SBB: A NEW BATTERY FOR THE ON-BOARD NETWORK

The Swiss Federal Railway (Schweizerische Bundesbahn, SBB) attempts to gradually replace lead-acid batteries that supply power to railway wagons. The new batteries should be essentially lighter and smaller, at the same time they should have an increased life span. A functional prototype developed by the Bern University of Applied Sciences (Berner Fachhochschule, BFH) in cooperation with the Swiss railway fulfills these requirements - and serves as a reference for the next procurement.

Lea Steurs from the SBB (management and logging of the test procedure) and Christian Vögtli from the BFH test the prototype battery on the regional train wagon DPZ. Photo: SBB

A technical report about the results of a pilot and demonstration project in the field of electricity, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Schweizer Eisenbahnrevue (issue January 2018).

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The entire Swiss rail network, some 3,200 kilometers long, is equipped with power lines. The lines provide trains with 15 kV of alternating current. Despite the direct connection to the transmission power line network, each of the approximately 3,500 railway vehicle - passenger coaches, railcar or locomotives - requires one or more batteries. The batteries feed the on-board network of railway wagons in emergency situations, but also in case of short supply interruptions, which occur during normal operation on the route or when recoupling wagons in the stations. The electrical system supplies the energy for lighting, doors and customer information systems. The battery is a safety-relevant system, as it ensures the operation of the magnetic rail brakes and is used in evacuation cases.

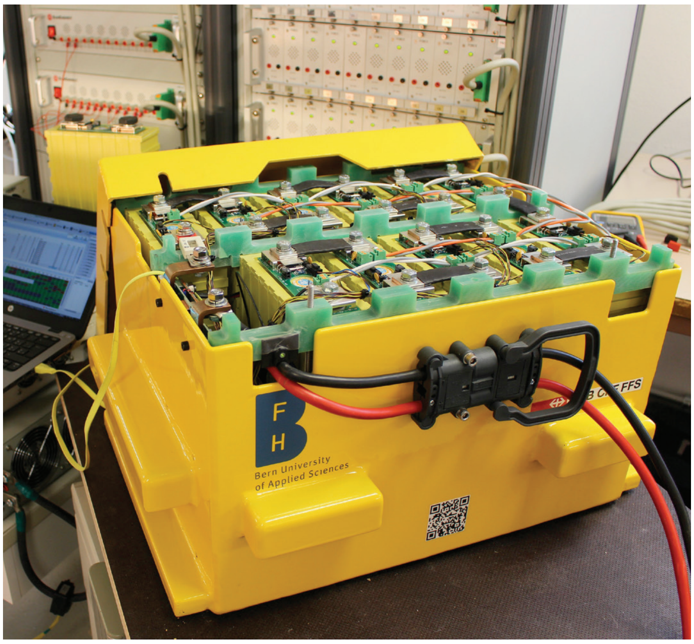
To date, SBB has mainly used 36 V lead-acid batteries, each weighing 334 kg. This means that around 2,000 tonnes must be transported by the the entire fleet of trains, which increases energy consumption accordingly. The SBB aims to begin replacing lead-acid batteries with new batteries that are lighter, more energy-efficient and cheaper over their lifecycle, thanks to new technology. Reduction of life cycle costs and sustainable use of valuable resources are the primary reasons for this technology switch. The development of such a battery, however, brings challenges: it must be installed into the existing environment of the railway cars without special adaptations. In mid-2014, the SBB launched the project 'New Battery Technology SBB.' The BFH-CSEM Energy Storage Research Centre in Biel, which was created in 2015 as a joint institution of the Bern University of Applied Sciences (BFH) and the Center Suisse d'Electronique et de Microtechnique SA (CSEM), is involved as a partner. The Swiss Federal Office of Energy (SFOE) is supporting the project as part of its pilot and demonstration program.

Contributing to Efficient Electricity Use

Three years after the project launched, a functional prototype battery is now available. The new battery satisfies the technical requirements of a modern SBB battery and also makes possible various implementation options. "This battery serves as a technical reference object for the planned procurement in early 2018. In the medium term, it is intended to equip some 2,200 older passenger carriages and locomotives with new batteries," says SBB project manager Ueli Kramer. The new battery is initially designed to retrofit older railway wagons with 36 volt on-board system. In the long term, it could be used in an adapted form in newer railway cars, those with on-board systems that are fed with 110 V. A corresponding

The EW4 travel wagon carries two parallel 36 V battery compartments, each currently housing in four hutches an 18 V lead battery. Photo: SBB project is already underway with an industrial partner, which incorporates the insights gained from the 36 volt prototype model.

The new battery is one of many measures that SBB intends to use to cut power consumption and operating costs over the medium term. In 2012, the Board of Directors of the Federal Railway approved a program to increase energy efficiency. By 2025, SBB intends to permanently save 600 gigawatt hours (GWh) of electrical and fossil energy per year. This corresponds to 20% of energy consumption (or the equivalent of the annual consumption of 150,000 four-person households). If the implementation of this ambitious goal is successful, SBB trains would in the future only use renewable energy and would be able to operate without nuclear energy. Energy efficiency is one of several reasons for the technical innovation. The main drivers are the increase in reliability as well as the reduction in the life cycle costs of the battery system, thanks to the extended service life.



The prototype model developed at the BFH-CSEM Energy Storage Research Centre in Biel consists of eleven lithium-ion battery cells and has a storage capacity of 6.5 kWh. Photo: BFH

Robustness Comes Before Maximum Energy Density

The type of battery described above would sporadically supply power to wagons and to a relatively small extent, in everyday SBB operation. This can be exemplified in a low-floor FLIRT multiple unit train (RABe523xxx), as is used in regional transport among other areas: during mornings when trains are brought into service, five minutes of energy (about 570 Wh) from the battery is required. During the day, the battery is then typically used briefly 18 times, namely when

WEIGHT REDUCED TO ONE THIRD

The prototype model developed by BFH consists of eleven lithium iron phosphate battery cells (LiFePO4). Each cell is equipped with a circuit connection board, by which among other things, the temperature of the cells can be determined. Control and monitoring takes place via the central battery management system (BMS).

The prototype model tolerates a charging voltage between 39 and 45 volts. This flexibility is necessary because of the charging voltage of the onboard electrical system, in terms of the charging characteristics of lead batteries, varies depending on the temperature in this voltage range. Compared to the previously used lead-acid battery, the prototype is one third as heavy (110 kg instead of 334 kg) and has half the volume (60 instead of 120 l). The developers are striving to replace the battery's fire-resistant steel hutch to further reduce weight. Fire protection has the highest priority for battery developers, especially because lithium-ion batteries have made headlines several times due to fires. "The problem with these incidents was rarely the very to their limits designed cells alone, but an over-exhausted and overloaded system. The fire risk is manageable in our case, since the electrical load and performance of the system is not critical," emphasizes BFH development engineer Christian Vögtli. "The BMS primarily provides operational reliability since the lithium-iron phosphate cells used, with their comparatively moderate energy density and high intrinsic safety, behave extremely stably even in the event of mishandling, which additionally mitigates the risk of fire." Ultimately, regardless of the technology used, battery suppliers are responsible for ensuring fire safety in accordance with the specifications of the planned call for bids. BV the train passes a section without power supply (protection sections at network section change); then the on-board systems draw approximately 150 Wh within a minute from the battery. When decommissioning the train in the evening, the battery delivers another 1800 Wh for 20 minutes. After each load, the battery is recharged. While the battery of an electric car must have a maximum energy density, this is not required of the SBB battery because of the very specific performance profile.

Rather, it is important that the battery is not damaged by strong vibrations and works reliably even at temperatures of -20 °C. The battery developed by BFH in close cooperation with SBB relies on lithium iron phosphate technology. Thanks to its robustness, this chemistry ensures a high level of safety and durability. The storage capacity was chosen to be similar to the previous lead acid battery so that a three-hour emergency operation of the vehicle is guaranteed, even under the most adverse circumstances. For the functional battery prototype, this corresponds to a capacity of 6.5 kWh when new.

Battery Management System Controls Charging Process

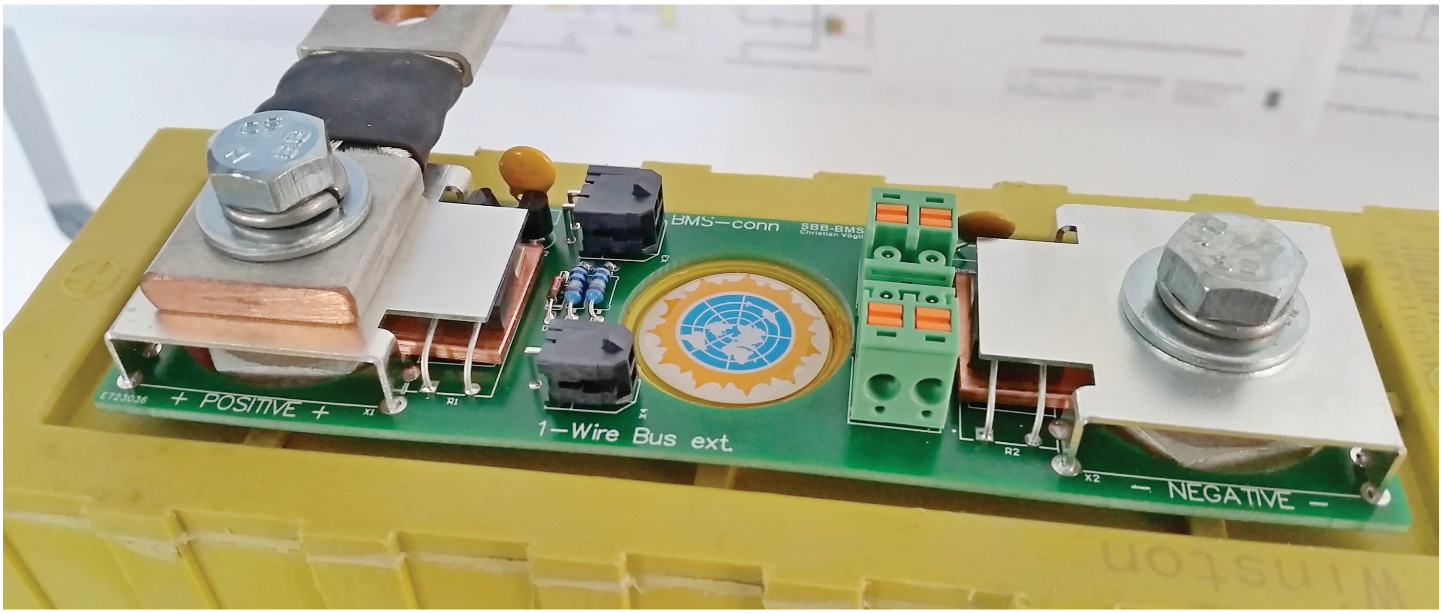
The control and monitoring of the functional prototype is provided by a specially developed battery management system (BMS). Among other things, the BMS ensures that the battery is recharged as needed and gently after each demand

DEFY TO LOW TEMPERATURES

In order to ensure a long life, lithium iron phosphate batteries must be gently charged, especially at temperatures of -20 ° C. In order to master this challenge, the BFH developers have pursued several approaches: on the one hand, special battery cells have been chosen that tolerate low temperatures well, as is shown by tests in the laboratory of the BFH-CSEM Energy Storage Research Centre.

In addition, an electric cell heater was included, with which the temperature of the battery mass was raised by 20 Kelvin with heat input through the poles (700 W for one hour). Finally, the prototype model contains a DC-DC converter, which allows a controlled, slowed down and therefore gentle charge of up to 800 W, independent of the fixed charging current settings of the on-board electrical system.

Not all of these precautions are necessary for the practical operation of the battery during winter temperatures. The desired service life and availability can be maintained with two of the three precautions, emphasize the project managers. How the SBB battery, which will be mass manufactured in the future, harmonises low-temperature chargeability with longevity, will be demonstrated during the bidding process. BV



Connection circuit board of a single battery cell: It contains connections for temperature and voltage measurements as well as for heating the cell. Photo: BFH

Presentation of the functional prototype at the Association of Public Transport (VöV). In the background, a regional train wagon DPZ outfitted with lead-acid batteries, which are being phased out. Photo: SBB

for energy. It regulates the charging process so that the battery can provide at least 2 kWh of energy at any time, which is required in accordance with the demands of emergency operation in the event of a power failure. For example, it ensures that light can be available for three hours. Due to the chemical properties of the battery - especially when new – it must not always be fully charged in warm ambient temperatures. Thanks to optimized control and low electrical load, battery life is expected to be at least twelve years in the future. Lead-acid batteries must be replaced as a precaution after five to seven years. "Since the new battery has twice the service life, the higher initial costs can be easily compensated for by appropriate coordination," says BFH development engineer Christian Vögtli.

The on-board network of railway wagons are normally fed from overhead powerlines, in which the 15 kV of alternating current goes through various stages through which it is transformed and rectified into about 42 V of direct current. The lead acid batteries used so far are permanently connected to the electrical system and are therefore always exposed to charge voltage. The new battery is different: it can temporarily disconnect from the electrical system, for example, when it is fully charged. This enables the battery voltage to go down after the charging process, which increases the life of the battery cells. For this purpose, a specially controlled semiconductor switch was developed; it is a primary technical feature of the new development. Despite the semiconductor switch, the battery remains ready for use at any time. If the on-board network malfunctions due to a power interruption, for example, the switch enables control of energy flow into the on-board network immediately and without active intervention. The semiconductor switch also allows a seasonally dependent and needs-based charge control.

Basis for the procurement in the battery market

The battery prototype developed in Biel also offers a new option for maintenance. Today, the batteries must be checked every six months (for outgassing, for example), and their expiration date must be checked visually. This could become superfluous in the future as the BMS automatically analyzes the state of health (SoH) of the battery and periodically sends the values via GSM to the service center (or at least will be clearly visible on the battery). Batteries would then no longer be replaced as a precaution, as is the case today, but only if their state of health no longer meets the requirements.

Originally, the SBB had planned to build several prototypes and to test them in railway operations to then produce the battery itself. Meanwhile, the company has strayed from this plan. "On the one hand, the increase in knowledge of technical issues would be disproportionate to the investment in a pilot operation. On the other hand, SBB strives to procure modular products under favorable market conditions, instead of acting as a manufacturer," says SBB project manager Ueli Kramer. The new battery with the required specifications should now be subject to a procurement process from experienced industrial suppliers in the growing battery market. "With the prototype model, we were able to develop the necessary knowledge, gain important experience and thus develop the specifications for a railway-compatible system according to the state of the art," says Kramer. "Each manufacturer can use the best available technologies in their products and adopt approaches and ideas of the prototype model in order to achieve the specified requirements." From the SBB development, other railways at home and abroad could also profit from the modernization of their battery systems.

- **Information** on the project is provided by Ueli Kramer (ueli.kramer [at] sbb.ch), Project Manager Energy Management and Head of Competence Center Energy Storage SBB, and Christian Vögtli (christian.voegtli [at] bfh.ch), Development Engineer at the BFH-CSEM Energy Storage Research Centre in Biel.

- **Information** from the SFOE is provided by Dr. Men Wirz (men.wirz [at] bfe.admin.ch), SFOE section Cleantech, and Roland Brüniger (roland.brueniger [at] brueniger.swiss), head of the SFOE research program Electricity Technologies.

- Further **technical papers** on research, pilot, demonstration and flagship projects in the field of electricity technologies can be found at www.bfe.admin.ch/CT/strom.

PILOT, DEMONSTRATION AND FLAGSHIP PROJECTS OF SFOE

The development of the prototype model of a new SBB battery is one of the pilot and demonstration projects with which the Swiss Federal Office of Energy (SFOE) encourages the development of economical and rational energy technologies and promotes the use of renewable energies. The SFOE sponsors pilot, demonstration and flagship projects with 40% of non-amortizable, chargeable costs. Applications can be submitted at any time.

- www.bfe.admin.ch/pilotdemonstration

- www.bfe.admin.ch/leuchtturmprogramm

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