1. Introduction

1.1. Background

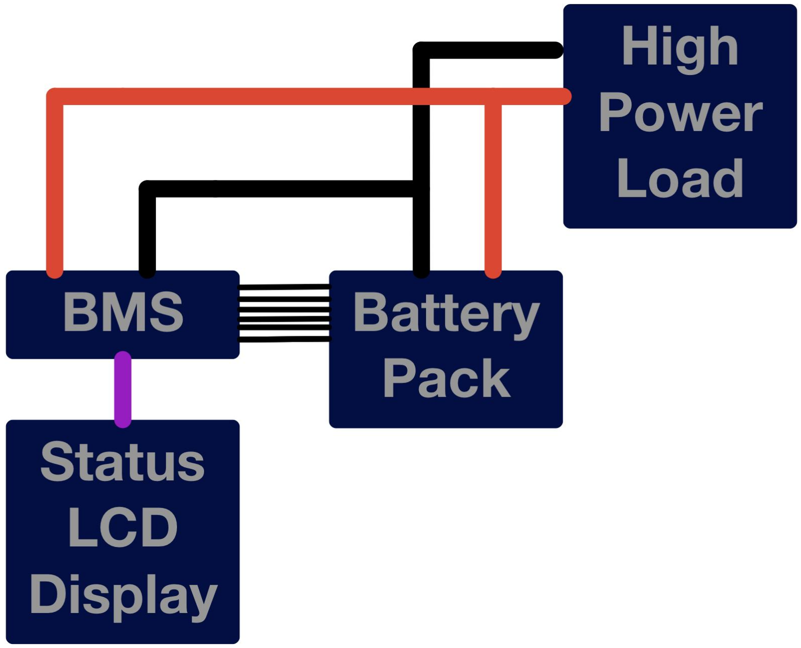
In an era of growing popularity of electric vehicles, more efficient battery management systems are crucial for the longevity of the battery life and range of the electric vehicle. The most efficient battery management systems provide active cell balancing, meaning that during charging or normal operation cells can be brought to the same state of charge, not allowing a condition when a cell is completely depleted while others still can provide power. Due to the covid-19 pandemic, there has been a shortage of silicon and delays of production of integrated circuits. Many companies and project enthusiasts were hit by this pretty badly as they can't use the same specialized ICs they used previously, causing increased development times, cost and uncertainty of new solutions to be future proof.

1.2. Objective

The goal of our project is intended to cover both of these issues. We are proposing to make a modular active balancing BMS using widely available chips at a low cost that can be easily substituted in the future. By using common components we can achieve flexibility for the users with different capacity of battery packs and increased product availability.

1.3. Solution

Our solution involves the use of a switch matrix and a differential ADC to collect voltage of each cell in a battery pack as well as a pack-to-cell balancing circuit using power from the whole battery pack redirected to a depleted cell. Our BMS will also have an LCD screen to show the status of the batteries and error messages. It should be noted that the battery pack itself is not part of the project.



1.4. High Level Requirements

1.4.1. BMS should precisely measure the voltage of each cell(+/-0.01V) within a range of 2v-4.5v.

1.4.2. BMS should monitor the temperature of the battery pack from -5C to 55C within 5C.

1.4.3. Display cell voltage and temperature on an LCD Display at a rate of 1Hz

1.4.4. The cell with the lowest voltage should be charged up to the average cell voltage at constant current, 6A, using the current from the battery pack

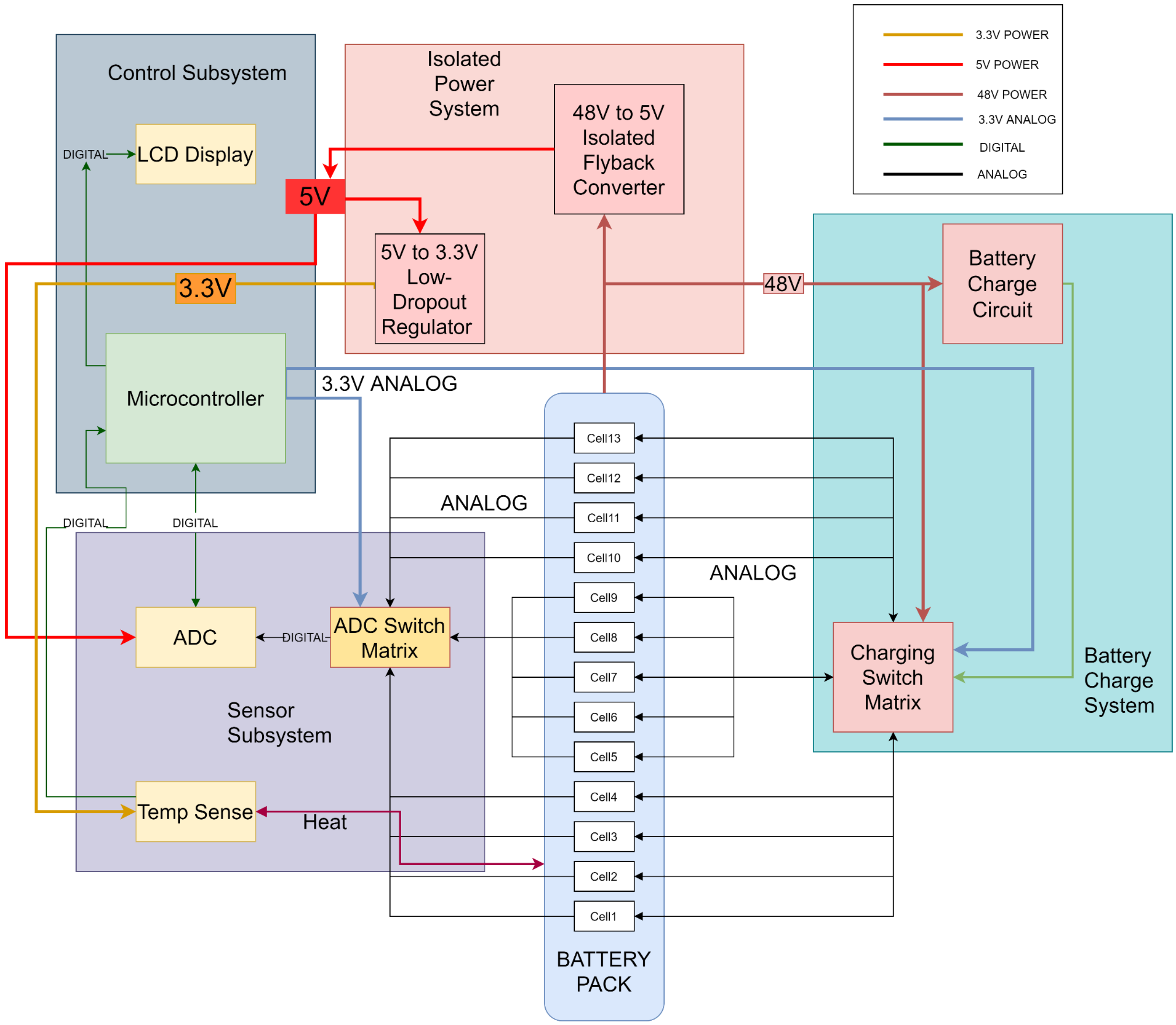
1.4.5. Temperature outside of 5C-35C will disable charging

1.4.6. Temperature outside of 0C-45C will disconnect the load from the pack.

1.4.7. If average cell voltage is under 3v, disconnect the pack and stop balancing.

2. Design

2.1. Block Diagram



The project consists of a Control Subsystem, Sensor Subsystem, Isolated Power System, Battery Charge System and the battery itself.

2.2. Isolated Power System

The isolated power system will provide 3.3V and 5V power rails that are isolated from the main battery pack. By keeping the power supplies isolated, our electronics will remain protected from any faults in the battery pack.

2.2.1. Subsystem Requirements:

2.2.1.1. Fused to the battery back at 10A.

2.2.1.2. 48V to 5V isolated flyback converter, rated for ~2A +/- 0.5A
2.2.1.3. 5V to 3.3V LDO, rated for 1A +/-0.5A

2.3. Battery Charge System

The Battery Charge System is responsible for actually charging an individual cell up to the pack average cell voltage. It consists of an isolated constant current power supply, which provides the charging current for a cell, and a power fet switch matrix.

2.3.1. Charge Switch Matrix

The Charge Switch Matrix will consist of an isolated floating gate driver that switches a NMOS power fet array. These FETs will be responsible for connecting the charging current to a single cell at a time. The FET array will be configured for bidirectional use and be connected between each battery cell.

2.3.1.1. Requirements
2.3.1.1.1. N Channel MosFets rated for at least 20V, 8A.
2.3.1.1.2. Isolated floating N-Type gate driver, capable of being controlled from a 3.3V STM32 GPIO

2.3.2. Battery Charge Supply

Provides the charging current used to balance cells.

2.3.3. Requirements
2.3.3.1. Isolated from main pack power
2.3.3.2. Supports 6A +/- 0.5 constant current flow from 48V input
2.3.3.3. Fused at 10A from the battery pack

2.4. Sensor Subsystem

2.4.1. ADC

Differential input ADC for measuring cell voltages. A single ADC will be connected to an arbitrary cell using an array of optocouplers. The ADC reading will then be communicated back to the Control Subsystem

2.4.1.1. Requirements
2.4.1.1.1. ADC rated for differential reading between 2 and 4.5V, accurate to 0.01V
2.4.1.1.2. Optocouplers with <50mA input current, and Collector - Emitter Voltage > 48V

2.4.2. Temperature

Monitors the temperature of each cell in the battery pack and reports the data back to the Control subsystem. To minimize I/O usage, the thermistors will be switched on a single I/O using a MUX

2.4.2.1. Requirements
2.4.2.1.1. Thermistor capable of measuring -10C-55C at 5C accuracy

2.4.2.1.2. Analog MUX capable of operating at a 3.3v logic level and can switch at least 13 inputs.

2.5. Control Subsystem

2.5.1. The Control Subsystem will use a microcontroller to control the ADC optocouplers, thermistor MUX, and power fets. To monitor the thermistors, it will cycle through the mux, and store current values for each cell in its RAM. It will also cycle through and monitor cell voltages when balancing is not occurring. Once a low cell is identified, it will enable the appropriate power fets, until the cell voltage is at an appropriate level. An I/O driver may be needed to manage everything. The Sensor Values and Charging status will be displayed on the LCD Screen. The microcontroller will also control a high-voltage, high-current contactor that connects the pack to the external load.

2.5.2. Requirements

2.5.2.1. Update each cell temperature at least 1Hz

2.5.2.2. Update each cell voltage at least 10Hz

2.5.2.3. Enable and disable cell charging at least 10Hz

2.5.2.4. Detect a temperature outside of 15-35C and disable charging

2.5.2.5. Calculate cell average voltage at least 10Hz

2.5.2.6. Display all sensors values and charging state on display at 1Hz

2.5.2.7. Disable contactor if temperature exceeds 45C or below 0C

2.5.2.8. Disable contactor if any cell voltage exceeds 4.2V or below 2.5V

2.6. Battery Pack

2.6.1. Characteristics of a battery pack provided to us by Illini EV Concept

2.6.1.1. 13s4p Li-Ion cell battery pack

2.6.1.2. Nominal Voltage: 3.6*13=46.8V

2.6.1.3. Max Voltage: 4.2*13=54.6V

2.6.1.4. Battery Capacity: 3Ah*4=12Ah

2.6.1.5. Energy Storage: 12*46.8=561Wh

2.6.1.6. Max Discharge Current: 20*4=80A

2.6.1.7. Max Normal Charge Current: 4*1.5=6A

2.7. Tolerance Analysis

We will demonstrate our working system on the Illini EV Concept 48V battery pack (13s4p configuration). We will have an unbalanced battery pack and first the BMS will check the safety of the battery pack by collecting the voltages of the cells, temperature of the pack. The status of the battery pack will be displayed on the LCD screen. When BMS finds the lowest charged cell, the balancing will start with messages on the screen of the process. Whenever the cell reaches the balanced level, charging will stop and a message will be shown on the screen. We will also be able to arbitrary discharge a single cell from a balanced pack to demonstrate continued use.

The largest challenge with this project will be the charge power convertor as no one on the team is familiar with constant current circuits. However, single cell lithium charge circuits are readily available and cheap. In the event of a time crunch, an off the shelf part can be used instead.

3. Ethics and Safety

3.1. Ethics

3.1.1. Our battery management system will not endanger any user or the environment. We will display the temperature and voltage of the cells on an LCD to make sure it is safe to handle and test.

3.1.2. We will credit other sources when applicable during the research phases

3.1.3. Will seek and accept feedback and criticism from TA meetings with the goal of improving and correcting any possible errors

3.2. Safety

3.2.1. The thermistor will help prevent overheating the battery cells

3.2.2. The balancing function of the BMS with prevent cells from being over discharged, which would damage the cell health

3.2.3. The BMS can also monitor cells to prevent overvoltage on cells, which could cause fire.

3.2.4. All of the components will be isolated and fused, preventing an electronics failure from shorting the whole pack.