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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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BATTERY MANAGEMENT SYSTEM

Yusuf Bello SALEH

Master's Thesis

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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THESIS APPROVAL

This thesis, which was prepared according to the thesis writing rules of the Graduate School of Natural and Applied Sciences, Fırat University, was evaluated by the committee members who have signed the following signatures and was unanimously approved after the defense exam made open to the academic audience.

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DECLARATION

I hereby declare that I wrote this Master's Thesis titled “Battery Management System ” in consistent with the thesis writing guide of the Graduate School of Natural and Applied Sciences, Firat University. I also declare that all information in it is correct, that I acted according to scientific ethics in producing and presenting the findings, cited all the references I used, express all institutions or organizations or persons who supported the thesis financially. I have never used the data and information I provide here in order to get a degree in any way.

23 August 2021

Yusuf Bello SALEH

PREFACE

The battery management system (BMS) is the most significant component in electric vehicles (EVs), especially when using lithium-ion batteries. In this study, a BMS was created to track each battery voltage and current in the pack, as well as the temperature of the batteries and a balancing mechanism.. A Fault Discovery Algorithm was also developed to assist in the detection of faulty cells.

I'd like to express my heartfelt gratitude to my supervisor, Prof. Dr. Hasan KÜRÜM, for his guidance, support, motivation, and patience throughout my studies and up until the completion of this thesis. Besides my Supervisor, Merve YILDIRIM, my Assistant Supervisor, deserves my heartfelt gratitude for her important advice and encouragement.

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Green energy is becoming increasingly significant in today's globe. Electric automobiles are currently the best alternative for the environment, personal and public transportation, due to air pollution. Batteries are used in electric vehicles, which can be dangerous if they are not used in a safe environment.

The goal of this thesis is to create a BMS that can monitor the voltages, currents, and cell balancing of each cell in the battery pack, as well as monitor the pack's temperature. This involves the system's hardware as well as the creation of a sample test component to evaluate the system's functionality. Electric vehicles' batteries must always be kept under control within their safety operational area (SOA). Multiple cells of battery cells are combined to get the desired voltage and capacity. To achieve the high voltage and capacity required for electric cars, a large number of cells are required. In this thesis, we came up with ways on how to monitor each battery cells functionality and we developed an Algorism for checking and detecting of bad cells for replacement in the battery pack and displayed those cells condition on LCD whether they are good or bad to notify the users, the present conditions of each cell for next line of action by the user.

This work comprises of four chapters, chapter one includes all theoretical aspects and the literature review of this thesis while chapter two is all about materials and methods used for the design of the BMS of this research including circuit design, PCB and 3D of the BMS and chapter three is findings of the end results obtained in this thesis lastly chapter four result discussion.

Keywords: Battery Management System (BMS), Battery pack, Cell balancing.

ÖZET

Batarya Yönetim Sistemi

Yusuf Bello SALEH

Yüksek Lisans Tezi

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Yeşil enerjiyi kullanmak günümüz dünyasında giderek daha önemli hale gelmektedir. Hava kirliliği nedeniyle elektrikli araçlar şu anda çevre, kişisel ve toplu taşıma için en iyi seçimdir. Elektrikli araçlarda kullanılan piller, güvenli bir çalışma alanında kullanılmadıkları takdirde tehlikeli olabilir.

Bu tezin amacı, pil paketindeki her hücrenin gerilimini, akımını, hücre dengelemeyi ve paketin sıcaklığını izleyebilen bir batarya yönetim sistemi (BYS) tasarlamaktır. Bunun için, sistemin donanımını ve işleyişini değerlendirmek amacıyla sistemin örnek bir test bileşeninin geliştirilmesi gerekir. Elektrikli araçların, güvenlikleri operasyonel alan (GOA) içerisinde her zaman kontrol altında tutulmalıdır. İstenen gerilim ve kapasiteyi elde etmek için birden fazla pil hücresi birleştirilir. Elektrikli arabalar için gereken yüksek gerilim ve kapasiteye ulaşmak için çok sayıda hücreye ihtiyaç vardır. Bu tezde, her bir pil hücresinin işlevini izleyerek kötü hücreleri tespit etmek ve bu hücreleri pil paketinde değiştirmek üzere bir algoritma geliştirilmiştir. Bu hücrelerin durumu LCD ekranda gözlenmiştir.

Bu çalışma dört bölümden oluşmaktadır: Birinci bölüm, tüm teorik çalışmaları ve bu tezin literatür incelemesini içerirken, ikinci bölüm tamamen devre tasarımı, PCB ve BYS'nin 3D'si dahil olmak üzere tezin pil yönetiminin tasarımı için kullanılan malzemeler ve yöntemleri içerir. Üçüncü bölüm, bu tezde elde edilen sonuçların bulgularıdır. Son bölüm ise sonuçlar ve tartışmalardan oluşur.

Anahtar Kelimeler: Batarya Yönetim Sistemi (BYS), batarya paketi, hücre dengeleme.

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SYMBOLS AND ABBREVIATIONS

Symbols

R_L	: Load Resistor
R_S	: Shunt Resistor
R_t	: Thermistor Resistance
R_f	: Feedback Resistor
R_{in}	: In Resistor
V_d	: Voltage Drop

Abbreviations

BMS	: Battery Management System
SOC	: State of Charge
SOH	: State of Health
SOA	: Safety Operational Area
CC	: Constant Current
CC	: Coulomb Counting
CV	: Constant Voltage
EV	: Electric Vehicle
PCB	: Printed Circuit Board
ADC	: Analog to Digital Converter
CO2	: Carbon dioxide
DOD	: Depth of Discharge
LTO	: Lithium Titanate Oxide
NCM	: Nickel Cobalt Manganese
LMO	: Lithium Manganese
NCA	: Lithium Cobalt Aluminum
LCO	: Lithium Cobalt Oxide
CAN	: Controller Area Network
CANH	: Controller Area Network High
bxCAN	: Basic extended Controller Area Network
GPIO	: General-Purpose Input/output
Tx	: Transmit
Rx	: Receive
SPI	: Serial Peripheral Interface
BMC	: Battery Control Unit

1. INTRODUCTION

Ground emissions cause the most air pollution and combustion engines in the world. Furthermore, conventional vehicles (fuel) contribute 25% of CO_2 emissions and air pollution to the atmosphere. As the number of people who drive private and public vehicles grows, so does air pollution. As a result, Electric vehicles are more acceptable. Electric vehicles are not new to the world, but technological advancements and a growing concern about pollution have branded them as the mobility of the future. The battery, which substitutes internal combustion engines, is the main component of the EV, in addition to the electric motor[1]. The rapid advancement of power electronics and control systems has paved the way for the usage of numerous types of electric vehicles.The primary goal of this study presented here was to develop a better battery management and control system for use in electric vehicles (EV)[2]. The following are the main components of an electric vehicle are Battery Management System (BMS), electric motor, motor control, DC-DC converter, EV battery charger, cable system, regenerative brake system, vehicle body and chassis are all critical factors, especially when using lithium-ion batteries[3]. Any electrical system that controls a rechargeable battery by preventing it from functioning outside its safe operating area (SOA) and monitoring its state of charge, temperature, voltage, and current is known as a BMS[4, 5].

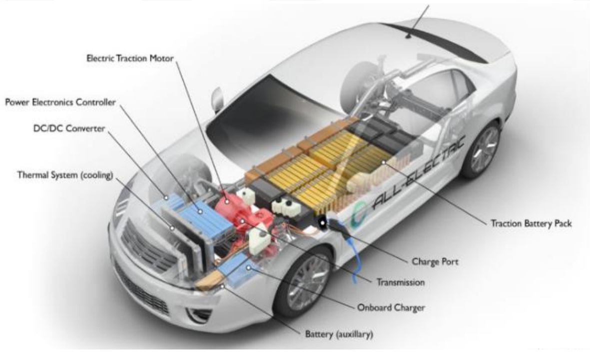

Figure 1.1. Electric Car structure and its components

From the figure 1.1. Above is the electric car structure and the various components that made it up.

1.1. Battery

The battery is an electrical system containing one or more cells whose chemical reactions in a circuit produce electron flow. The basic components that make up the battery are the anode (-), cathode (+), and electrolyte. The Battery is classified into primary and secondary cells. Their many batteries develop in the world for various applications use, which are all in that classifications[6].

Due to technological advancement and much researches, today their many batteries of different structures, electrochemistry, nominal voltage, and energy intensity. For some types of portable and mobile phones, batteries are a suitable source of electricity. The installation of a number of battery cells connected in a series of configurations forms a typical battery. Many types of batteries have rechargeable cells, so energy is stored inside the cells when external energy is added to the batteries. Although many chemical compounds for cathodes and electrodes are present in battery cells, some of the compounds include nickel-cadmium (NiCd), nickel-metal hydride (NiMH) and lithium-ion compounds (Li-ion). While a good power supply from battery cells can restore power, rechargeable batteries do not have an unlimited lifespan and the ability of cells to charge charges worsens the life of the device. Unexpected events may occur when the cell is held by the manufacturer before being assembled into a battery, or when the cell is assembled on a battery but the battery has not been sold, or when the consumer's long-term use of the battery cannot be recharged[7].

The presence of heat, which can affect batteries that are not stored in a controlled temperature environment, aggravates cell loss. Alternatively, batteries, such as spare batteries, which are stored near other normally functioning electrical circuits that emit heat, can be affected by heat-related cell losses. Also, the battery cells cannot discharge energy evenly inside the battery due to the internal resistance of the battery. Unlike other cells in a battery, all of these factors cause each cell in the battery to carry a different amount of charge. These varying levels of charge can lead to erroneous indications of low battery capacity and the potential for accidental power outages[3].

Battery detectors are used to monitor the remaining battery discharge time by monitoring the total charge of all cells in the battery and the cost of each cell. Normally, a preset charge threshold is set for both full and single-cell battery charging. The battery detects if one of the two dimensions falls below a predetermined minimum and ends up cutting off the power supply to the electrical unit. A single-cell preset threshold typically takes into account the instability of a cell; this allows a cell to operate at a charge rate that is slightly lower than a predetermined threshold of total battery charge for that cell. Techniques and systems have been developed to address cell imbalances. It is inaccurate and time consuming to measure the state of charge of individual cells and align the cells with the same charge when installed in a battery. Also, this manual procedure does not address cell loss after charging the battery[8]. Alternatively, by using a combination of load resistors and transistors installed in parallel with each cell, active cell balancing can be implemented using shunt transistor resistors and currents during battery cell charging. Using complex control algorithms, this form of cell balancing is implemented by software and simply mimics cell charge balance and looks to impose a natural cell charge balance and is therefore prone to various sources of error such as initial cell filling and cell open circuit voltage.

In the field of rechargeable batteries, it is also desirable to have a battery capable of balancing the charge of each cell to increase the discharge time of a manageable battery. In order to mimic the strength of the current balance of cells, it is also desirable that the batteries provide load balancing of the cells, which does not rely on complex software algorithms. A battery that maintains cell balance and uses calculated cell characteristic values to monitor cell balance is desirable. In addition, the system must balance the load in the battery cell. It is very suitable for the method which can be used before inserting the battery inside the battery, or the method which can be used after inserting the battery[9].
The Batteries that are commonly use in electric vehicles with their different properties and technology is given in the table below [10].

Table 1.1. Different batteries properties for comparison of lithium battery cell

Cell Type	**Nominal. Voltage [V]**	**Energy Density [Wh/kg]**	**Cycle Life**	**Memory Effect**	**Operating Temperature[°C]**
Pb-acid	2	35	1000	No	-15, +50
NiCd	1.2	50-80	2000	Yes	-20, +50
NiMH	1.2	70-95	<3000	Yes	-20, +60
Li-ion	3.6	118-250	2000	No	-20, +60
LiPo	3.7	130-225	>1200	No	-20, +60
LifePO4	3.2	120	>2000	No	-45, +70
Zn-air	1.65	460	300	No	-10, +55
Li-S	2.5	350-650	300	No	-60, +60
Li-air	2.9	1300-2000	100	No	-10, +70

From the table 1.1. above showed the lithium battery is choosed due its outstanding parformance.

1.1.1. Primary Cells Type of Batteries

The primary battery is a disposable battery that cannot be recharged and reused like a secondary cell. In general, the electrochemical reaction in the cell cannot be reversed, so the cell cannot be charged[11].

1.1.2. Secondary Cells Type of Batteries

A secondary battery is a type of electric battery that can be charged after use, discharged and recharged repeatedly, unlike a primary battery which is delivered fully charged and must be discarded after use, or a disposable battery after use. A rechargeable battery is a combination of one or more electrochemical cells. The term (accumulator) is used because it collects and stores energy through a reversible electrochemical reaction[11].

1.2. Types of Cell Constructions

In deciding the overall efficiency of cells, energy storage materials and general cell chemistry play an important role. However, there is a range of form factors available for lithium-ion cells; cell engineering also plays a role in the general application and thus in the final application of battery efficiency. In order to link and secure the structure of the battery pack, energy storage cells require engineering and reservation system support.

1.2.1. Cylindrical Type

The small cell cylinder type is the cheapest form of a lithium-ion cell. The most common version is the 18650 format, which is the most common in many consumer applications, such as smartphones, power tools, and electric motorcycles. There are eleven 18650 options optimized for power and/or electricity. Cells may have protected characteristics such as functions for extreme temperature and pressure cutting [12].

Figure 1.2. Lithium battery cell cylindrical type

In figure 1.2. its lithium battery cylindrical types 18650 that can be used by many BMS.

1.2.2. Prismatic Type

Prismatic lithium-ion cells are usually found in aluminium or steel. Mechanical properties provide stability, mechanical strength and water resistance. It also allows the use of a storage device as a pressure relief gap, which is not possible in cell pockets. In some cases, prismatic cells allow the packaging to work better than cylindrical cells because of the type of material. [12].

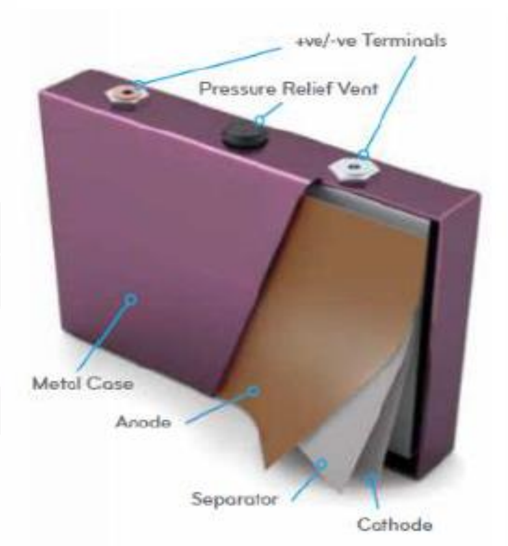

Figure 1.3. Lithium battery cell prismatic type

Figure 1.3 show prismatic lithium battery usually found in aluminium and steel materials.

1.2.3. Pouch Type

Pouch type cells are cells in the soft aluminium-plastic packaging stack of the inner electrodes. Current collectors were welded to the terminal pages from the seals inside to allow for external connection.

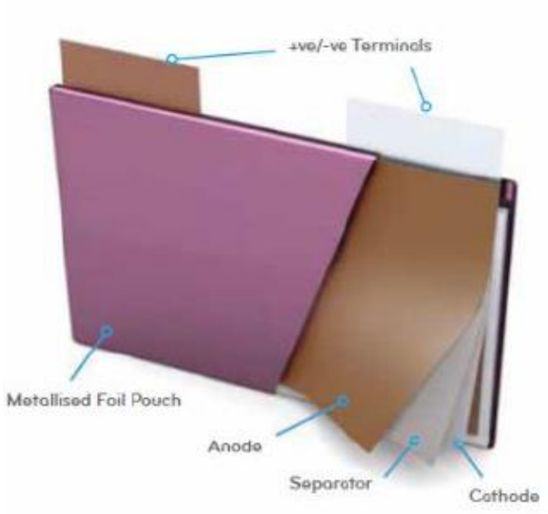

Figure 1.4. Lithium battery cell pouch type

In figure 1.4. is pouch lithium battery it has very low heat generation

Because component cells use smaller packages than metal and prismatic cells, the same chemical may be higher for the package, but they often require a different type of adhesive to reduce and hold the cells in the packaging package. A big face can help with heat treatment[12].

1.3. Chemistry of Regular Batteries and Cells

Many different cell chemistry is common and provides different energy, voltage and energy efficiency. The energy density of lithium cells is much higher than previous chemicals, which makes them very suitable for car applications. All are considered safer, less dangerous and last longer, more energy-efficient. The following sections introduce some of the most common chemistry[13].

1.3.1. Lead-Acid Type of Battery Cell

Lead-acid batteries consist of lead dioxide, spongy metal lead metal and sulfuric acid solution. Because of this heavy material, they are toxic and improper disposal can harm the environment. A typical cell voltage is 2 volts. Lead-acid is a popular low cost preloaded with good performance, moderately good low and high-temperature performance, easy refill tip, and good storage during intermittent charging. Available in large quantities and in a variety of sizes and designs. Lead-acid is a popular and affordable battery that comes in a variety of sizes and designs. It has good high speed performance, moderately good low and high-temperature performance, a simple charging tip, and good storage for intermittent applications.

It is widely used for energy storage, backup power, and battery power for engine starting, vehicle lighting and engine ignition in older generation electric and hybrid cars. The market for suspension batteries and electric car batteries continues to dominate. It will remain competitive with continued advancements and the development of advanced lead-acid batteries[13].

1.3.2. Nickel Cadmium (NiCad) Battery Cell

For the cathode, these cells use nickel hydroxide, cadmium as the anode, and alkaline potassium hydroxide for the electrolyte. Common nickel-cadmium cells use the chemical impregnation aqueous catheter method for electrode fabrication. It was used to start space exploration, to store electricity in spaceships. Compared to lead-acid batteries, batteries with high discharge current have higher energy resistance. However, this battery technology has serious disadvantages. It has a low charge and discharge efficiency, high self-discharges and memory[13].

1.3.3. Nickel Metal Hydride (NiMH) Battery Cell

The technology for nickel-metal hydrate batteries is intended to provide an alternative to the drawbacks of nickel-cadmium batteries. Instead of cadmium electrodes, metal hydrate is used. Nickel-metal hydrate batteries have higher self-discharge and less protection under overload conditions than nickel-cadmium batteries[13].

1.3.4. Lithium-ion Battery Cell

Due to its small equivalent weight and standard capacity, lithium-ions are used in rechargeable batteries with a charging energy density three times greater than conventional batteries. Alan has made great strides in die-hard to improve performance. It has high tensile strength, velocity and tensile strength as well as increased length and thermal stability for added safety. Attention has focused on reducing maintenance costs and the ability to ship faster, from a range of synthetic materials to cheaper and less toxic and environmentally friendly products[14]. To improve overall efficiency, research and development focus on many aspects of cell chemistry. However, much emphasis has been placed on the positive evolution of the cathode material, which had a significant impact on the outcome of the total energy density of some. Depending on the choice of electrolyte materials, lithium-ion batteries can be divided into two categories: Lithium-ion cells using liquid electrolytes and solid-state lithium-ion batteries using inorganic or polymeric electrolytes. There is a variety of lithium-ion cell chemistry each with unique features and properties.

1.3.5. Lithium Ion Polymer Battery Cell

Lithium-ion polymers have nearly identical properties to lithium-ion batteries. The only difference is that polymeric materials are used as the electrolyte solution in Li-ion polymer batteries. The electrolyte polymer has a higher electrical conductivity than another organic liquid electrolyte. Furthermore, the use of this material simplifies, accelerates, and broadens the production of lithium polymer batteries.

1.3.6. Lithium Ion Phosphate (LFP) Battery Cell

Please note that these are lithium-ion batteries with lithium iron phosphate as the positive electrode material. These batteries have benefits such as high energy density, high energy density, and so on. Conversion rate and safer use. In addition to low-cost and non-cancer content Materials, these batteries are preferred because of a lower fire risk. However, lithium iron phosphate batteries are 60 per cent less energy-intensive than conventional lithium cobalt oxide batteries. Since lithium iron phosphate as a cathode material can be synthesized from common elements, overall costs can be significantly reduced. Lithium iron phosphate batteries, which are relatively safer, are prominent due to their high conversion life and relatively lower costs. The use of these batteries is increasing in chargeable hand tools, electrical bicycles, and among hobbyists. However, compared to lithium-ion batteries, the performance of these batteries is lower [14].

1.3.7. Lithium Cobalt Oxide (LCO) Battery Cell

LCO is the most commonly used positive electrode in lithium batteries and has been used in laptops, cell phones, and tablets for many years. LCO cells outperform the average in terms of lifespan and energy density. Chemistry, on the other hand, is less temperature-stable than other metal oxide changes. Phosphate chemistry under extreme abuse conditions, such as cell perforations or short circuits, making them more susceptible to temperature changes. The use of electric and hybrid vehicles is limited due to these limitations.

1.3.8. Lithium Cobalt Aluminum (LCA) Battery Cell

The combination of cobalt, lithium, nickel and aluminium offers a very high energy density and power capacity. LCA cells are a little safer than LiCO2 cells. LCA cells have a longer lifespan than 18650 cells and can be utilized in large automobile batteries.

1.3.9. Lithium Manganese Oxide Spinal (LMO) Battery Cell

Manganese oxide (lithium) cells can be contained in cobalt-based compounds, causing a period. The energy density, on the other hand, is normally around 25%. Manganese, not cobalt, is a safe and environmentally favorable cathode material due to its low toxicity. Others may incur tiny and insignificant costs. The entire capacity to carry out activities, on the other hand, is often lower and is not governed by electrolytes.

1.3.10. Lithium Nickel Cobalt Manganese Oxide (NCM) Battery Cell

Although no chemical cell exists to explain all of the energy, power, cost, safety, and life-saving containers, mixed carbon monoxide systems, and NCM-based components, they can be improved to give higher energy efficiency or high-performance functions to make them safer and more cost-effective. Such as the LCO and LFP, but with a normal life expectancy [14].

1.4. Cell Electrical Properties

There are terms that are essential to identify the electrical properties and classifications of a battery are present as follow.

1.4.1. Voltage

The type of active material found in the cell sets the normal potential of the cell. From the normal electrode potential, the standard potential can be determined as follows:

$$oxidation\ potentia\ \text{(anode)} + reduction\ potential\ \text{(cathode)} = standard\ cell\ potential.$$

1.4.2. Capacity

The number of active components in a cell determines the cell's ability. It is measured in coulombs or ampere-hours and refers to the entire quantity of power used in the electrochemical reaction.

1.4.3. Battery Energy

A cell's capacity can also be calculated on an energy basis, taking both the voltage and the amount of power into account. This is the maximum amount of energy that an electrochemical system may create theoretically.

1.4.4. Energy Density

The quantity of energy stored in a certain place or region of space per unit volume is referred to as energy density. It can also refer to energy per unit mass, while gravimetric energy density is a more appropriate phrase.

1.4.5. Power Density

The quantity of power per unit volume is known as power density. Power density refers to a volume in energy transformers, such as batteries and power supply units.

1.5. Battery Cell Technical Specification

This section describes the terms battery cells, modules, and packs are all referred to as modules. that you might see on battery technical specification sheets[15].

1.5.1. Battery Nominal Voltage

This is the average voltage at the rate of discharge into the battery. The normal voltage is frequently assumed to be the battery voltage.

1.5.2. Battery Cell Cut-Off Voltage

This is the final voltage between the two electrodes produced during charging or discharging. This is the minimum allowable voltage and usually describes the empty state of the battery.

1.5.3. Battery Discharge Curve

This refers to the voltage change over time during the discharge process.

1.5.4. Life Cycle

This is the number of times you must charge (recharge and discharge) another battery before it loses its ability to spend. Such circumstances and regulatory unpredictability must be factored into the life cycle. The shape of the battery, its chemical composition, the release aid, the shape of the cells, and other critical features are all influenced by heat and moisture.

1.5.5. Maximum Continuous Discharge Current

The maximum current will be continuously discharged into the battery. This restriction is usually set by the battery manufacturer to prevent excessive discharge rates from damaging the battery or reducing its power.

1.6. Battery Technology

In order to understand the efficiency and characteristics of the batteries, there are some words that are important and described as follows, describing some of the battery variables that are used to describe the battery's current state.

1.6.1. Battery Open Circuit Voltage

It refers to the voltage between the positive and negative electrodes while the battery is not charged. The open voltage department is affected by the charge level of the battery, which rises as the charge level rises.

1.6.2. Battery Working Voltage

When a load is connected to the battery cell, the voltage between the positive and negative terminals is measured. is referred to as terminal or closed-circuit voltage. The working voltage fluctuates depending on the state of charge (SOC), as well as the discharge and charges current.

1.6.3. Discharge Rate

When describing the batteries, in order to normalize according to the size of the battery, the term "discharge current" is frequently used as the discharge rate, which is typically slightly different between the batteries. The rate at which the battery is depleted in comparison to its full capacity is known as speed discharge. The one cycle ratio indicates that the discharge current empties the entire battery in one hour. In order to determine the power output capability, the discharge rate may be used.

1.6.4. Depth of Discharge (DOD)

This is the percentage of battery capacity that has been discharged as a percentage of maximum capacity. A deep discharge is defined as one that has a DOD of at least 80%.

1.6.5. Internal Resistant

Is the total resistance between two battery electrodes called internal resistance, electrodes, active compounds and current collectors, dispersants, and electrolytes are all taken into consideration. In general, the lower the greater the quality that may be obtained, the higher the internal resistance. Also affected by the battery's load and discharge situation. As the internal resistance rises, more charging energy is converted to heat, reducing the battery's efficiency and thermal stability.

1.6.6. Self-discharged

In a battery, there is a phenomenon where reactions of internal chemical parts diminish the battery's storage capacity without the connection between the electrodes. Self-discharge shortens the battery's life and results in a charge that is less than full at first.

1.7. Lithium Battery Challenges

For decades, lithium-ion batteries have been available. Based on current battery chemistry, the technology is regarded to be relatively developed. Lithium-ion batteries are widely used in mobile electronic devices, such as cell phones and notebook computers, and are becoming more significant in electric cars. In sustainable energy networks, lithium-ion batteries are also being studied for storing sustainable energy from renewable sources. The growing need for energy storage necessitates the upgrade of existing lithium-ion batteries as well as the development of next-generation lithium-ion batteries, with a focus on lowering battery costs. Another key challenge is the development of new element chemistry. Lithium-ion battery technology should be replaced. High specific capacity electrode torque and high operating cell voltage are necessary to boost the energy density of lithium-ion batteries. The problem of security is another concern that must be appropriately addressed. Automobile industries must invest significant amounts in battery management systems to improve the safety of big battery packs in vehicles in order to assure universal adoption of electric vehicles and to increase the lithium-ion vehicle industry. Non-combustible lithium-ion batteries, such as liquid electrolyte or ceramic Li-ion batteries, and solid-state batteries, should be produced instead. In the next generation of lithium-ion batteries, the high-voltage (5 V) cathode and high-capacity anode are most likely to be utilized. Extensive research is therefore needed to gain a deeper understanding of this electrode matter. Stability and electrolyte contact are considered. Battery safety should also be increasingly emphasized instead of intensively seeking high energy density. Standardized monitoring protocols for the protection of batteries should be commonly used [16].

1.7.1. Advantages of Lithium Battery Cell

(a) Lithium-ion batteries are lighter than other charging batteries.

(b) Lithium-ion battery is highly energy efficient and capable of carrying more energy.

(c) This battery has a bigger operating temperature range.

(d) These batteries can be power easily.

(e) Lithium-ion batteries can store up to 6 times more energy than other batteries that can be charged. Getting the same amount of weight

(f) In terms of lithium-ion batteries, they are 75% more advantageous than other batteries. Loss of power

(g) The memory effect on lithium-ion batteries is not present.

(h) Compared to other batteries, these batteries can be charge and discharged more [17].

1.7.2. Disadvantages of Lithium Battery

(a) Lithium-ion from the date of manufacturing, the battery has a life span of 3-4 years.
(b) They lose more energy when exposed to heat compared to other batteries.
(c) When the batteries are fully discharged, the lithium-ion batteries can be broken down.
(d) These batteries are more expensive than other batteries.
(e) Compared to other batteries, these batteries are more flammable.
(f) These batteries need a battery control device [17].

All of these characteristics have made lithium-ion one of the most suitable in battery charging methods, and this lithium-ion has been the first option for battery technology by scientists and battery manufacturers.

1.8. Why Battery Management System is Need?

To prevent damage to the battery, various types of battery management systems (BMS) are employed. A battery monitoring device is the most popular sort, and it records critical operating characteristics like current, voltage, and internal temperature of the battery, as well as the state of charge during charging and discharging. If any parameter exceeds the value defined by the safe zone, the system delivers input to the monitoring circuit, which can trigger an alarm and even disconnect the battery from the charger or charger[18].

In electric cars, batteries are the primary source of energy. In this app, the battery monitoring and safety systems should be a battery management system, which keeps the battery ready to supply maximum power when needed while also extending and managing battery life. Battery overcharging or discharging. The BMS should include systems that control the load system and deal with thermal issues. For electric vehicles, BMS is part of a dynamic and fast-running energy management method. Other equipment on board, such as the climate controller, engine controller, communication bus, protection system, and vehicle controller, must also be communicated with BMS. The definition of BMS varies by application; the major tasks of the BMS can be summarized as follows.

(a) It ensures that the energy in the battery is balanced in order to power the product;
(b) It reduces the possibility of damage and battery failure.
(c) The charging and discharging processes of the battery are monitored and controlled.

1.8.1. Aim and Object of the BMS

As far as the definition is concerned, the basic tasks of the BMS are the same as their aims. Despite the fact that different forms of BMS have distinct goals, BMS in particular has the following objectives:

(a) Protects against failure and damage to the battery cells

(b) It shall extend the life of the battery as much as possible

(c) This means that the battery is still ready for use

1.9. BMS Functions

Some of the tasks are as follows: the keys of Battery Management System (BMS) functionalities are to protect the battery from an irregular operation.

1.9.1. Battery Discharging Control

The purpose of the BMS is to keep the battery from running outside of its safe operating range[19]. During discharging, the BMS must protect the cell from all potential dangers. Otherwise, the cell might be able to function outside of its parameters.

1.9.2. Charging Control

Incorrect battery charging is the leading cause of battery damage, followed by other factors. As a result, the BMS's charging power is an important feature. Lithium-ion batteries employ a two-stage charging mechanism known as the constant current (CC) constant voltage (CV) and charging method. The charger creates a constant current during the first stage of charging, known as the constant current stage (CC), which raises the battery's voltage. When the battery voltage reaches a consistent value and the battery is nearly full, it enters the constant voltage (CV) step. The charger maintains a constant voltage at this point, as the battery current decays exponentially until the battery is fully charged[20].

1.9.3. Determination of State of Charge

The health state of a battery is a calculation for comparing its overall condition to that of a new battery, as well as its ability to inflict functional damage. Any model, such as cell impedance or behaviour that changes dramatically with age, can be used to characterize a SOH cell. To test SOH, for example, a single set of cell impedance or conductivity can be utilized.[21].

1.10. Battery Pack Cell Balancing

Cell balancing is a technique for balancing weaker cells by balancing the charge, which extends the overall lifespan of the chain. With each charge and discharge cycle, minor discrepancies between cells due to manufacturing tolerances or operational conditions appear to escalate in chains of many battery cells. Weak cells can be processed while being charged, and they can be even weaker before being charged. It will eventually fail, resulting in unintentional battery failure. A battery management system (BMS) can combine one of three cell balancing systems to align cells and prevent the individual cells from overhaul, providing a real solution to this problem while taking the age and operating conditions of the cells into consideration[22].

(a) Active balancing method
(b) Passive balancing method
(c) Charge shunting method

1.10.1. Active Balancing Method

Stronger cells lose energy, which is transferred to the inactive cell balance of weaker cells. The reversal of active balancing approaches is the most basic notion of cellular balance. This approach takes the extra energy from the higher voltage cells while waiting for the lower voltage cells to catch up. The inversion approach can be separated into two subcategories based on the fact that the process is dissipative. When adopting dissipative technologies, a reasonable compromise must be established depending on the application, as excessive heat dissipation can increase the heat treatment's complexity. Uneven cell temperatures would be exacerbated by a cell imbalance [23].

1.10.2. Passive Balancing Method

Dissipative methods are employed in passive balancing to discover cells with the highest voltage charge in the pack, then the cell with the higher voltage is linked to a bypass resistor, the excess energy is taken from that cell, and the voltage on the weaker cells is matched[24].

1.10.3. Charge Shunting Method

All of the cells' voltages would be raised to the rated voltage of the well-charged cell switching. The current will charge the weaker cells until they are fully charged, or until the rated cell voltage is attained. [25].

1.11. Battery Pack

A battery pack is a collection of separate batteries that are connected in series or parallel to provide the power that electronic devices demand. Because of their great power density, lithium-ion batteries are the most frequent form of battery used in battery packs.

jumper cable to connect the negative slide of the first battery to the positive slide of the second battery to connect the battery pack. Connect the exposed positive and negative terminals to your application using another pair of wires. Make sure the battery you're connecting has the same voltage and capacity as the one you're connecting. If you do not, you will have difficulty charging and your battery's life will be cut short. Connecting the batteries in series raises the battery voltage while keeping the amplifier current constant (Ampere Hours). Never cross the remaining positive and negative poles when connecting the battery; otherwise, the battery will be short-circuited, causing damage or injury, and possibly battery failure.

Use the two bridges to link the positive terminals of the two batteries and the other bridge to connect the negative terminals of the two batteries to connect the batteries in parallel. From negative to negative, and from positive to positive. You can attach your load to either battery and simultaneously discharge both[25],[26]

However, attaching one end of the battery pack to the positive value and the other end of the pack to the negative is the recommended technique of maintaining the batteries equally. The current rating of parallel connections will improve, but the voltage will remain the same. Because the batteries' amps have increased, you may need a heavier cable in parallel connection situations to avoid cable damage.

Batteries can be connected in both serial and parallel modes. This may appear perplexing, but it is due to the fact that our voltage output and Amp/Hour ratio may be improved. To execute this successfully, we will need at least four batteries. You can create a series by connecting two parallel linked battery packs.

1.12. Battery Management Requirement

When picking between battery management system (BMS) architectures, there are at least five main requirements that must be balanced. Their relative relevance is determined by the application's specific features[27].

1.12.1. Accuracy

The battery monitor must be precise in order to get the most out of the maximum battery capacity. A vehicle, on the other hand, is a noisy system with electromagnetic interference across a wide frequency range. Any lack of accuracy will have a negative impact on the battery pack's longevity and performance[28].

1.12.2. Reliability

Automobile manufacturers, regardless of the power source, must follow exceptionally high-reliability requirements. In addition, a major safety issue is a high-energy power and inherently unpredictable existence of certain battery technologies. Under conservative settings, a failsafe device that shuts down is preferable to catastrophic battery failure. A well-designed battery pack system must have robust communications, limit failure modes, and identify defects to minimize both fault and genuine failure[29].

1.12.3. Manufacturability of BMS

Incorporating complicated circuitry and wiring to accommodate an electric vehicle and hybrid electric vehicles battery system adds to the complexity of automobile production. To meet the rigorous size and weight limitations and ensure that high volume production is feasible, the total number of components and connections must be decreased[30].

1.12.4. Cost of BMS Construction

Reduce the amount of relatively expensive components in the BMS, such as microcontrollers, interface controllers, galvanic insulators, and crystals, to lower overall system costs.

1.12.5. Power of the BMS

Battery charging is monitored using the battery monitor. Lower active current increases system efficiency, while lower standby current avoids the battery from being overcharged when the system is turned off.

1.13. Literature Review

The battery and its accompanying systems must be designed, monitored, and controlled in order for electric vehicles to have a future. To ensure safe and dependable operation and long life, the battery's runtime performance must be continuously checked and refined, in addition to an initial optimal design of the cell and pack-level structure. Better charging strategies must be developed in order to safeguard and sustain the battery[31]. Battery management systems (BMSs) are real-time systems that regulate several functions that are important for the proper and secure functioning of the electrical energy stored in the battery system. This includes temperature, voltage, and current monitoring, scheduling of maintenance, optimization of battery output, prediction and/or prevention of failure, as well as collection and analysis of battery data. BMS is frequently utilized in electric vehicles, but they are also widely employed in other battery applications such as material storage, uninterruptible power supplies, off-grid power systems, watercraft, and battery banks for alternative energy sources. The battery management device standards for these applications are likewise fairly similar to those used in the car industry[19]. Temperature and humidity, load capacity, pressure, air corrosion, vibration stress, input and output power, static settlement, and other factors all influence electric vehicles It operates in a complicated working environment with a variety of variables, including, as result, batteries operate in complicated surroundings, posing severe difficulties to battery safety, lifetime, and efficiency. Misuse of the battery might shorten its life or perhaps cause a hazard. Because of the differences in single-cell consistency, this problem is particularly evident with batteries. Battery safety and cycle life are becoming increasingly important in their use and management [32]. Aside from advancements in battery technology, a battery management system is a critical component in making the use of battery systems in electric vehicles and other applications safe, dependable, and efficient. The BMS is designed to address some of the problems about the integration of large battery systems in electric vehicles that material advancements in battery technology alone will not be able to address[33].

The BMS in an automobile is a critical component. It safeguards the battery against damage, anticipates battery life, and ensures that the battery remains functioning. The BMS achieves these objectives by combining one or more functions, such as cell protection, charge control, SOC and SOH determination[34]. In this research cell voltages, current, temperature monitoring and cell balancing are all considered.

The most difficult component of electric vehicles is their batteries. In this study, a BMS is designed to improve the battery pack by adding a Negative temperature coefficient (NTC) thermistor as a temperature sensor to each cell in a 1P 8C pack. The batteries used are ORION Lithium-Ion 18650 and the passive balancing method was adopted in this work. For chargeable batteries, balancing operation is important, generally balancing is used to protect serial cell groups and extend the life cycle. The method of passive balancing is simply based on dissipating excess charge through a bleed resistor and equalized the SOC of cells. This method of balancing does not rely on the cells' chemical characteristics and can be used with most types of cells. While active cell balancing is based on the type of energy transfer, there are many types of cell balancing methods. The transfer of energy may be from one cell to the whole battery, from the whole battery to one cell, or from one cell to another[23]. Normally in passive balancing allows both batteries to have the same SOC, but it has no effect on the battery-powered system's operating time. While it is a low-cost method of cell balancing, the discharge resistor wastes energy in the process. In this study, 2N7000 MOSFET is used. This method employs a resistor to deactivate the cell with the greatest voltage in a serial package. The weakest cell in the pack usually hits the maximum voltage threshold with the same current as of the other cells in the pack. The switch is actuated when the cell voltage approaches SOA, and the cell is permitted to flow via a resistor, also known as a bleeding resistor, to lower the voltage between the cell and the SoC to a safe level. This step is continued until all of the cells have reached the same voltage level. The microprocessor performs a voltage monitor, which converts the voltage from analogue to digital, to monitor voltage. Voltage measured by OP-AMP which keeps track of the voltage and use A/D converters to convert the voltage from analogue to digital[3]. In each cell, there are passive component resistors, MOSFET, and flying capacitor for overcharging voltage control and in combination with passive components were used for protection of the batteries against overcurrent. In this study, the field effect transistor and field effect transistor driver breaker blocks were created, with the FET-driver functional block being in charge of the charger-charger connection, isolating and connecting the package, and charging the battery. The FET drive's primary function is to measure battery voltage and current. The battery's operation is limited to charging, discharging, or idling, and the device requires the fewest connections to the battery. The direction of flow and real-time behaviour of a particular flow, test determination based on device state[35]. The battery management system, which is one of the vehicle's applications, is a vital component of an electric vehicle. The goal of the battery management system is to conduct operations such as condition monitoring and evaluation, charge and discharge control, and cell balancing in order to ensure battery stability[36].

The battery cells employed in this test are lithium-ion cells with top and lower voltage limitations of 4.2 V and 2.5 V, respectively, and a proper battery working temperature of -20°C to +60°C. This voltage is what a completely full charged and empty cell level of the battery is. The "full" charged indicates when the cell has reached full load after being charged with a constant voltage constant current at the proper temperature. Due to the increasing growth of electric cars (EVs), batteries must be created and fitted to tight vehicle EV standards. The BMS is an important component of an electric vehicle since it ensures that the battery functions safely and for a longer period of time. In reality, the costs associated with owning an EV have an impact on the total cost of ownership. Built-in capacity, although it still functions at the time. The cost of BMS is a small percentage of total costs, but it ensures the system's longevity. The hardware and software components of the BMS architecture are separated[37].

Hardware for obtaining battery status factors such as voltage, current, and temperature. The simultaneous acquisition of measurements was ensured in order to improve the accuracy of the estimates. A high sampling rate is essential to ensure that the device's dynamics can be regulated, and the electrical and thermal variables must be correctly computed to avoid error propagation and to allow trustworthy estimation of those parameters that are not directly measured[38]. Battery protection and alerts are managed by software that actively monitors all variables, manages internal communication between hardware blocks, manages communication with peripheral systems, and executes estimate or cell balance methods[39]. In a centralized architecture, the BMS central processor is responsible for measuring voltage, temperature, current, insulation resistance, estimation, and communication status, among other things. In a distributed architecture, there small voltage and discharge monitor circuit which communicate with master controller of the BMS. It's necessary to use a concentrated sample point, which has advantages including quick connection, low cost, and ease of maintenance. However, because of the huge number of traction batteries and the restricted space in automobiles, the central architecture is gradually fading in EVs[40]. The BCA's primary function is to process each BMU's battery parameters and estimate battery state, including the SOC, SOE, SOH, and SOF elements, which give vehicle control data and basic charge control, as well as transmit BMU (Battery Management Unit) control commands. Cell voltage, total voltage, current, insulation resistance, and temperature, as well as BCU (Battery Control Unit) control sequences, are all calculated using the BMU[32]. Battery voltage and temperature were monitored using LCD monitors as BMS monitors in this study, and cell voltage measurement is one of the most critical characteristics of external battery performance, and battery status is strongly dependent on it. For batteries connected in series, there are several methods for calculating voltage. High-voltage interference and insulation issues, as well as measurement cost and accuracy, are all carefully evaluated. As the number of serial connections grows, the common-mode voltage is provided to the battery cells. In hardware design, the common-mode voltage process is taken into account[41]. A battery in this study is made up of eight cells connected in series and parallel to suit the voltage and capacity demands Because the normal performance of each cell has an impact on the battery's performance, the voltage of the packet is constantly monitored. Typically, two systems are used to monitor cellular voltage: discrete and integrated[42]. In this work, the hardware of the BMS was integrated into MCU to monitor all variables and manage the internal communication with the hardware components of the BMS and software that are embedded in the MCU.

BMS is used in electric vehicles to monitor and control the charging and draining of rechargeable batteries, allowing for more efficient operation. While developing senility without causing damage, the battery management system keeps the battery safe and reliable. Different monitoring techniques are employed to maintain the state of the battery, including voltage, current, and ambient temperature. Different analogue/digital sensors with microcontrollers are utilized for monitoring purposes[43].

In this research work STM32 microcontrollers were used with 10 ADC pins, 9 out of 10 ADC pins will be configured to measured and monitor cell voltages, currents and temperature. Some other GPIO pins is will be used for the LCD monitor and MOSFET for controlling battery cells balancing, load and charge control circuits.

2. MATERIAL AND METHOD

In this section, we will present in detail the method and all the components used, including the schematic and block diagrams of the final design implemented and the various parts that made up the Battery Management System, such as the Temperature Sensor Circuit, Current Measurement Circuit, and Voltage Measurement Circuit, for this thesis. The Printed Circuit Board (PCB) and the 3D design layout will be presented in this chapter.

2.1. Microcontroller Circuit

Today's technology has progressed to the point that stand-alone devices can perform all required functions without the need for additional hardware. Microcomputers, also known as single board computers, have evolved from advanced microcontrollers. Strong microcontrollers are used to run these devices. These microcontrollers contain a lot of integrated circuits on board, so they can do a lot of things on their own [44]. STM32F103C8 was chosen as the microcontroller; the microcontroller's functionality is dependent on a small number of external components. A ceramic resonator was used as an external clock source, in addition to the bypass capacitors in the power supply pins. For the ADC readings of the board temperature sensors and the primary power supply rail, a resistor divider topology was used. LEDs were installed for debugging and to provide a visible indication of various device functions. The debugger/programmer connector on the Male header provides access to the microcontroller memory. the pins configurations and block diagrams are given below.

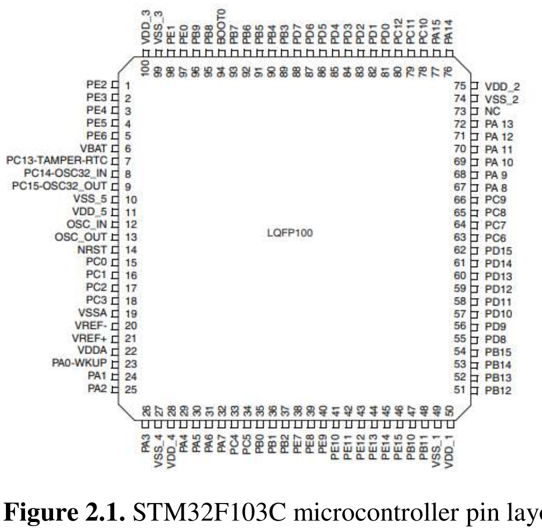

Figure 2.1. STM32F103C microcontroller pin layout

Figure 2.1 show Stm32f103c8 microcontroller with its pins number and label.

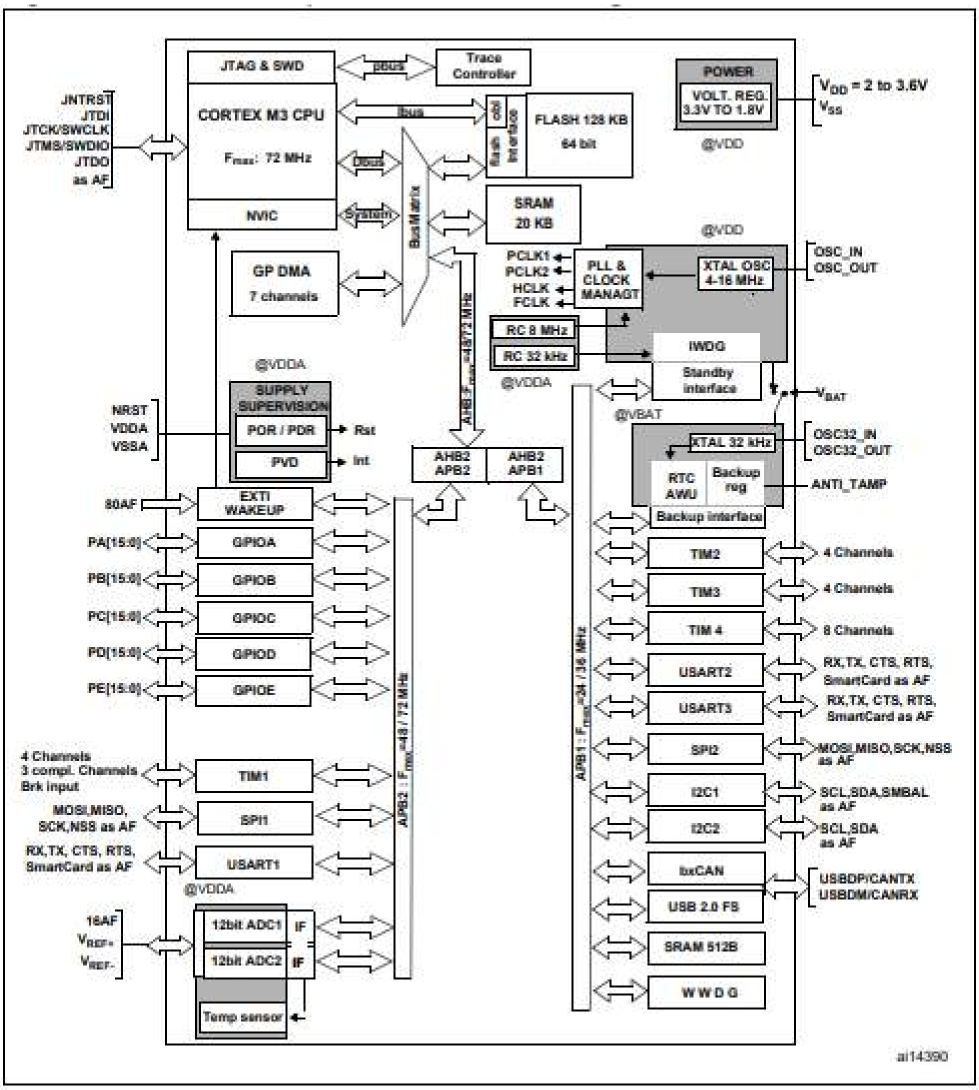

Figure 2.2. STM32F103C8 microcontroller block diagram

Figure 2.2. above block diagram show the memory map of stm32f103c8 microcontroller.

Various pins of the microcontroller were configured in this work for communication with external components the STM32F103C8 has ADC and CAN buses for interface with external hardware connections. This microcontroller has an ARM-based 32-bit MCU with a medium-density performance line, USB, 7 timers, 2 ADCs channels, 64 or 128 KB Flash memory, CAN, and 9 communication ports, its good feature make it suitable for this thesis work.

2.2. CAN Communication Circuit

The CAN bus is a highly successful communication protocol due to its high-speed capabilities, long-range reliability, and noise immunity. As a result of these factors, CAN contact has become the norm in automotive technology and high-noise situations. The CAN bus is made up of nodes, which are the devices that make it up. The CAN bus connects all nodes in parallel, which means that each node on the network is connected to every other node. Depending on the rate of message transmission, a single CAN bus can support a large number of nodes at once, but for most applications, up to 32 devices are recommended. It's also a good idea to keep the distance between the first and last nodes under 40 meters.

In this thesis, we explain how to set up a CAN node in loopback mode with the STM32F103C8 microcontroller. Figures 2.3,2.4, and 2.5 show the CAN receiver IC, schematic symbol, and CAN schematic connection, respectively.

Figure 2.3. CAN bus receiver IC structure

Figure 2.3. above show the structure of CAN transceiver SN65HVD230 used in this thesis.

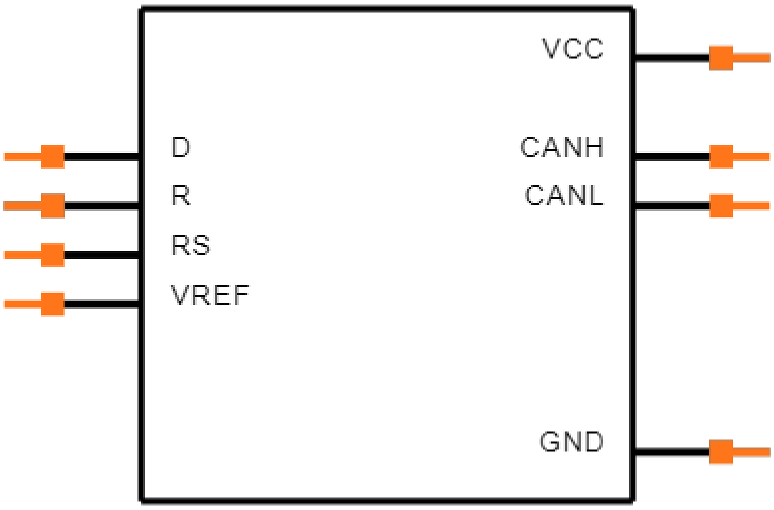

Figure 2.4. CAN bus block diagram and pins label

In figure 2.4. is the CAN bus diagram and its various pins label for connections.

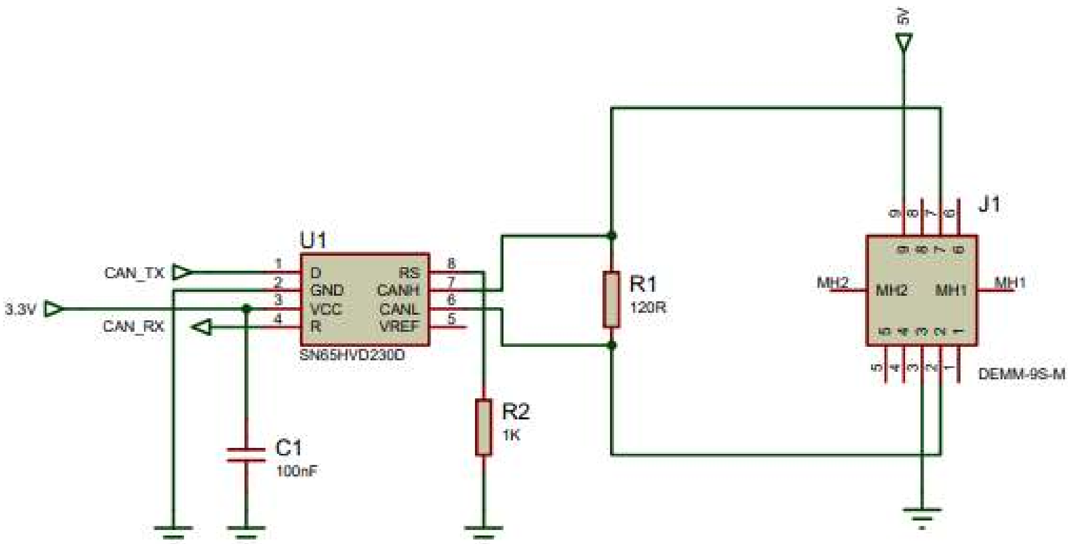

Figure 2.5. CAN bus transceiver and pins header schematic connection

Figure 2.5. is CAN bus circuit connection in a loopback mode for massage transmission.

The components that are used for the CAN implementation in this thesis are;

(I) 1 x STM32F103C8

(II) 1 x SN65HVD230D CAN transceiver IC

(III) 1 x 100nf Capacitor

(IV) 1 x 120R Resistor

(V) 1 x 1k Resistor

(VI) 1 x DEMM-9S-M CAN Connector

2.3. Temperature Measurement Circuit

In the measurement and safety of a Li-Ion battery, the NTC thermistor temperature sensor is critical. They give essential temperature data to assist Li-Ion batteries in performing at their best during the charging process. If the battery temperature is too low, the charging speed slows down, and if the battery temperature is too high, the charging speed becomes dangerous. Maintaining the right charging temperature range has the added benefit of extending battery life. The temperature of the Li-Ion battery will climb by 5 degrees Celsius (9 degrees Fahrenheit) within 2-3 hours of charging. This is a normal temperature spike that occurs throughout the charging process due to a chemical reaction. To avoid hazards, do not charge the battery beyond 10 degrees Celsius (18 degrees Fahrenheit). Temperature regulation during charging extends the life of lithium-ion batteries while lowering their risk. The ambient temperature around the battery has a significant impact on the temperature of the battery during charging. The heat created by the charging chemical reaction raises the battery's starting temperature. The charging temperature range for Li-Ion batteries is 10°C to 30°C. Overheating induced by overcurrent, overvoltage, excessive ambient temperature, or a combination of these conditions can result in thermal discharge. This is a dangerous situation that could result in a battery fire or possibly a massive explosion. To avoid thermal discharge, the battery's top temperature must not be surpassed. A method for charging Li-Ion batteries that is both safe and efficient has been devised. Advanced electronic control circuits are required in Li-Ion battery chargers to precisely manage the charging current, voltage, and temperature of the battery. Using predetermined set points and algorithms, this controller alters the charging voltage dynamically. The battery temperature is kept within the prescribed safe limits throughout the charging process. A temperature sensor installed on a Li-Ion battery is used by an analogue-digital controller, commonly known as an ADC, to provide temperature data to the controller. The controller adapts for high or low battery temperatures, extreme ambient temperatures, and entirely stops charging when the battery reaches extremely high temperatures using this input.

In high-power applications, the charge controller incorporates numerous temperature sensors embedded inside Li-Ion batteries. At least one sensor monitors each battery cell. The NTC thermistor is the sensor of choice for providing ADC temperature feedback. The charge controller controls the temperature of the battery cells individually or collectively, depending on the type of controller and the number of cells in the battery. The NTC thermistor sensor gets its temperature data via direct contact with the battery cell casing. A temperature sensor is put on the cell's electrical terminal to acquire the cell temperature. The NTC thermistor is used in this final project.

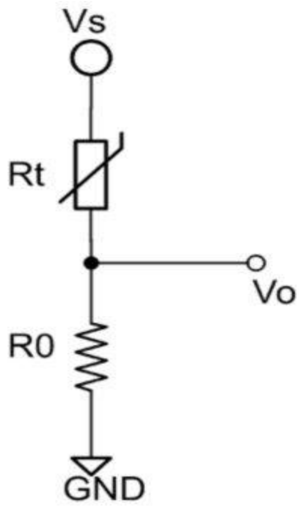

Figure 2.6. Setup of temperature measurements using thermistor and fixed resistor

The connection arrangement for temperature sensing and getting ADC values is shown in figure 2.6.

The figure above shows how the circuit connected for temperature measurement the supply voltage (Vs) is 3.3V connected in series with a thermistor resistance (Rt) which 10kΩ in our case and form a voltage divider with another 10kΩ fixed resistor in series and the middle voltage between them voltage divider (Vo) is the ADC voltage which it is connected directly to our microcontroller for temperature conversion.

2.3.1. Sensor Selection for Temperature Measurement

In Li-Ion battery charging, the right battery temperature sensor is crucial. We consider the following considerations while selecting a sensor.

(1) Accuracy: For critical temperature measurements, tight tolerances are needed.

(II) Reliability: Specifications that can be relied on and features that are consistent over time

(III) Responsiveness: The controller receives timely feedback because to the low thermal time constant.

(IV) Durability: Quality materials and accurate manufacturing ensure a long service life.

Additional considerations may be needed when selecting NTC thermistor temperature sensors for Li-Ion batteries:

. To ensure accurate measurements, the tolerance should not exceed 5% within the battery's expected operating temperature range.

. The battery environment and design decide whether the sensor will be embedded, contact mounted, or have a housing.

. Reasonable housings can provide simple and safe installation, efficient thermal conduction, and physical damage protection.

. High voltage isolation between the sensor housing and the thermistor output ensures protection and operational integrity.

In the thesis as we have monitor the temperature of the battery pack. So in the battery pack, a thermistor(NTC) was added to each battery cell in series for monitoring the temperature of each cell. For doing this we choose to used 10kΩ thermistor as a variable resistor connected in series to a fixed resistor of the same value 10kΩ to form a voltage divider and take that voltage at the middle to ADC pins of STM32 and convert the voltage to a temperature which will be displayed on LCD by using Steinhart equation.

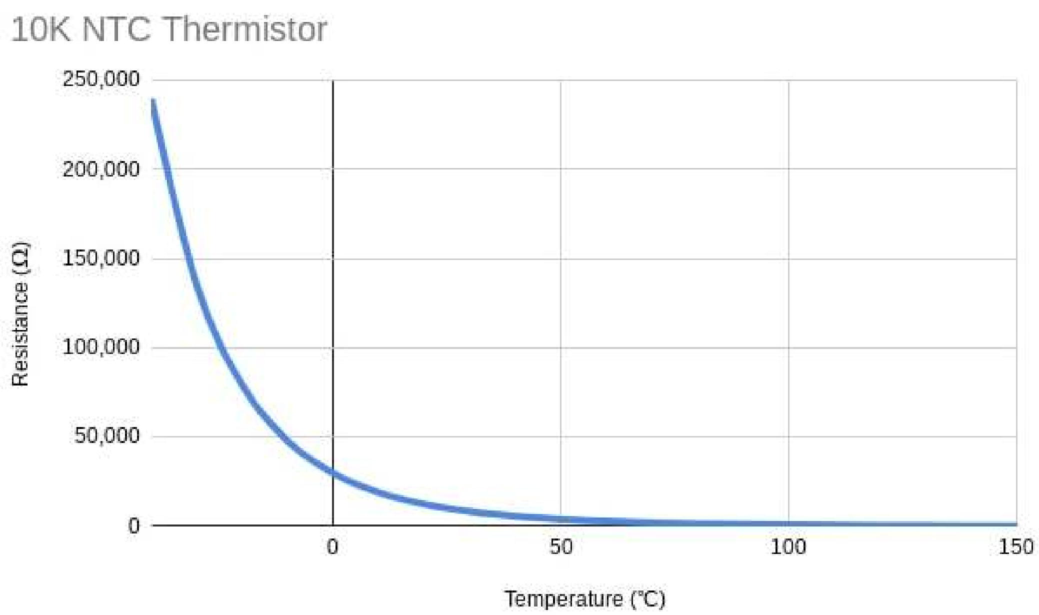

Figure 2.7. Characteristic curve for temperature respond using NTC thermistor

Figure 2.7. show temperature increased with decrease of resistance

Has seen from figure 2.7 above how the thermistor's resistance decreases as the temperature rises. If this were a resistor map, the "curve" would be a vertical line, with the resistance value remaining constant regardless of temperature. Because of this stable feature, resistors are ideal for use in electronics. A 10K resistor can often limit an electrical current to 10,000 ohms. At 25°C, a 10K thermistor, on the other hand, can only limit a current to 10,000 ohms. If the temperature is higher, say 50°C, the thermistor can only limit the current to 3,900 ohms. This temperature variability can make thermistors unsuitable for use in electronics, but they make excellent thermometers. We used NTC thermistors because they are the most common form available. This thermistor's distinguishing feature is that its resistance decreases as temperature rises. These sensors can be used in a number of industries, including HVAC, product processing, transportation, appliances, and many others. A thermistor produces residual heat as a byproduct of resisting current. A correction may be applied to sensed values to preserve accuracy if an NTC thermistor is known to work in temperatures that cause substantial heat. This self-heating effect can also occur at low temperatures with NTC thermistors, where it can dissipate much more readily into the surrounding process.

To determine the temperature, we must first determine the resistance. A microcontroller, on the other hand, does not have a built-in resistance meter. Instead, it only has an analogue-digital-converter, which is a voltage reader. As a result, we'll need to convert the resistance to a voltage, which we'll achieve by connecting two resistors in series. All we have to do now is calculate the voltage in the Centre, and thanks to the voltage-divider equation, as the resistance grows, so does the voltage. There is only one resistor that has to be replaced. The ADC resolution of our microcontroller is 12-bit (4096) and the reference voltage is 3.3V figure 2.8 blew show the NTC thermistor.

Figure 2.8. 10KΩ NTC thermistor resistor using for temperature measurement

Figure 2.8 Show NTC thermistor it can be used in battery pack temperature sensing.

2.4. Current Measurement Circuit

Current sensing has long been an important aspect of battery management systems (BMS), which track and protect high-capacity batteries. In both lithium-ion and sealed lead-acid batteries, current measurements are utilized to protect the battery from overuse and assure its safe operation by allowing for emergency shut-down in over-current situations. The accuracy of current measurements can be reasonably poor for security and safety functions alone. The over-current conditions which be defined conservatively by the device designer so that the safe shut-down threshold is not crossed even if the existing sensor grossly underestimates it. But in this study we only consider the current sensing of each cell to display those currents on LCD for user reference and know about the current conditions of the batteries, LM358P the operational amplifier (OP-AMP) were used as a current sensor. However, in some applications, existing sensing standards are becoming even more stringent. Manufacturers of electric vehicles, in particular, are working hard to improve their efficiency and attract customers to electric vehicles. The driver is concerned about the accuracy of the EV's "fuel gauge," which is the SOC measurement that indicates how much energy is available for use. The accuracy of an electric vehicle's fuel gauge that is, reading the SOC, which shows how much energy is available for use — is critical for the driver. Distant anxiety is one of the main barriers for customers to use electric vehicles, so the accuracy of an electric vehicle's "fuel gauge" that is, reading the SOC, which shows how much energy is available for use is critical for the driver. The BMS can optimize the activities of electric vehicles and industrial equipment for a long life by keeping the SOC value between 0 and 80% using accurate SOC monitoring.

Each battery cell is connected in parallel to the load resistor 47Ω except for the fourth cell that has 100Ω and 0.22Ω shunt resistor in series each, the LM358 non-inverting terminal is connected to the middle of load and shunt resistor which form a voltage divider, the inverting terminal is connected to 4.7KΩ which is connected to ground and feedback resistor 22kΩ from the output of LM358 a 1KΩ is connected in series to the output of LM358 then 0.1uF capacitor as filter as shown in figure 2.9.

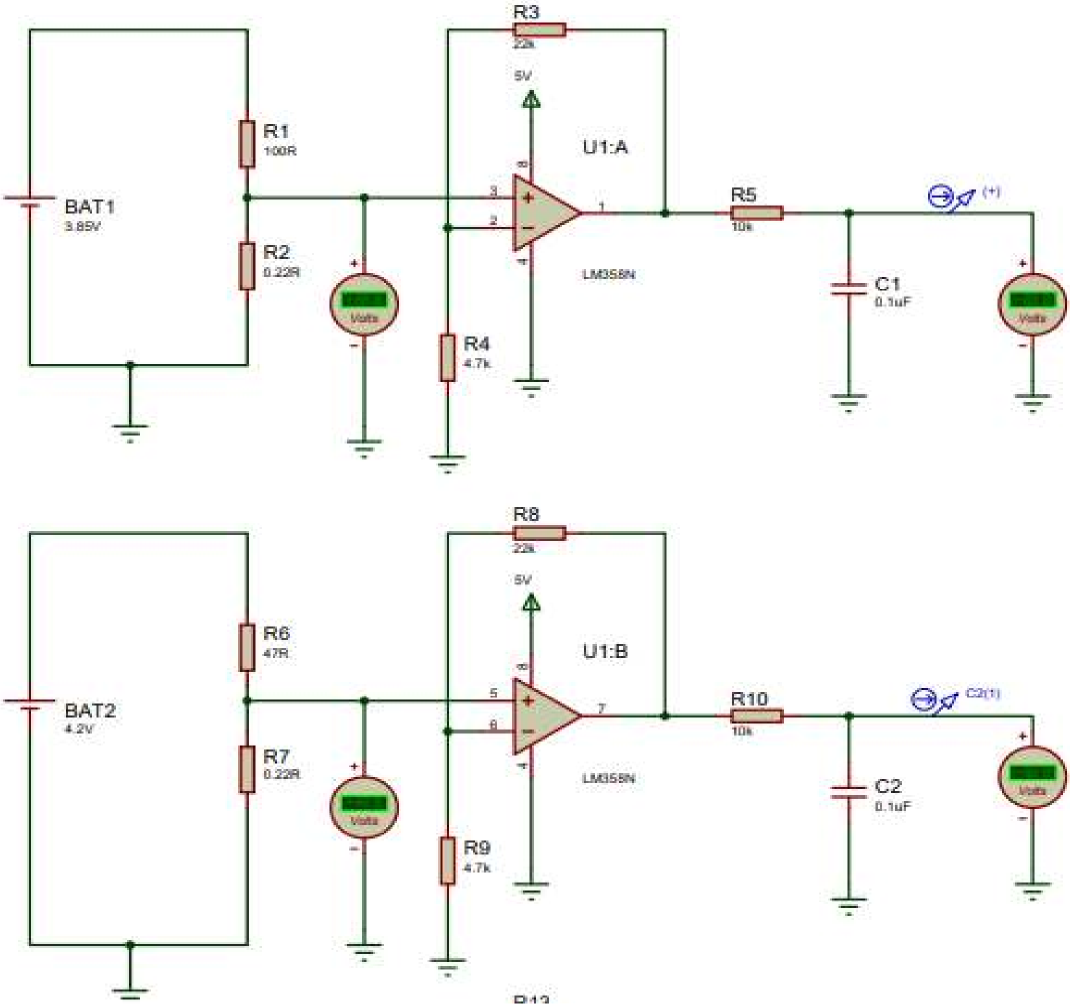

Figure 2.9. Current measurement circuit

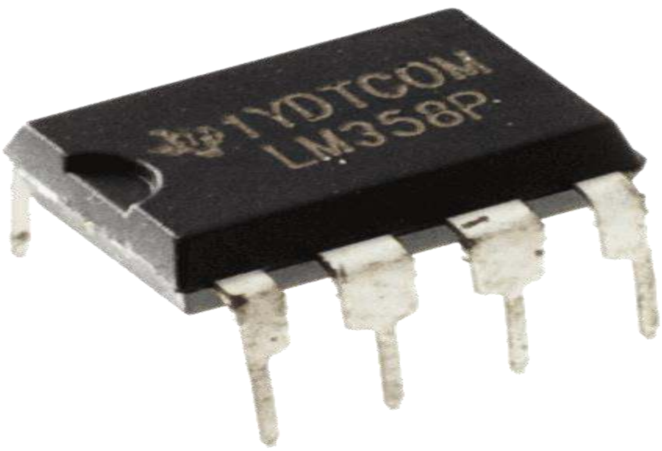

Figure 2.10. LM358

The output voltage after amplification we make sure it doesn’t exceed 5V because if the voltage is more than 5V microcontroller may get damaged, the LM358 as shown in figure 2.10 above and components needed to form the circuit for voltage measurement are;

(I) LM358

(II) Capacitor 0.1uF

(III) Load Resistor 3.3Ω

(IV) Shunt Resistor 0.22Ω

(V) Feedback Resistor 22KΩ

(VI) Resistor 4.7KΩ

2.5. Voltage Measurement Circuit

It's simple to measure the voltage of a single battery or a whole bank of batteries with any microcontroller. Many studies on how to do so can be found. But what if we want to calculate a single battery that is connected to a group of batteries in series or parallel? It will now be a difficult task to complete. There are, however, some creative approaches to this. Several methods for measuring the voltage of individual batteries in a sequence of strings/elements connected in series or parallel are described in this thesis. The initial step for BMS would be to figure out what state the lithium battery cells are in right now. This is accomplished by computing the voltage and current of the cells in the package (as well as their temperature, as previously described). SOC or SOH can be measured by BMS, and these two values can be used to balance cells. We can learn how to compute the individual voltage of lithium battery cells in this thesis. To complete the project, we'll utilize eight 18650 lithium cells connected in parallel to create a battery pack, and we'll use op-amps to create a basic circuit that calculates each cell's voltage and displays it on an STM32 LCD panel.

Calculating the voltages of individual cells in a series-connected battery is difficult because the reference point remains constant. Assume that the four cells are at 4.2 V and are therefore lighter. When we use a microcontroller like the STM32 to test the cell voltage, we can easily measure the voltage of the first cell because the other end is linked to the ground. Other cells, on the other hand, must be measured in relation to the previous cell's voltage; for example, while calculating the voltage of the fourth cell, we must measure the voltage of all four cells at the same time. This is a concern since the reference point cannot be moved off the ground. As a result, we'll need to build more circuits to aid in the calculation of particular voltages. The simplest method is to map the voltage levels with a potential divider and then compute them, however, this study will improve the read value resolution to more than 0.1V.

We already know that Op-Amp returns the difference between the two values of the voltage applied to its inverter and non-inverter pins when employed as a differential amplifier. To measure the voltage of four cells, we'll need two optional differential amplifiers OPA4197. Figures 2.11 illustrate a complete circuit diagram for multicell voltage control in a lithium battery pack utilizing OPA4197. Proteus was used to design the circuit, and it will also be used to create PCBs for the full BMS system.

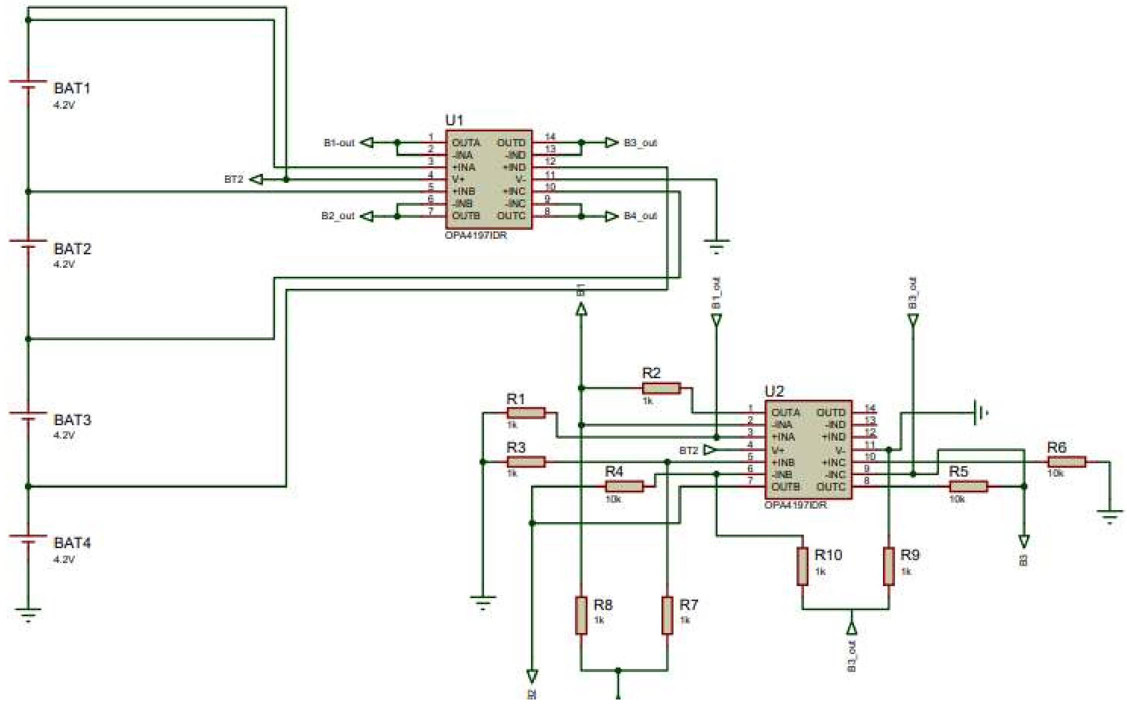

Figure 2.11. Voltage measurement circuit.

Figure 2.11. Show how to connect the OPA4197 differential amplifier measuring voltages of four cells.

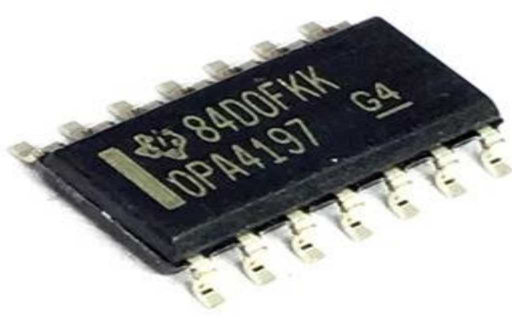

Figure 2.12. OPA4197 OP-AMP structure used for cell voltages measurement

Figure 2.12 show the OP-Amp used in this thesis for voltage monitoring of the cells in the battery pack.

Our circuit uses two OPA4197 high voltage four-band Rail to Rail op-amps, both of which are powered by the package's full voltage, as mentioned above. One IC U1 is utilized to make a voltage tracking or buffer circuit, while the other U2 is used to make a differential amplifier circuit. To prevent the cells from being loaded independently, a buffer circuit is necessary, which assures that no current may be taken from a single cell but only from the packet as a whole. Because the buffer circuit has a relatively high input impedance, we could previously read the voltage of the cell without draining energy from it. The voltage of the four cells is buffered by IC U1's four configurable amplifiers. The cells' input voltages are labelled B1 + to B4 +, while the buffered output voltages are labelled B1 out to B4 out. This buffered voltage is sent to a differential amplifier, which examines the voltage of each cell, as previously mentioned. All resistors are set to 1K because the differential amplifier's gain is set to the unit. Except for the two resistors that make up the voltage divider, any resistance value can be used if the voltage of the package is to be derived directly from the battery, which is not taken into account in this case. These two resistors form a potential distributor, allowing us to equalize the packet voltage of the battery and the number of voltages in the measuring cell.

The above circuit necessitates the use of a high voltage Rail to Rail amplifier, such as the OPA4197, due to two factors. Both Op-Amp integrated circuits operate at a maximum package voltage of 16.8V, implying that the Op-amp must be capable of handling high voltages. Also, because we're using a buffer circuit, the buffer's output voltage must match the packet voltage for the fourth cell terminal, which means the buffer's output voltage must match the operating amplifier voltage. As a result, we'll have to use the Rail-to-Rail amplifier that's available. The following components are required for the voltage measurement circuit to be implemented in this final project:

(I) 2 x OPA4197

(II) 10 x Resistors 1KΩ

2.6. Cell Balancing Circuit

Cell balance is a technique for achieving the best battery performance by maintaining the voltage level of each cell that makes up the battery. When multiple cells are united to produce a battery, it must always be verified that their chemical value and voltage are the same. The voltage levels in each cell begin to vary after the package has been built, filled, and unloaded for various reasons that will be described later. This voltage differential causes cell imbalance, which results in heat degeneration, cell degeneration, a lack of charge, and a lack of energy consumption.

A nominal lithium cell used in this study is rated for about 3.7V but can be charged up to 4.2V, but in applications such as electric vehicles, laptops, power banks and portable electronics, we need a lot more voltage than that. This is why we connected numerous cells in series and parallel in this prototype BMS to build a battery pack with greater voltage values. The voltage is increased when two or more batteries are linked in series. Eight 4.2V lithium cells are connected in series/parallel in this project, two in parallel and four in series, providing a 16.8V effective output voltage.

In this thesis, a passive balancing method was adopted. The simplest approach is the passive cell balancing method. It can be used in situations where space and expense are important considerations. In this setup, a load, such as a resistor, is employed to discharge the surplus voltage and balance it with the other cells. These resistors are known as bypass resistors or bleeding resistors. Each series-connected cell in a pack will have its own bypass resistor connected via a MOSFET switch, as shown in figure 2.13[45].

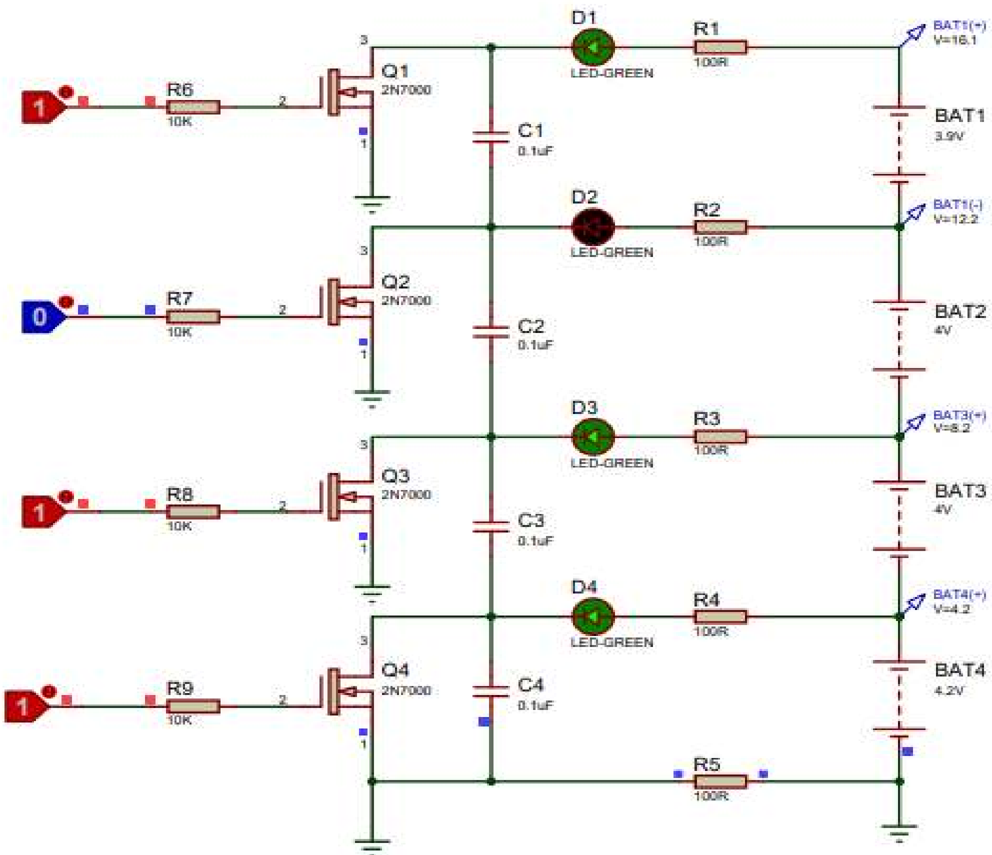

Figure 2.13. Passive cell balancing circuit connection.

Figure 2.13. The balancing circuit design to equalize the pack batteries to the same SOC.

Each of the four cells in the above test ring is connected to two bypass resistors using switches, such as the MOSFET. The controllers calculate the voltage in each of the four cells before turning on the MOSFET for the cell with the greatest voltage. The cell in issue begins to slide out of the resistors when the MOSFET is turned on. Because we know the resistance value, we can estimate how much load is dispersed in the cell. The capacitor linked to the parallel cell is used to filter voltage peaks during switching. As we can see from the simulation result the voltage value of battery cells in the simulation is different but when running the simulations voltage prove shown that the circuit was trying to balance the four-cell with help of the microcontroller. The components needed to implement the balancing circuit used in this thesis are;

(I) STM32f103c8

(II) 4 x Resistors 100Ω

(III) 5 x Resistors 10KΩ

(IV) Capacity 0.1uF

(V) 4 2N7000 MOSFET

2.7. Charging and discharging Circuit

This circuit, like the battery control unit's electrical control unit in this study, regulates the charging and load of the battery pack. Two MOSFETs IRF540 and 2N6845 were utilized, one to regulate the charging process and the other to regulate the load process. Two FETs were used to isolate and connect the battery between the charger and the load, and a diode was used to prevent the flow of energy from the battery to the charger. The connection was formed between the Q2 and Q3 MOSFETs, which are used for load and charge control, respectively. Voltage Q3 is a monitor, if the charger is connected and the battery is isolated from it, the current injected into the battery will cause the voltage to increase to the maximum supply voltage of the charger. which informs the BMS that a charger is available. A current is injected into the load to test if there is a load, and then the Q3 driver is started to determine the charging connection. The charging and recharging circuit is shown below.

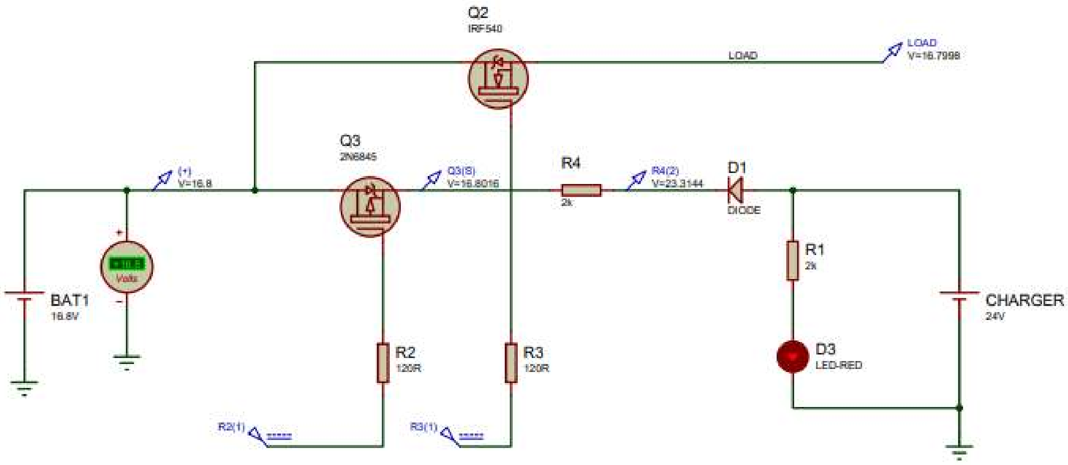

Figure 2.14. Load and charging circuit connection

Figure 2.14 shown the charging and discharging circuit for connection and isolation between load and charger.

2.7.1. Voltage Regulator

A voltage regulator is an electrical or electronic system that keeps a power source's voltage within safe limits. The 7805 and LM1117T voltage regulators are used in this study to keep voltages within the specified range that can be handled by the electrical equipment that uses that voltage. As previously mentioned the Battery pack used in this study has a total of 16.8V as a prototype so we used the voltage regulators to stepdown the voltage 5V and 3.3V because some of the electronic components used need 5V to carried their operation while the Microcontroller (STM32) needs only 3.3V for its operation in the circuit. The circuit connection of the voltage regulators used is shown in the figure below.

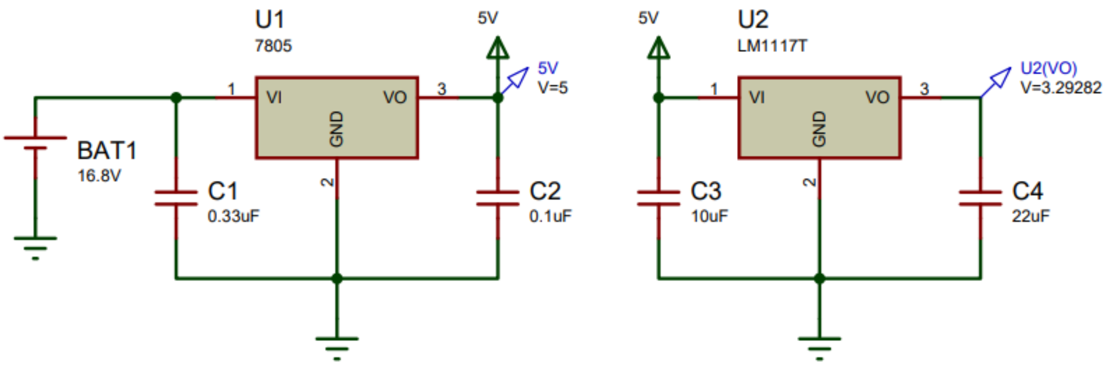

Figure 2.15. LM7805 for 5V and LM1117T for 3.3V voltage regulators connections

Figure 2.15 shown the LM7805 and LM1117T voltage regulators output respectively.

2.8. Battery Management System Circuit

The schematic architecture was completed in accordance with the specifications of the battery management system (BMS). Electronic components were chosen for the system's operating functions, and designs were created using reference documents for similar components. The circuit was designed in Proteus 8 Professional, and the complete circuit is shown below.

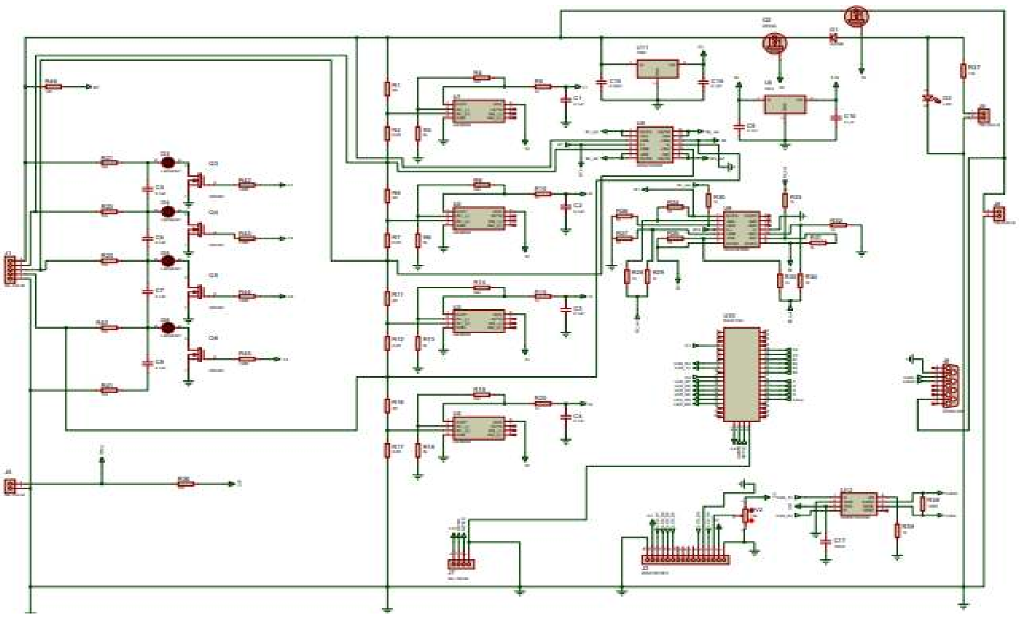

Figure 2.16. Battery management system circuit diagram

Figure 2.16 Is the entire BMS circuit design of this thesis for battery control and monitoring.

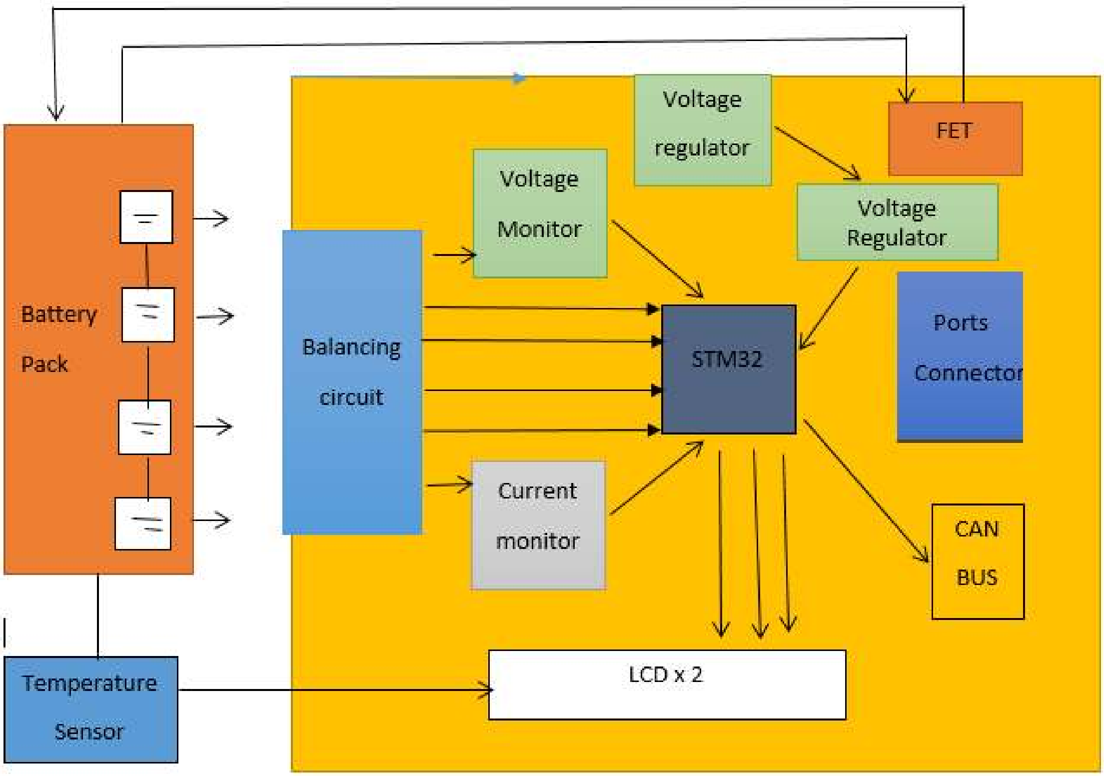

Figure 2.17. BMS general circuit block diagram connection

Figure 2.17. Shown the various blocks components used to made up this BMS design.

2.9. Design of PBC and Assembly

Proteus 8 Professional was used in this project for both the schematic circuit and the PCB design, as previously mentioned. There were two layers to the PCB and design. Following the completion of the schematic design, the necessary PCB sizes, material positioning, and connections based on the schematic design were defined. Based on current constraints, transitions between layers were set to acceptable sizes. The bottom layer was designated as the ground in each PCB configuration, and this layer was divided appropriately to disperse heat during operation. The PCB layout, the upper layer, down layer and 3D the view is shown in Figure 2.18,2.19,2.20 and 2.21 below.

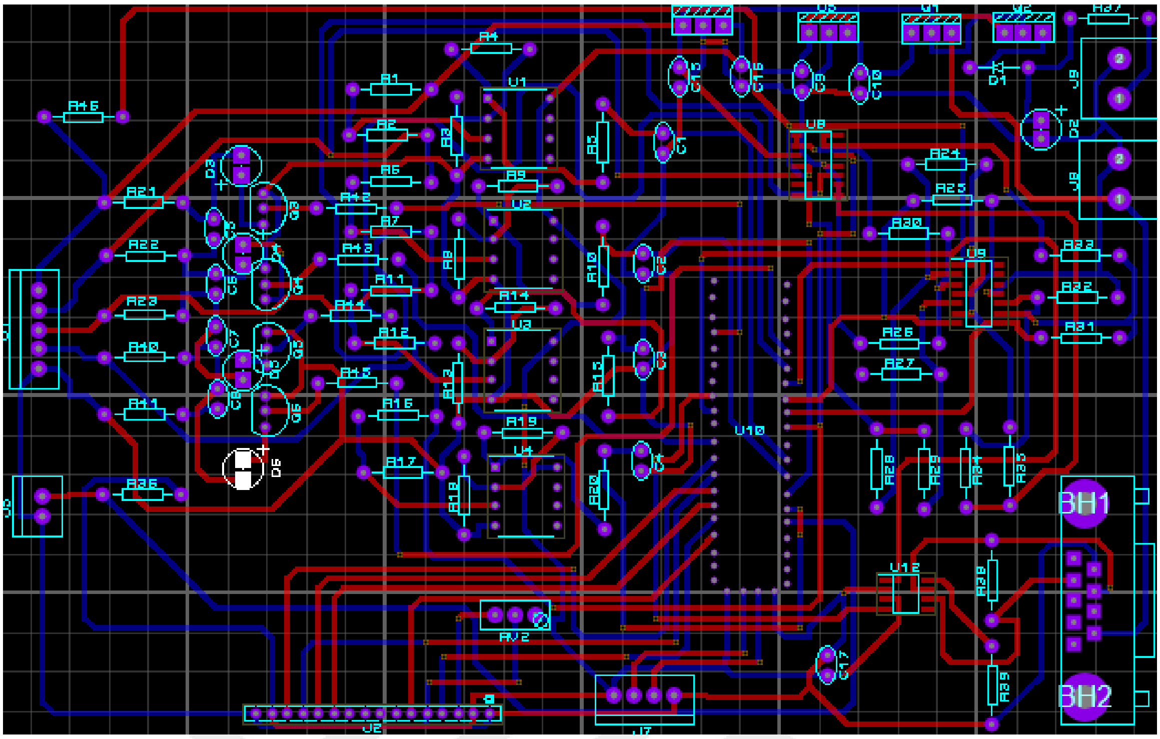

Figure 2.18. BMS PCB two-layer view

In figure 2.18. the red connections are live connections rails and blue is neutral rails of the PCB

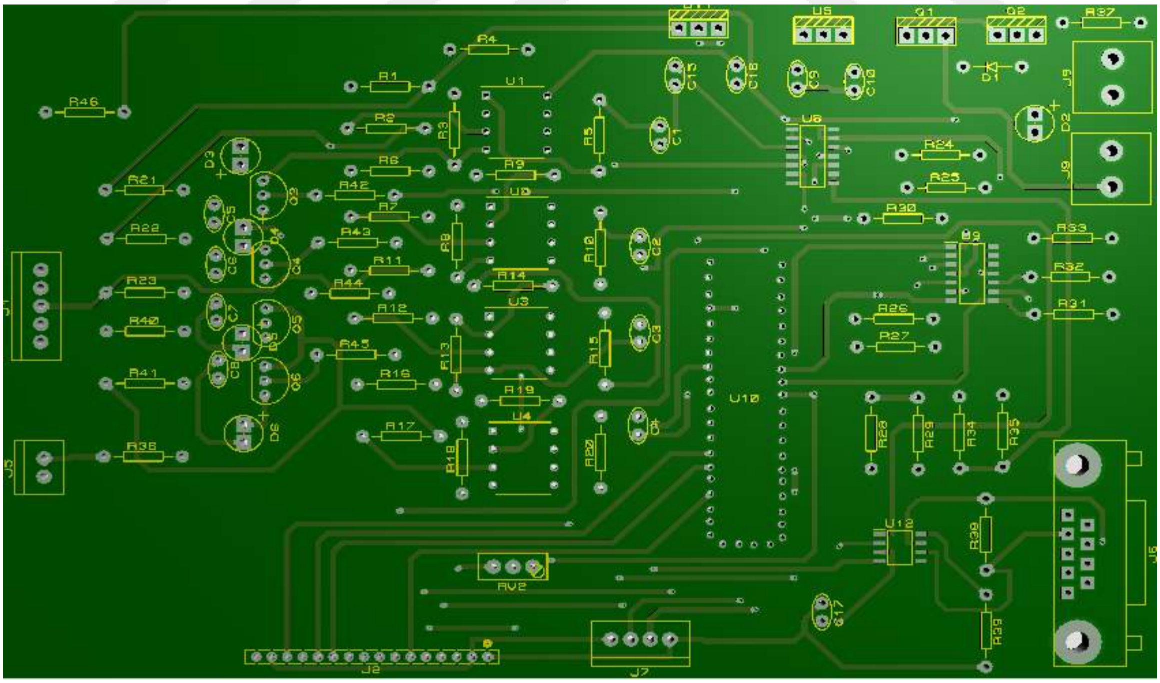

Figure 2.19. PCB upper layer view

Figure 2.19. Shown the surface layer of PCB for placing the circuit components

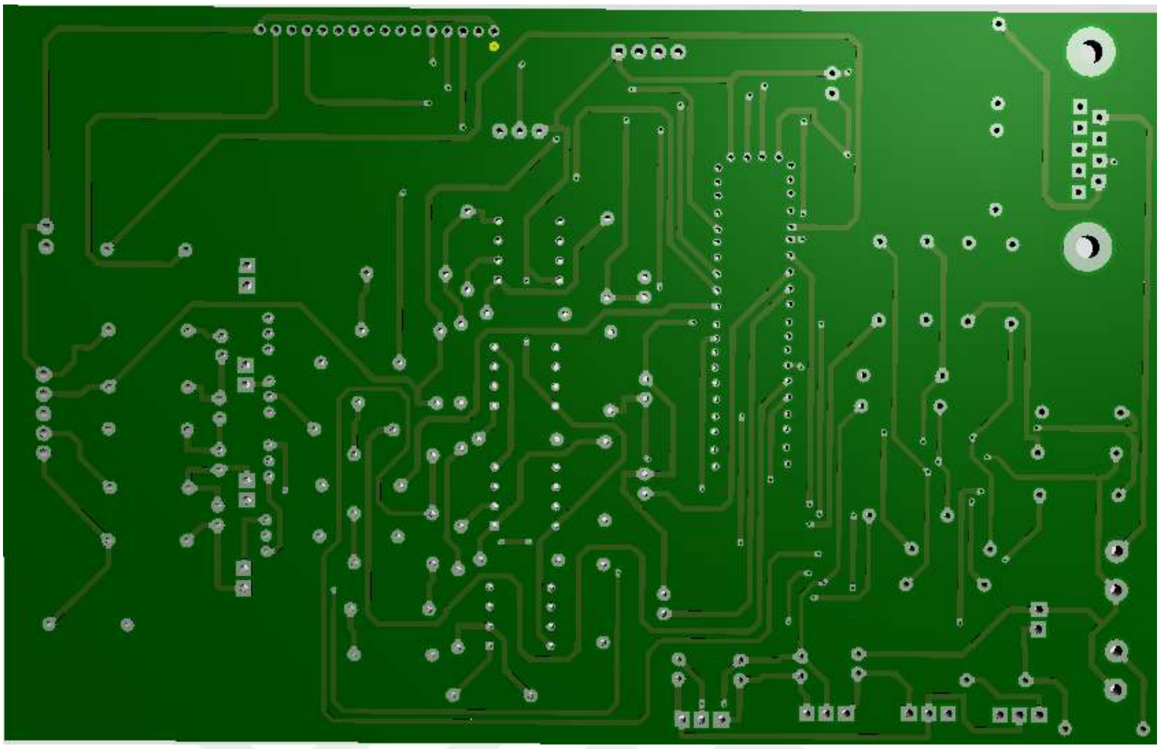

Figure 2.20. PCB down layer view

Figure 2.20. Shown the button layer of the PCB for soldering the components

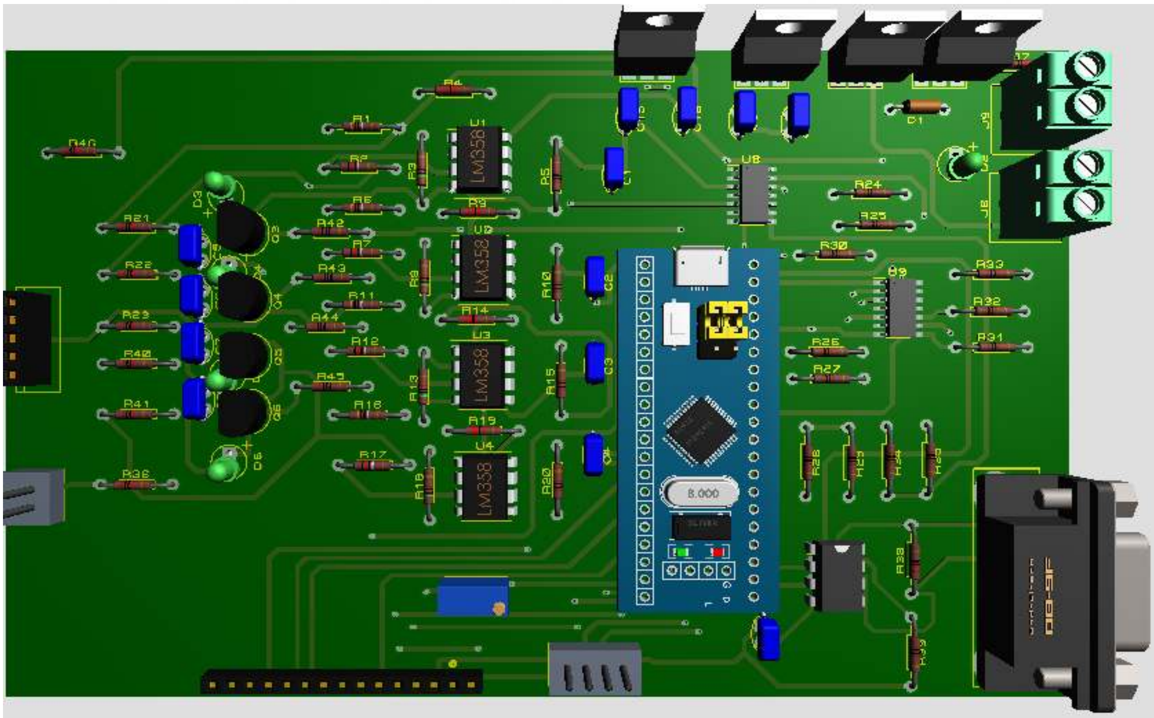

Figure 2.21. BMS 3D view general view

Figure 2.21. Shown the BMS view after the completion of the final circuit.

2.10. Software Function

The software used is STM32cubeMx to configure the various pins used by different components used in the system for BMS and Keil ARM µvision5 for the programming of the system. The program is meant to control a sequence of eight batteries connected in parallel to form a four-cell lithium-ion battery cell module. The voltages of up to four lithium-ion battery cells are continuously monitored by the system. The microcontroller has 10 ADC channels in which 9 0ut of 10 were used, 4 channels were used for voltage measurement, another 4 ADC channels were used for current measurements of the cells and one channel for temperature measurement of the battery pack. We used 4 GPIO channels for the cell balancing control by the microcontroller and CAN be also included in the system as well as Liquid Crystal Display (LCD). All the pins of the microcontroller are configured using Stm32cubeMX, St-link utility is used to debug the code into the microcontroller and Proteus professional 8 were used to design the hardware circuit. The algorithm was developed to check on the cells voltages, current and to detect the faulty cell and displayed on the LCD to notify the user.

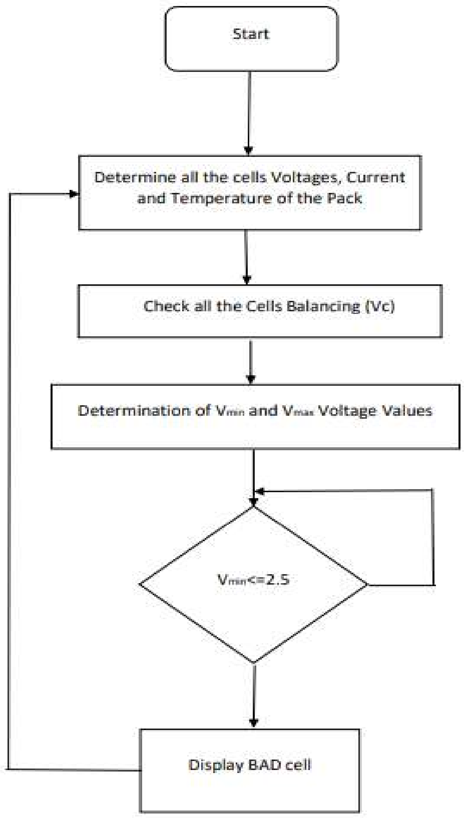

Figure 2.22. Algorithm implemented for cell balancing and fault detection

Figure 2.22. Shown steps followed in the programming of the microcontroller.

3. RESULTS

In this chapter we are going to discuss the result we obtain in this thesis, all results of the various part that made up the BMS design in simulation and practical work will be presented in this chapter.

3.1. Power Supply of the Circuit

In this design the circuit components are using 5V and 3.3, voltage regulators 7805 and LM1117T were used to regulate the voltage to the desired voltage of the various components of the circuit as shown below.

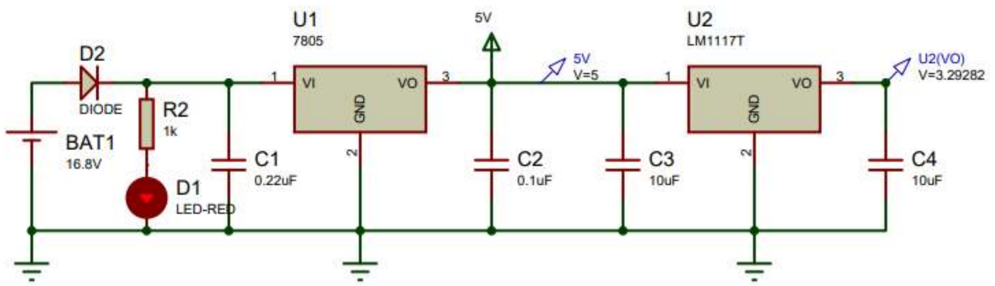

Figure 3.1. Power supply of the BMS circuit

Figure 3.1. Show the connections between LM7805 and LM1117T voltage regulators.

A capacitor 0.22uF was added at the input of 7805 voltage regulator, which is going to help smooth out interruption to the supply and also law frequency distortion and 0.1uF capacitor at the output of the regulator are to filler the voltage. For the input and output of the LM1117T voltage regulator, we used a 10uF capacitor for both sides as described by the manufacture in the datasheet. A protection diode was added at the input side this help protect the circuit if we connect the power supply from the battery pack in the wrong way we added a 10K resistor in series with Red LED to determine the presence of a power supply to the circuit. The 5V and 3.3V are achieved from the output of both the regulators.

3.2. STM32f103C8 Microcontroller

The Stm32f103c8 Blue Pill, as previously mentioned, is a development board based on the ST Microelectronics STM32F103C8 microcontroller, which includes an ARM Cortex-M3 core that works at 72MHz max. This microcontroller was a program by using Stm32cubeMX, Keil IDE and St-link software libraries in this work. The following tables are the blue pill pin configuration table and technical configuration table.

Table 3.1. STM32F103C8 microcontroller pins configuration.

Category	Pin Name	Details
Supply power	GND, 5V, 3.3V	• 3.3V – The chip can also be powered by the onboard regulator's regulated output voltage (drawing current is not recommended). • The onboard 3.3V regulator can be powered by 5V from USB or the onboard regulator. • GND – Ground pins
Input and output pins	PA0 – PA15 PB0 – PB15 PC13 – PC15	37 GPIO Pins
Analog Pins	PA0 – PA7 PB0 – PB1	ADCs with a 12-bit resolution are used on the pins.
External interrupts	PA0 – PA15 PB0 – PB15 PC13 – PC15	Interrupt functionality is available on all digital pins.
Serial	TX1, RX1 TX2, RX2 TX3, RX3	RTS and CTS pins on UART
PWM	PA0 – PA3 PA6 – PA10 PB0 - PB1 PB6 – PB9	There are a total of 15 PWM pins.
SPI	MISO0, MOSI0, SCK0, CS0 MISO1, MOSI1, SCK1, CS	2 SPI
Inbuilt LED	PC13	As a GPIO indicator, an LED is used.
I2C	SCL1, SDA1 SCL2, SDA2	Communication ports on inter-integrated circuits
CAN	CAN0TX, CAN0RX	CAN bus ports

Table 3.1. Explain the various pins of Stm32f103c8 microcontroller functions.

Table 3.2. STM32F103C microcontroller technical configuration and its pins detail

Microcontroller	**STM32F103C8**
Operating voltage	3.3 Volt
Digital Input and Output pins	37
ADC pins	10
Flash memory (KB)	64/128
DC source from Input and Output pins	6mA
Communication	I2C CAN, UART ,USB, SPI
Frequency (clock speed)	72MHz max.
SRAM	20KB

In table 3.2. Is the Stm32f103c8 microcontroller feature detail information.

3.3. Temperature Measurement

As previously mentioned the thermistors were palace in the Battery pack to sense the present temperature of the pack. 10KΩ NTC thermistors were used connected in series to the same value of fixed resistor of 10KΩ the first end of the fixed resistor to establish a voltage divider, one end is directly linked to the ground and the other end is attached to the first end of the thermistor. In which it's connected directly to the Pin PA0 of microcontroller (STM32) blue pill, the last than of the thermistor is connected to the 3.3V of the microcontroller as shown in the figure 3.2 below.

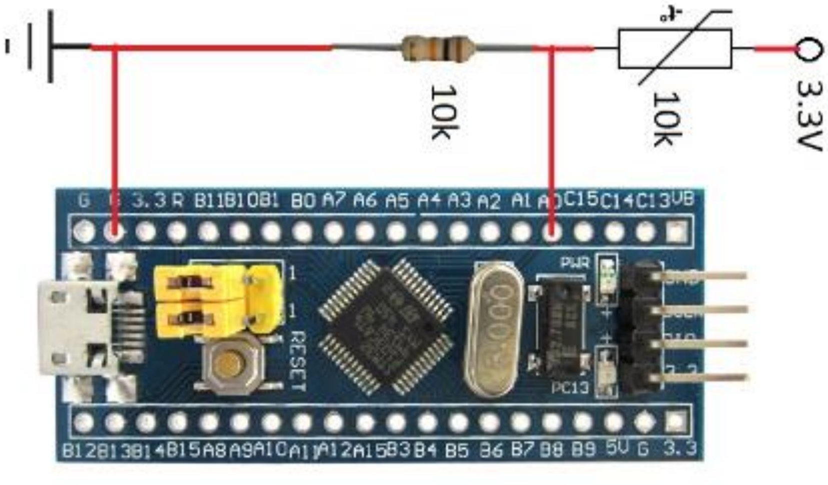

Figure 3.2. Temperature sensor circuit connection using stm32 microcontroller

Figure 3.2. Shown the connection between stm32 blues pill and thermistor for battery pack temperature measuring in this thesis.

Temperature monitoring is one of the most crucial aspects of battery maintenance, to measured temperature one as to be known of some parameters from the sensor datasheet or to carry some Lab experiment to find the parameters of that particular sensor in our case we used MF52A103J3950 NTC the Beta value of this thermistor is 3950 from the datasheet, the information given by the manufacture of this NTC are shown in the table below.

Table 3.3. MF52A103J3950 NTC thermistor parameter for temperature sensing.

Brand	**Nanjing Sheheng elect**
Resistance in ohm @ 25C°	10K
Resistance Tolerance	±5%
B25/50	3950
B Value Resistance	±1
Power (watts)	50mW
Package/Case	Through Hole, P=1.7mm

In table 3.3. The information from the datasheet of the NTC thermistor used in the battery pack is shown.

Considering the above table parameters, by using the following B-Parameter in equestions (1) and we can use Steinhart equestions (2).

$$\frac{1}{T} = \frac{1}{T_0} + \frac{1}{B} ln + \left(\frac{R}{R_0}\right) \quad (3.1)$$

To is room temperature 25 °C = 298.15 K, B from the table above is the (thermistor coefficient, 3950 in this case, and resistance at room temperature (Ro), which is 10KΩ. R is the measured resistance and get T is the temperature in kelvin, which is simple to convert to degrees Celsius.

$$\frac{1}{T} = A + BlnR + C(lnR)^3 \quad (3.2)$$

Where

T is in Kelvin

R is resistance of the temperature in degree Celsius

A, B and C are Steinhart Co-efficient.

In this study, we used the B-parameter question 1 above because the Beta values were already being given to us by the manufacturer, for we to use the second question 2, above we need to carry out some experiment to record the temperatures and resistances at three different temperatures changes maybe to take the resistance of the thermistor at temperature of 5°C,25°C and 35°C, then add three pairs of resistance values and temperatures to the equation to form three equations and put them in a matrix to calculate the values of A, B, and C. in Steinhart question.

For good temperature sensing, we have to determine the actual values of the fixed resistor and the thermistor as well because the resistor generally has a tolerance. We measured our 10KΩ fixed resistor with a multimeter and found that its 9.95KΩ. to know the actual resistance value of the 10KΩ thermistor resistance (Rt) we made up some connection on the breadboard at 24°C as follow.

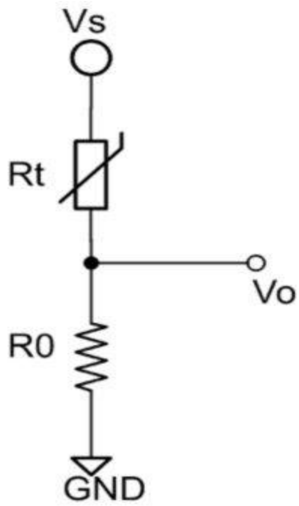

Figure 3.3. Thermistor resistance measurement circuit connection

Figure 3.3. Shown how to make the laboratory connections for finding the ADC values.

Supply voltage (Vs) = 3.3V;
Fixed Resistance (Ro) = 9.95KΩ;
Voltage divider (Vo) =1.57V
Thermistor resistance (Rt) =?
ADC resolution = 12 bit
To find the actual value of the thermistor (Rt); we have to find the voltage value at point (Vo) by using Voltmeter.

$$Vo = \frac{Ro}{Ro+Rt} \tag{3.3}$$

$$Rt = \frac{R(Vs-Vo)}{Vo} \tag{3.4}$$

By using equation 4 above

$$Rt = \frac{9.95k\Omega(3.3-1.57)}{1.57} = 10.96K\Omega = 10{,}960\Omega\ at\ 24°C$$

3.3.1. ADC values

The ADC values base on the data collected from the laboratory measurements are;

$$ADC\ Voltage = \frac{Vs}{ADC\ bit} = \frac{3.3V}{2^{12}} = \frac{3.3}{4095} = 0.805mV \tag{3.5}$$

$$ADC\ Values = \frac{Vo}{ADC\ Valtage} = \frac{1.57}{0.805mv} = 1950 \tag{3.6}$$

The temperature values in Celsius and Kelvin display on the LCD and we used STMstudio also and watched the present temperature values. Shown in the figure below.

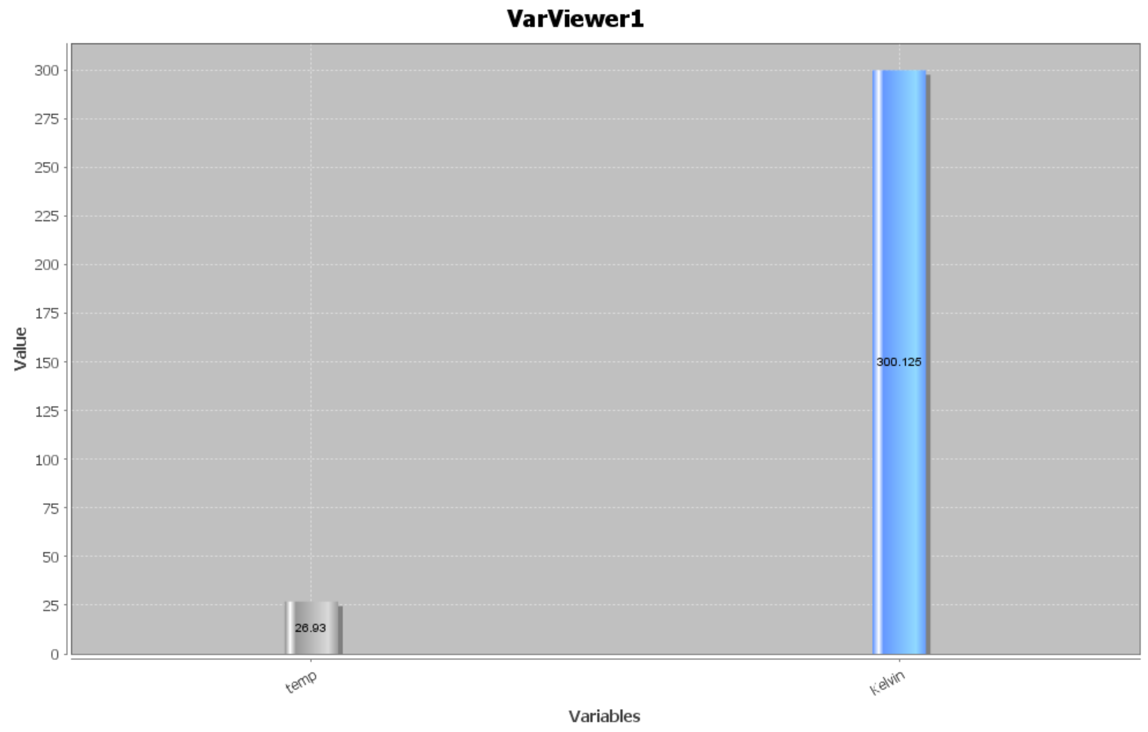

Figure 3.4. Temperature values view of the battery pack in celsius and kelvin from STMstudio

Figure 3.4. Shown the temperature of the battery pack in celsius 26.93°C and kelvin 300.125KΩ.

3.4. Current Measurement

In this study, we used Op-Amp (Non-inverting amplifier) by using a shunt resistor and measured the DC current. We have a voltage source which is our battery pack each stack in the pack has two batteries in parallel which we consider has on the cell since the voltage of each battery stack in parallel are equal to voltage. We connected our 8 battery pieces in parallel and series connections to form the battery pack used in this study. We used LM358P operational amplifier and measured each cell DC current through a shunt resistor. A shunt resistor is a resistor that is usually used for measuring the current through load it is a very small value resistor so it reduces the power rating of that resistor and also the voltage drops across it so the value of the shunt resistor in our case is 0.22Ω and the load Resistors are 47Ω for cell 1,2 and 3 while the fourth cell we used 100Ω because the fourth cell it's a higher voltage potential as shown in figure 3.5.

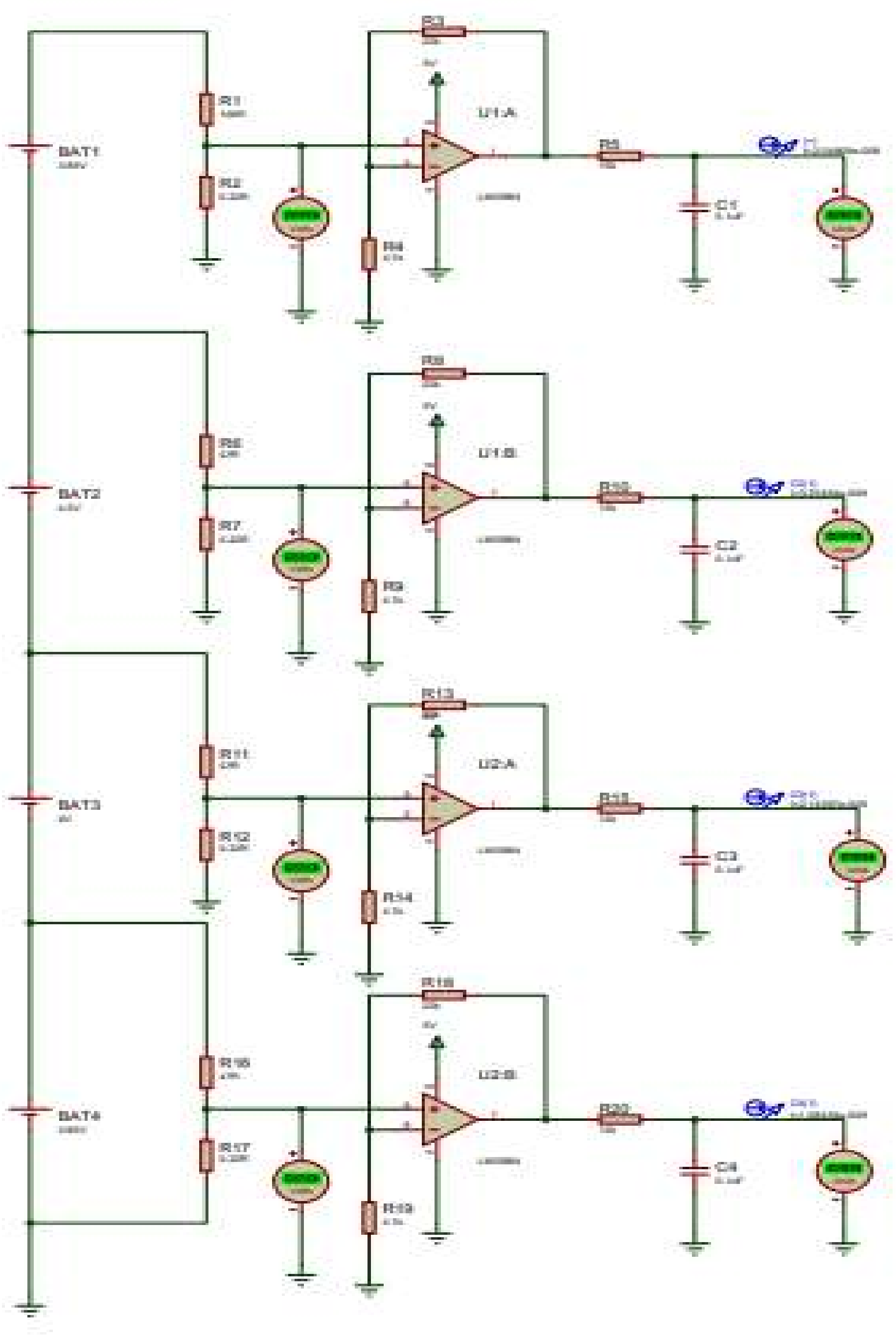

Figure 3.5. Current measurement circuit

Figure 3.5. shown the current sensing circuit for the four battery cells current measurement.

The connection of the current measurement circuit, as shown above, has been made to make sure that the output voltage of the circuit to the microcontroller does not exceed 5V because when the output voltage reaches 5V it may get to damage the microcontroller; the output is then connected to the ADC pins of the microcontroller and converted that voltage to current. So we attached a 4.7KΩ resistor to the ground and inverting terminal of the Op-Amp, then to the feedback resistor (Rf), which is 22kΩ. The Op-non-inverting Amp's terminal is linked to the load, and the shunt resistors combine to form a voltage divider, which is connected to the voltage source. 0.1uF capacitor was connected in the OP-Amp output as filter capacitor and 10KΩ resistor as load. After the connection has been made from the simulation result the output voltage does not exceed 5V for each cell to confirm that we have made some small calculations to find our output voltage theoretical to avoid damage to our microcontroller.

3.4.1. Verification of the OP-Amp Output Voltage

Cell_1

Load resistor (RL) =47Ω;

Shunt resistor (RS) = 0.22Ω;

Feedback resistor (Rf) =22kΩ;

In resistor (Rin)= 4.7KΩ;

Voltage (V)= 4.2 at fully charge;

Voltage drop (Vd) across the Shunt resistor (Rs);

$$Vd = \frac{(V * Rs)}{(R_L + Rs)} = \frac{(4.2 * 0.22)}{(47 + 0.22)} = \frac{0.924}{47.22} = 0.195V$$

Load Current (IL)

$$I_L = \frac{V}{R_L} = \frac{4.2}{47} = 0.09A$$

$$Gain = 1 + \left(\frac{Rf}{Rin}\right) = 1 + \frac{22k\Omega}{4.7k\Omega} = 5.68$$

Shunt resistor power rating

$$P = I^2 * R = (0.09)^2 * 0.22 = 0.04W$$

Cell_2

Load resistor (RL) =46Ω;

Shunt resistor (RS) = 0.22Ω;

Feedback resistor (Rf) =22kΩ;

In resistor (Rin)= 4.7KΩ;

Voltage (V)= 8.4 at fully charge;

Voltage drop (Vd) across the Shunt Resistor (Rs);

$$Vd = \frac{(V * Rs)}{(R_L + Rs)} = \frac{(8.4 * 0.22)}{(47 + 0.22)} = \frac{1.85}{47.22} = 0.04V$$

Load current (IL)

$$I_L = \frac{V}{R_L} = \frac{8.4}{47} = 0.18A$$

$$Gain = 1 + \left(\frac{Rf}{Rin}\right) = 1 + \frac{22k\Omega}{4.7k\Omega} = 5.68$$

Shunt resistor power rating

$$P = I^2 * R = (0.18)^2 * 0.22 = 0.08W$$

Cell_3

Load resistor (RL) =46Ω;

Shunt resistor (RS) = 0.22Ω;

Feedback resistor (Rf) =22kΩ;

In resistor (Rin)= 4.7KΩ;

Voltage (V)= 12.6 at fully charge;

Voltage drop (Vd) across the Shunt Resistor (Rs);

$$Vd = \frac{(V * Rs)}{(R_L + Rs)} = \frac{(12.6 * 0.22)}{(47 + 0.22)} = \frac{2.772}{47.22} = 0.059V$$

Load current (IL)

$$I_L = \frac{V}{R_L} = \frac{12.6}{47} = 0.27A$$

$$Gain = 1 + \left(\frac{Rf}{Rin}\right) = 1 + \frac{22k\Omega}{4.7k\Omega} = 5.68$$

Shunt resistor power rating

$$P = I^2 * R = (0.27)^2 * 0.22 = 0.016W$$

Cell_4

Load resistor (RL) =47Ω;

Shunt resistor (RS) = 0.22Ω;

Feedback resistor (Rf) =22kΩ;

In resistor (Rin)= 4.7KΩ;

Voltage (V)= 16.8 at fully charge;

Voltage drop (Vd) across the Shunt Resistor (Rs);

$$Vd = \frac{(V * Rs)}{(R_L + Rs)} = \frac{(16.8 * 0.22)}{(47 + 0.22)} = \frac{3.69}{47.22} = 0.078V$$

Load current (IL)

$$I_L = \frac{V}{R_L} = \frac{16.8}{47} = 0.36A$$

$$Gain = 1 + \left(\frac{Rf}{Rin}\right) = 1 + \frac{22k\Omega}{4.7k\Omega} = 5.68$$

Shunt resistor power rating

$$P = I^2 * R = (0.36)^2 * 0.22 = 0.16W$$

3.5. Voltage Measurement

Both OP-Amp OPA4197s was employed at the voltage of each cell of the battery, as indicated in the preceding section. We already know that Op-Amp gives the difference between the two voltage values supplied to the inverse and non-inverse pins in a differential amplifier. Since the differential amplifier's gain is set to unity, all of the resistors are set to 1kΩ. We measured the output voltage of each from OP-Amp and we make sure it’s less than 5V from each cell to avoid damaging the microcontroller because anything higher than 5V can damage the microcontroller. The circuit has been connected base on the design and the voltage level of each cell has been displayed on LCD and the wave voltage level of individual cell voltages is shown in the figure below.

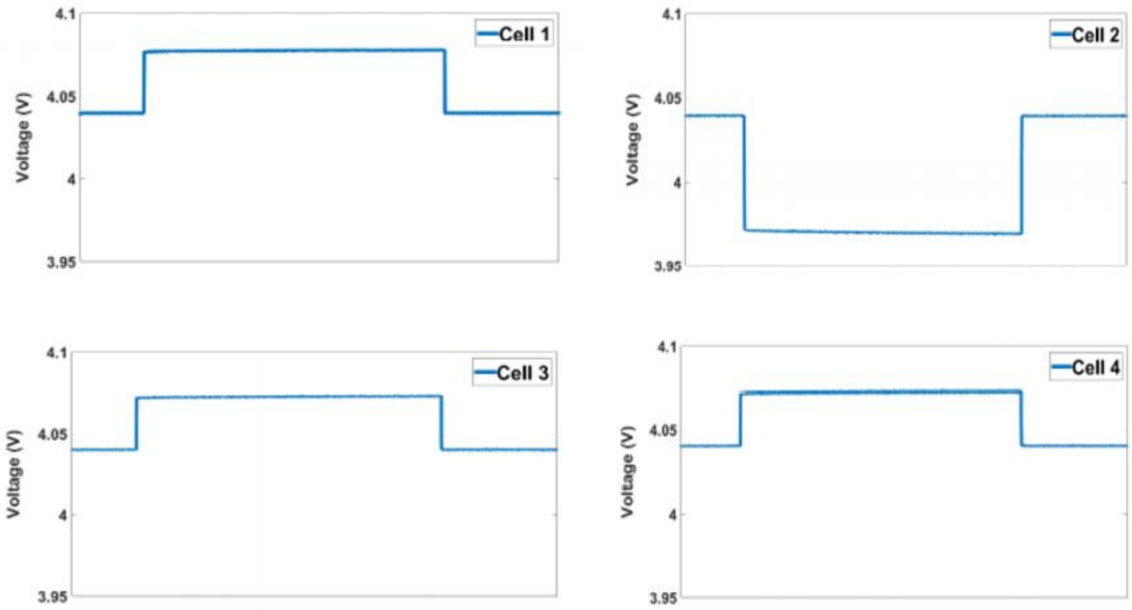

Figure 3.6. Individual cell voltages respond.

Figure 3.6. shown the four lithium batteries voltage levels respond for cell 1;2;3 and 4 using STMstudio.

3.6. Battery Balancing

As mention previous, the cell balancing employed in this thesis is passive cell balancing due to its being less expensive for initial cost and space management as we are to design the prototype of battery management to come up with the design concept of the BMS. 2N7000 NPN Mosfet was used for the cell ON/OFF, in laboratory practice, a bypass capacitor of 0.1uf was utilized as well as a 100R resistor to discharge the excess voltage and equalize it across the other cells. We used a 10K resistor between the gate of the MOSFET and input terminals of the STM32 microcontroller as protection against damage from the high voltage to the microcontroller. The LED were used is turn ON to indicate which cell are presently and go OFF for any respective cell that is fully charged. The battery balancing setup is shown in figure 3.7 below

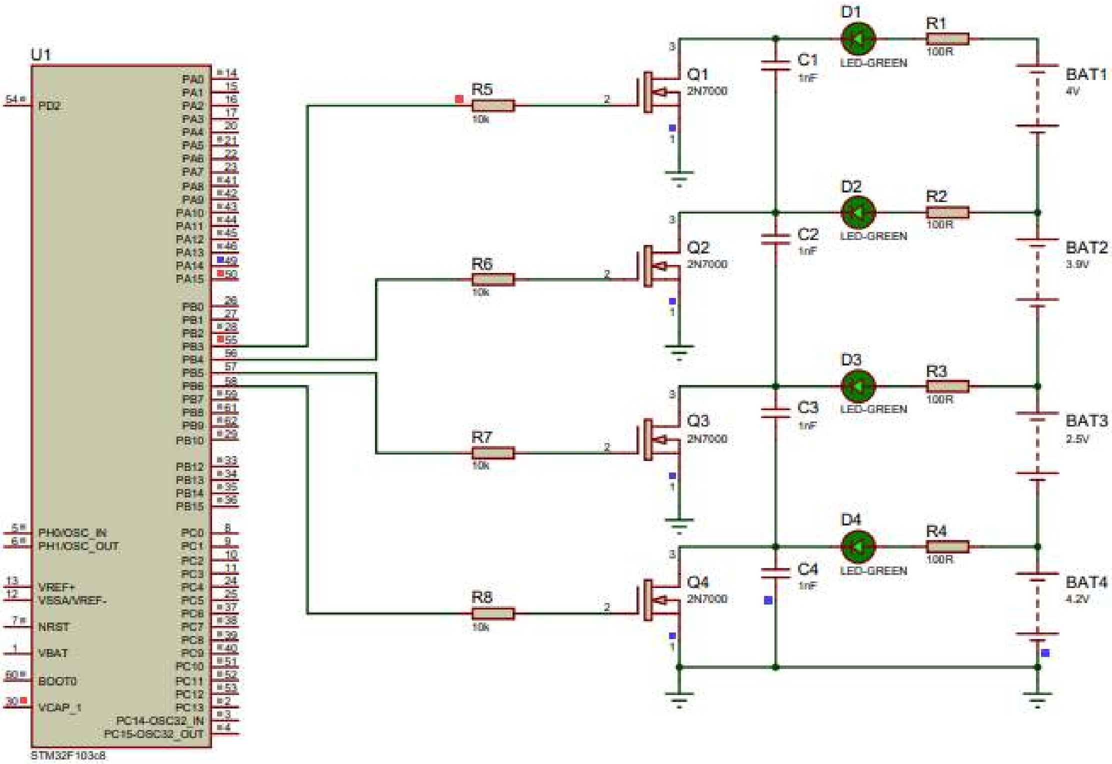

Figure 3.7. Battery cells balancing setup

Figure 3.7 depicts the passive balancing connection for four cells lithium batteries using an STM32 microcontroller.

We take voltage measurements of each cell with voltmeter after the cell balancing and from the result we found each cell's voltage in the battery pack are in equal range is show that the balancing circuit is working as expected. Response of the voltage of the cells has been watched from STMstudio which shows all cells are fully charged up to 100% of their capacity, the figure below shown the cells voltages at their fully charged.

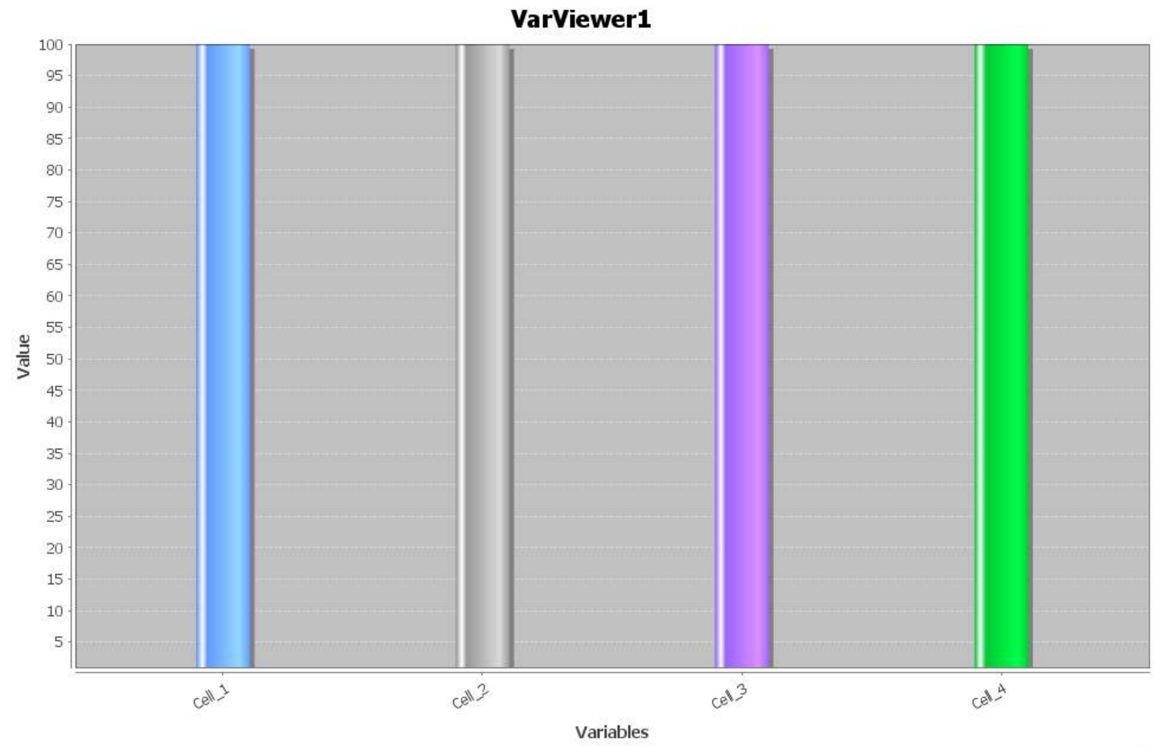

Figure 3.8. Voltages of the four lithium battery cells at their maximum full charge capacity (100%)

Figure 3.8. shown the cell 1, cell 2, cell 3 and cell 4 batteries SOC respectively.

3.7. Controller Area Network (CAN)

SN65HVD230D CAN Bus is utilized as a CAN transceiver, bxCAN (Basic Extended) is set in loopback mode, and bxCAN stores its own transmission message in the received mailbox once it is treated as received, as previously described. This technique is configured for the self-test function and does not rely on any external components. In this mode, bxCAN generates internal feedback from the Tx output to the Rx input. The true value of the CANRX input pin is ignored by bxCAN. The CANTX pin can be used to monitor the transmitted messages. In this work, only CAN Tx is activated for message transmission and the wave signal for is been watched on the oscilloscope screen from CANH. The transmission wave is shown in the figures below.

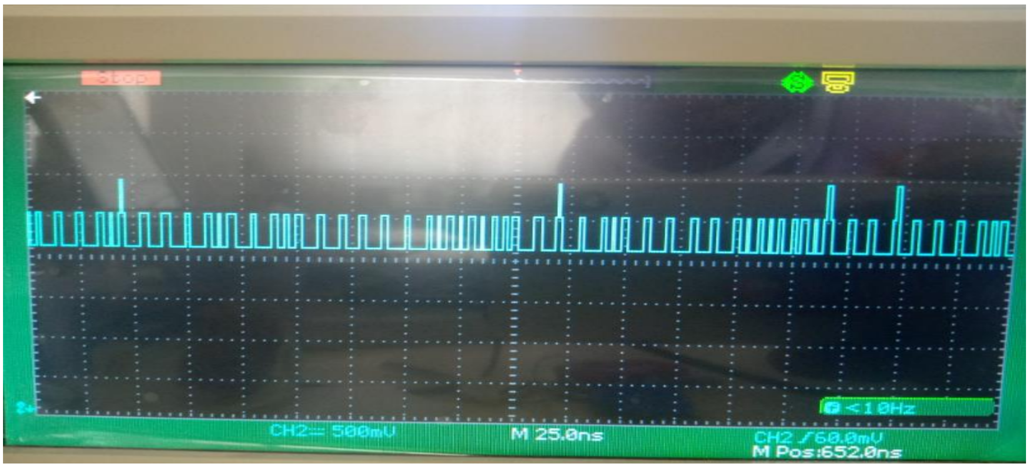

Figure 3.9. CANH transmission massage at 500mV and 25ns oscilloscope view

Figure 3.9. shown the oscilloscope displaying massage sent from Can transceiver for external communication.

Figure 3.10. CANH transmission massage oscilloscope zoom view

Figure 3.10. shown the massage transmitted from CAN Tx which is zoom on oscilloscope for clear display.

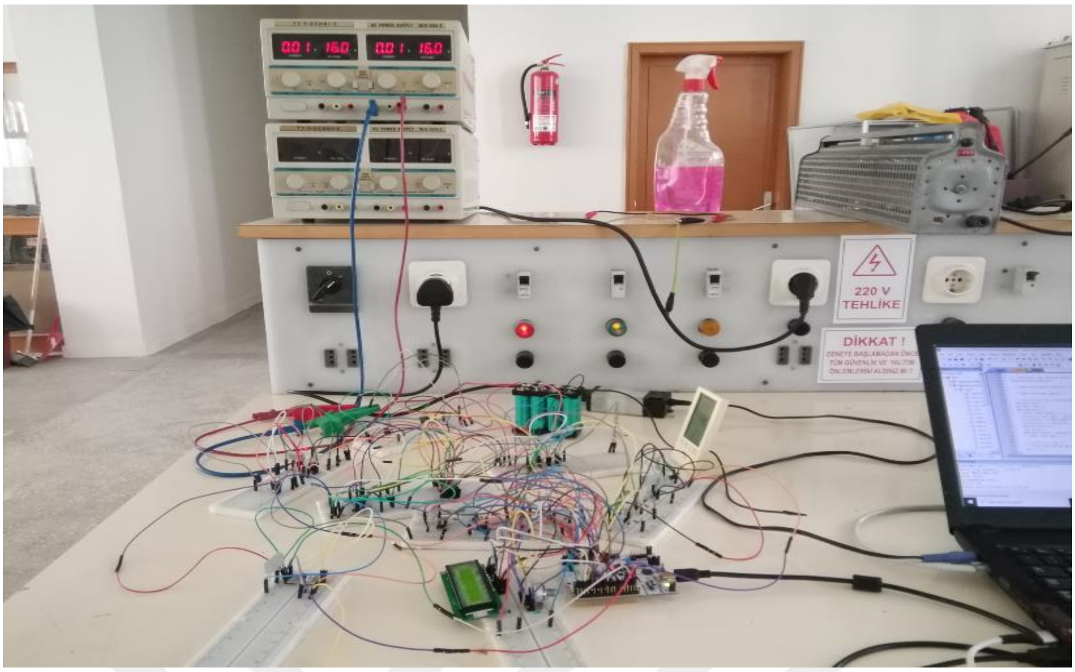

Figure 3.11. Laboratory experimental setup for microcontroller debugging.

Figure 3.11 shown the debugging connection during laboratory experimental work.

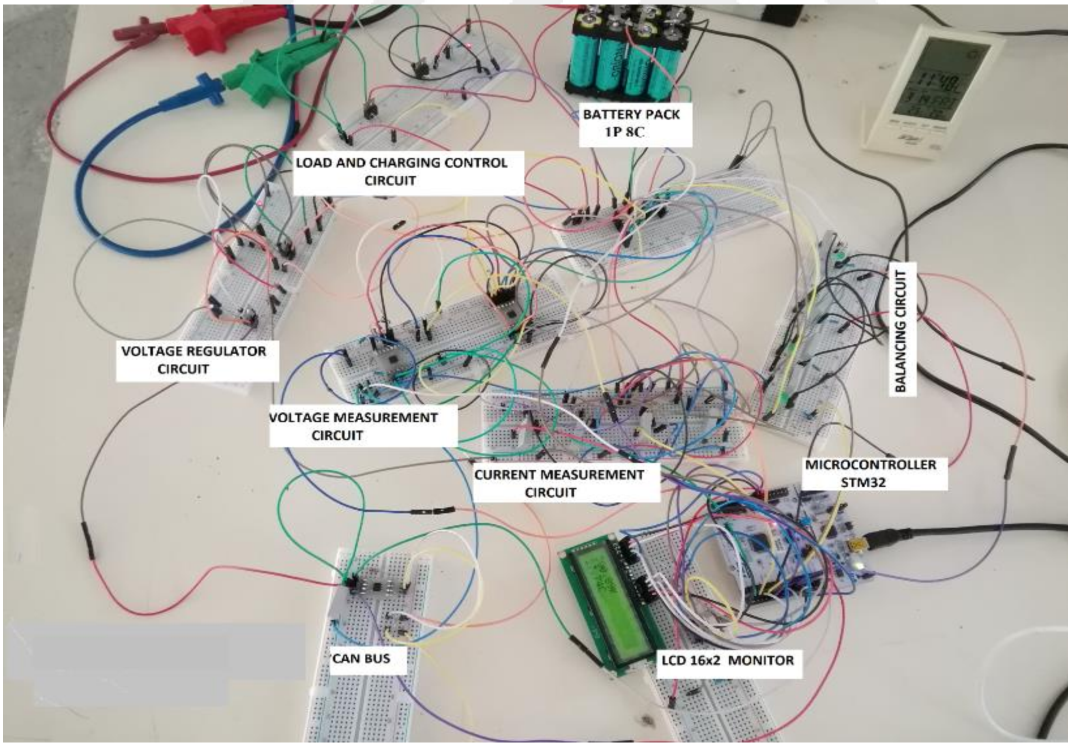

Figure 3.12. Laboratory experimental setup for general BMS circuit testing on breadboard

From figure 3.12. This is how the all parts that made up the BMS was integrated together for testing the entre circuit.

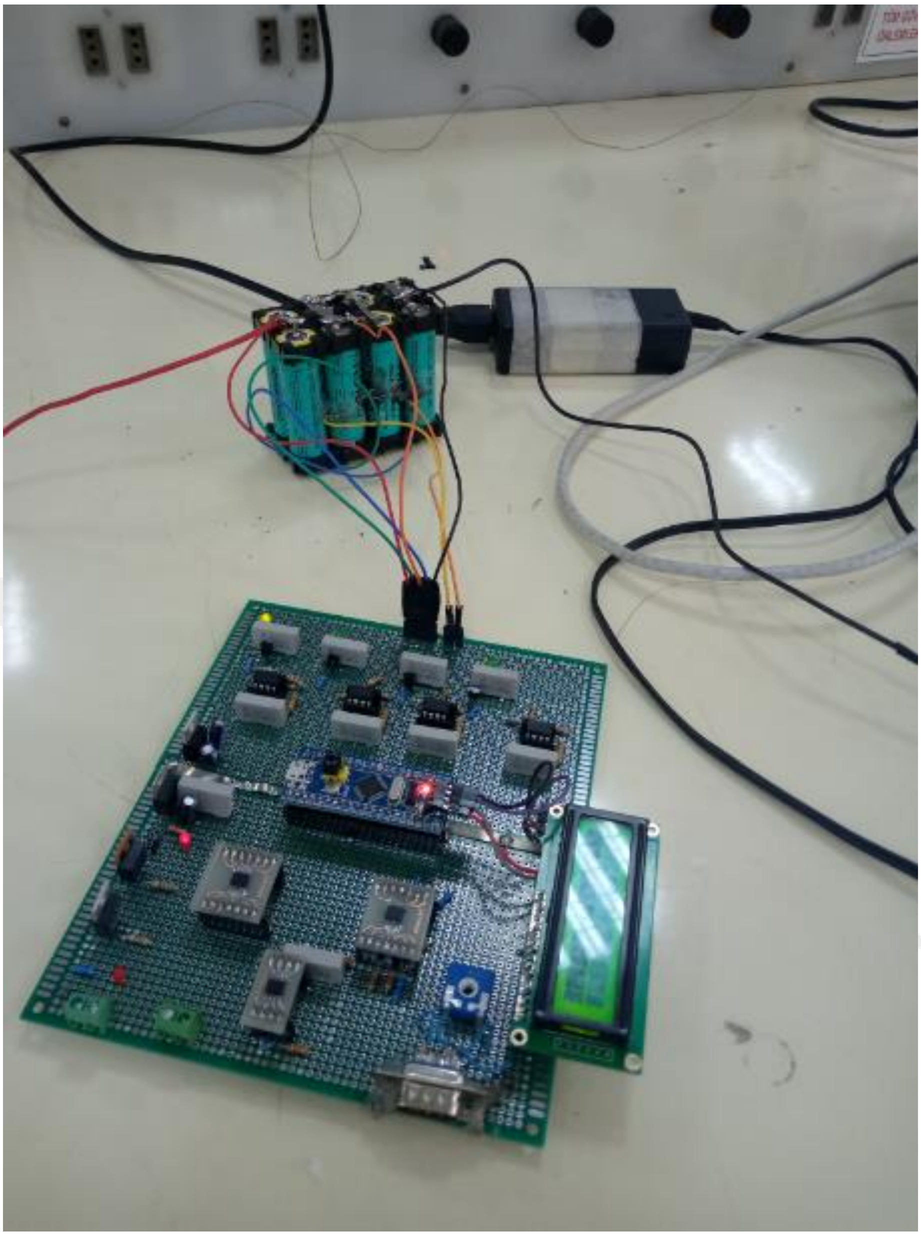

Figure 3.13. Completed laboratory implementation of the BMS final circuit

Figure 3.13. Shown the complete BMS of this study after soldering the final PCB.

4. DISCUSSION

The design of a Battery Management System is the focus of this study. Proteus 8 professional was used to create the circuit. The BMS design circuit in this study consisted of numerous sections, including the power regulator circuit, current measurement circuit, voltage measurement circuit, CAN, temperature measurement, and balancing circuit.

The outputs of voltage regulators which is the power supply of some components used in the design (Figure 3.1) showed two voltage regulators were used LM7805 and LM1117T from the simulation both produced the desired voltages of 5V and 3.29V respectively. In the BMS design of this research the LM358 used as OP-Amp for current measurement, LCD for cells monitoring and CAN connector all are using 5v from LM7805 while STM32, CAN transceiver and thermistor for current measurement are using 3.3V from LM1117T. after the voltage regulator design implementation on a breadboard it was been tested and working perfectly which means the desired result has been achieved.

The pins of the STM32 microcontroller are being configured by Stm32CubeMX in this research two microcontrollers STM32f103C8 and STM32f302R8 (Nucleo board) were used at different times to check the efficiency of each of the two microcontrollers all are working as expected. But base on my design and data used in this thesis I used STM32F103C8 due to its smaller in size and less expensive than the nucleo board. Various pins of the microcontroller are configured 9 ADC pins for voltages, current and temperature measurements. 2 Pin for serial ware, another 2 pins for clock settings and 10 GPIO pins. 4 pins to control MOSFET for cell balancing and the remaining 6 GPIO pins are for LCD connections. The table (Table 3.1 & 3.2) showed STM32F103C8 pins configuration and technical configuration respectively.

Figure 3.3 showed how to calculate the thermistor resistance by forming a voltage divider with a fixed resistor of equivalent values to the thermistor, in this research 10kΩ thermistor and fixed resistor was being used. At 24C the value of the thermistor resistance increased by applying the 3.3V to the circuit connection, from the data obtained the calculation showed the resistivity of the thermistor increased. Temperature measurement (Figure 3.2) showed the connections of temperature measurement by using a microcontroller with a thermistor as a variable resistor and the equivalent value of a fixed resistor. From the datasheet in Table 3.3 given by the thermistor manufacturing company, Steinhart equations are applied and find the present temperature at that time in kelvin and degree Celsius as showed by Stmstudio in (Figure 3.4) which is 300.125K and 26,93°C respectively. The current Measurement (Figure 3.5), showed the entire connection of the measurement circuit the pack is connected in a series-parallel connection and the maximum voltage capacity per cell is 4.2V. So when we add cells in series we are adding the voltage, the STM32 microcontroller pins can withstand to measure the ADC value between 0 to 5V so in this case, we can only measure the first cell current and voltage directly with a microcontroller we can measure the rest of the cell directly in this case we used LM358 Op-Amp (Non-Inverting amplifier) since we are using four cells in series 1P 8C battery pack. From the voltage divider of shunt resistor and load resistor of each cell of the LM358 non-inverting terminals we measured the voltage and the output of the LM358 from the simulation, the result is less than 5V by each of the four LM358 which means we can connect the output of these four LM385 direct to the Microcontroller to measure the currents of all cells. From the data of the circuit elements shunt resistor (Rs); feedback resistor (Rf); load resistor (RL); In resistor (Rin) and voltage of the cell (V), the output of the LM385 was also calculated to make sure the output is less than 5V to avoid damaging the microcontroller. After satisfied all, with the circuit simulation and calculated values of the LM385 output. The circuit has been connected to the breadboard and tested from the voltmeter the voltage values from the LM385 outputs is less than that 5V, so the microcontroller will not be damage.

Figure 3.6 showed the individual cell voltages, the battery used in this research is ORION that has 3.7v as nominal voltage and can charge up to 4.2v at the time of connecting the battery pack all the cells are almost fully charged as far that time all they are within the 3.95V to 4.06V. OPA4197 is rail to rail Op-Amp used and measured the voltage of the cell through the ADC pins of the microcontroller the voltage of each cell was been monitored on the LCD and Stmstudio all showed are in equal values.

Cell balancing (Figure 3.7) showed simulation balancing setup the LED in the circuit save as indicators which particular cell is charging or fully charged during the balancing period the 2N7000 MOSFET gate is trigged either low or high by the microcontroller circuit when all the cells voltages are equal all the LED would go off because the microcontroller switched off all of the MOSFET after the balancing. Figure 3.8, showed voltages of the cell at fully charge capacity (100%) after the balancing.

CAN bus transceiver SN65HVD230D, in this research the controller area network is set in Loopback mode. So only to transmit massaged from Tx the Rx does not been implemented in this case, Figure (3.9 & 3.10) showed the massaged transmitted on an oscilloscope from the CANH.

Figured 3.11 & 3.12, showed the general BMS circuit testing connections on the breadboard during the laboratory experiment of this research.

The previous chapter (Figure 2.18 & 2.21) showed the PCB two layers’ view and 3D view of the entire design implemented in this thesis.

CONCLUSIONS

A BMS was built as part of this thesis that can monitor the cell voltages and currents of each cell, as well as to measure the temperature of the battery pack, cell balancing, load and charge control, and an algorithm that can detect any problematic cells in the battery pack. The system's architecture designed in this research is centralized architecture topology implemented, to satisfy the specific needs of our system. All the parts that made up the system is designed and simulated in Proteus 8 professional also implemented on the breadboard for testing its real performance before making the prototype of the entire system.

The Battery Management System in this thesis designed its base on lithium-ion battery 1P 8C with a capacity of 16.8V, during the laboratory experimental work all the parts made of this system has been tested and its functionality is being satisfied.

Load and charging control circuits, voltage, current, and temperature measurement, and cell balancing were all integrated together and created the full system in this research, which had a completed design and prototype manufacturing. The laboratory experimental outcome yields a good result that, designed prototype BMS system is functioning perfectly to power any system of its capacity, monitor the voltage, current, temperature and control the cell balancing.

RECOMMENDATIONS

The purpose of this research is to come up with the concept on how to develop a battery monitoring system, that can monitor voltages, current, temperature and to balance the battery cells as well as to control the load and charging control and to detect any faulty cells, so that to keep the battery within the safety operational area.

From the knowledge, I obtain throughout this research there is a need for a higher capacity battery pack for use in electric vehicles operation so there are needs for a large number of battery cells depending on the capacity needed. In this research the microcontroller used is STM32 that has 2 ADC channels and 10 ADC pins, 9 ADC pins were used out of 10 for each of the four cells current, voltage and temperature.

If there is a need in the future to implement this research work to any electric vehicle battery storage a distributed architecture has to be adopted, microcontrollers with a higher number of ADC channels and numbers of ADC pins are needed to be used, for monitoring currents, voltages and temperature of each and every cell. Also, two microcontrollers can also be use one as a slave the other one as a master through SPI when implementing on small power supply capacity EVs like bike motorcycles.

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CURRICULUM VITAE

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