key elements, the paper aims to identify reliability features, ultimately leading to the extension of battery lifespan.

Keywords:

Electric vehicle battery, Reliability improvement.

1. Introduction:

Electric Vehicles (EVs) rely on specific types of batteries, such as advanced Pb-acid, NiMH, or Li-ion, as their primary power source, making these batteries a vital component of EV technology. As the EV industry continues to expand, the advancement of battery technology becomes increasingly crucial due to its integral role in powering these vehicles. However, one of the significant challenges hindering the widespread adoption of EVs is the need to ensure the performance and reliability of their batteries over a specified period.

According to Chan (2007), several factors contribute to the limitations of battery-powered EVs, including high initial costs, limited driving range, extended charging times, and reduced passenger and cargo space. The ideal EV battery should possess sufficient power to enable long-range driving on a single charge, while also delivering stable acceleration and ascending power capabilities. Moreover, ensuring high safety standards, minimal maintenance requirements, and recyclability are essential attributes that would make an EV battery an attractive option for consumers.

Therefore, the reliability of EV batteries plays a pivotal role in the decision-making process for car manufacturers looking to introduce EVs widely to consumers. As highlighted in Tollefson's (2008) article, battery technology represents a significant technical barrier for EV adoption, emphasizing the critical need for advancements in this field. This paper aims to address the challenges surrounding EV battery reliability by exploring failure recognition, testing methodologies, and life prediction techniques, with the ultimate goal of extending battery lifespan and enhancing overall EV performance.

2. Battery failure types:

Understanding the failure modes of Electric Vehicle (EV) batteries is crucial for enhancing their reliability and performance. Failure types can be categorized into battery operating conditions and chemical processes. Addressing these failures through appropriate testing methods and life prediction models is essential to ensure battery safety and compliance with regulations.

2.1. Battery operating conditions failures:

2.1.1. Grid corrosion:

The primary cause of battery failure is grid corrosion, where the positive grid corrodes over time, reducing conductivity and capacity. This corrosion accumulates at the bottom of the cell, forming a conductive path. To mitigate this, low porosity thicker grids manufactured using bottom-pour casting can be employed.

2.1.2. Grid growth:

Premature battery failure can occur due to grid growth, leading to cracks in the battery container, especially at terminal posts. Design modifications, such as integrating extra space for expansion, can address this issue.

2.1.3. Discharging of negative plate:

Over time, discharging of the negative plate occurs as it takes in oxygen released by the positive plate during charging. New battery designs incorporate catalysts that recombine oxygen and hydrogen, maintaining the negative plate at full charge.

2.2. Chemical process failures:

2.2.1. Dry-out:

Extensive overcharging or overheating can lead to dry-out, causing water loss from the cell and reduced separator conductivity. Adding catalysts that recombine oxygen and hydrogen can help recover lost water and prevent dry-out.

2.2.2. Sulfation:

Sulfation occurs when lead sulfate crystals form and fail to redissolve during charging, reducing battery capacity. Design modifications, such as appropriate plate grid design, can enhance the battery's ability to resist sulfation buildup.

By addressing these failure types through appropriate design modifications and employing advanced testing methods, the reliability and performance of EV batteries can be significantly improved, ensuring their longevity and safety for public use.

Table. 3.1: Tests in USABC Test Procedures Manual

Test Name	*Description*
Core Battery Performance Test	
Constant current discharge	Determines sustained discharge power capability of a battery at 2/3

Test Name	***Description***
	of its open circuit voltage at various depths of discharge (30s).
Peak power	Conducts constant power discharge/charge cycles to define battery voltage versus power behavior as a function of depth of discharge.
Variable power discharge	Simulates electric vehicle driving behavior, including regenerative braking, to assess battery performance and life.
Federal Urban Driving Schedule (FUDS) regime	A demanding profile reflecting high power peaks frequency and maximum regenerative charging to discharge power ratio.
Dynamic stress test regime	Effectively simulates dynamic discharging and can be implemented with standard laboratory equipment.
Special Performance Test	
Partial discharge, Stand loss, Sustained hill-climb power, Thermal performance, Battery vibration, fast charging	Various specialized tests to assess specific performance aspects of batteries.
Safety and Abuse Test	
Safety testing	Addresses conditions related to government regulations and expected accident exposures.
Abuse testing	Exposes batteries to mechanical, electrical, and environmental stresses to simulate worst-case scenarios.
Life Cycle Test	
Accelerated aging	Speeds up relevant failure modes and degradation mechanisms to determine aging factors precisely.
Actual-use simulation	Simulates real-world EV battery conditions to validate accelerated life-cycle test results.

Test Name	***Description***
Baseline life test	Determines battery life under reference test conditions for comparison with results from accelerated life testing.

These tests outlined in the USABC Test Procedures Manual cover a wide range of factors crucial for assessing the performance, safety, and longevity of EV batteries. They provide a comprehensive framework for evaluating battery reliability under various operating conditions and stressors, ensuring that batteries meet stringent performance standards and regulatory requirements.

3. Battery testing method:

The United States Advanced Battery Consortium (USABC) developed the EV battery test procedures manual (second revision) in January 1996, providing procedural information necessary for battery testing. Formed by the U.S. Department of Energy (DOE), USABC aims to develop advanced EV batteries competitive with conventional internal combustion engine vehicles in terms of performance and price.

The typical battery test flow outlined by the USABC EV battery test procedures manual includes core battery performance testing, special performance testing (optional based on manufacturer requirements), safety and abuse testing, and life cycle testing. Core battery performance testing focuses on mandatory electrical performance tests, while special performance testing addresses specific requirements. Safety and abuse testing ensure system safety and compliance with regulations, identifying any design deficiencies that may pose risks to public safety. Standard procedures in life cycle testing assess if the expected service life of EV batteries meets USABC requirements, using accelerated aging and normal use conditions to characterize degradation in electrical performance and identify relevant failure mechanisms. Table. 3.1 provides details of tests applied by USABC for battery testing.

In addition to USABC standards, some researchers have proposed battery testing methods tailored to specific battery types for EVs. For example, Poscoe and Anbuky (2003) developed an automated battery test system for VRLA battery behavioral research, focusing on key parameters such as voltage, current, and temperature. This testing technique serves purposes such as quality assurance, design verification, performance assessment for battery manufacturers, validation for battery users, and battery behavioral research for engineers developing prediction algorithms.

4. Life prediction method:

Battery lifetime prediction is a widely discussed topic among researchers globally, with various models proposed based on battery types and parameters.

Rahmatov and Virudhula (2001) introduced an analytical expression to estimate battery lifetime for different time-varying loads, considering changes in the concentration of electroactive materials inside the battery. Sauer and Wenzl (2007) discussed three approaches for VRLA battery lifetime prediction: physico-chemical aging model, weight Ah aging model, and event-oriented aging model, comparing them in terms of parameter identification, model complexity, and calculation speed.

Marano et al. (2009) employed different approaches for Li-ion battery lifetime estimation, including performance-based models and weighted Ah-throughput models. Performance-based models simulate changes in battery performance values over time. Save your chat history, share chats, and personalize your experience.

5. Ways of improvement:

Improving the reliability of Electric Vehicle (EV) batteries is critical for enhancing their performance and longevity. Here are several strategies for achieving this:

5.1. Thermal protection:

Maintaining the battery within the recommended operating temperature range (20°C to 30°C) is crucial for optimizing charge capacity and life cycle. Integrating heating and cooling elements into the battery system can help regulate temperature effectively. Research such as that by Jarrett and Kim (2011) on the design optimization of EV battery cooling plates can contribute to better temperature control.

5.2. State of charge (SoC) and state of health (SoH) monitoring:

Accurate estimation of SoC and SoH is essential for efficient battery management. SoC estimation, often referred to as the "Gas Gauge," allows users to gauge remaining energy accurately, while SoH measurement assesses the battery's ability to store energy over time.

Wang et al. (2007) emphasize the importance of precise SoC estimation for efficient battery pack management.

5.3. Cell equalization (balancing):

Balancing cells in an EV battery pack helps prevent large long-term imbalances and protects cells from overstress. Balancing methods involve redistributing charge from high-charge cells to lower-charge cells, reducing the risk of overcharging and overstressing individual cells.

5.4. Tolerance setting:

Minimizing variability among cells within a battery pack is crucial for preventing premature battery failure. Selecting cells from the same manufacturing batch and implementing tight tolerance and strict process control measures can improve battery reliability.

5.5. Battery management systems (BMS) improvements:

Enhancements to BMS can lead to more efficient battery operation strategies. Meissner and Richter (2005) stress the importance of technical improvements and procedures for optimal battery resource utilization, including knowledge of actual SoC and power capability. Karden et al. (2005) highlight the role of battery monitoring systems in enabling more effective battery operating strategies, thereby improving battery reliability in EVs.

6. Conclusion:

Improving the reliability of EV batteries involves understanding failure modes, conducting appropriate testing, and employing lifetime prediction methods. By implementing the proposed approaches, EV battery systems can meet performance expectations and extend battery life. However, ongoing refinement based on field data, usage patterns, and environmental conditions is crucial for further enhancing battery reliability. Despite these advancements, it's noteworthy that discussions among EV manufacturers about current reliability issues remain limited. Continued collaboration and research efforts are essential for addressing these challenges effectively.

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