A “second life” for lithium-ion battery modules

Add value.
Inspire trust.

White paper

Abstract

TÜV SÜD has evaluated modules from battery electric vehicles (BEVs) to determine their feasibility in so-called “second life” applications. Preliminary results suggest that used BEV battery modules may possess sufficient energy storage capacity to provide backup capacity for residential systems intended to store electrical energy generated from photovoltaic (PV) solar panels. This thesis is currently being evaluated under real world conditions in the “Efficiency House Plus” experiment in Germany, where a unit comprised of used BEV battery modules has been installed to store energy generated by the house’s solar panel installation.

Contents

About the TÜV SÜD expert

Tobias Mayer

Tobias Mayer is a founder and Managing Director of LION Smart GmbH, and has worked on number of advance energy technologies for automotive systems. Prior to founding LION Smart in 2008, Mayer worked at BMW AG, where he was involved in project management and quality management. Mayer graduated with a degree in engineering from the Technical University of Munich (Germany), concentrating in automotive engineering and systematic product development.

Introduction

The use of photovoltaic (PV) solar panels along with other alternative energy technologies to generate electrical energy for homes is rapidly increasing. This growth is being driven in part by advancements in PV technology that has reduced the cost of PV modules while increasing their energy generation efficiency, thereby making solar panel installations a cost-effective alternative energy generator. As solar energy generation increases, attention has turned to the challenges of battery-based energy storage capacity in energy-efficient homes.

Lithium-ion batteries and battery modules represent the most advanced battery technology available in the market today. Their energy storage capacity, stability and relative weight make them the preferred choice for powering the current generation of electric and electric hybrid automobiles. As the growing fleet of battery electrical vehicles (BEVs) ages, however, researchers are beginning to evaluate possible "second life" uses of these batteries and battery modules, including the prospect of their use in home energy storage systems.

Formed in 2010 and located in Garching, Germany, TÜV SÜD Battery Testing GmbH is a joint venture between LION Smart GmbH and TÜV SÜD AG, and is focused on performance, environmental and safety testing of battery cells, modules and packs. In recent years, TÜV SÜD has been evaluating modules from BEVs to determine possible second life uses. Although further research is required, preliminary results suggest that lithium-ion battery modules previously used in BEVs have sufficient energy storage capacity to provide critical backup capacity for residential systems intended to store solar-generated energy.

"Preliminary results suggest that lithium-ion battery modules previously used in BEVs have sufficient energy storage capacity to provide critical backup capacity for residential systems intended to store solar generated energy."

This white paper presents a summary of the research conducted by TÜV SÜD and the results of its testing, and identifies areas for future study.

Current battery storage technologies

At present, units designed to store energy generated by residential PV solar installations incorporate one or more types of rechargeable batteries. The most common battery technologies used in stationary battery storage today include lead-acid and sealed lead-acid, alkaline technologies including nickel-cadmium (NiCd) and nickel metal hydride (NiMH), and lithium-ion.

Lead-acid and sealed lead-acid systems have been used for decades in emergency generators and other emergency power systems. However, storage systems based on these battery technologies have limited life expectancies. In addition, further regulatory restrictions on the use of lead in batteries in the European Union (EU) are expected. As a result, lead-acid and sealed lead-acid battery systems are gradually being phased out in favor of other technologies.

For use in energy storage systems, both NiCd and NiMH batteries offer a relatively high level of safety and a reliable specific energy output. However, as with lead-based batteries, NiCd batteries are subject to further regulatory restrictions in the EU due to the presence of cadmium. In addition, a common disadvantage of alkaline battery technology is the so-called memory effect, which results in a gradual loss of battery capacity under partial discharge conditions.

Lithium-ion batteries offer the highest specific energy output, due to the large electrochemical potential of the light metal lithium. They also offer efficiencies of between 95-98%, with a monthly discharge rate of just 2% per month. However, compared with other battery technologies, lithium-ion batteries are the most expensive to manufacturer. Further, lithium-ion batteries are subject to deep discharging, overcharging and short circuits, making it essential to monitor cell voltage.

The potential for "second life" lithium-ion batteries

As noted above, large capacity lithium-ion batteries generally represent the most advanced technology for the storage of electrical energy. They are also expensive, thereby limiting their current use to electric and electric hybrid vehicles and other premium applications. However, to achieve performance expectations of BEV manufacturers and consumers, lithium-ion battery modules used in BEV applications are generally deemed to have reached the end of their useful life when they have lost between 15-20% of their original energy storage or peak power capacities.

Although battery modules at this stage may no longer be viable for use in BEVs and other high intensity applications, they may still be perfectly suitable for stationary energy storage. When second life applications of used BEV battery modules are considered, the economics of electric mobility applications can potentially be improved, providing consumers with more cost-effective options. At the same time, used BEV battery modules can bring advanced energy technologies to home energy storage systems at a lower price, fostering increased adoption rates for alternative energy generation.

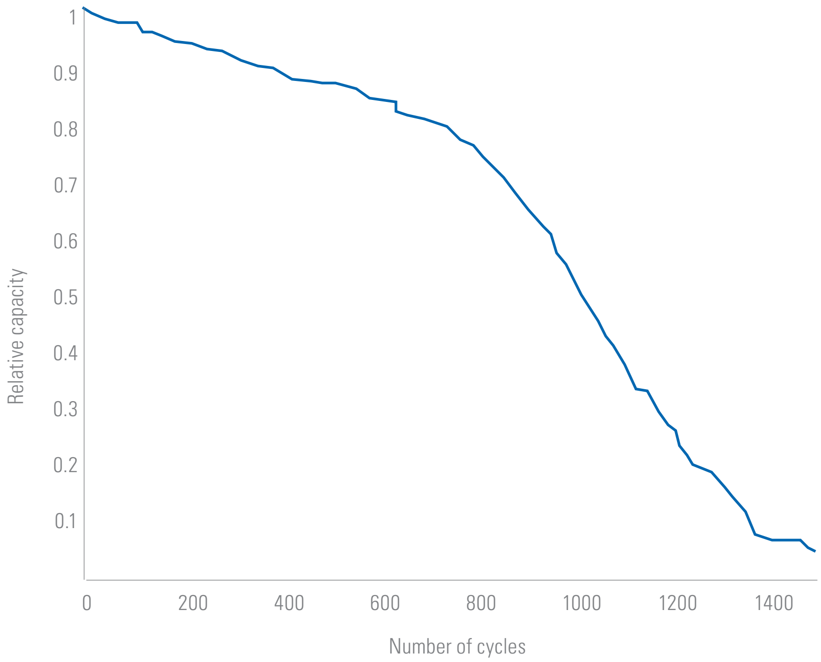


Figure 1: Results of how number of cycles impact the relative capacity of the battery modules tested

A key challenge in expanding the use of second life lithium ion battery modules for residential energy storage systems is the ability to efficiently and accurately determine the state of health (SOH) and remaining capacity of used battery modules. These characteristics are affected by a variety of factors connected with the original use of the battery module, such as operating temperatures, average driving distances, and the habits of individual drivers. This mix of factors typically results in a highly variable, non-linear aging of battery modules (see Figure 1).

Another challenge in gauging the SOH and remaining capacity of used battery modules is the rapidly evolving technology of lithium ion battery cells. Technological advancements typically lead to improved battery performance compared with previous product generations. But they can also result in different SOH and remaining capacity trends, further complicating efforts to identify comparable data.

TÜV SÜD research on second life battery characteristics

"The research involved the testing of 104 battery modules from BEVs that had been driven for up to 50,000 miles over a three to four year period."

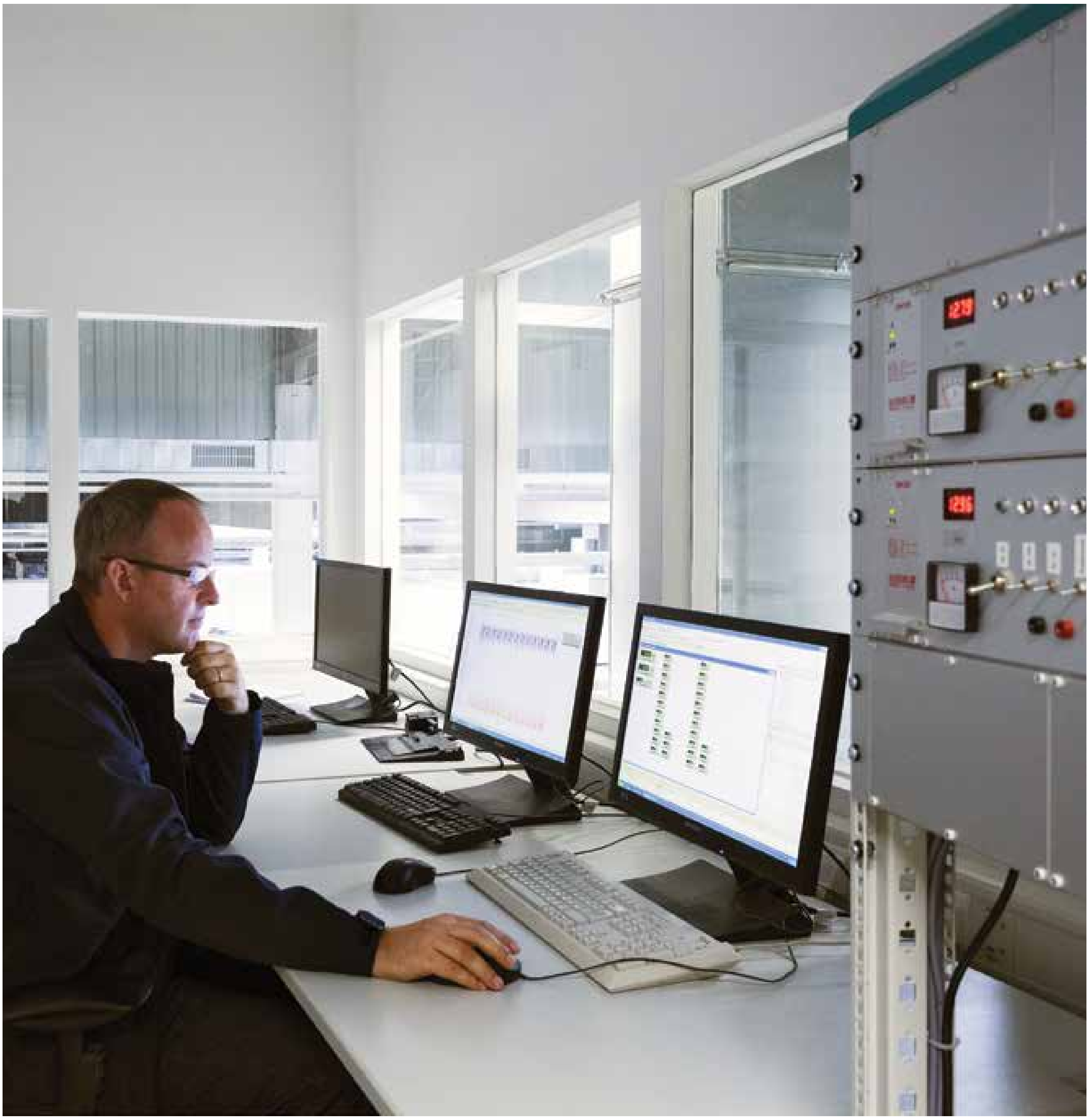
The research conducted by TÜV SÜD was commissioned by Germany's Federal Institute for Building, Urban Affairs and Spatial Development and funded by the Institute's Energy and Climate Fund. The research involved the testing of 104 battery modules from BEVs that had been driven for up to 50,000 miles over a three to four year period. The testing included evaluations of the overall SOH of each battery module and an estimation of its remaining useful life. In addition, 10 modules were subject to more extensive testing, and a single module was disassembled for testing at the battery cell level.

In an initial "quick test," all of the BEV battery modules were found to have retained more than 90% of their nominal capacity despite extended use. The quick test revealed no major deviations in the voltage characteristics of the used battery modules from new modules. So 10 of the modules were selected to assess ohmic resistance.

Generally, a new battery module should demonstrate an ohmic resistance of less than 3.0 milliohms. In these tests, the eight BEV battery modules with the shortest prior use showed an increase in ohmic resistance of less than 5% over the tested value of a new module. The two modules with the longest prior use showed a slightly larger (<13%) increase in ohmic resistance. However, in all cases, the ohmic resistance of the test modules was well below the recommended maximum for a new module.

A further examination was conducted on a single, disassembled BEV battery module to assess aging at the individual cell level. Two separate sets of cells from the used battery module were tested for capacities and internal resistances. The test results were then compared with results generated by the testing of brand new cells.

In this case, test results showed that cell capacity decreased depending on the age of the cells. Although the loss in cell capacity was comparable to the results on module level, the cells from the used battery module showed a lower dispersion rate than new cells. The same pattern occurred in the



testing of internal ohmic resistance. Ohmic resistance at the cell level was comparable to the results at the module level, but dispersion rates in new cells were higher than those found in cells from used battery modules.

Lastly, an electrotechnical impedance spectroscopy (EIS) was conducted on each used cell. Internal ohmic resistance and charge transfer reactions of cells were noted in the frequency range between 10 mHz and 10kHz (there were no notable reactions above or below this frequency range). The EIS testing results clearly illustrated the ageing on cells' ohmic resistance and their charge transfer reactions.

While not conclusive, these results suggest that ageing effects at the cell level may be affected by the voltage to which the cells were subjected during their initial operating life in the used battery module. Additional research is necessary to confirm the reasons behind the ageing effects noted during this testing.

Applying second life battery modules to home energy storage applications

To further explore the second life prospects of BEV battery modules, 70 of the battery modules with comparable SOH and remaining life profiles were assembled into a battery pack equipped with a battery management system (see Figure 2). The assembled battery storage system is capable of storing up to 43 KWh of solar generated electrical energy, with a maximum power output of 7.2KW.

This second life battery storage system has been installed in the "Efficiency House Plus," an energy self-sustaining home in Berlin, Germany developed by Germany's Federal Ministry of Transport, Building and Urban Development. The project will evaluate various approaches to energy conservation and reuse, and the second life battery pack will collect data over a two-year period to assess its actual performance under operating conditions in various seasons.

Figure 2: Reassembled second life battery pack

Research findings

The research conducted by TÜV SÜD on possible second life uses for BEV battery modules has resulted in the following preliminary conclusions:

- The overall SOH and estimated remaining useful life of the battery modules tested by TÜV SÜD exceeded expectations, and provide evidence supporting the feasibility of using BEV battery modules in second life applications.

- The use of an energy storage unit comprised of second life BEV battery modules in the "Efficiency House Plus" in Berlin demonstrates their potential to provide efficient and cost-effective storage for electrical energy generated by PV solar panels in residential applications.

- At the same time, the testing of used BEV battery modules to evaluate their SOH and estimated remaining useful life is time consuming and costly, and complicated by a number of factors including temperature and load. Testing models and methods will need to be developed to make evaluations of second life suitability more timely and cost-effective.

- Finally, the quick-testing conducted in this study only provides a picture of the current state of a battery module. A thorough evaluation of a used BEV battery module for suitability in second life applications is not possible without historical information regarding a module's prior use. Options for capturing essential operating data of BEV battery modules in use will need to be developed.

Areas of further research

Currently, LionSmart and the Technical University of Munich are developing a server-based battery management system that records and evaluates relevant BEV battery module data during actual operation. Although such a system is not without a cost, access to this additional historical information could serve to facilitate the servicing and repair of battery modules still in service. In addition, it may also provide clues about the SOH and remaining life of used BEV battery modules intended for second life applications, making the selection of suitable second life battery modules more efficient and economical.

In addition to this research, TÜV SÜD is continuously engaged in developing additional test models and methods to evaluate the quality and useful life of used battery modules. It is hoped that these new testing models and methods will speed the evaluation and selection process, resulting in less costly and time-consuming testing.

Summary and conclusion

The success of efforts to expand the use of PV solar panels and other alternative energy generators in residential structures depends in large part on access to reliable, efficient and cost-effective energy storage systems. Although more costly than other battery technologies, lithium ion batteries are ideally suited for use in such storage systems. Testing by TÜV SÜD has demonstrated that used BEV battery modules may remain viable for second life uses in less demanding applications, such as stationary energy storage, and this thesis is currently being evaluated under real world conditions in the "Efficiency House Plus" experiment in Germany. Further research is underway to develop a battery management system that can collect historical data regarding actual battery use, along with testing to identify more efficient methods to evaluate individual BEV battery modules for suitability in second life applications.

TÜV SÜD provides worldwide clients with more than a century of experience in performance and safety evaluation and testing, including e-mobility solutions for BEV batteries, new energy vehicles and charging infrastructures. With laboratories in North America, Germany, China, Korea and Singapore, TÜV SÜD's global testing network provides a full range of battery testing services and validation planning to the automotive industry.

GLOSSARY OF ACRONYMS

BEV – Battery electric vehicle
EIS – Electrotechnical impedance spectroscopy
PV – Photo voltaic
SOH – State of health

Contact us today and find out more about our battery testing solutions

www.tuvsud.com/battery
battery@tuvsud.com

Add value. Inspire trust.
TÜV SÜD is a trusted partner of choice for safety, security and sustainability solutions. It specialises in testing, certification, auditing and advisory services. Since 1866, the company has remained committed to its founding principle of enabling progress by protecting people, the environment and assets from technology-related risks. Through 24,000 employees across 1,000 locations, it adds tangible value to customers and partners by enabling market access and managing risks. By anticipating technological developments and facilitating change, TÜV SÜD inspires trust in the physical and digital world to create a safer and more sustainable future.

TÜV SÜD AG
Westendstr. 199
80686 Munich Germany
+49 89 5791 0
www.tuvsud.com