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Development and characterization of a novel Li-ion battery pack for the Swiss Federal Railways (SBB)

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In cooperation with
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Objective of the project

Every day, more than 2000 t of Lead Acid Batteries are transported on SBB railway vehicles (locomotives, passenger coaches, railcars) for several 100 km.

The objective of the project is to lower the operating costs of battery packs in the SBB railway vehicles, by redesigning the battery and redefining the battery's operational parameters to achieve a

- weight reduction of 65 %
- reduction of used space
- safe operation under extreme environmental conditions
- longer life span and a higher cycle efficiency

Current system configuration

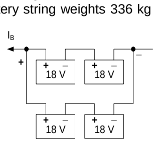
Usage of the batteries on board

The batteries are supplying the 36 V on board train power system which powers light, ventilation and control electronics (e.g. for doors) during regular breaks of the mains supply as well as in emergencies:

- Change of locomotives in the railway stations
- Trap point / protection route (overhead line with no voltage)
- Long lasting power failure of the overhead line (<3 h)
- Parallel support of the on board converters during the operation of the magnet track brake (emergency braking)

System configuration

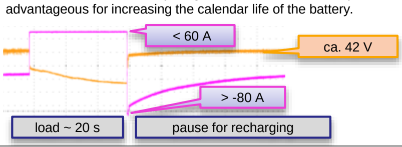
There are one to two 200 Ah battery strings in each railway vehicle. Each string consists of 18 vent regulated lead acid cells (VRLA) connected in series. One battery string weights 336 kg (2 trays). 9 cells are held in a metal tray.



No monitoring system is installed. The VRLA cells are replaced preventatively every 7 to 8 years.

Load profile

In typical cases, about 30 times a day, a discharge of 10 s to some minutes occurs, followed by long breaks. This weak load profile is advantageous for increasing the calendar life of the battery.



Further criteria for the redesign

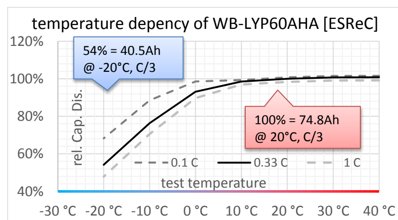
Within a detailed analysis, further criteria were defined as follows:

- The charge current from the vehicle bus cannot be adjusted by the battery controller. It is limited to 60 A in most cases.
- The voltage of the vehicle power system cannot be adjusted by the battery controller. It has different, partly temperature dependent voltages on each system.
- The battery is to be fully functional at from - 20 °C to + 40 °C.

Li-ion cell characteristics

Concerning the demand of calendar life, safety (thermal stability), cost and mainly technical aspects as low weight, low usage of space and charging at low temperatures beginning with -20°C, the robust Li-ion cell chemistry Li-Iron phosphate was chosen ($LiFePO_4$).

As with VRLA-batteries also $LiFePO_4$ –based batteries' capacity decreases at low temperatures. The characteristics have been tested at small sized cells from different manufacturers. The temperature decrease of a cell from one specific manufacturer is shown below:



The battery was designed so that more than 100 Ah are available at -20°C with a 20 A discharge.

The table below compares the former and the finally chosen cell.

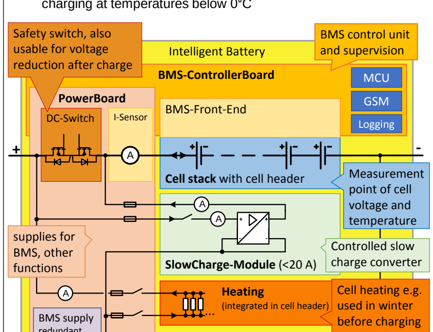
Key features of cell type	ZLWF200	WB-LYP160AHA
chemistry	lead acid (VRLA)	$LiFeYPO_4$ (LYP)
Specific energy *	23 Wh/kg	105 Wh/kg
Spec. energy at -20°C, C/10	14 Wh/kg	70 Wh/kg
Energy density (vol.) *	66 Wh/l	170 Wh/l
Service life	7 - 8 years	~14 - 20 years

* at a discharge rate of C/3 (3h or C/3 discharge) at 20°C cell temperature

Measures for a long battery life

The battery life is one of the most important parameters that affect the economy of the final battery system. In order to extend the cells' cycle and calendar life, some measures were implemented in the hardware and software.

- Semiconductor Switch interrupts fast charging from train power system and to lower pack voltage after end of charge
- Internal DC-DC-converter for I-U-controlled slow charge at cell temperatures below 10°C or state-of-charge (SOC) above 70%
- Resistive heating on top of each cell prior to and during charging at temperatures below 0°C

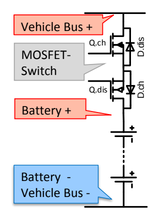


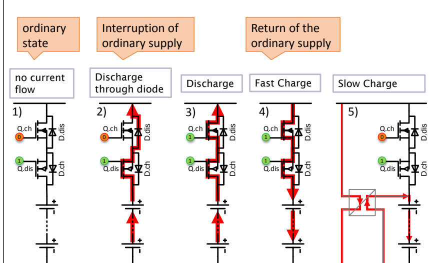
The measures lead to a battery that is compatible to all current limited vehicle power systems with voltages between 38 V and 45 V .

Hardware details

DC-Switch

The MOSFET-Switch consists of two anti serial connected FET-Arrays. This leads to the flexibility to interrupt the charging current path, without having a problematic reaction time for instantly supplying the vehicle power system after an interruption of the overhead line. As shown by the sequence pictured below, in the first moment after a interruption the body diode (D.dis) of the upper FET can carry the current (2) while a logic based current detection reactivates the Q.ch FET (3) preventing power losses over the diode.

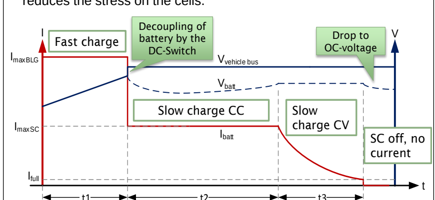




After the return of the main supply a fast charge of the battery is possible (4) as well as a battery controlled slow charge (5) with the internal SlowCharge-Module.

SlowCharge-Module

The switch in combination with the DC-DC-converter, leads to a situation-adapted charging regime, that is more efficient and reduces the stress on the cells.

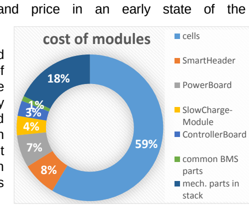


The BMS is controlled by a TI Hercules TMS570 safety-MCU.

Cost optimization

In the prototype development phase, it is already essential to know which functions or which modules add the highest cost to the final product. The collected information can help to optimise the battery regarding complexity and price in an early state of the development.

The cost share depicted reflects the estimation of the price for the production of 500 battery pack units. In a detailed breakdown, a distraction between the present prototype and an estimation of the series production was made.



The current analysis shows a high potential for cost optimisation in the mechanical parts of the battery.