A Project Report on

State of Charge Estimator with Battery Swapping Station Locator for an Autonomous Vehicle

Submitted in partial fulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY

in

Electrical and Electronics Engineering

by

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Under the Guidance of

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CERTIFICATE

This is to certify that **Kush Jain** has successfully completed the project work entitled "**State of Charge Estimator with Battery Swapping Station Locator for an Autonomous Vehicle**" in partial fulfillment for the award of **Bachelor of Technology** in **Electrical and Electronics Engineering** during the year **2018-2019**.

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28th March 2019

This is to certify that Kush Jain, student of Bachelor of Technology (B Tech), CHRIST (Deemed to be University), Bengaluru has done the final semester internship project at Centre for Digital Innovation, CHRIST (Deemed to be University), Bengaluru, from 3rd December 2018 to 22nd March 2019.

Project : Battery Management

The intern has completed the internship project with commitment and sincerity.

Prof Yong Woon Kim
Coordinator,
Centre for Digital Innovation

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Declaration

I, hereby declare that the project titled “**State of Charge Estimator with Battery Swapping Station Locator for an Autonomous Vehicle**” is a record of original project work undertaken by me for the award of the degree of **Bachelor of Technology** in **Electrical and Electronics Engineering**. I have completed this study under the supervision of **Dr Vijaya Margaret**, Department of Electrical and Electronics Engineering and **Mr Vikas Nagpal**, Centre for Digital Innovation.

I also declare that this project report has not been submitted for the award of any degree, diploma, associate ship, fellowship or other title anywhere else. It has not been sent for any publication or presentation purpose.

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Abstract

Poor utilization of the existing conventional sources such as petroleum, oil, etc has made the world to confront an energy emergency. In the midst of Battery Innovation and developing ecological concern, the Autonomous and Electric Vehicles are becoming a need more than a luxury. An Autonomous Vehicle or a self driving vehicle is basically a vehicle that makes use of various sensors, radar, video, camera and of late Artificial Intelligence as well, works on electricity, a renewable source of energy, is seen as the future.

The projects is based on solving two major issues faced by Autonomous Vehicles, one being optimum utilization of the Battery and second being longevity of the Battery pack. To solve these issues my project would firstly target an accurate measurement of the State of Charge as it would help prevent over and under charging as well as discharging of the Battery when it is being monitored with the help of a pre-existing monitoring system. Secondly to cancel out the ill effects of fast charging on a battery and also solve the long distance travel issues faced by a majority of the consumers, the project would implement battery swapping technology as well. This would allow the user to change the battery at various Battery Swapping Station in less than two minutes quicker then filling fuel at a petrol station and would allow the batteries to be charged at the Battery Swapping Station at optimal rates.

The State of Charge measurement module would make use of Li-ion battery along with current, voltage and temperature sensor in togetherness with a WIZwiki 7500P microcontroller. The current, voltage and temperature value would be monitored and based on a certain defined algorithm it would give the State of Charge reading. When the State of Charge reading falls below a certain pre-defined value, the user would be guided to the nearest Battery Swapping Station.

At the end of the project, the State of Charge measurement has been done and displayed on the android app and the Battery Swapping Station locator has been coded and implemented within the app as well.

Keywords: *Autonomous Vehicles, State of Charge measurement, Battery Swapping Technology*

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GLOSSARY

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Item	Description
ACC	**A**daptive **C**ruise **C**ontrol
AV	**A**utonomous **V**ehicle
BECM	**B**attery **E**nergy **C**ontrol **M**odule
BESS	**B**attery **E**nergy **S**torage **S**ystem
BSS	**B**attery **S**wapping **S**tation
CC	**C**onstant **C**urrent
CV	**C**onstant **V**olatge
DARPA	**D**efense **A**dvanced **R**esearch **P**rojects **A**gency
GUI	**G**raphic **U**ser **I**nterface
EV	**E**lectric **V**ehicle
LCD	**L**iquid **C**rystal **D**isplay
OCV	**O**pen **C**ircuit **V**oltage
RPS	**R**egulated **P**ower **S**upply
SoC	**S**tate **of** **C**harge
SoH	**S**tate **of** **H**ealth

Chapter 1

INTRODUCTION

The future would now be consisting of Electric Vehicles (EVs) and Autonomous Vehicles (AVs) due to the depleting fossil fuel reserves. Companies like Volvo, Mercedes Benz, etc are now diving into EV domain. Companies like Tesla, Waymo, etc are booming in this domain which spells the end for conventional vehicles.

With the onset of EVs and AVs, there is a lot to look forward to but at the same time the road is not as smooth as it seems to be and has a lot of roadblocks which have to be overcome if the world wants to see only EVs and AVs. This project will be dealing with two of the many road blocks, one of them being accurate State of Charge (SoC) measurement and the other being implementation of the Battery Swapping Technology with the Autonomous Vehicles.

1.1 Problem Formulation

The onset of Electric Vehicles and Autonomous Vehicles has begun due to fossil fuel reserve depletion and hence alternate sources of energy are being used and harnessed, i.e , in the current scenario, electricity.

The electric vehicles have batteries at their heart and hence for them to be a success, the batteries have to function to their optimum and be cost effective to the consumer utilising it. Hence to not only have an efficient but also a long lasting system it is necessary to overcome the roadblocks faced by the Autonomous Vehicles to ensure a hassle free experience to the user.

1.2 Problem Identification

One of the major issues with the AVs as well as EVs is that the heart of the system, i.e. the batteries get over-utilised due to absence of a monitoring system. The major component of the monitoring system is the SoC measurement system and it has to be an accurate system, because if it isn't it could lead to fatalities as well as could incur capital losses. An accurate SoC measurement system is necessary for a pre-existing monitoring system to function properly and could extend the life of the battery, prevent under and over charging of the battery and help optimise the battery as a whole.

The other issue with the battery is the longevity of the battery and it's long distance travel issues. This can be solved using the Battery Swapping Technology wherein batteries can be swapped easily at Battery Swapping Stations (BSS). This not only eliminates the issues of fast charging batteries, that would in hindsight reduce the battery life, but also allows the consumer to travel long distances without having to wait for the battery to charge. It is also a cheaper option than replacing the entire battery after its lifetime. The BSS would then charge the batteries at an optimal speed which would allow the batteries to have a longer life.

1.3 Problem Statement & Objectives

In building a hassle free Autonomous Vehicle, which would, not for a second make the consumer feel that anything has changed from a conventional vehicle, has it own limitations and this project tries to deal with two of the many limitations. The two problems are the SoC measurement and a Battery Swapping Station Locator, which when solved, would make the Autonomous Vehicle experience a hassle free experience for the user.

The objective of this project is to develop a SoC measurement unit as well as implement the Battery Swapping Technology to an autonomous vehicle. SoC measurement unit is developed using a current sensor and voltage sensor in association with Lookup table Algorithm and Coulombic Counting Algorithm in togetherness.

1.4 Limitations

The project is limited to just a prototype. The SoC measurement is being done only for Li-ion battery type, keeping in mind it is tipped to be the future standard in AVs as well as EVs. Incase the BSS locations have been added, the chip consisting of the old data has to be updated via wired connection to the system.

1.5 Organization of the Report

Chapter 1: Introduction
This chapter talks about how the project was conceptualised and formulated and what was the motivation behind doing the project.

Chapter 2: Literature Survey
This chapter deals with the literature survey and research that would be done before the project would be practically implemented and learnings from the research that are later utilised in the project.

Chapter 3: Design and Implementation of Proposed System
This chapter deals with the important domains in the project that have been identified and thoroughly understood, designed and implemented.

Chapter 4: Results
After the hardware implementation, this chapter deals with the results and analysis of the sub-systems present in the project.

Chapter 5: Conclusion
The project as a whole is concluded in this chapter and scope for future works is dealt within this chapter.

Chapter 2

LITERATURE SURVEY AND REVIEW

Numerous research papers and journals were read to comprehend the trends in the field of Autonomous vehicles, State of Charge (SoC) measurement and Battery Swapping Technology. Some of the papers are briefly summarized below:

2.1 Literature Collection and Segregation:

Rami Yamin and Ahmed Rachid have discussed about the measurement of State of Charge (SoC) as well as State of health (SoH) for a 48V battery pack of an E-scooter. A software based Kalman SoC sensor has been developed using a microcontroller with the help of a relatively simple battery model in combination with Kalman algorithm. The SoC has been estimated online (in real time) and displayed over a low power consumption Liquid Crystal Display (LCD) screen [1].

Yu et al., study the significance of SoC estimation for the safe operation of Li-ion Battery packs. Improving the accuracy of SoC estimation results in reducing the algorithm complexity which is important for the state estimation.Open Circuit Volatge (OCV) can also be used in the accurate estimation of SoC but has to be used in association with Coulombic Counting method [2].

Wen Yeau reviews the current advancements in State of Charge (SoC) assessing techniques for battery where the center of interest lies upon numerical standards and practical executions. As the battery SoC is a critical parameter, which reflects the battery execution, exact estimation of SoC will not only protect the battery, prevent overcharge or discharge, and improve the battery life, but in addition to that let the application make sound control techniques to accomplish the idea behind saving energy [3].

Xiao et al., bring to our notice about how achieving a proficient yet precise SoC calculation still remains a testing task. Developing an accurate SoC algorithm is a difficult task and that most of the work done in this domain uses a regression based time-variant circuit model. Also knowing OCV prompts SoC due to the notable mapping among OCV and SoC. A method proposed achieves not only a productive but exact OCV calculation that is applicable to all sorts of battery types. It utilizes a linear system analysis but without a circuit model, its then computes OCV based on sampled terminal voltage and discharge current. Tests demonstrate that the calculation is numerically steady, vigorous to previously noted errors, and acquires SoC with under 4% mistake contrasted with a point by point battery reproduction for a variety of batteries. The OCV calculation is additionally proficient, and can be utilized as a real-time electro-analytical tool uncovering what happens inside the battery [4].

Jayasinghe and Nadishan state that precise estimation of state of the charge (SoC) is very important for EV batteries. A novel strategy which assesses the SoC using a neural network, can be modified into a low cost microcontroller. The micro-controller screens the battery voltage and takes four tests following which the battery is disconnected from the load and screens the steady state terminal voltage when the vehicle is left for over half an hour to prepare a neural network. Every time the battery gets disconnected from the load while driving, the micro-controller takes four voltage tests in order to gauge the SoC with the help of the recently trained neural network. To build the precision, the battery temperature is too taken as an input [5].

McDowall talks about the Li-ion cell which depicts the different electrochemical couples that together structure the lithium-ion family. The qualities of the fundamental couples will be depicted, especially regarding safety enhancements and their potential operational tradeoffs. Cell electrochemistry, electrolyte, cell construction, etc in relation to the Lithium ion cell is brought to light. The main aim is to give an essential understanding of lithium-ion batteries and their potential for use in a number of applications [6].

Baccouche et al., center around the lithium-ion batteries that have higher power and energy thickness. So to decide the State of Charge (SoC) of the battery, a basic yet successful strategy has been executed, called the Coulomb Counting technique. Yet, this calculation likewise endures some mistakes because of initial SoC and accordingly to defeat these limitations, Open-Circuit Voltage (OCV) is utilised. The SoC-OCV relationship has been tested on a PIC18F MCU family [7].

Gregory L. Plett has established a framework about the working and modelling of lithium-ion cells and covers the highlights of a Battery Management System and how to make a decent SoC estimator utilizing different procedures [8].

Chang et al., center their thoughts around the State of Charge (SoC) and remaining charge estimation algorithm of each cell that are associated in a series connection. To analyze the cell to cell variation, SoC and remaining charge information is critical to improve the balancing circuit functioning. A basic current sensor-less SoC estimation algorithm with assessed current equalizer is utilized to achieve the above-mentioned objective. The test results show its high capability with precise outcomes [9].

Zheng et al., talk about the need for Battery Swapping Stations to become more synonymous due to increase in the trend of EV's which are a result of increased air pollution caused by exhaust system of conventional vehicles. Electric vehicles using batteries as their power source can reduce the overall transport cost and be eco-friendly at the same time. For example, the city electric buses which can adopt this model and provide data to prove not only is it an efficient way in terms of re-fuelling but it also reduces the charging impact on the batteries and hence becomes financially viable [10].

2.2 Critical Review of Literature

The idea taken from [2] was how the OCV graph calibration helps in the calibration of SoC. So in the code as well to create the look up table , it makes use of the OCV curve to estimate the SoC. Learnt the importance of accurate SoC measurement.

From [4] got a further idea in terms of advancements that can be done to the currently existing project and how the accuracy would reach a great level. Also, with neural networks discussed, it would be a possibility to create a common SoC measurement algorithm for any battery once enough training data is provided.

Characteristics and terminologies of a Lithium ion cell such as C-rate, mAh, Constant Current-Constant Voltage charging model was understood in [6] in depth along with safety measures to be taken while operating a Lithium ion battery. Various other application of Lithium ion cell showed it flexibilty in terms of application

From [7], the key ideas taken were : The Algorithm to estimate SoC using piecewise linear function of given SoC-OCV model and the basic software architecture.

From [8] the Battery Management System was understood as a whole which included SoC estimation using SoC-OCV model and Kalman Filtering. Both of these methods gave a great insight into how the SoC is measured in reality and helped formulating the most accurate method.

From [9] the major learning involved was about the challenges in measuring voltages and current in Series-Connected Lithium-Ion Batteries module and also how measurement of data for each cell is a must for accurate SoC measurement.

In [10] a complete overview of the new Battery Swapping Technology is given which talks about why is it so necessary in AVs and EVs and made the implementation of the BSS into this project alot more simpler.

In [11] a deep understanding of battery working and behaviours was understood and State of charge estimation using GNU octave was made possible.

2.3 Summary

From the papers above, the important domains such as Autonomous Vehicles, Batteries and Battery Swapping Stations have been identified for the project design and implementation and would be discussed in the next chapter.

Chapter 3

DESIGN AND IMPLEMENTATION OF PROPOSED SYSTEM

Based on the research and analysis done in the previous chapter, important domains for the project have been identified. Based on these domains, a thorough discussion on the design and implementation of the project has been carried out in this chapter.

3.1 Autonomous Vehicle

The possibility of self-driving vehicles goes back beyond Google's exploration in the present day. Indeed, the idea of a self-governing vehicle goes back to Futurama, a display at the 1939 as shown in Figure 3.1, New York World's Fair. General Motors set up the event to display its vision of what the world would look like in 20 years, and this vision incorporated a computerized expressway framework that would manage self-driving vehicles. While a world loaded up with automated vehicles isn't yet a reality, cars today do contain numerous autonomous highlights, for example, braking and assisted parking mechanisms. In the mean time, work self-driving vehicles continues, with the objective of making driving a vehicle more secure and less complex in the coming decades.

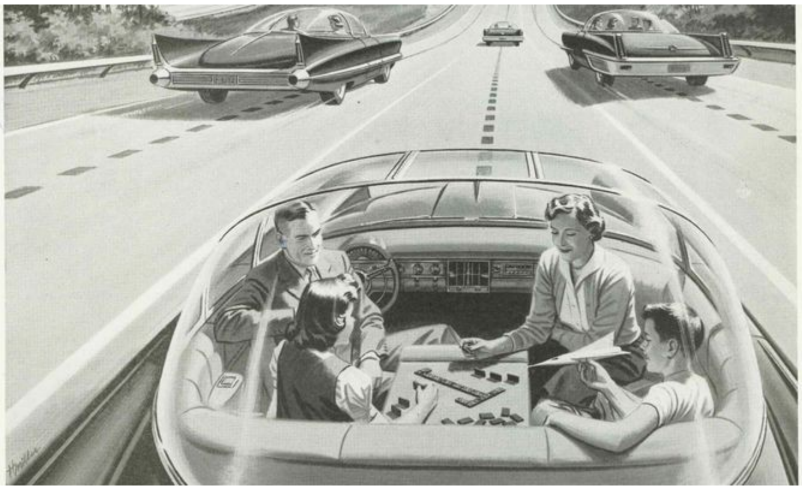

FIGURE 3.1: Driverless Car of Future

3.1.1 History

At the point when Robert Whitehead concocted the self-propelled torpedo during the 1860s, the early direction framework for maintaining profundity was so new and basic he called it ”The Secret”. Airplanes got autopilots only 10 years after the Wright siblings. Nowadays, your morning meal oat was likely accumulated by a driverless harvest collecting vehicle. Sailboats have auto-tillers. Semi-automatic military drones slaughter from the air, and robot vacuum cleaners befuddle our pets.
However one misleadingly unassuming dream has once in a while wandered past the pages of sci-fi since our grandparent's childhood: self driving family vehicle. Dissimilar to Mars wanderers or sailboats, self driving vehicles need to explore the mind boggling universe of city avenues, passing inches from delicate, quarrelsome people.

Draft animals and distracted pedestrians can usually keep to a path on their own. But with the first self-propelled vehicles came the need to have an alert human guide the craft at every moment, or risk disaster. The modern experience of driving was born – that peculiar mix of anxiety, alertness, and boredom.

Sailboats were likely the first self-propelled vehicles, and possibly the first to have some form of automated steering, the auto-tiller. This device uses ropes to connect something like a weathervane to the boat's tiller, so that the craft stays on course even with shifting winds.

The first widely used motorized vehicles were steamboats and trains. The latter adopted their guiding tracks more to support their huge weight than for directional control, but tracks serve both ends. Just a decade or so after its invention, the airplane got its first autopilot as shown in Figure 3.2.

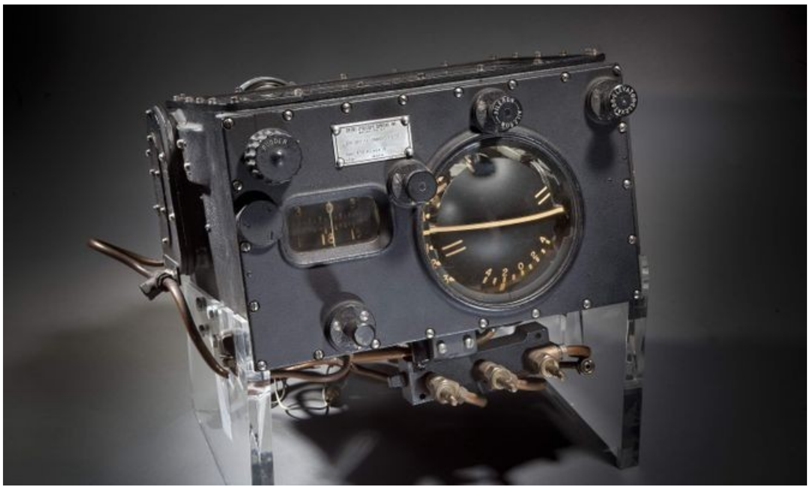

FIGURE 3.2: Mechanical Mike

As shown in Figure 3.3, the kind of self-guiding that carried torpedoes to their targets was repurposed for another medium – the air. By the early 1940s the German V-1 drone bomb was buzzing its way to London on stubby wings. Its successor, the V-2 rocket, touched the edge of space itself.

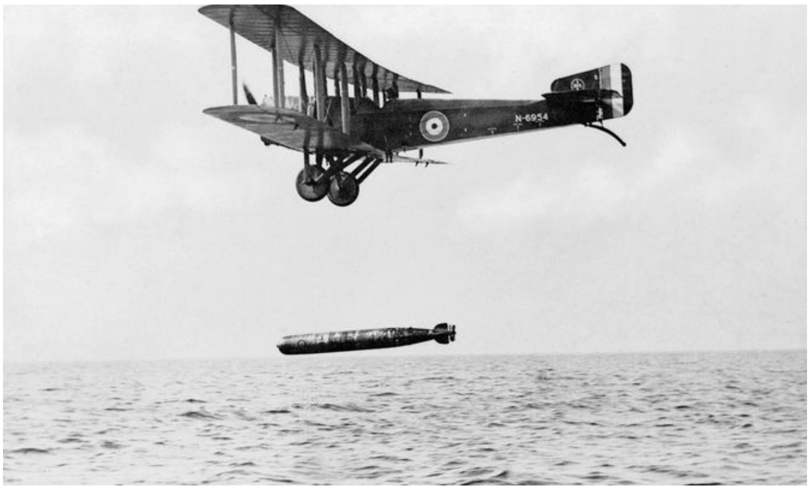

FIGURE 3.3: Self Propelled Aeroplane by Wright Brothers

Driverless vehicles and taxicabs have been improving the lives of millions in the pages of sci-fi since 1935.Joined by GM's computerized roadway designs in its original 1939 Futurama ride, the fundamental driverless dream has changed little in the evolving decades. Other than decreasing mishaps and blockage, such vehicles may free metropolis by removing the requirement for parking.

Obviously, in the pre-PC days of the 1930s, giving vehicles important smarts was truly the stuff of sci-fi. Be that as it may, there may be different ways.

A great part of the threat of early motoring was not the vehicles but rather the era's limited, poorly stamped streets, planned for the most part for nearby travel. Railways were, at that time, still the superhighways. By the 1920s, a couple started to dream of changing streets into something progressively like an advanced freeway framework, where controlled access would all the while raise speeds and diminish mishaps.

Italy and Germany's known expressway plans ceased there. Be that as it may, American originator and futurist Norman Bel Geddes matched the freeway vision with the sorts of electronic speed and crash control frameworks common to railways. His fabulous Futurama ride for General Motors at the 1939 World's Fair likewise envisioned channel like paths that would keep vehicles separated in their own "tracks". The thought was to drive to the freeway, at that point connect with the programmed frameworks and kick back until your exit. Related dreams included magnetic trails incorporated with the street's surface, or physical openings or troughs, or train-like rails engaging concealed steel wheels within each tire.

FIGURE 3.4: General Motors Show Futurama

In GM's 1939 show, as shown in Figure 3.4, Norman Bel Geddes made the main self-driving vehicle, which was an electric vehicle guided by radio-controlled electromagnetic fields created with charged metal spikes implanted in the roadway. By 1958, General Motors had made this idea a reality. The vehicle's front end was inserted with sensors called pick-up coils that could identify the electric current coursing through a wire installed in the street. The current could be controlled to advise the vehicle to move the guiding wheel left or right.

In 1977, the Japanese enhanced this thought, utilizing a camera framework that transferred information to a PC to process pictures of the street. Be that as it may, this vehicle could only just go at paces beneath 20 mph. Improvement originated from the Germans 10 years after the fact as the VaMoRs, a vehicle furnished with cameras that could drive itself securely at 56 mph. As innovation improved, so did self-driving vehicles's capacity to distinguish and respond to their surroundings.

Dreams of AVs and robotized expressways in the mid– twentieth century remained to a great extent in the eye of futurists and sci-fi fans. In 1958, for instance, Disney circulated a program titled "Magic Highway USA" that envisioned a future with, among different advancements, AVs guided by shaded interstate paths and worked with addresses coded on punch cards. It was not until the mid-1980s that the fundamental figuring and different technologies required to acknowledge (and reconsider) these dreams became accessible.

3.1.2 Understanding Autonomous and Automated Vehicles

Technological advancements are creating a continuum between conventional, fully human- driven vehicles and AVs, which partially or fully drive themselves and which may ultimately require no driver at all. Within this continuum are technologies that enable a vehicle to assist and make decisions for a human driver. Such technologies include crash warning systems, adaptive cruise control (ACC), lane keeping systems, and self-parking technology. NHTSA has created a five-level hierarchy to help clarify this continuum.A summarized form is given below:

- **Level 0 (no automation):** The driver is in complete and sole control of the primary vehicle functions (brake, steering, throttle, and motive power) at all times, and is solely responsible for monitoring the roadway and for safe vehicle operation.

- **Level 1 (function-specific automation):** Automation at this level involves one or more specific control functions; if multiple functions are automated, they operate independently of each other. The driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control (as in ACC); the vehicle can automatically assume limited authority over a primary control (as in electronic stability control); or the automated system can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., dynamic brake support in emergencies).

- **Level 2 (combined-function automation):** This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of controlling those functions. Vehicles at this level of automation can utilize shared authority when the driver cedes active primary control in certain limited driving situations. The driver is still responsible for monitoring the roadway and safe operation, and is expected to be available for control at all times and on short notice. The system can relinquish control with no advance warning and the driver must be ready to control the vehicle safely.

- **Level 3 (limited self-driving automation):** Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions, and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time.

- **Level 4 (full self-driving automation):** The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles. By design, safe operation rests solely on the automated vehicle system.

3.1.3 Development Stages

The advances made over the most recent 25 years can be comprehended as far as three progressive floods of developmental gains as shown in Figure 3.5.

- **Stage 1:** Foundational Research from around 1980 to 2003, college research departments, now and then in organization with transportation offices and car organizations, embraced fundamental investigations of self-governing transportation. Two primary innovation ideas rose up out of this work. As one push, scientists sought after the improvement of computerized parkway frameworks, in which vehicles depend altogether on the roadway foundation to direct them. One of the principal significant shows of such a framework occurred in 1997, over a 7.6-mile stretch of California's I-15 roadway close to San Diego. Driven by the California Partners for Advanced Transit and Highways (PATH) program, the "DEMO 97" program showed the platooning of eight AVs guided by magnets installed in the thruway and facilitated with vehicle-to vehicle (V2V) correspondence (Ioannou, 1998). A second research push was to create both semi-self- governing and self-governing vehicles that depended on nothing, if by any stretch of the imagination, on thruway foundation. In the mid 1980s, a group driven by Ernst Dickmanns at Bundeswehr University Munich in Germany built up a vision guided vehicle that explored at paces of 100 kilometres for each hour without traffic (Lantos and Mâarton, 2011). Carnegie Mellon University's NavLab built up a progression of vehicles, named NavLab 1 through NavLab 11, from the mid-1980s to the mid 2000s. In July 1995, NavLab 5 drove through the nation in a "No Hands Across America" visit, in which the vehicle guided self-sufficiently 98 percent of the time while human administrators controlled the throttle and brakes. Other comparable endeavours around the world looked to create and propel beginning AV and parkway ideas.

- **Stage 2:** Grand Challenges From 2003 to 2007, the U.S. Defense Advanced Research Projects Agency (DARPA) held 3 "Grand Challenges" that extraordinarily quickened progressions in AV innovation and reignited the open's creative energy. The initial two Grand Challenges was a 150- mile rough terrain race for 1 million and 2 million prizes, respectively. No vehicle finished the 2004 Grand Challenge—the best contender finished under eight miles of the course ("Desert Race Too Tough for Robots," 2004). However, five groups effectively finished the 2005 Grand Challenge course, held a negligible year and a half later. The quickest group finished the course in less than seven hours, with the following three quickest vehicles completing inside the following 35 minutes (DARPA, undated). In 2007, DARPA held its third and last AV challenge, named the ”Urban Challenge.” As the name recommends, vehicles hustled through a 60-mile urban course, obeying transit regulations and exploring close by different self-sufficient and human-driven vehicles. Six groups completed the course, and three finished the race inside a period of 4.5 hours, including time punishments for abusing traffic and security rules. This Grand Challenge initiated progressions in sensor frameworks and processing calculations to recognize and respond to the behaviour of different vehicles, to explore checked streets, and to obey traffic standards and signs.

- **Stage 3:** Commercial Development The DARPA Challenges strengthened relations between automobile makers and the training segment, and it prepared various undertakings in the car area to propel AVs. These incorporate the Autonomous Driving Collaborative Research Lab, an organization among GM and Carnegie Mellon University (Carnegie Mellon University, undated) and an association among Volkswagen and Stanford University (Stanford University, undated). Google’s Driverless Car activity has brought self-ruling vehicles from the college lab into business inquire about. The program started soon after the DARPA Urban Challenge and drew upon the gifts of designers and analysts from a few groups that took an interest in that challenge. In the years since, Google has created and tried an armada of vehicles and started crusades to exhibit the utilizations of the innovation through, for instance, recordings featuring versatility offered to the visually impaired (Google, 2012). Google isn’t the only one. In 2013, Audi and Toyota both uncovered their AV dreams and research programs at the International Consumer Electronics Show, a yearly occasion held each January in Las Vegas (Hsu, 2013).

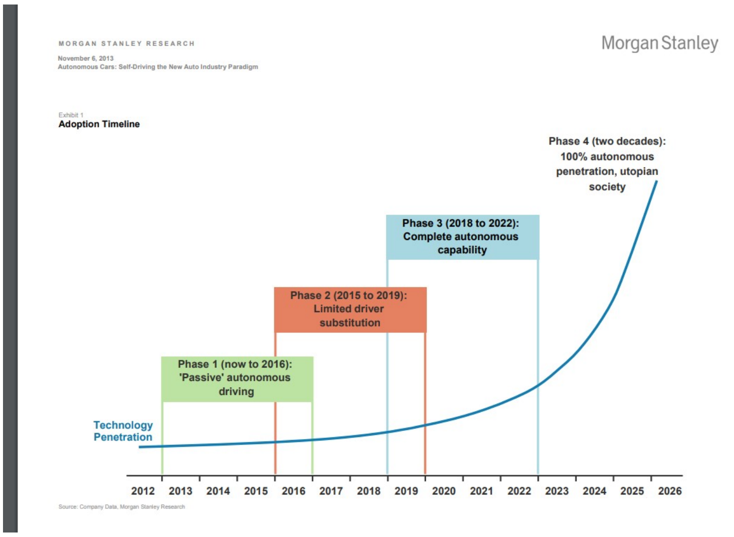

FIGURE 3.5: Phases of Development

3.1.4 Concerns

I. **Environmental Challenges**

Different difficulties presents different concerns. Certain surrounding conditions (e.g., serious precipitation, thick haze) may present issues for various sensors at one go. It must be noted, however, that these equivalent conditions present issues for people. Indeed, automated sensors, for example, radar may demonstrate more successful than human vision, and the quick response of arranging algorithms might be especially significant, making self-ruling frameworks defective yet conceivably more secure than human drivers in these unfriendly conditions. Territory likewise presents difficulties. A sensor arrangement suitable for a level situation might be improper for steep slopes, where sensors must look ”up” or ”down” slants. Distinctive territory can require diverse sensor setups, which may not be promptly variable. While sensors can be put on customizing mounts to oblige this issue, it creates complexity as well as increases cost (Urmson, Ragusa, et al., 2006). Street materials likewise change from locale to area. They are regularly concrete and black-top, yet can be made of soil, cobblestone, and different materials. Distinctive materials have diverse reflectivity, and sensors aligned to specific materials may experience issues distinguishing different materials with equivalent devotion. Development tasks and roadwork are especially hard to arrange, as there might be little consistency in signage and cautions, roadway materials may change all of a sudden and the moves expected to explore through development zones might be unpredictable and ineffectively stamped. In addition, these territories frequently include deviations from pre-developed maps, so vehicle limitation might be especially troublesome. Every one of these variables can have suggestions for where AVs can or can't effectively work. Climate and territory fluctuate fundamentally over the United States, as do the street materials and signage methods utilized by DOTs and different offices. A vehicle that works effectively on level territory in Louisiana may have noteworthy execution challenges on Colorado's blanketed and soak streets, or in New York City's blocked urban gorge.

II. **Integrity, Security and Verification**

AV programming and equipment will be tried widely, likely utilizing a significant number of the methods used to test flying machine frameworks and other complex reliable frameworks. Be that as it may, for all intents and purposes each shopper gadget, from mobile phones to automated vacuum cleaners, requires programming redesigns. This makes programming dependability challenges, as programming overhauls may should be in reverse good with prior models of vehicles and sensor frameworks. Besides, as expanding quantities of vehicle models offer independent driving highlights, programming and other framework redesigns should perform on progressively different stages, making unwavering quality and quality affirmation all the additionally difficult. Programming updates feature a more extensive worry with AVs: framework security. Vehicles that are associated with one another, to foundation, or to the Internet are progressively open to digital assault. David Strickland, previous head of NHTSA, has noted (2013). With this advancement comes expanded difficulties, basically in the territory of framework unwavering quality and digital security the last developing progressively basic as vehicles are progressively increasingly associated with a wide assortment of items regardless of whether the passage point into the vehicle is the Internet, secondary selling gadgets, USB ports, or cell phones, these new entryways bring new difficulties. Indeed, even principally detached vehicles might be in danger. Programming redesigns, for instance, will probably expect association with the Internet, which makes the likelihood of vehicles being assaulted by PC infections that degenerate the framework; for instance, an infection could enter the framework by taking on the appearance of an authentic programming overhaul. Keeping this requires amazingly secure associations with update servers and various "handshake" systems to guarantee that the wellspring of redesigns and the overhauls themselves are authentic and exemplary. Rampant, malignant performing artists may most likely lay hold of a solitary vehicle (or an armada of vehicles) to carry out wrongdoings, or even demonstrations of psychological warfare. Programming security isn't the main concern. Vandals or offenders may utilize GPS jammers or send other obstruction signs to upset AV sensors or transmit false sensor readings to a vehicle's sensors; e.g., sending false LIDAR comes back to a vehicle that is utilizing three- dimensional mapping to explore through its environment. While this might be increasingly hard to accomplish, it might likewise be progressively hard to identify since parodied sensor readings may seem real. Vehicle proprietors additionally present conceivable security dangers. Numerous innovation lovers look for access to their own frameworks to deal with components that are generally secured by the producer. The expressions ”jailbreaking” and ”rooting” allude to the demonstration of breaching the implicit security for cell phones (which is regularly cultivated through physical tampering) to give the proprietor more prominent access and adaptability; e.g., moving the telephone starting with one bearer then onto the next. AVs will unquestionably be as large an allurement for ”jail breaking” as clients look to improve execution or run their own product, in all likelihood while gambling wellbeing. This will expect producers to guarantee clients can't hack into the vehicle's equipment and programming frameworks. It might likewise expect states to perform yearly examinations of the vehicle framework's respectability. A mobile company executive when interview expressed that security issues are not truly known and identified. His worry was that, as vehicles become more automated and increasingly associated, they give another part of basic framework and a potential focus for a digital assault. He said the majority of an AV's frameworks should be intended to oppose conceivable interruption by programmers, referring to a model where programmers had the capacity to get to a vehicle's electronic frameworks through an apparently harmless framework to screen tire weight. He said safety efforts need to apply to all correspondences ways into the vehicle, regardless of whether it is Wi-Fi, cell interchanges, or DSRC.

Like any innovation, AVs will encounter disappointments and breaks. The most basic element will be the framework's capacity to distinguish disappointments and ruptures and act securely changing to a firmly controlled and straightforward wellbeing framework or declining to connect by any means.

3.2 Batteries

3.2.1 Terminologies

- **Anode:** An anode is an electrode at which an oxidation response happens. This implies the anode terminal is a provider of electrons.
- **Cathode:** A cathode is an electrode in a battery at which a reduction response happens. The cathode takes up electrons from an outer circuit.
- **Ageing:** The real reason for maturing of the battery is Sulphating. In the event that the battery is inadequately energized in the wake of being released, sulphate gems begin to develop, which can't be totally changed once again into lead or lead oxide. In this way the battery gradually loses its dynamic material mass and henceforth its release limit. Consumption of the lead framework at the anode is another basic maturing component. If there should arise an occurrence of lead-acid batteries antimony harming is a noteworthy reason for quickened maturing. Consumption prompts expanded lattice obstruction because of high positive possibilities. Further, the electrolyte can dry out. At high charging voltages, gassing can happen, which results in the loss of water. Hence, demineralised water ought to be utilized to refill the battery now and again.
- **Capacity:** The limit of a battery is characterized as the measure of energy that it can convey in a solitary release. Battery limit is typically indicated in amp-hours (or mille-amp-hours) or as watt- hours.
- **Cell:** The meaning of the cell is the fundamental electrochemical unit that is utilized to make electrical energy from put away compound energy or to store electrical energy as substance energy. An essential cell comprises of two terminals with an electrolyte between them.
- **Charge rate or C-rate:** C-rate is the release rate of the battery with respect to its ability. The C-rate Number is only the release current, at which the battery is being released, over the ostensible battery limit. It is determined as per equation 3.1.

$$C_{rate} = \frac{I_{\mathrm{dis}}}{C_{\mathrm{non}}} \tag{3.1}$$

Where,
I_{dis} is the release current
C_{non} is the ostensible battery limit

The release rate is at times alluded to as C rate and that number is the quantity of hours it takes the battery to be completely released. As such, it is the converse of the past documentation and it is determined as per equation 3.2.

$$C_{rate} = \frac{C_{\text{non}}}{I_{\text{dis}}} \tag{3.2}$$

- **Constant-Current Charge:** This alludes to a charging procedure where the dimension of current is kept up at a steady dimension paying little heed to the voltage of the battery or cell.
- **Constant-Voltage Charge:** This definition alludes to a charging procedure in which the voltage connected to a battery is held at a consistent incentive over the charge cycle paying little heed to the current drawn.
- **Cycle Life:** The limit of a battery-powered cell or battery changes over its life. The meaning of the battery life or cycle life of a battery is number of cycles that a cell or battery can be charged and released under explicit conditions, before the accessible limit tumbles to a particular exhibition criteria typically 80% of the evaluated limit.
- **Deep Cycle:** A charge release cycle in which the release is proceeded until the battery is completely released. This is ordinarily take to be the time when it achieves its cut-off voltage, normally 80% of release.
- **Depth of Discharge:** The Depth of Discharge (DoD) of a battery decides the part of intensity that can be pulled back from the battery. For instance, if the DoD of a battery is given by the producer as 25%, at that point just 25% of the battery limit can be utilized by the heap.
- **Electrode:** The terminals are the fundamental components inside an electrochemical cell. There are two in every cell: one positive and one negative anode. The cell voltage is controlled by the voltage distinction between the positive and the negative terminal.

- **Electrolyte:** The meaning of the electrolyte inside a battery is that the medium gives the conduction of particles between the positive and negative terminals of a cell.

- **Energy Density:** The volumetric vitality stockpiling thickness of a battery, communicated in Watt-hours per litre (Wh /l). Power Density: The volumetric power thickness of a battery, communicated in watts per litre (W/l).

- **Rated Capacity:** The limit of a battery is stated in Ampere-hours, Ah and it is the all-out charge that can be acquired from a completely charged battery under determined release conditions.

- **Self-Discharge:** It is discovered that batteries and cells will lose their charge over some stretch of time, and need re-charging. This self-release is ordinary, however different as indicated by various factors including the innovation utilized and the conditions. Self-release is characterized as the recoverable loss of limit of a cell or battery.

- **Specific Energy:** The gravimetric vitality stockpiling thickness of a battery, communicated in Watt-hours per kilogram (Wh /kg).

- **Specific Power:** The particular power for a battery is the gravimetric power thickness communicated in Watts per kilogram (W/kg).

- **State of Charge(SoC):**
  The SoC is characterized as the level of the releasable limit in respect to the battery appraised limit, given by the producer as per equation 3.3.

$$SoC = C_{\text{releasable}}/C_{\text{rated}} * 100\% \tag{3.3}$$

  The SoC reference ought to be the evaluated limit of another cell instead of the present limit of the cell. This is on the grounds that the cell limit steadily decreases as the cell ages. For instance, towards the finish of the cell's life its real limit will approach just 80% of its evaluated limit and for this situation, regardless of whether the cell were completely charged, its SoC would just be 80% of its appraised limit. Temperature and release rate impacts lessen the compelling limit considerably further. This distinction in reference focuses is critical if the client is relying upon the SoC estimation as he would in a genuine gas check application in a vehicle.

Putting together the SoC gauge with respect to the momentum limit of the battery instead of its evaluated limit when new is proportionate to dynamically decreasing the limit of the fuel tank over the lifetime of the vehicle without illuminating the driver. On the off chance that an exact gauge of the charge staying in the battery is required the maturing and ecological components must be considered.

- **State of Health (SoH):**
  The State of Health is an ”estimation” that mirrors the general state of a battery and its capacity to convey the predefined execution contrasted and a crisp battery. It considers such factors as charge acknowledgment, inside opposition, voltage and self-release. It is a proportion of the long haul capacity of the battery and gives a ”sign” not a flat out estimation, of the amount of the accessible ”lifetime vitality throughput” of the battery has been devoured, and what amount is left.

  Amid the lifetime of a battery, its act or ”well being” will in general crumble slowly because of irreversible physical and concoction changes which occur with use and with age until inevitably the battery is never again usable or dead.

  The SoH means that the point which has been come to in the existence cycle of the battery and a proportion of its condition in respect to a crisp battery.

  Not at all like the SoC which can be dictated by estimating the genuine charge in the battery there is no outright meaning of the SOH. It is an abstract measure in that extraordinary individuals get it from a wide range of quantifiable battery execution parameters which they translate as per their very own arrangement of guidelines. It is an estimation as opposed to an estimation. This is fine insofar as the gauge depends on a steady arrangement of guidelines yet it makes examinations between appraisals made with various test hardware and techniques temperamental.

  Battery producers don’t indicate the SoH since they just supply new batteries. The SoH just applies to batteries after they have begun their maturing procedure either on the rack or once they have entered administration. The SOH definitions are in this way determined by test hardware makers or by the client.

- **Trickle charge:** This terms alludes to a type of low dimension charging where a cell is either consistently or discontinuously associated with a steady current supply that keeps up the cell in completely charged condition. Current dimensions might be around 0.1C or less needy upon the cell innovation.

3.2.2 Types of Batteries

In this project, the main focus is on two battery types namely, Lead-Acid and Lithium-ion.

I. **Lead-Acid Battery**

Lead-Acid cell main components as shown in Figure 3.6;

(a) Lead dioxide (PbO_2) at positive plate.

(b) Sponge lead (Pb) at negative plate.

(c) An arrangement of sulfuric corrosive (H_2SO_4) in water as the electrolyte.

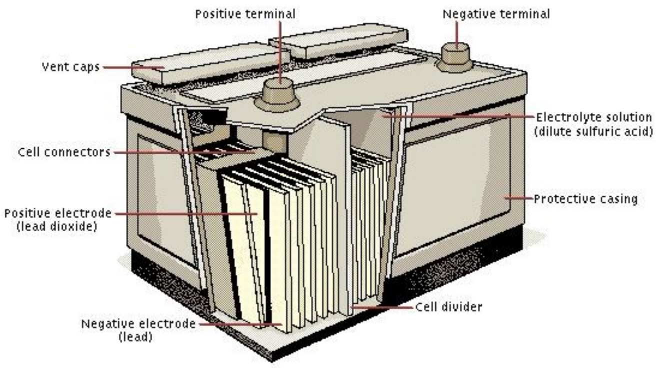

FIGURE 3.6: Lead Acid Battery

This response gives the perfect extents by weight of the reactants to convey limit at a low release rate when the measures of PbO2, lead and sulfuric acid would be all the while exhausted to zero. Regardless of having a low energy to-weight proportion and a low energy to-volume proportion, its capacity to supply high surge current implies that the cells have a generally huge capacity to- weight proportion. These highlights, alongside their minimal effort, make them alluring for use in vehicles to give the high current required via automobile starter engines.

- **Advantages Of Lead-Acid Battery:**
  (a) Capable to withstand long term inactivity with or without solvent.
  (b) Low maintenance.
  (c) Offers best value of power and energy per kWh.
  (d) Good in terms of reliability and working capabilities.
  (e) Offer low self-discharge.
  (f) Offer good performance at high temperature.
  (g) Inexpensive in manufacture.
- **Disadvantages Of Lead-Acid Battery:**
  (a) It is heavier compare to other batteries.
  (b) It is not environmentally friendly.
  (c) It charge slowly.
  (d) Low specific energy, poor weight to energy ratio.
  (e) It cannot be stored at discharge condition.
  (f) Less life cycle (300-500).

II. **Lithium-Ion Battery**

Lithium battery as shown in Figure 3.7, innovation has taken numerous years to create. It offers particular points of interest over other more established battery-powered battery advancements, for example, Nickel cadmium and Nickel Metal Hydride. In spite of the benefits of Lithium ion it has taken a long time to immaculate and empower it to achieve a development level where it could be broadly utilized. Presently it is utilized in numerous territories and its utilization has empowered may advancements, for example, cell phones, PCs and different things of ordinary use to move advances.

The three fundamental reasonable components of a lithium-molecule battery are the positive and negative electrodes and electrolyte.

Positive electrode is made up of metal oxide
Negative electrode is made up of graphite.
Electrolyte is made up of lithium salt.

Main charge carriers are lithium ion hence this battery is known as li-ion battery. Amid the general cycle there are two procedures related with development of the lithium ions:

Intercalation : The procedure where the lithium ions in the lithium ion battery are embedded into the terminal is called intercalation.

Deintercalation : This is the turnaround procedure and happens when lithium ions are removed from the anode, vice versa.

The electrolyte is routinely a mix of characteristic carbonates, for instance, ethylene carbonate or diethyl carbonate containing buildings of lithium ions. These non-liquid electrolytes generally use non-arranging anion salts, for instance, lithium hexafluoroarsenate monohydrate ($LiAsF_6$), and lithium triflate ($LiCF_3SO_3$). Lithium hexafluorophosphate ($LiPF_6$), lithium tetrafluoroborate ($LiBF_4$), and lithium perchlorate ($LiClO_4$).

In spite of the fact that lithium-ion batteries are by and large alluded to by their conventional name, there are really a few unique sorts of lithium ion battery. Despite the fact that they have numerous comparative attributes, each has its own and is ideal for various applications. Table 3.1 provides the entire datasheet of the Li ion cell.

FIGURE 3.7: Lithium Ion Battery

TABLE 3.1: Lithium Ion cell (4.2V) Data sheet

Capacity	Nominal Capacity : 2200 mAh
Nominal Voltage	3.7 V
Internal Impedance	$<=$ 80 mOhm
Discharge Cutoff Voltage	3 V
Max Charge Voltage	4.2 $+-$ 0.02 V
Standard Charge Current	0.5 C_a
Rapid Charge Current	1 C_a
Standard Discharge Current	0.5 C_a
Rapid Discharge Current	1 C_a
Max Discharge Current	2 C_a
Weight	45 $\pm$ 1g

- **Construction**

A battery-controlled lithium-ion battery pack is made of cells. Each battery has fundamentally three portions: a positive anode (related with the battery's certain or + terminal), a negative cathode (related with the negative or -ve terminal), and a substance called an electrolyte amidst them. The positive terminal is customarily created utilizing a manufactured compound called lithium-cobalt oxide ($LiCoO_2$) or, in increasingly current batteries, from lithium iron phosphate ($LiFePO_4$). The negative anode is normally created utilizing carbon (graphite) and the electrolyte changes beginning with one kind of battery then onto the following.

All lithium batteries work widely in a comparable way. Exactly when the battery is invigorating, the lithium-cobalt oxide, positive cathode surrenders a segment of its lithium ions, which go through the electrolyte to the negative, graphite anode and remain there. The battery takes in and stores imperativeness in the midst of this system. Exactly when the battery is discharging, the lithium ions move back over the electrolyte to the positive cathode, conveying the essentialness that controls the battery. In the two cases, electrons stream the other route to the particles around the outer circuit. Electrons don't course through the electrolyte: it's effectively a securing prevention, so far as electrons are concerned.

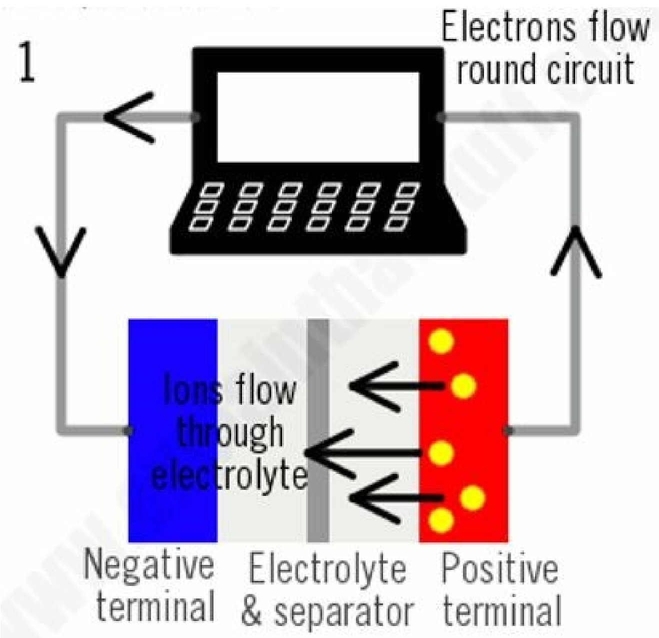

FIGURE 3.8: Charging & Discharging

(a) During charging, as shown in Figure 3.8, lithium ions (yellow circles) stream from the positive cathode (red) to the negative anode (blue) through the electrolyte. Electrons additionally stream from the positive terminal to the negative anode, however take the more drawn out way around the external circuit. The electrons and particles consolidate at the negative anode and store lithium there.

(b) When no more particles will stream, the battery is completely charged and prepared to utilize.

(c) During discharging, the particles stream back through the electrolyte from the negative anode to the positive cathode. Electrons stream from the negative to the positive terminal through the external circuit, driving your laptop. At the point when the particles and electrons consolidate at the positive anode, lithium is stored there.

(d) When every one of the particles have moved back, the battery is completely discharges and needs energizing once more.

- **Advantages:**

(a) Smaller and lighter: Li-ion battery is lighter than other battery-powered batteries regarding battery limit.

(b) High energy density: Li-ion battery has higher vitality thickness than other battery-powered batteries. This implies having high power limit without being excessively cumbersome.

(c) Low self-discharge: Li-ion battery additionally has a low self-release rate of about 1.5 percent every month. This implies the battery has a more drawn out timeframe of realistic usability when not in utilized in light of the fact that it releases gradually than other battery-powered batteries.

(d) Zero to low memory impact: Li-ion battery has zero to insignificant memory impact. Observe than memory effect is a marvel seen in battery-powered batteries in which they lose their most extreme vitality limit when rehashed energized subsequent to being just incompletely released. This memory effect is normal in nickel-metal hydride battery-powered batteries, for example, NiCad and NiMH.

(e) Fast charging: li-ion battery is fast to charge than other batteries.

(f) Long life: Li-ion battery can ordinarily deal with several charge-release cycles. Some lithium ion batteries misfortune 30 percent of their ability after 1000 cycles while further developed lithium ion batteries still have better limit simply after 5000 cycles.

- **Disadvantages:**

(a) Lithium-ion batteries are expensive.

(b) If lithium ion battery fully discharged, it cannot be use again.

(c) Lithium ion battery are highly sensitive with temperature. High temperature result in much faster discharging/degradation rate.

(d) It usually last for only two or three years from the date of manufacture although it is used or unused.

(e) Lithium-ion batteries can be a security danger since they contain a combustible electrolyte and may progress toward becoming pressurized on the off chance that they wind up harmed.

III. Lead Acid Vs Lithium Ion

As Generators can not be afforded by all, people invest in inverters, but the problem they face is that it is high maintenance. It is so because normal inverters are made of lead acid batteries, the major disadvantage's of these batteries are, The electrolyte in a typical lead-acid battery is made up of approximately thirty six p.c vitriol and sixty four p.c water. This acid resolution will cause chemical burns to the skin; so, you should use extreme caution when working around a lead-acid battery. When a accumulator is recharged, some of the electrolyte may evaporate and hydrogen gas will escape from the battery cell vents. Hydrogen gas is ignitable, so lead-acid batteries should be stored and recharged away from any sources of fire or flame. A accumulator is formed from many lead associated lead chemical compound conductor plates immersed in an acidic solution. An automotive battery will weigh between thirty and sixty pounds. Lifting a lead-acid battery improperly can cause injury. A lot of money and supervision goes into maintaining these back up energy devices, and people don't have the time for it.

3.3 Battery Swapping Stations

For EVs to be adopted at scale, the charging infrastructure and blueprint with the power grid must also evolve exponentially. It is therefore necessary that these technical issues be studied and that new methods of obtaining the energy in EVs and extending the range of EVs be developed. Today, an EV of 110 km range requires 2–3 hrs to charge the battery from 0% to 100% SoC using AC charging, or 30 min to 1 hr for DCFC. While fast charging shows potential, it still poses critical technical challenges and present day technologies do not offer the convenience that conventional vehicles offer in terms of refueling of energy within 5–10 min. This method is based on the assumption that consumers are willing to rent their battery as opposed to owning the battery. Several automakers and start-ups including Tesla Motors and Better Place have brought out a BSS similar to this model; however, consumer acceptance of not owning the battery and their original battery being tampered with during a swap has hampered the success of this model. A battery sharing station (BShS) and a battery sharing network (BShN) is a peaceful solution to cancel out the impact of the EVs' scale and improve the reliability/stability of the grid. The BShS is based on some of the concepts and methods that Tesla and Better Place have implemented in their BSS, but its main aim is solving the issues of consumer acceptance, standardization of battery architecture and mitigation of grid impact by EV battery charging [12].

3.3.1 Overview of Current Battery Swapping Station Technology

In this area, a general diagram of the primary segments of a BSS is represented, with the Tesla BSS as a contextual analysis. The BSS comprises of mechanical and auxiliary segments just as electrical segments. Figure 3.9, is a conceptual display of the BSS.

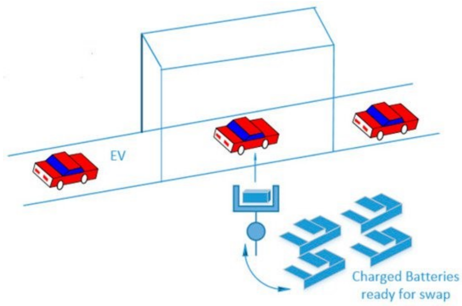

FIGURE 3.9: Conceptual Display of BSS

The Tesla BSS appeared in Figure 3.10 incorporates a vehicle stage, a vehicle lift, battery lifts, vehicle arrangement hardware rollers, electrical association arrangements, battery transport transports, and battery stockpiling racks and rails. Figure 3.10 demonstrates an EV that has touched base at a BSS and is prepared to be occupied with a swap.

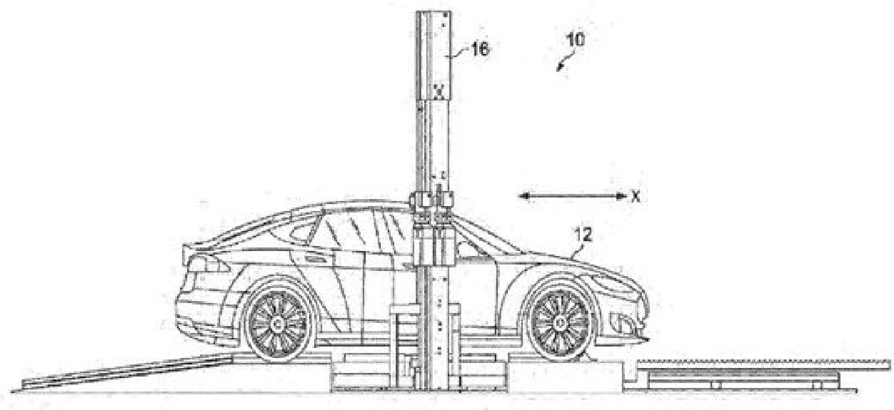

FIGURE 3.10: Tesla BSS

3.3.2 Electrical Design of BSS

In the present usage, the BSS is intensely reliant on the distribution framework(grid) and is a representation of the new high power utilization loads for the distribution framework administrators. The electrical segments of the BSS are for the most part made out of a distribution transformer, AC/DC chargers, battery packs, and a battery energy control module (BECM). Figure 3.11 is a square outline of the electrical connection between the segments of the BSS.

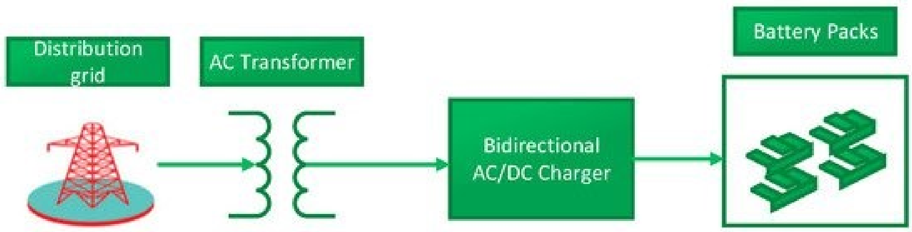

FIGURE 3.11: Block Diagram of BSS Electrical Design

The distribution network gives the AC power at the distribution voltage level, and in light of the powerful interest of the BSS, this voltage level will be between 33 kV and

11 kV. Charging power levels for EV battery packs run from Level 1 charging at 120 V/15 A 1-phase ; Level 2 Charging at 240 V (up to 80 A, 19.2 kW); and Level 3 Charging at 50 kW and up. Depending upon the extent of the BSS and the voltage level accessible at the distribution network, distinctive charging modes can be executed.

Charging profiles decide the rating of the AC/DC charger. For our situation, a unidirectional AC/DC charger is actualized which is associated with the AC transformer and changes over the AC capacity to DC capacity to charge the batteries directly. Figure 3.12 is a solitary switch unidirectional boost converter with passive filtering for the BSS AC/DC charger topology.

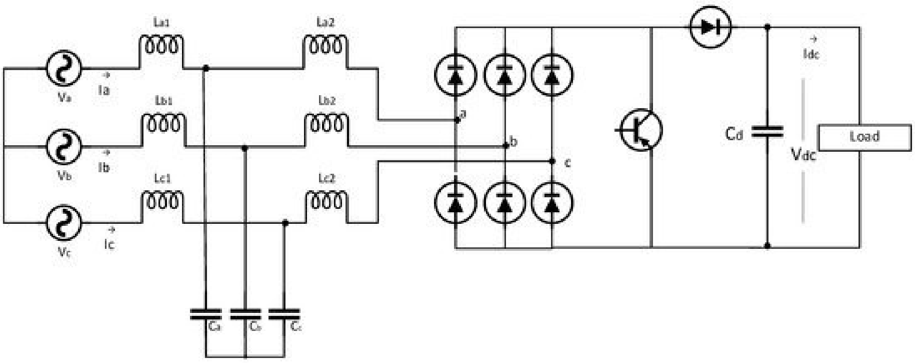

FIGURE 3.12: Unidirectional Boost Converter for BSS

3.3.3 Battery Swapping System Challenges and Opportunities

A noteworthy block to the reception of EVs is the mind-boggling expense of proprietorship, which is legitimately connected to the expense of the installed battery. In present day EVs today, the expense of the battery is 25-50% of the whole expense of the vehicle. BSS have an exceptional chance to diminish a portion of the agony focuses that EV appropriation faces. In a perfect BSS framework, an outsider will have the responsibility for battery and is in charge of supplanting the drained batteries of its accomplices or clients with completely charged ones, just as observing the soundness of the batteries and decommissioning/repurposing the batteries once the life is never again appropriate for the e-portability use case. This renting/pay-as-you-go model could be especially appealing for fleet use cases, for example, ride-sharing and bundle delivering companies (who drive countlessly every day and can't bear the cost of a great deal of downtime). However fundamentally diminished holding up times contrasted with DCFC, BSS can give two extra advantages to the power network as far as unwavering quality is concerned. The conduct of EV proprietors as far as charging is stochastic and eccentric, which could prompt unsustainable entrance of the matrix as EV appropriation increments in scale. BSS can consider controlled/booked charging of exhausted batteries, postponing charging of batteries to off-crest hours in this way going about as an extensive adaptable burden from the grids point of view. BSS can likewise go about as energy stockpiling aggregators with enough stockpiling ability to take part in electrical energy markets, giving administrations to the framework, for example, voltage support, regulation reserves, and energy exchange.

Be that as it may, the barriers that encompass BSS still remain: Standardization of EV battery packs; buyer acknowledgment of BSS demonstrate; dependable estimation of battery condition of-wellbeing. Another vital factor to consider is the appropriation and cost of BSS and charging foundation. Institutionalization of EV battery packs, while important, gives off an impression of being in all respects improbable; this is to a great extent because of the way that the aggressive edge for EV OEMs are firmly lined up with their hidden restrictive battery innovation. The battery pack is central most point of the vehicle's quality, soundness, and security at configuration time, making it progressively troublesome for OEM's to share a comparative battery design no matter how you look at it. Individual OEMs, however, can share battery structures over a few models as is found in the battery engineering plan of the Tesla Model S and Model X. A standard battery engineering design over models and brands of individual OEMs will cultivate the practicality of BSS models like OEM explicit administration businesses.

The worries of customers with respect to the BSS model are identified with both the user indecisiveness of not owning the battery at the moment of procurement of the EV or the EV proprietor accepting a battery which he/she has no certification of the current SOH and condition of wellbeing and corruption of the swapped battery as on account of the Tesla BSS.

Exact SoC and SoH estimation of the Li-ion battery to guarantee its protected activity and its abilities in BSS applications is basic. Precise estimation of Li-ion battery SOH and cycle life are practical in nature, requiring actuated ageing tests directed under a few conditions of Li-ion batteries explicit to the battery science. As EVs have advanced, a few methodologies have been proposed in the writing to anticipate the SoC and SoH of the EV battery both connected just as disconnected. An exact disconnected SoC and SoH estimation assumes a noteworthy job in the specialized practicality of BSS models as batteries are continually moved around; the significance of the online estimation of battery wellbeing and limit is featured in the following segment.

Another imperative displaying challenge is the advanced conveyance and estimating of BSS over the EV network. Displaying of BSS entrance and communication with the framework both as an adaptable burden and as a energy stockpiling market member or aggregator is additionally of most extreme significance. The participation of the BSS in the electrical market assumes an essential job in the financial suitability of the BSS.

3.4 Design

This section talks about the actual methodology that has been followed in the project.

3.4.1 CC-CV Method

A CC-CV method based system is used to charge the 4.2V battery due to numerous advantages this kind of method possesses. But before getting into that, it is important understand what a CC- CV method is. CC stands for Constant Current and CV stands for Constant Voltage and what happens here is that it tries to replicate the standard Lithium Ion charging graph as show in Figure 3.13.

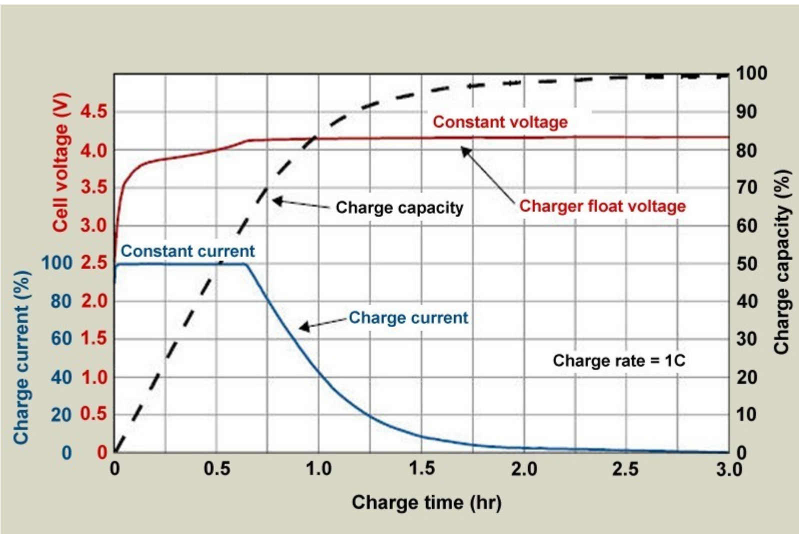

FIGURE 3.13: Unidirectional Boost Converter for BSS

Under the method of the CC/CV charging calculation, a steady current is supplied to charge the battery until the battery voltage ascends to a preset maximum charging voltage V, at that point the charging voltage is held consistent at V and correspondingly the charging current is diminished exponentially. The charging procedure stops when the charging current achieves a preset small current.

This method is of utmost importance because it not only elongates the life of the battery but also helps in accurate SoC measurement by preventing arbitrary values to show up.

3.4.2 Algorithms

The algorithm followed for the SoC measurement is a mixture of Look-Up table method as well as Coulombic Counting method. In this algorithm, the voltage of a 4.2V Lithium Ion cell is monitored and using this voltage value it is compared to the values present in the Look up table. Once the initially SOC has been estimated, the increase or decrease in SOC can be calculated using the Coulombic Counting method that continuously runs in the loop, continuously monitoring the current and the time for which the current is being measured.

- **Look-Up table Algorithm**

  Firstly, the Look up table is created using ThingSpeak along with a microcontroller sending data to ThingSpeak via Ethernet. The data sent includes voltage, current and time values till the battery is fully charged as well as when the battery is fully discharged. With the help of the time value and the current at each time the SoC at each voltage can be calculated. These value can now be put into the code using the basic if-else if logic and would help in the calculation of intial SoC only. This is what the Look-Up table algorithm is based on.

- **Coulombic Counting Algorithm**

  Now talking about the Coulombic Counting method, once the initial SoC is calculated, the voltage sensor and current sensor only need to monitor the battery and accordingly feed the data to the code and the code would then calculate the charge increment or decrement and accordingly update the SoC. This would run in a loop till charging or discharging of the battery is stopped.

3.4.3 Microcontroller

Selection of a microcontroller depends upon factors necessary for the application. In this project two microcontrollers have been used, one for uploading data to ThingSpeak and the other to be used in the SoC measurement all throughout the project.

For sending data to ThingSpeak, the WIZwiki 7500P as shown in Figure 3.14, is used due to its ability to easily send data over Ethernet connection. WIZwiki 7500P is a microcontroller manufactured by WIZnet inc. Coding for this microcontroller was done on its online compiler called mbed. WIZwiki- W7500 based on the W7500, the ARM Cortex-M0 that integrates 128KB Flash and hardwired TCP/IP core.

FIGURE 3.14: WizWiki 7500P

For the SoC measurement, the Arduino UNO board as shown in Figure 3.15, was used as adaptability of the code for this board was easier and the voltage sensor and current sensor was interfaced to this board and the values obtained were utilized to measure and calculate the SOC of the battery using the above algorithms. This board is a high speed controller and can perform complex mathematical calculations in a very small time. It is a 16MHz, 8-bit microcontroller board based on the ATmega328P. It has 14 digital input/output pins, of which 6 can be used as PWM outputs, 6 analog inputs, a 16MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button.

FIGURE 3.15: Arduino Uno

3.4.4 ThingSpeak

Data from the sensor is uploaded to ThingSpeak via Ethernet Connection using WIZwiki 7500P. This is done by entering the write API key to pass this data to "api.thingspeak.com" in the mbed code.

This data is stored in the form of fields as shown in Figure 3.16, and the project requires two fields. One which measures the Current against Time and the other measures Voltage against Time.

FIGURE 3.16: ThingSpeak

TABLE 3.2: Voltage Data

Date and Time	Raw Value	Voltage (in V)
2019-02-26 12:52:02 UTC	731	1.187209
2019-02-26 12:52:18 UTC	732	1.185153
2019-02-26 12:52:45 UTC	733	1.185151
2019-02-27 06:07:38 UTC	734	2.263142
2019-02-27 06:19:04 UTC	735	2.267498
2019-02-27 06:19:22 UTC	736	2.266523
2019-02-27 06:19:44 UTC	737	2.267498
2019-02-27 06:20:03 UTC	738	2.249099
2019-02-27 06:20:52 UTC	739	2.267498
2019-02-27 06:21:19 UTC	740	2.262167
2019-02-27 06:21:37 UTC	741	2.253449
2019-02-27 06:21:57 UTC	742	2.267498
2019-02-27 06:31:24 UTC	743	2.27
2019-02-27 06:31:54 UTC	744	2.27
2019-02-27 06:32:37 UTC	745	2.28
2019-02-27 06:32:54 UTC	746	2.27
2019-02-27 06:33:11 UTC	747	2.27
2019-02-27 06:33:28 UTC	748	2.27
2019-02-27 06:33:45 UTC	749	2.25
2019-02-27 06:34:03 UTC	750	2.25
2019-02-27 06:34:20 UTC	751	2.27
2019-02-27 06:34:38 UTC	752	2.26
2019-02-27 06:34:55 UTC	753	2.26
2019-02-27 06:35:12 UTC	754	2.26
2019-02-27 06:35:29 UTC	755	2.28
2019-02-27 06:35:47 UTC	756	2.25
2019-02-27 06:36:04 UTC	757	2.27
2019-02-27 06:36:21 UTC	758	2.28
2019-02-27 07:23:42 UTC	759	2.263142

This data is then stored in ThingSpeak in the form of a .csv file which is then utilized to create the Look-Up table to be used to measure the initial SoC.

3.5 Simulation

The CC-CV model was simulated in MATLAB software.

3.5.1 CC-CV Modelling

As shown in Figure 3.17, CC-CV charging model was carried out on a Lithium ion battery using two Batteries. Here, one battery was used as the charging source and the other battery to be charged by it. Breakers were utilized to control the charging of the battey via the source battery at a particular instant or to allow discharging of the battery when connected to a load at another instant.

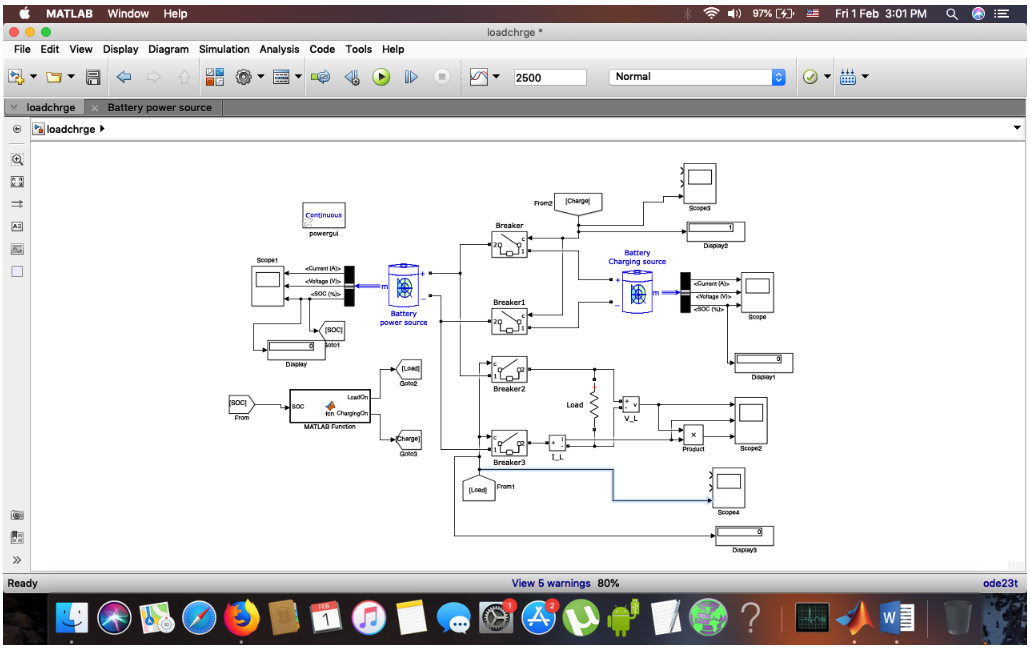

FIGURE 3.17: Circuit Showcasing CC-CV Modelling

As shown in Figure 3.18, the battery charging source as well as battery power source graph are obtained.

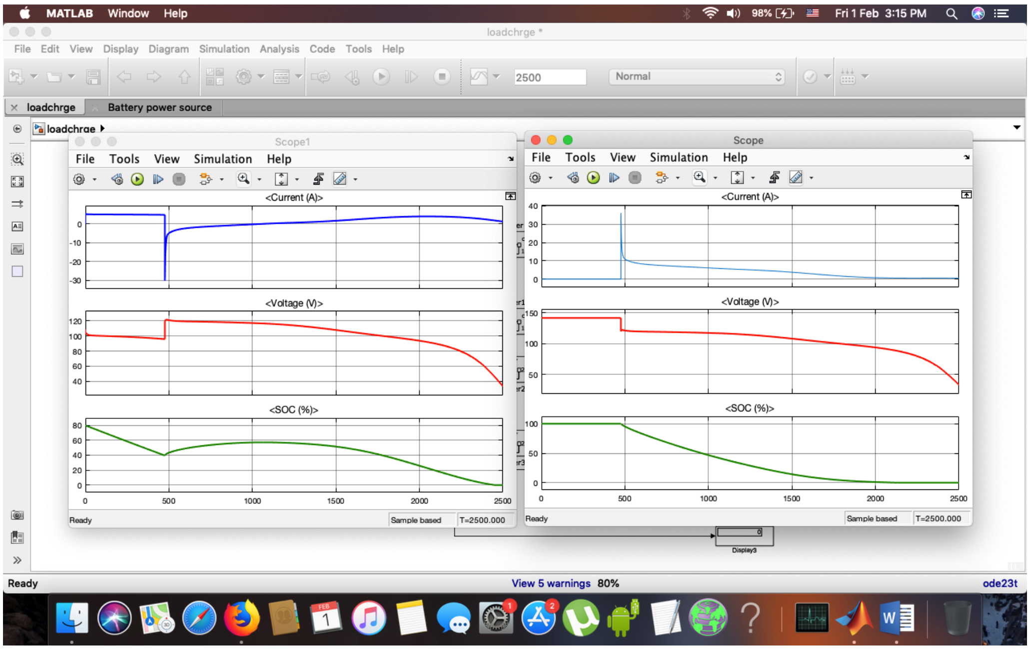

FIGURE 3.18: Matlab Simulation

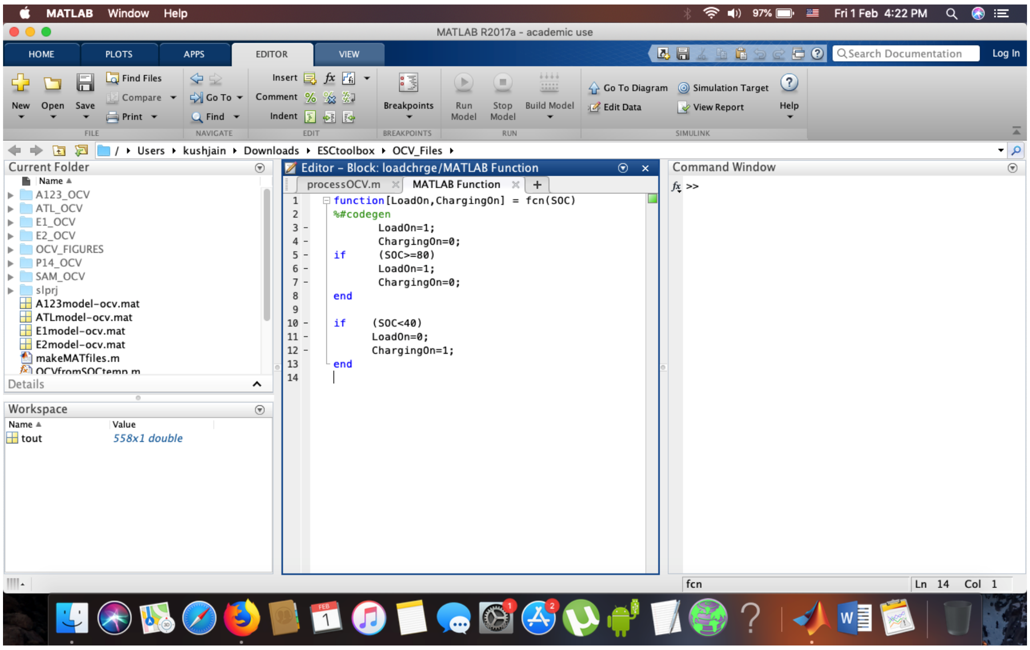

FIGURE 3.19: Matlab Code

Another component of the simulation as shown in Figure 3.19, is the MATLAB function which is based on a basic logic which states that if the SoC is above 80% the charging source will be disconnected and the Load will be connected and if the SoC is below 40% the charging source will be connected and the load will be disconnected.

3.6 Hardware Implementation

3.6.1 CC-CV Circuit

The CC-CV circuit was implemented as shown in Figure 3.20.

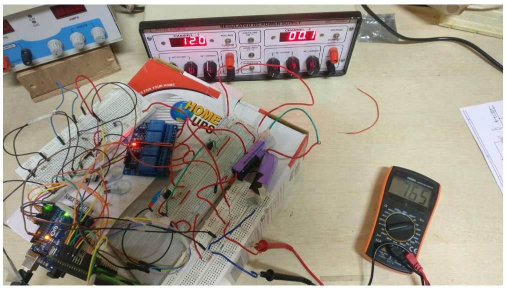

FIGURE 3.20: CC & CV Circuit

3.6.2 Sensors

This project requires two sensors, the generic 0-25V voltage sensor, as shown in Figure 3.21 and the ACS 712 hall effect sensor as shown in Figure 3.22. The voltage Sensor was connected to the A1 pin of the Arduino UNO and current sensor to the A0 pin of the Arduino UNO.

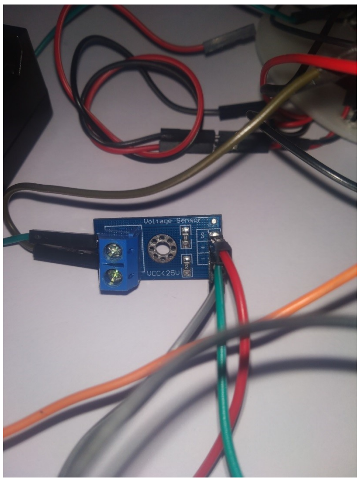

FIGURE 3.21: Voltage Sensor

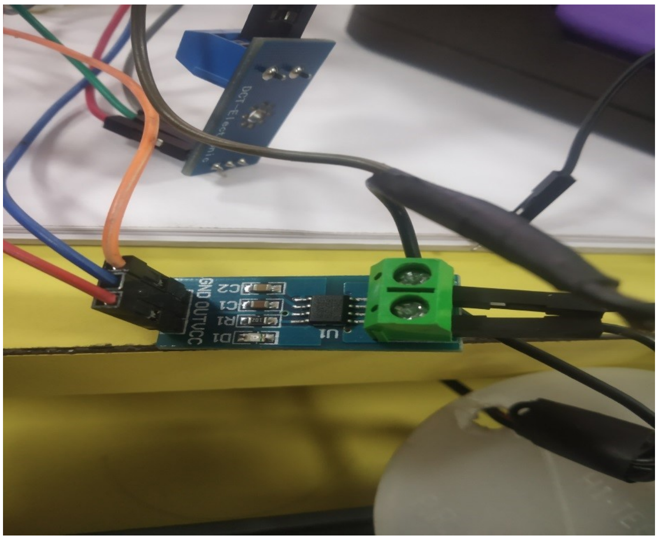

FIGURE 3.22: Hall Effect Sensor

3.6.3 Microcontroller

WIZwiki 7500P as shown in Figure 3.23, used for the database creation and Arduino UNO to be used for SoC measurement and Battery Swapping Station locator have both been implemented. Arduino UNO as shown in Figure 3.24, analog pins were used to connect the Volatge Sensor(A1) and Current Sensor(A0). The 5V pin and Ground (GND) was also used.

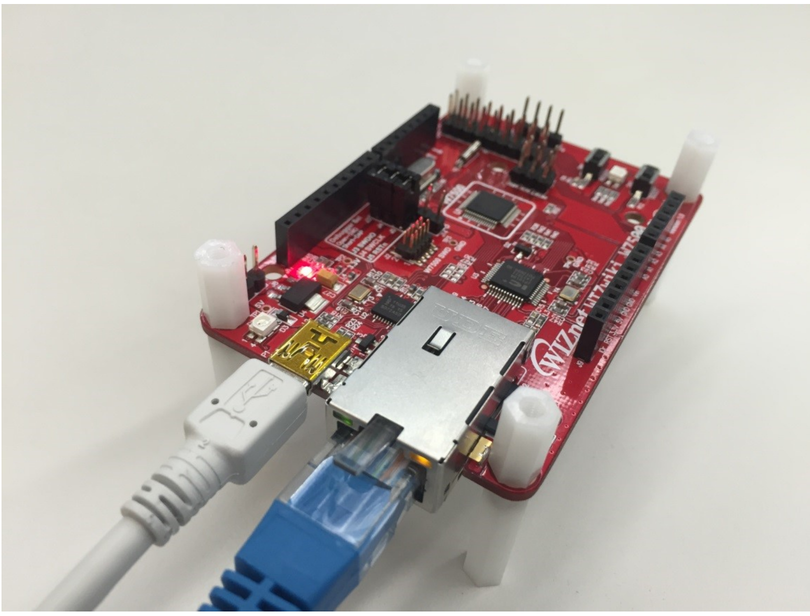

FIGURE 3.23: WIZwiki 7500P

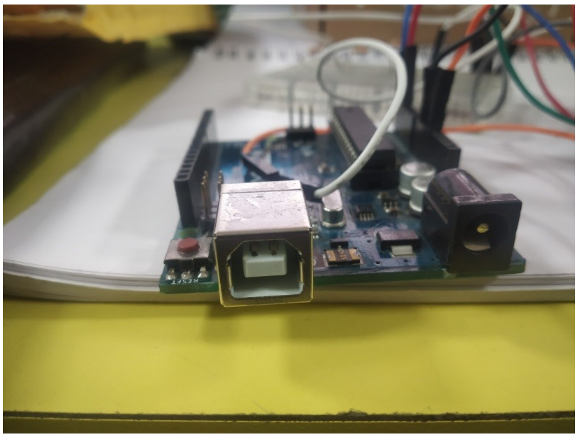

FIGURE 3.24: Arduino UNO

3.6.4 MIT App Inventor

In order to allow the user to find a Battery Swapping Station whenever the Battery SoC falls below a pre-determined value, an app was created which would be present with the mobile phone of the user and would not require any external GPS sensor and would use the GPS sensor present in the phone itself. Now the only part that remained was providing the user a GUI (Graphic User Interface) and make it easier and more appealing to the user who can see this while driving and be guided to the BSS via the navigation feature within the app.

This was achieved with the help of MIT app inventor 2, which is basically an intuitive, visually appealing coding environment that allows anyone and everyone to build functional apps for smartphones. Blocks-based tool helps in the creation of complex, performance apps in significantly lesser time than the apps built in common coding environments.

3.7 Cost Estimation

This kind of a product is a multi-utility product which would be an add-on feature in any upcoming Autonomous Vehicle System that has Battery Swapping capability.

TABLE 3.3: Cost Estimation

Sl. No.	Components	Price/Unit	No. of Units	Total(_)
1	Arduino Uno	250	1	250
2	WIZwiki 7500P	1962	1	1962
3	Lithium ion cell	250	1	250
4	Voltage Sensor	100	1	100
5	Current Sensor	270	1	270
6	Bluetooth Module	240	1	240
7	Breadboard and wires	100	1	100
8	Resistors	30	1	30
			Total	3202

The cost of such a product would be around INR 8000 in the market, whereas this is almost 2.5 times cheaper as shown in table 3.3.

3.8 Summary

The design of the project and how it has to be implemented has been discussed in the above chapter and the upcoming chapter analyses the implementation that would be carried out to obtain the final product.

Chapter 4

RESULTS

4.1 Results and Analysis

The functions of sub-circuits were analysed individually and integrated together in the previous chapter. Each sub-circuit with their outputs is discussed in this chapter.

4.1.1 CC-CV charging circuit

In this circuit, the battery was connected to the RPS (Regulated Power Supply) and initially constant current of 1C was provided. As soon as the voltage at the battery terminal reached 4.2V the constant current source was disconnected and a constant voltage source was connected with a supply voltage of 4.2V. The RPS is then disconnected only the current supplied to the battery being monitored by the current sensor reached 0.01C.

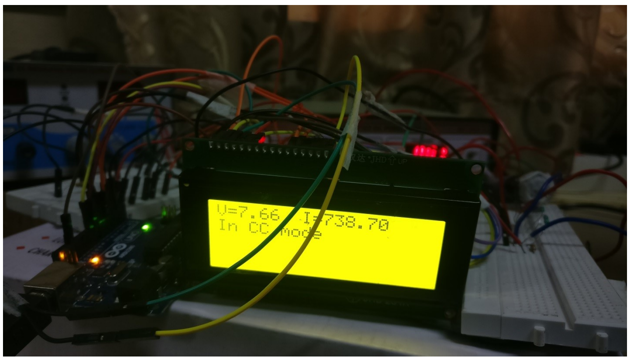

FIGURE 4.1: CC Mode

Charging circuit of the Li-ion battery was successfully implemented as shown in Figure 4.1.

4.1.2 Database Creation

Here the WIZ-wiki 7500P was used to transfer Voltage and Current data from sensor to ThingSpeak using a code written in mbed. This is then used to form the Database for the look up table that would be utilised for the calculation of SoC.

The circuit as shown in Figure 4.2 :

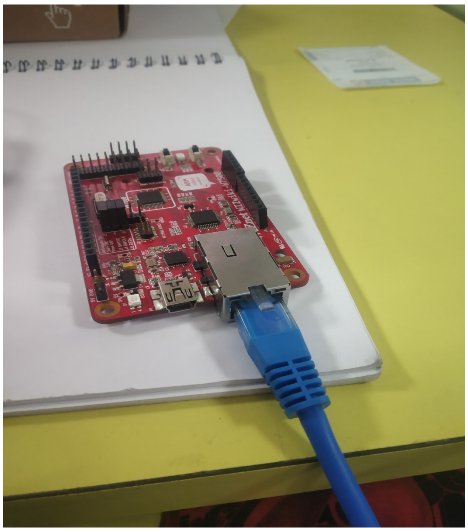

FIGURE 4.2: SoC Calculation

The data was successfully sent over to ThingSpeak via WIZwiki 7500P and creation was complete.

4.1.3 Arduino Uno

The heart of the project lies in the SoC code and the Battery Swapping Station locator code, which is present in the Arduino UNO, coded in the Arduino environment. The sensors are connected to the analog pins A1 and A0 to measure the voltage and current respectively. The data is received as a raw value and this raw value is then converted to respective voltage and current value based on equations written in the code. This value is then used to calculate the respective SoC and total charge in the circuit.

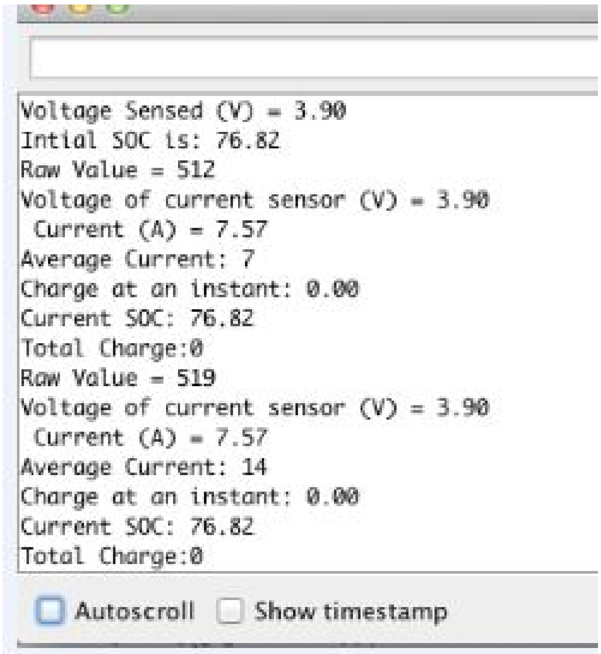

FIGURE 4.3: SoC on Arduino Serial Monitor

The code was successfully run in the Arduino Environment and the SoC value was displayed on the android app as well as serial monitor as shown in Figure 4.3.

4.1.4 MIT App Inventor

In this prototype, the user would connect to the SoC module using Bluetooth connection which would keep updating the SoC box present in the app. The app created was based on the logic that if the SOC falls below 20%, the user would be navigated, within the app, to the BSS to exchange the battery and carry on a hassle free journey.

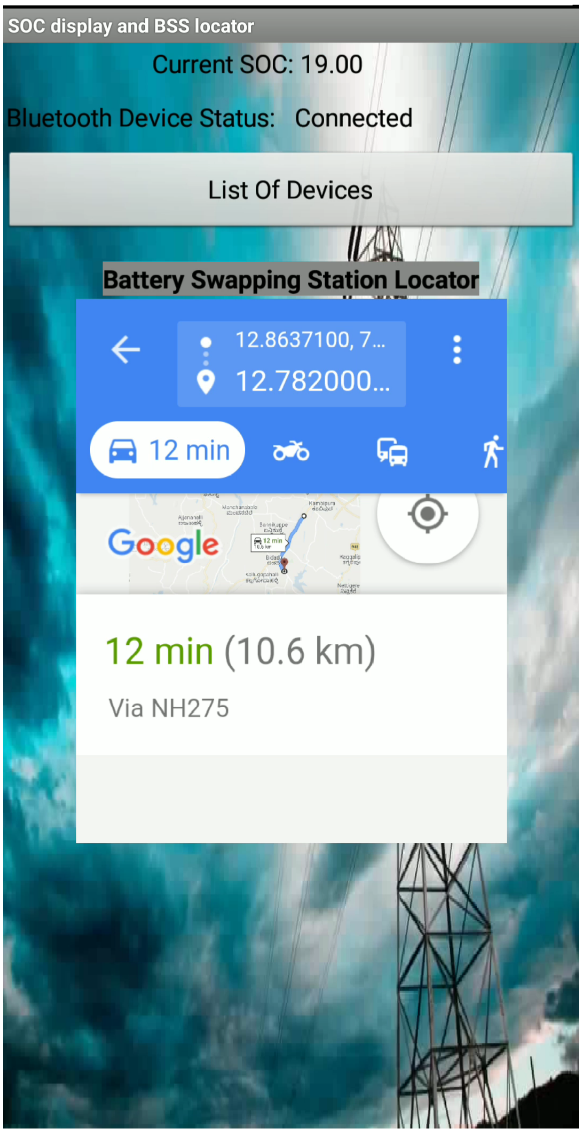

FIGURE 4.4: MIT App GUI

The app displayed the SoC value as well as activated the navigation when the SoC fell below 20%. Successful implementation of the app achieved as shown in Figure 4.4.

4.2 Summary

The design as discussed in Chapter 3 was implemented, and the results obtained were analysed in this chapter thoroughly.

Chapter 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

With the increasing trends in Electric Vehicles and Autonomous Vehicles, the SoC measurement and Battery Swapping techniques will become more and more prominent so as to reduce the wastage in any form as well as extend the life of batteries and hence make these vehicles feasible for consumers. Accurate measurement of the SoC is a must and needs to be worked upon continuously with the future technologies that are coming up. The main aim is to make the user feel that nothing has changed from a petrol/diesel car and the shift from conventional source to non-conventional source is smooth.

This project's main aim is to get the SoC as accurately as possible using the two algorithms in combination (Look Up & Coulombic Counting Algorithm). Simulation, Hardware Implementation and analysis were performed and successfully tested on a 4.2V Lithium ion cell. Battery Swapping Station locator was also successfully created and tested.

5.2 Scope for Future Work

This project can be improved in the following ways:

- By using ANN (Artificial Neural Network) Algorithms to make more adaptable in varied conditions. This project focusses only on SoC measurement of Li-Ion cell but using training data from various cells and feeding this data to the neural network, a common SoC code can be developed which would eliminate the complex issues of measuring SoC of various cells using different algorithms.
- Battery Swapping Station locator can be improved by using Wi-Fi enabled chip so that the BSS database can be updated at regular intervals and also incase of improvement in the code, the firmware can also be updated for any further improvements that are to be implemented.

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APPENDIX A

Code Snippet

Ethernet Interfacing and ThingSpeak Connection:

```
  #include "mbed.h"
#include "EthernetInterface.h"
#include "Adafruit_SSD1306.h"
#include "HTTPClient.h"
#include "reScale.h"

#if defined(TARGET_WIZWIKI_W7500)||defined(TARGET_WIZWIKI_W7500P)
    uint8_t mac_addr[6] = {0x00, 0x08, 0xDC, 0x53, 0xAE, 0x90};
#endif
// W7500 onboard LED & Init
DigitalOut rled(LED1,1);
DigitalOut gled(LED2,0);
DigitalOut bled(LED3,1);

// I2C Class
I2C i2c(PA_10,PA_9);

// OLED Class
Adafruit_SSD1306_I2c gOled(i2c,NC,0x78,64,128);

Serial pc(USBTX, USBRX);
Serial device(D1,D0);
EthernetInterface eth;

// Declare TCP Connection Class
TCPSocketConnection sock;

DigitalOut myled(D1);
  double V = 0;
double Current = 0;
float voltage=0;
double RawValue=0;
double volt=0;
 //int voltage = 0;
DigitalOut myled_R(LED_RED);

AnalogIn cin(A0);
AnalogIn vin(A1);
AnalogIn bin(A2);
AnalogIn nin(A3);




int main() {
```

```
    pc.baud(115200);

    printf("Wait a second...\r\n");

   eth.init(mac_addr);     //Use DHCP
eth.connect();

      printf("IP Address is \%s\r\n\r\n", eth.getIPAddress());
        printf("MASK Address is \%s\r\n\r\n", eth.getNetworkMask());
        printf("GATEWAY Address is \%s\r\n\r\n", eth.getGateway());
        printf("MAC Address is \%s\r\n\r\n", eth.getMACAddress());
    char str[512];

    char msg[512]= "";




     int cin_val = 0;
    int vin_val = 0;
        int bin_val = 0;
            int nin_val = 0;

    while (1) {
        printf("Entered!");
        for(int i = 0; i < 1000; i++)
      {
        cin_val += cin.read()*1000;
        vin_val += vin.read()*1000;
        bin_val += bin.read()*1000;
        nin_val += nin.read()*1000;
      }
      cin_val/=1000;
      vin_val/=1000;//voltage
      bin_val/=1000;//current
      nin_val/=1000;

      for(int i = 0; i < 1000; i++)
      {
       V = (V + ((3.3/4095) * bin_val)); // (5 V / 1024 (Analog) = 0.0049) which converter Measured an
      }
      V/=1000;
      Current = (V -0.6)/(0.185);
     for(int i = 0; i < 1000; i++) {
       reScale _scale (0,1023,0,16.5);
       voltage = voltage+(_scale.from(vin_val)); // (5 V / 1024 (Analog) = 0.0049) which converter Mea
      }

      voltage = voltage/1000;

        // output the voltage and analog values
        printf("=====================\r\n");
        //printf("analog value x1000 : \%d\r\n",cin_val);          // analog value 0 ~ 1000
        printf("analog value x1000 : \%d\r\n",vin_val);
```

```
        //printf("analog value x1000 : \%d\r\n",bin_val);
        //printf("analog value x1000 : \%d\r\n",nin_val);
        printf("\n VFC (V) = \%f\r\n",V); // shows the measured voltage
        printf("\n Current (A) = \%.2f\r\n",Current);
        printf("\n Voltage (V) = \%f\r\n",voltage ); // shows the measured voltage

           sock.connect("api.thingspeak.com",80);

        sprintf(msg,"https://api.thingspeak.com/update?api_key=RPR5D5L24YOWVOEV&field2=\%f&field3=\%f"
        HTTPClient http;
        int ret = http.get(msg, str, sizeof(str));
         if(!ret)
        {
          pc.printf("\r\nPage fetched successfully - read \%d characters\r\n", strlen(str));
          pc.printf("Result: \%s\r\n", str);
        }
         else
        {
          pc.printf("Error - ret = \%d - HTTP return code = \%d\n", ret, http.getHTTPResponseCode());
        }

        wait(16);
        sprintf(msg,"https://api.thingspeak.com/update?api_key=RPR5D5L24YOWVOEV&field3=\%d",vin_val);
        pc.printf("msg : \%s\r\n",msg);

        ret = http.get(msg, str, sizeof(str));
        if(!ret)
        {
          pc.printf("\r\nPage fetched successfully - read \%d characters\r\n", strlen(str));
          pc.printf("Result: \%s\r\n", str);
        }
         else
        {
          pc.printf("Error - ret = \%d - HTTP return code = \%d\n", ret, http.getHTTPResponseCode());
        }


         //sock.close();
      wait(16);
    }}
```

SoC Arduino Code:

```
#include <SoftwareSerial.h>

SoftwareSerial BTserial(10, 11); // RX | TX
double Vc = 0;
double Current = 0;
//double Q=0;
double voltage=0;
float Q[100];
double SOC;
int i=0,t=0;
float  V =0,q;
int C=0;
int n=1,f=0;
int state=0;
int flag=0;
void setup(){
Serial.begin(9600);
BTserial.begin(9600);
do{

SOC==0;
for(int i = 0; i < 1000; i++) {
int volt = analogRead(A1);// Voltage Sensor
V = (V + map(volt,0,1023, 0, 2500)); // (5 V / 1024 (Analog) = 0.0049) which converter Measured analog
delay(1);
}
V /=100000;// divide by 100 to get the decimal values
//voltage -=0.15;
V=V-1.7;
//Serial.print("Voltage Sensed (V) = "); // shows the measured voltage
//Serial.println(V); //the2after voltage allows you to display 2 digits after decimal point  if(V >= 3

 if(V >= 3.3 && V < 3.452) // seg-1
   {state=1;}

  else if(V >= 3.452 && V < 3.508) // seg-2
    {state=2;}

  else if(V >= 3.508 && V < 3.595) // seg-3
    {state=3;}

  else if(V >= 3.595 && V < 3.676) // seg-4
    {state=4;}

  else if(V >= 3.676 && V < 3.739) // seg-5
    {state=5;}

  else if(V >= 3.739 && V < 3.967) // seg-6
   {state=6;}

  else if(V >= 3.967 && V < 4.039) // seg
```

```
    {state=7;}

  else  if(V >= 4.039 && V < 4.132) //
    {state=8;}

switch (state)
{
 case 1:
    SOC = (26.55*(V)) - 88.6;
    flag==1;
    break;
case 2:
    SOC = (125*(V)) - 431.1;
        flag==1;
     break;
case 3:
  //if(V >= 3.508 && V < 3.595) // seg-3
    SOC = (149*(V)) - 516.1;
        flag==1;

        break;
case 4:
   //if(V >= 3.595 && V < 3.676) // seg-4
    SOC = (344*(V)) - 1225.0;
        break;
case 5:
   //if(V >= 3.676 && V < 3.739) // seg-5
    SOC = (229.5*(V)) - 800.9;
        flag==1;

        break;
case 6:
   //if(V >= 3.739 && V < 3.967) // seg-6
    SOC = (111.9*(V)) - 359.9;
        flag==1;

        break;
case 7:
   //if(V >= 3.967 && V < 4.039) // seg
    SOC = (104.8*(V)) - 332.0;
        flag==1;

        break;
case 8:
   //if(V >= 4.039 && V < 4.132) //
    SOC = (90.61*(V)) - 274.7;//
        flag==1;

        break;
default:
SOC=0;
Serial.println("N/A");
    delay(1000);
}
```

```
}while(SOC<=0);

  //Serial.print("Intial SOC is: ");
  Serial.println(SOC);


}
void loop(){

// Voltage is Sensed 1000 Times for precision

   for(i=0;i<n+1;i++)
    {
   //Serial.print("Raw Value = "); // shows the measured voltage
//Serial.println(analogRead(A0));//Current Sensor
for(int i = 0; i < 1000; i++) {
Vc = (Vc + (0.00488758553 * analogRead(A0))); // (5 V / 1024 (Analog) = 0.0049) which converter Measur
delay(1);
}
Vc = Vc /1000;
//Serial.print("Voltage of current sensor (V) = "); // shows the measured voltage
//Serial.println(V); // the2after voltage allows you to display 2 digits after decimal point
Current = (V -2.51)/(0.185); // Sensed voltage is converter to current
Current+=0.04;
//Serial.print(" Current (A) = "); // shows the voltage measured
//Serial.println(Current,2); // the2after voltage allows you to display 2 digits after decimal point
  f=f+Current;
  f=(f/n);    //current
  //Serial.print("Average Current: ");
  //Serial.println(f);
  Q[i]=((f*10)/3600);  //InstantaneousmAH
  //Serial.print("Charge at an instant: ");
  //Serial.println(Q[i]);
  SOC=(SOC-(Q[i]*100/2.2));
  //SOC=19;
  //Serial.print("Current SOC: ");
  Serial.println(SOC);
      n=n++;
C+=Q[i];
//Serial.print("Total Charge:");
//Serial.println(C);
BTserial.print(SOC);

BTserial.print(";");
 delay(10000);


    }
    }
```