IOT ENABLED WITH ADVANCED LI-ION BATTERY WITH BMS SYSTEM

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINAR **EXTERNAL EXAMINAR**

ABSTRACT

This report provides an overview of the latest developments in Li-ion battery technology and Smart Battery Management Systems (BMS) for IoT-enabled devices. Li-ion batteries have emerged as a popular choice for powering IoT devices due to their high energy density, low self-discharge rate, and long lifespan. The report covers the chemistry of Li-ion batteries, including their structure, cathode, anode, electrolyte, and separator, as well as the principles of charging and discharging, and the factors affecting battery performance and lifespan. The importance of BMS is also discussed, including its definition, functions, types, components, and communication protocols used. The report also explores the various IoT applications of Li-ion batteries and BMS, including smart homes, wearables and health monitors, smart agriculture, industrial IoT, and smart cities. Safety and regulatory standards are also highlighted, including risks associated with Li-ion batteries, safety features, regulatory standards, and certification and testing requirements. Finally, the report concludes with recent developments and future trends in Li-ion battery technology and BMS, including advances in battery chemistry, novel materials for electrodes and electrolytes, integration of renewable energy sources, predictive maintenance and artificial intelligence, and opportunities and challenges for the industry.

The Internet of Things (IoT) is a technology that connects devices and appliances to the internet, enabling them to communicate with each other and with users. One of the most important components of IoT devices is the battery that powers them.

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LIST OF ABBREVATIONS

Abbreviation	Description
BMS	Battery Management System
CAN	Controller Area Network
LIN	Local Interconnect Network
LIB	Lithium-Ion Battery
LCO	Lithium Cobalt Oxide
LMO	Lithium Manganese Oxide
NMC	Nickel Manganese Cobalt
SOC	State Of Charge
SOH	State Of Health
DOD	Depth Of Discharge
EV	Electron Volt
ESP32	Espressif Systems
PWM	Pulse Width Modulation
UART	Universal Asynchoronous Receiver-Transmitter
SPI	Serial Peripheral Device

IDE	Integrated Drive Electronics
LED	Light Emitting Diode
EMF	Electro Magnetic Field
PLC	Programmable Logic Controller
NFPA	National Fire Protection Association

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CHAPTER 1

INTRODUCTION

The Internet of Things (IoT) is a technology that connects devices and appliances to the internet, enabling them to communicate with each other and with users. One of the most important components of IoT devices is the battery that powers them. In recent years, Li-ion batteries have emerged as a popular choice for powering IoT devices due to their high energy density, low self-discharge rate, and long lifespan. In this report, we will explore the latest developments in Li-ion battery technology and Smart Battery Management Systems (BMS) for IoT-enabled devices.

The Internet of Things (IoT) is rapidly changing the way we live and work. With an estimated 50 billion connected devices expected to be in use by 2030, IoT is set to revolutionize various industries, including healthcare, agriculture, transportation, and manufacturing. One of the key challenges facing the IoT industry is powering these devices reliably and efficiently. In recent years, Li-ion batteries have emerged as a popular choice for powering IoT devices due to their high energy density, low self-discharge rate, and long lifespan. Furthermore, Smart Battery Management Systems (BMS) play a critical role in optimizing battery performance and ensuring their safety.

This report provides an overview of the latest developments in Li-ion battery technology and Smart BMS Systems for IoT-enabled devices.

CHAPTER 2

LITERATURE REVIEW

I. In this paper [1] Buqa, Al-Nuaimi, and Khan (2019) provide a comprehensive review of battery management systems (BMS) for lithium-ion battery-based electric vehicles. The authors discuss the functions of BMS, which include monitoring and balancing the cells, protecting the battery from overcharging and overheating, and estimating the state of charge and state of health. They also describe the different types of BMS, such as passive and active balancing, and the communication protocols used, such as CAN and LIN.

II. In this paper [2] Chen et al. (2020) propose an IoT-based battery management system (BMS) for lithium-ion batteries in electric vehicles. The authors discuss the limitations of traditional BMS, which typically only collect and analyze battery data at the individual cell level. The proposed system integrates an IoT platform to collect data from various sensors installed in the battery pack, such as temperature and voltage sensors, and utilizes cloud computing to analyze and optimize battery performance.

III. In this paper [3] Liu, J., Wang, J., Zhang, Y., & Wang, C. (2021) An overview of lithium-ion battery safety concerns and precautions is given in this article. It discusses the basic components of a lithium-ion battery, such as the cathode, anode, electrolyte, and separator materials. The hazards of lithium-ion batteries, including thermal runaway and overcharging, are also covered in the article, along with the safety mechanisms that can be added to batteries to reduce these risks. The article also describes the certification and regulatory requirements that lithium-ion batteries must achieve in order to be safe. Future directions for lithium-ion battery safety research are covered in the article's conclusion, including the creation of novel materials and the incorporation of cutting-edge sensor technology into battery systems.

IV. In this paper [4] Peled, E. (2017) provides a comprehensive overview of the history of lithium-ion batteries. It begins by discussing the early development of lithium-ion batteries in the 1970s and 1980s, including the discovery of intercalation chemistry and the first experimental lithium-ion batteries. The chapter then describes the major technological advancements that led to the commercialization of lithium-ion batteries in the 1990s, such as the development of safer electrolytes and the use of graphite as the anode material.

V. In this paper [5] Scrosati, B. (2019) In this article, Scrosati provides a personal perspective on the development of lithium-ion batteries (LIBs). He describes how the development of LIBs has revolutionized the field of portable electronics, as well as electric vehicles and energy storage systems. Scrosati notes that the key challenge in the development of LIBs has been to find materials that can provide high energy density while maintaining good safety and long cycle life. He describes the different types of cathode materials that have been developed over the years, including those based on cobalt, nickel, and manganese.

CHAPTER3

LI-ION BATTERY

3.1 Overview of IoT and Li-ion Batteries

1.1 provides an overview of IoT and Li-ion batteries. It begins by defining IoT and its potential applications in various industries. The chapter then discusses the advantages of Li-ion batteries for IoT devices, including high energy density, low self-discharge rate, and long lifespan. It also covers the various types of Li-ion batteries, including Lithium Cobalt Oxide (LCO), Lithium Manganese Oxide (LMO), Lithium Iron Phosphate (LFP), Lithium Nickel Cobalt Aluminum Oxide (NCA), and Lithium Nickel Manganese Cobalt Oxide (NMC), and how they compare with other types of batteries.

3.1.1 Definition of IoT

The Internet of Things (IoT) refers to a network of interconnected physical devices, vehicles, appliances, and other items embedded with sensors, software, and connectivity, allowing them to exchange data and communicate with each other and with users. The goal of IoT is to create a seamless and intelligent environment that enhances our daily lives, optimizes various industries, and improves sustainability.

IoT devices can range from simple sensors that measure temperature and humidity to complex systems that control industrial machinery, smart homes, and cities.

3.1.2 Advantages of Li-ion batteries for IoT devices

Li-ion batteries have several advantages that make them a popular choice for IoT devices, including:

1. High energy density: Li-ion batteries have a higher energy density than other types of rechargeable batteries, allowing them to store more energy in a smaller space. This makes them ideal for small IoT devices that require long battery life.

2. Low self-discharge rate: Li-ion batteries have a lower self-discharge rate than other rechargeable batteries, meaning they can retain their charge for longer periods. This is essential for IoT devices that need to operate for extended periods without recharging.

3. Long lifespan: Li-ion batteries have a longer lifespan than other types of batteries, making them a more cost-effective solution for IoT devices. They can withstand a higher number of charge and discharge cycles without significant degradation in performance.

4. Lightweight and compact: Li-ion batteries are lightweight and compact, making them ideal for small IoT devices that require portability and mobility.

5. Quick charging: Li-ion batteries can be charged quickly compared to other rechargeable batteries, allowing IoT devices to be charged faster and with less downtime.

6. Safe and reliable: Li-ion batteries have a lower risk of leakage and explosion compared to other types of batteries, making them a safer and more reliable power source for IoT devices. Additionally, Smart BMS Systems can further improve the safety and reliability of Li-ion batteries by monitoring and controlling battery performance.

3.1.3 Types of Li-ion batteries

There are several types of Li-ion batteries, each with its unique characteristics and performance. The most common types of Li-ion batteries include:

1. Lithium Cobalt Oxide (LCO): LCO batteries are the most common type of Li-ion battery and are widely used in consumer electronics due to their high energy density. They are lightweight, have a long cycle life, and can deliver high power.

2. Lithium Manganese Oxide (LMO): LMO batteries have a lower energy density than LCO batteries but are more stable and safer. They are commonly used in power tools, electric vehicles, and medical devices.

3. Lithium Iron Phosphate (LFP): LFP batteries have a lower energy density than LCO batteries but are more stable and safer. They are commonly used in electric vehicles, solar energy storage, and backup power systems.

4. Lithium Nickel Cobalt Aluminum Oxide (NCA): NCA batteries have a higher energy density than LCO batteries and are commonly used in electric vehicles due to their high power output and long cycle life.

5. Lithium Nickel Manganese Cobalt Oxide (NMC): NMC batteries have a higher energy density than LMO batteries and are commonly used in electric vehicles, power tools, and consumer electronics. They are also known for their long cycle life and thermal stability.

3.1.4 Comparison of Li-ion batteries with other types of batteries

Li-ion batteries have a number of benefits over other battery types, including:

1. Higher energy density: Compared to other battery types like lead-acid and nickel-metal hydride (NiMH) batteries, Li-ion batteries have a higher energy density. Li-ion batteries can therefore store more energy in a more compact and lightweight form factor.

2. Longer cycle life: Compared to other battery types like NiMH and lead-acid batteries, Li-ion batteries offer a longer cycle life. Li-ion batteries can therefore be charged and discharged more frequently before deteriorating and losing their capacity.

3. Lower self-discharge rate: Compared to other battery types like lead-acid and NiMH batteries, Li-ion batteries have a lower self-discharge rate. As a result, Li-ion batteries may maintain their charge for longer when not in use.

4. Faster charging: Compared to other battery types like NiMH and lead-acid batteries, Li-ion batteries can be charged more quickly. Li-ion batteries can now be recharged more quickly, which makes them more practical for use with mobile and Internet of Things (IoT) devices.

5. Safer: Compared to other battery types like lead-acid batteries, which can produce poisonous fumes when overcharged or overheated, lithium-ion batteries are generally thought to be safer. Additionally, corrosion and leakage are less common with lithium-ion batteries.

6. Environmentally friendly: Compared to other battery types, such as lead-acid batteries, which contain hazardous chemicals that can harm the environment when disposed of improperly, lithium-ion batteries are more environmentally friendly. The components of Li-ion batteries can be recycled and used to create new batteries.

3.2 Li-ion Battery Chemistry

Rechargeable batteries known as lithium-ion batteries are made primarily of lithium ions. A Li-ion battery's battery chemistry normally consists of an electrolyte, a negative electrode (anode), and a positive electrode (cathode). The anode is often constructed of graphite or other carbon-based materials, whereas the cathode is typically made of a lithium metal oxide. Typically, an organic solvent is used to dissolve a lithium salt to create the electrolyte.

Lithium ions are removed from the cathode and transported through the electrolyte to the anode during battery charging. Lithium ions are taken up by the anode, which causes a flow of electrons through an external circuit to generate electricity. The procedure is reversed when the battery is depleted, and the lithium ions to the cathode again, generating an electric current.

Lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium nickel cobalt aluminium oxide (NCA), and lithium nickel manganese cobalt oxide (NMC) can all be used as the cathode material. The energy density, power output, and safety of the battery can all be impacted by the cathode material selection. The electrolyte and anode materials that are selected might also impact the battery's performance and security.

Overall, Li-ion battery chemistry is superior to other battery types in that it has a better energy density, a longer cycle life, and a faster charging rate.

3.2.1 Structure of Li-ion batteries

The positive electrode (cathode), negative electrode (anode), electrolyte, separator, and current collectors are some of the parts that make up a lithium-ion battery. These parts are often layered together to form a cell, which is subsequently contained in a battery pack.

A lithium metal oxide, such as lithium cobalt oxide (LCO), lithium manganese oxide (LMO), or lithium nickel cobalt aluminium oxide (NCA), is generally used as the cathode. Typically, graphite or other carbon-based materials are used as the anode. A lithium salt is often dissolved in an organic solvent, such as ethylene carbonate or diethyl carbonate, to create the electrolyte.

The separator, which separates the cathode and anode while allowing lithium ions to pass through, is a thin, porous membrane. Typically, the divider is composed of a such as polyethylene or polypropylene, are polymer materials.

Typically, copper for the anode and aluminium for the cathode are used to make the metal foils that make up the current collectors. The electrical current is distributed throughout the cell via the current collectors, which act as contact points for the external circuit.

The anode and cathode of the Li-ion battery are normally separated from one another by a separator, which is typically stacked in layers. The electrodes are connected to the current collectors, and the entire cell is enclosed in a metal or polymer container.

Performance, energy density, and safety of a Li-ion battery can be impacted by the design and placement of its parts. Li-ion battery technology is always being improved to increase power and decrease weight.

3.2.2 Cathode, anode, electrolyte, and separator

The four essential parts of a Li-ion battery are the cathode, anode, electrolyte, and separator, each of which serves a particular purpose:

1. Cathode: A lithium metal oxide, such as lithium cobalt oxide (LCO), lithium manganese oxide (LMO), or lithium nickel manganese cobalt oxide (NMC), often makes up the cathode, which is the positive electrode in a lithium-ion battery. Lithium ions are removed from the cathode and transported to the anode by the electrolyte during discharge.

2. Anode: Usually made of graphite or other carbon-based materials, the anode is the negative electrode in a Li-ion battery. Lithium ions are taken up by the anode during discharge, which causes an electron flow across an external circuit and the generation of electrical power.

3. Electrolyte: Lithium ions flow between the cathode and anode during charge and discharge cycles through a liquid called an electrolyte. A lithium salt is usually dissolved in an organic solvent, like ethylene carbonate or diethyl carbonate, to create this substance.

4. Separator: Lithium ions can travel through the separator, which is a thin, porous membrane that divides the cathode and anode. Typically, a polymer substance, such polyethylene or polypropylene, is used to create the separator.

The material selection for each of these components has an impact on the Li-ion battery's performance, energy density, and safety. Li-ion battery design is continually changing to address safety issues, lower costs, and enhance performance. For instance, new electrolyte and separator materials are being developed to improve safety and lower the risk of thermal runaway, as well as novel cathode materials to increase energy density.

3.2.3 Principles of charging and discharging

Li-ion batteries operate primarily through two processes: charging and discharging. These procedures' guiding concepts are as follows:

1. Charging: Lithium ions are moved from the positive electrode (cathode) back to the negative electrode (anode) during the charging process using an external power source. This procedure, known as recharging, involves the transfer of electrons from the power source to the battery via the external circuit. Lithium ions are stored in the graphite material when they return to the anode, which results in a potential difference between the two electrodes.

2. Discharging: When a battery is discharging, lithium ions that have been stored flow from the anode to the cathode, creating an electric current that can be utilised to power devices. The graphite material releases electrons as lithium ions exit the anode; these electrons travel via the external circuit and are taken up by the cathode, resulting in a potential difference between the two electrodes.

Electrochemical reactions that take place at the electrodes and in the electrolyte control the charging and discharging processes. Lithium ions and electrons are moved during these reactions, and chemical compounds are formed and broken down.

A smart battery management system (BMS) can be used to regulate the rates of Li-ion battery charging and discharging. In order to maximise battery performance and lengthen its lifespan, the BMS can track the state of charge (SOC) and state of health (SOH) of the battery and adjust the charging and discharging rates.

3.2.4 Factors affecting battery performance and lifespan

The performance and lifespan of a Li-ion battery can be influenced by several factors, including:

1. Temperature: A battery's ability to function and last longer can be compromised by high temperatures which hasten the battery's deterioration. Low temperatures, on the other hand, may result in a decrease in capacity and an increase in internal resistance, which may impact the battery's capacity to generate power.

2. The percentage of the battery's capacity that has been consumed is known as the depth of discharge, or DOD. The battery's longevity may be negatively impacted by deep discharge cycles, which decrease its total capacity and raise internal resistance. It is suggested to keep a Li-ion battery's DOD at about 80% of its maximum capacity in order to extend its lifespan.

3. Charging rate: A Li-ion battery's performance and longevity can be impacted by charging it too quickly or too slowly. Undercharging can lower the battery's total capacity, while overcharging can heat up the battery and harm its internal parts. The battery's performance and lifespan can be improved by charging it at a reasonable rate.

4. Storage: Long-term Li-ion battery storage without sufficient maintenance will shorten the battery's lifespan. The battery needs to be kept at a temperature of roughly 50 percent of its maximum charging capacity. Inaction may result in a decrease in overall capability and an increase in internal resistance.

5. Component quality: The battery's overall performance and lifespan can be significantly impacted by the materials used in its construction. A longer lifespan and better overall performance can come from high-quality components, whereas a shorter lifespan and worse performance can come from low-quality components.

6. working conditions: The battery's overall lifespan and performance can be impacted by its working circumstances, such as the type of application and usage frequency. Batteries used frequently or in high-intensity applications may have a shorter lifespan than batteries used sparingly or in low-intensity applications.

It is crucial to keep these things in mind while developing and utilising a Li-ion battery in order to maximise its performance and lifespan. The battery's longevity and general performance can be increased with proper maintenance, charging, and storage procedures.

CHAPTER 4

DEVELOPMENT OF THE PROJECT WORK

4.1 Smart Battery Management Systems

4.1.1 Functions of BMS

An electrical device called a Smart Battery Management System (BMS) is used to control and track the charging and draining of Li-ion batteries. The fundamental job of a BMS is to make sure that the battery is charged and discharged safely and effectively, hence maximising performance and extending battery life. Some of the key features of a BMS include:

1. Cell balancing: To make sure that battery cells are charged and discharged equally, a BMS can track and balance the voltage of each individual cell. This aids in preventing each cell from overcharging or overdischarging, which can harm the battery.

2. Monitoring of the battery's State of Charge (SOC): A BMS can keep track of the battery's SOC and provide precise data on the amount of charge left in the battery. This aids in preventing the battery from being overdischarged, which can shorten its lifespan and harm it.

3. Temperature Monitioring: Monitoring the battery's temperature will help to ensure that the battery is charged and discharged within safe temperature ranges. Low temperatures can affect the battery's capacity and performance, while high temperatures can harm the battery and shorten its lifespan.

4. Protection from overvoltage and undervoltage: A BMS can safeguard the battery against these circumstances, which might harm it or shorten its lifespan. In the case of an overvoltage or undervoltage condition, the BMS has the ability to cut the battery off from the load or charging source.

5. Current restriction: A BMS can restrict the battery's charging and discharging current, ensuring that it is done so safely and effectively. By doing this, the battery's lifespan is increased and damage is prevented.

6. Monitoring of the battery's State of Health (SOH): A BMS can keep track of the battery's SOH and provide data on its general performance and health. This enables prompt maintenance or battery replacement by assisting in the identification of any faults or problems with the battery.

Overall, a Smart Battery Management System is a crucial part of a Li-ion battery system, assisting in ensuring effective and safe operation as well as extending battery life and improving performance.

4.1.2 Definition and importance of BMS

An electrical device called a battery management system (BMS) controls and monitors the charging and discharging of batteries to guarantee the safe and effective operation of the batteries. Lithium-ion (Li-ion) batteries, which are frequently utilised in portable gadgets, electric cars, and renewable energy systems, require a BMS.

A BMS's capacity to enhance battery performance, increase battery life, and guarantee safe operation makes it crucial. A BMS typically has a number of characteristics, including cell balancing, temperature monitoring, overvoltage and undervoltage protection, state of charge (SOC) and state of health (SOH) monitoring, as well as current limiting.

Users may decide when the battery needs to be recharged thanks to SOC monitoring, which offers information on the battery's remaining charge capacity. SOH monitoring gives customers information on the battery's general health and performance, enabling them to spot any abnormalities or concerns with the battery. Cell balancing makes sure that each battery cell is charged and drained equally, protecting the battery from overcharging or overdischarging of particular cells.

The battery is charged and discharged within safe temperature ranges thanks to temperature monitoring. Protection from overvoltage and undervoltage stops the battery from being overcharged or overdischarged, which can shorten the battery's lifespan or cause damage. By using current limiting, the battery is charged and drained safely and effective rate, shielding the battery from harm and extending its life.

In conclusion, a BMS is an important part of a battery system, particularly for Li-ion batteries. It optimises the battery's performance, increases its longevity, and makes sure it operates safely and effectively.

4.1.3 Types of BMS

Battery Management Systems (BMS) come in a variety of varieties that are grouped according to their design, complexity, and use. Among the popular BMS varieties are:

1. A passive BMS is an easy-to-use, inexpensive device that balances the voltage of each battery cell using resistors or other passive components. A passive BMS is typically employed in low-power applications and does not actively regulate the charging and discharging of the battery.

2. Active BMS: An advanced system that actively regulates the charging and draining of the battery is known as an active BMS. To balance the cells and safeguard the battery from overvoltage, undervoltage, and overcurrent situations, it uses active components like MOSFETs or relays. High-power

applications like electric cars and grid-connected energy storage systems frequently employ active BMSs.

3. Hybrid BMS: A hybrid BMS combines the advantages of passive and active BMS, offering a dependable and affordable method of managing batteries. To maximise battery performance and lifespan, it uses passive balancing for low-power cells and active balancing for high-power cells.

4. Integrated BMS: An integrated BMS is a whole battery management system that has all the required parts and features, including temperature monitoring, cell balancing, SOC monitoring, and communication interfaces. It is made to be quickly and simply integrated with the battery pack and other systems, giving battery management a plug-and-play option.

5. Distributed BMS: A distributed BMS is a decentralised system that employs a number of BMS modules to control the battery pack's cells or modules. Each BMS module keeps track of and balances a smaller group of cells, and it interacts with other modules to guarantee the battery pack operates safely and effectively. In large-scale energy storage systems, a distributed BMS offers a flexible and scalable approach for battery management.

In general, the unique application, battery chemistry, and power needs determine the type of BMS that is chosen.

4.2 Components of BMS

COMPONENTS :

4.2.1 ❖ 18650 Li-ion cell

4.2.2 ❖ ESP32

4.2.3 ❖ 100k NTC 3950 THERMISTOR

4.2.4 ❖ RELAY MODULE

4.2.5 ❖ LM2596 DC-DC BUCK CONVERTOR

4.2.1 18650 Li-ion cell

Figure1.1 Lithium-ion battery pack

1. Lithium-ion batteries are a family of rechargeable battery types in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging.

2. Li-ion batteries can use several different materials as electrodes. The most common combination is that of lithium cobalt oxide (cathode) and graphite (anode), which is most commonly found in portable electronic devices such as cell phones and laptops.

3. In this work, the battery pack is made from a group of small-sized Li-ion cells. The small-sized cells are readily available and can be used to build any custom-capacity battery pack.

4. Li-ion is proven to have a much higher charge density. For the same capacity, Li-ion will be much smaller than its lead-acid counterpart. It requires low maintenance unlike nickel-based and lead-acid batteries. More importantly, it is eco-friendly and less harmful than most other batteries.

BATTERY RATINGS

The battery pack is made from multiple cells in series and parallel combinations to obtain the required capacity. The cell chemistry chosen is Li-ion and the cell size is 18650. The cells must be of EV grade and should have a minimum of 2500mah. 16.8 voltage standard is given . The Ah rating of the battery pack is 2.55Ah.

Figure 1.2 Lithium-ion cell

Battery pack Calculation

Li-ion Cell rating

PARAMETER	RATING
Nominal Voltage	3.7 V
Nominal Capacity	2550mah
Charging Current	1C
Maximum Discharge Current	3C

Table 1.3 Li-ion rating

Measuring cell voltage

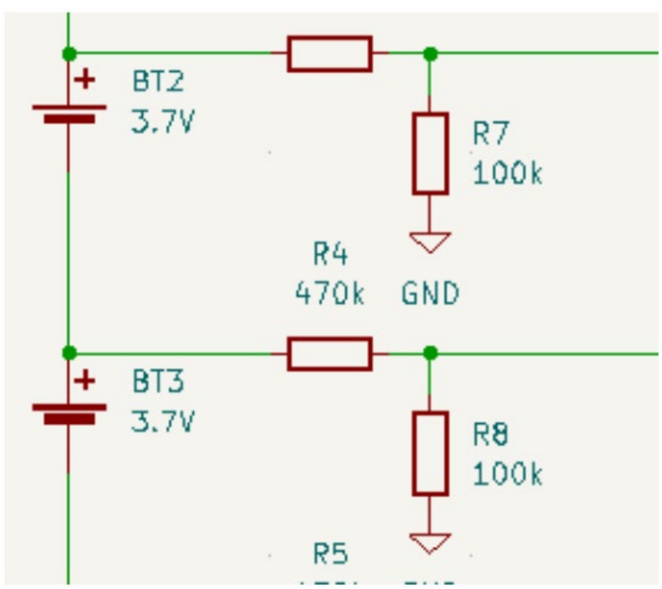


Figure 1.4 Cell voltage measurement circuit

Any Battery Management System (BMS) that measures cell voltage performs an essential task since it offers vital details about the charge and health of each battery cell in the pack. Depending on the type of BMS and the quantity of cells in the battery pack, there are many ways to measure cell voltage.

Using a voltage divider circuit, which comprises of two resistors connected in series, is one of the most popular ways to measure cell voltage. The positive terminal of the cell is linked to one resistor, and the negative terminal is connected to the other resistor. The BMS circuitry uses an analog-to-digital converter to measure the voltage across the second resistor, which is proportional to the cell voltage.

Utilising a specialised voltage monitoring IC, which is intended to measure the voltage of each cell in the pack and transmit the information to the BMS controller, is another way for determining cell voltage. The voltage monitoring IC measures cell voltage with extreme accuracy and precision and may either be used alone or integrated into the BMS controller.

The BMS must balance the batteries in addition to measuring the cell voltage to make sure they are all charged to the same level. A balancing circuit, which is connected across the pack's higher voltage cells and dissipates the excess charge as heat, is often used to do this. Depending on the situation, the balancing circuit may be passive or active.

Overall, assessing cell voltage is a crucial part of any BMS because it enables the system to keep track of the battery pack's health and level of charge, as well as to prevent situations where the voltage is too high, too low, or too charged, which could harm the cells or shorten their lifespan.

4.2.2 ESP32

Figure 1.5 ESP32

System-on-chip (SoC) microcontroller ESP32 is a low-cost, low-power device made for Internet of Things (IoT) applications. It is produced by Espressif Systems and is the popular ESP8266 microcontroller's replacement. A dual-core 32-bit Xtensa LX6 CPU powers the ESP32, which also has a variety of digital and analogue inputs and outputs, built-in Wi-Fi, and Bluetooth connectivity.

The ESP32's adaptability and flexibility, which make it suited for a variety of IoT applications, is one of its main features. The ESP32 can connect to the internet and other devices thanks to inbuilt Wi-Fi and Bluetooth connections, and its dual-core CPU offers outstanding performance and efficiency for challenging workloads and real-time applications.

Additionally, the ESP32 has a number of capabilities and add-ons that make it simple to connect to sensors, actuators, and other devices. These include support for a variety of sensors, such as temperature, humidity, and motion sensors, as well as digital and analogue inputs and outputs, pulse-width modulation (PWM), serial communication (UART, SPI, and I2C).

The Arduino IDE, the MicroPython programming language, and the ESP-IDF software development framework are just a few of the development tools and software platforms that the ESP32 is supported by in addition to its physical features. As a result, without substantial hardware or software experience, developers may quickly prototype and deploy IoT applications with the ESP32.

The ESP32 is an effective and adaptable microcontroller that provides a selection of capabilities and connectivity choices for Internet of Things applications. Both amateur and professional developers favour it because of its affordability, efficiency, and usability.

4.2.3 100k NTC 3950 THERMISTOR

Figure 1.6 100k NTC 3950 Thermister

A typical type of temperature sensor used in many industrial and electronic applications is the 100k NTC 3950 thermistor. It is based on the thermistor principle, which describes a class of resistor that adjusts its resistance value in reaction to temperature variations.

The 100k figure represents the thermistor's nominal resistance at a reference temperature of 25 Celsius (77 Fahrenheit). In contrast to a PTC (Positive Temperature Coefficient) thermistor, the NTC (Negative Temperature Coefficient) implies that the resistance of the thermistor lowers as the temperature rises.

The thermistor's B-value, which measures how sensitive it is to temperature, is represented by the number 3950. The thermistor's resistance changes throughout a temperature range of 25 to 50 degrees Celsius (77 to 122 degrees Fahrenheit) are represented by the B-value. A thermistor that changes its resistance more quickly in response to temperature variations has a greater B-value.

Thermostats, HVAC systems, and industrial process control are just a few examples of applications where the 100k NTC 3950 thermistor is frequently utilised in temperature sensing and control. It is also commonly used in applications for 3D printing to keep track of the hotend and bed temperatures and to give precise temperature control for printing.

The 100k NTC 3950 thermistor is an all-purpose temperature sensor that is dependable and versatile and may be used in a variety of applications to detect temperatures precisely. It is a popular option for temperature monitoring and control in a variety of industries and applications due to its compact size, low cost, and great sensitivity.

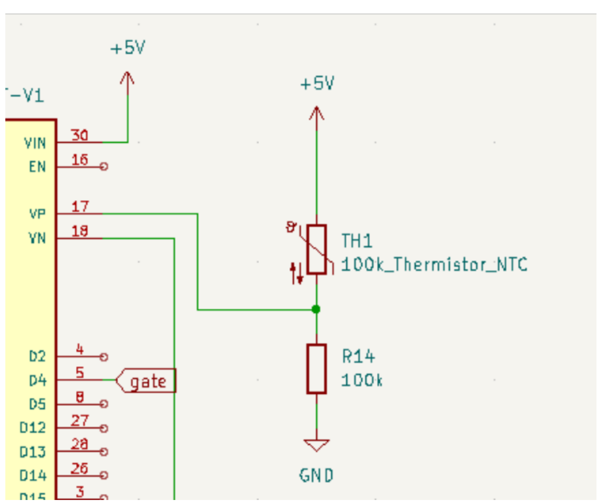


Figure 1.7 Tempertaure Measurement circuit

4.2.4 RELAY MODULE

Figure 1.8 Relay module

An electronic device called a relay module is used to use a low-power signal to manage high-power electrical loads. It is made up of a relay, an electrically powered switch used to regulate current flow in a circuit, and a control circuit, which generates the low-power signal required to turn on the relay.

In automation and control systems, relay modules are frequently used to switch high-power loads like motors, lights, and heaters. They can also be used to operate other appliances like fans, pumps, and alarms.

Depending on the requirements of the particular application, relay modules are available in a number of configurations and sizes. While some relay modules just have one relay, others could have several relays that can each be operated separately. Input and output protection, LED indicators, and built-in diodes to guard against back EMF are other features that they might include.

Relay modules' ability to switch high-power loads with a low-power signal is one of their benefits. They can thus be utilised with a variety of control systems, such as microcontrollers, PLCs, and other digital control devices. Relay modules are dependable and tough, and they can survive extreme temperatures and other challenging operating circumstances.

Relay modules are a flexible and dependable method for managing high-power electrical loads in a variety of applications. They are an effective and safe means to switch electrical circuits, and automation and control systems can readily incorporate them.

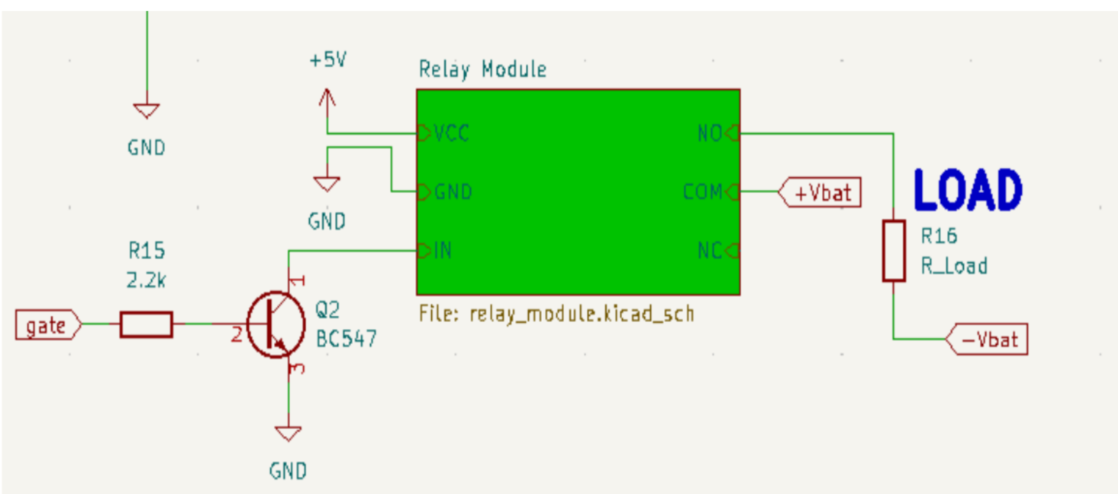


Figure 1.9 Protection using relay module

Integrated Cell Balancing Circuit Diagram

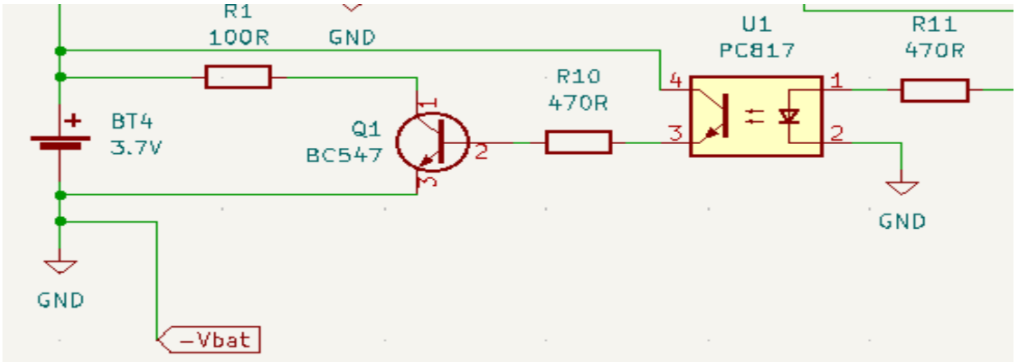
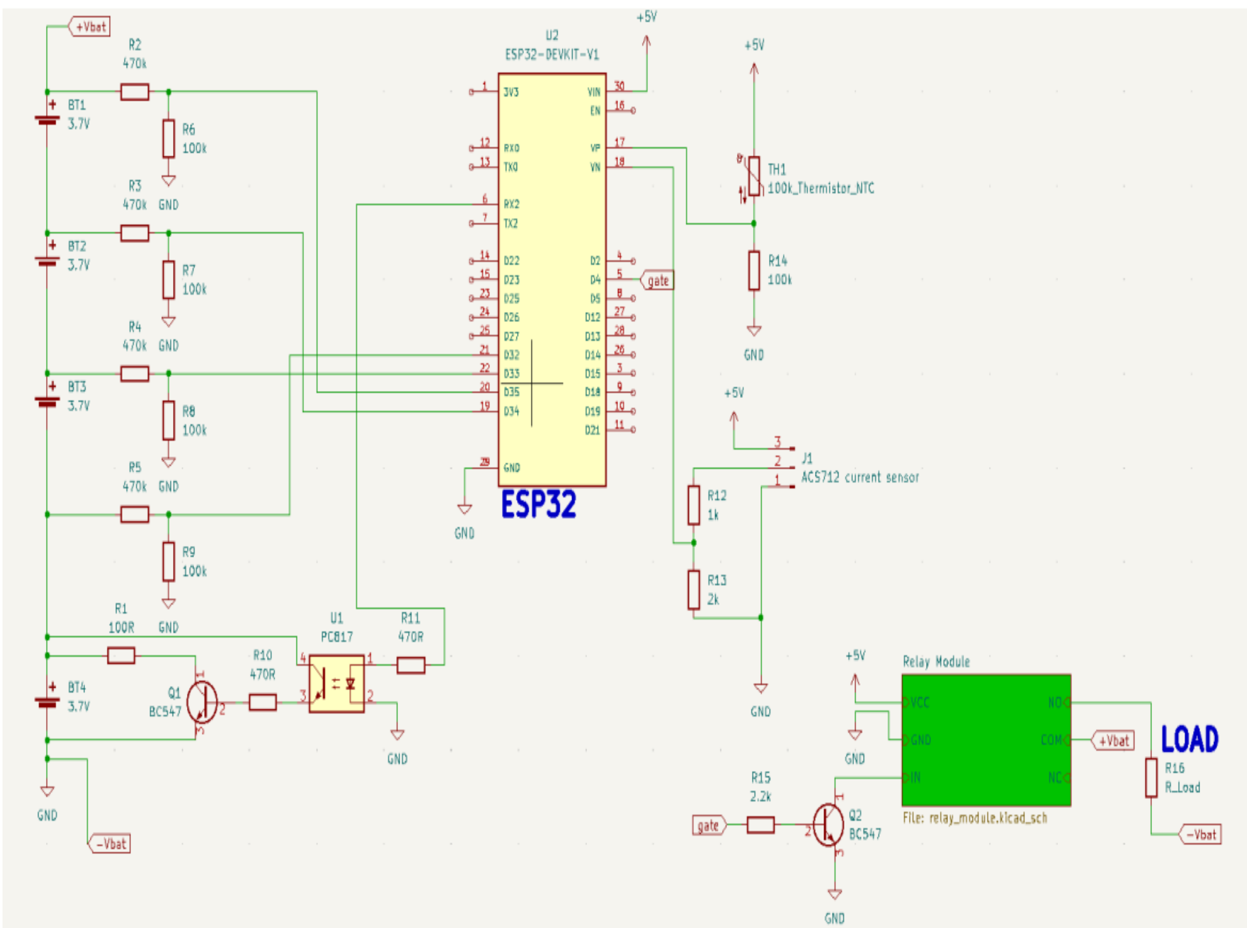


Figure 2.0 Integrated cell balancing circuit

CIRCUIT DIAGRAM FOR BMS

Figure 2.1 Circuit Diagram for BMS



4.2.5 LM2596 DC-DC BUCK CONVERTOR

Figure 2.2 LM2596 DC-DC BUCK CONVERTOR

A common step-down voltage regulator module used in electrical circuits to convert a higher voltage to a lower value is the LM2596 DC-DC buck converter. To achieve high efficiency and consistent output voltage, it makes advantage of the pulse-width modulation (PWM) concept.

The LM2596 module is made up of an integrated circuit (IC) that manages the power MOSFET's switching, which controls the output voltage. The output voltage is drawn from the module's output terminals, while the input voltage is connected to the module's input terminals. The output voltage can be adjusted using a potentiometer using the LM2596's adjustable voltage regulator, which is also included.

The LM2596 DC-DC buck converter's excellent efficiency, which can reach 92%, is one of its key advantages. This is accomplished by employing a switching regulator circuit, which is more effective than linear regulators since it minimises the amount of power wasted as heat. The LM2596 is excellent for a number of applications since it can handle a wide range of input voltages.

The LM2596 module is frequently used in electrical applications that need regulated DC voltage, like battery chargers, LED lighting systems, and portable electronics. It can be used to transform high-voltage inputs to lower voltages for electronic control systems in automotive and industrial applications.

All things considered, the LM2596 DC-DC buck converter is a flexible and dependable voltage regulator module that offers reliable and efficient power conversion for a variety of electronic applications. Electronics fans and experts alike appreciate it because of its excellent efficiency, adjustable voltage output, and wide input voltage range.

4.3 Communication protocols used in BMS

Communication protocols are an essential component of battery management systems (BMS) as they allow for the exchange of information between different components of the system. There are several communication protocols used in BMS, including:

CAN Bus (Controller Area Network): This is a popular communication protocol used in automotive and industrial applications. It enables rapid communication between the battery management unit, battery cells, and various control units, among other system components.

System Management Bus (SMBus): This two-wire communication protocol is frequently used in BMS for applications including charging and monitoring. It enables data transfer between the BMS and other system parts, including the charger or the battery cells.

I2C (Inter-Integrated Circuit) is a two-wire protocol for low-speed data transfer between BMS parts like voltage sensors and temperature sensors.

Modbus is a serial communication technology that the BMS uses to send data between its many parts. Applications for industrial and process control frequently use it.

Ethernet is a communication protocol that is frequently used in computer networks for data transfer. Applications for remote monitoring and control are also employed in BMS.

Bluetooth and Wi-Fi are two popular wireless communication protocols for BMS applications that provide remote battery system monitoring and control.

4.4 IoT Applications of Li-ion Batteries and BMS

Li-ion batteries and BMS have many applications in IoT systems. Some of the most common applications include:

1. Smart homes: Li-ion batteries and BMS can be used in smart home systems to provide backup power during power outages. They can also be used to store excess energy generated by solar panels for later use.

2. Wearable devices: Li-ion batteries and BMS are commonly used in wearable devices such as smartwatches and fitness trackers. They provide the required power for these devices and ensure their safe and reliable operation.

3. Smart agriculture: Li-ion batteries and BMS can be used in IoT-based agricultural systems to power sensors and other devices. They can also be used to store energy generated by renewable energy sources such as wind or solar.

4. Industrial automation: Li-ion batteries and BMS are commonly used in industrial automation systems to power sensors, actuators, and other devices. They provide reliable and efficient power for these systems and can help to reduce downtime.

5. Smart transportation: Li-ion batteries and BMS are widely used in electric vehicles (EVs) and hybrid electric vehicles (HEVs) to power the motor and other systems. They are also used in IoT-based transportation systems to power sensors and other devices.

6. Energy storage systems: Li-ion batteries and BMS are commonly used in energy storage systems to store excess energy generated by renewable energy sources. They can be used to provide backup power during power outages or to provide power during peak demand periods.

7. Medical devices: Li-ion batteries and BMS are used in various medical devices such as portable defibrillators, insulin pumps, and patient monitoring systems. They provide the required power for these devices and ensure their safe and reliable operation.

In conclusion, Li-ion batteries and BMS have a wide range of applications in IoT systems, and their use is expected to increase in the coming years as the demand for IoT-based systems continues to grow.

4.5 Battery Safety and Regulatory Standards

Battery safety and regulatory standards are essential for ensuring that Li-ion batteries are designed, manufactured, and operated in a safe and reliable manner. The following are some of the most important battery safety and regulatory standards:

1. UN 38.3: This is a global standard for the transportation of lithium batteries. It specifies the testing requirements for lithium batteries to ensure their safe transportation by air, sea, or road.

2. IEC 62133: This is a safety standard for secondary cells and batteries containing alkaline or other non-acid electrolytes. It specifies the requirements and tests for the safety of lithium batteries.

3. UL 1642: This is a safety standard for lithium batteries used in portable electronic devices. It covers the construction, performance, and testing requirements for lithium batteries.

4. IEC 60086: This is a series of standards that covers primary batteries (non-rechargeable) and secondary batteries (rechargeable) for use in portable applications.

5. ISO 26262: This is a functional safety standard for road vehicles. It covers the development and testing of safety-critical systems, including those that use lithium batteries.

6. IEEE 1725: This is a safety standard for lithium batteries used in portable electronic devices. It covers the design, construction, and testing requirements for lithium batteries.

7. NFPA 70: This is the National Electrical Code (NEC) in the United States, which covers the installation and use of electrical systems and equipment, including batteries.

These standards are developed by international organizations, such as the International Electrotechnical Commission (IEC), and national organizations, such as the National Fire Protection Association (NFPA) in the United States. Compliance with these standards is necessary for the safe design, manufacturing, and use of Li-ion batteries in various applications, including portable electronic devices, electric vehicles, and energy storage systems.

4.5.1 Risks associated with Li-ion batteries

Although Li-ion batteries offer several advantages over other types of batteries, there are also some risks associated with their use. Some of the risks include:

1. Thermal runaway: Li-ion batteries can undergo a chemical reaction that leads to overheating, which can cause a fire or explosion. This is known as thermal runaway.

2. Overcharging: Overcharging can cause the Li-ion battery to overheat, which can lead to thermal runaway.

3. Mechanical damage: Damage to the battery, such as puncturing or crushing, can also cause the battery to overheat and lead to thermal runaway.

4. Short circuit: A short circuit can occur if the positive and negative terminals of the battery come into contact with each other, which can cause the battery to overheat and lead to thermal runaway.

5. Aging: Over time, the performance of Li-ion batteries can degrade, which can affect their capacity and safety.

To mitigate these risks, manufacturers implement several safety features such as overcharge protection, over-discharge protection, and short circuit protection in BMS. Also, users should follow the manufacturer's recommendations for proper handling, charging, and storage of Li-ion batteries to prevent accidents.

4.5.2 Safety features in Li-ion batteries

Manufacturers of Li-ion batteries implement several safety features to prevent accidents and ensure the safe use of their products. Some of the safety features in Li-ion batteries include:

1. Overcharge protection: This feature prevents the battery from being charged beyond its maximum voltage, which can cause the battery to overheat and lead to thermal runaway.

2. Over-discharge protection: This feature prevents the battery from being discharged below its minimum voltage, which can damage the battery and affect its performance.

3. Short circuit protection: This feature prevents a short circuit from occurring by disconnecting the battery from the load when a short circuit is detected.

4. Temperature protection: This feature prevents the battery from overheating by disconnecting it from the load when the temperature exceeds a certain threshold.

5. Cell balancing: This feature ensures that all the cells in the battery are charged and discharged evenly, which can extend the life of the battery and improve its performance.

6. Pressure relief valve: This feature is designed to release excess pressure that may build up inside the battery during charging or discharging.

7. Gas vent: This feature allows the release of gas that may build up inside the battery during charging or discharging.

These safety features are usually integrated into the BMS of the Li-ion battery and are designed to prevent accidents and ensure the safe use of Li-ion batteries.

4.5.3 Certification and testing requirements

Certification and testing requirements are necessary to ensure that Li-ion batteries and their associated BMS comply with safety standards and regulations. Some of the key certification and testing requirements include:

1. UN 38.3: This certification is required for the transportation of Li-ion batteries by air, sea, or land. The certification ensures that the batteries have passed a series of tests related to safety, including vibration, shock, and impact resistance, and have been proven to be stable and safe for transportation.

2. IEC 62133: This certification is required for Li-ion batteries used in portable electronic devices. The certification ensures that the batteries have passed a series of tests related to safety, including temperature cycling, short circuit, and overcharge testing.

3. UL 1642: This certification is required for Li-ion batteries used in stationary applications, such as renewable energy storage systems. The certification ensures that the batteries have been tested for safety and performance in stationary applications.

4. IEC 62619: This certification is required for the safety of BMS used in Li-ion batteries. The certification ensures that the BMS have been tested for safety

and performance, including the ability to detect faults and prevent thermal runaway.

5. IEEE 1725: This certification is required for Li-ion batteries used in portable electronic devices. The certification ensures that the batteries have been tested for safety and performance, including the ability to withstand mechanical stress, short circuit, and overcharge.

Testing requirements include environmental tests, performance tests, safety tests, and abuse tests. These tests are conducted to ensure that the Li-ion batteries and BMS meet safety standards and regulatory requirements, and are safe for use in different applications.

CHAPTER 5

SOFTWARE DESIGN

5.1 ESP32 CODE:

```
#include <Arduino.h>
#include <ArduinoJson.h>
#include <WiFi.h>
#include <AsyncTCP.h>
#include <ESPAsyncWebServer.h>
#include <movingAvgFloat.h>

#define DEBUG_ERR true
#define DEBUG_ERR_SERIAL \
  if (DEBUG_ERR) Serial

#define DEBUG_WARN true
#define DEBUG_WARN_SERIAL \
  if (DEBUG_WARN) Serial

#define DEBUG_INFO true
#define DEBUG_INFO_SERIAL \
  if (DEBUG_INFO) Serial
```

```
//VP-36, VN-89
#define THERMISTOR_PIN 36
#define RELAY_PIN 4

//thermistor
#define RT0 100000   // Ω
#define B 3977      // K
#define VCC 5    //Supply voltage
#define R 100000  //R=100KΩ

float v_bat;
float v_adc[4];
float v_cell[4];
movingAvgFloat v_avg[] = { movingAvgFloat(10), movingAvgFloat(10),
movingAvgFloat(10), movingAvgFloat(10) };
movingAvgFloat temp_avg(10);
float temp;

// Replace with your network credentials
const char *ssid = "ESP32 SMART BMS";
const char *password = "smartbms";
const char *host = "esp32";

AsyncWebServer server(80);
```

```
const char* PARAM_INPUT_1 = "mosfetState";
bool mosfetState = false;

void handleNotFound(AsyncWebServerRequest *request);
float getTemperature();

void setup() {
  // pinMode(32, INPUT);
  // pinMode(33, INPUT);
  // pinMode(34, INPUT);
  // pinMode(35, INPUT);
  Serial.begin(115200);
  pinMode(RELAY_PIN, OUTPUT);

  for(int i = 0; i < 4; i++) {
    v_avg[i].begin();
  }

  WiFi.softAP(ssid, password);
  IPAddress IP = WiFi.softAPIP();
  Serial.print("AP IP address: ");
  Serial.println(IP);

  server.on("/hello", HTTP_GET, [](AsyncWebServerRequest *request)
            { request->send(200, "text/plain", "Hello World" );});
```

```
  server.on("/stats", HTTP_GET, [](AsyncWebServerRequest *request){
    AsyncResponseStream *response = request->beginResponseStream("application/json");
    DynamicJsonDocument doc(512);
    doc["v_bat"] = v_bat;
    doc["soc"] = ( v_bat/(4.2 * 4) ) * 100;
    doc["temp"] = temp;
    doc["mosfetState"] = mosfetState;
    JsonArray doc_v_cell = doc.createNestedArray("v_cell");
    for (int i = 0; i < 4; i++) {
      doc_v_cell.add(v_cell[i]);
    }
    Serial.println("Received: /stats");
    serializeJson(doc, Serial);
    serializeJson(doc, *response);
    request->send(response);
  });

  server.on("/update", HTTP_GET, [] (AsyncWebServerRequest *request) {

    String inputMessage1;
    // GET input1 value on <ESP_IP>/update?output=<inputMessage1>&state=<inputMessage2>
    if (request->hasParam(PARAM_INPUT_1)) {
      inputMessage1 = request->getParam(PARAM_INPUT_1)->value();
```

```
    digitalWrite(RELAY_PIN, inputMessage1.toInt());
    mosfetState = inputMessage1.toInt();
  }
  else {
    inputMessage1 = "No message sent";
  }
  Serial.print("MOSFET: ");
  Serial.print(" - Set to: ");
  Serial.println(inputMessage1);
  request->send(200, "text/plain", "OK");
});

server.onNotFound(handleNotFound);

DefaultHeaders::Instance().addHeader("Access-Control-Allow-Origin", "*");
DefaultHeaders::Instance().addHeader("Access-Control-Allow-Methods", "GET,
POST, PUT");
DefaultHeaders::Instance().addHeader("Access-Control-Allow-Headers",
"Content-Type");
server.begin();

DEBUG_INFO_SERIAL.println("Setup End");
}

void handleNotFound(AsyncWebServerRequest *request) {
if (request->method() == HTTP_OPTIONS) {
```

```
    request->send(200);
  } else {
    request->send(404, "application/json", "{\"message\":\"Not found\"}");
  }
}

void loop() {
  // put your main code here, to run repeatedly:
  for(int pin=32, i = 0; i<4; pin++, i++) {
    float v = analogReadMilliVolts(pin) / 1000.0;
    // float v = analogRead(pin);
    // v = ((v*3.3) / 4095.00);
    v_adc[i] = v * (470+100)/100;
    v_avg[i].reading(v_adc[i]);
  }
  v_bat = v_avg[3].getAvg();
  v_cell[0] = v_avg[0].getAvg();
  v_cell[1] = v_avg[1].getAvg() - v_avg[0].getAvg();
  v_cell[2] = v_avg[2].getAvg() - v_avg[1].getAvg();
  v_cell[3] = v_avg[3].getAvg() - v_avg[2].getAvg();

  // v_bat = v_cell[3];
  // v_cell[0] = v_cell[0];
  // v_cell[1] = v_cell[1] - v_cell[0];
  // v_cell[2] = v_cell[2] - v_cell[1];
```

```
  // v_cell[3] = v_cell[3] - v_cell[2];

  temp = getTemperature();
  DEBUG_INFO_SERIAL.print ("Temperature: ");
  DEBUG_INFO_SERIAL.println (temp);

  if(DEBUG_INFO){
    DEBUG_INFO_SERIAL.println("v_adc[]:");
    for(int i=0; i<4;i++){
      DEBUG_INFO_SERIAL.println(v_adc[i]);
    }
    DEBUG_INFO_SERIAL.println();
  }

  delay(1000);
}

float getTemperature() {
  float RT, VR, ln, TX, T0, VRT;
  T0 = 25 + 273.15;

  VR = analogReadMilliVolts(THERMISTOR_PIN) / 1000;
  // VRT = analogRead(THERMISTOR_PIN);
  // VR = ((3.3 / 4095.00) * VRT);
```

```
  VRT = VCC - VR;      //Conversion to voltage
  RT = VRT / (VR / R);               //Resistance of RT

  ln = log(RT / RT0);
  TX = (1 / ((ln / B) + (1 / T0))); //Temperature from thermistor

  TX = TX - 273.15;                //Conversion to Celsius
  if(TX > 0) {
    return TX;
  }
  else {
    return 0.01;
  }
}
```

Language: C++

Framework : PlatformIO/Arduino

Lines: 181 lines of code

FLOWCHART

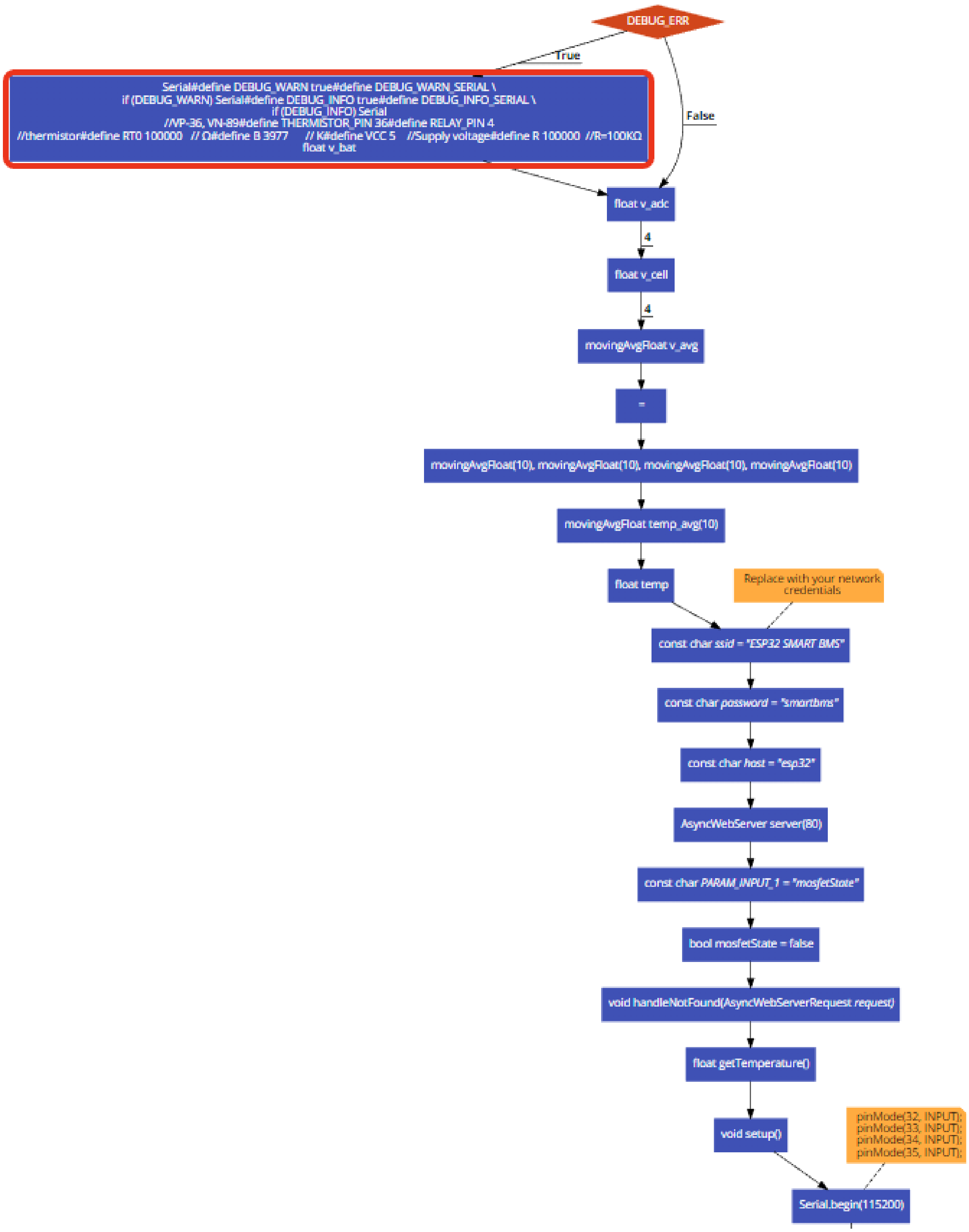


Figure 2.3 Flow Chart

5.2 Andriod app code:

```
import 'package:flutter/material.dart';
import 'package:flutter_riverpod/flutter_riverpod.dart';
import 'package:go_router/go_router.dart';

import './presentation/dashboard_page.dart';
import './presentation/settings_page.dart';

final GlobalKey<NavigatorState> _rootNavigatorKey =
    GlobalKey<NavigatorState>(debugLabel: 'root');
final GlobalKey<NavigatorState> _shellNavigatorKey =
    GlobalKey<NavigatorState>(debugLabel: 'shell');

final _router = GoRouter(
  navigatorKey: _rootNavigatorKey,
  initialLocation: '/',
  routes: [
    ShellRoute(
        navigatorKey: _shellNavigatorKey,
        builder: (context, state, child) {
          return ScaffoldWithNavBar(child: child);
        },
        routes: [
          GoRoute(
```

```
        path: '/',
        builder: (context, state) => const MyHomePage(
            title: 'dashboard',
          ),
        routes: [
         GoRoute(
            path: 'settings',
                builder: (context, state) => const SettingsPage())
         ]),
])
],
);

class ScaffoldWithNavBar extends StatelessWidget {
/// Constructs an [ScaffoldWithNavBar].
const ScaffoldWithNavBar({
required this.child,
super.key,
});

/// The widget to display in the body of the Scaffold.
/// In this sample, it is a Navigator.
final Widget child;

@override
```

```
Widget build(BuildContext context) {
return ProviderScope(
child: Scaffold(
body: child,
bottomNavigationBar: BottomNavigationBar(
items: const <BottomNavigationBarItem>[
        BottomNavigationBarItem(
        icon: Icon(Icons.dashboard),
        label: 'Dashboard',
        ),
        BottomNavigationBarItem(
        icon: Icon(Icons.settings),
        label: 'Settings',
        ),
],
currentIndex: _calculateSelectedIndex(context),
onTap: (int idx) => _onItemTapped(idx, context),
),
),
);
}

static int _calculateSelectedIndex(BuildContext context) {
final String location = GoRouterState.of(context).subloc;
if (location.startsWith('/settings')) {
```

```
return 1;
}
if (location.startsWith('/')) {
return 0;
}
return 0;
}

void _onItemTapped(int index, BuildContext context) {
switch (index) {
case 0:
GoRouter.of(context).go('/');
break;
case 1:
GoRouter.of(context).go('/settings');
break;
}
}
}

Widget getRouter() {
return MaterialApp.router(
theme: ThemeData(
brightness: Brightness.dark,
/* dark theme settings */
```

```
),
routerConfig: _router,
);
```

Language: Dart

Framework: Flutter

Lines: 851 lines of code

5.3 RESULT

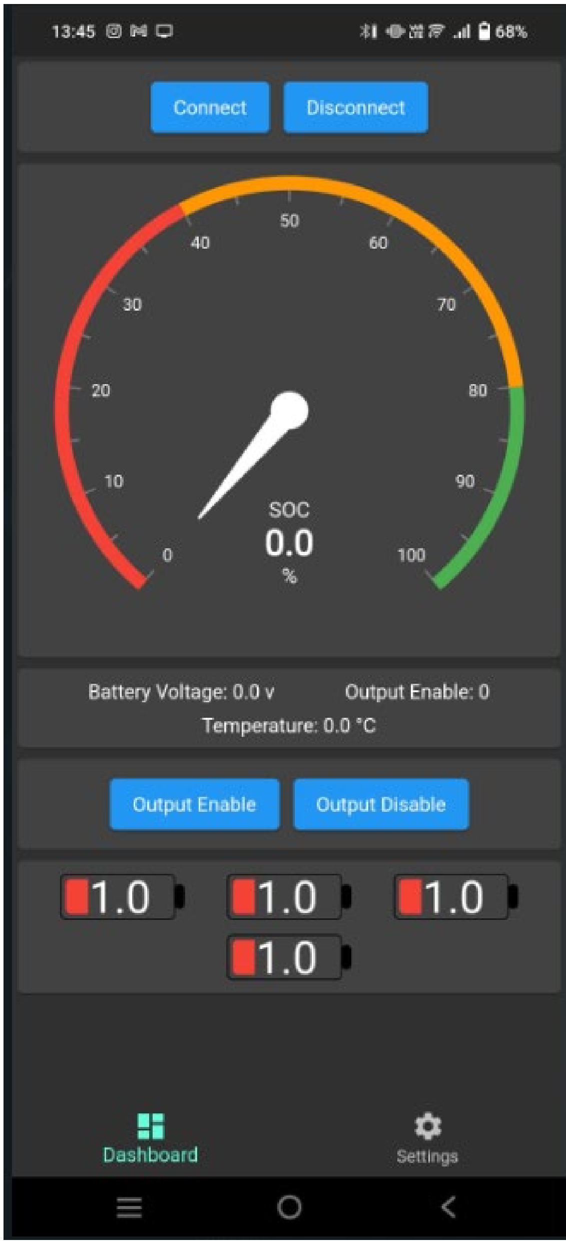


Figure 2.3

DASHBOARD INTERFACE

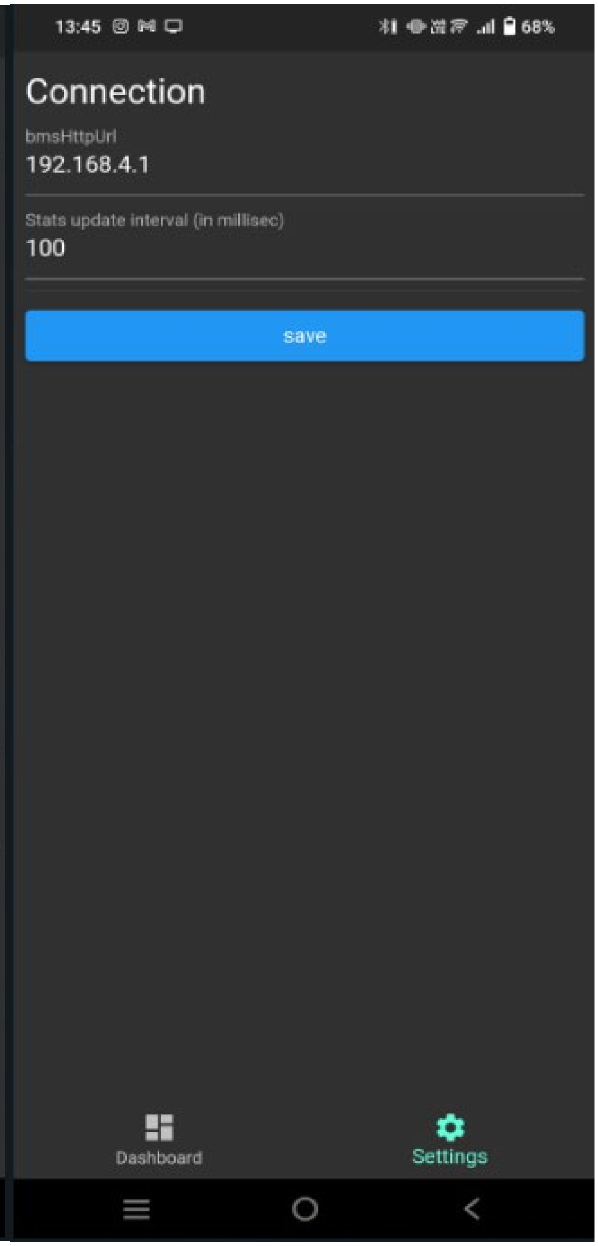


Figure 2.4

SETTINGS INTERFACE

CHAPTER 6

CONCLUSION

In conclusion, the use of Li-ion batteries and Smart Battery Management Systems (BMS) is rapidly growing due to the increasing demand for IoT devices and renewable energy storage systems. These technologies offer numerous benefits, such as improved energy efficiency, reliability, and safety of devices and systems.

However, the use of Li-ion batteries also comes with challenges such as battery safety, performance, and cost-effectiveness. The development and use of BMS are critical for ensuring the safe and optimal performance of Li-ion batteries. In addition, the certification and testing requirements are essential for ensuring the reliability and safety of these technologies.

Overall, the adoption of Li-ion batteries and BMS has the potential to bring about significant positive changes for both industry and society. However, it is important that these technologies are developed and used responsibly, with a focus on safety, sustainability, and ethical considerations. By doing so, we can harness the full potential of these technologies while minimizing the negative impacts on the environment and society.

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