SRILANKA INSTITUTE OF INFORMATION TECHNOLOGY

Faculty of Engineering

MINI ELECTRIC SCOOTER

by

Kaluthotagei Thanura Dasanras Jayatissa

A thesis submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science of Engineering Honours in Electrical and Electronic Engineering

August 2022

DECLARATION

I hereby declare that this thesis submitted to the Department of Electrical and Electronic Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology in partial fulfillment of the requirements for the award of the degree of Bachelor of Science of Engineering Honours in Electrical and Electronic Engineering is based on work done by me. The contents of this thesis have not been submitted by me to any other university of institute for the award of any other degree or diploma.

Signature:

Name in Full: Kaluthotagei Thanura Dasanras Jayatissa

Registration No: EN19379616

Date: 26/08/2022

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to our project's supervisor, Dr. Lasantha Senevirathna, for his important advice, ongoing support, encouragement, guidance, and inspiration. Also, I am extremely grateful to Prof.Chulantha Kulasekere and Mr. Nushara Wedasingha for their support and guidance throughout the project. I also want to express my gratitude to the Sri Lanka Institute of Information Technology's professors, lab assistants, and colleagues for their assistance in making this research a success. I sincerely appreciate everything my group members have done to make this project a success. Finally, I also want to thank my family and all of the people that supported us with this effort.

Executive Summary

The whole world is initiating to ban the sale of new petrol and diesel vehicles in future as the whole world is leading to a "green revolution" to cut off the emissions from the fossil fuel-based vehicles and to manage global warming. At present, Sri Lanka is out of fuel and the authorities are struggling to manage the deepening economic crisis. Strict energy-saving measures such as a limited fuel quota are issued for vehicles, etc. are implemented in the country and the search for alternative sources has begun.

So, we propose designing and manufacturing environmentally friendly electric scooters in Sri Lanka to boost the country's population of electric scooter consumers. It can be a perfect solution to Sri Lanka's fuel crisis and will aid to reduce the present economic nightmare of the country. It will also prevent carbon emissions to the environment and will help to manage air pollution and global warming. It also gives additional benefits such as avoiding traffic jams, especially in urban areas, the people with low mobility can ride this safely with minimum effort, the maintenance cost is very low when compared to a combustion engine-based scooter and can be used as a sports equipment for the kids. The data and the statistics show that the number of electric scooter users in most European countries is growing rapidly and that the concept of electric scooters has already had a positive impact on the environment. Those countries have already begun manufacturing and promoting electric scooters among the public.

The electric scooter is a battery-operated one-person capacity vehicle which runs based on electrical energy and the battery is used to supply the necessary energy to the motor. We are very keen on getting the maximum battery efficiency, so it will boost the number of kilometers that can be ridden from a one-charge cycle and will limit the required electrical energy to charge the battery. Our product will have unique features such as a CVT gear system, auto brake system, cruise control system, GPS tracker system, automatic light system, and a fully detailed LED display which will show all the necessary information such as the speed of the electric scooter, the current weather forecast details. These features will separate our work from the already available similar products.

List of Abbreviations

CVT - Continuously Variable Transmission

GPS - Global Positioning System

USA – United States of America

SoC - State of Charge

SoH - State of Health

LCD - Liquid Crystal Display

LED - Light Emitting Diode

API - Application programming interface

JSON - JavaScript Object Notation

NiMH - Nickel Metal Hydride

Wi-Fi - Wireless Fidelity

GSM - Global System for Mobile communication

Table of Contents

List of Figures

List of tables

Chapter 01

INTRODUCTION

"Development of environmentally friendly vehicles" has been a popular topic that many researchers have approached in recent years mainly due to the present concerns about global warming and urban air pollution throughout the whole world. A major factor for the poor air quality condition in urban areas has been the emissions from gasoline-based engine vehicles. These Vehicle emissions mainly contain two harmful pollutants such as carbon monoxide and nitrogen oxides. According to the data from the "World Resources Institute", Transportation has accounted for 16% of the global greenhouse gas emissions in 2020. [1,2,4]

Figure 1.1 below shows the percentage emissions of greenhouse gases from various sectors in 2020 globally.

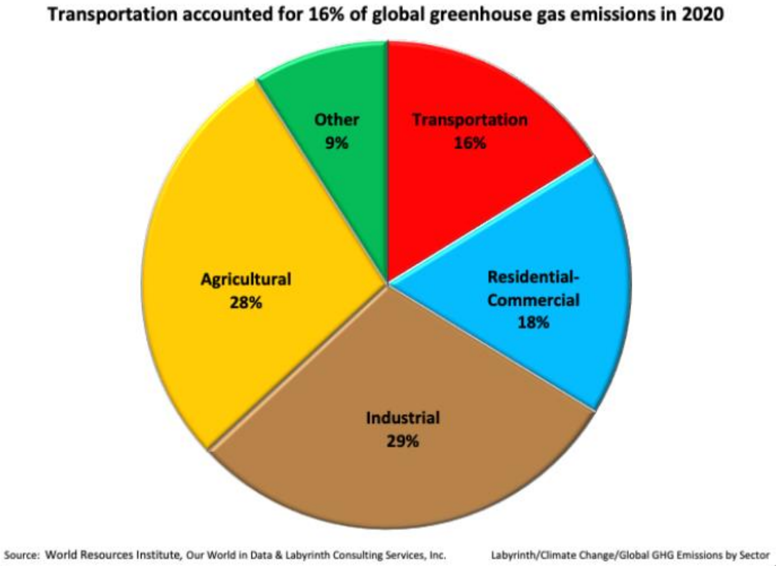

Figure 1.1: Percentage emissions of greenhouse gases from various sectors in 2020 globally (Source: World Resources Institute)

The greenhouse gas emissions from the transport sector in Sri Lanka are also increasing rapidly with the growth of the gasoline-based engine vehicle population. According to the data from the "WORLD DATA ATLAS", the greenhouse gas emissions from the transport sector for Sri Lanka in 2020 were 9 metric tons and have increased by an average annual rate of 4.42% since 1971. Busy cities such as Colombo, Galle, and Kandy have been heavily affected by air pollution due to the high traffic congestion and overcrowded buses in those areas of the country. People utilize their vehicles even to travel to short distances. [9,10,12]

Table 1.1 below shows the vehicle population growth of Sri Lanka from 2012 to 2017.

Year	2012	2013	2014	2015	2016	2017
Motor Cars	499,714	528,094	566,874.00	672,502.00	717,674.00	756,856.00
Motor Tricycle	766,784.00	850,457.00	929,495.00	1,059,042.00	1,115,987.00	1,139,524.00
Motor Cycles	2,546,447	2,715,727	2,988,612.00	3,359,501.00	3,699,630.00	4,044,010.00
Buses	91,623.00	93,428.00	97,279.00	101,419.00	104,104.00	107,435.00
Dual purpose vehicles	280,143	304,746	325,545.00	365,001.00	391,888.00	408,630.00

Table 1.1: Vehicle population growth of Sri Lanka from 2012 to 2017

In addition to the above-mentioned factors, Sri Lanka is currently facing an economic nightmare that it has never seen before. Due to a lack of US currency in the country, limited fuel is being imported and the fuel is supplied to the vehicles according to a limited quota system. The main organization in charge of the majority of the country's gasoline market, "Ceylon Petroleum Corporation," has experienced a sharp increase in fuel costs and is operating at a loss. The Minister of Power and Energy has already given hints that they are looking forward to initiating a rapid renewable energy generation plan in the future.[4]

So, it's high time for Sri Lanka to manufacture and promote vehicles among the public, which will demand less fuel energy and will be environmentally friendly. An electric scooter will be a great start to this process. The electric scooter is a battery-powered one-person capacity automobile, which moved using a hub motor fixed to the rear wheel. So the electric scooter is a rear wheel drive vehicle. It could be the ideal solution to Sri Lanka's gasoline crisis and will help to lessen the nation's current economic misery. Electric scooter usage is quite uncommon among the public in Sri Lanka, and they are also not particularly common in the country due to many reasons such as unaffordable prices, the mindset of the people, insecureness feeling about the imported products after paying a huge amount of money, etc. An imported electric scooter will set you back between $450 and $650. Because of Sri Lanka's increasing dollar exchange rate, this will be extremely expensive and beyond of many people's reach. So, starting to design and manufacture electric scooters in Sri Lanka will resolve the above issues and people will tend to use them more instead of gasoline-based engine vehicles. The promotion of green technology automobiles, such as electric vehicles, has been undertaken globally at present on a huge scale. The number of electric scooter users has increased rapidly during the last several years in most countries such as Europe, the United States, China, and India and there are looking to expand them further in the future. The global electric scooter market is expected to grow at a Compound annual growth rate of 7.8% from 2022 to 2030 and most of the countries are planning to ban the sale of new petrol and diesel vehicles in future. The United States government has planned to end gasoline-powered vehicle purchases by 2035 to lower emissions and promote electric cars and is planning to have net-zero emissions by 2050. [12,14]

Figure 1.2 below shows the expected increase in the global electric scooter market from 2022 to 2030.

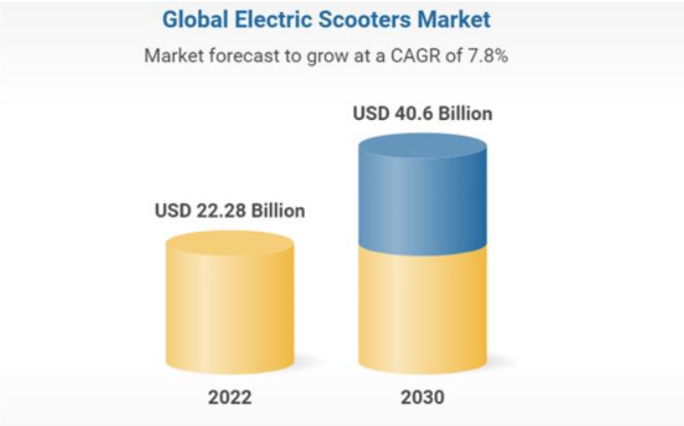

Figure 1.2: Expected increase in the global electric scooter market from 2022 to 2030 (Source: https://www.researchandmarkets.com/reports/5503381/global-electric-scooter-market-2021-2026-by)

The reasons for the expected increase in the global electric scooter market are that electric scooters are becoming more and more popular among young people, the middle-class people can afford to buy an electric scooter, rapid urbanization, etc. An electric scooter will provide many benefits to the users in addition to the common benefits for the country and the environment.

A comparison of energy cost, maintenance cost, and CO2 emissions between electric vehicles and internal combustion engine vehicles is shown in figure 1.3 below. [15]

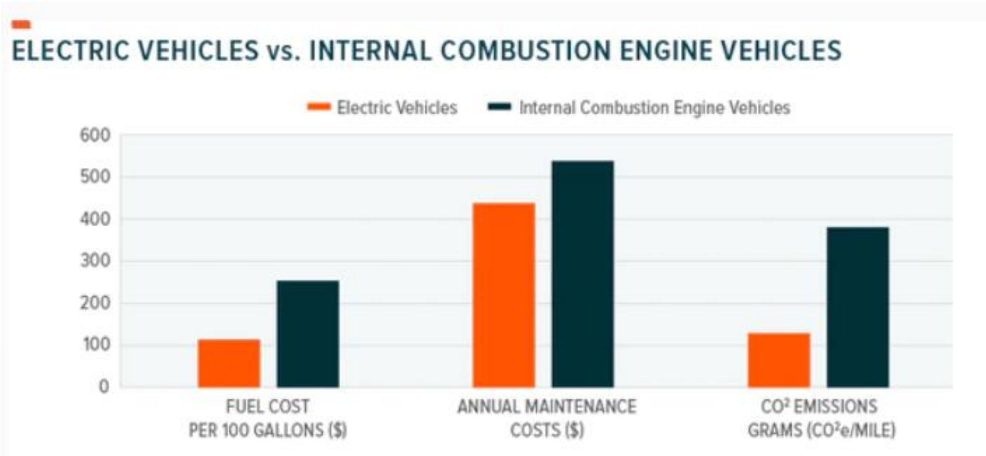

Figure 1.3: A comparison of energy cost, maintenance cost, and CO2 emissions between electric vehicles and internal combustion engine vehicles

(Source: https://evannex.com/blogs/news/four-charts-showcase-why-electric-cars-will-take-over)

Along with that, an electric scooter will offer the following advantages.

- The ride is safe and requires little effort for people with limited mobility.
- Health and fitness benefits.
- Helps to avoid traffic jams in urban areas.
- To replace car trips.
- These can be used as sports equipment by children.
- No need for a license, insurance, or registration

1.1 Research Objectives

The foremost objective of the research is to design and develop an electric scooter with unique features using new technologies. To address this, the thesis focuses on the following specific objectives:

- To construct a compact designed high-quality electric scooter within one year at a cost not to exceed Rs 75000.00, which can be introduced to the market.
- To promote the manufacturing of electric scooters in Sri Lanka, which will assist to reduce the toxic emissions to the environment and the country's gasoline crisis.
- To design and develop the Battery Management System (BMS) for the electric scooter.
- To develop a Global Positioning System (GPS) tracker for the electric scooter.
- To develop a weather forecast data display system using a weather API for the electric scooter.
- To investigate and study more deeply various batteries used in electric vehicles.
- To develop skills such as time management, teamwork, project development, problem-solving, etc.
- To increase mobility in people.
- To reduce the traffic congestion and overcrowded buses in urban areas.

1.2 Contribution of the Thesis

The thesis provides the following contributions:

- An electric scooter powered by a 24V battery pack and comprised of many unique features such as a Continuously Variable Transmission (CVT) gear system, auto brake system, cruise control system, Global Positioning System (GPS) tracker, automatic light system, and a fully detailed LED display.
- A Battery Management System (BMS) will improve the efficiency and durability of the battery pack.
- A compacted product with a lightweight design.
- An electric scooter that can ride up to a maximum speed of 15 km/h to 20 km/h and can ride around 5 to 7 kilometers from one charge cycle.
- A final quality product that is very user-friendly.

1.3 Structure of the Thesis

Chapter 2: This chapter includes the background readings and literature reviews about electric scooter projects, that are researched to complete this project. The background readings about the Battery Management System are also discussed.

Chapter 3: A broad summary of the software implementations and the hardware implementations of the proposed product is represented in this chapter. The technologies and the methodologies used are discussed broadly.

Chapter 4: This chapter presents the results of the software and hardware implementations of the work. The limitations of the implementations are also discussed.

Chapter 5: The conclusion of the project is presented in this chapter.

Chapter 01

LITERATURE REVIEW

2.1 Introduction

This chapter mainly discusses the background information about electric scooters and the already available similar electric scooter projects. The techniques used in those projects are discussed and analyzed briefly.

2.2 Background and Motivation

As a rapidly progressing EV technology throughout the world, electric scooters are presenting a huge challenge for traditional and gasoline-based engine vehicles. The ultimate goal of this literature review is to study and analyze the existing approaches that have addressed the same issue and to justify the importance of our solution. In addition to that, the other purposes of this literature review are to get a better understanding of the future impact of the electric scooters worldwide and the present statistical data about the electric scooter riders in the world and to understand the impacts on the natural environment. The market for electric scooters is expanding rapidly but varies geographically. The main reason for the rapid expansion of this new method of transport is its primary characteristics of it such as being eco-friendly, flexible, user-friendly, economical, and relatively cheap when compared with conventional motorbikes. Those characteristics have given the electric scooters great acceptance from the public. The worldwide sales of electric scooters are expected to reach 100 million units by 2035. [24] According to research done by the Institute of Transport Economics, electric scooter users cycled more than conventional bike users and electric scooter users travel less with a private car than conventional motorbike users.[25] Electric scooters offer a huge contribution to the carbon reduction of the land-based transport system, and they are also associated with other benefits for the health and physical activity of the general public. Transportation is responsible for 24% of the global CO_2 emissions from gasoline combustion and is continuing to rise rapidly. It is also estimated that electric scooters can reduce transportation CO_2 emissions by 24.4 million tons.[26],[27] In Sri Lanka, the impact of electric scooters is yet to be understood. The reasons for that are the unaffordable prices of electric scooters, fear to change the trend, unawareness about electric scooters, etc. With the shortage of petrol and diesel at present in the country, increasing electric bike usage will have a huge contribution to overcoming the economic crisis in Sri Lanka and it will save crores of foreign currencies.

2.3 Similar Existing Projects

Design and Fabrication of an Electric Bike by A Karthi 1,N Afridhin2, D Aravind3, G Kamalesh4, K Rathish Kumar5

The working principle this invention is mainly converting electrical energy stored in a D.C battery to electromotive power using a D.C to A.C converter and supply that power to an A.C motor. [28] The main component they have used for this methodology are as follows.

• Battery

A lithium-ion battery is used as the power source of the electric bike, and it weighs around 4kg. The main factors that have led to choosing a lithium-ion battery have been the high durability, lightweight, and no memory effect. The anode of the battery is metallic lithium and therefore also call lithium metal batteries. Electrodes of the lithium-ion batteries are made of very lightweight carbon and lithium. Due to the high reactivity of lithium, a lot of energy can be stored in the atomic bonds and therefore lithium-ion batteries consists of very high energy density. [29]

• Motor

They have used a 48V DC brushed motor which has a capacity of 750W and a maximum of 1000 rpm. The structure of the bike is somewhat similar to the conventional motorbike. So, the whole weight of the structure including the motor and the battery is large about 146 kg. Therefore, they have used a DC motor with high capacity. A normal electric scooter uses a motor which have a capacity of around 250W. The gear ratio of the motor used is 6:1. That means the torque output of the motor is 5 times and the speed output is 1/5 times. [30]

• Motor Controller

To provide an easy ride to the cyclist they have used controllers. Using controllers affords several more features like easier acceleration and speed controlling. To provide an easy ride to the cyclist they have used controllers. Using controllers affords several more features like easier acceleration and speed control. The motor controller used here has a rated power of 750W and a rated current of 30A.

• Throttle

The throttle has been used in here similar to the motorcycle, to continue forward and control the acceleration. Simply it behaves as the gas pedal of a motor vehicle.

• Battery Charger

The battery charger used here has the option of choosing the necessary charging current up to 4A. If the battery is fully discharged, they have an estimated 3 to 4 hours charging period for the battery of the electric bike to be fully charged and they have strongly recommended not to leave the battery in the fully discharged state for a longer period and they recommend charging after every ride. Because lithium-ion batteries can malfunction when kept flat for a longer period.

The following can be mentioned as the main benefits of this work.

- Easy handling of deployable batteries
- Lowest unit cost and lowest energy consumption (they are proposing to use solar panels for more energy utilization)
- High efficiency

When compared with our proposed work, this project has the disadvantages of the larger weight of the electric bike. When the weight is larger it is very hard to carry from one place to another. So, portability is a question. And the cost of our proposed work is low when compared to this. The high-capacity motor used in this will cost a high amount. The high-capacity motor is required because of the larger weighted structure.

Electric Bike (250 WATTS, 48 VOLTS)

The high-level methodology of this invention is converting the already existing Yamaha Rx-100 conventional gasoline bike into a 100% electricity-based motorcycle. They made sure that, after the conversion, the electric model should have equal performance to the original Yamaha Rx-100 gasoline model and the electric model should be a competitive product for the already available 100cc conventional bike models available at present. They have studied deeply the 100cc conventional motorbikes and the factors affecting their market value of them. The 100cc gasoline bikes normally have a very good mileage when compared to other gasoline-based bike models. The double-cradle frame chassis and suspension system of the Yamaha Rx100 bike are used for the electric model as well. [31]

They have mainly used the following components for their implementation.

• Motor and motor controller

A 48V synchronous brushless DC motor which has a capacity of 250W is used here. This motor is capable of operating at or above 10,000 rpm speed without depending on the loaded condition. Also, the quick acceleration and deceleration capability is an outstanding feature of this motor. They have mentioned this motor is with a high-power density and it’s highly reliable (10,000 hours lifespan expectancy). In brushless DC motors, the magnetic fields generated by the stator and the rotor have the same frequency. They have identified the controller as the brain of the bike. Which regulates the speed. and the sensing unit is also within this controller. The motor controller has a maximum current of 35A and a phase angle of 120 degrees. The phase angle affects the output voltage. So, it will affect the speed of the motor and hence the speed of the electric bike.

• Battery and the power management system

They have used a 48V battery pack that weighs around 30kg to power the motor and it takes around 6 hours for full charging. Four 12v batteries are connected in series to create the 48V battery pack. The batteries used are the sealed lead-acid (SLA) batteries. A 48V dc to 12V dc converter is used to supply power to the electronic parts and the headlight system. A Miniature Circuit Breaker (MCB) switched is used for protecting the 48V circuit in case of any short circuit.

The figure 2.1 below shows the internal structure of the sealed lead-acid (SLA) battery used in this work.

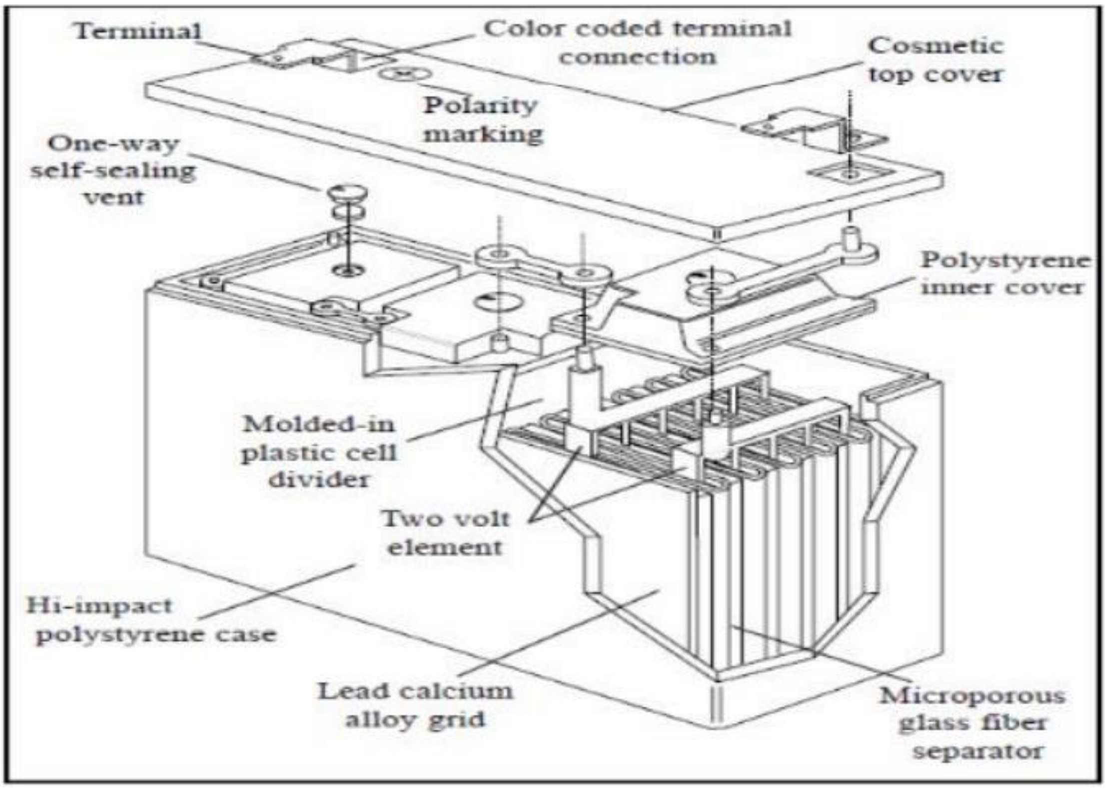

Figure 2.1: Internal structure of the SLA battery used in the conversion of Yamaha Rx-100 into an electric model

• The chain system

Instead of using a hub motor, they have used chain driven mechanism for the rear wheel.

Electric two-wheeler by Rajesh Kumar Chadalavada

They have implemented this concept in two prototypes. The first one is E-bike and the second one is E- a scooter. The electric two-wheeler is equipped with an electric motor capable of storing 0.25kW power within about thirty minutes. And it contains suitable brakes and several reflective devices. with these fittings, they are recommending the maximum speed of this vehicle as 25km/hr. [32]

They have mentioned the following features as advantages of their invention.

- Low-cost traveling and maintaining
- Light weight minimum noise
- No license registration or helmet required
- Safe and comfortable

The way they have addressed the safety of this vehicle battery is an outstanding point in this project. Safety-wise they have concerned with current, overcharging, and over-discharging situations. They have addressed those issues with safety circuits. Using these battery safety circuits they have implemented a battery management system. Which manages the battery voltage within 4.35V-2.5V.

And, they have pointed out,

- Taking too much time for charging(8hrs)
- Lack of service stations to recharge unlike the petrol ones
- High cost
- Low speed
- Requiring high care to the battery
- Not suitable for rainy days (as it will reduce the battery lifespan)

As the negative aspects or disadvantages of their invention.

As of their findings within the study, they have summarized the material Inventory, emissions, and energy use of electric bike as follows.

Figure 2 below shows the summarization of the material Inventory, emissions, and energy use of the electric two-wheeler.

Weight of Electric Bike Materials (kg/bike)		
	BSEB	**SSEB**
Total Steel	18.15	26.18
Total Plastic	5.67	15.22
Total Lead	10.28	14.70
Total Fluid	2.94	4.20
Total Copper	2.55	3.46
Total Rubber	1.14	1.22
Total Aluminum	0.52	0.58
Total Glass	0.00	0.16
Total Weight	**41.25**	**65.73**
Associated Energy and Emissions of Manufacturing Processes		
	BSEB	**SSEB**
Energy Use (ton SCE)	0.179	0.261
Energy Use (kWh)	1,456	2,127
Air Pollution (SO_2) (kg)	1.563	2.198
Air Pollution (PM) (kg)	5.824	8.173
Greenhouse Gas (ton CO_2 equivalent)	0.603	0.875
Wastewater (kg)	1,488	2,092
Solid Waste (kg)	4.463	7.139

BSEB = bicycle-style e-bike, CO_2 = carbon dioxide, kg = kilogram, kWh = kilowatt-hour, PM = particulate matter, SCE = standard coal equivalent, SO_2 = sulfur dioxide, SSEB = scooter-style e-bike.

Figure 2.2: Summarization of the material Inventory, emissions, and energy use of the electric two-wheeler

2.4 Comparison our proposed work with the models discussed above

The main factor that could be highlighted in our proposed work when compared to these models, is the lightweight structure of our model. In the first two models discussed above, a conventional gasoline motorbike structure is used. So, to operate a larger structure a high-capacity motor and battery pack should be used and hence the manufacturing cost will be high. In our proposed work manufacturing cost will be far less than the cost in these models. The portability of our model will also be easy due to the lightweight structure.

The other factor is the battery type used in the "ELECTRIC BIKE (250 WATTS, 48 VOLTS)" model. In this project, they have used Sealed Lead Acid (SLA) batteries. In our model, we are planning to use lithium-ion batteries. Lithium-ion batteries are much more reliable, efficient, and durable and have a high capacity when compared with lead-acid batteries. However, the cost of lithium-ion batteries is much higher, but the energy density of a lithium-ion cell is also higher. Lithium-ion batteries are designed in a way that can be recharged to use several times. That's a very important factor when considering the electric scooter. So, the lithium-ion battery pack will suit more to an electric scooter than the lead-acid battery pack. [33]

Our proposed work consists of a fully detailed LCD that will display all the necessary information that the rider should know such as the speed, weather forecast, and the battery level. It is also a very important feature when compared with these models.

The GPS tracker and the automatic lighting system in our model. Our model consists of a GPS tracker. So, the electric scooter can be tracked from anywhere. The automatic lighting system will make the electric scooter more user-friendly and effective. These two are other two important features that will make our proposed work more important when compared to these works.

Also, the features like the automatic brake system, cruise control system, and the CVT transmission system will highlight the significance of our proposed work when compared to these works.

2.5 Battery Management System (BMS)

Battery management systems are used to conserve the durability of the batteries or a battery pack. A Battery Management system protects each cell of the battery from overcharging, overcurrent, and overvoltage. A cell balancing circuitry is used to protect each cell from those factors. The current, voltage, and temperature of the battery circuit can also be monitored using a Battery Management system. By using these three parameters a BMS can estimate crucial states of the battery pack such as the battery capacity, state of health, and state of charge. [37] The State of Charge (SoC) of a battery means the capacity of the battery at a given moment. It is expressed as a percentage. The State of Health (SoH) of a battery means the condition of the battery relative to a brand-new battery. It is also expressed as a percentage. If a battery pack is used without a BMS, its efficiency can depreciate along with time, and it can also burn due to overcharging. [34] An electric vehicle model requires a fast-charging system. So, the chance that the battery can get overcharged is very high. In an electric vehicle, a Battery Management System is an essential factor because it affects the safety and reliability of the overall electric vehicle system. Lithium-ion batteries have become a dominant power source in electric vehicle models nowadays. [35] The safety issues of the lithium-ion batteries are mainly related to the cell level and the material level. [36] The following figure 3 shows some instances where a battery explosion has happened in famous developed electric vehicles in the world. [38]

Date / place	Type of application	Incident summary
April, 2011 / Hangzhou, China	Zotyc M300 EV	internal short circuit in defective battery pack due to insulation damage between battery cells and walls of the aluminum container
June, 2011 / National highway traffic safety administration (USA)	Chevrolet volt EV	fire occurred 3 weeks after a crash test
May, 2012 / Shenzhen (China)	Nissan GT-R EV in BYD e6 taxi	electric arcs caused by short-circuit of high voltage distribution lines and car body ignited combustible material in the vehicle
January 7, 2013 / Japan airlines Boston's Logan International Airport	aircraft battery (Boeing 787 Dreamliner)	Battery overheated and started a smoky fire
January 16, 2013 / All Nippon Airways Takamatsu Airport on Shikoku Island	aircraft battery (Boeing 87-8 model)	error message indicating a battery malfunction, and odd smell detected in the cockpit and cabin
March 18, 2013 / Mitsubishi motors Mizushima battery pack assembly plant	Mitsubishi i-MiEV	the lithium-ion battery of an i-MiEV caught fire while connected to a charge-discharge test equipment
March, 2013 / Mitsubishi motors Dealership in Yokohama	Outlander P-HEV Mitsubishi motors	the battery pack of an Outlander P-HEV overheated and melted some of the battery cells after vehicle had been fully charged and stood for 1 day
October 1, 2013 / Kent, Washington (USA)	Tesla Model S	fire in the Model S battery pack caused by the direct impact of a large metallic object to one of the 16 modules within the pack

Figure 2.3: Battery explosions happened in famous electric vehicle models

When using lithium-ion batteries, it must be ensured that they are operated in a safe region. The current limit and the voltage limit of the battery are determined by the battery manufacturers. Those factors must be highly considered when preparing a BMS circuit. The following figure 4 below shows the behavior of the battery capacity and the battery life cycle as a function of the applied voltage in a Lithium-ion battery. The battery life cycle means the number of charging and discharging cycles in a battery before it becomes flat. [39]

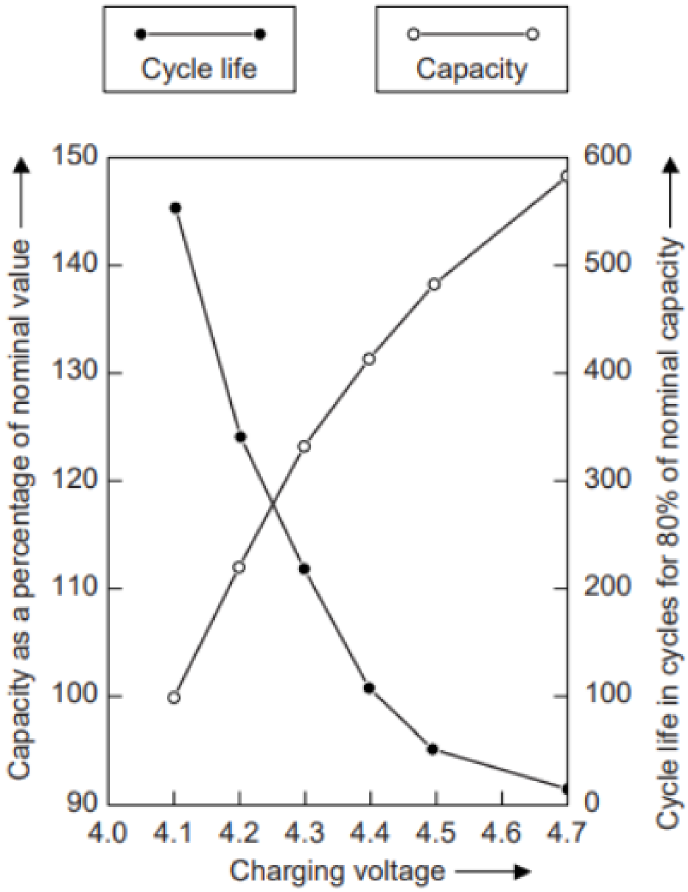

Figure 2.4: Behavior of the battery capacity and the battery life cycle as a function of the applied voltage in a Lithium-ion battery

According to the figure above when a higher voltage is applied, the battery capacity will be higher, but the life cycle will be decreased. So, by supplying the recommended voltage for the battery, the durability of the battery can be increased and also can be prevented from explosions.

The following figure 5 below shows the behavior of the time necessary to charge a lithium ion battery to a capacity of 0.77Ah as a function of the charge current. The maximum voltage is maintained at a constant value of 4.1V. [39], [40]

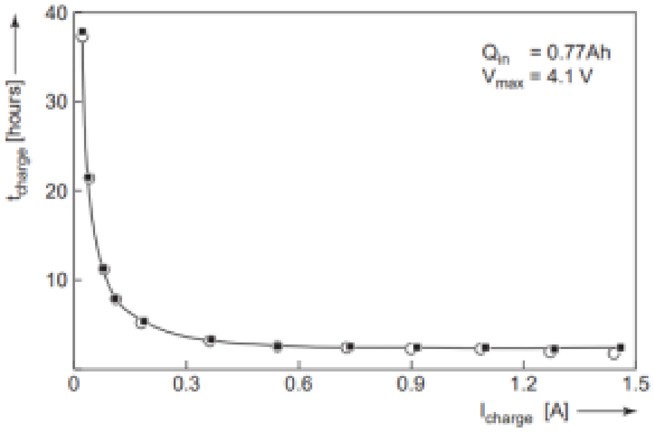

Figure 2.5: Behavior of the time necessary to charge a lithium-ion battery to a capacity of 0.77Ah as a function of the charge current

The following figure 6 is the basic structure of the Battery Management system model developed by H.J. Bergveld.

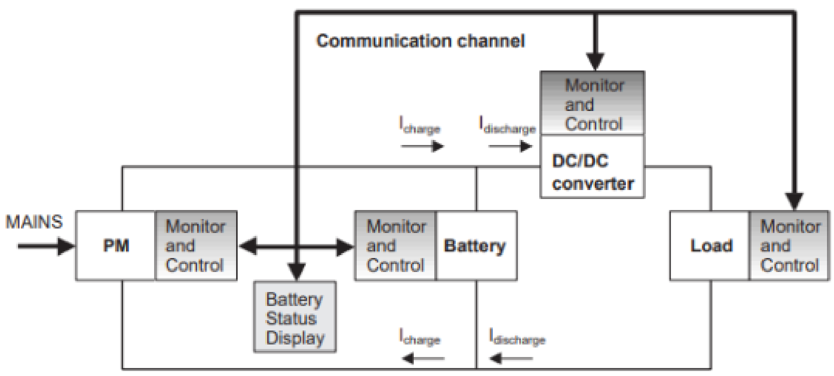

Figure 2.6: Basic structure of the Battery Management system model developed by H.J. Bergveld

Every block of the structure contains the symbol "Monitor and Control". That means that each block in the BMS should be monitored and controlled. Here the State of Charge (Soc) level is displayed using a string of LEDs. An LCD display can also be used to display the Soc level. The power module (PM) is the module that charges the battery. In this module, the input voltage and the current should be monitored and controlled. [39]

The State of Health of the battery pack can be defined and estimated using different battery characteristics and ways. [41]

By using the remaining battery charge

$$\boldsymbol{SoH = \frac{Q_{aged}}{Q_{new}}}$$

$$Q_{aged} = Maximum\ current\ available\ power$$

$$Q_{new} = Maximum\ power\ when\ the\ battery\ is\ not\ in\ use$$

By using the battery capacity

$$\boldsymbol{SoH = \frac{C_M}{C_N}}$$

$$C_M = Battery\ capacity$$

$$C_N = Nominal\ battery\ capacity$$

By using the battery power

$$\boldsymbol{SoH = \frac{(CCA_{ocmp} - CCA_{\min})}{(CCA_{new} - CCA_{min})}}$$

$$CCA_{ocmp} = Real\ time\ battery\ power$$

$$CCA_{min} = Predicted\ starting\ power\ of\ a\ battery\ in\ a\ fully\ charged\ state$$

$$CCA_{new} = Minimum\ starting\ power\ required$$

By using the internal resistance of the battery

$$\boldsymbol{SoH = \frac{R_{EOL} - R_O}{(R_{EOL} - R_{new})}}$$

$$R_{EOL} = Internal\ resistance\ of\ the\ battery\ at\ the\ end\ of\ its\ life\ time$$

$$R_O = Internal\ resistance\ of\ the\ battery\ at\ the\ current\ state$$

$$R_{new} = Internal\ resistance\ of\ the\ battery\ at\ the\ initial\ state$$

The SoC of the battery is the indication of the available charge at each moment of time. [42]

$$\boldsymbol{SoC} = \frac{(\boldsymbol{Available\ charge\ capacity})}{(\boldsymbol{Capacity\ of\ a\ fully\ charged\ battery})}$$

$$= \frac{\boldsymbol{Q_{current}}}{\boldsymbol{Q_{FC}}}$$

If the initial SoC is known the, the SoC can be estimated from the load current drawn from the battery.

$$\boldsymbol{SoC(t) = \ SoC_{t_0} - \left(\frac{\int_{t_0}^{t} \eta I_L(\tau) d\tau)}{Q} \right)}$$

$$SoC_{t_0} = Initial\ SoC$$

$$I_L = Load\ current$$

$$\eta = \text{ coulombic efficiency (assumed as } \eta = 1)$$

2.6 Summary

In this chapter, some of the already existing models that have addressed the same issue that we have addressed were discussed briefly. The technologies and the components used in them were analyzed and studied. Then our proposed work was compared to them, and the significance of our work was highlighted. Finally, a brief review of my scope of the project was discussed briefly using the already available models

Chapter 03

METHODOLOGY

3.1 Introduction

This chapter includes an overview of the software implementations and the hardware implementations of the project, and the techniques used are also discussed.

3.2 Overview of the proposed work

The proposed work is to design and develop an electric scooter that will have unique features and will be user-friendly. Our proposed electric scooter consists of two wheels, and it will be a rear-wheel drive vehicle. A DC brushless motor is used for the movement of the electric scooter and the motor is fixed to the rear wheel of the electric scooter. A battery pack is used to provide the necessary power to the motor and the other electronic components of the electric scooter. A DC-DC convertor will be used to supply the necessary the voltages required for the electronic components such as the sensors, lights, and the LED display. The main units of the product are the motor controller unit, Battery Management System, and Continuously Variable Transmission (CVT) unit. The motor control unit is responsible for controlling the speed and the acceleration of the electric scooter. It regulates the output current flow to the motor according to the inputs taken from the throttle. The Battery Management System will increase the efficiency and durability of the battery by controlling each cell of the battery. It will prevent the battery from overcharging, over current, and over-voltage. The Battery Management System will also determine the State of Health (SoH) and State of Charge (SoC) of the battery pack. The continuously Variable Transmission (CVT) unit uses the data from the gyroscope sensor as the input and by using this data the movement of the pulleys in the gear system is controlled automatically. In addition to the main units of the electric scooter, there are units such as the Global Positioning System (GPS) tracker, automatic light control system, auto brake system, cruise control system, real-time speed monitoring system, and a weather forecast system. The weather forecast data and the real-time speed will be displayed in a LED display of the electric scooter and the real-time GPS coordinates of the scooter can be obtained on the mobile phone via a text message. All the sensors will be controlled from the microcontroller and for the proposed work we have used an Arduino microcontroller. Also, the Nodemcu ESP8266 microcontroller is used.

Figure 3.1 below shows the basic overview diagram of our proposed work.

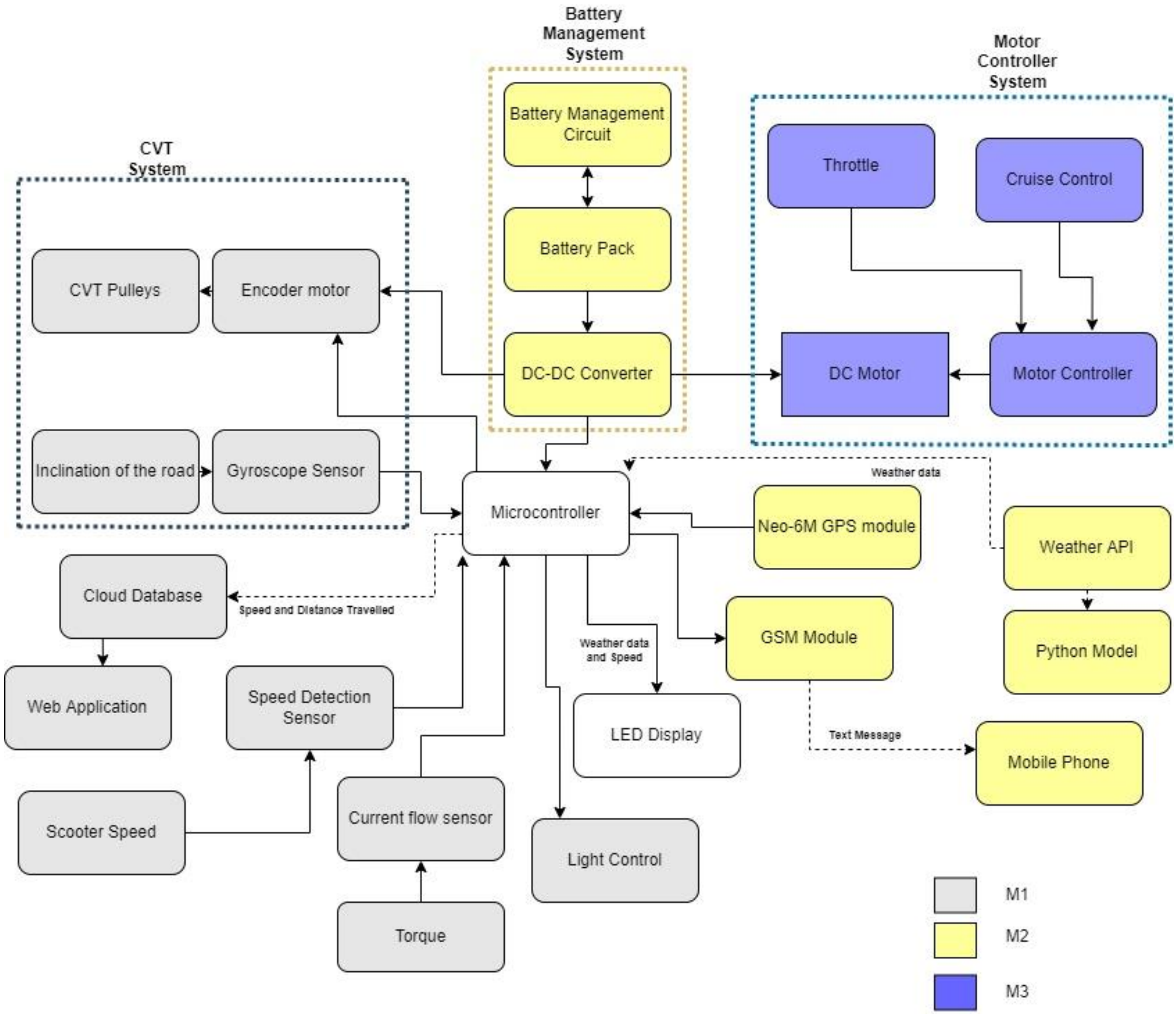

Figure 3.1: Basic overview diagram of our proposed work

3.3 Individual Contribution

3.3.1 Battery Management system

3.3.1.1 Designing of the DC power supply to charge an individual battery cell

Nickel Metal Hydride (NiMH) batteries was used to create the battery pack. Nickel Metal Hydride (NiMH) batteries are used in producing hybrid battery packs for hybrid vehicles. NiMH batteries have a high energy density and high durability when compared with lead acid batteries. These types of batteries can be recycled and used again. These types of batteries contain a high metal content as the positive electrode is associated mainly with nickel. The negative electrode is made using a hydrogen-absorbing alloy. The following charge and discharge reactions represent the electrochemistry of a Nickel Metal Hydride battery. [16,17]

Positive electrode:

$$Ni(OH)_2 + OH^- \leftrightarrow NiOOH + H_2O + e^-$$

Negative electrode:

$$e^- + H_2O + Alloy \leftrightarrow Alloy(H) + OH^-$$

A NiMH hybrid battery cell has a nominal voltage of 7.2V and it can be fully charged up to 8.2 V. The nominal capacity is around 6.5Ah. The charging of the NiMH batteries should be done very carefully and in the right manner using a constant current to make sure the batteries will have a long life and good performance. When the NiMH batteries are overcharged, it leads to overheating and damaging the cell resulting in loss of capacity since these batteries are very sensitive. There are various techniques used for charging NiMH cells such as Timer charging, Thermal detection, and slow charging. Timer charging means charging the battery at a specific time and estimating that the battery has reached its end of charge when the time finishes. This technique can result in overcharging the battery since the capacity of the battery cannot be approximately identified. Thermal detection means monitoring the cell temperature to determine whether the battery has reached its end of charge. The problem with this technique is the low accuracy since the accurate measurement of the temperature rise can be difficult to monitor because the cell's center will be significantly hotter than the exterior surface.[18,19]

Before creating the battery pack, each cell should be charged to the maximum level since the battery cells I found have not been used recently. Firstly, I modeled two AC to DC conversion circuits on MATLAB Simulink.

Figure 3.2 below shows the basic MATLAB Simulink model created for converting AC voltage to DC voltage. Here four thyristors are used as the rectifying bridge to provide full wave rectification. A thyristor acts the same as a rectifying diode which conducts current only in a single direction. An AC power source is used here as the input.

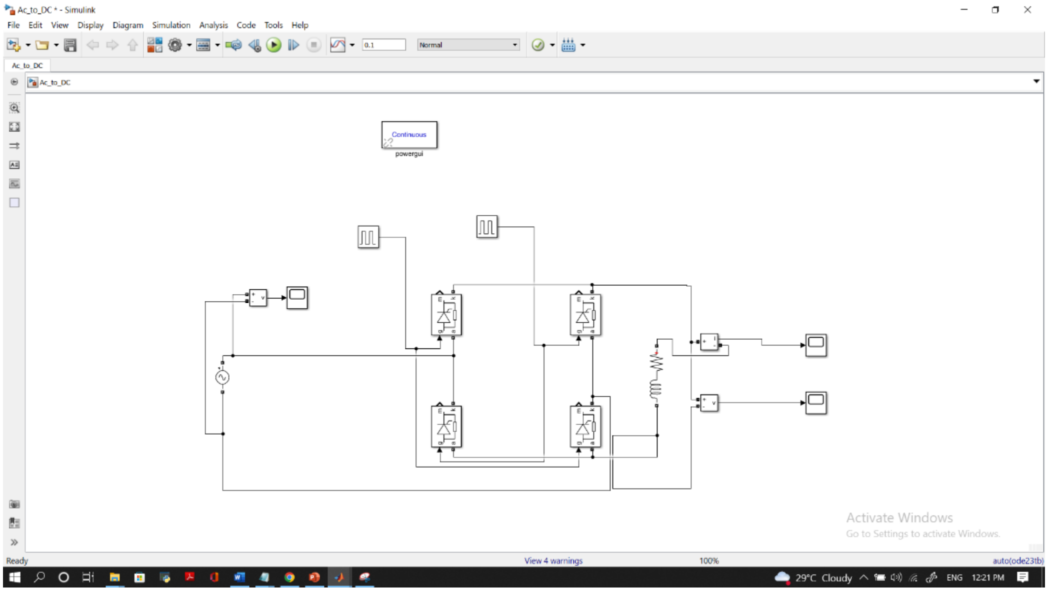

Figure 3.2: MATLAB Simulink model for converting AC voltage to DC voltage.

Figure 3.3 below shows the 12V DC power supply circuit modeled in the MATLAB Simulink. Here 230V to 12V linear transformer with two windings is used and four diodes are used to provide the full-wave rectification. The RMS value of the AC voltage is also calculated.

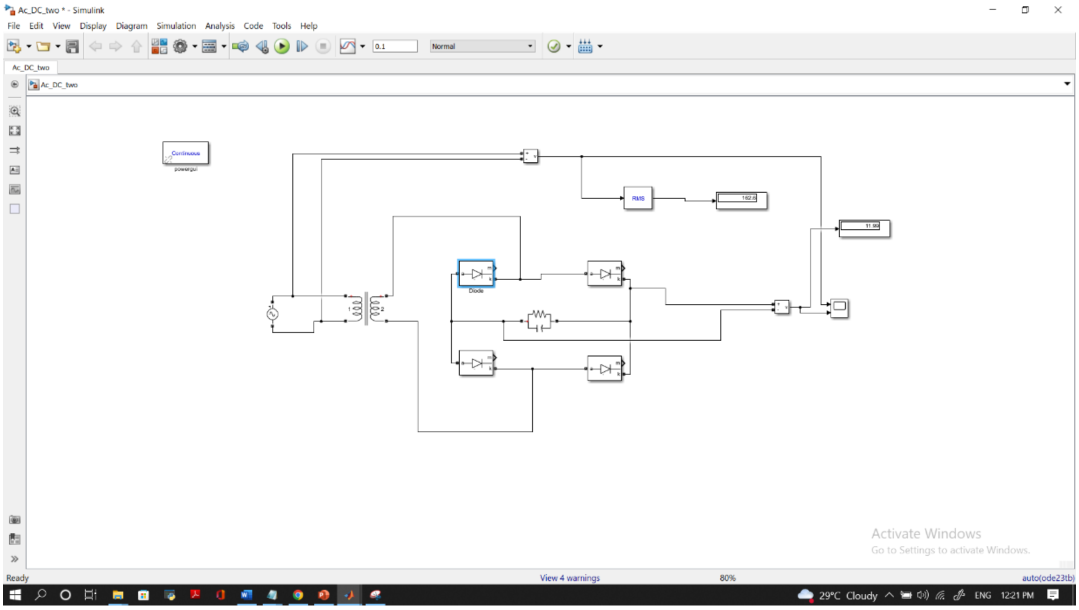

Figure 3.3: 12V DC power supply circuit modeled in the MATLAB Simulink

Then the 0-12V variable power supply was created physically using a center-tapped 300mA 12Vx2 step-down transformer to charge the battery cells separately before creating the battery pack. Here the transformer used is center tapped. So, the two 1N4007 diodes and the center-tapped wire are used to provide the full-wave rectification to efficiently convert the Alternating current (AC) into Direct Current (DC). Then the 35V 2200uF capacitor is used to level the current fluctuations and to provide a smooth output. A 100K ohm potentiometer is used to vary the voltage. We can get the required output voltage by adjusting it as required. The D400 NPN transistor and the 2N3055 NPN transistor are used as series pass transistors. Figure 3.4 below shows the circuit diagram of the 0-12V variable power supply.

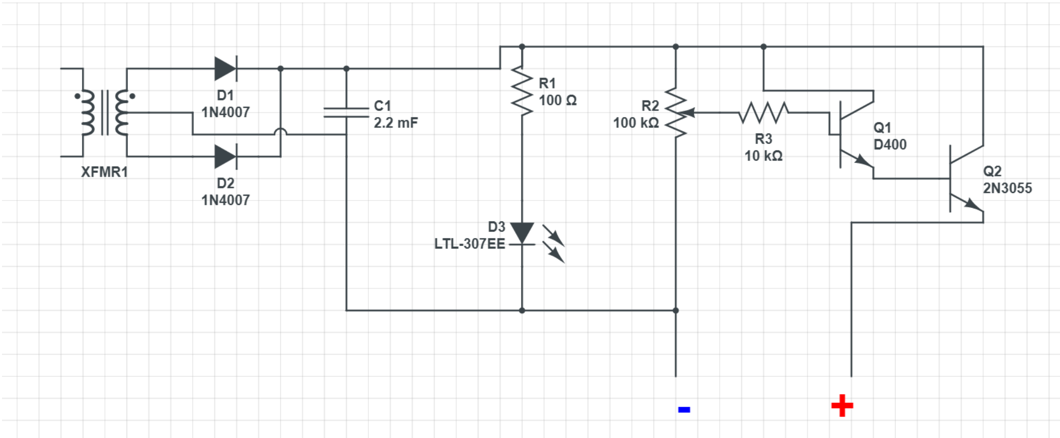

Figure 3.4: Circuit diagram of the 0-12V variable power supply

Figure 3.5 below shows the 0-12V variable power supply

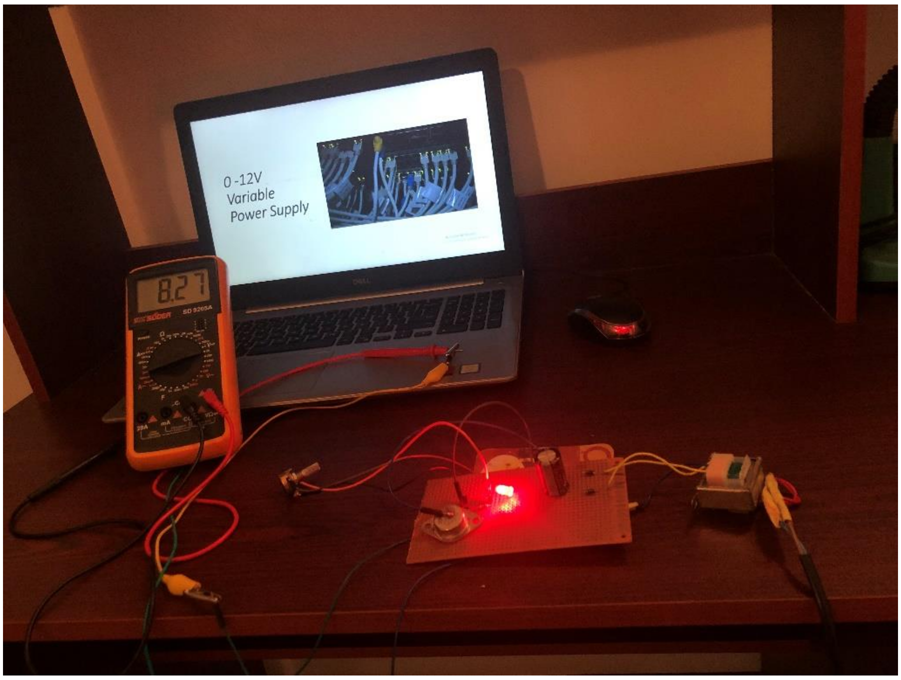

Figure 3.5: 0-12V variable power supply

3.3.1.2 Designing of the BMS circuit

Then the Battery Management System circuit for protecting the battery from over-charging, over-voltage, and over-current was designed. This circuit also functions to balance the cells of a battery pack when the battery pack is charging. An individual cell should have a separate discharging system. In the circuit for one individual cell, the TIP2955 PNP transistor is connected in series with four 1N4007 diodes and it will simulate the load. The base of the TIP2955 transistor is connected to a TL431 shunt voltage regulator. The TL431 has three pins such as the anode pin, the cathode pin, and the reference pin. The reference pin is used to set the reference voltage of the regulator. The TL431 can regulate a voltage from 2.5V to 36V. Figure 3.6 and figure 3.1 below shows the pin diagram and the voltage regulator circuit of the TL431 voltage regulator respectively.

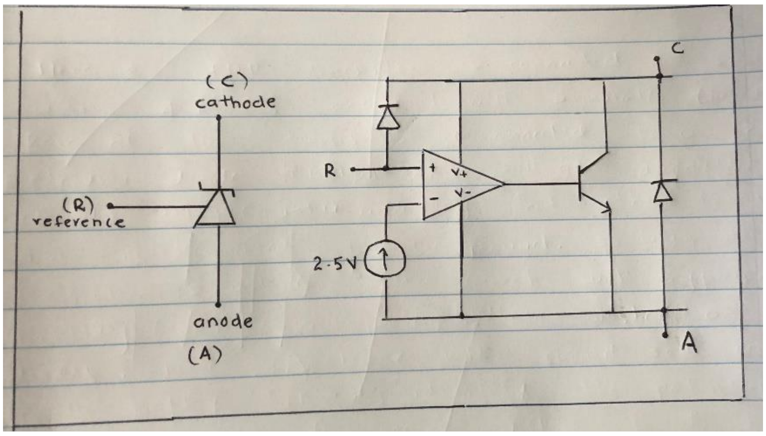

Figure 3.6: Pin diagram of the TL431 voltage regulator

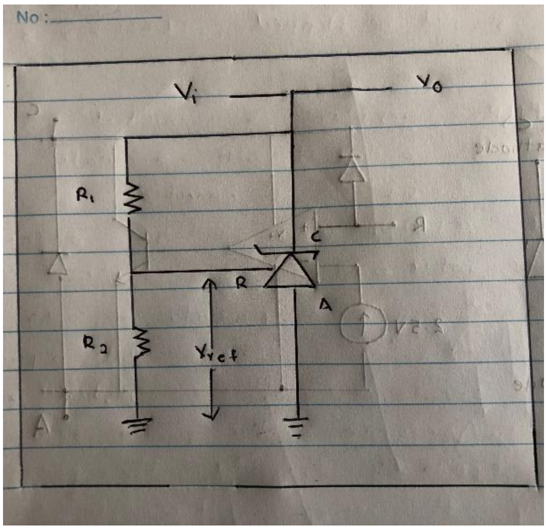

Figure 3.7: Voltage regulator circuit of the TL431 voltage regulator

$$\boldsymbol{V_0 = V_{ref}\left(1 + \frac{R1}{R2}\right) \quad , V_{ref} = 2.5V}$$

In the circuit, the TL431 regulator will get close at a certain voltage value, and by that, the transistor base gets connected to the ground. So, when this TIP2955 transistor is active, the current flow will bypass the battery cell and the power will be wasted on the four diodes. Firstly, the reference voltage of the TL431 regulator should be set accordingly to the battery type used by adjusting the potentiometer. For example, if a lithium-ion battery is used, the reference voltage should be set to a value just below 4.2V and if a Nickel Metal Hydride (NiMH) hybrid battery cell is used, the reference voltage should be set to a value just below 8.1V or a value around 8V. That's how we can set when the charging process should be stopped. When we supply the necessary voltage to the battery, the battery will start charging and the current will flow through the battery. If the battery's current voltage is below the pre-configured reference voltage of the circuit, the TL431 regulator will be open now. So, the TIP2955 transistor is now off because it has a 1K ohm pull-up resistor at its base. So, in this instance, the current flow in the circuit is only through the battery cell. When the battery reaches the pre-configured reference voltage, the TL431 regulator will get close and will make a connection between the base of the TIP2955 transistor and the ground of the circuit. So now the transistor is active, and the current will flow through it and through the four diodes, which will act as the new load of the circuit. So, the current will not flow through the battery anymore protecting it from over-charging. This is how the charging process is stopped. Also, when the TIP2955 transistor is active, the voltage is connected to the resistor and the LED in the circuit. So, the LED will turn on when the charging process is completed. An LM317 regulator can be connected at the input to supply the necessary voltage and current accurately. The LM317 can output a voltage from 1.25V to 37V and the input voltage can be varied from 3V to 40V. Figure 3.8 below shows the voltage and current control circuit of the LM317 regulator.

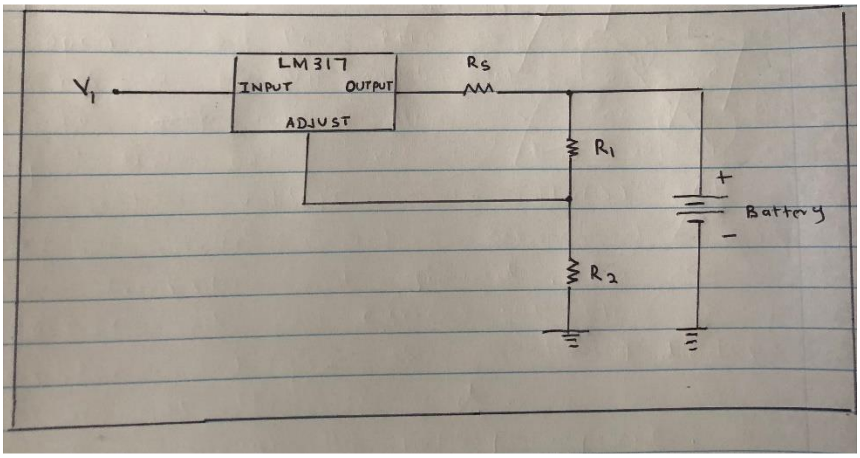

Figure 3.8: Voltage and current control circuit of the LM317 regulator

$$V_{output} = 1.25(1 + \frac{R2}{R1}) \quad , \quad I_{output} = \frac{1.25}{Rs}$$

The figure 3.9 below shows the BMS circuit design for charging one battery cell.

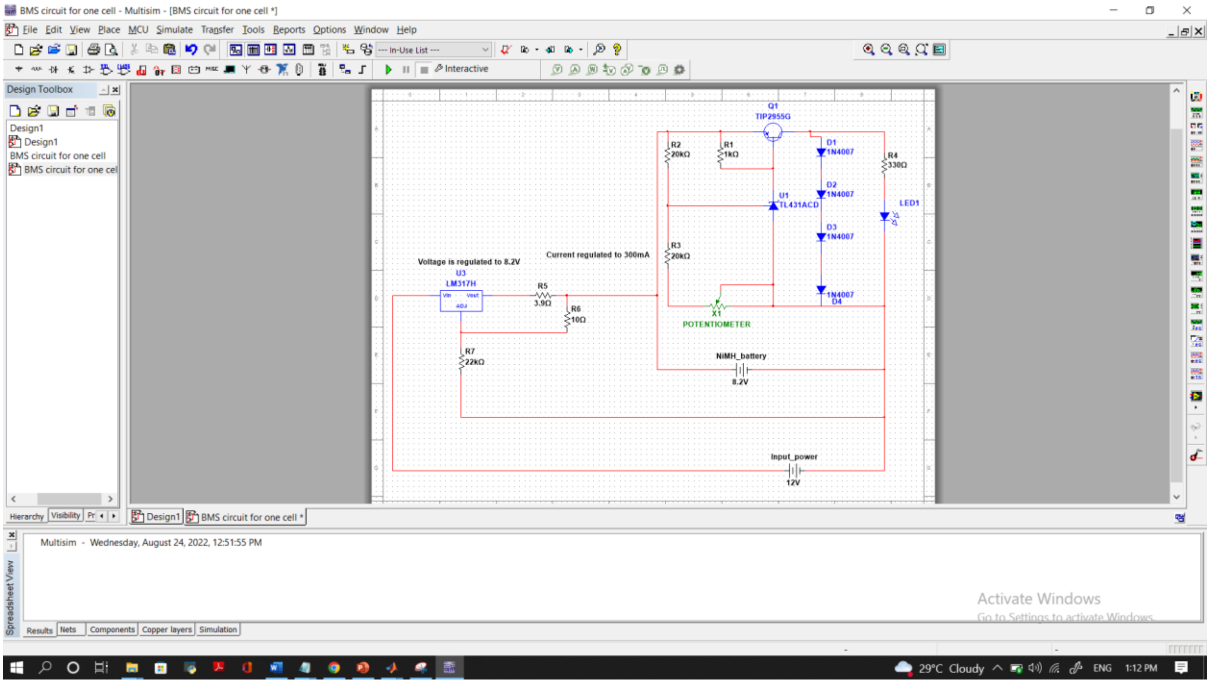

Figure 3.9: BMS circuit for charging one battery cell

Figure 3.10 below shows the BMS circuit for charging one battery cell created on a breadboard.

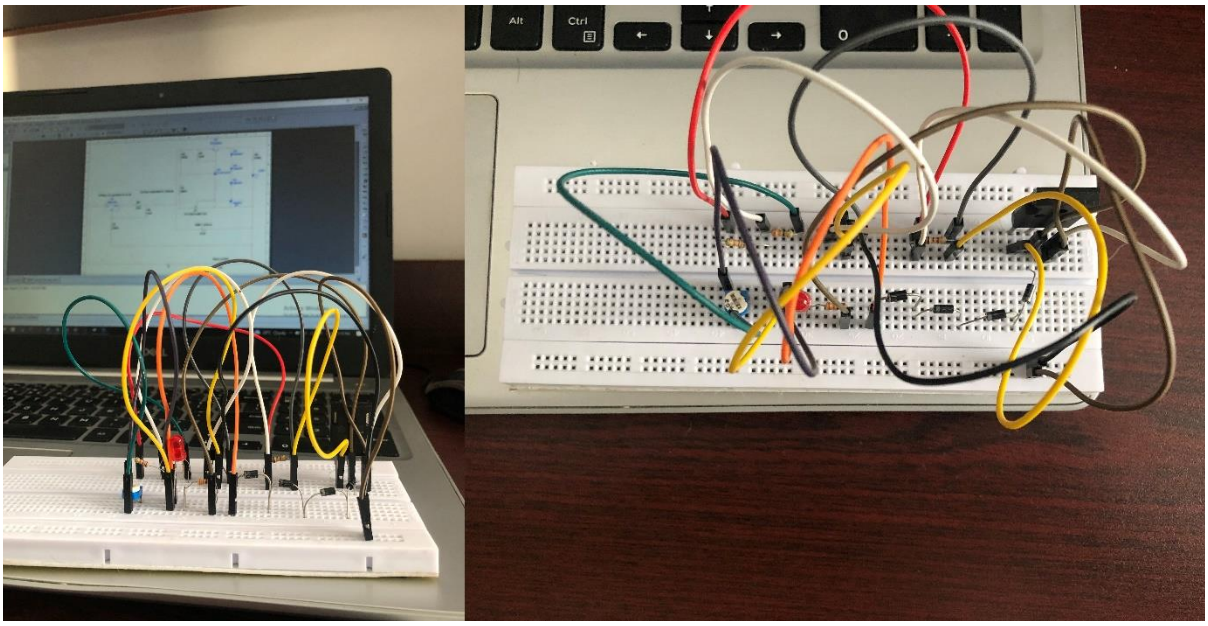

Figure 3.10: BMS circuit for charging one battery cell created on a breadboard

3.3.1.3 PCB Designing of the BMS circuit

The PCB design was done using the EasyEDA software and the EAGLE software. Figure 3.11 below shows the circuit schematic of the PCB design and Figures 3.12 and 3.13 below show the circuit board of the PCB design.

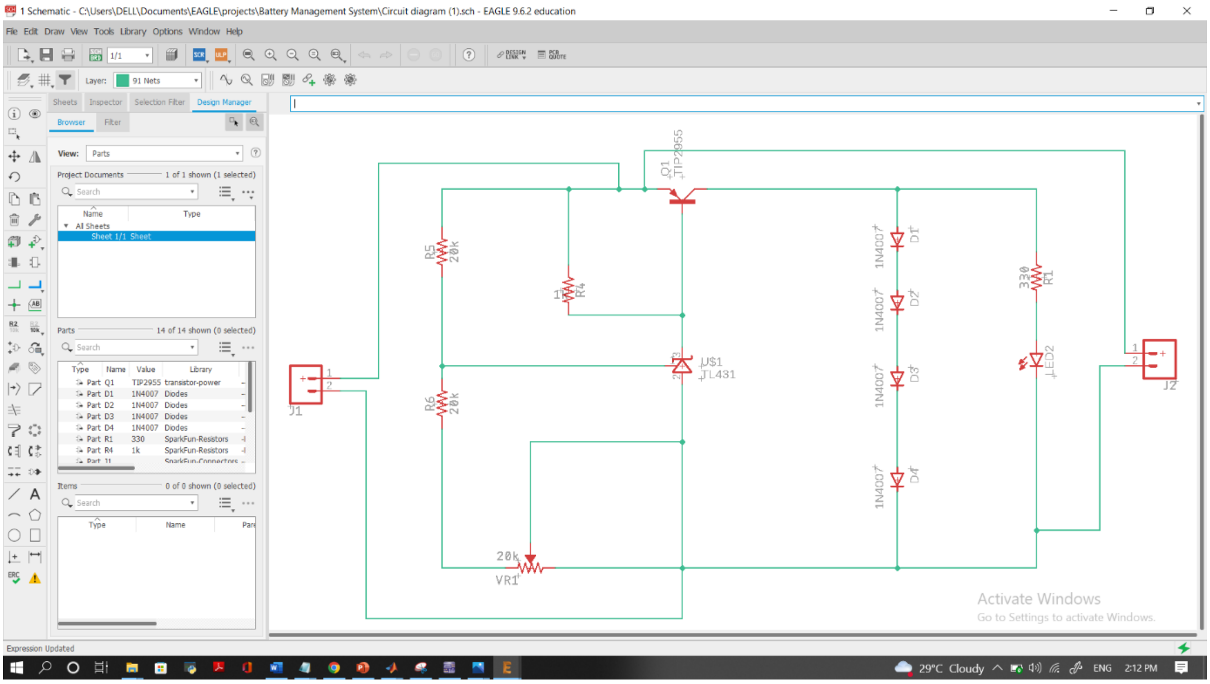

Figure 3.11: Circuit schematic of the PCB design

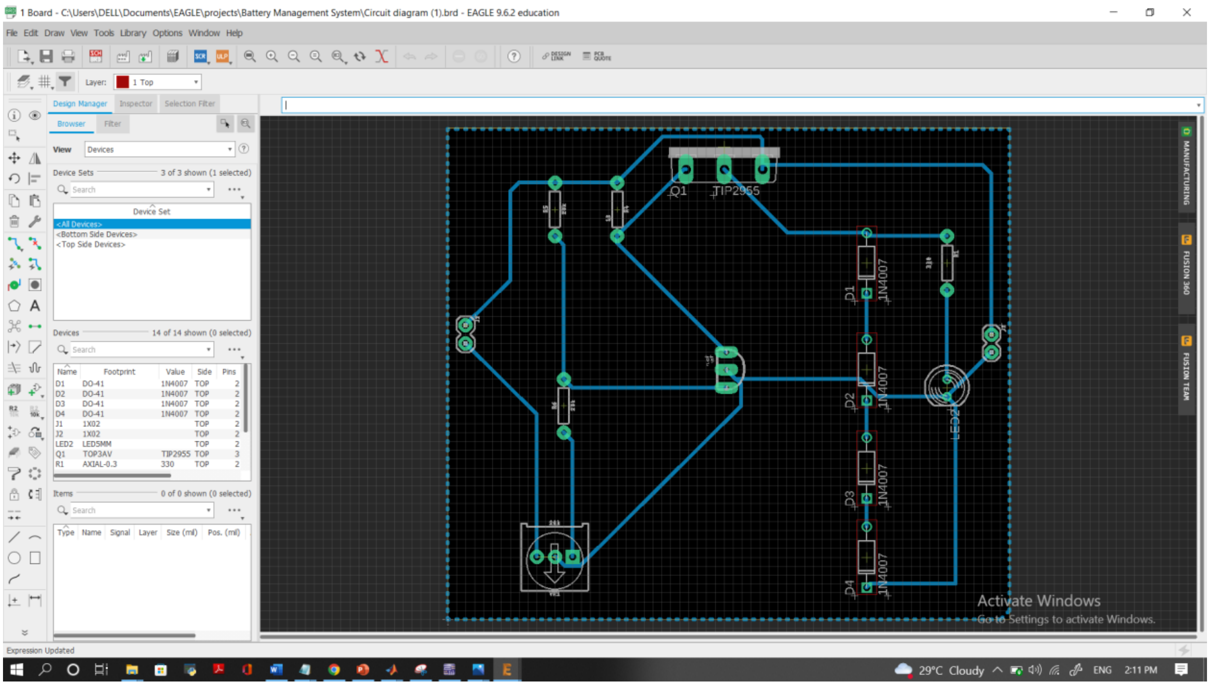

Figure 3.12: Circuit board of the PCB design

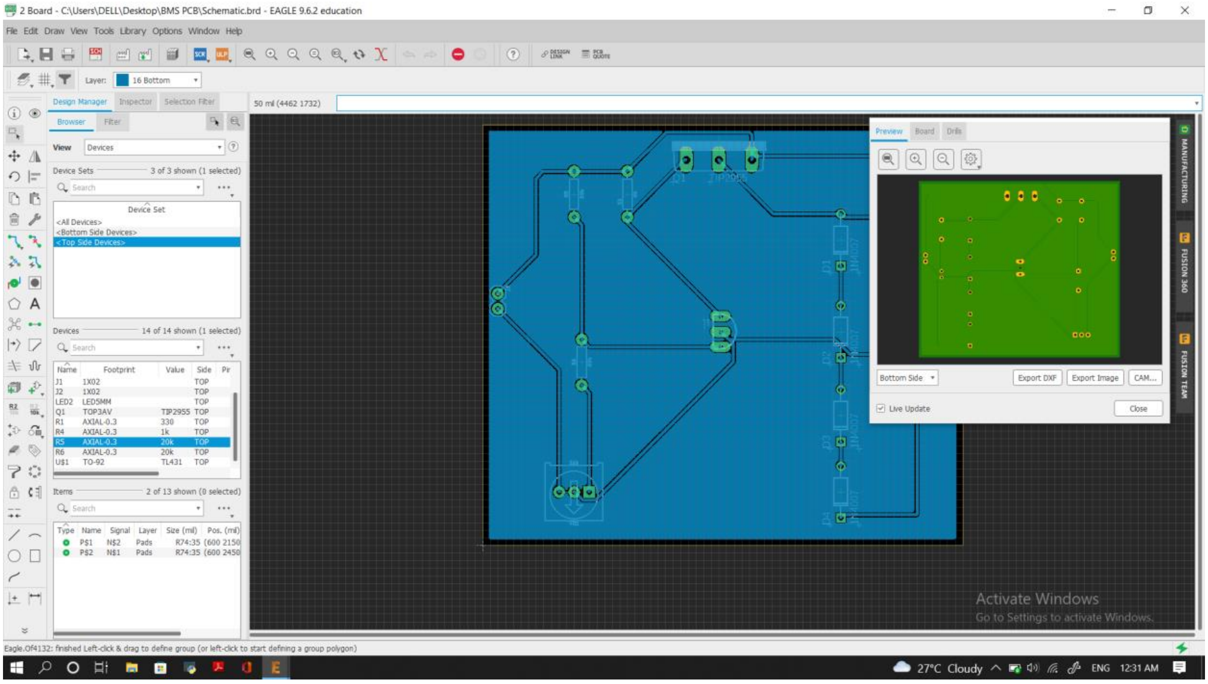

Figure 3.13: Circuit board of the PCB design

Figure 3.14 below shows the 3D view of the PCB design.

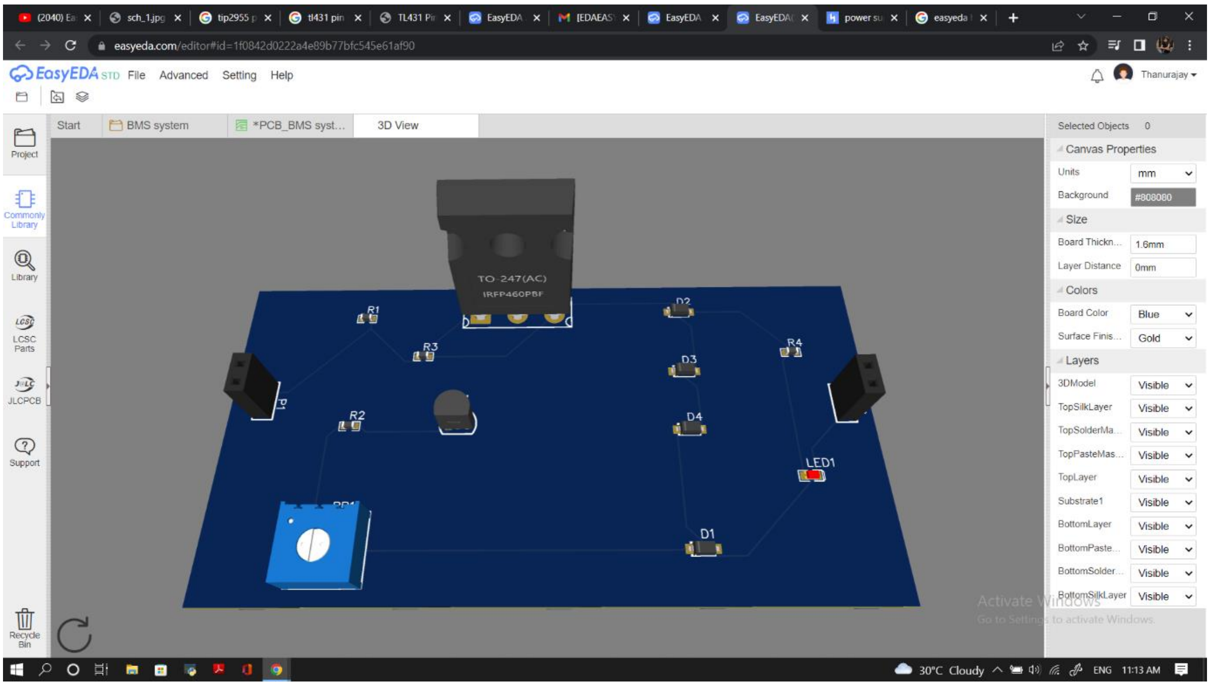

Figure 3.14: 3D view of the PCB design

3.3.1.4 Individual battery cell charging

Each cell was charged separately before creating the battery pack. For this, I used the 0-12V variable power supply I created.

At first, I tested the circuit with an 18650 lithium-ion battery which has a capacity of 4300mA and a nominal voltage of 3.7v and 4.2v when fully charged. At first, I adjusted the reference voltage of the TL431 to 3.65V by connecting the multimeter to the circuit output since I did not need the lithium-ion cell to be fully charged because I was just testing the circuit. The input power to the circuit was given to the emitter of the TIP2955 transistor and the anode of the TL431 regulator. After the input was given to the circuit, the brightness of the LED changed when the variable resistor was adjusted.

Figure 3.15 below shows a photo taken during the testing of the BMS circuit using a lithium-ion battery.

Figure 3.15: Testing the BMS circuit using a lithium-ion battery cell

Then I charged each NiMH hybrid battery cell separately using this circuit and the variable power supply. Here, to control the input voltage I used a 7808-voltage regulator instead of the LM317 regulator since the maximum current from the power supply is 300mA (because the transformer used is a 300mA one). Hence there won't be any excess current to the battery cell when charging. The reference voltage of the TL431 was adjusted to 8V because I was not sure about the capacity of these battery cells. It took a long time for a battery cell to be charged since the supply current was only 300mA. Normally we can supply up to 500mA safely to a NiMH hybrid battery cell when those are charged separately.

Figure 3.16 below shows a photo taken during the charging of one NiMH battery cell.

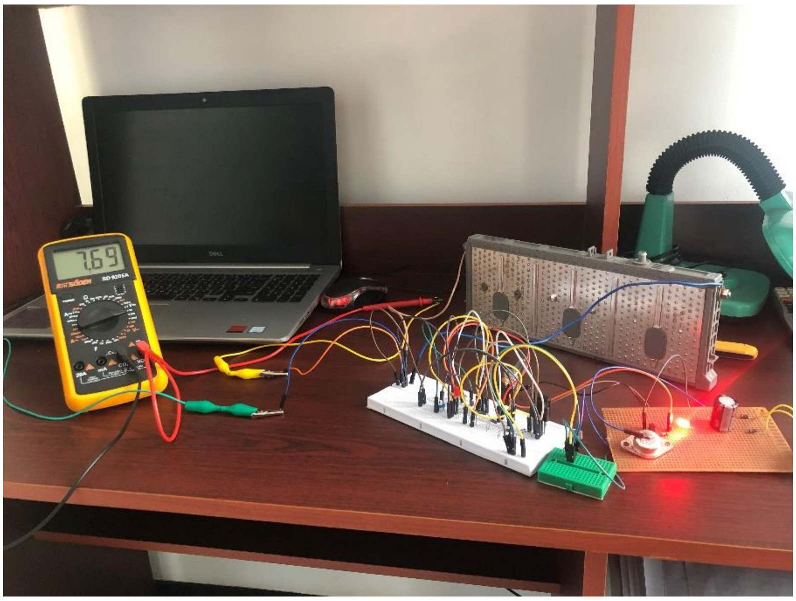

Figure 3.16: Charging of one NiMH hybrid battery cell

3.3.1.5 Designing of the 24V battery pack

A 24V 13Ah (312W) battery pack was designed using Nickel Metal Hydride (NiMH) batteries using the 3s2p battery configuration after each cell was charged separately.

Figure 3.17 below shows the battery pack design.

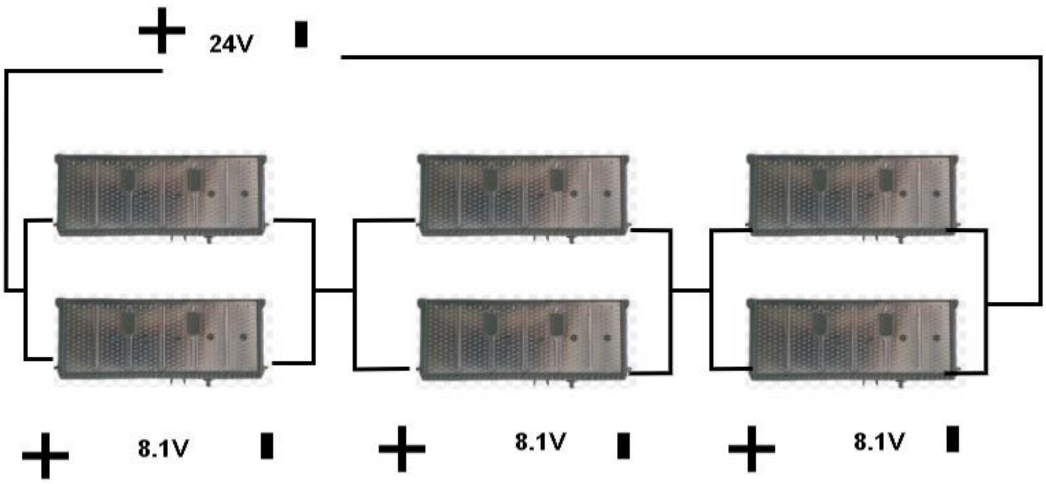

Figure 3.17: Battery pack design.

Then the battery pack was modeled and run on the MATLAB Simulink. From this Simulink model, the decrease of the State of Health (SoH) of the battery pack with time can be seen.

Figure 3.18 and figure 3.19 below show the MATLAB Simulink model of the 24v battery pack and the battery specifications of the MATLAB model respectively.

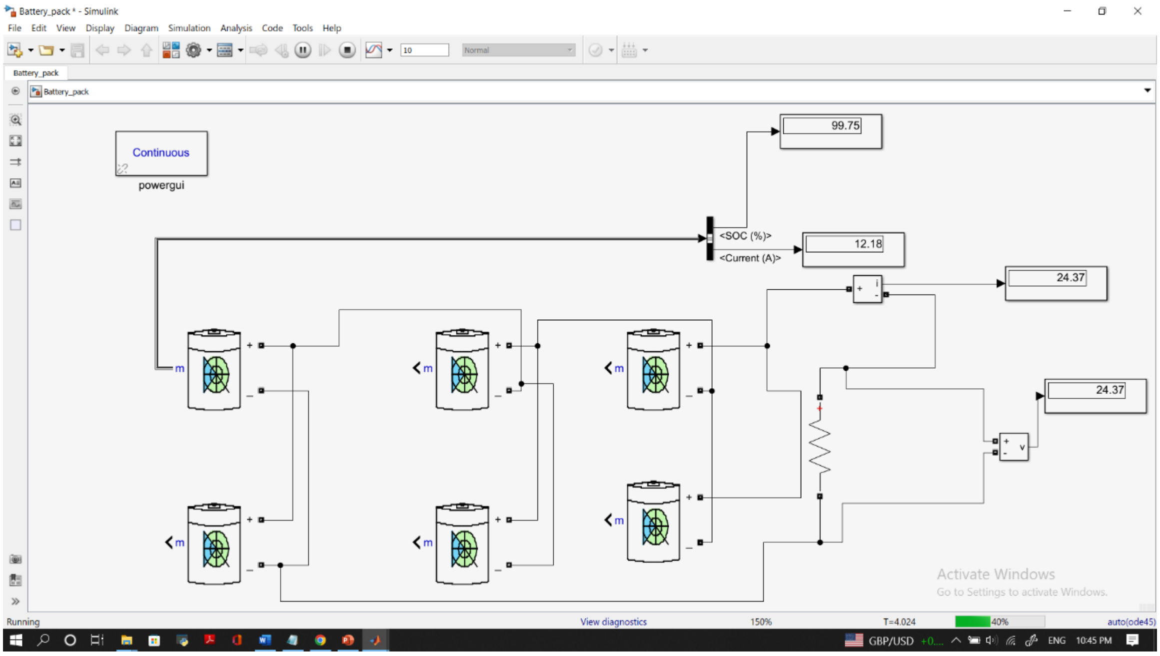

Figure 3.18: MATLAB Simulink model of the 24v battery pack

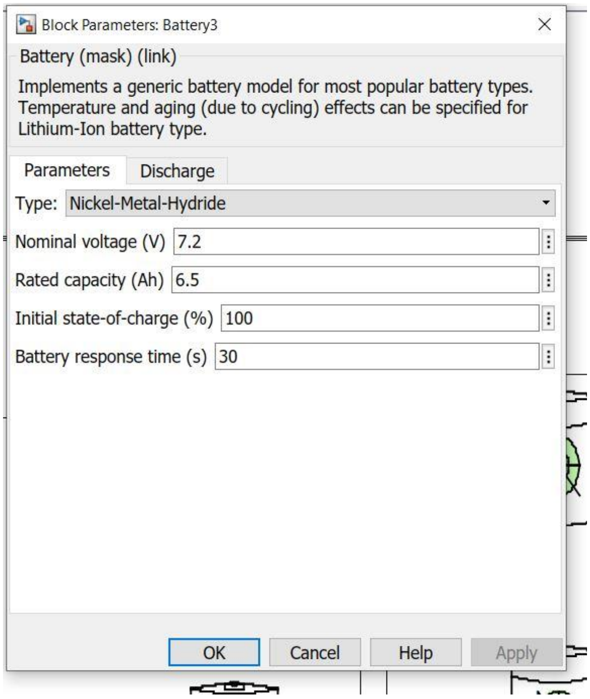

Figure 3.19: Battery specifications of the MATLAB model

Finally, the battery pack was created by joining six NiMH hybrid battery cells to the 3s2p configuration. Figure 3.20 below shows the 24V battery pack.

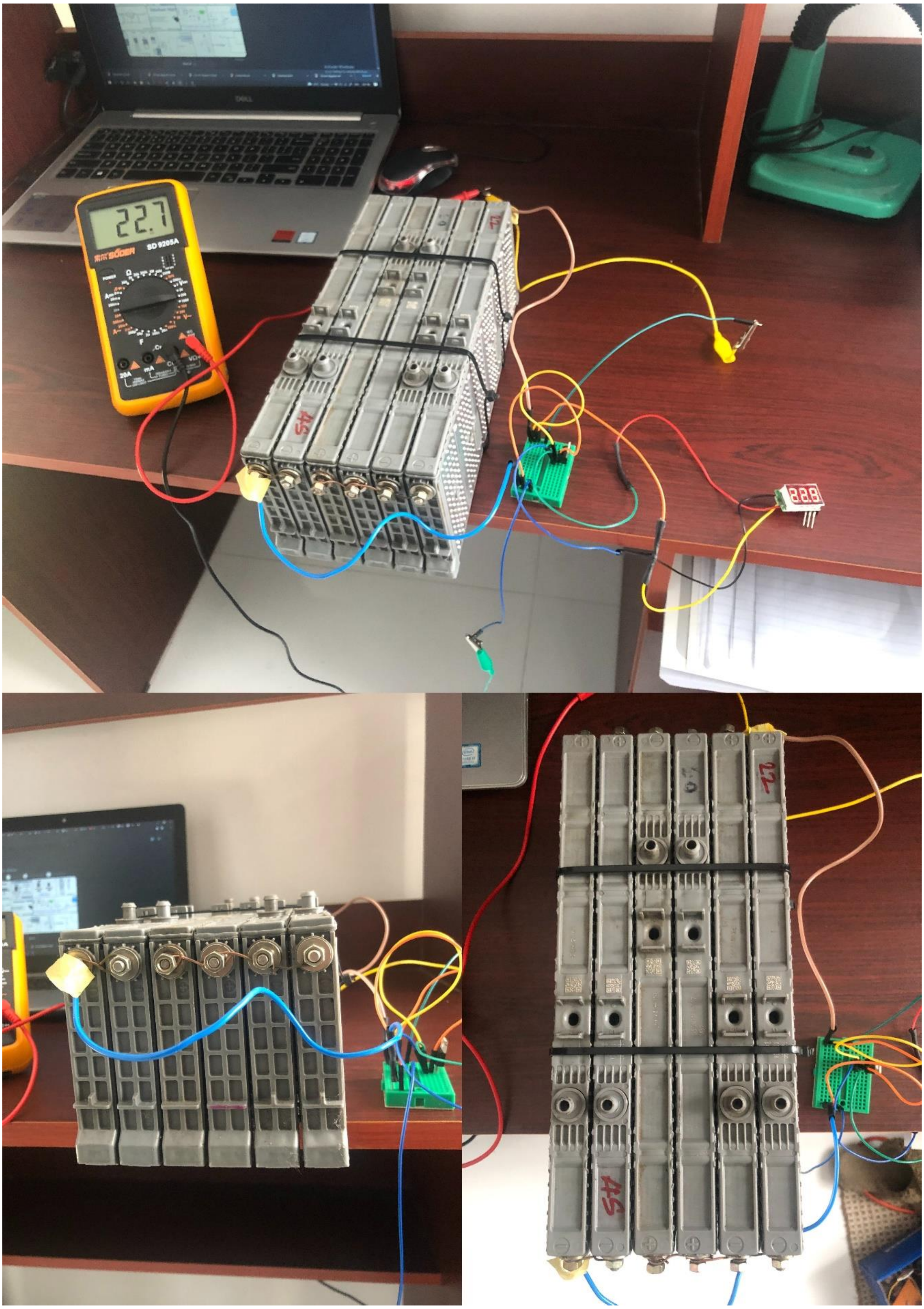

Figure 3.20: 24V battery pack

3.3.1.6 Designing the 24V power supply to charge the battery pack

To charge the 24v battery pack, I designed a 24v DC power supply using a 12Vx2 3A center-tapped transformer. Here the center tapped wire is not used since the output voltage must be 24v. Hence four 1N5408 diodes are used to create the rectifier bridge to obtain a full wave rectification. 1N5408 is a high-power rectifier diode and it has a maximum rectification current of 3A it also supports a repetitive reverse voltage of 1000V. Then a 50V 4700uF capacitor is used to level the current fluctuations and to obtain a smoother ripple-free DC output signal. A 7824-voltage regulator is connected at the output to provide a steady 24v output DC voltage.

Figure 3.21 below shows the circuit diagram of the 24V power supply

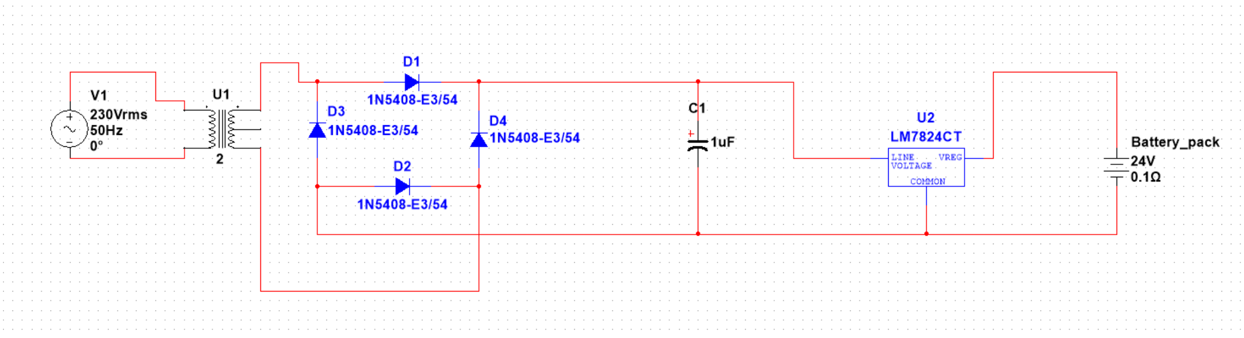

Figure 3.21: Circuit diagram of the 24V power supply

Then 24V power supply was created. Figure 3.22 below shows the 24V 3A power supply.

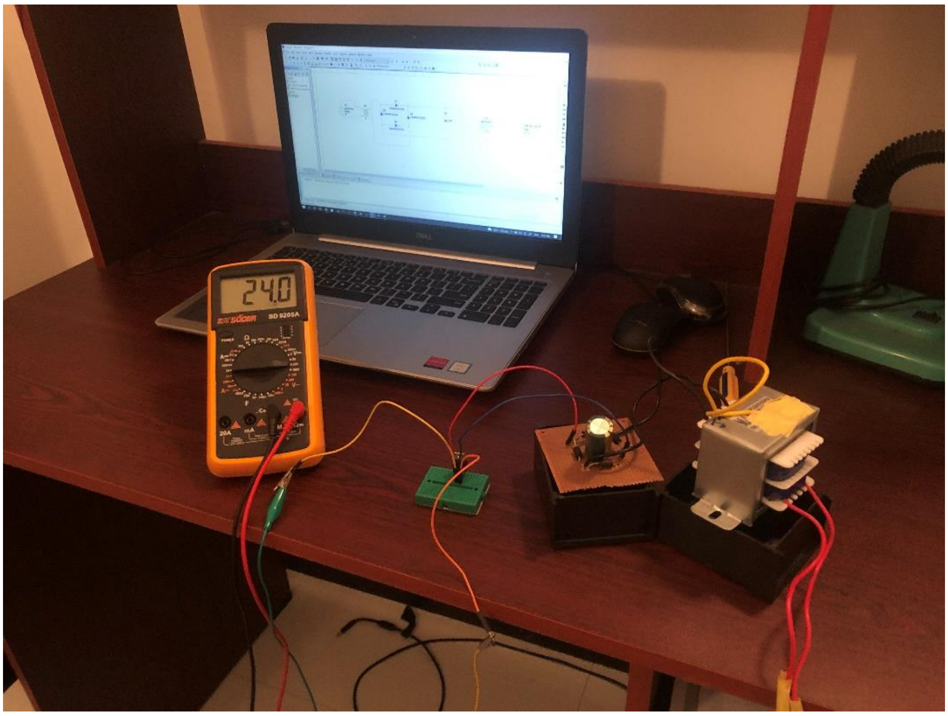

Figure 3.22: 24V power supply to charge the battery pack

3.3.1.7 Charging the battery pack

The battery pack was prepared using the 3s2p configuration. That means three battery cells are in series and two strings of these in parallel. For the three battery cells connected in series, three separate BMS circuits should be connected. So, three equivalent BMS circuits should be connected to protect the battery pack from over-charging, over-voltage, and from over current. The circuit also functions to balance each cell of the battery pack by cell balancing. When one of the three battery cells gets charged to the maximum level, the BMS circuit will stop the charging process of that cell only.

Figure 3.23 below shows the BMS circuit for the 3s2p 24V battery pack.

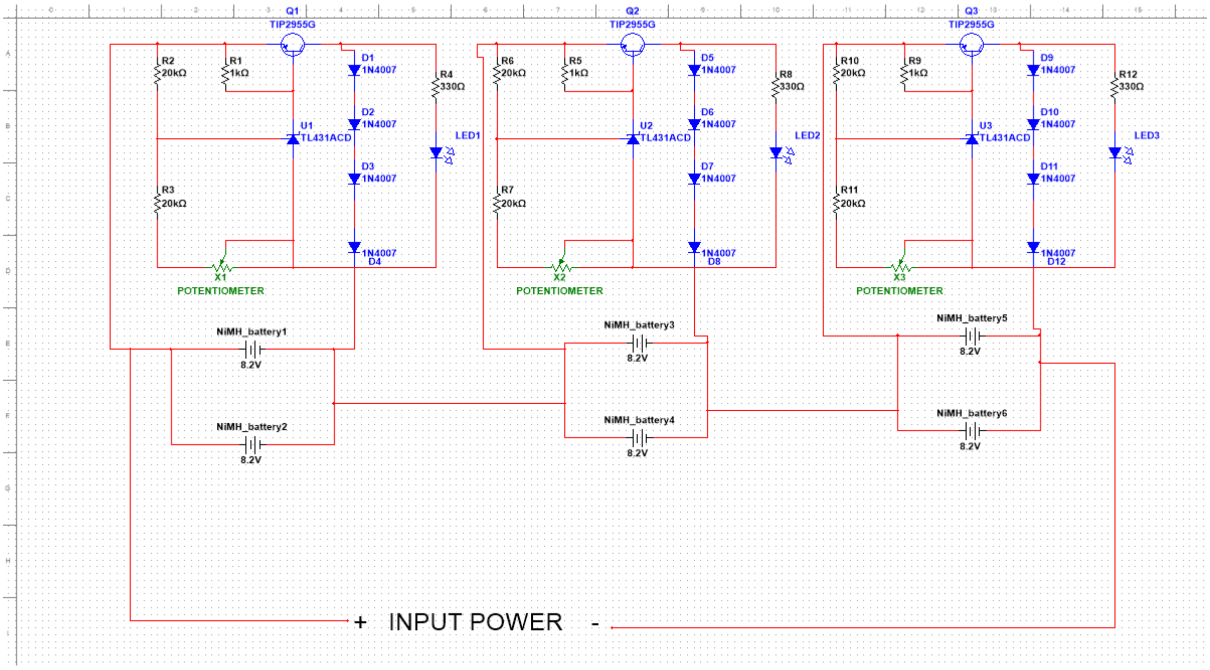

Figure 3.23: BMS circuit for the 3s2p 24V battery pack

Then the complete circuit was soldered on a dot board to test the circuit. Here the circuit cannot be tested in the breadboards because the breadboards and jumper wires cannot withstand the high voltage and high current flow through the circuit for a long time. The jumper wires get heated quickly and burn off. The breadboards also malfunction when the voltage and current flow is too high. So, the complete circuit was soldered on a dot board and flexible wires were used for testing the charging of the battery pack.

Figure 3.24 below shows the complete BMS circuit for the 3s2p battery pack soldered on the dot board.

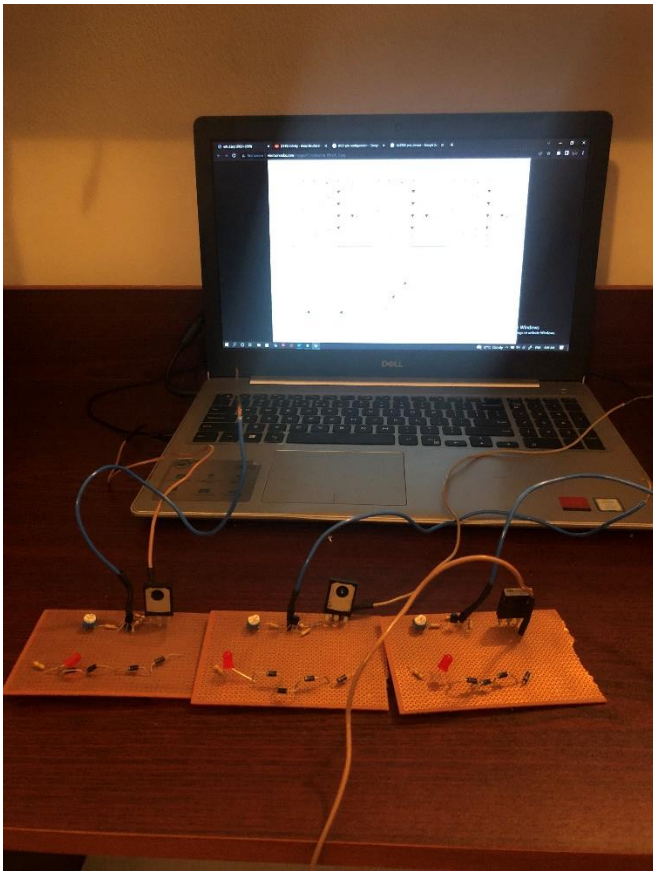

Figure 3.24: Complete BMS circuit for the 3s2p battery pack soldered on the dot board.

Figure 3.25 below shows the connection of the BMS charging circuit with the battery pack.

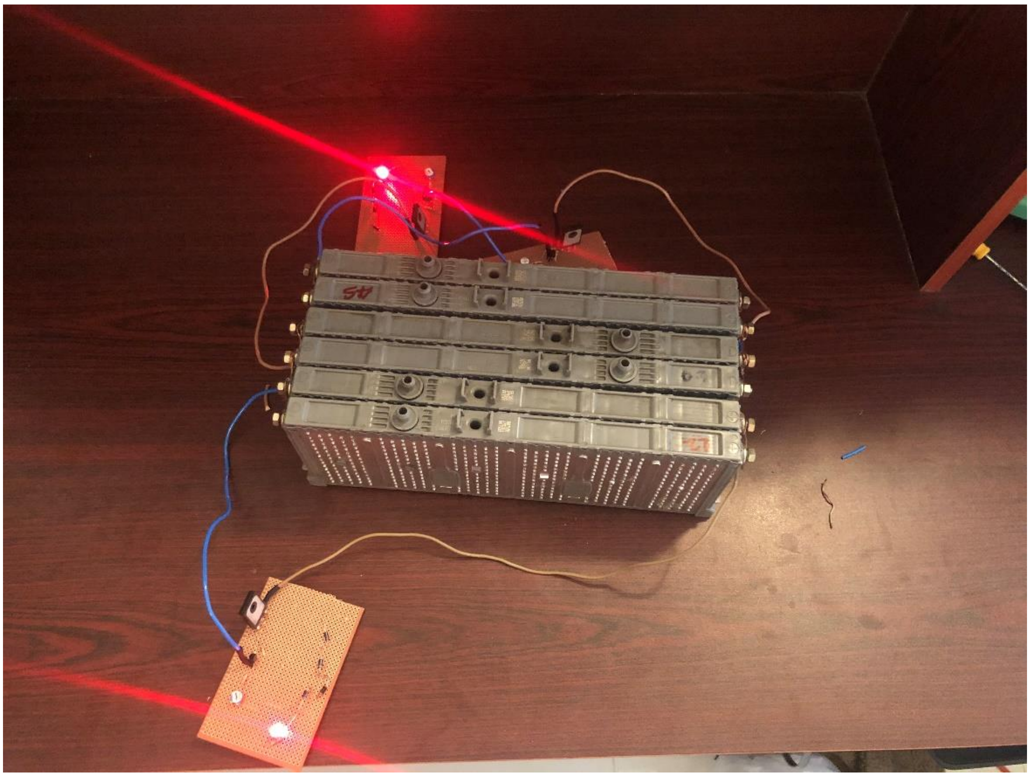

Figure 3.25: Connection of the BMS charging circuit with the battery pack

3.3.1.8 Designing of Battery Management System (BMS) models in MATLAB Simulink

<u>Passive cell balancing</u>

Here the passive cell balancing technique is used to balance the cells of the battery. Passive cell balancing means the discharge of cells that is overcharged through a passive element like a discharge resistor. In this MATLAB model, a discharge resistor is used to discharge the battery cells and the State of Charge (SoC) of the batteries. A switch is used to control the process. When a battery cell is needed to be discharged, the switch will close. Then the battery will be discharged through the resistor. A MATLAB function is used to operate this process. The basic idea behind the function is that if one cell is overcharged more than the other two cells, the switch of that cell should be on and otherwise should be off. Likewise, three if statements are written to the three cells. The initial State of Charge of the three cells is set to three different values at the start. When we run the model, the State of Charge of the three batteries will come to an equal value by discharging the necessary cells.

Figures 3.26 and 3.27 below show the passive cell balancing model and the MATLAB function of it respectively.

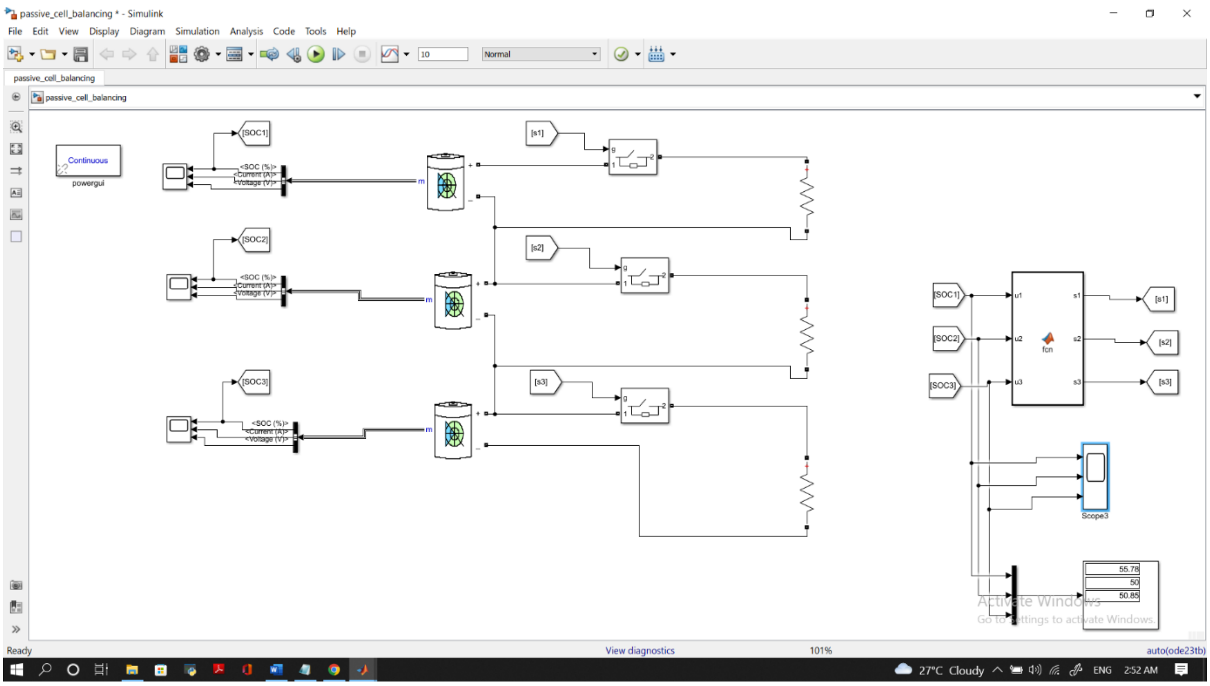

Figure 3.26: Passive cell balancing MATLAB model

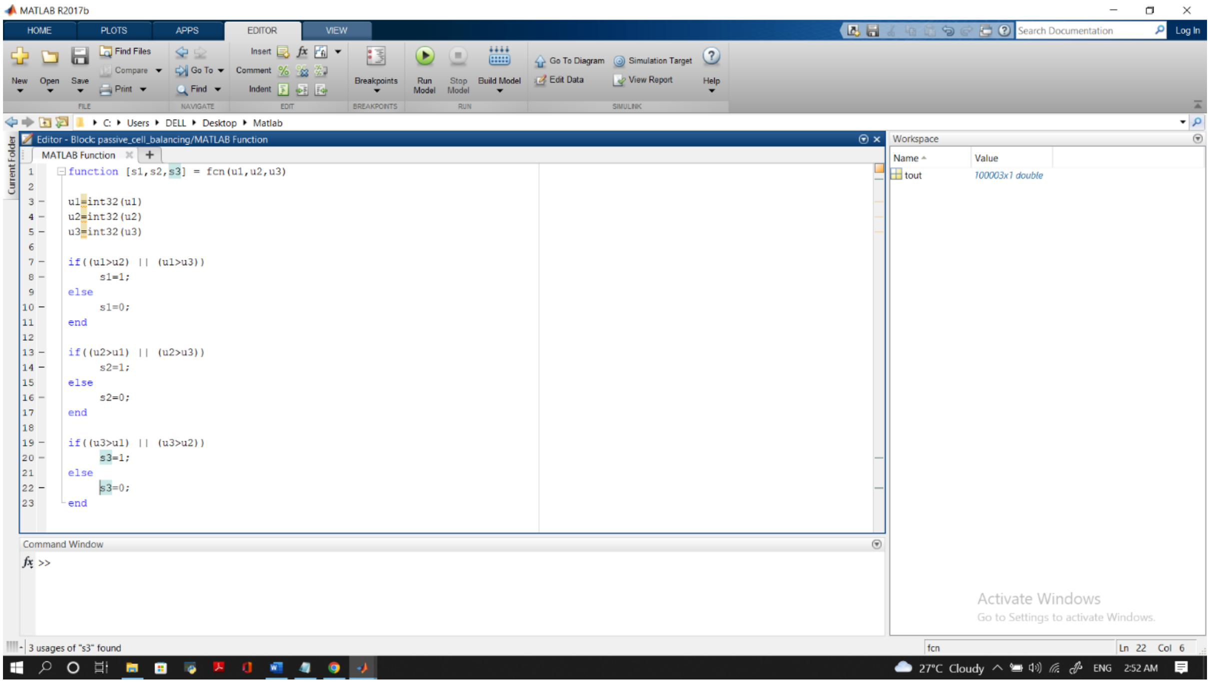

Figure 3.27: MATLAB function of the passive cell balancing model

<u>Charging and discharging a battery based on SoC limits.</u>

In this MATLAB Simulink model, the charging and the discharging of the battery are done based on the State of Charge (SoC) limits. Here battery 1 is used to supply the power to the load. A resistor is used as the load. Battery 2 is used as a DC source to charge battery 1. The initial SoC of battery 1 is set to a custom value. In the MATLAB function, a small program is written to charge the battery when the SoC level decreases to a certain value less than the initial SoC.

```
function [Discharge,Charge] = fcn(SOC)
Discharge=1;
Charge=0;
if (SOC>=95)
   Discharge=1;
   Charge=0;
end
if (SOC<94)
   Discharge=0;
   Charge=1;
end
```

In the above program, the minimum SoC of battery 1 is set to 94%. So, the battery should start to charge once the SoC level drops to 94%.

Figure 3.28 below shows the SoC-based charging and discharging model on MATLAB Simulink.

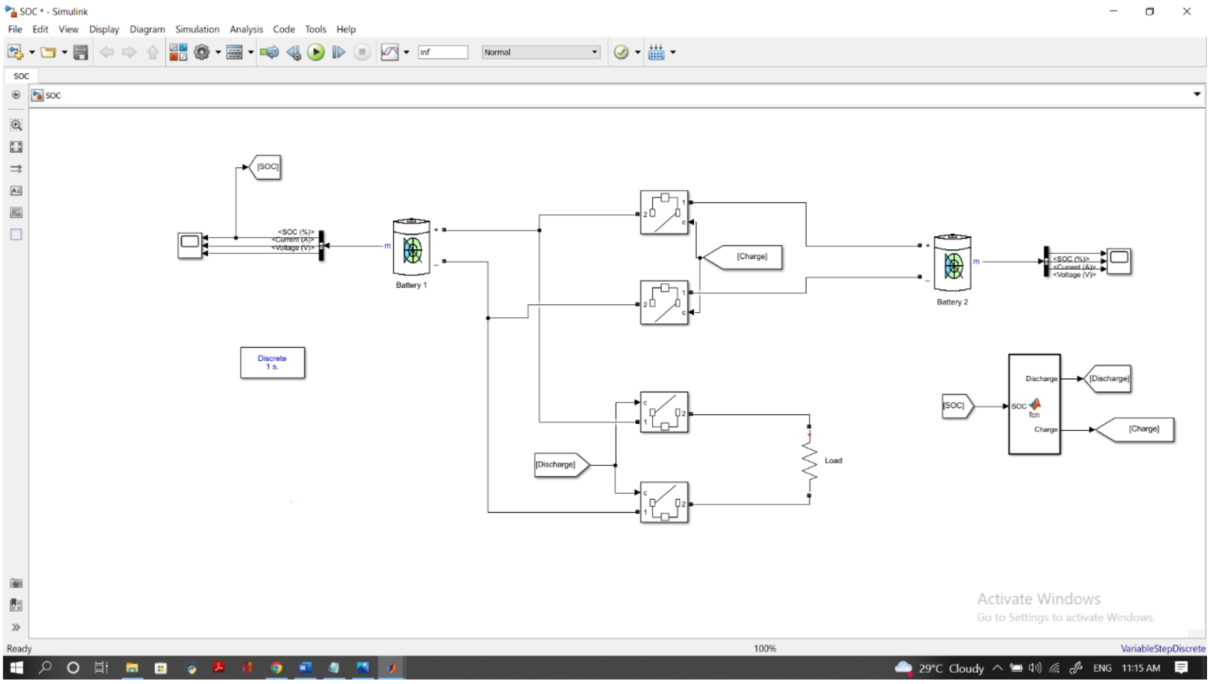

Figure 3.28: SoC-based charging and discharging model on MATLAB Simulink

<u>State of Charge (SoC) behavior of a battery pack when charging, discharging and cell balancing</u>

In this model, the behavior of the State of Charge (SoC) of a battery when charging and discharging can be observed by changing the three constant values in the Simulink model. The three battery cells are Nickel Metal Hydride (NiMH) batteries with a nominal voltage of 7.2V and a full charge voltage of 8.2V. The constant is connected to a Mosfet and it acts as a switch. When the charging constant is set to 1, the batteries will start to charge and the SoC of the battery will increase. When the discharging constant is set to 1, the three battery cells will start to discharge and the SoC of each cell will start to decrease. For cell balancing, a product function is used. Three product functions are used to discharge the three cells. When both the SoC constant and the [gn] (n = 0,1,2) constant is set to 1, that cell will decrease. Here the [gn] is controlled by the MATLAB function program. So, when the SoC constant is set to 1, the SoC levels of the three battery cells will be kept at an equal value by discharging the necessary cells. The discharging process is done by the load resistor.

Figure 3.29 below shows the battery pack model on MATLAB Simulink to observe the behavior of SoC of each cell in various instances.

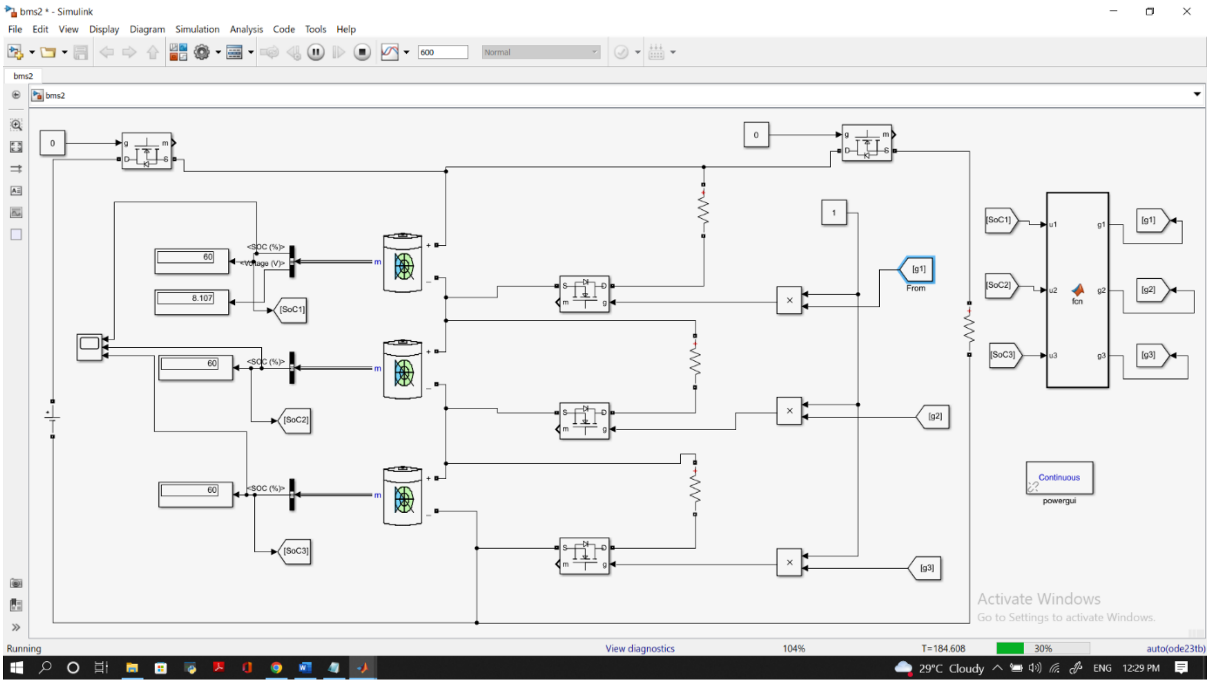

Figure 3.29: MATLAB battery pack model to observe the behavior of SoC of each cell in various instances

Figure 3.30 below shows the MATLAB function program used for the above model.

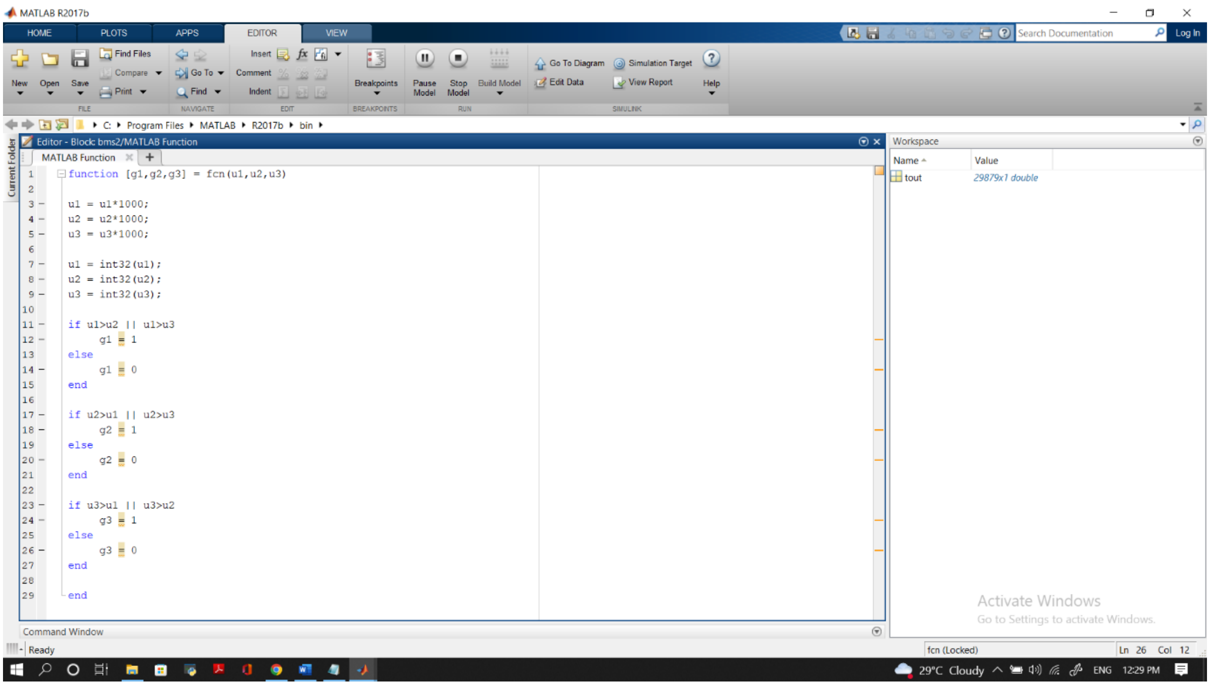

Figure 3.30: MATLAB function program of the battery pack model

3.3.2 Weather forecast display system

The OpenWeatherMap API was used to obtain the real-time weather data. Firstly, I created a Python model on PyCharm software to test the data from the OpenWeatherMap API. Firstly, an account and an API key was created on OpenWeatherMap. Then the API key is stored in the windows environment variables and python is used to read the environment variable. Then an API request is made to the OpenWeatherMap API using the requests library in python. After that, we will receive the data from the OpenWeatherMap in the JSON format, and finally, the data is decoded.

Figure 3.31 below shows the weather API model in Python.

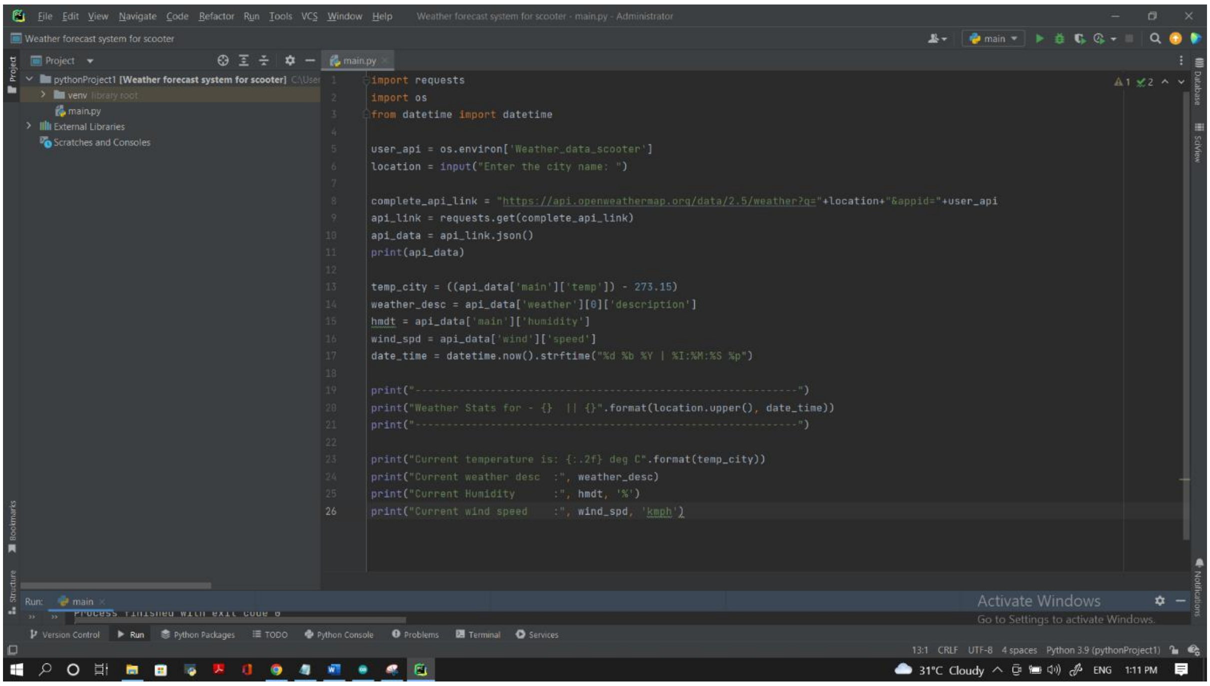

Figure 3.31: Weather API model in Python

Then the weather data was displayed in a LED display using an ESP8266 NodeMCU through the Wi-Fi network. Here the ESP8266 NodeMCU connects to the Wi-Fi network and acts as the client. Then the ESP8266 NodeMCU sends an HTTP request to the OpenWeatherMap server. Then the response is received in JSON format similar to the Python model. Then the JSON data is decoded.

Figure 3.32 below shows the weather data displayed on the LED display.

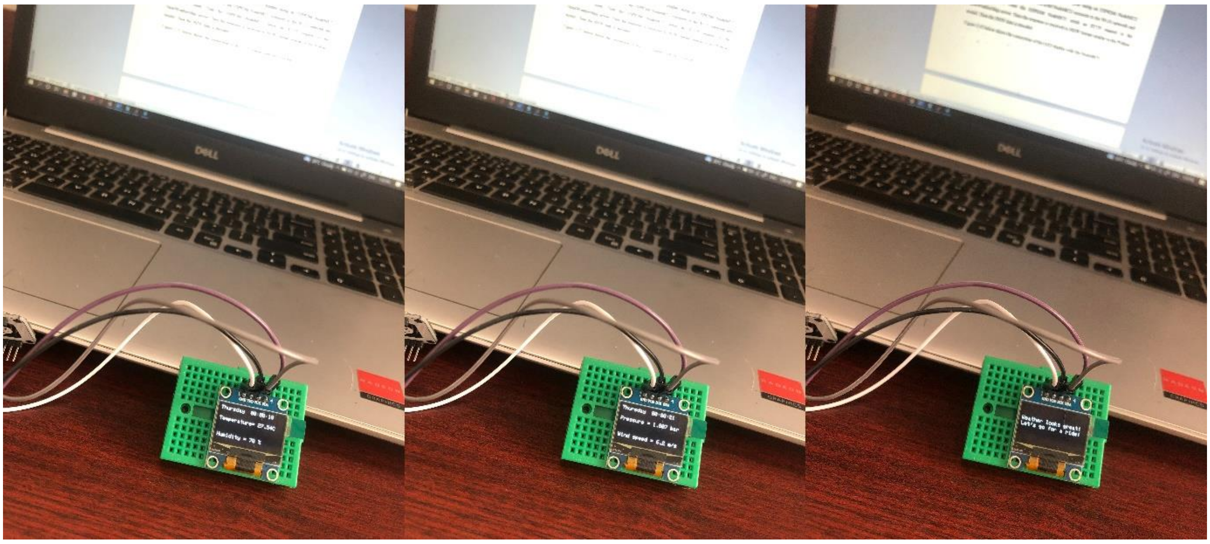

Figure 3.32: Weather data displayed on the LED display

3.3.3 GPS tracker

At first, I simulated a circuit in proteus with a virtual GPS module. Figure 3.33 below shows the simulation circuit with the virtual GPS module.

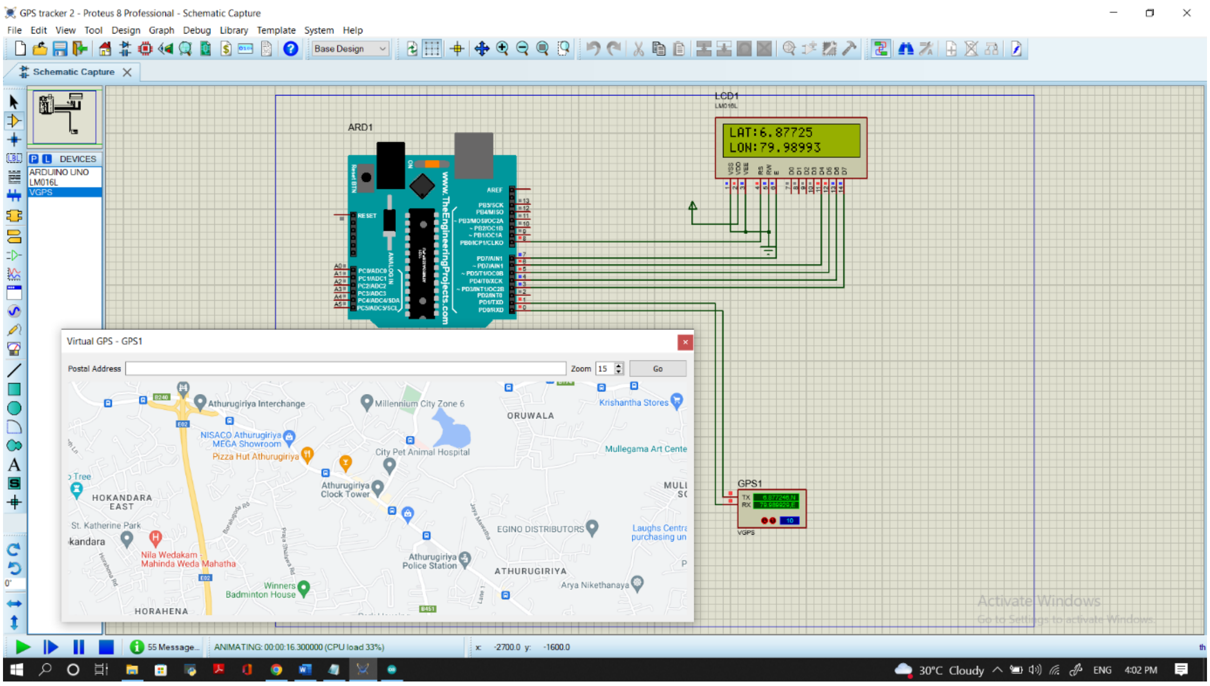

Figure 3.33: Simulation circuit with the virtual GPS module

Then I simulated a circuit using the GPS module and the SIM900D GSM module. Here the communication between the two virtual terminals is done from the SIM900D GSM module.

Custom GPS coordinates are entered into the Arduino code manually. One virtual terminal act as the mobile phone receiving the GPS coordinates.

Figure 3.34 below shows the simulation circuit using the GPS module and the SIM900D GSM module.

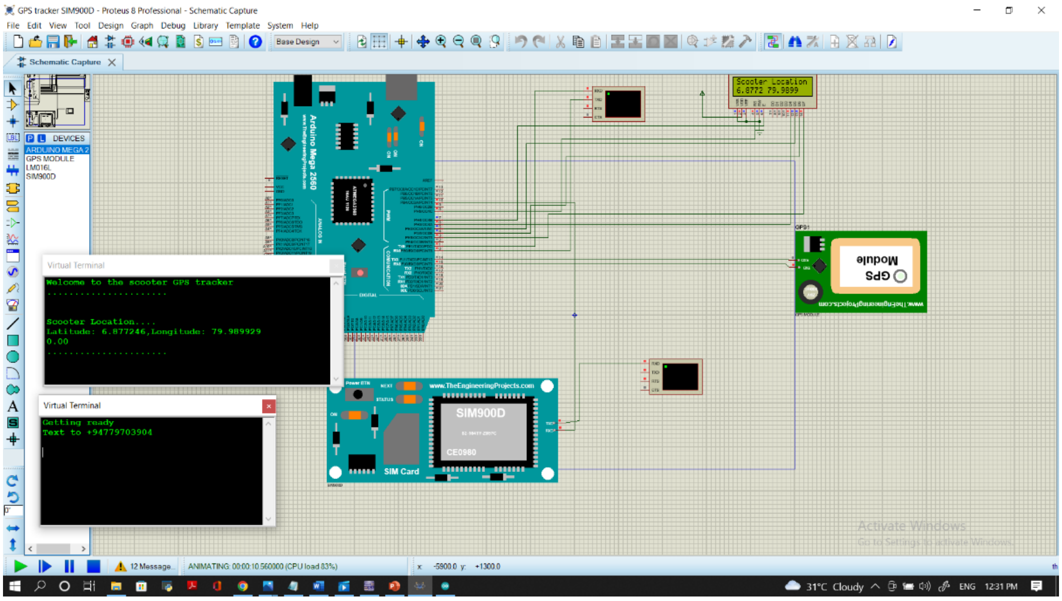

Figure 3.34: Simulation circuit using the GPS module and the SIM900D GSM module.

Then I used a NEO-6M GPS Module with Arduino to obtain the GPS coordinates of the current location. The NEO-6M GPS Module has 4 pins. The GND pin and the VCC pin are used to power up the module. The Tx and the Rx pins are used to use for serial communication. The module possesses a built-in antenna that has strong satellite search capability. The module takes some time to get connected to the satellite. We can see whether the module is connected to a satellite or not through the indicators in the module. Figure 3.35 below shows the NEO-6M GPS module circuit and the output.

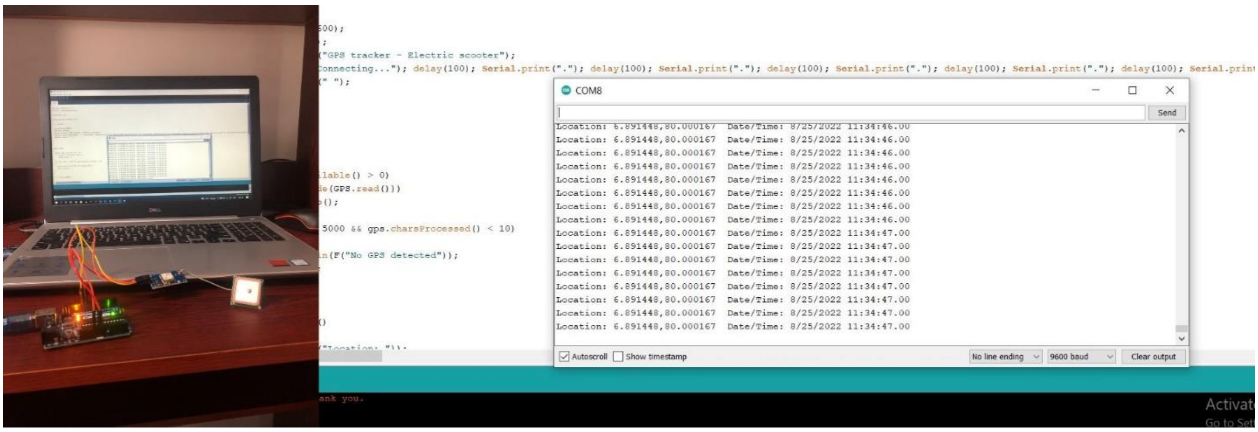

Figure 3.35: NEO-6M GPS module circuit and the output

3.4 Summary

This chapter addressed the overview methodology of the proposed work briefly. The individual contribution has been discussed broadly using the technologies and theories used for the software and Hardware implementations. Chapter 4 will analyze the results of the implementations briefly.

Chapter 04

RESULTS AND LIMITATIONS

A MATLAB Simulink model was created for converting AC voltage to DC voltage. The input and output signal waveforms are shown below in figure 4.1. The waveform on the left side scope is the AC waveform. The waveform shown by the right-side scope is the DC waveform. Here four thyristors are used as the rectifying bridge to provide full wave rectification. Here we can observe that the output DC waveform is not smooth, and it has some ripples. To make the DC waveform smoother and ripple-free, a capacitor can be used.

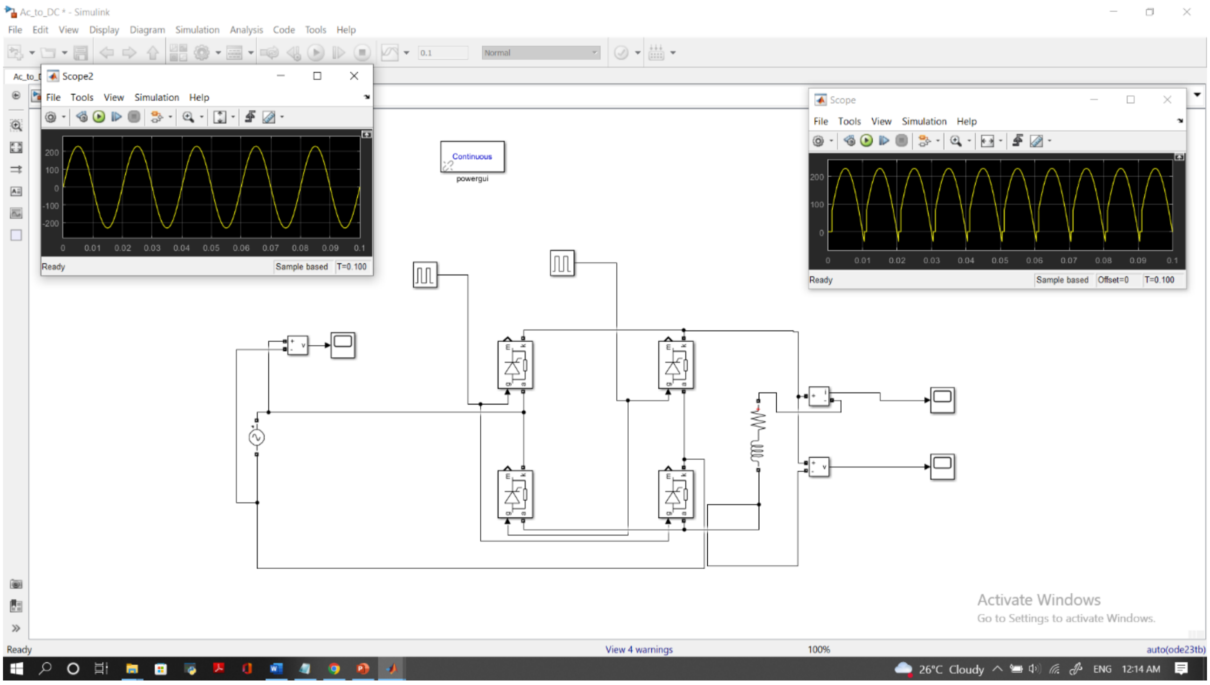

Figure 4.1: The input and output signal waveforms of the AC to DC conversion Simulink model in MATLAB

A 12V DC power supply was modeled in the MATLAB Simulink. Here 230V to 12V linear transformer with two windings was used and four diodes were used to provide the full-wave rectification. The RMS value of the AC voltage is also calculated.

$$V_{rms} = \frac{V_{p-p}}{\sqrt{2}}$$

$$= \frac{230}{\sqrt{2}}$$

$$= 162.63$$

Figure 4.2 below shows the input and output waveforms of the circuit. The AC waveform is shown on the left side and the DC waveform is shown on the right side. Here we can see a smoother and ripple-free output DC signal. The reason for that is the parallel RC branch connected to the bridge rectifier.

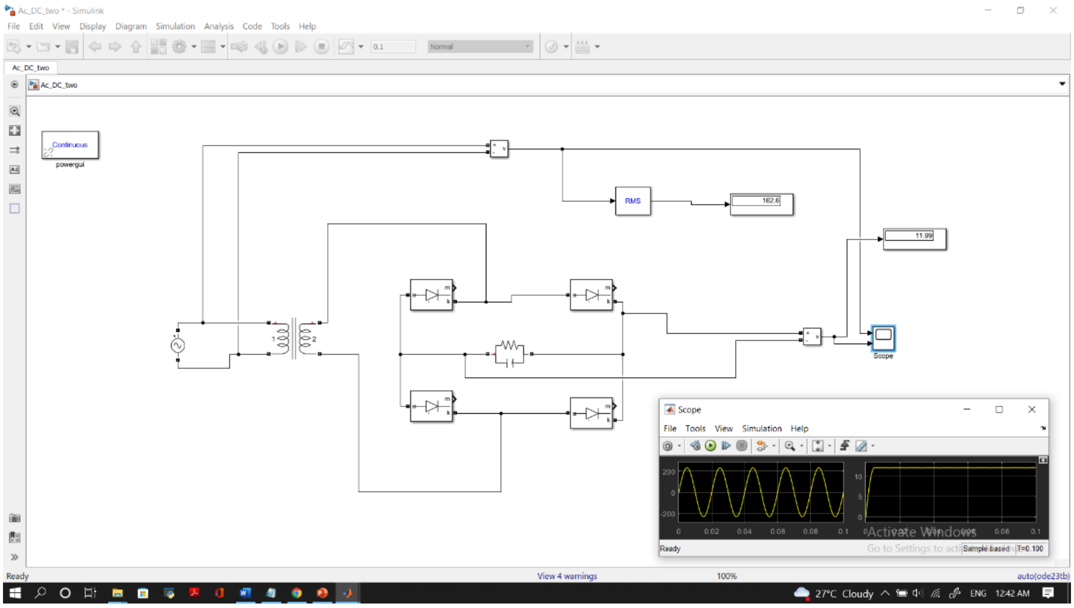

Figure 4.2: Output waveforms of the 12V DC power supply modeled in the MATLAB Simulink

In the passive cell balancing MATLAB model, the initial State of Charge (SoC) of the three battery cells was set to 60%, 50%, and 55% respectively. After running the model, the SoCs of the three batteries were equal to 50%. The two overcharged cells have discharged while the cell with the initial Soc of 50% has been kept on that value. Figure 4.3 below shows the behavior of the SoCs of the three battery cells.

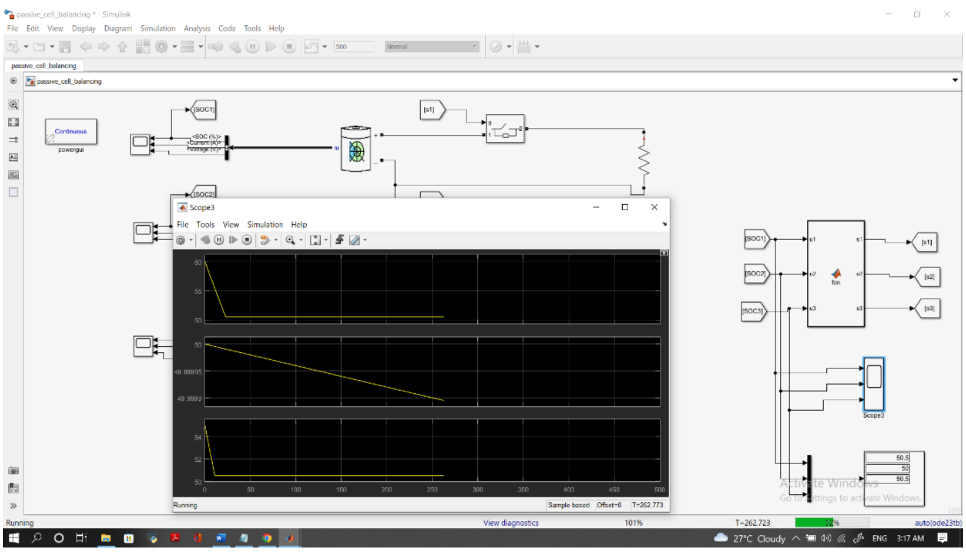

Figure 4.3: State of Charge (SoC) behavior of the passive cell balancing MATLAB model

In the above figure 4.3, we can see that the SoC of batteries that had an initial SoC of 60% and 55% has decreased to 50% and then kept constant while the other battery's SoC has been kept constant on 50%.

In the SoC-based charging and discharging model on MATLAB Simulink, two batteries were used. Battery 2 was used as a DC source to charge battery 1. So, the Nominal voltage and rated capacity of battery 2 were set higher than battery 1. The Nominal voltage of battery 1 was set to 12V. The initial SoC of battery 1 was set to 95%. The MATLAB function program was written to discharge the battery if its SoC is greater than or equal to 95%. When the SoC of the battery reaches 94% it should again start charging. The minimum SoC was set at 94% because I wanted to get the testing results quickly. However, it also takes some time to decrease the SoC by 1%. Figure 4.4 below shows the behavior of the SoC, current, and voltage of battery 1 after the model is run.

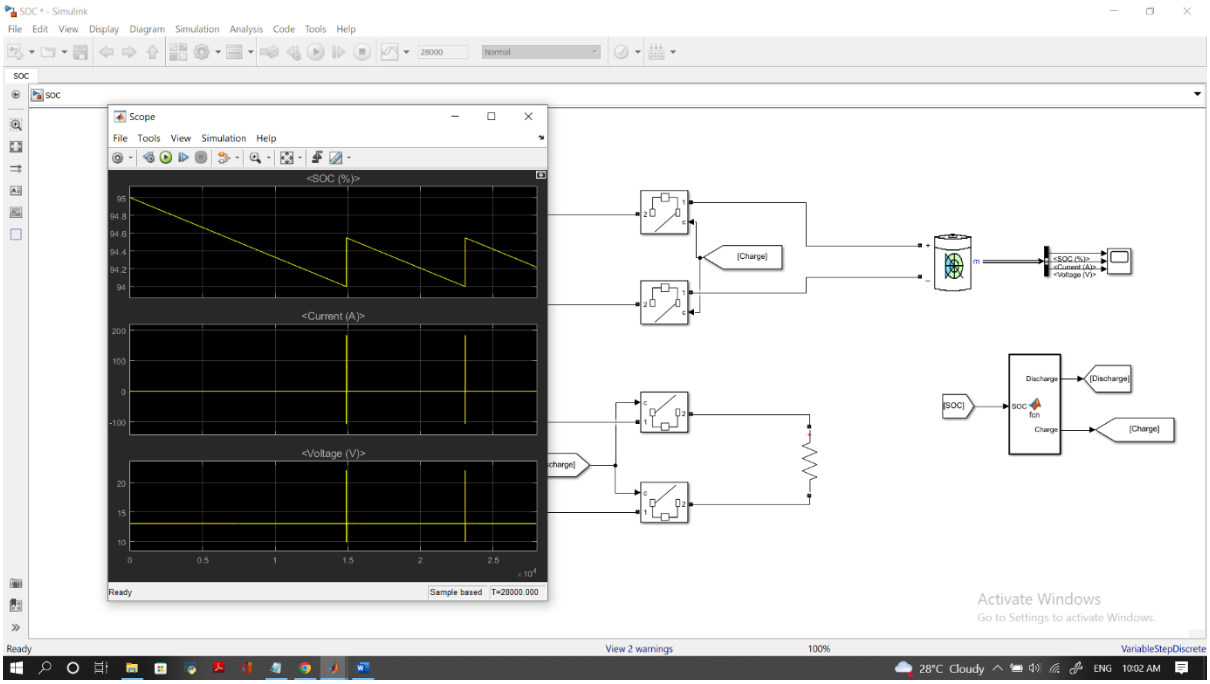

Figure 4.4: Behavior of the SoC, current, and voltage of the SoC-based charging and discharging model on MATLAB Simulink

In above figure 4.4, we can see that the SoC value has decreased from 95% to 94%, and then it has again started to charge. At the moment when battery 1 starts charging again, the current has decreased, and the voltage has increased.

In the MATLAB battery pack model to observe the State of Charge (SoC), firstly the three cells were balanced using passive cell balancing. The initial SoCs of the three cells were set to 60%, 65%, and 68% respectively. Here also the two overcharge batteries were discharged to an SoC level of 60% and then kept constant. So now the SoCs of all three cells are at 60%. Figure 4.5 below shows the SoC behavior of the three battery cells when the battery pack is discharged using passive cell balancing.

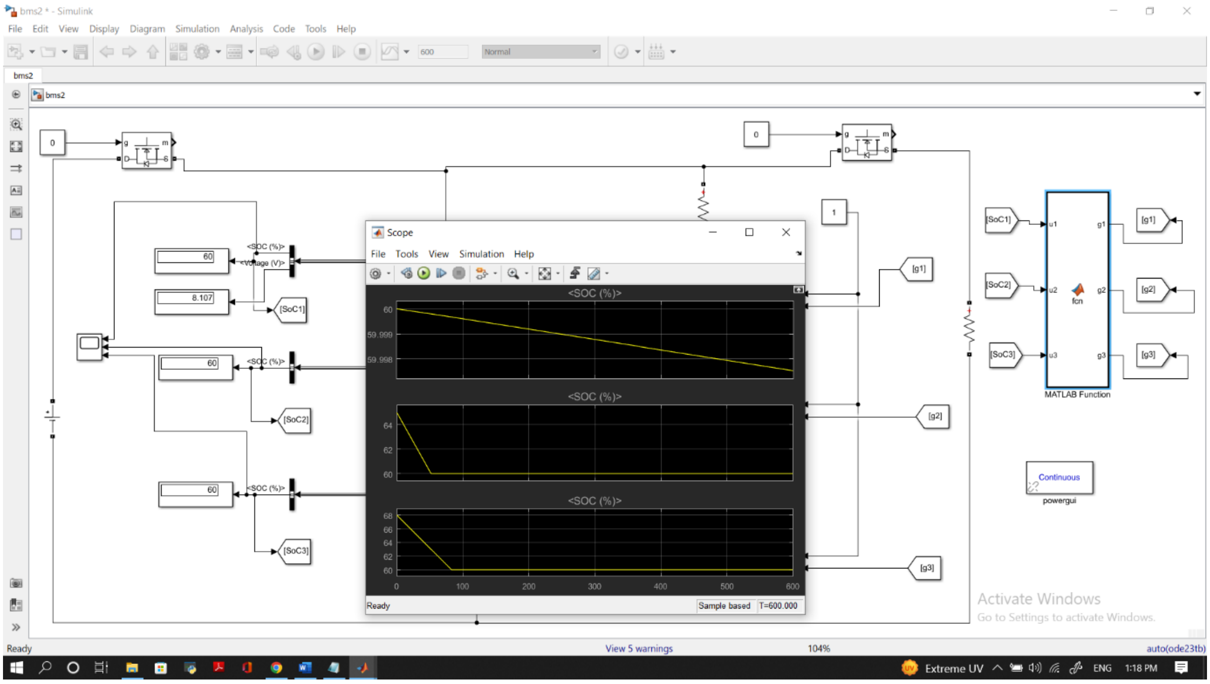

Figure 4.5: SoC behavior of the three battery cells when the battery pack is discharged using passive cell balancing

Then the charging constant is set to 1. Now the battery pack starts to charge. When charging the battery pack, the SoC values of each battery cell are kept equal. Figure 4.6 below shows the SoC behavior of the three battery cells when the battery pack is charged.

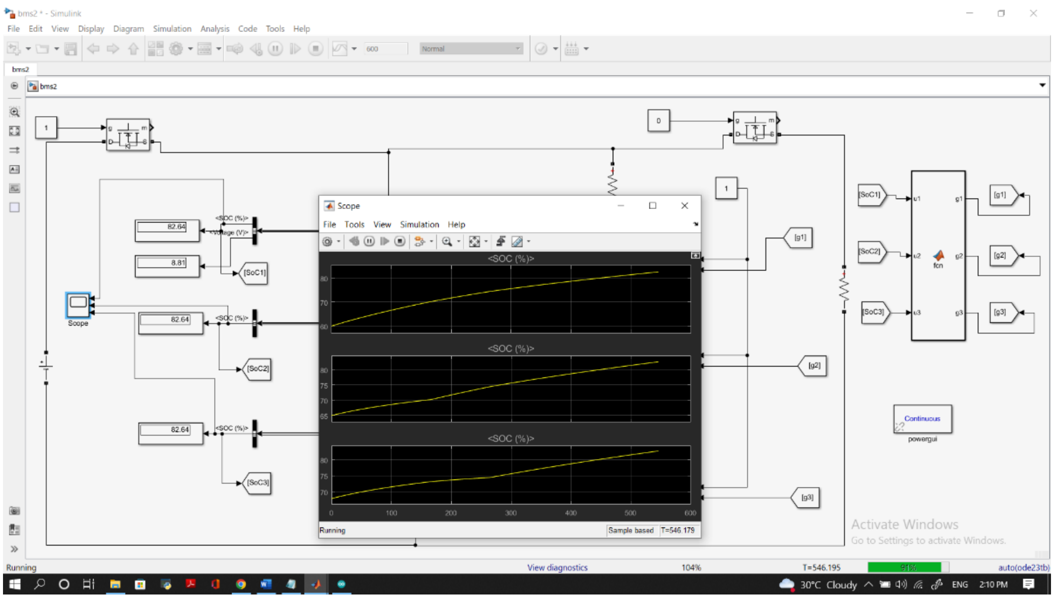

Figure 4.6: SoC behavior of the three battery cells when the battery pack is charged

Limitations

- The NiMH battery cells used for creating the battery pack are used cells. So, the capacity of these battery cells might be low than the rated capacity. Due to this, the power of the battery pack might be less than the calculated value. So, there can be fluctuations in the number of kilometers that can go from one battery charging cycle.
- The Battery Management System (BMS) charging circuit wastes power through the diodes after the battery is fully charged. So, there is a power waste.
- The battery pack might take a longer period to charge.
- The weather forecast system always needs an active Wi-Fi connection to fetch data from the API. That means the ESP8266 NodeMCU board should be connected to active Wi-Fi.
- The GPS coordinates from the NEO-6M GPS Module might not be accurate.

Chapter 05

CONCLUSION

Introducing the mini electric scooter to the Sri Lankan market is an ideal solution for the ongoing fuel crisis and current economic misery in Sri Lanka. This is a battery-operated, one-person capacitating vehicle. Although the electric scooter is an already popular vehicle, the one introduced via this study is content with several new features, such as a CVT gear system, auto brake system, cruise control system, GPS tracker system, automatic light system, and a fully detailed LED display which will show all the necessary information such as the speed of the electric scooter, the current weather forecast details. Also, the Battery Management System (BMS) conserves the durability of the batteries or the battery pack and protects each cell of the battery from overcharging, overcurrent, and overvoltage. Although the electric scooter concept is somewhat new to Sri Lankans, Mainly in European countries, the United States, and China, this is a very popular concept. There are lots of barriers to importing electric scooters here in Sri Lanka as an imported electric scooter will set you back between $450 and $650. Because of Sri Lanka's increasing dollar exchange rate, this will be extremely expensive and beyond many people's reach. According to research, the worldwide sales of electric scooters are expected to reach 100 million units by 2035. Ongoing transportation methods are responsible for 24% of the global CO_2 emissions from gasoline combustion and is continuing to rise rapidly. Research has estimated that electric scooters can reduce transportation CO_2 emissions by 24.4 million tons. Therefore, this is not a solution just for the fuel crisis, it also prevents the release of several harmful pollutants such as carbon monoxide and nitrogen oxides and will help to manage air pollution and global warming, and this will be a good method to avoid traffic jams also. This electric scooter is powered up by a 24V battery pack it can ride up to a maximum speed of 15 km/h to 20 km/h and can ride around 5 to 7 kilometers from one charge cycle. We are looking forward to finishing manufacturing a user-friendly Electric scooter by the end of the next semester.

REFERENCES

[1] 2022. [online] Available at: <https://www.reuters.com/article/climate-change-britain-factbox-idINKBN27Y19F> [Accessed 16 August 2022].

[2] Nytimes.com. 2022. Fuel-Starved and Stuck in Crisis, Sri Lanka Orders Work From Home. [online] Available at: <https://www.nytimes.com/2022/06/17/world/asia/sri-lanka-fuel-crisis.html> [Accessed 17 August 2022].

[3] Cars, H., 2022. Electric Car and the Environment - 823 Words | Essay Example. [online] Free Essays. Available at: <https://ivypanda.com/essays/electric-car-and-the-environment/> [Accessed 16 August 2022].

[4] Lu, C., 2022. Sri Lanka’s Economic Nightmare Continues. [online] Foreign Policy. Available at: <https://foreignpolicy.com/2022/06/29/sri-lanka-economy-fuel-shortage-rajapaksa/> [Accessed 17 August 2022].

[5] pdfcoffee.com. 2022. Project Report On Electric Two Wheeler Lithium Ion Battery Electric Scooter PDF - PDFCOFFEE.COM. [online] Available at: <https://pdfcoffee.com/project-report-on-electric-two-wheeler-lithium-ion-battery-electric-scooter-pdf-pdf-free.html> [Accessed 18 August 2022].

[6] 2022. project report on Electrical Scooter. [online] Available at: <https://www.studocu.com/in/document/maharaja-surajmal-institute-of-technology/mechanical/project-report-on-electrical-scooter-all/21313312> [Accessed 17 August 2022].

[7] 2022. Design and Fabrication of Electric Scooter. [online] Available at: <https://learnmech.com/design-and-fabrication-of-electric-scooter-report-download/> [Accessed 18 August 2022].

[8] Coltura - moving beyond gasoline. 2022. Facts About Gasoline — Coltura - moving beyond gasoline. [online] Available at: <https://www.coltura.org/gasfacts> [Accessed 18 August 2022].

[9] Knoema. 2022. Sri Lanka CO2 emissions from transport, 1970-2021 - knoema.com. [online] Available at: <https://knoema.com/atlas/Sri-Lanka/topics/Transportation/CO2-Emissions-from-transport/CO2-emissions-from-transport#:~:text=In%202020%2C%20CO2%20emissions%20from,average%20annual%20rate%20of%204.42%25.> [Accessed 19 August 2022].

[10] Knoema. 2022. World and regional statistics, national data, maps, rankings. [online] Available at: <https://knoema.com/atlas> [Accessed 19 August 2022].

[11] Globalfueleconomy.org. 2022. [online] Available at: <https://www.globalfueleconomy.org/media/461037/asia_fuel-economy_sri-lanka_baseline.pdf> [Accessed 19 August 2022].

[12] 2022. Comparison of Emission Levels of Passenger Transport Modes in Sri Lanka. [online] Available at: <https://www.researchgate.net/publication/331976249_Com> [Accessed 18 August 2022].

[13] ltd, R., 2022. Electric Scooters Market Size, Share & Trends Analysis Report by Product (Retro, Standing/Self-Balancing, Folding), by Battery (Sealed Lead Acid, NiMH, Li-ion), by Voltage, and Segment Forecasts, 2022-2030. [online] Researchandmarkets.com. Available at: <https://www.researchandmarkets.com/reports/4668027/electric-scooters-market-size-share-and-trends> [Accessed 21 August 2022].

[14] REUTERS. 2022. U.S. government to end gas-powered vehicle purchases by 2035 under Biden order. [online] Available at: <https://www.reuters.com/world/us/biden-pledges-end-gas-powered-federal-vehicle-purchases-by-2035-2021-12-08/> [Accessed 19 August 2022].

[15] EVANNEX Aftermarket Tesla Accessories. 2022. Four charts show why electric vehicles are the future. [online] Available at: <https://evannex.com/blogs/news/four-charts-showcase-why-electric-cars-will-take-over> [Accessed 22 August 2022].

[16] 2022. Nickel–metal hydride and nickel–zinc batteries for hybrid electric vehicles and battery electric vehicles. [online] Available at: <https://www.sciencedirect.com/topics/engineering/nickel-metal-hydride> [Accessed 22 August 2022].

[17] Sae.org. 2022. Nickel Metal Hydride (NiMH) Hybrid Battery Systems - SAE Training. [online] Available at: <https://www.sae.org/learn/content/pd291811/> [Accessed 22 August 2022].

[18] Techopedia.com. 2022. What is a Nickel-Metal Hydride Battery (NiMH)? - Definition from Techopedia. [online] Available at: <https://www.techopedia.com/definition/24210/nickel-metal-hydride-battery-nimh> [Accessed 22 August 2022].

[19] HYBRIDS. 2022. NiMH Battery Specifications - HYBRIDS. [online] Available at: <http://www.hybrids.co.nz/battery-specs/> [Accessed 25 August 2022].

[20] Homemade Circuit Projects. 2022. Variable Voltage, Current Power Supply Circuit Using Transistor 2N3055 - Homemade Circuit Projects. [online] Available at: <https://www.homemade-circuits.com/how-to-make-versatile-variable-voltage/> [Accessed 25 August 2022].

[21] Monolithicpower.com. 2022. Voltage Regulator Types and Working Principle | Article | MPS. [online] Available at: <https://www.monolithicpower.com/en/voltage-regulator-types> [Accessed 15 August 2022].

[22] Garaipoom, A., 2022. How many amps & hours to charging a battery be full | ElecCircuit.com. [online] ElecCircuit.com. Available at: <https://www.eleccircuit.com/how-many-amps-hours-to-charging-battery-full/> [Accessed 21 August 2022].

[23] Thakur, M., 2022. NodeMCU: ESP8266 Arduino JSON parsing example | Circuits4you.com. [online] Circuits4you.com. Available at: <https://circuits4you.com/2019/01/11/nodemcu-esp8266-arduino-json-parsing-example/> [Accessed 25 August 2022].

[24]*Calbike.org*, 2022. [Online]. Available: https://www.calbike.org/wp-content/uploads/2019/02/A-North-American-Survey-of-Electric-Bicycle-Owners.pdf. [Accessed: 05- Jun- 2022].

[25]A. Fyhri, "Do people who buy e-bikes cycle more?", 2022.

[26]I. Phillips, "E-bikes and their capability to reduce car CO2 emissions", 2022.

[27]M. Mcqueen, "The E-Bike Potential: Estimating regional e-bike impacts on greenhouse gas emissions", 2020.

[28]*Irjet.net*, 2022. [Online]. Available: https://www.irjet.net/archives/V7/i2/IRJET-V7I2501.pdf. [Accessed: 07- Jun- 2022].

[29]HowStuffWorks, Tech, Electronics and Tech, "How Lithium-ion Batteries Work", *HowStuffWorks*, 2022. [Online]. Available: https://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery.htm. [Accessed: 07- Jun- 2022].

[30]HowStuffWorks, Science, Transportation and Equipment, "How Gear Ratios Work", *HowStuffWorks*, 2022. [Online]. Available: https://science.howstuffworks.com/transport/engines-equipment/gear-ratio.htm. [Accessed: 07- Jun- 2022].

[31]"Project Electric Bike - PDFCOFFEE.COM", *pdfcoffee.com*, 2022. [Online]. Available: https://pdfcoffee.com/project-electric-bike-pdf-free.html. [Accessed: 08- Jun- 2022].

[32]"Project Report On Electric Two Wheeler Lithium Ion Battery Electric Scooter PDF - PDFCOFFEE.COM", *pdfcoffee.com*, 2022. [Online]. Available: https://pdfcoffee.com/project-report-on-electric-two-wheeler-lithium-ion-battery-electric-scooter-pdf-pdf-free.html. [Accessed: 07- Jun- 2022].

[33]"Lead acid vs lithium-ion battery comparison", 2022. [Online]. Available: https://news.energysage.com/lithium-ion-vs-lead-acid-batteries/. [Accessed: 08- Jun- 2022].

[34]V. Sudhan, "BATTERY THERMAL MANAGEMENT SYSTEM A PROJECT REPORT", *Academia.edu*, 2022. [Online]. Available: https://www.academia.edu/42673938/BATTERY_THERMAL_MANAGEMENT_SYSTEM_A_PROJECT_REPORT. [Accessed: 09- Jun- 2022].

[35]G. Kermani, "Characterization and Modeling of the Mechanical Properties of Lithium-Ion Batteries", 2022. [Online]. Available: https://www.semanticscholar.org/paper/Review%3A-Characterization-and-Modeling-of-the-of-Kermani-Sahraei/df96b77ddc68e0d7d36de118f489002ed8615644. [Accessed: 09- Jun- 2022].

[36]J. Duan, "Building Safe Lithium-Ion Batteries for Electric Vehicles", 2022. [Online]. Available: https://www.semanticscholar.org/paper/Building-Safe-Lithium-Ion-Batteries-for-Electric-A-Duan-Tang/b7aa4537c0d93c5c0799aa692b9e26ff73d3f61d. [Accessed: 09- Jun- 2022].

[37]B. Balasingam, "Battery Management Systems—Challenges and Some Solutions", 2020. [Online]. Available: https://www.researchgate.net/publication/341873093_Battery_Management_Systems-Challenges_and_Some_Solutions. [Accessed: 09- Jun- 2022].

[38]S. Abada, "Safety focused modeling of lithium-ion batteries", 2022. [Online]. Available: https://www.semanticscholar.org/paper/Safety-focused-modeling-of-lithium-ion-batteries%3A-A-Abada-Marlair/09f7d2bec47540c7905ef7ae26a838356b2965f9?sort=relevance&page=2. [Accessed: 10- Jun- 2022].

[39]*Ris.utwente.nl*, 2022. [Online]. Available: https://ris.utwente.nl/ws/portalfiles/portal/6087760/thesis_bergveld.pdf. [Accessed: 08-Jun- 2022].

[40]"Battery Management Systems", *Google Books*, 2022. [Online]. Available: https://books.google.lk/books?id=vTX7CAAAQBAJ&pg=PA165&lpg=PA165&dq=C.M.+Doyle,+T.F.+Fuller,+J.+Newman,+%E2%80%9CModelling+of+Galvanostatic+Charge+and+Discharge+of+the+Lithium/Polymer/Insertion+Cell%E2%80%9D,+J.+Electrochem.+Soc.,+vol.+140,+no.+6,+pp.+1526-1533,+June+1993&source=bl&ots=iqaDhRTUeq&sig=ACfU3U3JUz06zthh7JbgLuWHiIhZZ1HB-A&hl=en&sa=X&ved=2ahUKEwjM4-Hl5Kn4AhVoR2wGHZF-B6cQ6AF6BAgCEAM#v=onepage&q=C.M.%20Doyle%2C%20T.F.%20Fuller%2C%20J.%20Newman%2C%20%E2%80%9CModelling%20of%20Galvanostatic%20Charge%20and%20Discharge%20of%20the%20Lithium%2FPolymer%2FInsertion%20Cell%E2%80%9D%2C%20J.%20Electrochem.%20Soc.%2C%20vol.%20140%2C%20no.%206%2C%20pp.%201526-1533%2C%20June%201993&f=false. [Accessed: 11- Jun- 2022].

[41]S. Wang, "Lithium-ion battery SOC and SOH co-estimation based on Adaptive Fading Kalman filter algorithm and Second-order PNGV equivalent circuit model", 2022. [Online]. Available: https://www.researchgate.net/publication/359816306_Lithium-ion_battery_SOC_and_SOH_co-estimation_based_on_Adaptive_Fading_Kalman_filter_algorithm_and_Second-order_PNGV_equivalent_circuit_model. [Accessed: 06- Jun- 2022].

[42] *Era.library.ualberta.ca*,2022.[Online].Available: https://era.library.ualberta.ca/items/9603aeaf-c292-406f-89c8-30915beef618/view/0d7b0d85-4282-4f73-873b-bc02f5fd7c7b/Bavand_Amin_202105_MSc.pdf. [Accessed: 10- Jun- 2022].

APPENDICES

Battery pack power = $24\,V * 13Ah = 312W$

Time required to fully charged the battery pack using a 24V 3A charger = $\frac{13Ah}{3A}$

$$= 4\ hours\ and\ 20\ minutes$$

Github link for all the codes and files –

https://github.com/thanurajayatissa/Mini-electric-scooter