Topology of Battery Management System for Second Life Battery Energy Storage System

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***Abstract*— With the growing development of electromobility, the number of manufactured batteries is also increasing, which will eventually need to be recycled. One of the recycling options is to use worn but still functional batteries in energy storage systems, giving them a second life. Each battery assembly requires a Battery Management System (BMS) for proper and safe operation. For recycled cells, the BMS system is more complex due to significant differences in wear and, consequently, in parameters between the cells. Therefore, active balancing of each cell in the assembly is necessary in such a configuration. Additionally, increased safety measures must be taken for such an assembly.**

Keywords—Active Balancing, BMS, Electromobility, Energy Storage, Temperature Monitoring, Voltage Monitoring

I. Introduction

With the growing development of electromobility and thus the associated production of batteries for this industry, the question of future recycling arises. The battery in an electric vehicle in one of its most critical components. These batteries heavily depend on the size-to-capacity ratio, as space for batteries in electric vehicle is very limited. The capacity of batteries decreases by using, reducing the range of the electric vehicle and it can reach very low and unsustainable levels over time. Such a battery can no longer be used in an electric vehicle. One option for utilizing a worn-out battery with reduced capacity is to incorporate it into a stationary energy storage system.

Stationary energy storage systems are not much limited by the space used and we can use more batteries with smaller capacity. In this way, we can give old batteries from an electric vehicle a second life.

BMS is designed for battery management. The system monitors battery pack parameters, such as cell voltages, temperatures, and current throughout the battery pack, and it uses balancing to equalize differences between individual cells [1], [2], [3].

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II. Requirements for BMS design

Special requirements are placed on battery management system for second-life batteries. Second-life batteries are already used in another application, and different batteries may have varying degrees of wear and tear. Even batteries of the same type can exhibit drastically different parameters. For this reason, it is necessary to utilize active balancing circuits that effectively equalize these differences. Active balancing circuits also allow the integration of batteries with different parameters into the assembly. Used battery cells are more prone to failure than new cells, which is why it's important to monitor the temperature of each cell. Therefore, the system provides multi-channel temperature measurement. The system also supports connecting a variable number of battery cells into the assembly [4], [9], [10].

III. BMS Architecture

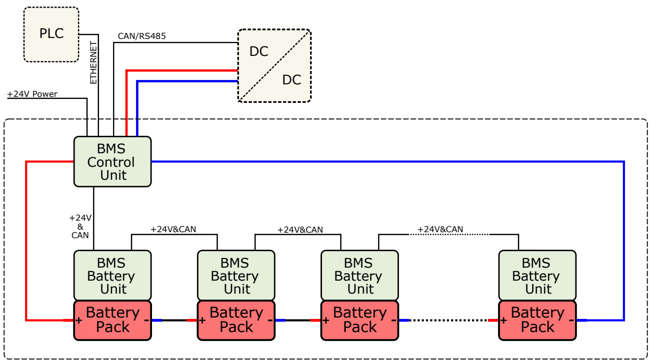

Fig. 1: BMS Architecture

The battery storage management system consists of two main parts: the control unit and the battery units. There is always one control unit in the chain, and there are multiple battery units in the chain, one for each battery pack. The battery unit consists of two parts: the front panel of the pack integrating the control of the battery unit and the monitoring and balancing boards. System architecture is shown on Fig. 1.

The battery units communicate with the control unit via a CAN bus. The control unit collects measured data from the battery units, performs specific calculations, and further manages the battery assembly and battery units. Additionally, the control unit supplies 24V power to the battery units.

The control unit also communicates with higher-level systems such as the PLC controller or the connected DC/DC converter for this battery assembly. It transfers information about the battery assembly and its status to the higher-level system.

Up to 24 battery units can be connected to the control unit. In practice, this number is further limited by the maximum voltage of the battery system, which can be as high as 1100V.

IV. Control Unit

The control unit of the BMS, also known as the main unit, communicates with the individual battery units, from which it collects information about the individual battery cells, including voltage and temperature values. Additionally, the control unit measures the total voltage of the battery assembly and the current flowing through it. These values are input into control conditions and algorithms, based on which the balancing of individual cells is managed. Information about the state of the battery assembly is further transmitted to the higher-level system, such as the PLC controller or the power DC/DC converter. Communication with the higher-level system can utilize interfaces such as CAN, Ethernet, or RS485. The topology of the control unit is shown in Fig. 2. The individual components of the control unit and their circuit solutions will be discussed in the following sections of this chapter.

Furthermore, the control unit integrates power disconnect circuits, which disconnect both the positive and negative output poles of the entire battery assembly. This function is crucial for safety and protection of the battery storage, especially in emergency situations such as overloading, overheating, or short circuits. The printed circuit board of control unit is shown in Fig. 3.

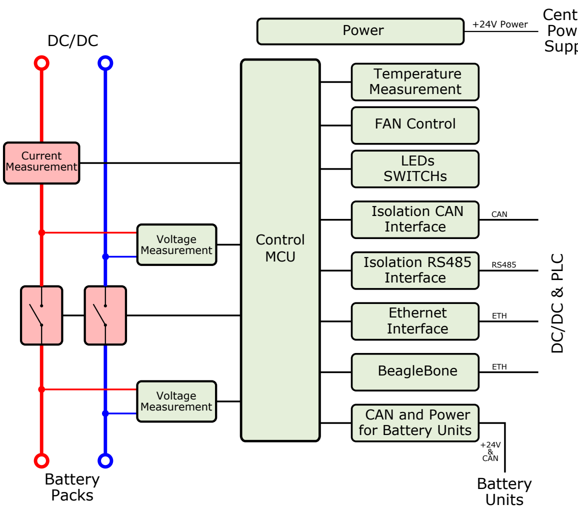

Fig. 2: Control unit topology

A. Control MCU

The main component of the control unit is the control microcontroller labeled STM32G474VET6, which features an ARM Cortex M4 core. The microcontroller operates at a frequency of up to 170 MHz and offers a wide range of communication and computational peripherals.

B. External system communication

External communication is used for transmitting the state of the battery assembly to the surrounding systems and the superior control of the entire battery storage system. The control unit implements CAN, RS485, and Ethernet interfaces for this purpose. The CAN and, optionally, RS485 interfaces are primarily intended for communication with the DC/DC converter connected to the battery assembly. The Ethernet interface is primarily designed for communication with the control system, i.e., the PLC control of the entire storage system. The Ethernet interface can implement various communication protocols, including simple UDP datagram communication or protocols like Modbus TCP or MQTT.

The control unit is also equipped with a USB port, which allows connecting a personal computer with an application for system configuration. Using the application, you can configure the system's communication interfaces, types, the number, and the arrangement of battery cells in the assembly, as well as other BMS options.

C. Single-board computer

The functionality of the control microcontroller can be extended with a single-board computer like the BeagleBone. This allows for a significant increase in computational power and the expansion of the capabilities of the entire control unit. The BeagleBone computer can implement various advanced features useful in the battery management system. Thanks to its performance and open hardware, it can implement sophisticated algorithms and technologies that would be too demanding for the control microcontroller alone. For example, it can be used to implement state of charge (SOC) calculation algorithms or predictive diagnostic algorithms using neural networks or deep learning. Additionally, the BeagleBone provides connectivity to a local area network (LAN) or the internet. If the BeagleBone is not installed, LAN connectivity is achieved through a communication module with the integrated circuit W5500 chip from Wiznet.

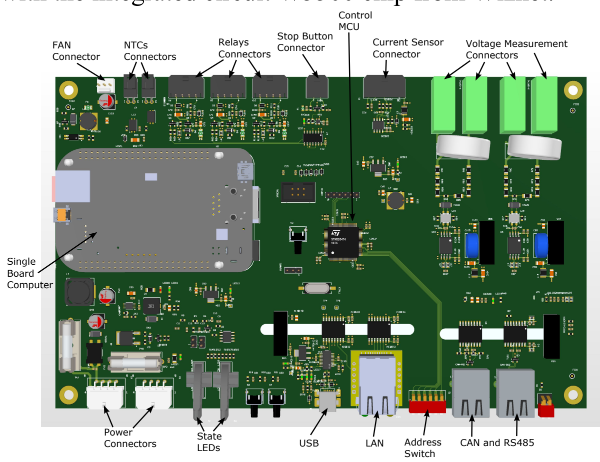

Fig. 3: Printed circuit board of control unit

D. Current Measurement

The current measurement of the battery assembly is carried out using a non-invasive method, using a through current sensor. Specifically, it is possible to use a sensor from the LEM company's HO 100-/SP30 series. The signal from the current sensor is processed through an input amplifier and an analog-to-digital converter within the microcontroller. In the series, sensors with nominal currents of 50, 100, 150, 200, and 250 A are available. It is therefore possible to select a sensor with a suitable range for a given application. Alternatively, it is possible to choose a different current sensor with a voltage output. Calibration of the current measurement can then be achieved through software.

E. Voltage Measurement

The voltage measurement of the entire battery assembly is implemented at two locations, namely before the power disconnect elements, on the battery assembly side, and after the disconnect elements, on the DC/DC converter side. The fundamental component of the setup is a precision, galvanically isolated amplifier from Texas Instruments with the model designation AMC1350. The measurement input of the amplifier is connected through a voltage divider, and the output is connected to an analog-to-digital converter in the microcontroller. The maximum measured voltage, and thus the system voltage, can be up to 1100V. Calibration of measurements can be done in software.

F. Safety Disconnecting the battery assembly

In the standby state of the battery storage or in emergency situations such as overheating or overload, it is necessary to disconnect the power lines, i.e., the high-voltage output of the battery assembly. Disconnection is achieved using power contactors in both the positive and negative branches of the output power lines. The decision to engage or disengage the disconnecting devices is made by the control microcontroller. Another option for disconnecting the power lines is manual, using a stop button. For the disconnection or connection of the battery assembly, high-voltage power contactors from the HVC200, HVC300, HVC500 series in the portfolio of TDK are selected.

V. Battery Unit

The battery unit of the BMS system is designed to manage the individual battery cells within the entire assembly. The battery unit consists of a front panel board that implements the control of the battery unit and cells boards for monitoring and balancing, with the possibility of up to three boards, each capable of monitoring and balancing up to 6 cells. Therefore, each battery unit manages up to 18 cells, with the caveat that not all positions need to be occupied. The unit measures parameters of the connected cells, such as voltage and temperature, evaluates these parameters, and transfers them to the control unit. Communication with the control unit occurs through a CAN bus.

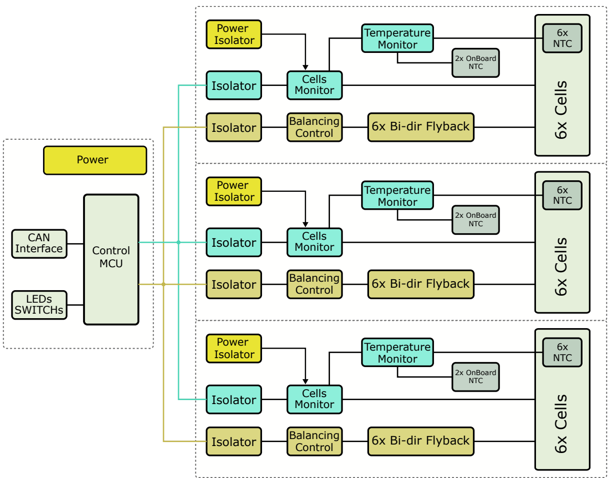

Fig. 4: Battery unit topology

Furthermore, the unit implements an active balancing circuit for each cell. This is a bidirectional flyback converter-based balancing circuit with a shared voltage bus. The balancing function is controlled by algorithms from the control unit. The topology of the battery unit is indicated in the Fig. 4.

A. Front Panel

The front panel board is mounted at the front of one battery pack enclosure. The front panel board houses a control microcontroller that governs the functions of the battery unit. The design of the front panel printed circuit board is shown in Fig. 5 and Fig. 6.

Connectors, LED indicators, and switches are routed out of the enclosure through suitable openings in the cover, enabling access from outside the box. These components are visible in the Fig. 6.

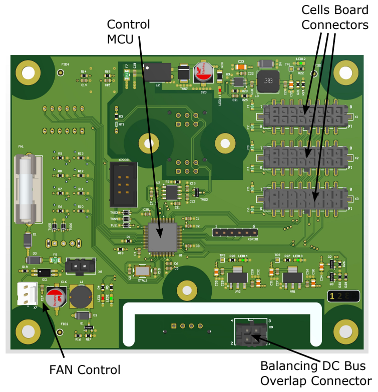

Fig. 5: Printed circuit board of battery unit front panel (TOP side)

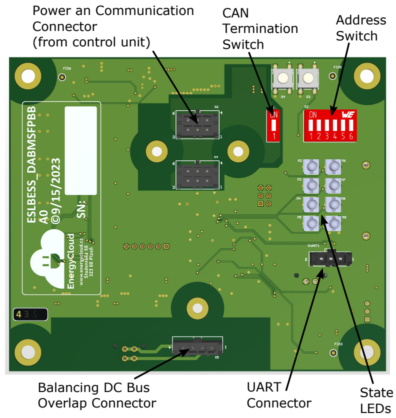

Fig. 6: Printed circuit board of battery unit front panel (BOT side)

B. Control MCU

The control microcontroller controls the individual components of the battery unit, preprocesses the measured values, and transfers them to the control unit. It also receives commands from the control unit. The microcontroller used is the STM32F072R8T6TR, featuring an ARM Cortex-M0 core. It can operate at a frequency of up to 48 MHz.

C. Cells Monitoring

The unit must monitor the voltage and temperature of each cell in the pack. Voltage measurement needs to be highly precise because even a small voltage difference (e.g., 10mV) can lead to cell degradation. Monitoring the temperature of each cell enhances reliability, and any defects can be detected more quickly than if cells were monitored as a group. The monitoring circuit can be powered either from the cell assembly or using an isolated power source if the cell voltage is not sufficiently high.

For monitoring the voltage and temperature of cells, a specialized integrated circuit LTC6811 [5] is used. This integrated circuit can monitor up to 12 battery cells with different chemical compositions and, therefore, different voltage parameters. In this application, only 6 voltage measurements are utilized. The cells are connected through overvoltage protection and RC filtering circuits to reduce noise. NTC sensors are used for temperature monitoring, and they are connected to the respective pins of LTC6811 via a multiplexer.

D. Cells Balancing

The battery unit is capable of fully balancing 18 cells. For each cell, the battery unit employs a dedicated bidirectional flyback converter. Each monitoring and balancing board of the battery unit has 6 balancing converters. Unlike passive balancing, the process of active balancing is more efficient and leads to better utilization of the overall capacity of battery cells even when there are significant differences between individual cells. The bidirectional flyback converter can effectively equalize cell imbalances during both charging and discharging of the battery assembly [1], [7].

The control of active balancing for individual cells is managed by the integrated LTC3300-2 [6] circuit, which can control up to six independent bidirectional flyback converters [2], [3]. The LTC3300 integrated circuit controls transistors on both the primary and secondary sides based on the current flowing through the primary and secondary windings of the flyback transformer. Currents on the primary and secondary sides are measured using shunt resistors. The primary side is connected to individual battery cells. The secondary sides are connected in parallel on the board, forming a DC balancing bus. The configuration of the common balancing bus is described in the following paragraph.

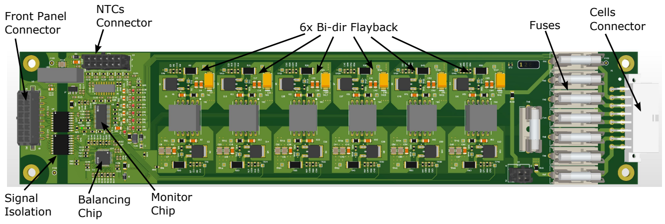

Fig. 7: Printed circuit board of battery unit monitoring and balancing

E. Balancing DC Bus Connection

The balancing DC bus connects the bi-direct flyback converters on the cell board on the secondary side, which means there are always 6 flyback converters. This bus is then connected to 12 battery cells. The negative pole of the DC balancing bus is always connected to the negative pole of the balanced set of six cells. The positive pole is then connected to the positive pole of the twelfth cell. An exception in the configuration must be made for the last six cells in the assembly, where the positive pole is connected to the sixth cell. This way, the DC balancing buses are interconnected between individual packs, which is why there is a connector on the front panel for what is called 'balancing bus interleaving.' This configuration is crucial for balancing to work between all cells in the assembly.

F. Front Panel Board and Cells Board Connection

The printed circuit boards of the front panel and the boards integrating balancing and monitoring are interconnected via SPI buses and power supply. Separate SPI buses are utilized for the monitoring control circuit and the balancing control circuit, but they are shared across all 3 cell boards, as evident from the architecture of the battery unit. Therefore, both SPI communication buses interface with three integrated circuits of the same type. Communication with the respective integrated circuit on the SPI bus is achieved using the chip select signal.

On each cell board, both SPI buses are isolated with an isolation integrated circuit. The voltage between the control circuits on the front panel board and the cell boards can be as high as the voltage of the entire battery assembly, which can reach up to 1000 V in the case of many series-connected cells. Hence, it is essential to isolate the SPI buses using a suitable integrated circuit with adequate electrical strength.

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