Students at the Universität Stuttgart are developing an electric race car with an innovative battery management system

A Winning Formula

The E0711-2

Motors:	2 permanent magnet synchronous motors, each 50 kW
Control:	MicroAutoBox II
Recharcheable batteries:	Lithium polymer pouch cells with 588 V
Weight:	266 kg
Acceleration:	0 to 100 km/h in 3.0 s

Formula Student has very strict rules on the safety of electrically powered race cars. GreenTeam Uni Stuttgart guarantees safety by using dSPACE technology to develop their high-speed vehicle.
The new dSPACE MicroAutoBox II controls the vehicle dynamics, monitors the safety system and controls the battery management.

The GreenTeam in Formula Student Electric

GreenTeam Uni Stuttgart is a non-profit organization with over 30 active student members who develop and build electric race cars according to the rules of Formula Student Electric. What's special is that the entire development process, from the idea and design for the car to parts manufacture to prototype assembly and testing, is carried out by the students themselves.
Founded in 2009, the team's goals are to develop a Formula Student race car with a purely electric drive and to actively participate in Formula Student Electric competitions.
To develop their first electric race car, the students optimized and modified the racing team's combustion engine-driven 2008 world championship vehicle, the F0711-3. Their main focus was on integrating the electric motor, the high-voltage battery and the necessary control system.

Electrical Vehicle Components

The E0711-2 race car that was developed for the 2010/11 season has two 50-kW electric motors, type AMK DT7-80-20-POW, installed longitudinally, which drive the rear wheels independently of each other. The required operating voltage is supplied by a high-voltage Lithium polymer (LiPo) battery. It has 8.4 kWh capacity with a maximum voltage of 588 V and an energy density of 180 Wh/kg. The batteries in the Stuttgart race car are arranged in three series of 140 sequentially switched cells, giving the vehicle three independent batteries connected in parallel.

Functions of a Battery Management System

A battery management system (BMS) controls the electrical and thermal processes in a battery of several connected, rechargeable cells that have to be monitored and controlled. In automotive technology, a BMS also controls different vehicle operating states, optimizes the battery's lifetime and performance, and if necessary puts it into a safe state.
For example, if the vehicle is switched off, the BMS goes into sleep mode. If the vehicle is in waking mode (programmable cyclically), the BMS can monitor variables such as voltage, current strength and temperature

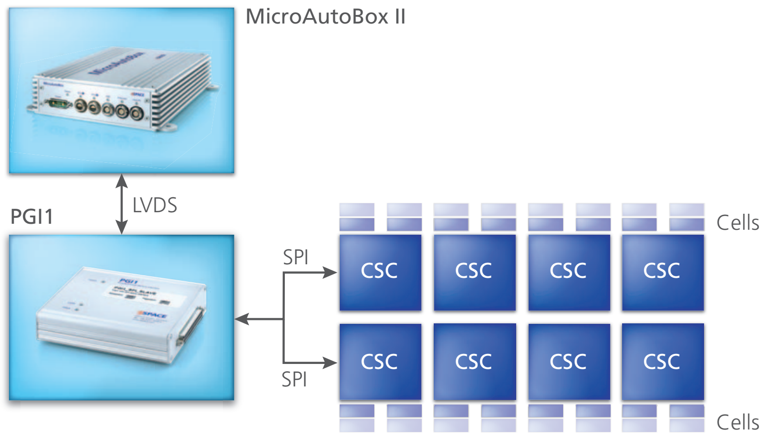
for irregularities or failures. These are transmitted to the driver and the racing team in real time so that they can take appropriate action.

Requirements for the Battery Management System

The rules of Formula Student Electric Germany (FSE) state that the battery system in the E0711-2 race car must switch off automatically if its cells are working outside the specified parameter limits. To cover the BMS' entire functional scope, other input variables must also be captured and evaluated in order to optimize battery management. These include the voltages and temperatures of the individual cells. States such as overcharging, deep discharge, overcurrents, short circuits and the ambient temperature also have to be captured. This minimizes the risk of a weak or failing battery cell affecting the other cells in the series-connected system, which would impair overall performance. This is especially important in Formula Student Electric, because the battery in an electric race car has to keep going till it reaches the finish line without recharging, even in a long-distance (22 km) race.

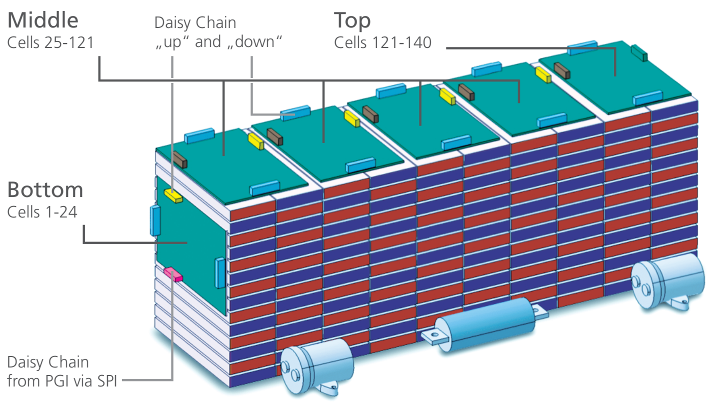
Conception of the BMS

This is the approach the team uses to ensure the battery operates reliably: The consumed power is controlled as a function of temperature T and state of charge SOC. Overcharging and deep discharge are prevented by interval control: The charging process is interrupted at the top limit (4.2 V), and then all the cells are balanced to the lowest



Battery management system: The dSPACE MicroAutoBox II is connected to the dSPACE interface module PGI1 via the LVDS bus and controls the BMS. Via SPI buses, the PGI1 receives information from the cell supervisory controllers that monitor the individual cells.

> "With the MicroAutoBox II and the dSPACE Programmable Generic Interface, we can capture and control the high-voltage battery's elementary variables precisely."
>
> *Leonardo Uriona, E0711-2 Team Leader*



The bottom battery module (BOT) contains battery cells 1-24, the middle modules (MID) contain battery cells 25-121, and the TOP module contains battery cells 122-140. The bottom module forms the interface to the dSPACE PGI1 module via the SPI bus. The top module ends the daisy chain of the bus system that transports the data.

Edward Eichstetter (left)
Edward Eichstetter is team leader for the overall vehicle in the GreenTeam Uni Stuttgart, Germany.

Leonardo Uriona (right)
Leonardo Uriona is team leader for the overall vehicle electronics in the GreenTeam Uni Stuttgart, Germany.

voltage. As soon as all the cells have the same voltage, another attempt is made to charge them up to 4.2 V. The charging process continues in this iterative fashion until all the cells have reached their maximum SOC. At the bottom charge limit (3.5 V), the system calculates the expected voltage drop so that the battery load does not go below the minimum.
The BMS can use the SOC curves, the temperature and the kilometers still to be driven in order to calculate how much power can be released. It does this with the dSPACE MicroAutoBox II.

dSPACE Technology in the Race Car

The MicroAutoBox II is the computing center for the battery management system. It monitors the overall system and processes the information from the dSPACE Programmable Generic Interface (PGI1) via a low-voltage differential signaling (LVDS) bus. The PGI1 then communicates with the individual cell supervisory controllers (CSCs) via the Serial Peripheral Interface (SPI).
The battery cells and various control mechanisms are evaluated by a BMS model based on a dSPACE engineering solution. The dSPACE-supported battery management system has proved a success for GreenTeam and will be used in the same form in actual competition. The high reliability of the vehicle functions is demonstrated by the racing team's many wins with their second-generation electric race car.

Development Progress

The GreenTeam Uni Stuttgart has already taken 3 top places in 4 competitions. In 2010, they won the overall victory in Germany and in Italy. The team showed its determination again in 2011, winning second place in Italy.
These successes inspired the team to compete on the Hockenheimring in Germany and in Italy every year with the E0711-2, a newly developed and improved race car. The team also aims to take part in other international competitions.
In the meantime, GreenTeam is busy working on the E0711-3, the third generation of their self-developed electric race cars. ■

Edward Eichstetter
Leonardo Uriona
GreenTeam Uni Stuttgart