KOCAELI UNIVERSITY

MECHATRONICS ENGINEERING

SENIOR DESIGN PROJECT

FINAL REPORT

PROJECT TITLE: BATTERY MANAGEMENT SYSTEM FOR ELECTRIC VEHICLES

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by

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ABSTRACT

In this study, a measurement system has been designed to measure the voltage of the battery pack, which is the most crucial component of electric vehicles. Existing systems have been researched, methods in the literature have been reviewed, and by conducting a cost-performance analysis, the most suitable system has been determined. Since voltage measurement of batteries in electric vehicles holds critical importance, the error criterion has been prioritized. For accurate transfer of voltage data and usage in the battery management system, the LTC6802-2 integrated circuit compatible with the Serial Peripheral Interface Bus (SPI) communication has been utilized. This integrated circuit, capable of measuring up to 96 batteries in series, has a maximum total measurement error of approximately 0.25%. The SPI communication protocol can transmit data to the CPU accurately. The STM32f407 board has been employed as the microcontroller. The collected data has been compared with a precise measuring device.

Keywords: Battery Management System, Battery Voltage Measurement, Passive Balance ,LTC6802-2, STM32, C#, Li-on batteries,

CHAPTER 1

1.1 INTRODUCTION

Battery refers to a group of cells created by combining multiple cells. Batteries consist of cells connected in series and parallel. Parallel connections increase capacity and the current that can be drawn, while series connections increase voltage. In a battery pack, the cells connected in series must have precisely equal capacity and voltage. In cases where this cannot be ensured, as charge-discharge cycles are performed, an imbalance occurs between the cells, leading some cells to become overcharged or over-discharged. This situation can lead to very dangerous situations, such as explosions or fires in some types of lithium batteries, while in some safer types, it may not result in such severe consequences but can cause capacity reduction, chemical leakage, inefficiency, and voltage drops. Imbalance and cell loss in battery packs are unwanted conditions, and to prevent this, electronic control and safety circuits called the Battery Management System (BMS) are used.

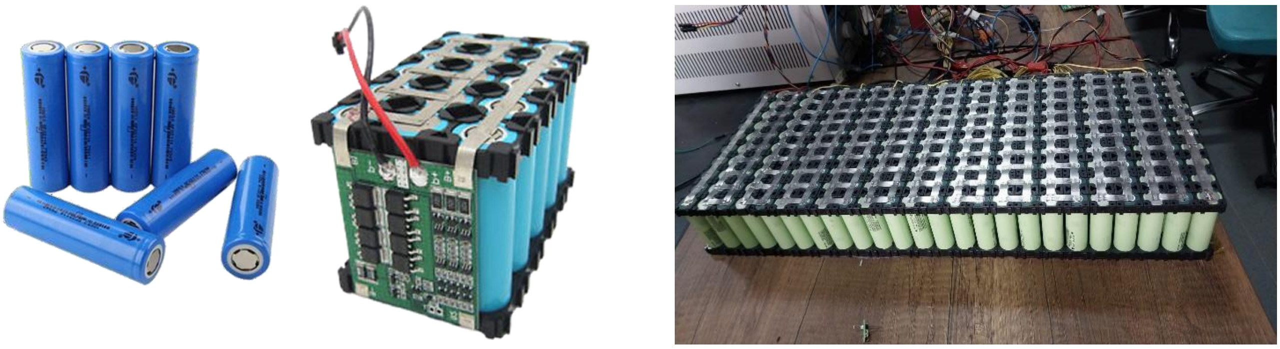

Figure 1.1: Example Battery Packet

1.2. COMMERCIAL PRODUCTS

- Tesla, Inc.: Tesla's BMS system was developed to monitor and optimize the battery performance of its electric vehicles. This system continuously monitors and manages the voltage, temperature and other parameters of each battery cell. Using BMS, Tesla balances battery cells, prevents overcharging and extends battery life. The company constantly updates its BMS software, improving the performance of vehicles and increasing safety.

- LG Chem: LG Chem offers customizable BMS solutions for electric vehicles, portable devices and energy storage systems. The company's BMS technology optimizes the safe charging and discharging of batteries and prevents overcharging. LG Chem's BMS software is designed to improve energy efficiency and extend battery life.

- Panasonic Corporation: Panasonic has extensive experience in lithium-ion battery technology and BMS. The company offers BMS solutions for electric vehicles, which monitor vehicle batteries, ensure stability and improve safety. Panasonic protects battery cells against overheating and overcharging with BMS technology.

These companies are leaders in the development and application of BMS technology and offer BMS solutions for many different applications such a electric vehicles, energy storage systems and portable devices. BMS plays a important role in meeting the needs of users and industry by ensuring the safe and efficient operation of battery systems.

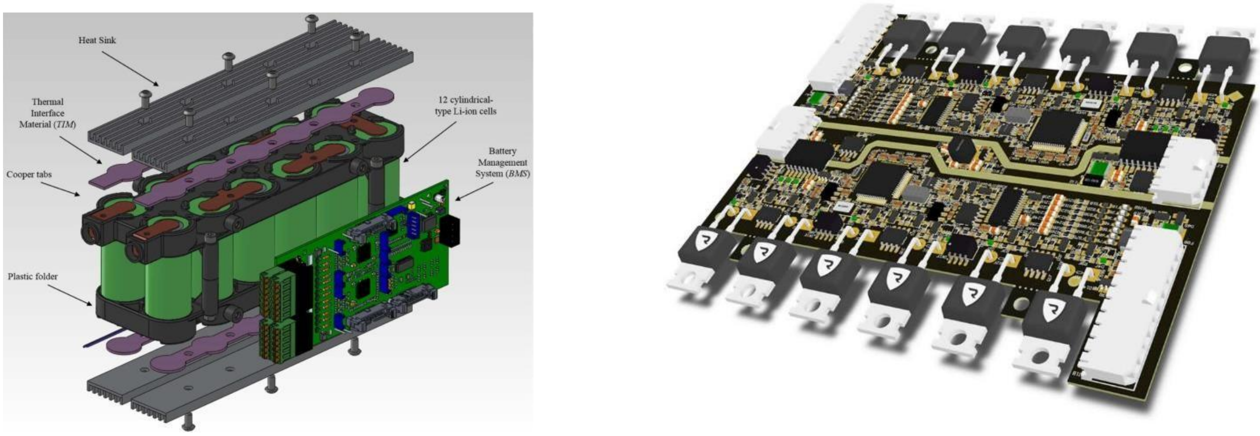

Figure 1.2: Examples Battery Management Systems

1.3. STATE-OF-THE ART ON RELATED TECHNOLOGIES

Tesla's latest development bms;

The 24 VDC pack from the Tesla ModelS have a rated capacity of 5.3 kWh and consist of six modules. The key is that the cells in each module may end up with different performance characteristics which is why they are no longer used in a vehicle. EMUS Tesla Module retrofit BMS module supports cell voltages from 2 V to 4.55 V with a balancing current of 0.5 A and a maximum cell power (Pmax) of 2 W. This is ten time the power supported by Tesla's original BMS board. EMUS Tesla Module retrofit BMS board is the device that once mounted on a battery pack measures cells voltages, temperatures, its own temperature, and broadcasts all measured values to the main unit. Also, using previously mentioned values it regulates the balancing current to keep the cell's voltage lower than the balancing threshold, while at the same time keeping its own temperature lower than a certain maximum value to protect itself from overheating

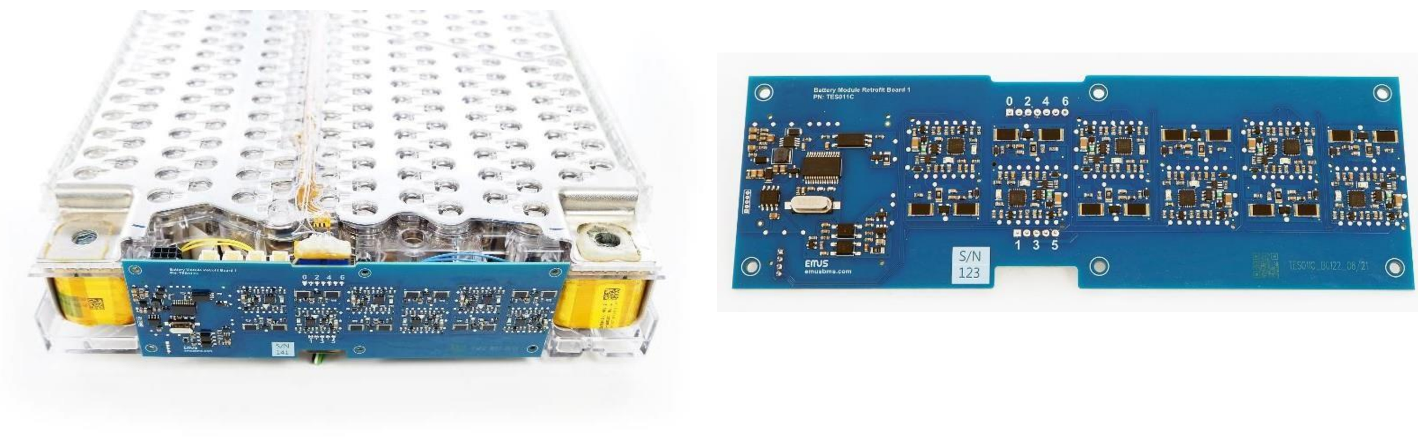

Figure 1.3: Tesla's the latest BMS

1.4. PATENT

Tesla recently filed its patent for the Multi-Channel and Bi-Directional Battery Management System in the European region under the code EP3646044. This patent was originally submitted to the World Intellectual Property Organization in 2019 as WO2019006204 and has been subsequently filed in specific regions such as China, Japan, and most recently, Europe.

The Abstract of EP3646044 suggests that Tesla's recent filing closely resembles, if not mirrors, its original WO2019006204 submission. Both patents delve into the details of a battery management system (BMS) utilizing a daisy chain loop for multi channel communication among circuits within a battery system. The system ensures two-way communication between the host and various clients, guaranteeing the functionality of every part of the system. Tesla has provided a visual representation of how the battery management system operates in the figures below.

The decision to file the BMS patent in Europe may be driven by various factors, potentially including the ongoing construction of Giga Berlin in Germany. The European-based factory is anticipated to produce battery cells for over 500,000 vehicles manufactured at the Berlin plant. Speculation has arisen about the possibility of Tesla also manufacturing battery storage systems at the Gigafactory Berlin complex due to its expansive size.

It's worth noting that Tesla's BMS patent may already be integrated into all its products, including its Energy department. Before the global pandemic led to widespread lockdowns, Tesla Energy was poised for significant progress this year, having taken a back seat to the company's automotive sector during the Model 3 ramp-up in Fremont, CA .Tesla recently filed its patent for the Multi channel and Bi directional BMS in the European region under the code EP3646044. This patent was originally submitted to the World Intellectual Property Organization in 2019 as WO2019006204 and has been subsequently filed in specific regions such as China, Japan, and most recently, Europe.

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Tesla’s BMS patent could already be implemented across all its products, including its Energy department. Before the virus caused multiple lockdowns all over the world, Tesla Energy was ready to hit the ground running this year after taking a back seat to the company’s automotive sector during the Model 3 ramp in Fremont, CA.

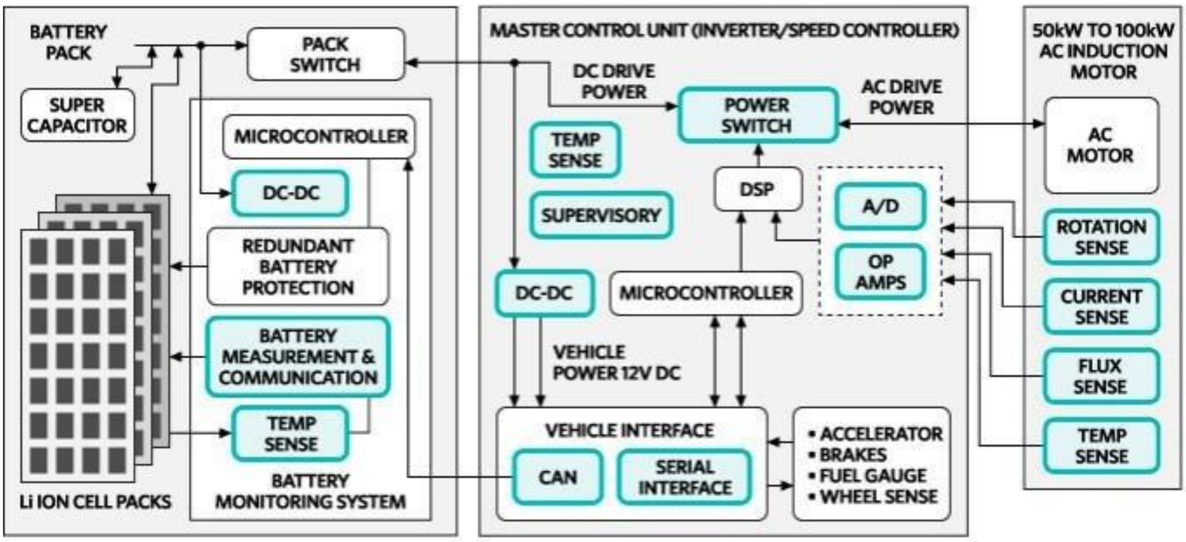


Figure 1.4: Tesla’s BMS Flow Chart

CHAPTER 2

2.1. Definition of the Problem:

The aim of our project; Cars have been one of the most crucial machines for humanity for the past 150 years. Despite the majority of today's cars predominantly relying on internal combustion engines, growing concerns and research efforts have led to a shift towards electric motor vehicles due to issues such as air pollution, global warming, and the depletion of petroleum reserves. It is essential to model these vehicles, design them within specified constraints, and develop battery management systems, which are the most critical components for battery health. In the scope of this study, a battery management system will be designed for use in an electric vehicle.

Humanity has been faced with a new issue named global warming in the last 50 years. According to research, the increase in the average near-surface air temperature on Earth during the 100-year period ending in the year 2000 was determined to be 0.6 ± 0.2 degrees. However, this increase escalated to 0.74±0.18°C in the past century, ending in 2005.

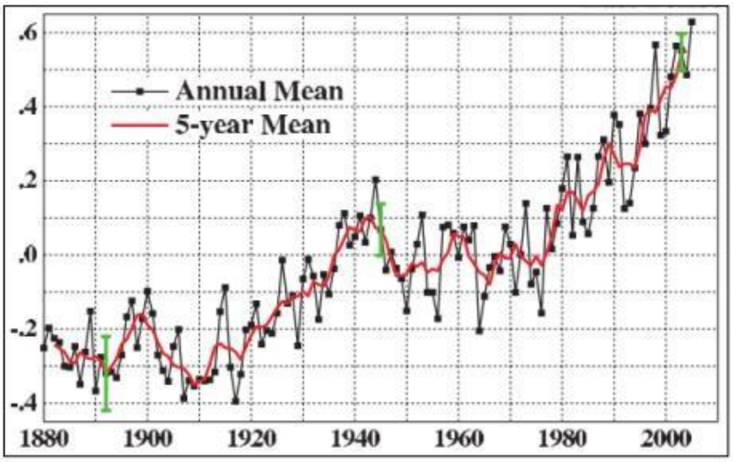


Figure 2.1: Sea water temperatures

Figure 2.1: shows sea water temperatures resulting from global warming over the last 120 years. In the graph, 0 degrees (reference point) is determined as the average temperature between 1961 and 1980. As can be seen from the graph, sea water temperature has increased by approximately 0.8 degrees in the last century..

According to the studies of the Carbon Dioxide Information Analysis Center (CDIAC), carbon emissions caused by fossil fuels have increased significantly in the last century [5]. Carbon emissions caused by fossil fuels are shown graphically in **Figure 2.2:**

Figure 2.2: Global carbon emissions from fossil fuels

As evidenced by the graph, the amount of carbon emissions caused by fossil fuels has increased approximately 20 times since the beginning of the century. Consequently, investments should be made in electric vehicle technology. This increase underscores the significance of electric vehicle technology. The intense carbon emissions associated with fossil fuels highlight the potential of electric vehicles to mitigate environmental impacts. In this context, investments in electric vehicle technologies are seen as an effective strategy to achieve carbon emission reduction goals. The adoption of this technology also necessitates the development and optimization of battery management systems, as these systems are critical components that determine the performance and energy efficiency of electric vehicles.

2.2. Project Requirements:

When designing a Battery Management System (BMS) for a battery pack with 24 series and 4 parallel configurations, there are several essential requirements to consider. Here are some fundamental requirements and ideas about sensors that can be used:

1. Voltage Monitoring:

- Sensors are needed to monitor the voltage of each series-connected battery.

- Cell-level voltage monitoring helps prevent imbalances in charge/discharge conditions.

2. Current Monitoring:

- Current sensors are used to monitor battery flow and control safe charge/discharge limits.

- HALL current sensors can be used for direct current measurement.

3. Temperature Monitoring:

- Temperature sensors should be used for each cell or module.

- Temperature is crucial for maintaining the health and safety of the battery.

4. Balanced Charging and Discharging:

- A balancing circuit is necessary to correct voltage differences between cells in the battery.

- Balanced charging and discharging can help extend the battery's lifespan.

5. Overvoltage and Undervoltage Protection:

- The battery must be kept within specified voltage limits.

- Measures should be taken to protect the battery in cases of overvoltage and undervoltage conditions.

6. Communication Protocols:

- Appropriate communication protocols (e.g., CAN bus) should be used to enable the BMS to communicate with other systems.

7. Error and Safety Monitoring:

- The BMS should be capable of detecting error conditions and activating safety measures.

- The ability to safely disable the battery in emergencies is crucial.

8. Environmental Durability:

- The BMS should be resistant to various external factors (humidity, dust, vibration, etc.).

Based on these requirements, we will design a Battery Management System to ensure the safe and efficient operation of the battery.

2.3. BATTERY TYPES

Batteries can be categorized into three main groups based on their characteristics. The first group consists of non-rechargeable batteries, commonly referred to as dry-type batteries. Unlike rechargeable batteries, these cannot be charged once their chemical energy is depleted. Dry batteries find applications in various devices such as small radios, flashlights, measuring instruments, and alarm systems. They are designed for one-time use, offering a convenient and quick solution for specific purposes. Additionally, dry batteries are typically stored in a complete and ready-to-use state.

The second group includes nickel-based batteries, such as nickel/cadmium, nickel/iron, nickel-metal hydride, and lead-acid batteries. The third group comprises lithium-based batteries, including lithium-ion and lithium-polymer batteries. These batteries, both nickel-based and lithium-based, are considered viable options for Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV). They play a crucial role in powering these vehicles, offering diverse options to meet the specific energy storage needs of electric and hybrid transportation systems.

Zinc Batteries: Well-suited for devices with low electricity requirements, zinc batteries are single-use. Devices like TV remotes, small flashlights, desk and wall clocks find them particularly suitable. The most common types include the AAA thin battery, AA battery, C medium battery, D big size battery, 9V battery, and a few more intermediate varieties.

Alkaline Batteries: Designed for high-power-demand devices, alkaline batteries are also disposable. While they can be used in digital cameras, providing continuous image capture for only 1-2 days, they may not be cost-effective for regular use. However, they excel as a battery model for devices such as wristwatches or car remotes, lasting for months or even years. Alkaline batteries can store up to ten times more energy than zinc batteries.

Rechargeable Batteries:

The second category encompasses rechargeable batteries, serving as a portable energy source that stores chemical energy and converts it into electricity as needed. These batteries are preferred for their extended service life, allowing for repeated charging approximately between 500-1000 times on average. Widely utilized in high-tech products today, rechargeable batteries offer both higher capacity options and economic advantages due to their reusability. Unlike disposable batteries, rechargeable ones generally lack production and expiration dates, with an average shelf life of 3-5 years. The typical usage life falls within the range of 500 to 1000 charge lifetimes.

Ni-Cd Batteries: Despite being considered outdated, Ni-Cd rechargeable batteries remain popular in today's portable devices. One notable characteristic of Ni-Cd batteries is their ability to retain capacity for an extended period without losing it. Unlike Ni-Mh batteries, Ni-Cd batteries, even when charged and left unused for 1-2 weeks, do not experience a significant loss in capacity. Although they possess a lower capacity compared to Ni-Mh batteries, they are favored for their ability to maintain capacity during standby mode. Ni-Cd batteries find applications either individually or grouped in devices such as drills and measuring instruments, with the grouped form commonly referred to as a "battery." Like other rechargeable batteries, Ni-Cd batteries maintain a long life during regular charging, but rapid charging for emergency use can reduce their overall lifespan. Typically, the average life of a Ni-Cd battery is around 5 years under normal charging conditions with a lifespan of 500-1000 charges.

Lithium Batteries: Lithium Batteries: It is a highly preferred battery type in today's technology. Among industrial devices such as industrial machine cards and computer memory cards planned uses. Electric Vehicles, Low current devices, e.g. Electronic scales and glucose meters for diabetes also used lithium batteries. There There are many models of lithium batteries; the main industrial models are 1/2AA, AA, C, but The most preferred model in daily use devices is the CR series CR2016, CR2025, CR2032…etc. The lifespan of lithium batteries is 3-10 years.

2.4. COMPARISON OF BATTERIES

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1] Cobalt	Li-ion[1] Manganese	Li-ion[1] Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	−20 to 50°C (−4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	−20 to 50°C (−4 to 122°F)	−20 to 65°C (−4 to 149°F)		−20 to 60°C (−4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

Figure 2.2: Different Battery Types Specification Table

Batteries, with their unique features, find applications across diverse fields. Figure 2.2 presents a feature comparison table for a comprehensive examination of these applications.

a. In terms of Wh/kg analysis, Cobalt-based Li-ion batteries emerge as frontrunners, showcsing an impressive energy capacity of up to 250 Wh/kg.

b. Cycle life calculations involve depth of discharge measurements. Unlike Cobalt, Phophate-baed batteries exhibit resilience, enduring up to 2000 charge-discharge cycles.

c. Li-ion batteries take the lead in Self Discharge values when evaluated.

d. The unit representing instantaneous power requirements in batteries is known as the C Rate. Li-ion batteries surpass 30C in C values, making Li-Po batteries preferable for low-weight unmanned aerial vehicles. Notably, C Rate values can reach as high as 120C.

e. Regarding maintenance requirements, Li-ion batteries stand out once again. Unlike Lead Acid, NiCd, and NiMH batteries, which may require periodic discharging based on usage conditions, Li-ion batteries have no such requirements.

f. In contrast to Acid, NiCd, and NiMH batteries that handle their protection needs, Li-ion-based batteries require a controller board for proper usage, commonly referred to as the "Battery Management System."

The scrutiny of various battery types and their characteristics reveals that Li-ion batteries possess distinct advantages in numerous aspects. They are preferred over alternative technologies due to benefits such as high rated voltage, elevated energy density, extended lifespan, and the absence of memory effect. Li-ion batteries excel not only in energy capacity, charging time, and C rate values but also stand out as the battery type with the least toxic contamination.

However, when examining drawbacks, considerations such as low overcharge tolerance, high cost, and the necessity for a protective circuit board come to the forefront.

2.5. Lithium Batteies

- Rechargeable Li-ion batteries distinguish themselves as unparalleled energy storage devices due to their superior energy density and specific power delivery. Conversely, their reduced weight, lower self-discharge rates, and extended battery lifespan position them as the preferred choice among rechargeable batteries. The lithium-ion battery stands out as the most rapidly advancing energy storage device, benefitting significantly from the widespread adoption of innovative energy technologies, particularly in the domain of electric vehicles.

- The market offers several diverse types of lithium-ion battery cells, each characterized by unique electrochemistry, resulting in distinctive thermal and energy qualities. Moreover, battery cells are available in various shapes and sizes, including but not limited to cylindrical cells such as 18650 and 26650, pouch cells, and prismatic cells.

They can be dangerous if used incorrectly. If they are exposed to high temperatures or intense sunlight, they may ignite or explode. If the lithium-ion battery is short-circuited, there is a risk of ignition or explosion.

2.5.1 Battery Types

Lithium ion batteries stand out as one of the most prominent battery types due to their remarkable charge density relative to their weight and size. Further advancements in lithium-ion battery technology have led to the development of lithium polymer batteries and lithium titanate battery cells. Lithium-Ion Polymer batteries share the basic characteristics of traditional lithium-ion batteries but distinguish themselves by having a lower charge density. The usage advantage of a lithium-ion polymer battery can be tailored to meet the specific needs of the user.

A more recent innovation in lithium-ion battery technology is the Titanate battery, designed specifically for applications in nanotechnology. The lithium-ion titanate battery boasts a significant advantage in rapid charging, thanks to its high current, and it can endure up to 25 thousand recharge cycles during its lifetime. For instance, 35 kWh and 70 kWh lithium titanate batteries can achieve a 95 percent charge in less than 10 minutes with a 250-kW power supply. One of the most common applications for these batteries is in electric vehicles equipped with electric motors.

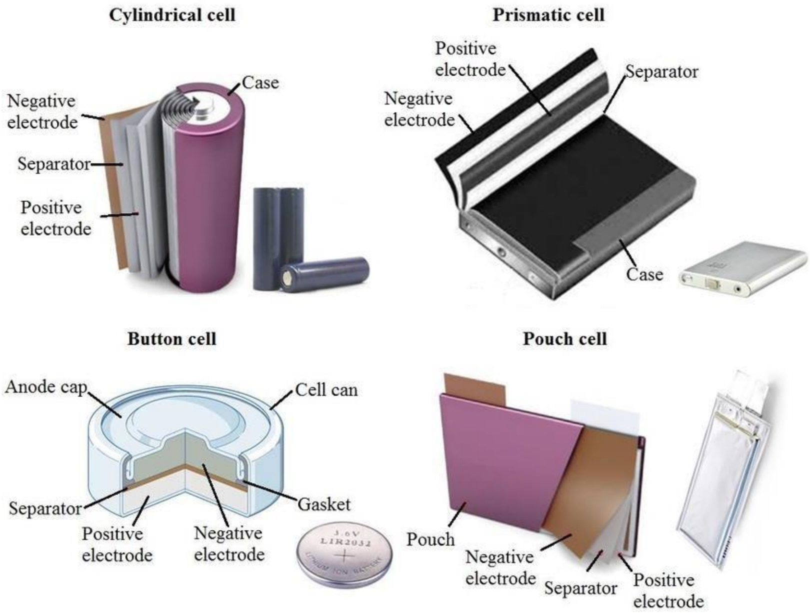


Figure 2.3: The most common lithium-ion cell types.

2.5.2 Battery Capacity

Lithium-ion batteries, renowned for their ability to prolong the lifespan of portable devices, represent a technological leap with their superior longevity, increased power, rapid charging capabilities, and reduced weight compared to conventional battery types. The high rechargeable densities of lithium-ion batteries contribute to their enhanced performance. Unlike some traditional batteries, lithium-ion batteries do not require complete discharge before recharging. They can be charged at any point and withdrawn from the charge at the desired level. **Figure 2.4** illustrates the capacity values for various battery types.

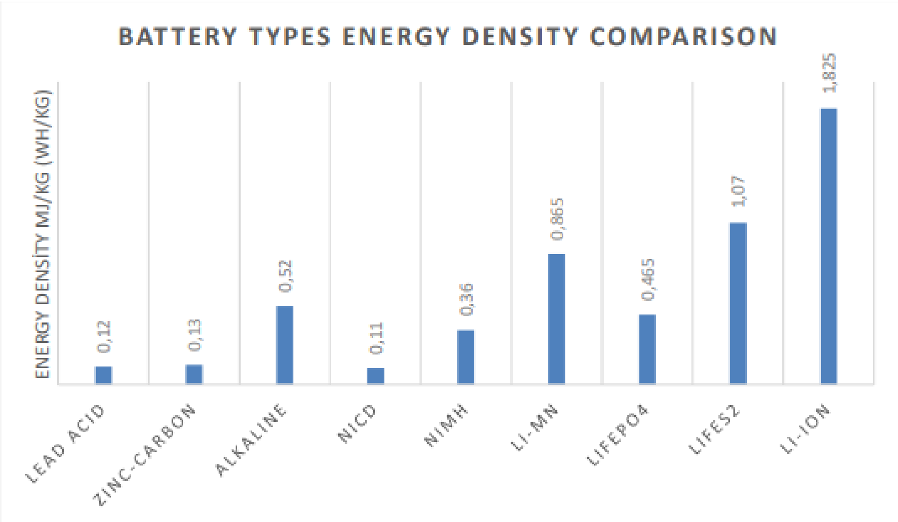


Figure 2.4: Battery Types Energy Density Comparison Graph

2.5.3 Battery Voltage

The voltage levels of batteries differ based on their types. Following a comprehensive research effort, various battery types were scrutinized, and the comparative analysis is depicted in **Figure 2.5. .**

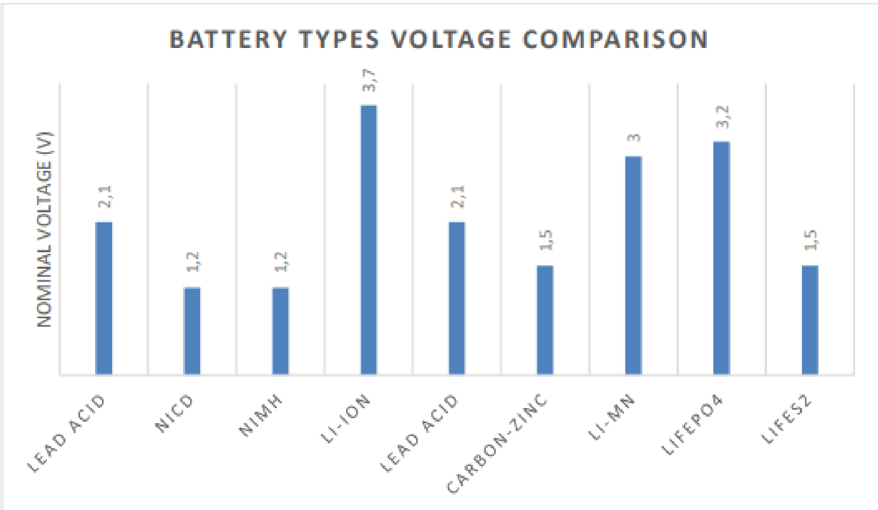


Figure 2.5: Battery Types Voltage Comparison Graph

2.5.4 Charge and Discharge

Li-ion batteris offer numerous advantages, but their optimal performance relies on adhering to correct charging and discharging practices. Incorrect charging methods can result in damage and a shortened battery lifespan. Therefore, meticulous attention to charging conditions is essential to maximize battery longevity. To achieve this, battery management systems are employed during the charging process of lithium-ion batteries. This system enables constant monitoring and control of charge levels, discharge activities, and temperature values, contributing to the preservation of battery health and longevity.

During charging, it’s crucial to maintain a steady voltage at its highest value with a constant current until it reaches %80 of the battery voltage. Subsequently, charging should continue at a constant voltage, and it should be halted when the current drops below a specified threshold. In battery packs with Li-Ion cells connected in series and parallel, protective circuits are necessary to prevent overcharging and excessive discharge.

Charging lithium-ion batteries differs from the process used for Ni-Cad or NiMH batteries, and it is not possible to charge them with the same electronic board. In the context of charging lithium-ion batteries, voltage takes precedence over current. The charging method for lithium-ion batteries has evolved to be somewhat similar to lead-acid batteries.

A significant distinction in charging lithium-ion batteries lies in their higher voltage per cell, operating within voltage ranges of 3.7 - 4.2 V per cell. To ensure a complete charge, lithium-ion cells require more precise voltage tolerance. Accurately determining the full charge state is crucial because lithium-ion batteries do not tolerate overcharging. Overcharging can lead to overheating, not only shortening the battery's lifespan but also posing serious risks, including the potential for the battery to catch fire or explode in extreme cases.

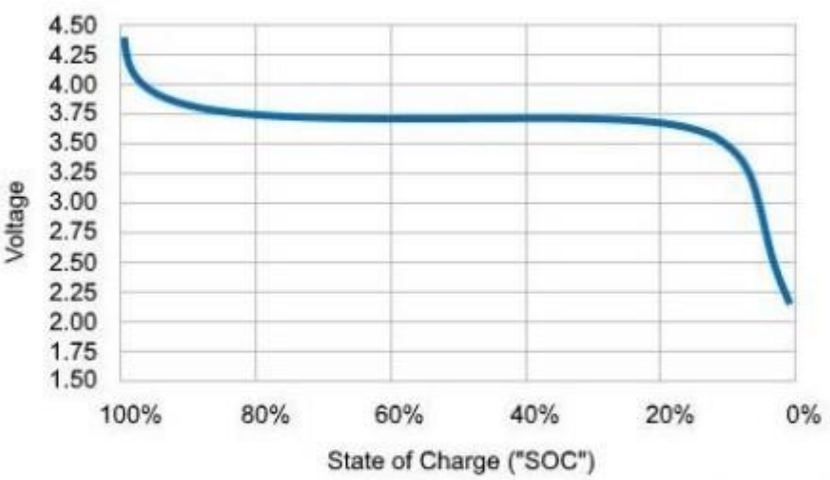


Figure 2.6: Li-ion Battery State of Charge (SOC) Graph

Lithium-ion batteries charge at 4.2 volts per cell, with a tolerance of around 50 millivolts per cell. The charging process introduces stress and oxidation to the battery, influencing its service life and capacity. Additionally this can potentially pose security risks.

2.5.5. Advantage and Disadvantage

In recent years, the rapid rise in concerns about global warming and greenhouse gas emissions has led to a substantial increase in the use of electric vehicles. Consequently, rechargeable batteries are gaining prominence as a promising alternative power source for electric vehicles. Among the various options, lithium-ion batteries stand out due to their numerous advantages.

a. **High rated voltage**
b. **High energye**
c. **Long life of Battery**
d. **Light-weight And Portable Material**
e. **Used With-out Fully Chargede**

Due to their distinctive features, lithium-ion battery types are widely utilized in electric cars. The key differentiator and advantage over other rechargeable battery types lie in their high energy density. However, despite these advantages, there is a risk of lithium-ion batteries exploding. Ongoing and varied research is being conducted to enhance the characteristics of lithium-ion batteries, often hailed as the technology of the future, and to mitigate their drawbacks..

2.6. BATTERY EQUIVALENT CIRCUIT

The battery model is employed to depict the battery's characteristics across various operating conditions, encompassing temperature, voltage discharge rate, and State of Health (SOH). Within the framework of the specified model, it becomes possible to analyze the battery's reactions under different circumstances. Majority of existing bms utilize Equivalent Circuit Models (ECM) due to their advantages in terms of simplicity and robustness . Among various modeling methodologies found in the literature, the equivalent circuit model demonstrates reasonable accuracy while incurring a low computing cost .

2.6.1 Simple Equivalent Model

In Figure 2.1, the most commonly utilized battery model is depicted, consisting of an ideal battery characterized by $V0$ as the open-circuit voltage (OCV), Rint as the constant equivalent internal resistance, and Vt as the terminal voltage. When the battery is fully charged, the terminal voltage can be established by measuring the open circuit, while Rint can be determined by introducing a load and measuring both the voltage and current at the terminal.

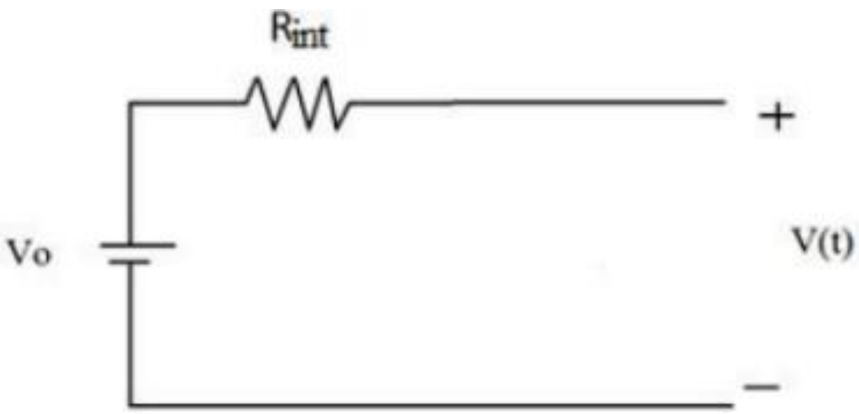


Figure 2.7: Simple Equivalent Model Circuit

$$V(t)=OCVz(t)-i(t)\,R_{int} \qquad (1)$$

$$dz/dt= (i(t))/Q \qquad (2)$$

$$i(t)=z(t_0)- 1/Q \int_{t0}^{t} i(T)d(T) \qquad (3)$$

The open-circuit voltage of a fully charged battery surpasses that of a fully depleted one. The battery's state of charge, denoted by z(t) in equations (2) and (3), is %100 when fully charged and %0 when fully drained. While the $Rint$ model appears relatively simple, it overlooks the variable nature of internal resistance concerning temperature, state of charge, and electrolytic concentration.

This type of model is suitable only for replicating specific circuits and is inadequate for representing electric automobiles or hybrid vehicles.

2.6.2 Electrical Equivalent Circuit Model

By creating an electrical equivalent circuit model for the battery, it becomes possible to perform mathematical calculations on this model and conduct simulations using relevant software. Battery modeling plays a pivotal role in the analysis of the charge/discharge characteristics of batteries. The electrical model is established using parameter values derived from battery charge/discharge tests for both the battery and circuit elements. While some electrical equivalent circuit models assume that circuit parameters remain constant, in reality, these values are dynamic and can fluctuate based on internal battery dynamics, including factors such as charge status, temperature, current, capacity, and life cycle.

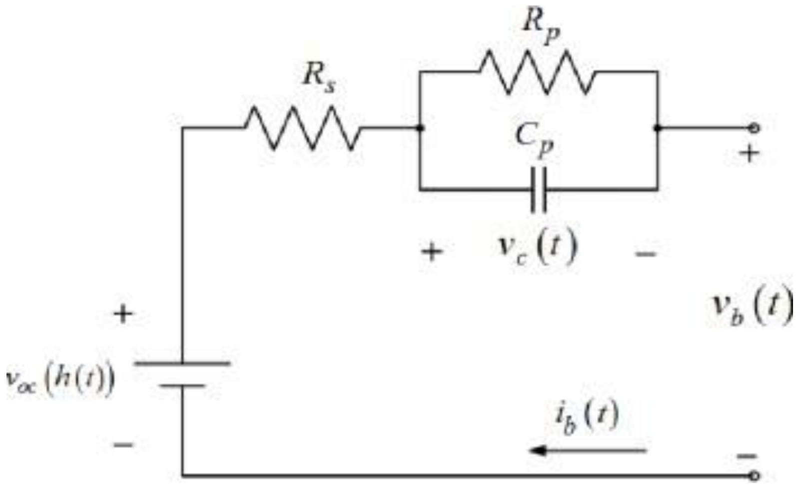


Figure 2.8: Battery Equuivalent Circuit

In Figure 2.8 the schematic of the battery equivalent circuit is shared. Internal resistance model, N-RC model, PNGV model, and GNL model are some of the battery equivalent circuit models .

	:	**Targeted Design**
Battery Packaging Design	:	24 Series 4 Parallel
Output Voltage	:	88.8 V (Nominal)
Output Current	:	11.6 A (Nominal)
Balancing Method (active or passive)	:	Passive
Circuit Design Type	:	Master – Slave
SOC Estate Algorithm	:	Coulomb Counting Method
Control Algorithm	:	Selection algorithm

Chart 2.1: Features of BMS and battery packet

We will use ASPİLSAN company's INR18650A28 Lithium Ion Rechargeable batteries in our electric vehicle. Features of the battery we will use; The chemistry and composition of INR18650A28 is nickel-rich lithium-nickel-manganese-cobalt oxide. Its size is 18650; Its capacity is 2900 mAh and voltage is 3.68V. By connecting INR18650A28 batteries with a capacity of 2900 mAh in a configuration of 24 series and 4 parallel, we will obtain a battery pack with a voltage of 88.8 V, a capacity of 11.6 Ah, and a power of 1030.08 Wh.

Manufacturer	**Aspilsan**
Model	INR18650A28
Nominal Voltage	3.68 V
Maximum Voltage	4.2 V
Minimum Voltage	2.5 V (adverse conditions)
Nominal Capacity	2900 mAh
Maximum Charging Current	1.36 A
Maximum Discharge Current	10 A
Maximum Continuous Discharge Current	5.8 A (2C)
Optimum Operating Temperature During Discharge	+45°C
Weight	48.0 gr
Charge/Discharge Cycle	550

Chart 2.2: Features of INR18650A28

Figure 2.9: ASPILSAN company's INR18650A28 battery

2.7 SPECIFICATIONS FOR THE MODEL

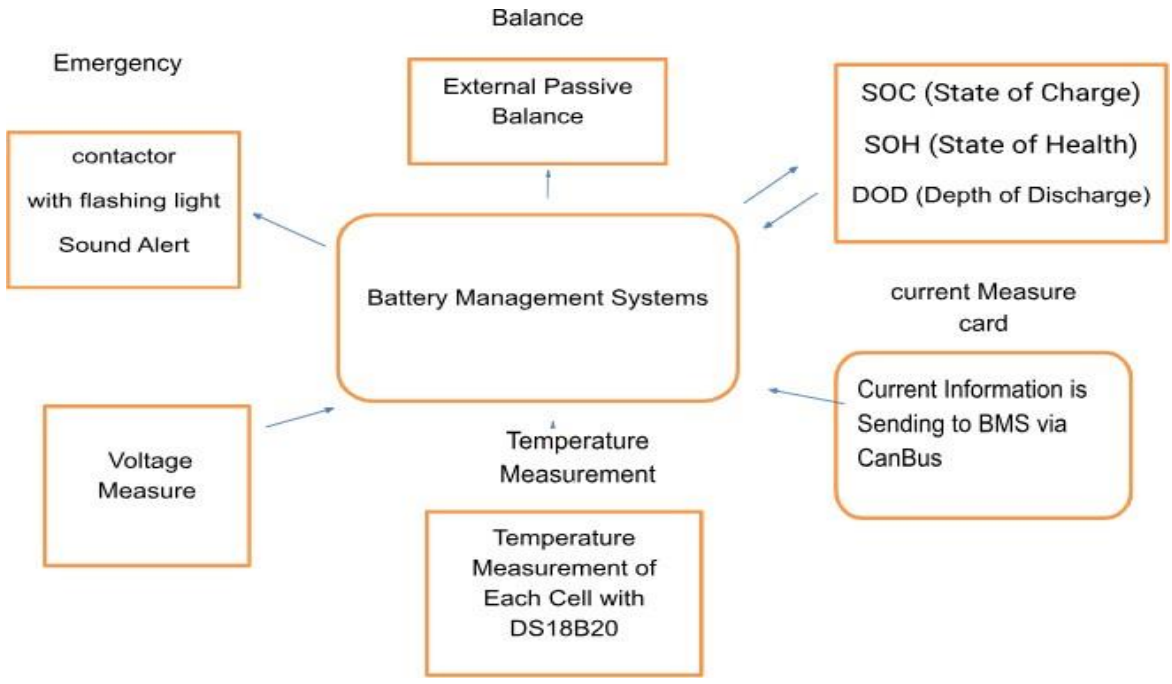


Figure 2.10: Battery Management System’s Diagram

CHAPTER 3

PROJECT PLANNING AND MANAGEMENT

This capstone project focuses on the crucial element of electric vehicle technology the battery management system. As a team of four individuals, our goal is to design an effective battery management system to enhance the performance and safety of electric vehicles. In this report, we will elaborate on the organization of our project, along with a timeline and the distribution of tasks, outlining the progression of our Project .

3.1. ORGANIZATION OF THE PROJECT

Hardware Design: Ahmet Yiğit Karaoğlu

Embedded Software ; Ahmet Yiğit

Karaoğlu

User Interface : Hakan Özkum

In our project, the three fundamental areas have been designated according to our expertise. **Ahmet Yiğit Karaoğlu** is working on the **Hardware Design** section, while **Yakup Sefa Duman** is taking on responsibilities in the **Embedded Software** department. Additionally, in the **User Interface** domain, **Hakan Özkum** is tasked with enriching our project and optimizing the user interface. Each team member has been envisioned to contribute to the holistic success of the project by showcasing their skills in their respective expertise areas.

3.2 EXPLANATION Of THE TASKS AND THEIR DEFINITIONS

3.2.1 Literature Survey (ALL TEAM)

3.2.1.1 BATTERY MANAGEMENT SYSTEM DESIGN TOPOLOGIES

The Battery Management System (BMS) cannot function independently within the overall framework of a battery pack; it necessitates collaboration with other system modules to attain the system's objectives. Essential components such as a battery management module, a battery interface module, battery units, and battery control form integral parts of a comprehensive intelligent energy automation system. This system serves to safeguard the battery and enhance its lifespan. The architecture of the BMS unit encompasses elements like data collection, condition monitoring, and control, playing a critical role in the effective management of large-scale batteries. This topology addresses individual electrical connections, batteries or battery cells, control structure, and communication architecture. When considering factors such as system costs, installation ease, maintenance, measurement accuracy, and, most importantly, security, careful consideration is required.

3.2.1.1.1 Centralized System

In centralized Battery Management Systems (BMSs), a singular module, connected to the battery or battery cells through numerous wires, handles all functions. The structure of the central BMS is illustrated in Figure 3.1. The central BMS is responsible for collecting data, including unit cell voltage, string current, and temperature measurements.

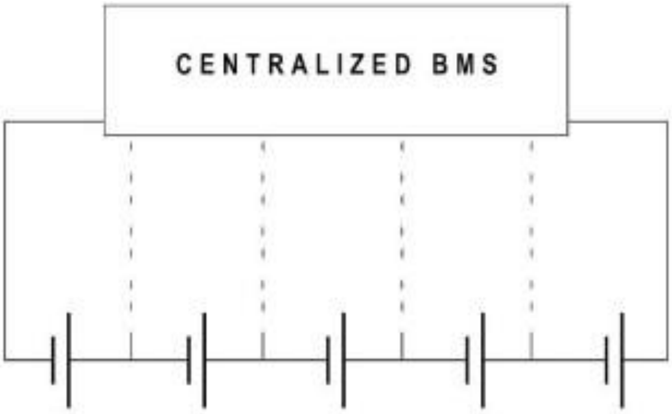


Figure 3.1: Schematic of Centralized BMS

3.2.1.1.2 Modular System

In a modular application, the battery pack is divided into segments according to the capacity of the Battery Management System (BMS). At times, BMS sub-modules may be supervised by a primary BMS module, responsible for overseeing the status of the sub-modules and establishing communication with peripheral equipment.

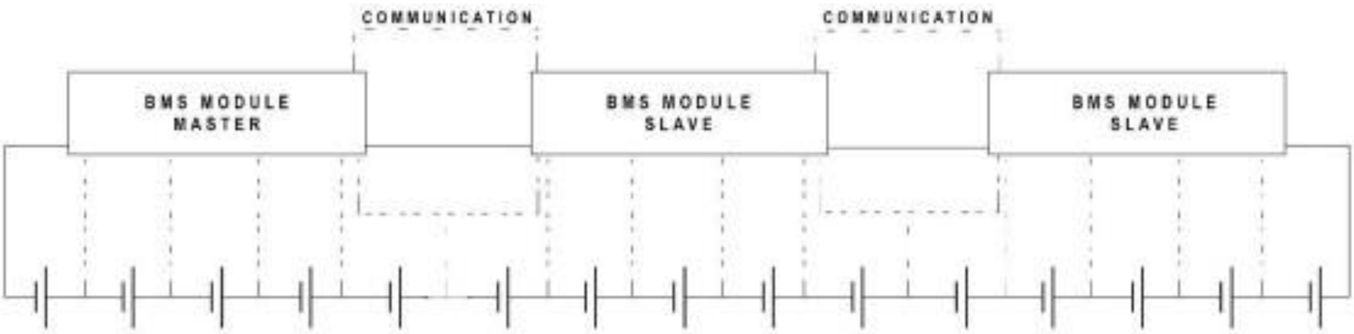


Figure 3.2: Schematic of Modular BMS System

The master module oversees the entire battery pack and communicates with the rest of the system, while the other modules are tasked with recording and transmitting measured data to the Master BMS. Since these modules are positioned close to the battery pack, the need for lengthy wires is minimized. The BMS's functionality can be easily duplicated on separate modules, enhancing functional security and providing an advantage over centralized BMSs. When there's a need to increase the battery pack's capacity, a new BMS module can be added, allowing for quick system improvement.

Thanks to the modular system, troubleshooting and maintenance become more straightforward, and high-capacity battery packs are achievable. However, the cost may be higher compared to centralized BMSs due to the requirement of a distinct BMS for each module.

3.2.2. CELL BALANCING METHODS

Maintaining equal voltages among cell groups is a critical factor in ensuring the longevity of the battery. This is because, in a series-connected battery group, the discharge status is influenced by the cell with the lowest voltage in the group, resulting in a reduction in battery life. Likewise, during charging, a cell with a high voltage can disrupt the balance in the battery, preventing the cell with a lower voltage from reaching a full charge.

Some of the reasons that cause imbalances between cells are:

a) Differences due to production

b) Differences in cell impedance

c) Thermal unbalance

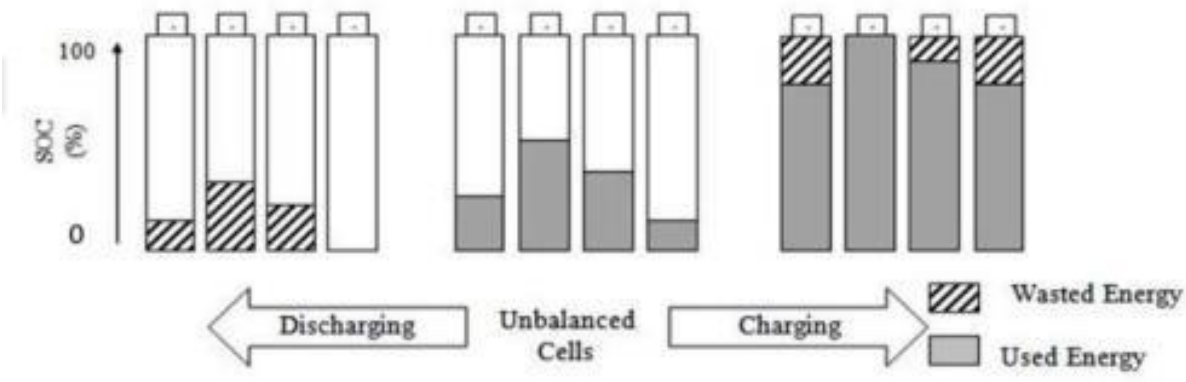


Figure 3.3: The Effect of Unbalanced Cells In The Battery

There are two types of balancing strategies: passive and active methods. The choice between them depends on the characteristics and cost considerations of the system to be implemented. In passive cell balancing systems, excess energy in the high-capacity cell is dissipated as heat through a resistor, while in active cell balancing systems, the energy is actively transferred from the high-voltage cell to the low-voltage cell, resulting in increased efficiency.

3.2.2.1 Passive Balancing

In passive balancing battery management systems, which is the first of these balancing techniques, excess energy is dissipated using bypass resistors if the difference between any two cells exceeds a predetermined threshold value. Passive balancing aims to equalize the state of charge at a specific point, typically when it is either at the highest charg or lowest charge. This is achieved by discharging energy, facilitated by a controlled short circuit through a resistor, from cells with a higher state of charge.

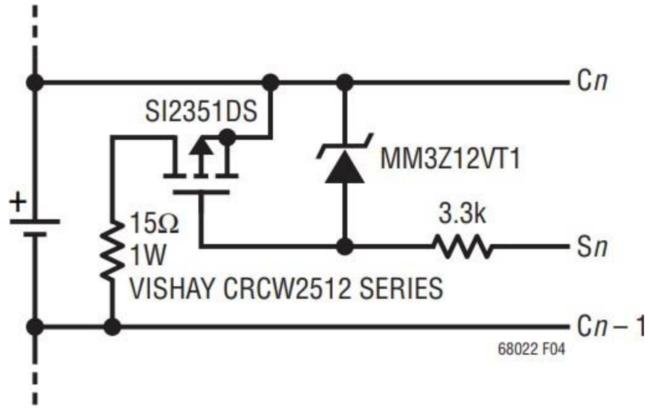


Figure 3.4: External Discharge FET Connection (One Cell Shown)

Figure 3.4: illustrates a distinct balancing circuit, implementing a different design by incorporating an external mosfet into the system. This modification serves to reduce the operational burden on the balancing ıc.

But the major drawback of this balancing method lies in the dissipation of energy as heat. Considering the entire battery pack, the amount of energy expelled as heat could reach a significant level that cannot be disregarded. In the passive balancing method, a fixed or switched resistor is utilized. in constant resistance balancing methods, the efficiency decreases as continuous current is drawn from the cells.

When the filling process is finished, the energy difference between both cells is reduced to the specified level.

3.2.2.2 Active Balancing

Another balancing method is active balancing, which is a system that uses capacitors and coils to transmit energy from the high-load cell to the low-charge cell.

Capacitor Based

i. Single Row Capacitor

ii. Dual Row Capacitor

Inductance/Transformer Based

i. Single - Multi Inductance

ii. Single Winding Transformer

Converter Based

i. CUK Converter

ii. Step-Down Converter

iii. Full Bridge Converter

Capacitor based balancing

This balancing mechanism is the system that transfers the energy in a selected cell to another cell by storing it on a capacitor. Different balancing designs can be made by using different numbers of switches and capacitors.

Inductance balancing

In the inductance balancing method, one or more inductors can be used for energy transfer, as in systems with capacitors. The control mechanism provides the transmission to the cells to be transferred by applying the required switching signal.

3.3 Conceptual Design

3.3.1 Hardware Design (Ahmet Yiğit Karaoğlu)

The hardware design of a Battery Management System (BMS) for a 24-series connected battery pack. Effective management of battery packs used in electric vehicles is crucial foroptimizing performance and ensuring safety measures. Within the scope of this thesis, a hardware design for a BMS, suitable for a specific electric vehicle application, will be developed and thoroughly examined.

The hardware design will encompass the necessary components for voltage monitoring, current measurement, temperature control, and balanced charging/discharging processes for24 series-connected cells. Additionally, the design will focus on key factors such as durability, energy efficiency, and cost-effectiveness.

This thesis will provide a detailed analysis of a BMS hardware design that contributes to thesustainability of electric vehicle technology. It aims to strengthen the infrastructure for the widespread use of electric vehicles in the future.

3.3.1.1 Battery Management ICs

The bq76PL455 and LTC6802 are both integrated circuits used in battery management systems (BMS), but they differ in specific features and applications. The bq76PL455, produced by Texas Instruments, is designed particularly for high-voltage battery packs. It can monitor and balance up to 16 series-connected cells and is notable for its safety monitoring features. This chip offers internal error correction for communication lines and advanced diagnostic capabilities, making it ideal for complex battery systems. On the other hand, Analog Devices' LTC6802 chip can monitor and balance up to 12 series-connected cells. The LTC6802 is especially known for its high-precision voltage measurements and low power consumption. Additionally, this chip features a robust SPI communication interface, making it preferred for applications requiring high reliability. In summary, the bq76PL455 offers greater cell monitoring capacity and advanced safety features, while the LTC6802 stands out with precise measurement and energy efficiency. Both chips provide superior features for different application needs, and thus their usage can vary accordingly.

3.3.1.2 LTC6802-2

Battery management systems utilize various balancing techniques, with active and passivebalancing being the two primary methods.

Active balancing involves the BMS independently charging or discharging cells andtransferring this charge between cells or batteries.

In the passive balancing method, the cell with the highest voltage is discharged through parallel high-power resistors connected to each cell until it aligns with the cell with the lowestvoltage in the system. Excess energy acquired during battery charging is discharged through series resistors in the system. The system maintains balance by cyclically activating and deactivating balancing resistors, effectively dissipating surplus energy.

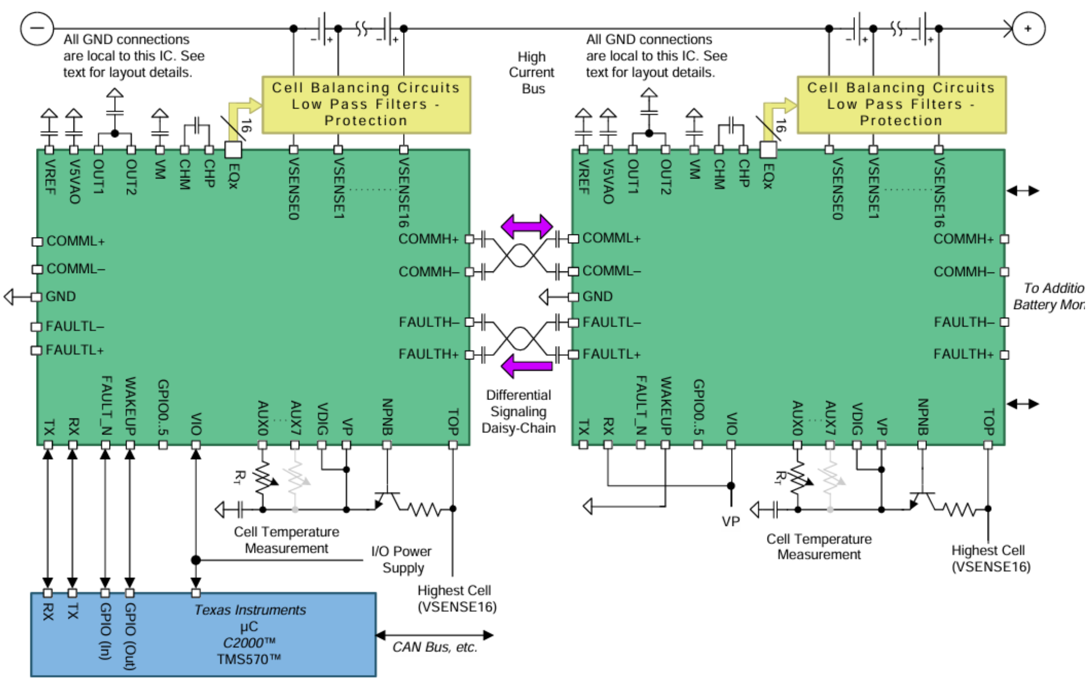


Figure 3.5: BQ76PL455 IC's Schematic and Wiring Diagram

Features

- Monitors and balances 6 to 16 cells per device

- Highly accurate monitoring with a 14-bit ADC and internal reference

  - All cells converted in 2.4 ms (nominal)

  - Eight AUX inputs for temperature and other sensors (0V to 5V input)

- Integrated protector with separate Vref for overvoltage (OV) and undervoltage (UV) comparators and programmable VCELL set points

- High system robustness:

  - Up to 1-Mb/s stackable isolated differential UART

  - Up to 16 ICs in daisy-chain with twisted pair

  - Passes Bulk Current Injection (BCI) test

  - Designed for robust hot-plug performance

- Passive balancing with external n-FETs and active balancing with EMB1428Q/EMB1499Q

- Supports functional safety standards (e.g., ISO26262)

  - Built-in self-tests to validate internal functions

  - Supports open wire detection

- AEC-Q100 qualified:

  - Device Temperature Grade 2: -40°C to 105°C operating range

- Device HBM ESD Classification Level 2

- Device CDM ESD Classification Level C3

Applications

- Electric and Hybrid Electric Vehicles (EV, HEV, PHEV, Mild Hybrid)

- 48-V systems (single-chip solution)

- Energy Storage Systems (ESS) and UPS

- E-Bikes, E-Scooter

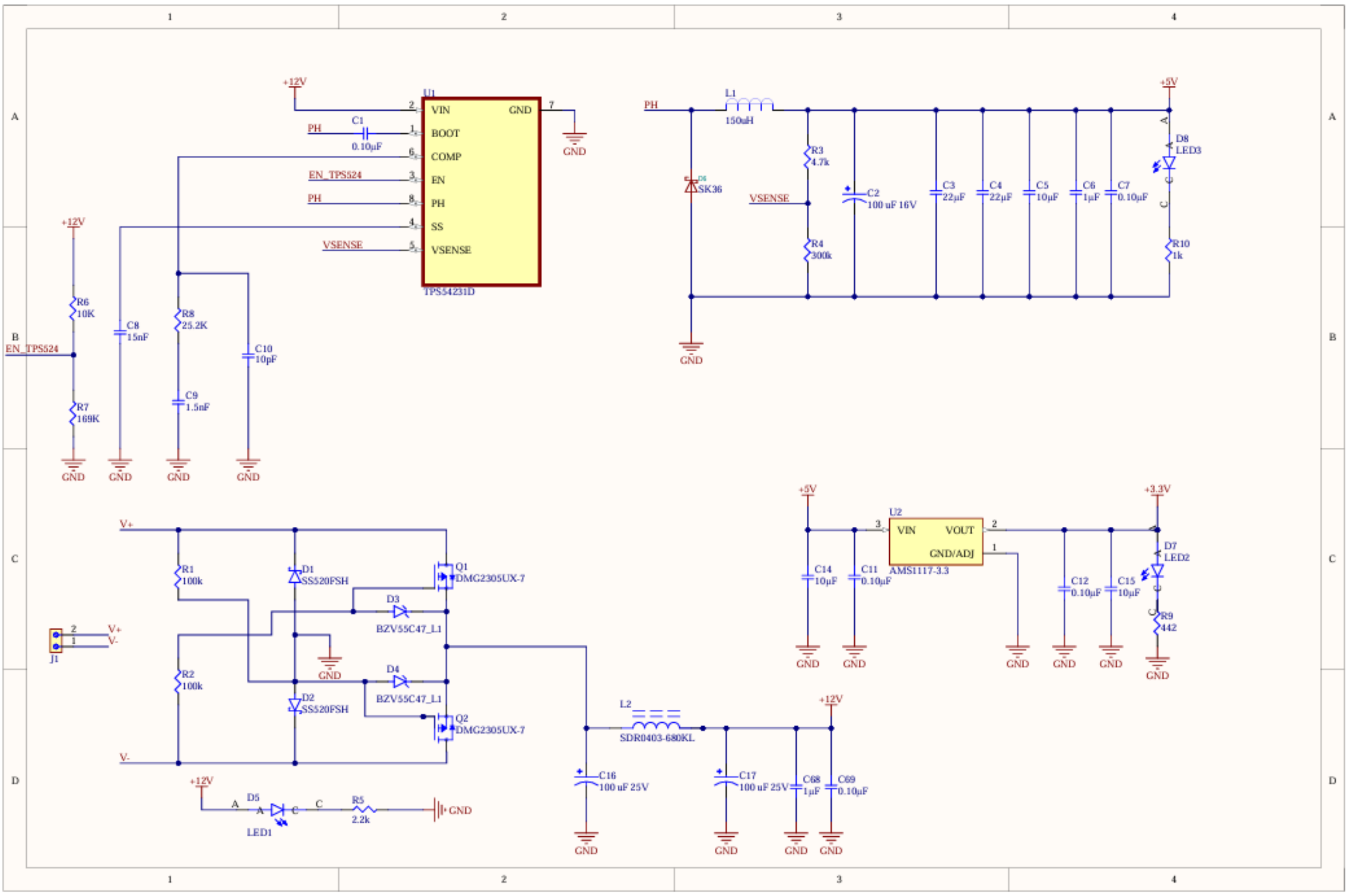


Figure 3.6: Example circuit designed to read 12 series cell voltagesExample (schematic 1)

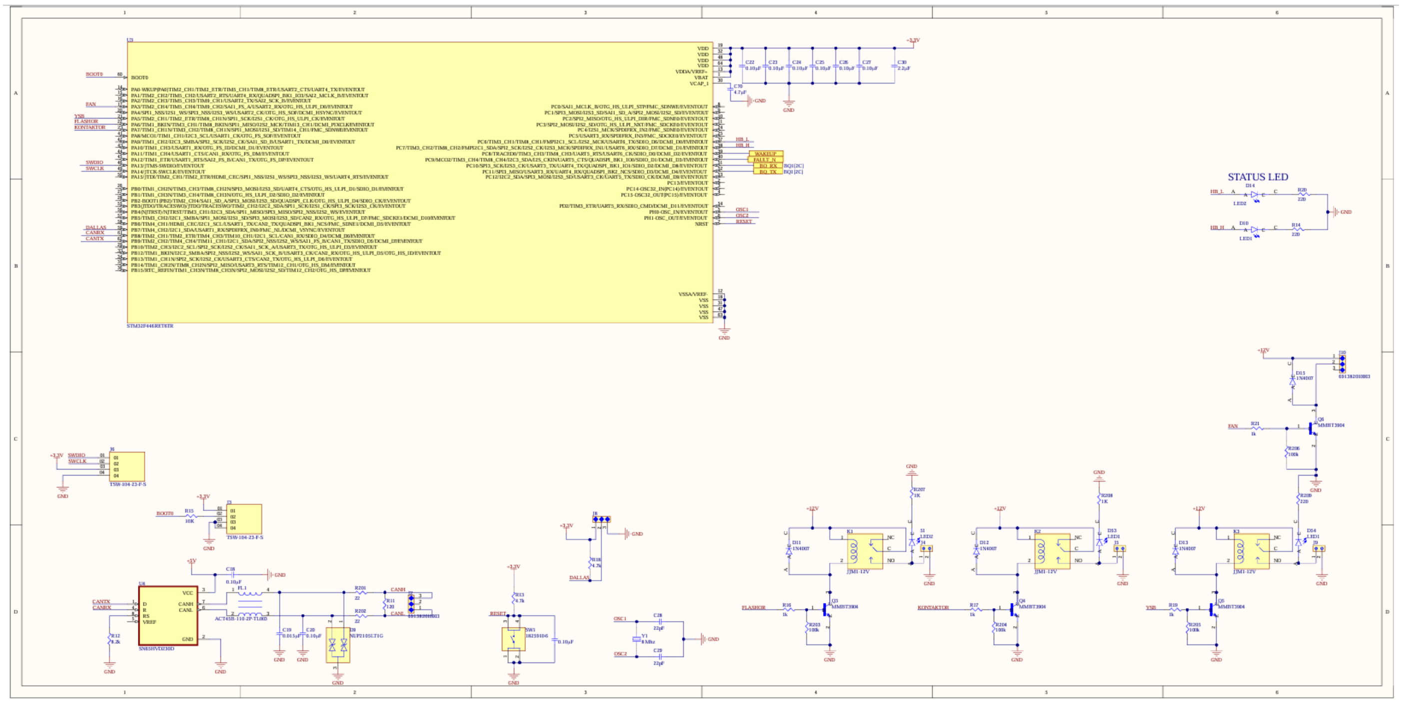


Figure 3.7: Example circuit designed to read 12 series cell voltagesExample (schematic 2)

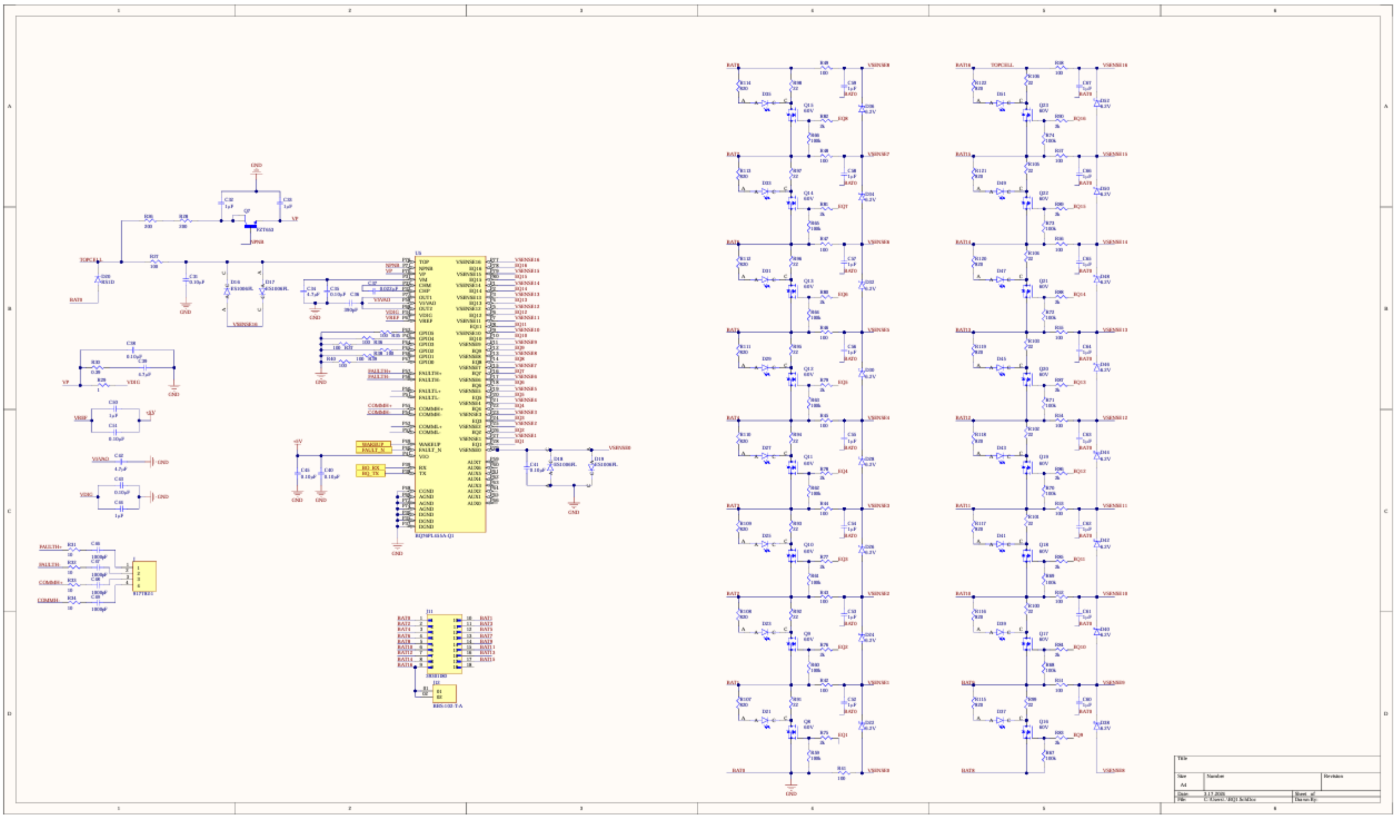


Figure 3.8: Example circuit designed to read 12 series cell voltagesExample (schematic 3)

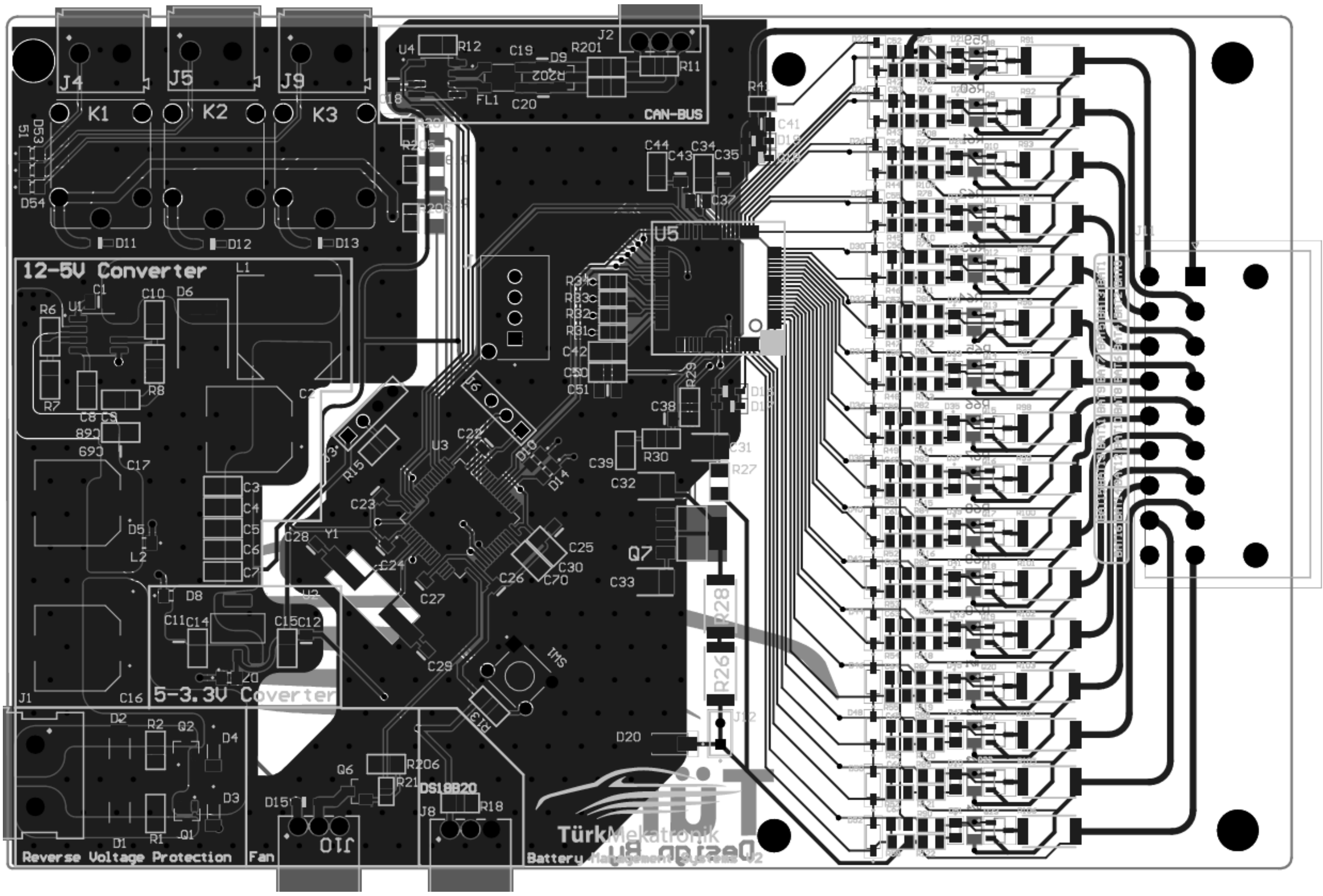


Figure 3.9: Example circuit PCB designed to read 12 series cell volta

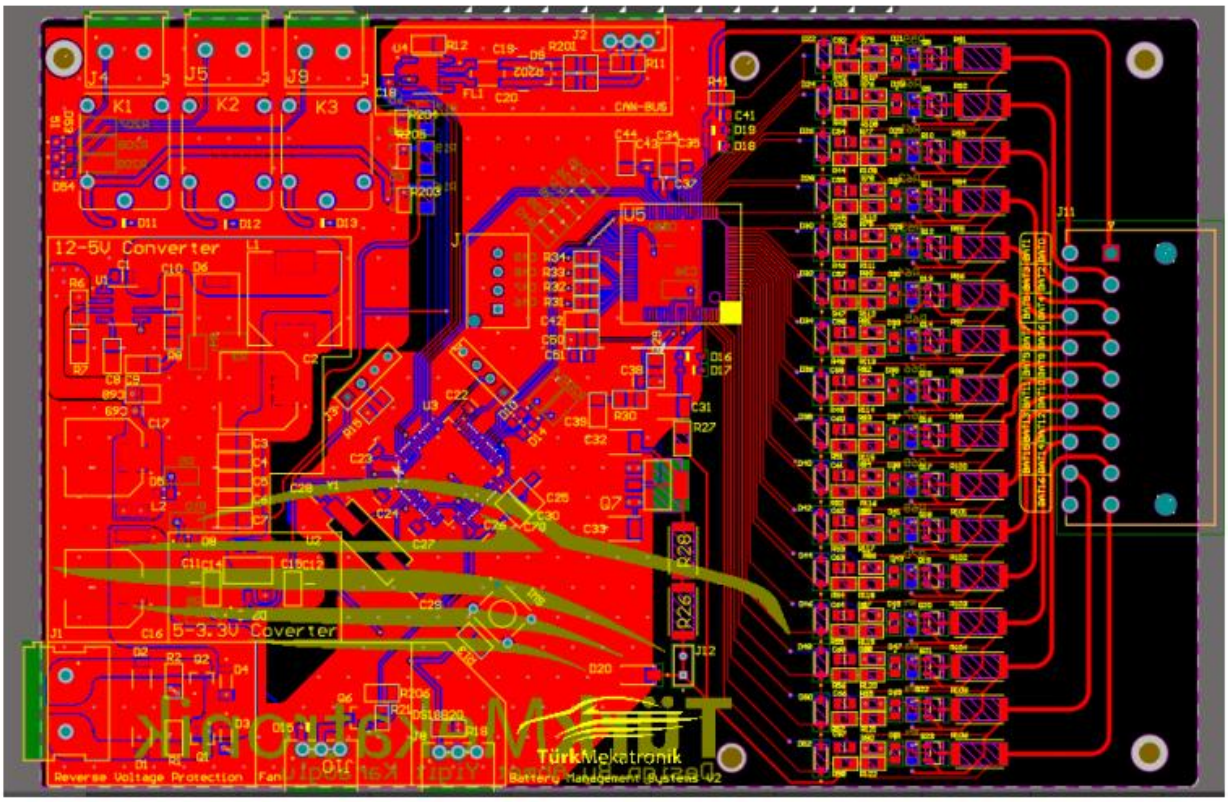


Figure 3.10: Example circuit PCB designed to read 12 series cell voltagesExample

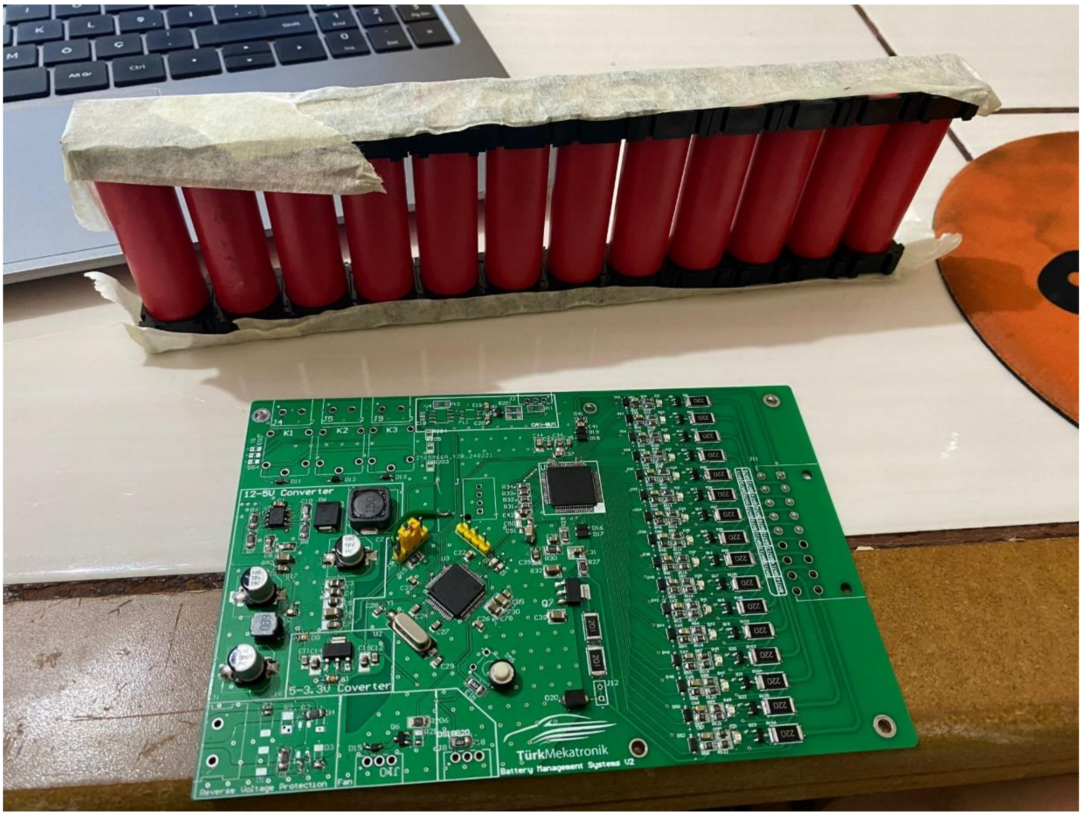


Figure 3.10: Manufactured pcb appearance

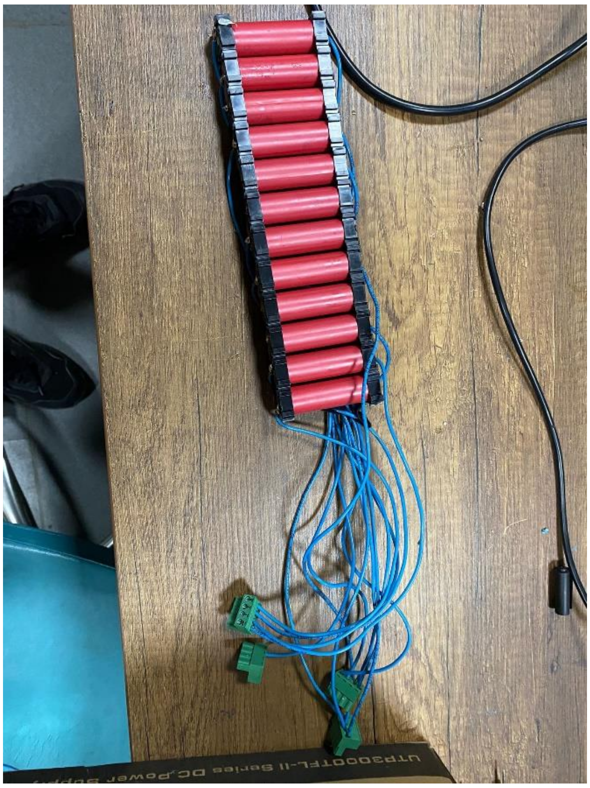


Figure 3.10: 12 serial battery packs produced for testing

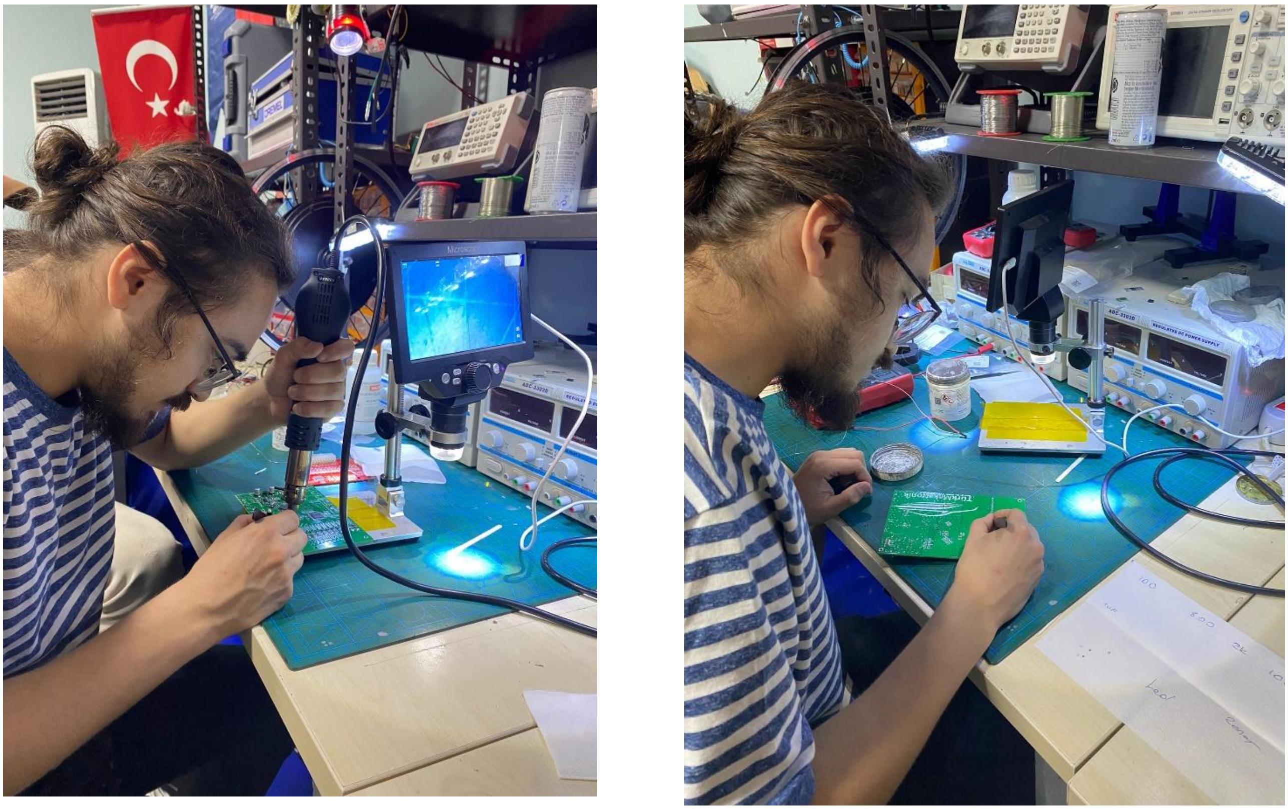


Figure 3.11: photos during soldering

Figure 3.11: Battery pack planned to be actually used

3.3.2 Embedded Software (Ahmet Yiğit Karaoğlu)

Algorithm

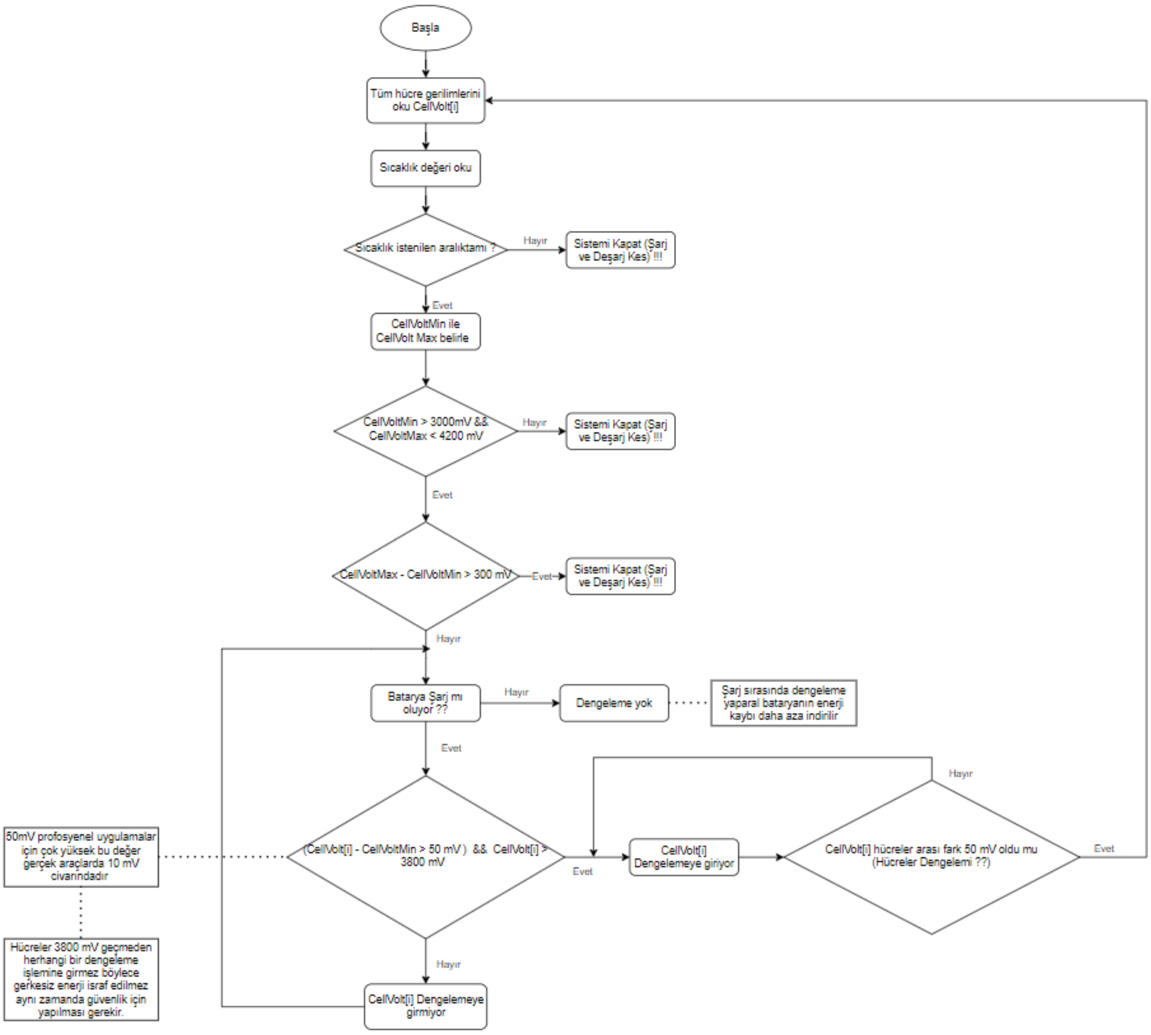


Figure 3.9: FlowChart for BMS

3.2.2.1 Embedded Software for BQ76PL455 (STM32CubeIde IDE)

```
	uint8_t receivedData[6];
	uint8_t BQResponse[64];

	// Cell & Pack Configs (mV)

	#define CELL_DISBALANCE_THRESHOLD 100 // mV
	#define BALANCING_THRESHOLD 3800     // mV - Minimum cell voltage to start
balancing
	#define OVER_VOLTAGE_THRESHOLD 4200  // mV - Cell over-voltage protection
threshold
	#define UNDER_VOLTAGE_THRESHOLD 3000 // mV - Cell under-voltage protection
threshold
	#define MINIMUM_VOLTAGE_LIMIT 2000   // mV - Minimum voltage limit of a cell
	#define CELL_SKIP_LIMIT 250          // mV - Algorithm ignores cells below this
voltage limit
	#define PACK_DISBALANCE_LIMIT 300    // mV - Algorithm will throw error and
blocks <AUTOBALANCE> feature when the pack seperation (voltage differance between Max
and Min Cells in the pack) is above this limit


    float TotalVolt = 0.0;
    float MinVolt, MaxVolt;

    bool isBqBusy = false,
       UnderVoltageFlag = false,
       OverVoltageFlag = false,
         BatteryPackErrorFlag = false,
       CellErrorFlag = false;

    int CellVolt[6],
            MinCellVolt = 9999,
            MinCellVoltIndex,
        MaxCellVolt = 0,
        MaxCellVoltIndex,
        PackDisbalance = 0,
        CellDisbalance = 0;

    uint16_t
        DischargeFlags = 0x00;

/* USER CODE END Includes */

/* Private typedef -----------------------------------------------------------*/
/* USER CODE BEGIN PTD */

/* USER CODE END PTD */

/* Private define ------------------------------------------------------------*/
/* USER CODE BEGIN PD */

/* USER CODE END PD */

/* Private macro -------------------------------------------------------------*/
/* USER CODE BEGIN PM */

/* USER CODE END PM */

/* Private variables ---------------------------------------------------------*/
UART_HandleTypeDef huart1;

/* USER CODE BEGIN PV */
```

```
/* USER CODE END PV */

/* Private function prototypes -----------------------------------------------*/
void SystemClock_Config(void);
static void MX_GPIO_Init(void);
static void MX_USART1_UART_Init(void);
/* USER CODE BEGIN PFP */

/* USER CODE END PFP */

/* Private user code ---------------------------------------------------------*/
/* USER CODE BEGIN 0 */

void BQSetup()    //Initializing BQ Configs
{
        HAL_GPIO_WritePin(GPIOB, GPIO_PIN_8, GPIO_PIN_SET); //Waking BQ up
        HAL_Delay(50);

        SET_OV_THRESHOLD[3] = ((OVER_VOLTAGE_THRESHOLD * 65535) / 5000) >> 8;
        SET_OV_THRESHOLD[4] = ((OVER_VOLTAGE_THRESHOLD * 65535) / 5000) % 256;
        SET_UV_THRESHOLD[3] = ((UNDER_VOLTAGE_THRESHOLD * 65535) / 5000) >> 8;
        SET_UV_THRESHOLD[4] = ((UNDER_VOLTAGE_THRESHOLD * 65535) / 5000) % 256;

              //----- DEVICE IDENTIFICATION -----
      bqWrite(SET_UV_THRESHOLD, sizeof(SET_UV_THRESHOLD),
sevenByteDataWithCRC,&huart1);
    HAL_Delay(5);

    bqWrite( SET_AM_PERIOD, sizeof( SET_AM_PERIOD), sixByteDataWithCRC,&huart1);
    HAL_Delay(5);

    bqWrite( SET_AM_CHANNELS, sizeof(SET_AM_CHANNELS), nineByteDataWithCRC,&huart1);
    HAL_Delay(5);

    bqWrite( DISCHARGE_SETTINGS, sizeof(DISCHARGE_SETTINGS),
sixByteDataWithCRC,&huart1);
    HAL_Delay(5);

    bqWrite(DISCHARGE_STOP, sizeof(DISCHARGE_STOP), sevenByteDataWithCRC,&huart1);
    HAL_Delay(5);

           }
void CalculateTotalVolt()
{
    TotalVolt = 0.0;
    for (int i = 0; i <= 6; i++)
    {
        TotalVolt += CellVolt[i];
    }
}
void CalculateMinMaxVolt()
{
      MinVolt = CellVolt[0];  MaxVolt = CellVolt[0];

    for (int i = 1; i < 6; i++)
    {
        if (CellVolt[i] < MinVolt)
            MinVolt = CellVolt[i];
        if (CellVolt[i] > MaxVolt)
            MaxVolt = CellVolt[i];
    }
}
int GetBit(int Value, int Index)
{
  return (1 == ((Value >> Index) & 1));
}
```

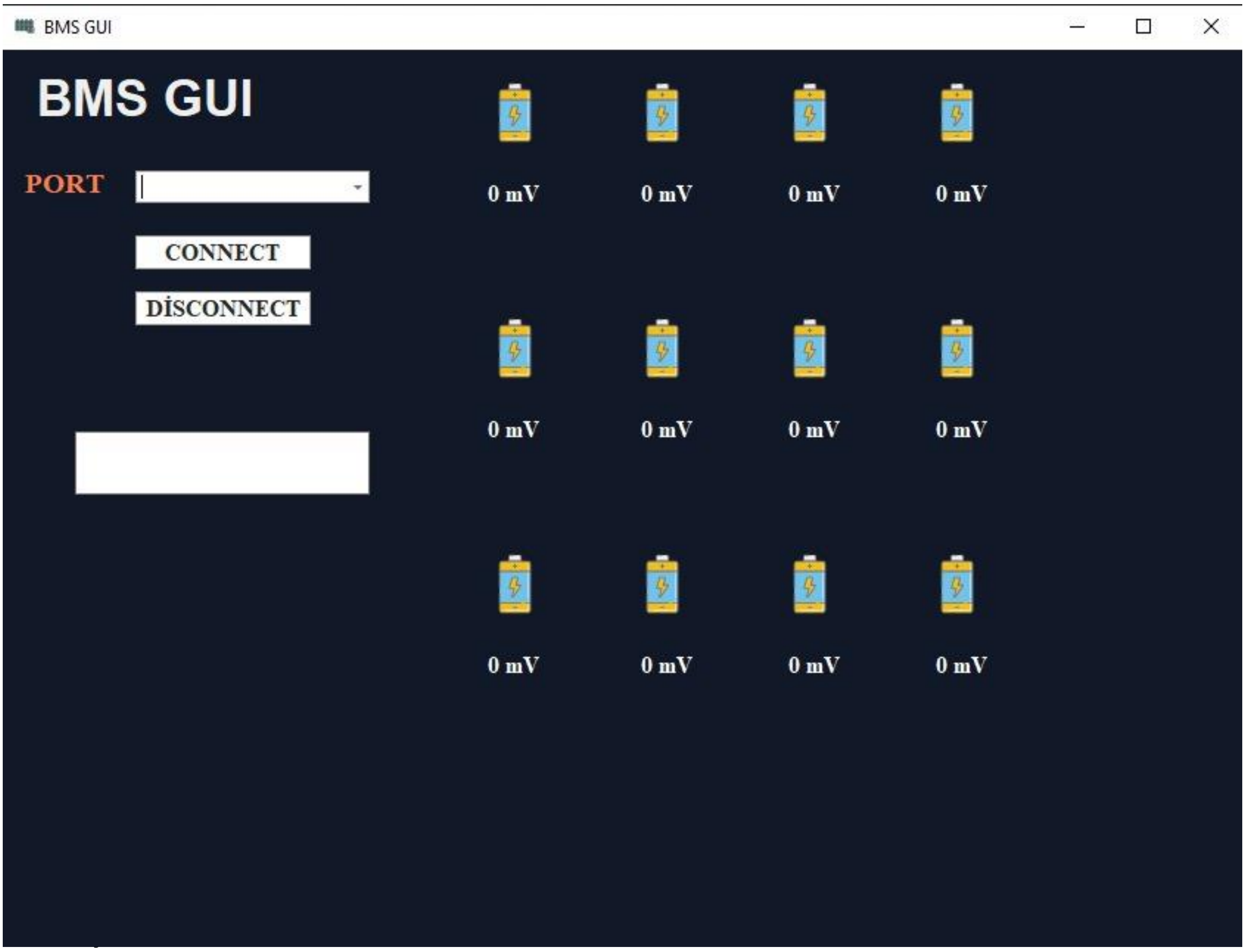
```
int SetBit(int Value, int BitPosition, int NewValue)
{
  if (NewValue == 1)
  {
    Value |= 1 << BitPosition;
    return Value;
  }
  else
  {
    Value &= ~(1 << BitPosition);
    return Value;
  }
}
void CheckVoltageFlags()
{
       if (MaxCellVolt > OVER_VOLTAGE_THRESHOLD)  //4200 mV
          OverVoltageFlag = true;
        else
          OverVoltageFlag = false;
        if (MinCellVolt < UNDER_VOLTAGE_THRESHOLD)  //3000 mV
          UnderVoltageFlag = true;
        else
          UnderVoltageFlag = false;
} int main(void)
{

  /* USER CODE BEGIN 1 */

  /* USER CODE END 1 */

  /* MCU Configuration--------------------------------------------------------*/

  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();

  /* USER CODE BEGIN Init */

  /* USER CODE END Init */

  /* Configure the system clock */
  SystemClock_Config();

  /* USER CODE BEGIN SysInit */

  /* USER CODE END SysInit */

  /* Initialize all configured peripherals */
  MX_GPIO_Init();
  MX_USART1_UART_Init();
  /* USER CODE BEGIN 2 */

  BQSetup();

 // HAL_UART_Receive_IT(&huart1, receivedData, 6);

  /* USER CODE END 2 */

  /* Infinite loop */
  /* USER CODE BEGIN WHILE */
  while (1)
  {
    /* USER CODE END WHILE */

    /* USER CODE BEGIN 3 */
```

```
      CollectSamples();
      CalculateTotalVolt();
      CalculateMinMaxVolt();
      BalanceCheck();

      HAL_Delay(500);
  }
  /* USER CODE END 3 */
}

/**
  * @brief System Clock Configuration
  * @retval None
  */
void SystemClock_Config(void)
{
  RCC_OscInitTypeDef RCC_OscInitStruct = {0};
  RCC_ClkInitTypeDef RCC_ClkInitStruct = {0};

  /** Initializes the RCC Oscillators according to the specified parameters
  * in the RCC_OscInitTypeDef structure.
  */
  RCC_OscInitStruct.OscillatorType = RCC_OSCILLATORTYPE_HSE;
  RCC_OscInitStruct.HSEState = RCC_HSE_ON;
  RCC_OscInitStruct.HSEPredivValue = RCC_HSE_PREDIV_DIV1;
  RCC_OscInitStruct.HSIState = RCC_HSI_ON;
  RCC_OscInitStruct.PLL.PLLState = RCC_PLL_ON;
  RCC_OscInitStruct.PLL.PLLSource = RCC_PLLSOURCE_HSE;
  RCC_OscInitStruct.PLL.PLLMUL = RCC_PLL_MUL9;
  if (HAL_RCC_OscConfig(&RCC_OscInitStruct) != HAL_OK)
  {
    Error_Handler();
  }

  /** Initializes the CPU, AHB and APB buses clocks
  */
  RCC_ClkInitStruct.ClockType = RCC_CLOCKTYPE_HCLK|RCC_CLOCKTYPE_SYSCLK
                              |RCC_CLOCKTYPE_PCLK1|RCC_CLOCKTYPE_PCLK2;
  RCC_ClkInitStruct.SYSCLKSource = RCC_SYSCLKSOURCE_PLLCLK;
  RCC_ClkInitStruct.AHBCLKDivider = RCC_SYSCLK_DIV1;
  RCC_ClkInitStruct.APB1CLKDivider = RCC_HCLK_DIV2;
  RCC_ClkInitStruct.APB2CLKDivider = RCC_HCLK_DIV1;

  if (HAL_RCC_ClockConfig(&RCC_ClkInitStruct, FLASH_LATENCY_2) != HAL_OK)
  {
    Error_Handler();
  }
}

/**
  * @brief USART1 Initialization Function
  * @param None
  * @retval None
  */
static void MX_USART1_UART_Init(void)
{

  /* USER CODE BEGIN USART1_Init 0 */

  /* USER CODE END USART1_Init 0 */

  /* USER CODE BEGIN USART1_Init 1 */

  /* USER CODE END USART1_Init 1 */
  huart1.Instance = USART1;
  huart1.Init.BaudRate = 250000;
```

```
  huart1.Init.WordLength = UART_WORDLENGTH_8B;
  huart1.Init.StopBits = UART_STOPBITS_1;
  huart1.Init.Parity = UART_PARITY_NONE;
  huart1.Init.Mode = UART_MODE_TX_RX;
  huart1.Init.HwFlowCtl = UART_HWCONTROL_NONE;
  huart1.Init.OverSampling = UART_OVERSAMPLING_16;
  if (HAL_UART_Init(&huart1) != HAL_OK)
  {
    Error_Handler();
  }
  /* USER CODE BEGIN USART1_Init 2 */

  /* USER CODE END USART1_Init 2 */

}

/**
  * @brief GPIO Initialization Function
  * @param None
  * @retval None
  */
static void MX_GPIO_Init(void)
{
  GPIO_InitTypeDef GPIO_InitStruct = {0};
/* USER CODE BEGIN MX_GPIO_Init_1 */
/* USER CODE END MX_GPIO_Init_1 */

  /* GPIO Ports Clock Enable */
  __HAL_RCC_GPIOD_CLK_ENABLE();
  __HAL_RCC_GPIOA_CLK_ENABLE();
  __HAL_RCC_GPIOB_CLK_ENABLE();

  /*Configure GPIO pin Output Level */
  HAL_GPIO_WritePin(GPIOB, GPIO_PIN_15|GPIO_PIN_8|GPIO_PIN_9, GPIO_PIN_RESET);

  /*Configure GPIO pin : PA7 */
  GPIO_InitStruct.Pin = GPIO_PIN_7;
  GPIO_InitStruct.Mode = GPIO_MODE_INPUT;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);

  /*Configure GPIO pins : PB15 PB8 PB9 */
  GPIO_InitStruct.Pin = GPIO_PIN_15|GPIO_PIN_8|GPIO_PIN_9;
  GPIO_InitStruct.Mode = GPIO_MODE_OUTPUT_PP;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  GPIO_InitStruct.Speed = GPIO_SPEED_FREQ_LOW;
  HAL_GPIO_Init(GPIOB, &GPIO_InitStruct);

/* USER CODE BEGIN MX_GPIO_Init_2 */
/* USER CODE END MX_GPIO_Init_2 */
}

/* USER CODE BEGIN 4 */

/* USER CODE END 4 */

/**
  * @brief  This function is executed in case of error occurrence.
  * @retval None
  */
void Error_Handler(void)
{
  /* USER CODE BEGIN Error_Handler_Debug */
  /* User can add his own implementation to report the HAL error return state */
  __disable_irq();
  while (1)
```

```
/* USER CODE END Error_Handler_Debug */
```

3.3.3 User interface: (Hakan Özkum)



management system user interface

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.IO.Ports;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;
using DevExpress.XtraEditors;
using static System.Windows.Forms.VisualStyles.VisualStyleElement;

namespace bmsui
{
   public partial class Form1 : Form
```

```
{
   SerialPort port;
   string buffer = string.Empty;
   public Form1()
   {
      InitializeComponent();
   }



   private void ımageEdit1_EditValueChanged(object sender, EventArgs e)
   {

   }

   private void labelControl2_Click(object sender, EventArgs e)
   {

   }

   private void Form1_Load(object sender, EventArgs e)
   {
      //comboBoxEdit1.Items.Clear();
      //foreach (var port in SerialPort.GetPortNames())
      //    comboBox1.Items.Add(port);
      comboBoxEdit1.Clear();
      foreach (var port in SerialPort.GetPortNames())
      {
         comboBoxEdit1.Properties.Items.Add(port);
      }
   }

   private void connect_Click(object sender, EventArgs e)
   {
      SerialPortProgram();
   }
   private void backgroundWorker1_DoWork(object sender, DoWorkEventArgs e)
   {
      try
      {
         buffer += port.ReadExisting();
         if (buffer.Contains("e"))
         {
            string[] datas = buffer.Split(',');
            buffer = string.Empty;
            labelControl3.Text = datas[0];
            labelControl4.Text = datas[1];
            labelControl5.Text = datas[2];
            labelControl6.Text = datas[3];
            labelControl7.Text = datas[4];
            labelControl8.Text = datas[5];
            labelControl9.Text = datas[6];
            labelControl10.Text = datas[7];
            labelControl11.Text = datas[8];
```

```
                labelControl12.Text = datas[9];
                labelControl13.Text = datas[10];
                labelControl14.Text = datas[11];


            }
          }
          catch (Exception ex) { textBox1.Text = ex.Message.ToString(); }

        }
        private void comboBox1_SelectedIndexChanged(object sender, EventArgs e)
        {
          port = new SerialPort(comboBoxEdit1.SelectedItem.ToString(), 115200, Parity.None, 8,
StopBits.One);
        }
        public void SerialPortProgram()
        {
          port.DataReceived += Port_DataReceived1;
          port.Open();
          Console.ReadLine();
        }

        private void Port_DataReceived1(object sender, SerialDataReceivedEventArgs e)
        {
          if (!backgroundWorker1.IsBusy)
            backgroundWorker1.RunWorkerAsync();
        }



        }
    }
```

3.4 TIMELINE

TimeLine BMS

	1-15 Aralık	15 Aralık - 1 Ocak	1-15 Ocak	15 Ocak - 30 Ocak	1-8 Şubat	8-15 Şubat
Hardware design	Litarütür Araştırması	Örnek Devre Tasarımı ve Baskı Devre Örnek alımı	Batarya Paketi ile BMS bağlantısı Alınması, Sıcaklık sensörü testi	Nihai PCB Tasarımı (Yurt Dışında PCB kartı sipariş edilecektir.)	PCB Dizgi işlemi	BMS kartının son testi
C# interface	Örnek arayüz tasarımı araşırması	Arayüz tasarımı başlangıç	Kablosuz haberleşme modulü testi (LoRa)	C# arayüzü son testi		
Embedded Software	Akış Diyagramı ile algoritma oluşturma	STM32 kartı ile LTC6802-2 entegresi arasında SPI haberleşme protokolü araştırması	CanBus hattı ile Gerilim, Sıcaklık, akım gibi verilerin haberleşme testi	PCB kartı üzerinde yazılım testi gerçekleştirilmesi	Gömülü yazılım son test	

Chart 4: Time Line

Working with a battery pack, especially one with a voltage of 100V, can pose serious risks. It is imperative to prioritize the safety of equipment during the course of this project. Additionally, we have an ample supply of electronic components, and in the event of any damage to them, replacement components are readily available in Turkey.

During the design process, we will utilize the EasyEDA program for PCB layout in hardware design. For user interface, we prefer to use C#, and in embedded software, we opt for the STM32 microcontroller with a 32-bit architecture.

This approach not only ensures the safety of the team while working with a potentially hazardous 100V battery pack but also guarantees the availability of replacement components in case of any damage to the existing electronic components. In the hardware design phase, the PCB layout will be accomplished using the EasyEDA program. For user interface, C# will be employed, and in embedded software, the STM32 microcontroller with a 32-bit architecture will be the preferred choice.

CHAPTER 4

Our main concern in our project is the cost. In this regard, we strive to implement alternativedesigns considering both functionality and price. We opted for a passive balancing method inthe battery management system, considering both affordability and performance. The easy availability of BQ76PL455in our country played a crucial role in our design preference.

4.1 CONCEPT DEVELOPMENT AND PRESENTATION

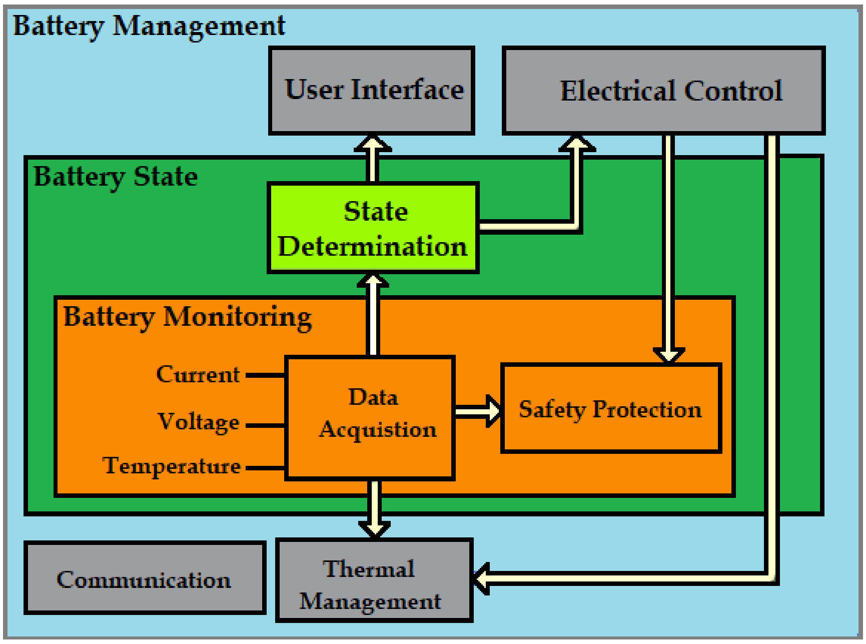
In this section, we will delve into the concept development and presentation of the Battery Management System (BMS), incorporating insights from our previous discussions. The primary objective of the BMS is to tackle critical challenges in electric vehicle technology,with a focus on enhancing energy efficiency, optimizing performance, and ensuring safety.

Our conceptual framework involves the integration of advanced hardware and software components, including the utilization of the BQ76PL455 chip. The hardware design, crafted through the EasyEda program and featuring the STM32F407 microcontroller alongside theLT6802-2, establishes the groundwork for a robust BMS with enhanced monitoring capabilities.

The software, developed using the STM32CubeIde program, is tailored to efficiently manageand monitor the battery, leveraging the capabilities of both the microcontroller and the BQ76PL455 chip.

Furthermore, our concept emphasizes the significance of a user-friendly interface designed in C#. This user interface, scheduled for completion by the end of January, will provide a comprehensive user experience by displaying crucial information such as the voltage of the 24series battery cells.

As we progress through the concept development, our goal is to present a comprehensive approach that not only addresses technical intricacies but also highlights the BMS's role incontributing to the sustainability and



performance optimization of electric vehicles

Figure 4.1: State Estimination

A simulation for a 3-series 1-parallel battery configuration has been conducted at a 0.25C discharge rate in the Matlab Simulink program for reference purposes. As a result of our simulation, a State of Charge (SOC) value of 75% has been calculated. The theoretical calculations align with the simulation data, supporting each other.

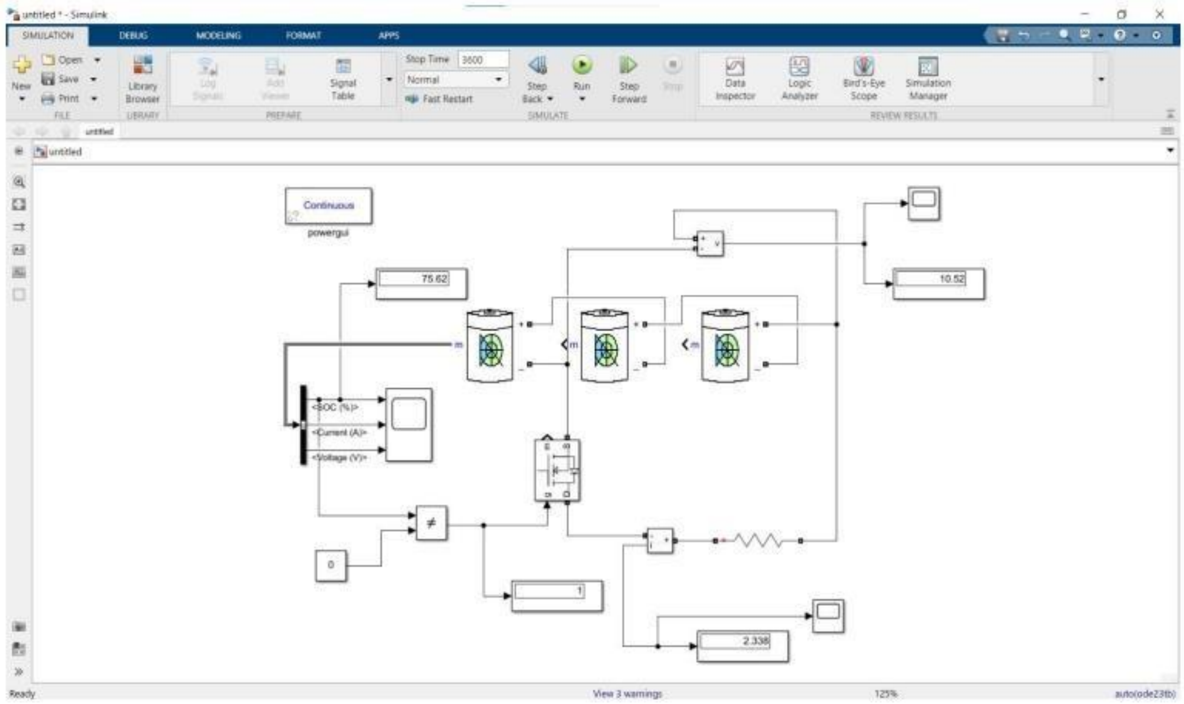


Figure 4.2: 3 Series 1 Parallel BMS Simulation

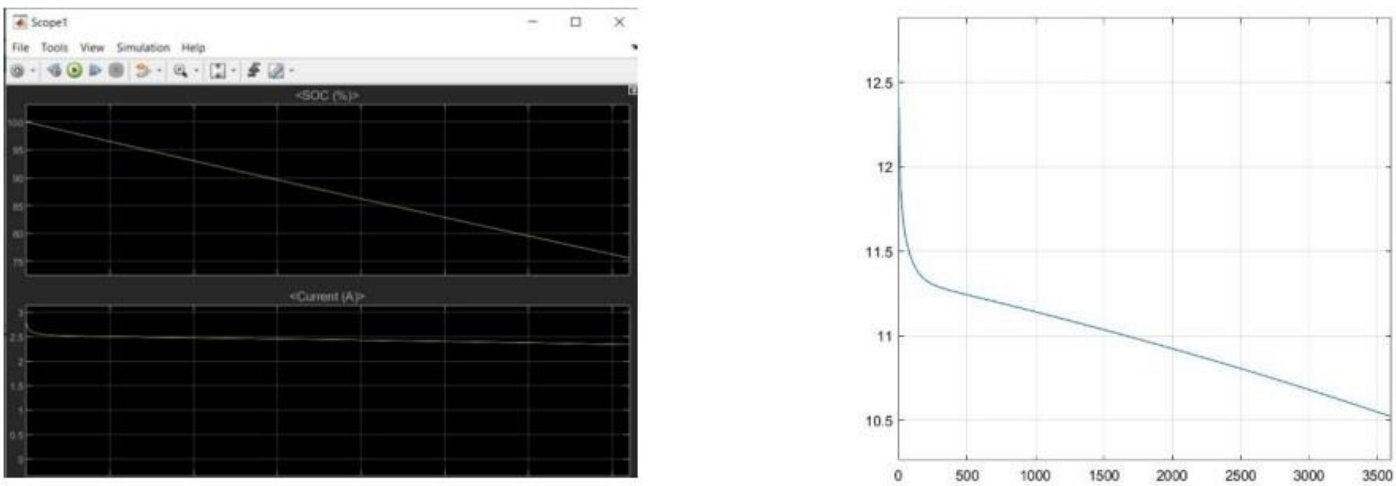


Figure 4.3: SOC, Current (left) and voltage graph (Right)

4.2 EVALUATION OF CONCEPTS

Passive Balancing

- Resistive discharging of higher voltage

cells to the lowest denominator

Pros	**Cons**
• Integrated ASICs	• Slower Balancing
• Least expensive	• Wastes energy to heat

Active Balancing

- Charges a low cell from a higher cell

Pros	**Cons**
• Quicker to balance	• More Complex
• Capable of nurturing	• More expensive
• Recovers energy	

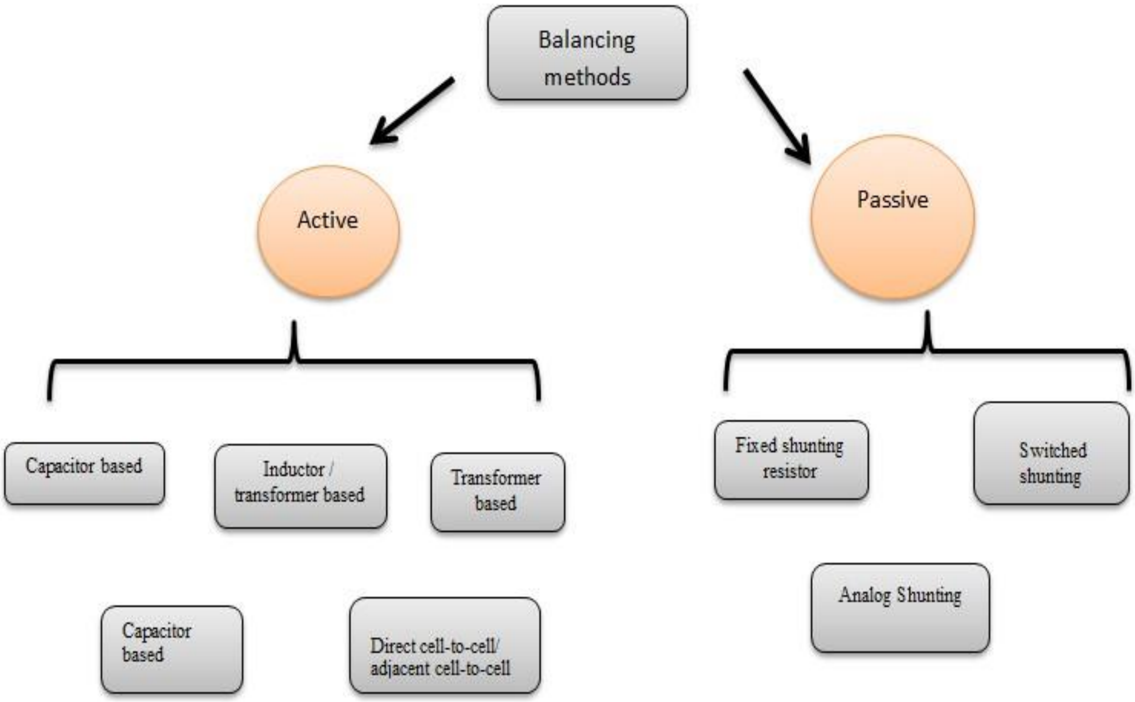


Figure 4.4: Cell Balancing

Car model	Battery voltage	Battery cells
Ricardo McLaren P1	550V	324
BMW i3	360V	96
Tesla Model S60	300V	5,376
Ford Fusion Hybrid	275V	76
Chevrolet Malibu ECO	115V	32
Chevrolet Volt	360V	288
Mitsubishi I-MiEV	330V	88
Nissan Leaf	360V	192
Toyota Prius PlugIn	207V	56

Ford Fusion Hybrid

Nissan Leaf

Prius Plug-In Hybrid

Chevy Volt

Figure 4.5: Battery Comparison of electric vehicles on the market

Car model	Cell balancing method	Cell balancing technique	Cell balancing current[1]
Ford Fusion Hybrid	Passive	Resistive	17 mA
Chevrolet Malibu ECO	Passive	Resistive	17 mA
Chevrolet Volt	Passive	Resistive	125 mA[2]
Mitsubishi I-MiEV	Passive	Resistive	92 mA
Nissan Leaf	Passive	Resistive	8.7 mA
Toyota Prius	Active	Charge pump	Unknown
Ricardo McLaren P1	Active & Passive	Charge transfer & resistive	1Amp Active 250 mA Passive

Figure 4.6: Battery Cell Balancing Comparison of electric vehicles on the market

As seen in the figure, contemporary electric vehicles on the roads predominantly employ passive balancing as the cell balancing method. The use of passive balancing is favored due to both cost-effectiveness and operational simplicity. Our decision to adopt passive balancing is significantly influenced by this trend..

Car model	ASIC	# cells	Communications from ASIC to Micro
Ford Fusion Hybrid	Analog Devices AD7280	6 Cells	SPI Daisy Chain
Chevrolet Malibu ECO	Hitachi-HCC03LLV1018	6 Cells	Serial Daisy chain
Chevrolet Volt	STMicro L9763	8 Cells	SPI Daisy Chain
Mitsubishi I-MiEV	Linear-LTC6802G-2	12 Cells	SPI Daisy Chain
Nissan Leaf	NEC DS15110	4 Cells	UART interface
Toyota Prius	???? 2P25 SF367	4 Cells	Serial Daisy chain
Ricardo McLaren P1	Microcontroller	14 Cells	NA

Figure 4.7: Voltage & Balance ASICs of electric vehicles on the market

Car model	Voltage Sense	Temperature Sense	Passive Balance	Active Balance	Isolation	Leakage Detection	Contactor Drivers	Accessory Drives	Charger interface	CAN Communication	Voltage < 250V	CPU 32 Bit	Distributed	Centralized
Ford Fusion Hybrid	X	X	X		X	X	X	X	X	X	X	X		X
Chevrolet Malibu ECO	X	X	X		X	X	X	X	X	X		X		X
Chevrolet Volt	X	X	X		X	X	X	X	X	X	X	X	X	
Mitsubishi I-MiEV	X	X	X		X	X	X	X	X	X	X	X	X	
Nissan Leaf	X	X	X		X	X	X	X	X	X	X	X		X
Toyota Prius	X	X		X	X	X	X	X	X	X		X	X	
Ricardo McLaren P1	X	X	X	X	X	X	X	X	X	X	X	X	X	

Figure 4.8: Architecture Functions Summary of electric vehicles on the market

4.3 SUMMARY AND CONCLUSION

In summary, the evaluation of cell balancing methods, particularly focusing on passive and active balancing, reveals distinct advantages and disadvantages for each approach. The comparison, as illustrated in Figure 2, outlines the key pros and cons associated with both passive and active balancing techniques. Considering the prevalent use of passive balancing in contemporary electric vehicles, as highlighted in **Figure 4.6**, our decision to adopt this method is strategically aligned with industry trends. The cost-effectiveness and operational simplicity associated with passive balancing play a pivotal role in influencing our choice.

In conclusion, the careful evaluation of cell balancing methods has informed our decision to favor switched passive balancing for the Battery Management System (BMS). This approach, supported by industry trends and cost-effectiveness, positions our BMS design as a promising solution for efficient and sustainable energy management in electric vehicles.

Figure 4.9: Example Electrical Car

REFERENCES

[1] E. Verband der Elektrotechnik and Institute of Electrical and Electronics Engineers., PCIM Europe 2019 ; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management

[2] S. Kivrak, T. Özer, and Y. Oğuz, “Battery Management System Implementation with Pasive Control Method,” in 2018 IV International Conference on Information Technologies in Engineering Education (Inforino), 2018, pp. 1–4. doi: 10.1109/INFORINO.2018.8581758

[3] A. Melih YILDIZ, “ANADOLU STRATE Jİ DERGİSİ Journal of Anadolu Strategy Battery Management System Architectures For Unmanned Air Vehicles: A Strategic Issue.”

[4] Karadeniz Orçun, “LİTYUM TABANLI ENERJİ DEPOLAMA ÜNİTELERİ İÇİN BATARYA YÖNETİM SİSTEMİ TASARIMI,” Istanbul University, Istanbul, 2017

[9] Erdinc, O., Vural, B., Uzunoglu, M., "A dynamic lithium-ion battery model considering the effects of temperature and capacity fading," Clean Electrical Power, 2009 International Conference, 2009, s:383-386.

[10] Sabine P, Marion P, Jossen A. Methods for state-of-charge determination and their applications. J Power Sources 2001;96(1):113–20.

[11] Coleman M, Lee CK, Zhu C, Hurley WG. State-of-charge determination from EMF voltage estimation: using impedance, terminal voltage, and current for leadacid and lithium-iron batteries. IEEE Trans Ind Electron 2007;54(5):255–2557. [12] Panasonic lithium ion batteries technical handbook ‘03/‘04.

[12] Venkatasubramanian, V.; Rengaswamy, R.; Yin, K.; Ka, S.N. A review of process fault detection and diagnosis Part I: Quantitative model-based methods. Comput. Chem. Eng

[13] S. Nork and K. Scott, “Passive Balancing Allows All Cells to Appear to Have the Same Capacity.”

[14] L. Technology Corporation, “LTC6803-2/LTC6803-4 - Multicell Battery Stack Monitor.” [Online]. Available: http://www.linear.com/leadfree

[15] M. Khalid, S. S. Sheikh, A. K. Janjua, and H. A. Khalid, “Performance Validation of Electric Vehicle’s Battery Management System under state of charge estimation for lithium-ion Battery,” in 2018 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube), 2018, pp. 1–5. doi: 10.1109/ICECUBE.2018.8610969.

[16] F. Si, Z. Li, X. Long, F. Jiang, and W. Hua, “Research on Estimation of Battery State of Electric Vehicle Battery Management System,” in 2020 IEEE 5th Information Technology and Mechatronics Engineering Conference (ITOEC), 2020, pp. 465–469. doi: 10.1109/ITOEC49072.2020.9141648.

[17] A. Reindl, H. Meier, M. Niemetz, and S. Park, “Decentralized Battery Management System with Customized Hardware Components,” in 19th IEEE Student Conference on Research and Development: Sustainable Engineering and Technology towards Industry Revolution, SCOReD 2021, 2021, pp. 350–355. doi: 10.1109/SCOReD53546.2021.9652737.

[18] https://gazelektrik.com/faydali-bilgiler/elektrik-tuketimi /

[19] https://www.ti.com/

[20] H. A. Gabbar, A. M. Othman, and M. R. Abdussami, “Review of Battery Management Systems (BMS) Development and Industrial Standards,” Technologies (Basel), vol. 9, no. 2, p. 28, Apr. 2021, doi: 10.3390/technologies9020028.

[21] S. Barcellona, L. Cristaldi, M. Faifer, E. Petkovski, L. Piegari, and S. Toscani, “State of health prediction of lithium-ion batteries,” in 2021 IEEE International Workshop on Metrology for Industry 4.0 and IoT, MetroInd 4.0 and IoT 2021 - Proceedings, Jun. 2021, pp. 12–17. doi: 10.1109/MetroInd4.0IoT51437.2021.9488542

[22] H. Wu, “Hardware-in-loop verification of battery management system,” 2011. doi: 10.1109/PESA.2011.5982950

[23] Erdinc, O., Vural, B., Uzunoglu, M., "A dynamic lithium-ion battery model considering the effects of temperature and capacity fading," Clean Electrical Power, 2009 International Conference, 2009, s:383-386.

[24] Shin, D.; Yoon, B.; Yoo, S. Compensation Method for Estimating the State of Charge of Li-Polymer Batteries Using Multiple Long Short-Term Memory Networks Based on the Extended Kalman Filter. Energies 2020, 14, 349.

[25] Andrea, D. Battery Management Systems for Large Lithium-Ion Battery Packs; Artech House: Norwood, MA, USA, 2010.

[26] Copper Development Association. Market Evaluation for Energy Storage in the United States; KEMA, Inc.: Burlington, MA, USA, 2012

[27] Tian, J.; Xiong, R.; Shen, W. State-of-Health estimation based on differential temperature for lithium ion batteries. IEEE Trans. Power Electron. 2020, 35, 10363–10373.

[28] He, J.; Wei, Z.; Bian, X.; Yan, F. State-of-Health Estimation of Lithium-Ion Batteries Using Incremental Capacity Analysis Based on Voltage–Capacity Model. IEEE Trans. Transp. Electrif. 2020, 6, 417–426.

[29] Yang, Y.; Bremner, S.; Menictas, C.; Kay, M. Battery Energy Storage System Size Determination in Renewable Energy Systems: A review. Renew. Sustain. Energy Rev. 2018

[30] Özay, O., Modelling And State Of Charge Estimation For Lithium-Ion Batteries, M.Sc. Thesis Istanbul Technical University, 2

[31] Kivrak, S. & Özer, T. & Oğuz, Y., Design and Implementation of Battery Management System Based on Passive Balancing Method for Electric Vehicles Using STM32f103C8 Microcontroller. 20. 426-433. 10.35414/akufemubid.691456, 2020.

[32] Orecchini, Fabio & Santiangeli, Adriano & Dell'Era, A.. EVs and HEVs Using Lithium-Ion Batteries. Lithium-Ion Batteries: Advances and Applications. 205-248. 2014

[33] Balasingam, Balakumar & Ahmed, Mostafa & Pattipati, Krishna. Battery Management Systems—Challenges and Some Solutions. Energies. 13. 2825. Development of Enhancing Battery Management for Reusing Automotive LithiumIon Battery, 2020.

[34] https://www.tesla.com/ (Ocak, 2024)

[35] Ruslan Koptiev, “ACS712-arduino,” GitHub, 11 Sep. 2018. [Online]. Available: https://github.com/rkoptev/ACS712-arduino

[36] W.-Y. Chang, “The State of Charge Estimating Methods for Battery: A Review,” ISRN Applied Mathematics, vol. 2013, Jul. 2013.

[37] Samsung SDI, “Introduction of INR18650-25R,” Oct. 2013. [Datasheet]. Available: https://www.powerstream.com/p/INR18650-25R-datasheet.pdf.

[38] R. Ford and C. Coulston, Design for Electrical and Computer Engineers, McGraw-Hill, 2007, p. 37

[39] K. W. E. Cheng, B. P. Divakar, H. Wu, K. Ding, and H. F. Ho, “Battery-Management System (BMS) and SOC Development for Electrical Vehicles,” IEEE Trans. on Vehicular Technology, vol. 60, no. 1, pp. 76–88, Jan. 2011.

[40] Buchmann, Isidor, “What Causes Li-Ion to Die?” batteryuniversity.com, Aug. 2017. [Online]. Available: https://batteryuniversity.com/learn/article/bu_808b_what_causes_li_ion_to_die.

[41] C. Mikolajczak, M. Kahn, K. White, and R. T. Long, “Lithium-Ion Fire Hazard Assessment,” Fire Protection Research Foundation, Jul. 2011.