Dipartimento di Ingegneria e Scienza dell'Informazione

Corso di Laurea in
Informatica

Elaborato finale

Battery Management System Developement

Applications in a Formula SAE electric race car

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Ringraziamenti

...thanks to...

Contents

Sommario

This thesis covers the challenges of developing a battery management system for a Formula SAE electric race car.
The document focuses on the error management software and cell balancing algorithms, explaining the implementation choices and analyzing experimental results.

Sommario è un breve riassunto del lavoro svolto dove si descrive l'obiettivo, l'oggetto della tesi, le metodologie e le tecniche usate, i dati elaborati e la spiegazione delle conclusioni alle quali siete arrivati.

Il sommario dell'elaborato consiste al massimo di 3 pagine e deve contenere le seguenti informazioni:

- contesto e motivazioni
- breve riassunto del problema affrontato
- tecniche utilizzate e/o sviluppate
- risultati raggiunti, sottolineando il contributo personale del laureando/a

1 Introduction

Battery electric vehicles are shaping the future of transportation. As the name implies, the basis of every BEV is the battery. Batteries are complex electro-chemical components that need to be constantly monitored in order to ensure maximum safety and efficiency. Especially in an automotive environment, where vehicles are often subject to unoptimal and variable working conditions, a battery management system is a safety-critical component that ensures the correct operation of a battery is necessary. Since the BMS can severely influence the performance of a vehicle, it is important to have a well designed and calibrated management system that isn't too invasive to the vehichle's operation.

1.1 Formula SAE

Formula SAE is an international design competition founded by the Society of Automotive Engineers in 1980, in which university students have to develop, build and race an open-wheel, single seater race car.
In Europe, Formula Student Germany releases the rulebook [1] that delineates how a Formula SAE car should be constructed to be eligible to participate in european competitions. TODO: battery rules here?

1.2 Tractive System

The tractive system is the whole high-voltage system of the car. It comprises the battery pack, the inverters and the electric motors that drive the wheels of the car. The E-Agle TRT's car is powered by two independent three-phase permanent-magnet motors that drive the rear wheels of the car.

1.3 Battery Architecture

TODO: add circuits
A battery is an electrical energy storage system that relies on chemical reactions to generate a volt-

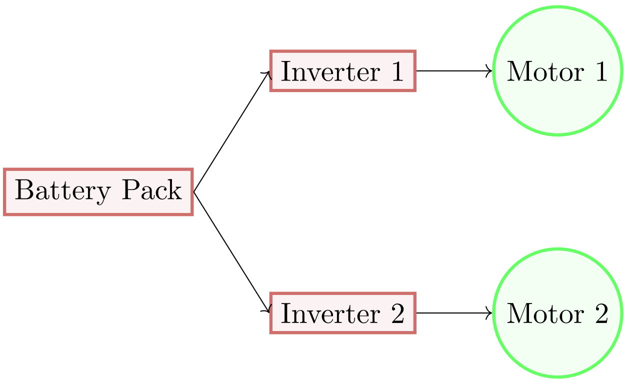

Figure 1.1: Tractive system block schema

age. The main properties of a battery are: nominal voltage, internal resistance, energy capacity and discharge rate.
The voltage of a battery is influenced by many factors including: state of charge, temperature and applied load. The open-circuit voltage of a Lithium-Ion battery cell is 4.2V at 100% state of charge and 3.0V at 0%. When a load is applied to a cell, the voltage drops according to Ohm's law: $V_{dropped} = R_{internal} * I_{load}$.

1.3.1 Battery Pack

A battery pack is a group of cells connected in series and parallel to form a bigger battery. Arranging the cells in series means that the current will only travel down a single path, passing through every cell. In this case the potential of each cell is summed.
In a parallel arrangement, electrons travel down multiple paths, splitting the current across more cells. This increases the current output of the battery, but the voltage is kept equals to a single cell's. A parallel connection of cells is also called a module, as it can be seen as a single, bigger battery cell. The structure of a battery pack is based on it's specific application. For example, if high voltage was to be requested, the battery would have had many modules in series whereas, if the application required an high power output or larger capacity, more cells in parallel would be arranged.

In a Formula SAE car, the optimal setup is a lightweight, high-voltage and high-power battery pack. The rulebook limits voltage to 600V [1, EV 4.1.1] and power to 80kW [1, EV 2.2.1], so the resulting battery will have as many cells in series as permitted and as little parallels as needed to reach the required power and capacity target. E-Agle TRT car's pack features 108 cells in series and only 4 in parallel, for a total of 432 cells and ˜388V of nominal voltage (3.6V per cell). The high power requirement is fullfilled by the use of high-discharge rate cells, 45A in this case that result in an output of 180A of continuous discharge current. As a consequence, The maximum theoretical power output is ˜70kW and the energy capacity amounts to 6.2kWh.

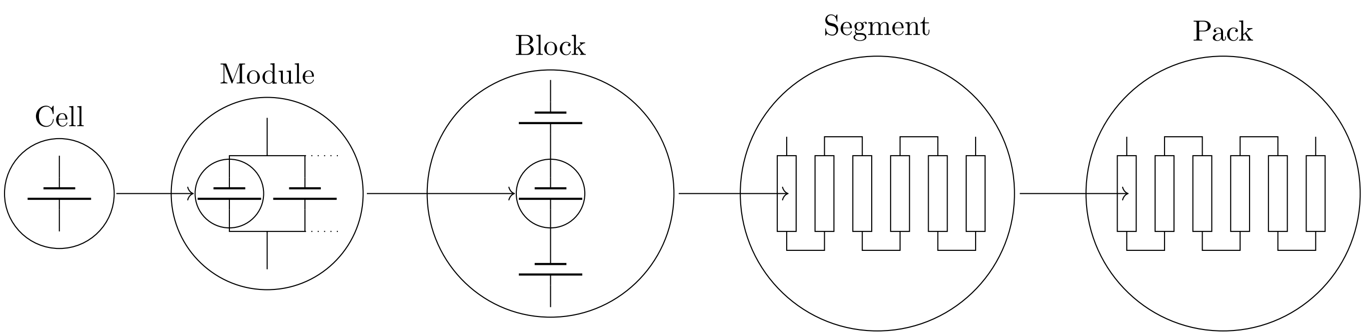

Figure 1.2: Battery pack elements naming scheme

As explained in figure 1.2, the pack is subdivided in parts that can be summarised as follows:

- A cell is the basic unit of a battery pack.
- A parallel of four cells forms a module (also called cell in some cases).
- Blocks are a series of three modules, that are mounted in a single physical element.
- The rulebook mandates the separation of the pack into smaller segments with precise characteristics [1, EV 5.3.2]. In this case a segment is a series of six blocks, totalling a maximum voltage of 75.6V and $\tilde{1}$.2kWh of energy, below the limit of 120V and 1.6 kWh.
- Finally, the battery pack is a collection of six segments in series.

1.3.2 Internal Connections

To better control the pack, two Accumulator Isolation Relays (AIR) [1, EV 5.6] are located at both poles of the pack to disconnect its output when not needed. These relays are controlled by the BMS and can also be switched off by external devices such as emergency buttons located around the car.

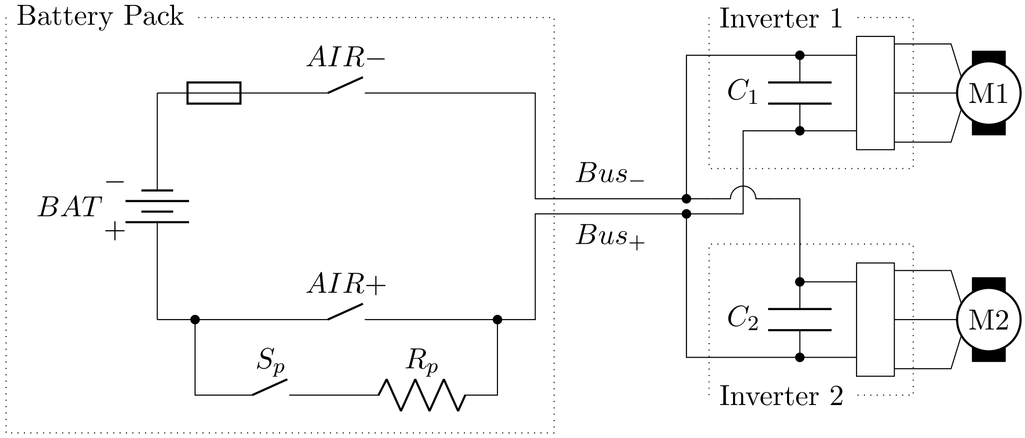

Figure 1.3: Tractive system schema

1.4 Battery Management

Battery management is a collection of operations that ensure the safety and efficiency of the battery pack's operation.
A battery management system should constantly measure cell temperatures, module voltages along with the total pack current output and check that each of those values is within specification. If anomalies are detected, the battery should be disconnected immediately.

1.5 Module Balancing

Cells are not perfectly identical and can have slight variations in internal resistance between each other. These imperfections mean that after some use, modules can start to deviate in voltage output between one another. This poses a limitation on the depth at wich the battery can be charged or discharged, reducing the total usable capacity of the pack.
Solving this problem involves charging or discharging every module until they all are inside an acceptable threshold.
Example: TODO: module voltages chart and explanation

2 BMS Hardware

The need to measure a large amount of voltages and temperatures scattered around the battery pack means that a decentralized structure for the BMS components is preferable. The two main types of logic boards are the **Mainboard** and the **Cellboard**. Every cellboard measures voltages and

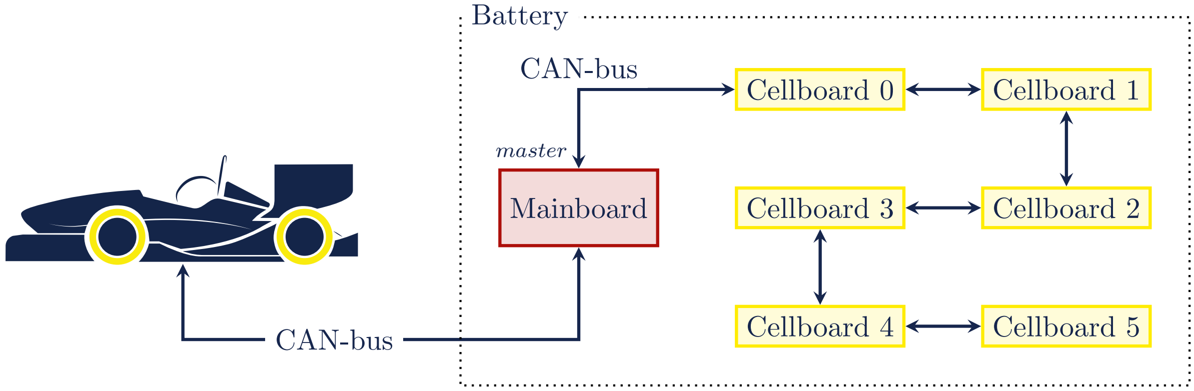

Figure 2.1: BMS hierarchy

temperatures of a *section* of the pack, and sends data back to the Mainboard via CAN bus. The Mainboard inteprets the received data and takes actions based on them.

2.1 Mainboard

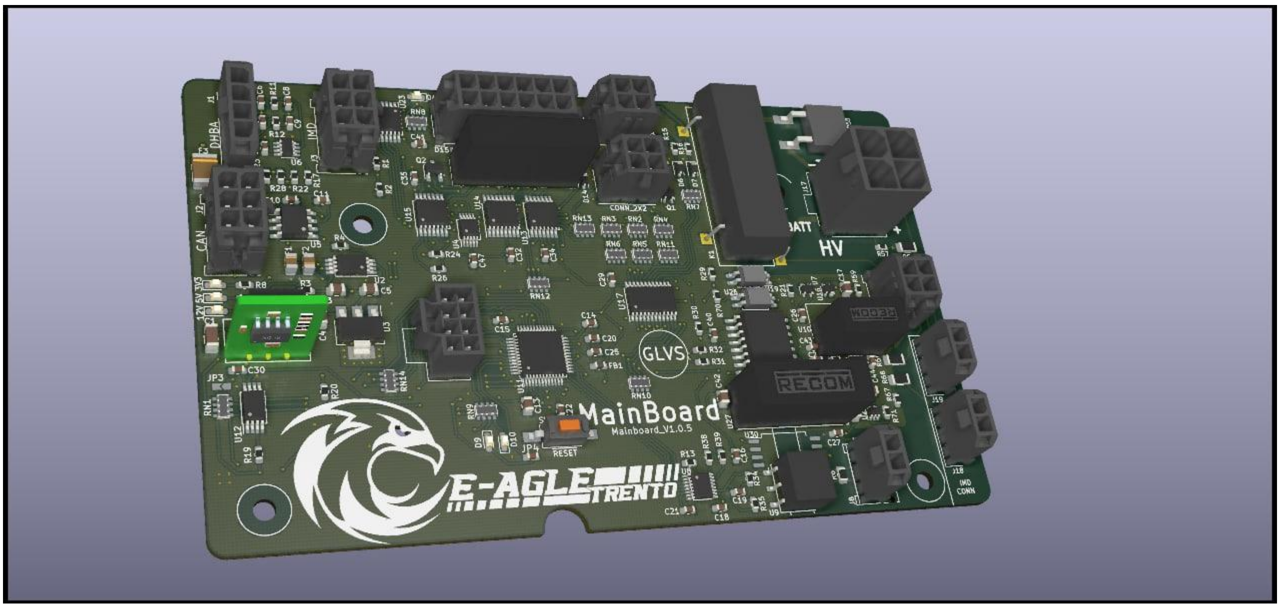

Figure 2.2: Mainboard PCB

The Mainboard is the central control unit of the BMS. It consists of a microcontroller that handles the pre-charge circuit, two CAN-bus lines and some external peripherals.

2.2 Cellboard

The Cellboards are dedicated to the measurement of module voltages and cell temperatures. The reading of those values is handled by a specialized battery management chip that communicates via

SPI to the on-board microcontroller.

3 Cell Balancing

As discussed in the introduction, the problem of battery balancing is fundamental to maximize the net battery capacity. As measured

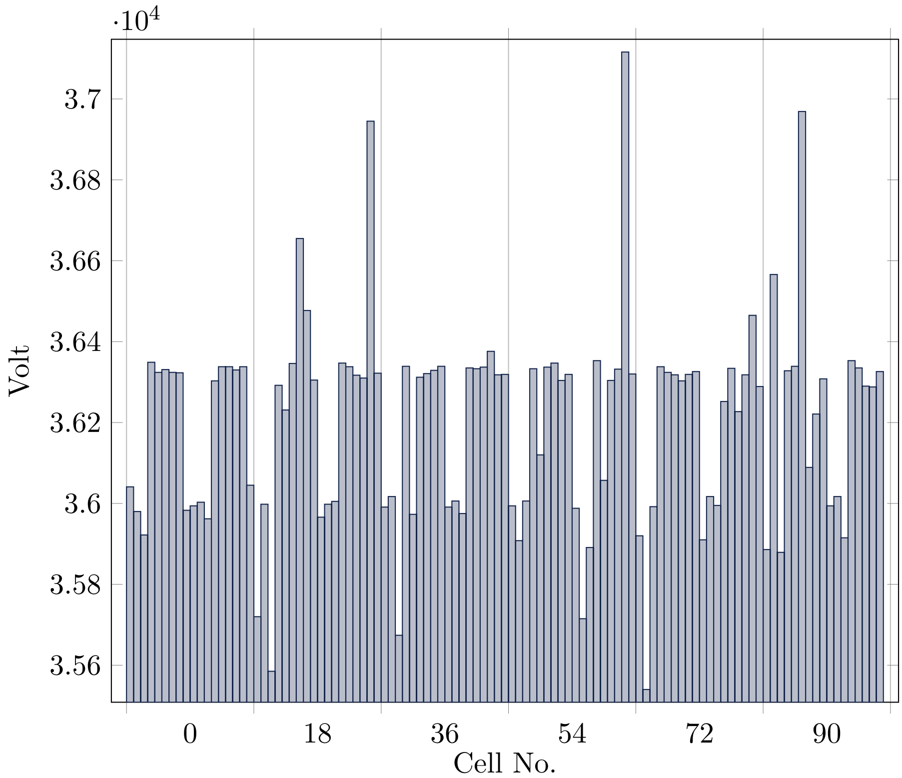

Figure 3.1: Umbalanced cells

3.1 Strategy

3.2 Evaluation

Bibliography

[1] Formula Student Germany GmbH. Formula student germany 2020 rules v1.0. https://www.formulastudent.de/fileadmin/user_upload/all/2020/rules/FS-Rules_2020_V1.0.pdf, 2020.

Allegato A Titolo primo allegato

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