Electric Vehicle Enhanced Range, Lifetime And Safety Through INGenious battery management

D6.2 - Requirements and architecture concept of a highly modular prototyping hardware platform

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EXECUTIVE SUMMARY

This report describes a set of requirements on a highly modular battery management system (BMS) prototyping hardware platform. The requirements include thermal and mechanical properties of the hardware, power consumption, interfaces and surveillance functionalities, as current, temperature and voltage measurements and cell balancing capability.

Based on these requirements, an architecture concept for the BMS hardware platform is proposed. The general idea is to divide single BMS functionalities as voltage measurements or cell balancing on separate plug-in printed circuit boards (PCBs). Such boards are connected via a mutual backplane, which offers power supply and communication channels. Each plug-in board is divided into a controller and extension board. The controller board is responsible for communication and calculations, whereas the extension board allocates the hardware related BMS components.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS

ACRONYM	DEFINITION
BMS	battery management system
CAN	control area network
CB	controller board
DOW	description of work
EB	extension board
GPIO	general purpose input output
I2C	inter-integrated circuit
NTC	negative temperature coefficient
PCB	printed circuit board
RESM	reduced electrochemical simulation model
SOA	safe operating area
SPI	serial peripheral interface
WP	work package
WPL	work package leader

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Battery management systems (BMS) are the main safety element for battery systems, apart from the chemical and technical benefits of the respective cell technology. The main task is to ensure a safe and reliable operation of a battery system as well as each individual cell. Thus, the BMS has to monitor, control and protect the battery system and every single cell.

The following document describes the requirements on a highly modular BMS to be used for research and development purposes. The open source software, developed in the project, should also be implemented on this platform. In this document, requirements are presented which are necessary for the data acquisition, data processing as well as electrical and thermal management. In addition, the communication with internal and external components of the BMS is specified.

1 MAIN CONTENT

In the following sections, the requirements and the architectural concept of the highly modular battery management system will be presented. Before we explain the requirements in detail, we define the term requirement and the context as well as the stakeholder and the boundary conditions in which the system will be used.

1.1 DEFINITION OF THE TERM REQUIREMENT

A requirement describes the expectations of a customer, user or stakeholder to a product. In (IEEE, 2010) the term requirement is defined as:

1. A condition or capability needed by a user to solve a problem or achieve an objective
2. A condition or capability that must be met or possessed by a system, system component, product, or service to satisfy an agreement, standard, specification, or other formally imposed documents
3. A documented representation of a condition or capability as in (1) or (2)
4. A condition or capability that must be met or possessed by a system, product, service, result, or component to satisfy a contract, standard, specification, or other formally imposed document. Requirements include the quantified and documented needs, wants, and expectations of the sponsor, customer, and other stakeholders.

Requirements define partial aspects of a complex system to be developed and thus form the basis for each project. Requirements are differentiated into functional and non-functional requirements. The functional requirements describe what a system must perform, whereas the non-functional describe properties of the system. Furthermore, the requirements form the basis for the further project planning, the risk management and the acceptance tests by the users, customers and stakeholders (Ebert, 2012). Further, the requirements of a system can be divided into product requirements and component requirements.

Product requirements describe the functions and properties a system has to fulfil, seen from the user's point of view. Beyond that, they consider the system within an environment (context) in which the system is used. (Ebert, 2012)

Component requirements describe the internal and external interfaces as well as properties that a system that is composed of many subcomponents should have. Component requirements describe the expectations at a subcomponent, which the subcomponent has to fulfil. From the component vendor's point of view, the component requirements are in turn product requirements that the vendor must meet. Both types of requirements are strongly depending on each other. (Ebert, 2012)

Normally, requirements are written in natural language. This has the advantage that the requirements can be read and understood by every stakeholder. However, this also creates problems. In particular, due to language ambiguities, the requirements can be interpreted differently by different stakeholders. To reduce the linguistic effects, the use of sentence templates is recommended. (Pohl, 2011)

1.2 Stakeholder, Use-Cases, Context and Boundary Conditions

It is also necessary to take into account the different viewpoints of the users and stakeholders on a product. The following stakeholders were identified by the requirements analysis:

- Engineer (e.g. hardware developer, software developer, algorithm developer)
- Other systems (e.g. control units, personal computers, etc.)

According to the user, it is necessary to know the specific requirements and the intended usage of the system. In addition to the users and their interests, it is also relevant to define the boundaries and the environment (context) in which the system should be used. In this context, it is also considerable to define the boundary conditions that delimit the system from the context. Figure 1.1 shows some identified use cases and the related stakeholders. An include association in the Figure 1.1 represents that a function requires another function to accomplish a use case whereas an extend association describes a refinement of a function.

One identified stakeholder is an external control unit which should be able to start the operation of the BMS. Afterwards, the external control unit can start the state monitoring of the connected battery cells. For this reason, the BMS continuously perform the state estimation, which is based on the measured voltage and current of the individual battery cells. Furthermore, the external control unit should be able to request the state of the attached cells and to stop the operation of the BMS. Also, the external control unit should be able to start a performance prediction and control the cell-balancing.

Another stakeholder is an engineer who develops new hardware and replaces subcomponents of the system. Another task that the engineer has to fulfil with the system is the development of new software and algorithms. Therefore, each subcomponent must be programmable, parameterizable and debuggable. In addition, an engineer must be able to start a one-time measurement operation and read the measured values.

Resulting from the stakeholder and use case analysis, the application scenario (context) of the highly modular BMS will be a laboratory environment or the development department. Therefore, a boundary condition of the BMS is a non-permanent and supervised operation of the system. Furthermore, a usage of the BMS in a production environment, in vehicles, military, aviation, medical fields or other safety critical areas is excluded.

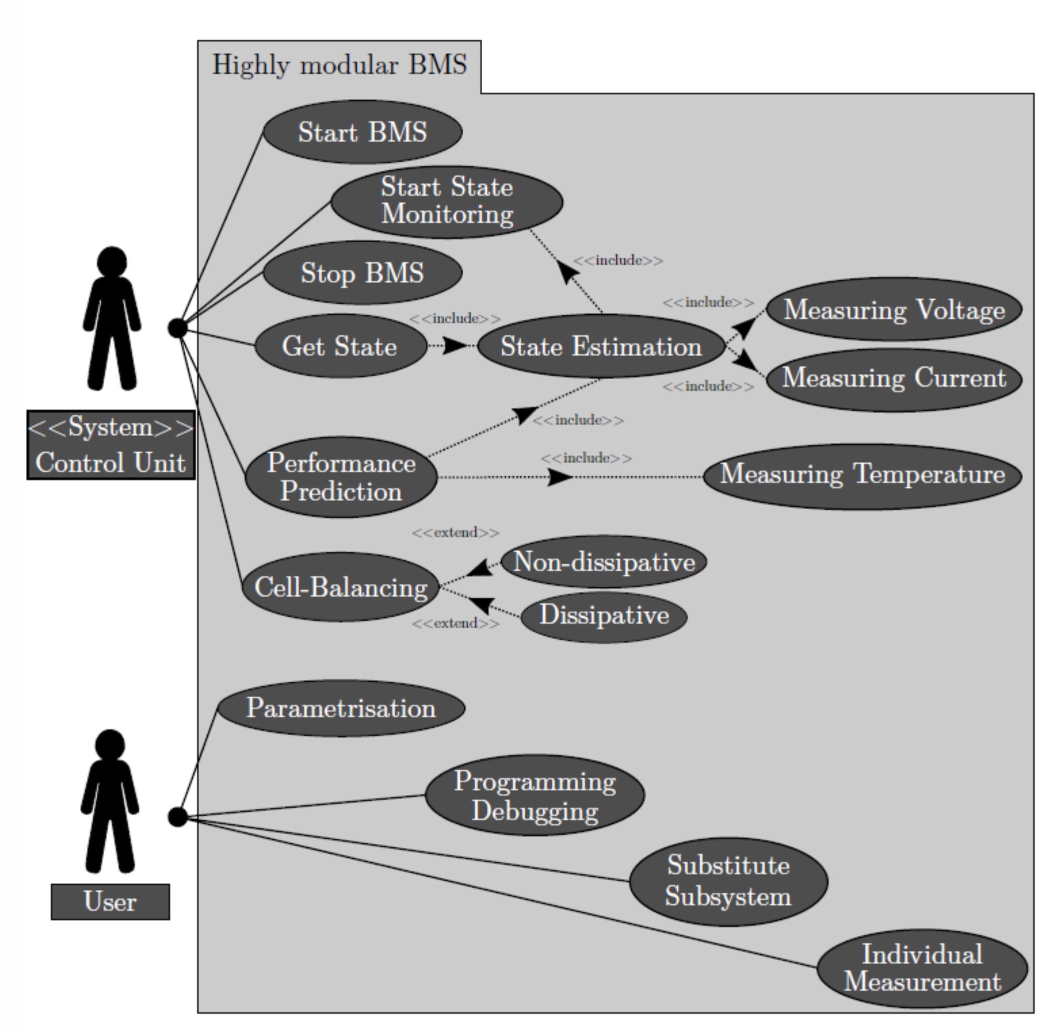

Figure 1: Use case diagram with some identified stakeholders and the associated use cases.

1.3 Requirements

The requirements for the highly modular BMS are specified in the following section.

1.3.1 General requirements

For the first development step, product requirements are imposed on the highly modular BMS in a very general manner. Under these requirements, the structure of the entire BMS is defined as a modular design including several subsystems. Thus, the product requirements such as expandability and substitutability of the BMS-subsystems are guaranteed.

Req-.No.	Description
1	The system is to be constructed modularly.
2	The system should consist of several subsystems.
3	The subsystems should be exchangeable.
4	The system should be modularly expandable.

Table 1: General requirements

1.3.2 Thermal requirements

The thermal requirements that the highly-modular battery management system has to fulfil were derived from the definition of the context and the boundary conditions.

Req-.No.	Description
5	The system should be used in a temperature range from +10 up to +40 °C.

Table 2: Thermal requirements

1.3.3 Mechanical requirements

The mechanical requirements of the battery management system resulting from expert discussions with the stakeholders. The aim of the platform is the exchange of single BMS components without the need for a new development of the entire hardware. Therefore, the product requirement arises that in addition to the software, the hardware must be designed modularly.

Req-.No.	Description
6	The system should be compatible with 19-inch rack (IEEE, 1991).
7	The subsystems should fulfil the required geometrical dimensions of the Europakarte (160 mm x 100 mm) (IEEE, 1998).
8	The subsystems should be modularly exchangeable.
9	The internal supply- and data-interface should be designed with 96-pole (IEEE, 1998).

Table 3: Mechanical requirements

1.3.4 External interfaces

In expert discussions with hardware developers, battery experts and technicians, there are the product requirements that the interface of the external battery cells should be realized with reverse polarity protected connectors. Software and algorithm developers requested that internal communication signals of the BMSs should be available for debug purposes. In addition, external systems should be connected to the platform via standardized technologies. In the automotive area, the control area network (CAN) communication technology is an established standard, therefore CAN should be preferred.

Req-.No.	Description
10	The system should be constructed with terminals protected against reverse polarity.
11	The internal data communication should be accessible from the outside.
12	The system should be designed with interfaces to external systems.
13	The internal data communication should be implemented by an isolated CAN interface.

Table 4: External interfaces requirements

1.3.5 Power supply

The system is operated with an external power supply and at a voltage level of 24V. The galvanic isolation between the supply grid and the interface of the BMS is crucial for the construction of the external power supply. First expert estimate stated a minimum external power supply level of 60W.

Req-.No.	Description
14	The system should be operated with an external power supply.
15	The external power supply should be galvanic isolated.
16	The external power supply should provide a minimum power of 60W.
17	The external current supply should provide a voltage of 24V.

Table 5: Power requirements

1.3.6 Current measurement

Monitoring the Safe-Operating-Area (SOA) for all connected cells within a stack is the main task of the BMS-system. The monitoring includes the cell voltage as well as the cell current for each cell. The current of the battery stack should be monitored and the current ranges from -12A to +12A. The smallest resolution of the system current should be -10mA and +10mA. The current should be measured with a sampling rate of at least 1kHz and the energy supply of the sensors is provided by the system/subsystem.

Req-.No.	Description
18	The system should measure the system current within a range from -12A to +12A.
19	The minimal resolution for the current monitoring should be +/- 10mA.
20	The system should guarantee a galvanic isolation between the current monitoring and the internal data signals.
21	The system should provide the energy supply of the related sensor.
22	The sampling rate for the current monitoring should be at least 1kHz.

Table 6: Current measurements requirements

1.3.7 Temperature measurement

Beside monitoring the safe operating area (SOA), the temperature of the cell will be used for accurate state estimation in terms of using the reduced electrochemical simulation models embedded in a microcontroller. For a safe operating state, the temperature must remain in a certain, cell specific temperature range. In this project, a temperature range from -20°C to +60°C is sufficient to measure the cell temperature. The temperature measurement for every single cell will be conducted via a resistor with negative temperature coefficient (NTC). As an option, also Pt100 and Pt1000 sensors may be used in the further course of the project. As thermal processes occur more slowly than electrical processes, the sampling rate for the cell temperature measurements is set to 1 Hz. The values of the single cell temperatures should be digitised of at least 12Bit.

Req-.No.	Description
23	The system should measure the cell temperature within a range from -20°C to +60°C
24	The temperature measurement should be realized by NTC-resistors.
25	Every measured cell temperature should be digitised.
26	The accuracy of the digitisation should be at least 12Bit.
27	The sampling rate for the cell temperature measurement should be at least 1Hz.

Table 7: Temperature measurements requirements

1.3.8 Cell voltage measurement

Monitoring the SOA for all connected cells is the main task of the BMS. The cell voltage and current are therefore monitored for every single cell. The cell voltage monitoring prohibits every cell to exceed the cut-off voltage for the charging as well as the discharging process. At least six cells in series must be monitored within a stack in terms of the highly modular BMS. The sampling rate for the cell voltage measurement will be at least 1 kHz. For further processing within the BMS-system, the values of the single cell voltages must be digitised. The conversion from analog to digital requires a sufficient accuracy. The measurement range of the cell voltages reaches at least from the cut-off voltage of the discharging process to the cut-off voltage of the charging process. The range of the voltages should be between 0V and 5V and is measured with a sampling rate of 1 kHz.

Req-.No.	Description
28	The system should monitor the cell voltage of at least 6 cells in series within a stack.
29	The measureable voltage range should be from 0V to 5 V.
30	The sampling rate for the cell voltage measurement should be at least 1 kHz.
31	Every measured cell voltage should be digitised.
32	The resolution of the digitised cell voltage value should be at least 16 bit.

Table 8: Cell voltage measurements requirements

1.3.9 Balancing

One of the main focuses of the Everlasting project deals with the investigation of balancing strategies of non-dissipative and dissipative balancing systems. For this investigation, six single cells are considered. Non-dissipative balancing systems require a setup with compensating currents up to 4A per cell whereas dissipative balancing systems are operated with compensating currents of 100 mA at a minimum level, according to expert estimate.

Req-.No.	Description
33	The system should support a non-dissipative balancing.
34	The system should support a dissipative balancing.
35	The non-dissipative balancing should be configured for compensating currents up to 4 A per cell.
36	The dissipative balancing should be configured for compensating currents of at least 100 mA per cell.
37	The non-dissipative balancing should be configured for at least 6 cells.
38	The dissipative balancing should be configured for at least 6 cells.

Table 9: Balancing requirements

1.3.10 Computing power

In the work of Northrop et al. (Northrop, 2014) the proof of concept was delivered for the implementation and simulation of reduced electrochemical simulation models (RESM) of lithium-ion batteries on microcontroller. The 32-bit processor of the Atmel company was used for the implementation. The basic parameters are extracted from this work (Northrop, 2014) and serve as minimal requirements for the implementation of RESMs on microcontrollers.

Req-.No.	Description
39	The numerical simulation of RESMs on microcontroller requires at least one controller of the ARM M4 series.
40	The controller should have at least 64kByte random access memory.
41	The controller should have at least 512kByte read-only memory.
42	The clock rate of the controller should have at least 16MHz.

Table 10: Computing power requirements

1.3.11 Internal interfaces

The modular structure of the BMS requires the definition of interfaces which enable data transfer between the subsystems. In the automotive sector, the communication interface CAN has been established as a standard medium in this matter. CAN will also be used in this system. The calculation processes should be conducted in the controller unit (CU). The data transfer between the CU and the sensors will be implemented via serial peripheral interface (SPI). The data transfer between the sensors and the CU should be implemented via inter-integrated circuit (I2C). Every communication technique will be galvanic isolated to an adequate extent in order to prevent exceeding voltages from the CU.

Req-.No.	Description
43	The internal communication between CUs should be realized via CAN.
44	The communication should be realized by SPI.
45	The communication should be realized by I2C.
46	The SPI interface should have a galvanic isolation.
47	The I2C interface should have a galvanic isolation.

Table 11: Internal interfaces requirements

1.3.12 Internal power supply

The modular structure of the BMS-system assumes several subsystems. Every subsystem requires an energy supply in case of operation. In electronics development, a certain supply voltage has been established at the level of 5V for semiconductor devices. Beside the already defined external 24V supply voltage for the entire system, the additional supply voltage is required at the level of 5V for the subcomponents. The conversion and electronically modification of the 5V energy supply will be centralised and provided via interfaces for every subcomponent in order to design the BMS-system more efficiently. The external 24V energy supply will also be provided via these interfaces.

Req-.No.	Description
48	The internal 5V energy supply should be provided via a conversion of the external 24V energy supply.
49	The internal conversion of the 24V external energy supply into a 5V internal energy supply is centralised.
50	Every subcomponent should exhibit an interface for the 5V energy supply.
51	Every subcomponent should exhibit an interface for the 24V energy supply.
52	The internal 5V and external 24V energy supply should be provided via one single connector.

Table 12: Internal power supply requirements

2 ARCHITECTURAL CONCEPT

The deployment of a highly modular BMS platform is limited to the laboratory environment. Such platform is intended to be used for investigations of BMS algorithms and hardware functionalities, giving a certain freedom in terms of geometrical disposal and interchangeability of subsystems. The design of such BMS platform does not depend on any given battery system, much more it allows a maximum flexibility regarding the installed hardware components.

The basic concept of the modular BMS platform is to divide single BMS tasks on separate plug-in boards, which are connected via mutual backplane. Such backplane provides energy supply and communication channels for each plug-in board. A BMS functionality as cell voltage measurement for example can be easily exchanged by replacing a voltage measurement plug-in board with another. Such concept gives an easy way to exchange and to add single BMS sub-systems. The housing of the BMS platform is a 19-inch rack system, due to its high accessibility in the laboratory environment. Such system holds slots for plug-in boards with the dimension of 100mm x 160mm.

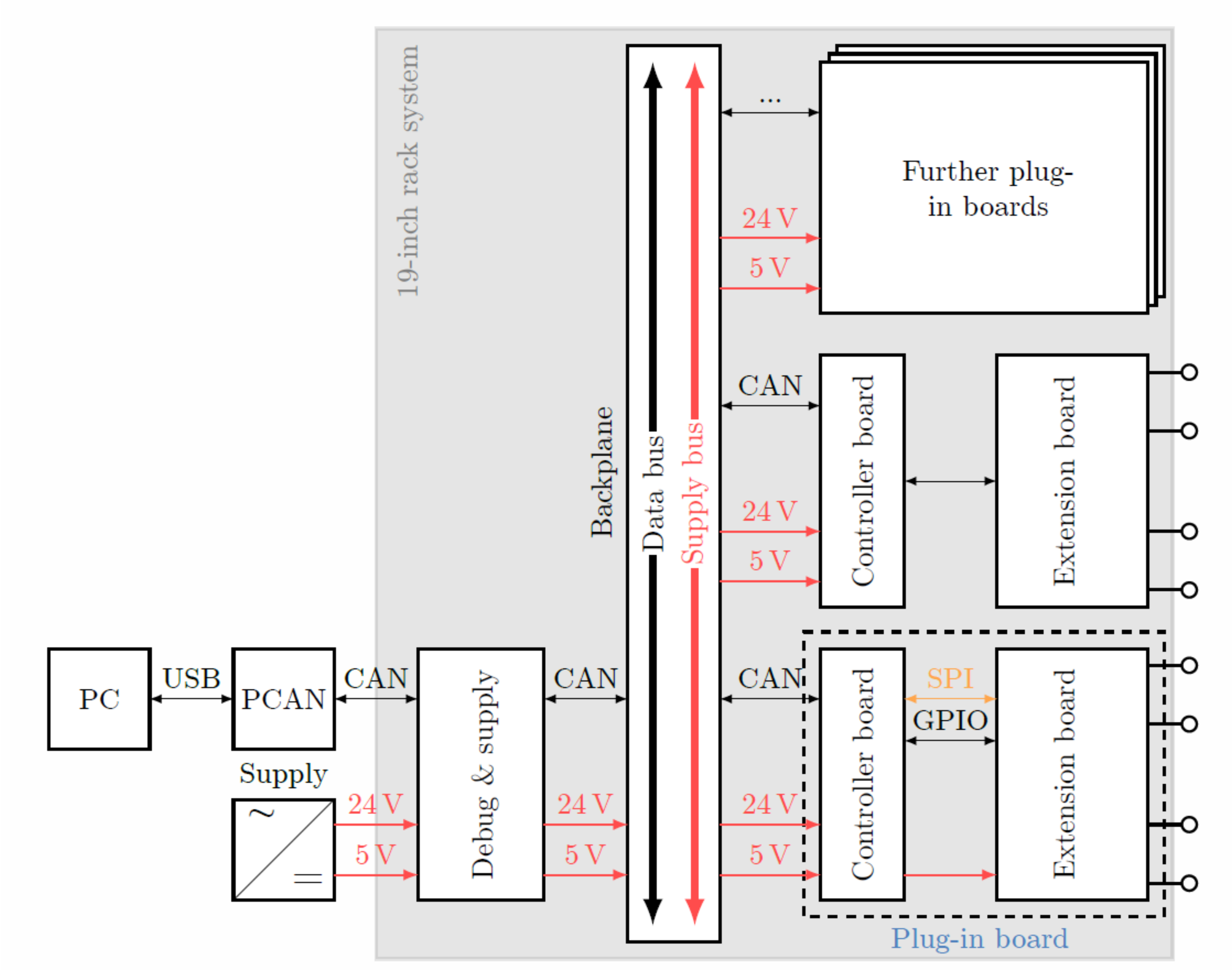

Figure 2: Architectural concept of the BMS shown as block diagram with interfaces

Regardless of the BMS task, which is implemented on a plug-in board, every board needs a conditioning of the voltage supply, communication drivers and at least one micro-controller. In order to exploit the redundancy the concept provides a separation of redundant components and actual BMS relevant components on two pluggable boards. The board with all redundant components is called controller board (CB) and BMS functionality is implemented on the extension board (EB). An overview of the hardware concept for a highly modular BMS platform is shown in Figure 1.2.

The mechanical connection of the controller board is given by a 96-pin receptacle to a backplane. The backplane interface provides 24V and 5V supply, additionally it provides two galvanic isolated CAN adapter for communication between single plug-in boards. The 5V supply is used to power the micro-controller and the 24V supply is used to power the extension boards. In order to avoid failures concerning the in series connected cells a galvanic isolation of the power supply for the extension board is needed. The isolated supply subdivides itself into 5V, 24V and into an adjustable positive and negative supply. Further the micro-controller on the controller board provides isolated SPI and I2C communication channels to the extension board and additional GPIOs (General Purpose Input Output). The overview of the controller board is shown in Figure 1.3.

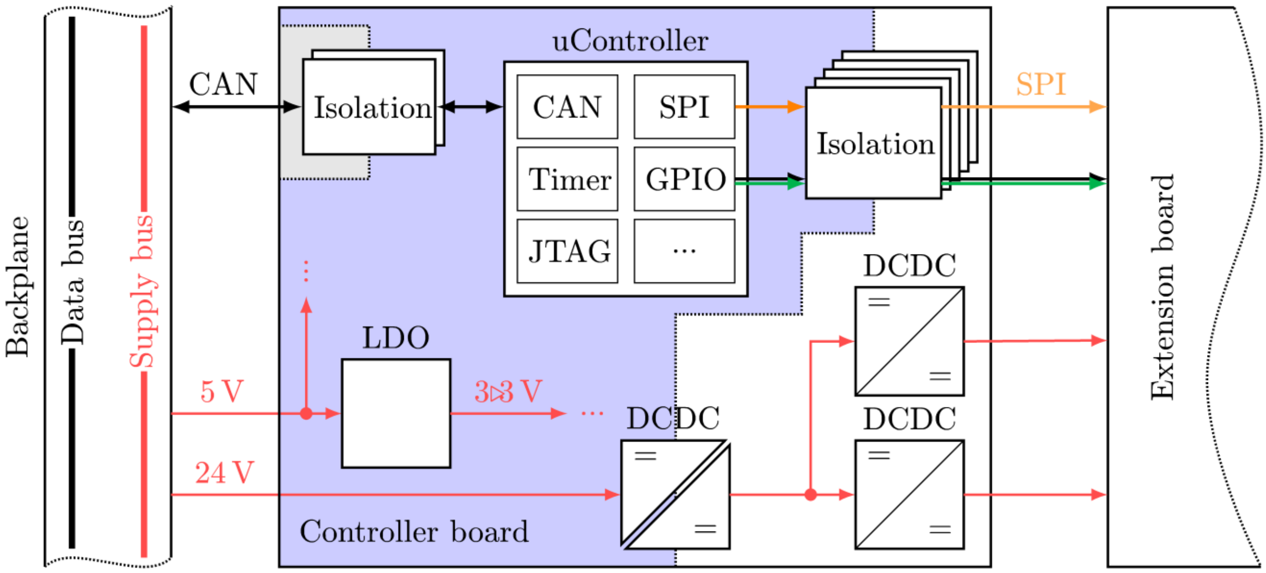

Figure 3: Architectural concept of the controller board shown as block diagram with interfaces

CONCLUSIONS

In the report, the requirements for a highly modular battery management system are presented.

First, the term *requirements* is defined. It has been shown that a distinction must be made between component requirements and product requirements. Product requirements describe the requirements from the stakeholder’s point of view, while the component requirements describe the requirements of the subcomponents of the battery management system.

In the next step, the stakeholders and the use cases of the stakeholders were identified. Also the limitations of the system were determined by an analysis of the context and the boundary conditions. Afterwards, the component and product requirements of the highly modular battery management system are presented and described in detail.

Finally, an architectural concept was developed based on the identified requirements. With this architectural concept, the requirements of the highly modular battery management system can be met. Such system will be the experimental platform for the evaluation of load management strategies from WP5 and also it will be used for the evaluation of the model order reduced physico-chemical models from WP1.

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