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Smart Battery Backup for Uninterrupted Energy Part 3: Battery Management System

Christian Cruz, Staff Applications Development Engineer, and
Marvin Neil Cabuenas, Senior Firmware Engineer

Abstract

This article describes the algorithm developed by Analog Devices for the Open Compute Project (OCP) Open Rack V3 (ORV3) battery backup unit (BBU) for the battery management system (BMS), an essential device of any data center BBU. Its primary responsibility is to ensure the safety of the battery pack by monitoring and regulating its state of charge (SOC), health, and power. Because of this, it is important to design and implement the BMS with great care as it is a complex and important component in the data center.

Introduction

It is necessary to understand the operation of a BMS while exploring the BBU reference designs of ADI. The BMS is responsible for monitoring and regulating the condition of the battery, ensuring that it operates within safe parameters. This includes monitoring battery stack voltages, battery stack temperatures, and overall battery stack current levels, as well as managing charge and discharge cycles. Implementing a robust BMS allows for optimal efficiency and safety in system-level solutions. Ensuring long battery life is essential for peak performance. Frequent overcharging or overdischarging without knowing can damage its health and shorten its battery life cycle. By carefully monitoring the battery's state of health (SOH) and giving it proper use, it will avoid any untimely shutdown or breakdown and perform at its best.

Furthermore, monitoring the battery's SOC is important for the overall health of the battery stack. Over time, batteries lose capacity, and draining them to zero can speed up this process. The sweet spot for longevity is keeping the battery charged between 20% and 80%. Being aware of the battery's SOC ensures that the BBU module remains functional for a longer period of time.

Besides SOH and SOC, the need for a better understanding of depth of discharge (DOD) must be addressed. DOD is an important factor to consider when using rechargeable batteries. It refers to the percentage of battery capacity that is consumed in a single discharge cycle. In general, it is recommended to avoid discharging the battery below 20% DOD to extend its overall life. However, some batteries can handle deeper discharges without significant damage. It is important to consult the manufacturer's guidelines for specific discharge depth recommendations for a particular battery.

Moreover, it is imperative to meticulously consider the battery chemistry aspect. In the design of the BBU module, the utilization of lithium-ion (Li-ion) batteries was a cautious choice. This selection stems from the widespread utilization of Li-ion batteries, which seamlessly aligns with the adoption mandated by the OCP ORV3 specifications.[1] The rationale behind this alignment is underpinned by the remarkable attributes of Li-Ion batteries, namely their exceptional energy density and remarkably low weight. Notably, delving deeper into the chemistry of Li-Ion cells reveals a paramount truth: their composition is an intricate linchpin that invariably dictates their performance, safety profile, and overall durability.

Another area to consider is cell balancing. Cell balancing is an important concept in the field of battery technology. As the demand for efficient and high performance batteries continues to increase, achieving optimal cell balance has become increasingly important. Cell balancing refers to the process of equalizing the voltage or SOC of individual cells within a battery pack. In a multicell battery pack, each cell has its own unique characteristics and may experience variations in performance over time. Factors such as manufacturing tolerances, variations in cell capacities, and differences in usage patterns can lead to imbalances in cells. These imbalances can result in a reduction in overall battery capacity, decreased efficiency, and even premature failure of the battery pack. The design calls to have a passive balancer on the BBU. Thus, passive balancing involves using resistors to bleed or dissipate excess energy from cells with higher voltage levels. This method is relatively simple and cost-effective but can result in energy loss and heat generation. By ensuring that each cell within a battery pack is operating at optimal levels, cell balancing improves the overall efficiency and effectiveness of energy storage systems, contributing to a more sustainable and reliable operation of the BBU module system. The BMS microcontroller used in the BBU is the MAX32625. The BMS microcontroller is responsible for two important processes. See Figure 1.

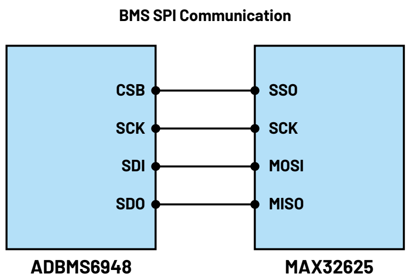

Figure 1. A BMS microcontroller (MAX32625) attached to a BMS IC (ADBMS6948).

1. Communicating to the BMS IC (ADBMS6948) to get telemetry data for cell voltages, cell temperature, undervoltage, overvoltage, and overall battery stack current level.

2. Passing all the telemetry data gathered from the device toward the main microcontroller via I²C communication.

The BMS microcontroller communicates with the ADBMS6948 through the SPI protocol. By sending the appropriate command codes, the BMS microcontroller allows the device to gather telemetry data and perform its operation at the same time. Refer to Figure 2. All the collected data from the BMS IC will be sent and processed by the BMS MCU.

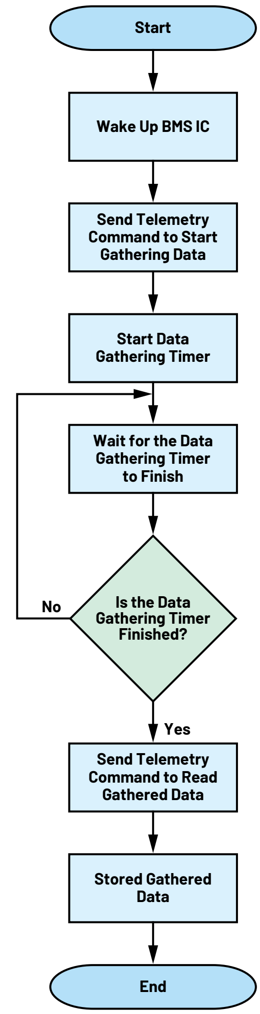

Figure 2. The BMS microcontroller process in commanding and storing data of the BMS chip.

Another important task of the BMS microcontroller is to send the collected data to the main microcontroller to be used for charging and discharging algorithms, as well as fan speed control. This is done through I²C protocol communication with the BMS microcontroller with registers to be read by the main microcontroller. The register map for the BMS microcontroller can be seen in Table 1.

Table 1. BMS Microcontroller Register Map

Register	Address	Length in Bytes
CMD_Voltage	0x00	0x16
CMD_Temperature	0x01	0x08
CMD_SOC	0x02	0x16
CMD_Fan_Error	0x03	1
CMD_EOL	0x04	1
CMD_Stop_Discharge	0x05	1
CMD_BMS_Fault	0xE0	0x06
CMD_Manufactured_Date	0xF0	0x07
CMD_Serial_Number	0xF1	0x07

Please note that all BMS microcontroller registers are read-only registers at the moment. The build date and serial number are captured only once to be stored in an external EEPROM of the main microcontroller.

Cell Detection and Balancing Operation

Cell Charging Techniques

Constant voltage (CV) and constant current (CC) are two distinct charging techniques employed in battery charging systems to optimize the charging process and enhance battery life.

CV Charging

CV charging is a charging method where a fixed voltage is applied to the battery stack during the initial phase of charging. As the charging process begins, the BBU module operates in charge mode and maintains a steady voltage level of 44 V while allowing the charging current of 5 A to decrease gradually as the battery's SOC increases. This approach is particularly effective in preventing overcharging, as the voltage remains constant and does not exceed the battery's safe voltage limit. Once the battery stack voltage reaches 37 V to 40 V or a predefined threshold, the charger may transition to a different charging phase, such as reducing the charging current from 5 A to 0.5 A.

CC Charging

CC charging, on the other hand, involves applying a consistent charging current to the battery stack terminals. During this phase, the charging current remains constant at 5 A while the battery voltage gradually rises as the battery charges. This method is particularly useful for rapidly charging the battery stack with low initial charge levels. It ensures a controlled flow of current into the battery stack until a certain voltage level is reached. Once the battery stack voltage reaches a predetermined point, the charging process may transition to a different phase, such as reducing the constant current from 5 A to 2 A or a constant voltage phase.

Both CV and CC charging methods are frequently coupled in BBU module battery stack charging mode to obtain an optimal charging profile. The early CC phase aids in the rapid delivery of energy to the battery, while the second CV phase avoids overcharging by restricting voltage. This combination technique provides efficient charging, extends battery life, and maintains the battery pack's safety and performance. Proper CV and CC charging mechanism implementation is critical for BBU module charging operation.

Cell Detection Method

The cell detection method is a pivotal aspect of battery management systems. This technique is designed to accurately ascertain the voltage and state of each individual cell in a battery pack. By employing sophisticated sensing circuitry and measurement algorithms, the cell detection method enables the system to gather real-time data regarding the voltage, temperature, and overall health of every cell. This information is then utilized to make informed decisions regarding charging, discharging, and balancing operations, thereby ensuring optimal performance, safety, and longevity of the battery pack. Effective cell detection is paramount for maintaining the overall efficiency and reliability of modern energy storage systems.

The ADBMS6948's 11 ADCs are dedicated to sensing the battery stack's 11 differential cell inputs. The battery stack has an 11-series and 6-in parallel configuration and is connected to the C0 to C10 pins, which are the BMS's ADCs. They have an input range of –2.5 V to +5.5 V and a sampling frequency of around 4 MHz, producing 16-bit results every 1 ms with an LSB of 150 µV. Eleven additional ADCs are dedicated to measuring the 11 differential inputs simultaneously utilizing S-pins with an input range of 0 V to 5.5 V and sampling frequency of around 4 MHz, producing 13-bit results with an LSB of 1.6 mV every 8 ms. These S-ADCs enable redundant cell voltage measurement via a completely independent measurement approach from the C-ADCs.

Passive Balancing Operation

Passive balancing is a technique commonly employed in the management of battery systems, wherein the utilization of passive components, notably resistors, is combined with the integration of MOSFETs arranged in parallel with individual cells. These integrated components assume the role of voltage bleeders or energy dissipators, facilitating the controlled dissipation of surplus energy from cells exhibiting elevated voltage or energy states. The consequential outcome is the gradual harmonization of voltage potentials or energy states across the battery cells, thereby promoting voltage and energy equilibrium over an extended period.

If the cells in a battery pack become imbalanced, the BMS must be balanced by discharging the cells that have greater voltage. S-ADCs pins on the ADBMS6948 can be used to discharge individual cells. The built-in MOSFETs at the S-ADCs pins can be used to discharge cells. Each S-ADC's pin can be controlled separately or continuously using PWM. By configuring the PWMA, PWMB, and CFGB registers, it is also feasible to balance the cells while the BMS microcontroller is in sleep mode operation.

Cell Charging with Coulomb Counter

The primary purpose of a coulomb counter is to accurately measure the amount of electric charge (measured in coulombs) that flows in and out of a battery or circuit. This measurement allows for better control of battery stack charging and discharging, ensuring longer battery stack life, improved efficiency, and more accurate capacity monitoring.

The ADBMS6948 has an integrated coulomb counter. This allows monitoring of the amount of charge flowing through the battery during the charging process. The coulomb counter, also known as an integrated current sensor or charge monitor, measures the total amount of electrical charge (in coulombs) transferred to or from a battery. When charging a cell using a coulomb counter, the counter monitors the amount of charge delivered to the battery. This is done by measuring the current flowing through the battery and integrating it over time to calculate the total charge. Thus, estimating the SOC of the battery and implementing charging algorithms can optimize the charging process.

The basic operation of an ADBMS6948 coulomb counter involves integrating the current flowing in or out of the battery stack over time to calculate the total charge transferred. Here's how it works:

- Current measurement: The device measures the current flowing into or out of the battery stack. This is typically done using a current sensor such as a shunt resistor connected at the low side of the battery stack.
- Integration: The measured current is integrated over time using the ADBMS6948. Integration involves summing up the current values at regular intervals to calculate the accumulated charge.
- Capacity calculation: The accumulated charge is converted into ampere-hours (Ah) or coulombs. This provides information about the remaining capacity of the battery stack.
- Monitoring and display: The calculated capacity is processed, transferred to the main MCU, and displayed to the graphical user interface for further processing. This information is valuable for battery management, determining the SOC, and preventing overcharging or overdischarging.

When charging, the coulomb counter continuously measures the current flowing through the cell and integrates it over time. By knowing the initial SOC of the battery, you can estimate the SOC during charging by adding the integrated charge to the initial value. This estimate helps prevent overcharging and allows for the implementation of charging algorithms that optimize the charging process for factors such as temperature, battery age, and chemistry.

Check ADI's previous articles for battery balancing and life optimization tips. These resources are highly recommended for those who seek further details on the subject matter. Two articles were authored by Kevin Scott and Sam Nork pertaining to the types of cell balancing: "Passive Battery Cell Balancing" and "Active Battery Cell Balancing." For more details on cell characterization, please refer to "Characterizing a Li+ Cell for Use with a Fuel Gauge."

Summary

Therefore, the integration of ADI's ADBMS6948 BMS with a BBU is of utmost importance. A BMS offers many benefits that improve the performance, safety, reliability, and longevity of the battery system. By optimizing battery performance, a good BMS helps maximize battery life span and capacity, ensuring efficient use of its energy storage capabilities. It actively manages the charging and discharging processes, preventing overcharging, overdischarging, and overheating that can damage the battery. Safety is a critical aspect, especially with battery systems. A BMS incorporates safety features and monitoring mechanisms to prevent thermal runaways and minimize potential hazards. It protects against overcurrent, overvoltage, and abnormal temperature conditions, protecting the battery system and the surrounding environment. Energy efficiency is another major advantage of a BMS. Optimizing the charge and discharge processes minimizes energy losses and improves the overall efficiency of the BBU. This translates into cost savings, reduced environmental impact, and increased use of available energy resources.

The BMS also accurately monitors and estimates the battery stack's SOC and SOH. This information is crucial for properly managing battery usage, calculating remaining runtime, and planning maintenance or replacement. The addition of a coulomb counter is important for precise measuring and monitoring. This information is essential for efficient battery management and extending battery life in diverse applications, which enhances system reliability and reduces the chance of unexpected failures.

Overall, ADI's ADBMS6948, BMS inclusion in the BBU serves an important role in guaranteeing a data center's best performance, safety, and dependability. It delivers critical information that every user should be aware of to extend its serviceable operation.

The fourth part of this series, "Smart Battery Backup for Uninterrupted Energy Part 4: BBU Shelf Operation" will go over how ADI designs and delivers a graphical user interface while also allowing the user to communicate with and collect data from the six BBU modules on the BBU shelf. It will also go over the functioning and operation of the MAX32625, which serves as the MCU dedicated to the BBU shelf.

The first part, "Smart Battery Backup for Uninterrupted Energy Part 1: Electrical and Mechanical Design," discusses the BBU's electrical and mechanical design considerations. The second part, "Smart Battery Backup for Uninterrupted Energy Part 2: BBU Microcontroller Functions and Operations," goes into further detail about the main microcontroller's software.

References

[1] David Sun. "Open Rack/SpecsAndDesigns." Open Compute Project.

About the Author

Christian Cruz is a staff applications development engineer at Analog Devices Philippines. He holds a bachelor's degree in electronics engineering from the University of the East in Manila, Philippines. He has more than 12 years of engineering experience in the field of analog and digital design, firmware design, and power electronics, which includes power management IC development as well as AC-to-DC and DC-to-DC power conversion. He joined ADI in 2020 and is currently supporting power management requirements for cloud-based computing and system communications applications.

About the Author

Marvin Neil Solis Cabueñas graduated with a bachelor's degree in electronics engineering from De La Salle University in Manila, Philippines. Before joining Analog Devices in 2021, Marvin worked as a systems engineer for Azeus Systems Philippines, Inc., then worked as a network engineer for Technistock, Philippines, Inc. from 2014 to 2017, and as a research and development engineer for Nokia Technology Center Philippines from 2017 to 2020. He has more than 10 years of work experience in different fields such as embedded systems programming, digital signal processing, simulation modeling, and others. He currently works as a senior software systems engineer working on various power related technology projects. He is currently working toward his master's degree in electrical engineering at the University of the Philippines.