Storage systems for renewable energy under scrutiny

Battery storage | Lithium-ion batteries are becoming a popular choice stationary storage systems but so far lack any consistent standards governing safety and performance. Matthias Vetter and Stephan Lux from Fraunhofer ISE report on two major research projects that could pave the way for new safety standards for li-ion batteries

Credit: Sonnen

In 2016 in Germany 34.2% of electricity was generated by renewable energy sources. A major topic is the fluctuation of photovoltaic systems and wind turbines. Increasing the flexibility of the power system through storage systems is therefore being addressed by science and industry at all levels.

Currently Germany, with its large-scale dissemination of roof-mounted PV systems, is becoming a leading market for so-called home storage systems. These storage systems can significantly increase the self-consumption of the PV energy produced by rooftop arrays and are becoming more and more economically feasible as storage prices are dropping very fast.

As these storage systems are installed in private households, they have to be durable, safe and efficient. A study by RWTH pointed out that as of spring 2016 approximately 34,000 systems had been installed in Germany with a storage size between 2 and 10kWh. There are different storage technologies on the market, but the majority of these systems are based on lithium-ion batteries. However, adequate standards and testing procedures do not exist for this technology. The Fraunhofer Institute for Solar Energy Systems ISE is now working on two research projects which address the aspects related to the acceptance and dissemination of the technology. The German Federal Ministry for Economic Affairs and Energy (BMWi) is providing funding for both projects.

Lithium-ion under the microscope

In principle also other established technologies such as lead-acid batteries and promising new technologies such as sodium-ion batteries are an alternative for residential applications. However, those new technologies have to compete with lithium-ion batteries, which have longer calendar and cycle lifetimes, provide higher efficiencies, are able to provide a huge range of services and require less space, compared, for example, to conventional lead-acid batteries. Therefore lithium-ion batteries are gaining popularity for use in stationary applications (grid-coupled and grid-independent), as well as for their use in electric mobility applications. Synergy effects can be realised here that quickly lead to economies-of-scale effects although the requirements for these two applications differ.

The safety of lithium-ion-based storage systems is coming under closer scrutiny

Safety, a central issue for lithium-ion batteries, depends on different factors weighted according to the application. Heat localised over a small area at defects will dissipate slowly and can lead to material failure or fire in the worst case, as lithium-ion batteries contain flammable electrolyte and may produce their own oxygen in case of a so-called thermal runaway. One burning cell may ignite the adjacent cell (propagation effect), leading to a hazardous event. Functional safety of the battery system, consisting of battery management, cells, switching units and power electronics, is another issue as overcharging and deep discharge has to be prevented for each single cell in the system.

Many different approaches to ensure safety exist. The basic prerequisites are the selection of cells with high quality and a reliable battery management system, as well as an efficient and effective thermal management.

Whereas for example lead-acid batteries have been tested in practice for many years and a huge amount of information on field experiences is available, lithium-ion batteries must first prove themselves as stationary

Credit: Fraunhofer ISE

Fraunhofer ISE's test rig for PV home storage systems. Before battery storage tests start the set-up as well as all necessary process steps are checked once again

storage systems in order to win the trust of consumers. Long-term experience has not yet been available in such applications and therefore cannot be applied.

Standards

One important issue is that fixed standards for home storage do not exist yet. If the current situation is considered, a mixture of rules is used being partially in a draft version up to now.

Currently used standards for certification (as of January 2017):

- Transportation: UN38.3
- Safety: AR-E 2510 – 50, AR-E 2510 – 2, EN62619, EN61000, EN61010-1
- "Safety guidelines Lithium-ion home battery storage systems" (rev. 1, NOV 2014)

The "Safety guidelines Lithium-ion home battery storage systems" were developed under a voluntary scheme organised by German trade association BSW-Solar. Leading research organisations, manufacturers and test institutes worked together, but the safety guidelines are not a legal standard today. The Application Rules AR-E 2510-50 and AR-E 2510-2 are intended for stationary storage and published by electronics association VDE but unfortunately they have remained in draft form only for some years. The EN62619 focuses mainly on industrial applications such as fork-lift trucks while the standards EN 61000 and 61010-1 are not made for systems containing lithium-ion batteries. So the UN 38.3 Transport directive is still one of the most trusted standards for those devices.

A final standard should cover aspects of functional safety, propagation and especially the safety behaviour of aged systems as lifetimes of more than 10 years are the target in stationary applications.

Project 'Safety First': Safe grid-supportive storage for households

In the joint research project 'Safety First', Fraunhofer ISE is partnering with the Karlsruhe Institute for Technology (KIT) and the Centre for Solar Energy and Hydrogen Research (ZSW) to investigate the current safety, quality and grid suitability of commercially available residential battery storage systems. In this project, scientists develop recommendations for manufacturers, standardisation bodies and authorities based on their investigations on home storage systems for increasing self-consumption. These home storage systems based on lithium-ion batteries are becoming increasingly inexpensive and thus more attractive for the end user. Up to now, however, standardised, verifiable criteria for assessing the efficiency and safety of these systems have been lacking. Therefore the goal of this project is to assess commercially available PV home storage systems in order to prepare future safety standards.

Figure 1. Storage systems under test at Fraunhofer ISE

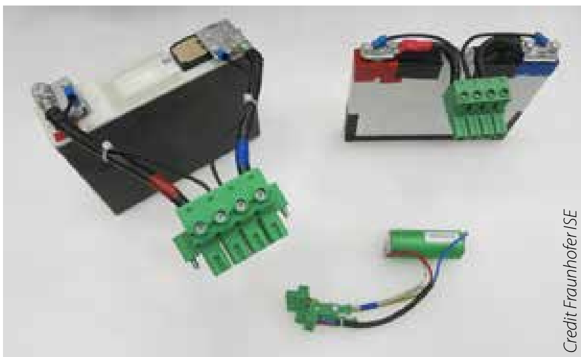


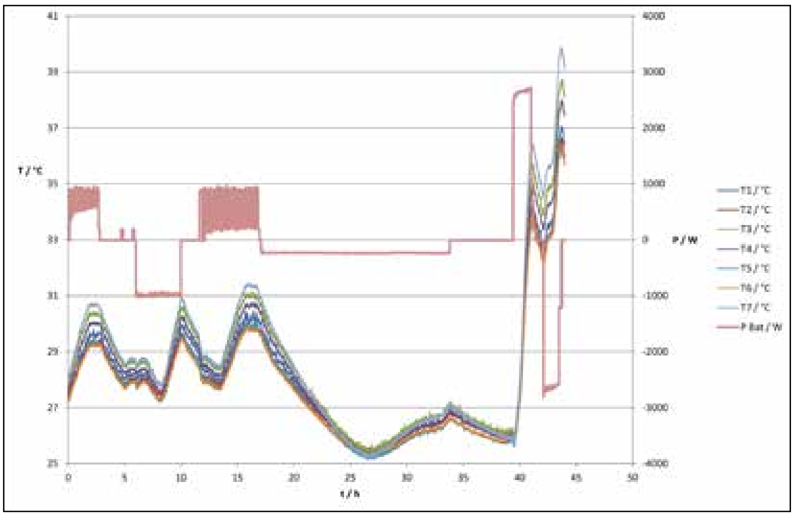
Figure 2. Lithium-ion cells used in home storage system prepared for test

In the project, 20 home storage systems undergo long-term tests, carried out on test rigs that imitate actual operation in private households (Figure 1). Using special load profiles, it is not only possible to analyse the safety of new batteries direct from the factory but also at later ageing stages. Data is collected on the safety properties and the expected lifetime of the storage systems. Also the change of the efficiency over the lifetime will be registered.

Complementary to the analyses on the home storage systems, singular lithium-ion battery cells are selected and analysed at Fraunhofer ISE and at ZSW (Figure 2). Fraunhofer ISE analyses and evaluates the ageing properties of various cell types and the entire system in parallel. With this acquired knowledge, information about ageing and safety can be collected in the future by merely performing short investigative tests. Based on the results in the laboratory, the research team compiles recommendations so that the properties of modern lithium-ion batteries are factored into the standards, test specifications and funding.

Beyond those, internal parameters like temperature distribution, single cell voltage and current distribution in modules that are switched in parallel are collected to capture inhomogeneity in the storage systems. This inhomogeneity tends to increase over the lifetime of the system and may lead to failures and safety issues.

In the example in Figure 3 the power of a commercially available battery module is depicted along with the temperature of seven temperature sensors that are mounted in the battery module. The measurement was done at an ambient temperature of 25 degrees Celsius and the battery module is passive-cooled by natural convection. It is obvious that at very low power levels the temperature distribution is



Credit Fraunhofer ISE

Figure 3. Power profile with temperature distribution in a typical lithium-ion module of a commercial available home storage system

very equal, but if the battery is operated at maximum power, the maximum temperature is 14 degrees kelvin above ambient temperature and the temperature spread inside the module reaches 4 degrees kelvin between cells. In the event of operating these systems in a Mediterranean or tropical climate, for example, fast degradation and inhomogeneous ageing effects are expected.

Project 'SpeiSi': Safety of stationary storage systems for solar electricity

Fraunhofer ISE is additionally working on a research project, headed by TÜV Rheinland, on the topic of safety and reliability of PV systems with storage. Project 'SpeiSi' investigates the safety of such systems, which are installed mainly with the aim of increasing self-consumption.

In cooperation with TÜV-Rheinland, the German Section of the International Solar Energy Society and the Centre for Solar Energy and Hydrogen Research (ZSW), the project will analyse weak points in the handling, installation and operation of solar-plus-storage systems. Existing regulations for stationary battery systems consider separate battery rooms for systems with emergency or back-up power or for systems with an uninterruptable power supply (UPS). The regulations must be adapted to accommodate a broader use of stationary energy storage with higher energy content like lithium-ion batteries in private homes. Beyond this, the project will aim to develop criteria for determining the performance of PV storage systems, allowing further information about the quality of the energy management to be gained.

At Fraunhofer ISE three aspects affecting the safety of stationary PV storage systems are being considered as part of this programme. For one, a study was carried out on suitable storage technologies and their respective potential hazards. Secondly the probability of light arcs developing in the system and their detection – or better yet the avoidance thereof – was investigated. Thirdly the behaviour of switching and safety devices undergoing pronounced cyclical stress was analysed. In particular, the researchers would like to find out if the electrical connections become weaker over the course of time, which would lead to a higher fire risk.

SpeiSi is building a network between the different stakeholders involved in storage technology such as producers, operators, insurance companies and fire brigades. In January a workshop with fire brigades was organised in Cologne to exchange information about technology, incidents with storage systems and directives that are existing and that might be needed in the future. One point of discussion was if we need a register of installed storage systems so that relief forces are informed if they will find batteries or PV installed.

The main task of the projects SpeiSi and Safety First is to examine new storage technologies especially in home appliances, and by finding the weak points improve the technologiy to make it safe and reliable. We want to disseminate knowledge to customers , fire brigades and extend standards and amend directives to cope with the progress in technology. ■

Authors

Dr Matthias Vetter is head of the department of electrical energy storage at Fraunhofer ISE. He is an electrical engineer of 19 years' experience, having undertaken his PhD thesis in the field of modelling and development of control strategies for fuel cell systems. Among other topics, his work focuses on autonomous systems and mini-grids, decentralised grid-connected PV battery systems, development of battery systems for stationary and automotive applications.

Stephan Lux serves as head of the battery modules and systems team at the Fraunhofer ISE in Germany. He received his degree in communication technology from the University of Applied Sciences Offenburg in 1994 and his degree in electrical engineering from the University of Hagen in 2008.