Development and Performance Analysis of Solar Electric Vehicle

A Thesis

Submitted as the Partial Fulfillment for the Degree of

Bachelor of Science in Electrical and Electronic Engineering

Department of Electrical and Electronic Engineering

BRAC University

Dhaka-1212, Bangladesh

Declaration

We hereby declare that the project titled "Development and Performance Analysis of a Solar Powered Electric Vehicle" submitted to BRAC University, Department of Electrical and Electronic Engineering is our thesis for the fulfillment of Bachelors of Science in Electrical and Electronics Engineering. This is our own work and it has not been submitted elsewhere for the award of any other degree or any other publication.

Date:

Supervisor

Dr. Md. Mosaddequr Rahman

Shoummo Ahmed

Sayeef Asrar

Rizvan Nahif

Md. Billal Hossen

Chowdhury Rabib Rubayet

Acknowledgement

We are immensely thankful to our thesis supervisor Dr.Mosaddequr Rahman, Professor of Electrical and Electronic Engineering Department, BRAC University for his continuous guidance and suggestions in our thesis. We would not have been able to move ahead with our thesis without his valuable insight. We are also thankful to Imran Bin Jafar and Abdullah Al Mahmud, Research Assistants, Electrical and Electronic Engineering Department, BRAC University who have also helped us with valuable instructions and suggestions.

Abstract

The objective of this Thesis paper is to document the various results obtained through tests and experiments in order to deduce the practicality of the "Solar Powered Electric Vehicle" in Bangladesh, especially in urban areas like Dhaka for daily commute. The system design of the vehicle utilizes solar power obtained and converted to electrical energy using solar panels which then charges the lead acid battery through a charge controller. The vehicle runs on a motor powered by the battery storage unit via a motor driver. The paper looks into how the car is developed, battery modeling to figure out the discharging characteristics and results from charging the batteries using solar panels. The paper also looks into experiments done on electromagnetic interferences that affect any devices in the car. In addition, results and interpretation of data recorded during various test drives are included for the readers to figure out the effectiveness of the "Solar Powered Electric vehicle" in everyday life.

Table of Contents

Declaration 2

Acknowledgement 3

Abstract 4

Chapter 1: Introduction 13

1.1 Motivation 13

1.1.1 Pollution: 13

1.1.2 Fossil Fuel: 14

1.1.3 Solar Power: 14

1.2 Project Objective 14

1.3 Project Scope 15

1.4 Project Overview 16

Chapter 2: System Description and Literature Review 17

2.1 Solar Panels: 17

2.2Lead Acid Battery 18

2.2.1 Electrochemistry: 19

2.2.3 Discharge: 19

2.2.4 Charge: 20

2.2.5 Charging Stages: 20

2.2.6 Advantages & Disadvantages of Lead-Acid Battery: 21

2.3 Charge Controller 22

2.3.1 AC plug in Charger Controller 22

2.3.2 Solar Panel Charge Controller 22

2.4 DC Motor 22

2.4.1 Series Wound Brushed DC Motor 22

2.4.2 Operating Principle of Brushed DC Motor 23

2.4.3 Speed Control of a DC motor 23

2.4.4 Torque-Speed Characteristics of a Series DC Motor 25

2.4.5 Specifications of the Series Wound DC Motor 25

2.4.6 Advantage and Disadvantage of Series Wound DC Motor 25
2.5 Braking System 26
2.6 Accelerator 27
2.7 Working Principle of Differential Gear 28
2.7.1 Main Mechanisms: 28
2.7.2 Differential Parts... 29
2.7.3 Power Flow... 29
2.7.4 Hypoid Gears.. 30
2.7.5 Other Functions of Differential Gear: 30
2.7.6 Ring and Pinion problems: 30
2.8 Working Principle of Combination Switch... 31
Chapter 3: Data Analysis and Results... 34
3.1: Solar Charging 34
3.1.1 Solar Panel/Photovotaic Terminology:.. 34
3.1.2 System Model 34
3.1.3Battery Model:.. 35
3.1.4 Battery Charging... 36
3.1.5 Experiment on Charging a Lead-Acid Battery by Solar Panels. 36
3.2 Battery Model... 57
3.2.1 Battery Condition Parameters:.. 57
3.2.2 Methodology:.. 58
3.2.3 Thevenin Battery Model with Dynamic Response:.. 58
3.2.4 Experimentof BatteryDischargingand DataAnalysis.. 60
3.3 Battery State of Charge Estimation... 68
3.3.1 Battery Charging at Constant Current 68
3.3.2 Battery Discharging at Constant Current.. 71
3.4 Battery Ageing Effect Based On Specific Gravity Test... 74
3.4.1 Background... 74
3.4.2 Estimation of Specific Gravity and State of Charge: 75
3.4.3 Experiment on Electrochemical Model to Determine Battery Health and Battery Ageing 78

3.4.4 Data Analysis and Result 79
3.5 Electromagnetic Interferences (EMI) 84
3.6 Performance Analysis 88
3.6.1 Field Test without Interval (day 1) 88
3.6.2 Field Test with Interval (day 2) 89
3.6.3 Analysis of Field Test Data 93
3.6.4 Result of field tests 97
Chapter 4: Vehicle Performance at a Glimpse 100
Chapter 5: Limitations and future work 101
Chapter 5: Conclusions 103
Bibliography 104

List of Tables

Table 1.1:(Proc. of International Conference on Environmental Aspects of Bangladesh……..13

Table 2.1: Rating of Solar Panel………………………………………………………….. 18

Table 3.1 :BCI (Battery Council International) standard for SOC estimation.(Buchmann)……74

List of Figures

Figure 1.1: Distance from Hazrat Shahjalal International Airport to Motijheel(Google Maps)..15

Figure 1.2: System Architecture of the Solar Electric Vehicle……………………………….16

Figure 2.1: Solar Panel Conversion system…………………………………………………..17

Figure 2.2: Lead Acid Batteries……………………………………………………………18

Figure 2.3: Lead Acid Battery Discharge Process……………………………………………19

Figure 2.4: Lead Acid Battery Charge Process……………………………………………….20

Figure 2.5: Lead Acid Battery Charging Stages……………………………………………...21

Figure 2.6: Equivalent Circuit of a series DC motor…………………………………………22

Figure 2.7: Operating principle of DC Motor…………………………………………………...23

Figure 2.8: Ideal torque-speed characteristics of a series DC motor……………………………25

Figure 2.9: Master Cylinder Braking System……………………………………………...26

Figure 2.10: Working Principle of the accelerator……………………………………...27

Figure 2.11: Throttle Potentiometer…………………………………………………………….28

Figure 2.12: Differential Gear……………………………………………………………..29

Figure 2.13: High quality Mitsubishi combination switch……………………………………...29

Figure 2.14: High quality Mitsubishi combination switch……………………………………...31

Figure 2.15: Side view of the combination switch used in the car……………………………...32

Figure 3.1 : Photovoltaic Cell Model……………………………………………………...34

Figure 3.2: Circuit Diagram of Battery Charging by Solar Panel……………………………….36

Figure 3.3: Solar Charging Battery Voltage vs. Time (30 March, 2015) ………………………37

Figure 3.4: Solar Charging Battery Voltage vs. Time (30 March, 2015)……………………….38

Figure 3.5: Solar Charging Battery Voltage vs. Time (2 April, 2015)………………………….38

Figure 3.6: Solar Charging Battery Voltage vs. Time (4 April, 2015)………………………….39

Figure 3.7: Solar Charging Battery Voltage vs. Time (5 April, 2015)………………………….39

Figure 3.8: Solar Charging Battery Voltage vs. Time (6 April, 2015)………………………….40

Figure 3.9: Solar Charging Battery Voltage vs. Time (8 April, 2015)………………………….40

Figure 3.10: Solar Charging Battery Voltage vs. Time (9 April, 2015)………………………...41

Figure 3.11: Solar Charging Panel Voltage vs. Time (30 March, 2015)………………………..42

Figure 3.12: Solar Charging Panel Voltage vs. Time (31 March, 2015)………………………..42

Figure 3.13: Solar Charging Panel Voltage vs. Time (2 April, 2015)…………………………..43

Figure 3.14: Solar Charging Panel Voltage vs. Time (4 April, 2015)…………………………..43

Figure 3.15: Solar Charging Panel Voltage vs. Time (5 April, 2015)…………………………..44

Figure 3.16: Solar Charging Panel Voltage vs. Time (6 April, 2015)…………………………..44

Figure 3.17: Solar Charging Panel Voltage vs. Time (8 April, 2015)…………………………..45

Figure 3.18: Solar Charging Panel Voltage vs. Time (9 April, 2015)…………………………..45

Figure 3.19: Solar Charging Battery Current vs. Time (30 March, 2015)……………………...46

Figure 3.20: Solar Charging Battery Current vs. Time (31 March, 2015)……………………...46

Figure 3.21: Solar Charging Battery Current vs. Time (2 April, 2015)………………………...47

Figure 3.22: Solar Charging Battery Current vs. Time (4 April, 2015)………………………...47

Figure 3.23: Solar Charging Battery Current vs. Time (5 April, 2015)………………………...48

Figure 3.24: Solar Charging Battery Current vs. Time (6 April, 2015)………………………...48

Figure 3.25: Solar Charging Battery Current vs. Time (8 April, 2015)………………………...49

Figure 3.26: Solar Charging Battery Current vs. Time (9 April, 2015)………………………...49

Figure 3.27: Battery charged on 30 March, 2015……………………………………………….50

Figure 3.28: Battery charged on 31 March, 2015……………………………………………….51

Figure 3.29: Battery charged on 2 April, 2015………………………………………………….52

Figure 3.30: Battery charged on 4 April, 2015………………………………………………….53

Figure 3.31: Battery charged on 5 April, 2015………………………………………………….54

Figure 3.32: Battery charged on 6 April, 2015………………………………………………….54

Figure 3.33: Battery charged on 8 April, 2015………………………………………………….55

Figure 3.34: Battery charged on 9 April, 2015………………………………………………….55

Figure 3.35: Totalbattery charged over time…………………………………………………...56

Figure 3.36: Thvenin Battery Model……………………………………………………………59

Figure 3.37: Battery Discharging Circuit Setup………………………………………………...60

Figure 3.38: (V_{OC}- V_t)-I characteristics at 88.38% SOC……………………………………62

Figure 3.39: (V_{OC}- V_t)-I characteristics at 83.38% SOC……………………………………62

Figure 3.40: (V_{OC}- V_t)-I characteristics at 65.88% SOC……………………………………63

Figure 3.41: (V_{OC}- V_t)-I characteristics at 55.88% SOC……………………………………63

Figure 3.42: (V_{OC}- V_t)-I characteristics at 45.88% SOC……………………………………….64

Figure 3.43: (V_{OC}- V_t)-I characteristics at 30.88% SOC……………………………………….64

Figure 3.44: (V_{OC}- V_t)-I characteristics at 10.88% SOC……………………………………….65

Figure 3.45: Varying Internal Resistance with SOC relationship………………………………66

Figure 3.46: Varying Internal Resistance with SOC relationship………………………………67

Figure 3.48: Battery charging at 3A current(constant)…………………………………………68

Figure 3.49: Battery charge……………………………………………………………………..69

Figure 3.50: Terminal Voltage Vs. Time while charging……………………………………….69

Figure 3.51: SOC Vs. V_{OC} while charging……………………………………………………...70

Figure 3.52: Battery discharging at constant current (4A)……………………………………...71

Figure 3.53: Battery discharge…………………………………………………………………..71

Figure 3.54: Terminal Voltage Vs. Time………………………………………………………..72

Figure 3.55: DOD Vs. V_{OC} while discharging…………………………………………………..72

Figure 3.56: Specific Gravity Test Procedure…………………………………………………..78

Figure 3.57: Specific Gravity of Battery Cells at SOC 62.76%..79

Figure 3.58: Average Specific Gravity of Battery Cells at SOC 62.76%....................................80

Figure 3.59: Specific Gravity of Battery Cells at SOC 67.03%..81

Figure 3.60: Average Specific Gravity of Battery Cells at SOC 67.03%...................................82

Figure 3.61: Average Specific Gravity with increased SOC……………………………………83

Figure 3.62: Magnetic Field Strength vs. Current………………………………………………85

Figure 3.63: Magnetic Field Strength Vs. Velocity……………………………………………..86

Figure 3.64: Coaxial Cable……………………………………………………………….......87

Figure 3.65: Voltage and Current trend in 1st Field Tes……………………….....…………88

Figure 3.66: Voltage and Current trend of in Lap 1 ..……………………………………………89

Figure 3.67: Voltage and Current trend in Lap 2 ……………………………………………..90

Figure 3.68: Voltage and Current trend in Lap 3 ...…………………………………………..90

Figure 3.69: Voltage and Current trend in Lap 4 ……………………………………………….....91

Figure 3.70: Voltage and Current trend in Lap 5 …………………………………………………91

Figure 3.71: Voltage and Current trend in Lap 6 …………………………………………………92

Figure 3.72: Voltage and Current trend in Lap 7 …………………………………………………92

Figure 3.73: Batterydischarge in field test without interval ……………………………...93

Figure 3.74: Battery discharge in lap 1 of field test ………………………………………94

Figure 3.75: Battery discharge in lap 2 of field test ………………………………………94

Figure 3.76: Battery discharge in lap 3 of field test ………………………………………95

Figure 3.77: Battery discharge in lap 4 of field test ………………………………………95

Figure 3.78: Battery discharge in lap 5 of field test ………………………………………96

Figure 3.79: Battery discharge in lap 6 of field test ………………………………………96

Figure 3.80: Battery discharge in lap 7 of field test ………………………………………97

Chapter 1: Introduction

Ever since the dawn of civilization, the human beings have used various forms of energy sources to make their life easier. The fossil fuel was first used commercially in the 18th century and has been the primary source of energy production ever since. The ease of extraction and utilization of fossil fuel means that its use has risen exponentially. The entropy curve shows we need fossil fuel for mass level energy generation so far. The fossil fuel however is not inexhaustible, and over the years as its use has increased it has had a devastating impact on the environment. Bangladesh being an over populated country; energy production from renewable energy is limited.So, using the renewable energy sources as an auxiliary system might save the fossil fuels for future and can be one of the great leap towards a better future.

1.1 Motivation

The idea of renewable energy is not new but the need for it now is greater than ever before. Fossil Fuel is limited and we will run out of it in the near future. To make matters worse pollution from fossil fuels has now reached an alarming level. Introducing solar powered Electric vehicle to replace conventional gasoline powered car has two-fold advantages, Firstly, solar power is renewable and abundant and secondly, an electric vehicle powered by solar would have zero emission

1.1.1 Pollution: According to WHO Bangladesh is 4th among 91 countries with the worst urban air quality resulting from increased motorization and poor condition of vehicles. The levels of harmful gases and suspended particulate matter in Dhaka city are much higher than the amended Bangladesh standards. The Table 1.1 on the next page shows Ambient Air Quality of Dhaka city.

Location	CO ($\mu g/m^3$)	NO_X ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	CO_2 (ppm)
Mohakhali	2519	376	Trace	547.66	435
Farmgate	7730	752	Trace	289.92	590
Mogbazar	5726	339	Trace	383.53	475
Sonargaon	3435	75	Trace	161.93	500
Science Lab	5726	113	Trace	167.64	500
Note: Amended Bangladesh Standards [ECR, 2005] SO_2: 365 µg/m3 (24-hour average) CO: 10000 µg/m3 (8-hour average) NOx: 100 µg/m3 (Annual) PM10: 150 µg/m3 (24-hour average)					

Table 1.1:(Proc. of International Conference on Environmental Aspects of Bangladesh (ICEAB10), Japan, Sept. 2010. PA02 Air Pollution Aspects of Dhaka City.)

Despite the fact that CO and SO_2 levels have fallen since the introduction of CNG run vehicles, Dhaka's air quality is still poor and only going to deteriorate in the future. Introduction of Solar Electric Vehicle to replace the combustion engine vehicle, therefore, could greatly improve the air quality of Dhaka.

1.1.2 Fossil Fuel: According to Bangladesh Petroleum Corporation (BPC)from 1999 to 2006 demand for petroleum in the transport sector has increased by 5.09% from 1.56 million MT to 2.03 million MT. In addition, the demand for Compressed Natural Gas (CNG) has risen from 0.23 billion cubic feet (BCF) in 2002-03 to 11.99 BCF in 2006-07. Consumption of fossil fuel will increase further in the near future. To reduce our dependency on fossil fuel we must look for alternative and renewable sources of energy immediately.

1.1.3 Solar Power: We are running out of fossil fuel and at the same time its price is rising. Out of all the available renewable sources of energy, the one that is most abundant and comparatively easier to harness is solar power. Average intensity of solar power that reaches earth is $1367W/m^2$. We use very little of this vast source of energy, but as the efficiency of the solar panels is increasing; people are looking at it more as a viable energy source. Many household have already implemented solar panels to meet their electricity needs. Solar power can potentially be used to run electric vehicles as well.

Numerous researches around the world are now directed towards development of renewable energy and cutting emission. Our work on solar car is aimed at trying to bridge the gap of practicality between an electric car and conventional gasoline vehicle as well as to see if the solar electric vehicle is in fact a feasible alternative in Bangladesh.

1.2 Project Objective

The main objective of constructing the solar powered electric vehicle is to develop a21stcentury vehicle which is environment friendly with low maintaining cost. Along with the high fuel price for cars which are mostly used by the office commuters of not only Dhaka city but also the whole world, the new threatening topic of climate change should also be taken into account. By considering all these facts using a solar powered vehicle is the best option, which provides energy at low cost and also does not pollute the environment like the CNG or petroleum run vehicles.

The Solar Electric Vehicle is developed so that it can travel a round trip distance from Hazrat Shahjalal International Airport to Motijheel of Dhaka city which is the maximum distance covered by city commuters (around 32km). The Solar Electric Vehicle must cover this distance to be considered a feasible alternative to existing fossil fuel powered vehicles, at the same time, minimizing the cost by using the best found renewable energy which would drastically improve the air in Dhaka city.

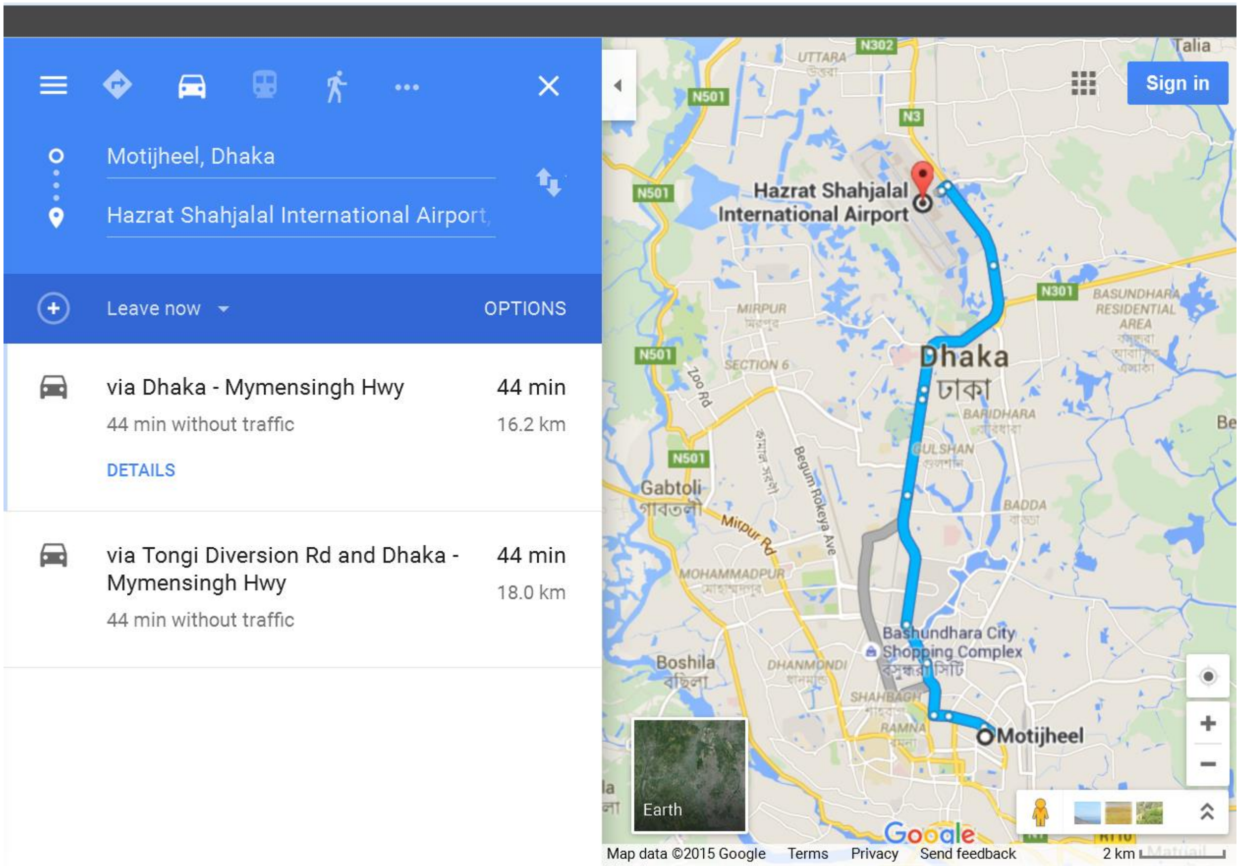


Figure 1.1: Distance from Hazrat Shahjalal International Airport to Motijheel (Google Maps)

1.3 Project Scope

We wanted to develop an Electric Vehicle which can use solar energy as well as use the grid if necessary as a source of energy. To achieve our afore-mentioned objective of 32km round trip in Dhaka city, solar charging experiment is done to calculate the charging rate of the battery using solar power to figure out its contribution as power source for the vehicle. Battery model is done to analyze the existing condition of the battery. Several field tests will also be conducted and compared with the battery model to calculate the realistic range of the vehicle from full charge to full discharged state. Embedded system is also to be developed to determine the instantaneous state of charge as well as the speed and the current flowing to the motor.

1.4 Project Overview

The system of solar powered vehicle was designed in such a way that the DC motor can use the stored power in the lead acid battery to run the vehicle. The motor driver circuit was implemented in the system to control the speed of the vehicle by pulse width modulation technique. On the other hand, the storage unit or battery can be charged through solar panels or from grid. For both of the cases, charge controller was used to obstruct over charge or over discharge of battery; at the same time to detect the state of battery so that it can feed back a pulse width modulated (PWM) flow of charge from panel to battery. The vehicle has all the mechanical components of a basic vehicle except the combustion engine and gearbox.

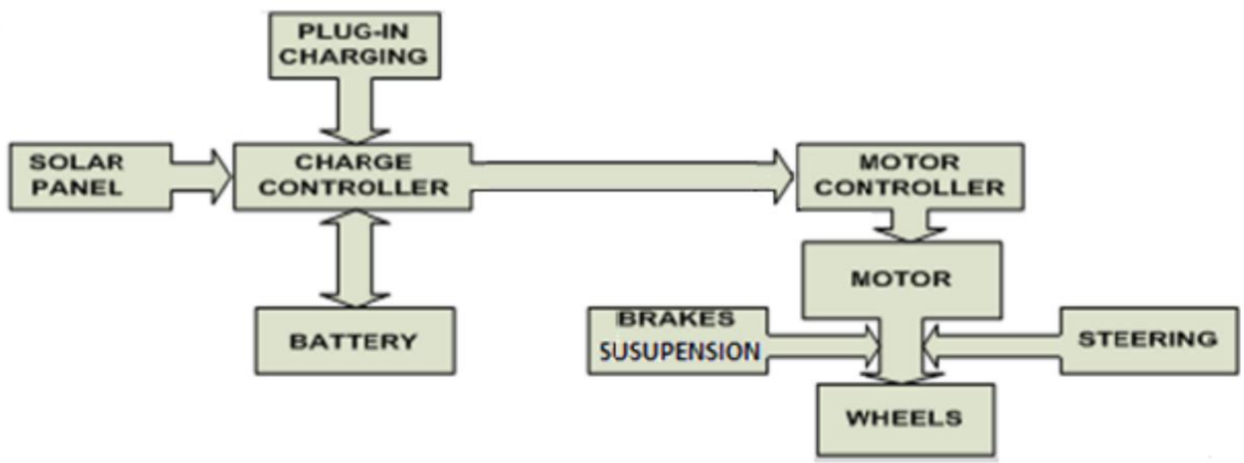


Figure 1.2: System Architecture of the Solar Electric Vehicle

Chapter 2: System Description and Literature Review

2.1 Solar Panels:

Solar panel converts radiated energy in the form of light photons produced by the Sun into electrical energy. These panels are composed of silicon based semiconductors. When the radiation comes in contact with the silicon atoms the photons are absorbed and the electrons are separated from the rest of the atoms and this free electrons carries the duty to carry and create electric current and the electricity which is generated here is mostly stored in batteries for further usage.

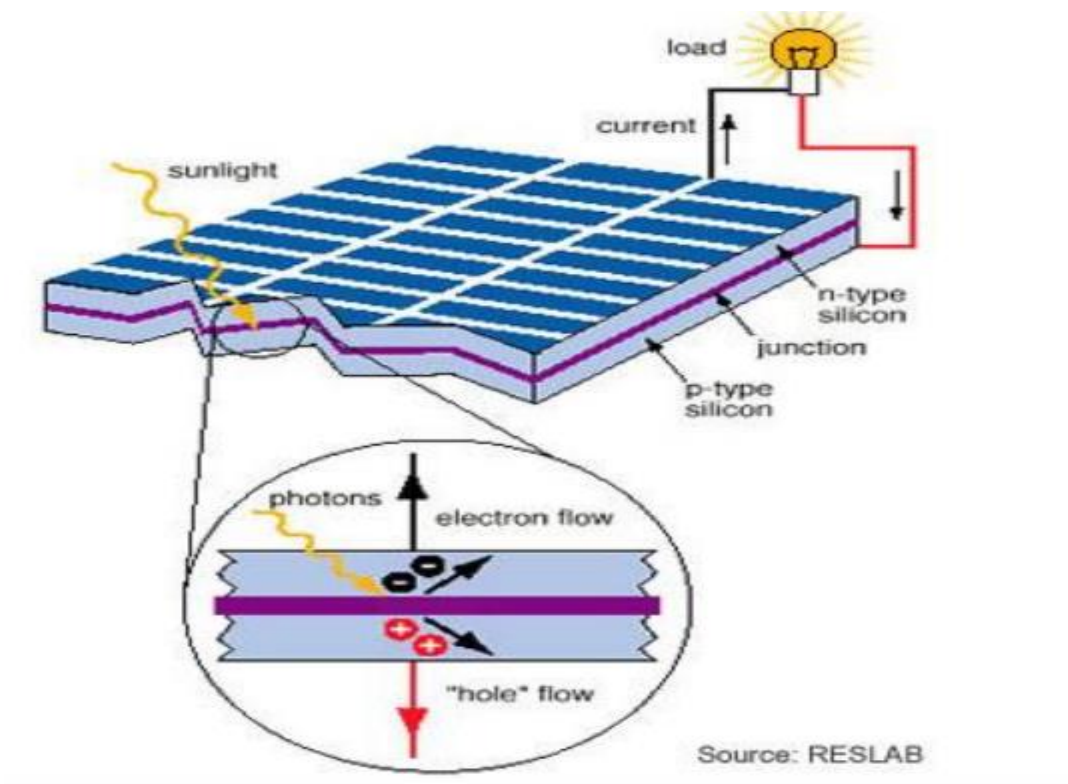


Figure 2.1: Solar Panel Conversion system

Among the three types of solar panels i.e. Monocrystalline Silicon, Polycrystalline silicon, Amorphous Silicon 'thin film' modulethe project was designed to use monocrystalline silicon solar panel. Monocrystalline solar panels are the most effective and efficient among all three. Each of its module is made from a single silicon crystal.

Rating of the solar panel used in this project is given below (provided from company):

50 Watt Monocrystalline Bendable	Photovoltaic Module
Max Power(P_{max})	50W
Max Power Voltage(V_{mp})	17.6V
Max Power Current(I_{mp})	2.84A
Open Circuit Voltage(V_{OC})	21.2V
Short Circuit Current(I_{SC})	3.05A
Maximum System Voltage	600V
Series Fuse Rating	10A
Temperature Co-efficient	
Power	-0.38%/^{o}C
Voltage	-60.8mV/^{o}C
Current	2.2mA/^{o}C
Cell Efficiency	21.5%
Number of Cells in Series	32
Max Power Tolerance	±5%
Weight	0.7kg
Dimension	545*535*3

Table2.1: Rating of Solar Panel

2.2Lead Acid Battery

A Lead-acid battery consists of flat lead plates drenched in a pool of electrolyte. Although it has changed a little since the invention of it by ‘GastonePlante` in 1859, it is still vastly used for its ability to supply high current required by the automobile starter motors at low cost.

Figure 2.2: Lead Acid Batteries

2.2.1 Electrochemistry: These batteries are composed of lead dioxide (PbO_2) cathode, sponge metallic lead(Pb) anode and sulfuric acid solution (35% of H_2SO_4& 65% of H_2O) as electrolyte. In case the electrodes come into contact with each other through physical movement of the battery or through changes in thickness of the electrodes, an electrically insulating but chemically permeable membrane separates the two electrodes, which also prevents electrical shorting through the electrolyte. Lead-acid batteries store energy by a reversible chemical reaction. So it operates in a constant process of charge and discharge.

$$PbO_2 + Pb + 2H_2SO_4 \leftrightharpoons 2PbSO_4 + 2H_2O$$

2.2.3 Discharge: Discharging a battery causes the formation of lead sulfate crystal as both the positive and negative terminals and the release of electrons due to the change in valance charge of the lead.The sulfate is supplied by the electrolyte and as a result the electrolyte becomes less concentrated.At full discharge the two electrodes are the same material with nochemical potential or voltage between them.Practically,however,discharging stops at a cutoff voltage long before this point.

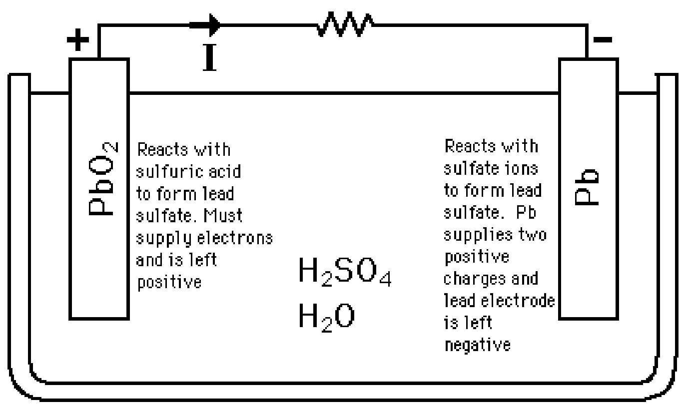


Figure 2.3: Lead Acid Battery Discharge Process

The chemical reaction takes place while discharging a battery is given below,

$$PbO_2 + 2H \rightarrow PbO + H_2O$$

$$PbO + H_2SO_4 \rightarrow PbSO_4 + H_2O$$

$$PbO_2 + H_2SO_4 + 2H \rightarrow PbSO_4 + 2H_2O$$

A troublesome feature of the lead-acid battery is it gets discharged if not used at a regular basis. The rate increases at high temperatures and decreases at low temperatures.

2.2.4 Charge: Lead-acid battery uses the Constant Current Constant Voltage(CC/CV) charge method. Until the upper voltage limit is reached a regulated current raises the terminal voltage and when it reaches then the current drops due to saturation. For the work to be done properly lead-acid batteries are needed to be charged in three stages, which are

1. Constant Current Charge
2. Topping Charge
3. Float Charge.

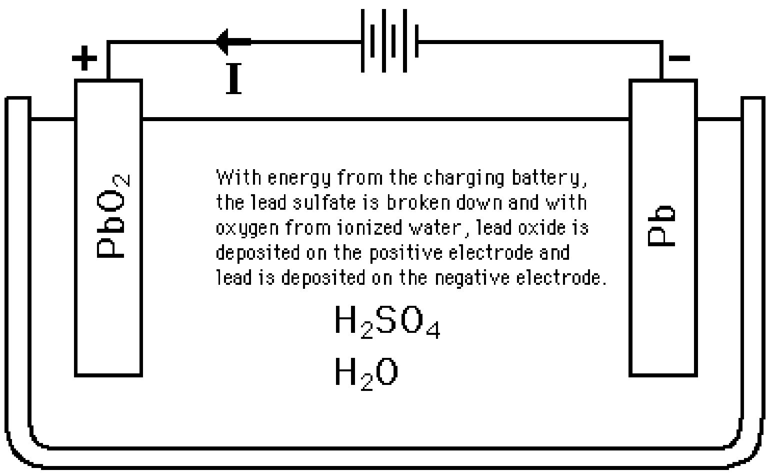


Figure 2.4: Lead Acid Battery Charge Process

While charging the battery, the following reaction takes place,

$$PbSO_4 + 2H \rightarrow H_2SO_4 + Pb$$

$$PbSO_4 + 2H_2 + SO_4 \rightarrow Pb0_2 + 2H_2SO_4$$

2.2.5 Charging Stages:

1. *The Constant-Current Charge:* The bulk of the charge and takes up roughly half of the required charge time. The constant-current charge apparently charges 70% the battery.
2. The *Topping Charge:* continues at a lower charge current and provides saturation. The topping charge is necessary for the well-being of a battery. The rest 30% of charge is done on this process with slower topping charge which approximately takes 7-10 hours.
3. The *Float Charge:* compensates for the loss caused by self-discharge.

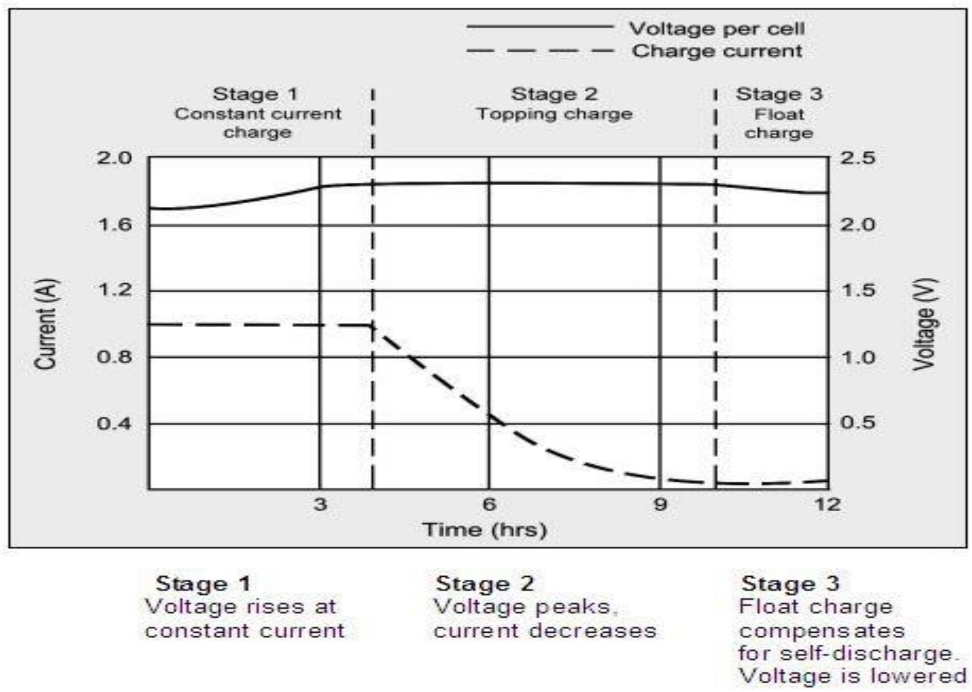


Figure 2.5: Lead Acid Battery Charging Stages

Battery being fully charged the current drops to a pre-determined level or levels out in stage the float voltage must be reduced at full charge.

.

2.2.6 Advantages & Disadvantages of Lead-Acid Battery:

Advantages:

- Inexpensive and simple to manufacture; low cost per watt-hour.
- Low self-discharge; lowest among rechargeable batteries.
- High specific power, capable of high discharge currents.
- Good low and high temperature performance.

Disadvantages:

- Low specific energy; poor weight-to-energy ratio.
- Slow charge; fully saturated charge takes 14 hours.
- Must be stored in charged condition to prevent sulfating.
- Limited cycle life; repeated deep-cycling reduces battery life.
- Flooded version requires watering.

2.3 Charge Controller

2.3.1 AC plug in Charger Controller

In addition to solar charging, the vehicle can also be charged from AC sources. The charge controller contains a full wave rectifier circuit to convert the AC to DC to charge the batteries. The charge controller also monitors the battery voltage and adjusts the current flow according to its charging state. It also protects the battery from over charging.

2.3.2 Solar Panel Charge Controller

The current supplied from the solar panels fluctuate based on sunlight. The current flowing from the panels also needs to be adjusted before it is used to charge the batteries. This charge controller also takes the state of charge (SOC) of the battery into consideration to regulate the current flow.

2.4 DC Motor

For our thesis we selected the Series Wound Brushed DC Motor. In this type of motor the same current flows through the stator and the rotor. This type of motor has high initial torque which is ideal to move the vehicle at the beginning. In addition, speed adjustment of this type of motor can be easily achieved.

2.4.1 Series Wound Brushed DC Motor

The series wound DC motor consists of field windings and armature windings connected in series therefore the current is same in both. Using Kirchhoff voltage law, the equation for the motor is as follows.

$$V_t = E_a + I_a(R_a + R_s$$

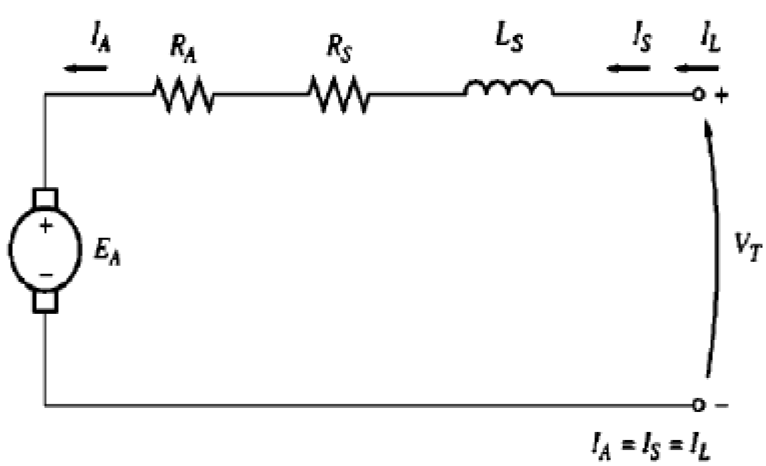


Figure 2.6: Equivalent Circuit of a series DC motor

2.4.2 Operating Principle of Brushed DC Motor

A DC motor is a device that converts electrical energy (direct current) into mechanical energy. It contains a commutator attached to an armature carrying current supplied from a DC source through brushes placed within the north and south poles of a permanent magnet or electro-magnet.

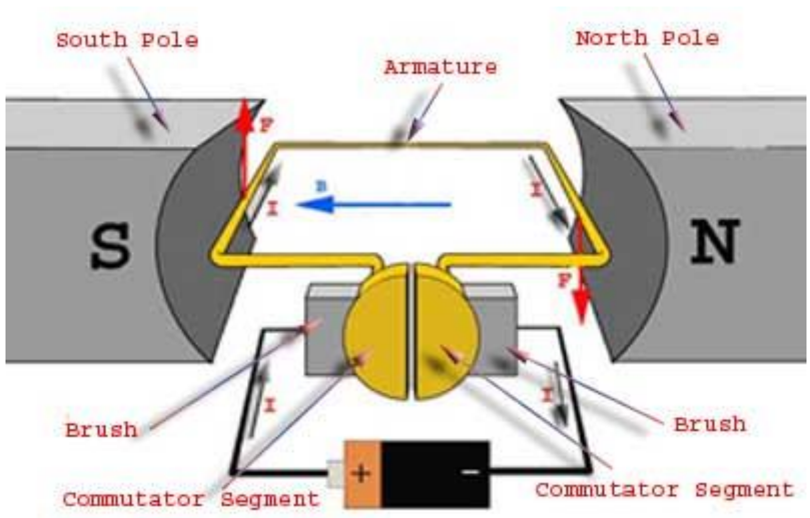


Figure 2.7: Operating principle of DC Motor

The magnetic field of the magnets and that of the current carrying wires in the coil reacts to produce a force on each armature in different directions, which causes the coil to rotate.

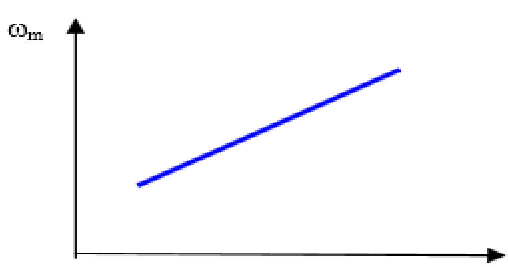
2.4.3 Speed Control of a DC motor

The expression for speed in a dc motor is given by:

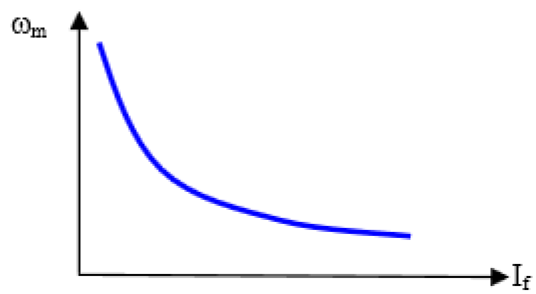
$\omega_m = (V_T - I_a R_a)/K\phi$

From the expression therefore we can see that the speed (ω_m)of the motor can be controlled in 3 methods:

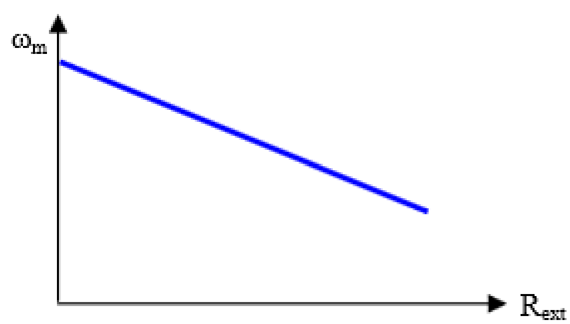
1. **Armature voltage control** (By varying V_T): Increase in terminal voltage increases the speed.



2.Field Control (By varyingϕ): Speed is inversely proportional to flux which is proportional to current in the field circuit. A variable resistor is used to vary the current in the field circuit.



3. Armature resistance control (By varying R_a): A variable resistor is added in series to the armature circuit. Increasing the resistance decreases the speed.



Note: For Series motor, the speed is usually controlled by changing an external resistance in series with the armature. The other two methods described above are not applicable to DC series motor speed control.

2.4.4 Torque-Speed Characteristics of a Series DC Motor

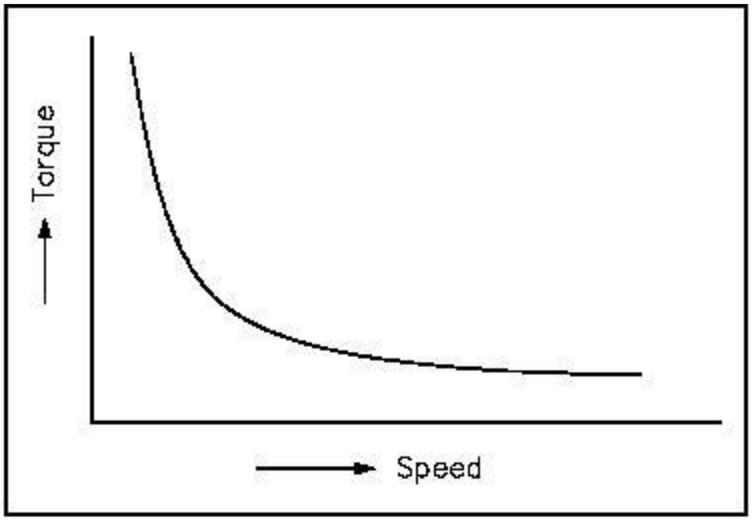


Figure 2.8: Ideal torque-speed characteristics of a series DC motor

The torque-speed characteristics shown in figure 2.9 shows that the torque of a series DC motor is very high at low speed and vice versa. This makes this motor ideal for our vehicle as there are no gears and a large torque is required to make the vehicle moving.

2.4.5 Specifications of the Series Wound DC Motor

1) Rated Power: 1.1KW
2) Rated Voltage: 60V
3) Rated Current: 22A
4) Rated speed : 3600 rpm

2.4.6 Advantage and Disadvantage of Series Wound DC Motor

Advantages:

1) Simple (no motor controller needed)
2) Low cost

Disadvantages:

1) Less efficient
2) Causes electrical and electromagnetic noise
3) Regular maintenance required as brush and commutator wear out.

2.5 Braking System

The dual circuit system is commonly used in master cylinder brakes for safety so that if there is a leak in one of the system the other can stop the car. The 'return springs' brings back the piston to original position. When the pedal is pressed the pushrod moves forward in both the circuits and hydraulic pressure is applied to both the wheel cylinders. The first circuit return spring is lighter than the second circuit which means that initially the pressure does not build up in the secondary circuit, it does when pedal is pushed further. As the second circuit rear seal moves forwards, fluid must pass down its equalization port to prevent suction from forming behind the rear seal. When the pedals are released the return spring pushes everything back. The seals uncover the intake ports which causes fluid to escape into the reservoir. This happens as the fluid expands due to heating when pedal is pressed.

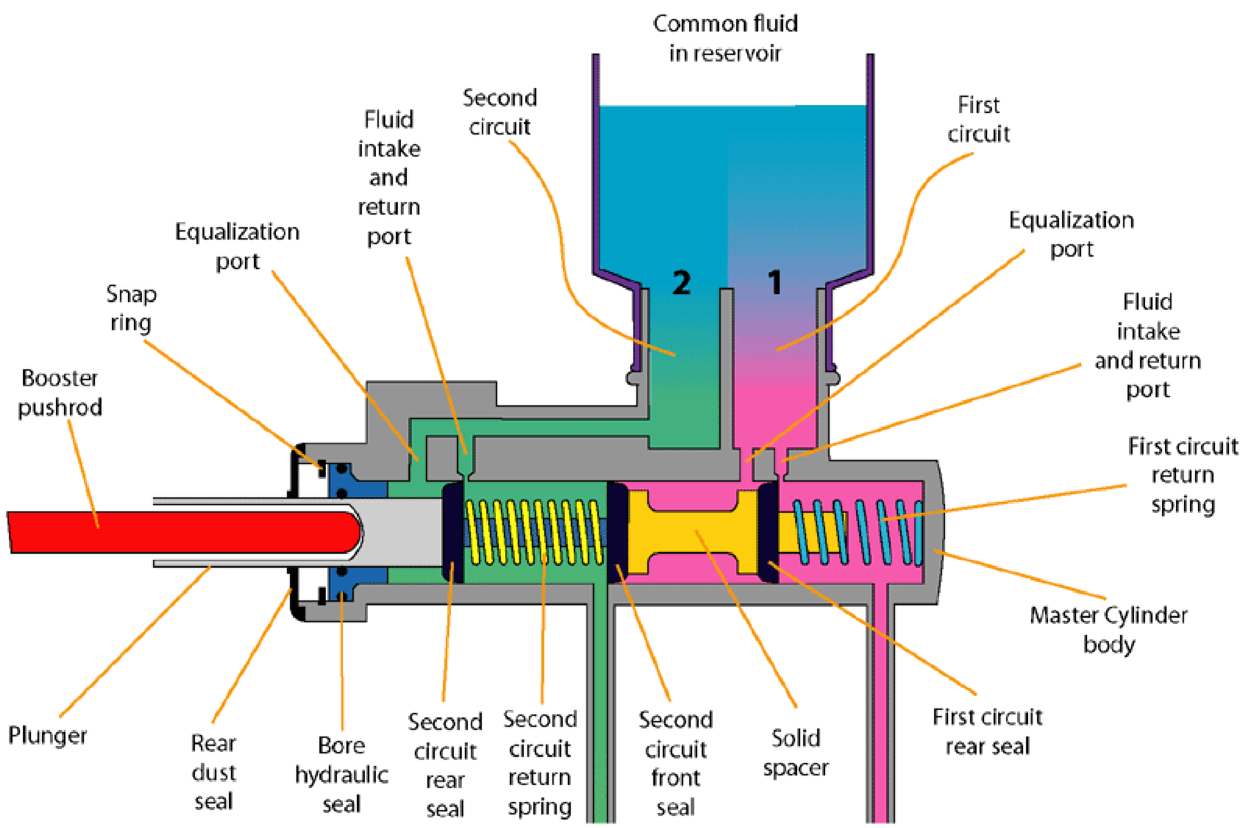


Figure 2.9: Master Cylinder Braking System

2.6 Accelerator

Accelerator is the part of an electric car which controls the acceleration of the car by controlling the power supplied to the motor. When the driver hits the acceleration pedal or throttle pedal increases the power supplied to the motor resulting motor rotation and acceleration.

The throttle pedal or accelerator pedal of an electric car is connected to a potentiometer with a wire which is connected to the motor through the controller.

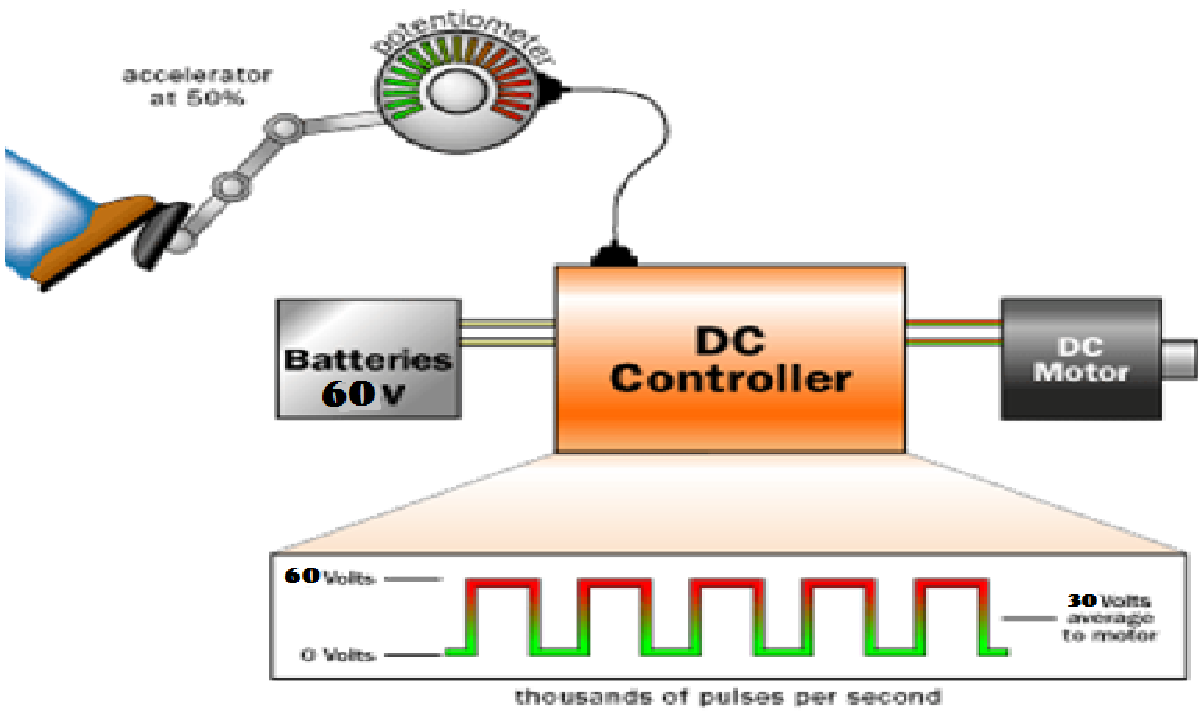


Figure 2.10: Working Principle of the accelerator

The potentiometer can be used of resistance 1k-10k. Generally the potentiometer is of resistive elements. This type of potentiometer is enclosed, dust and waterproof. There is a return spring with it to rotate it back to its maximum resistance when the pressure on the throttle pedal is released. There are two connections inside it +5V and GND and also an output signal for the controller. The wire from the pedal is connected with the lever adjusted with the shaft of the potentiometer. There are micro grooves to prevent slipping between the lever and the shaft allowing initial lever position anywhere within 360 degree. Initially when the pedal is not pressed the resistance of the potentiometer is maximum. So the controller does not allow any current flow to the motor. When the driver hits the throttle the potentiometer rotation due to the pull reduces the resistance of the potentiometer which generates current flow to the controller and the motor starts. If the pedal is pressed all the way down the resistance of the potentiometer becomes minimum allowing maximum current flow resulting maximum speed of the motor.

So, motor speed increases with the pressure on the throttle pedal. In other words, motor speed depends on the position of the throttle pedal.

Figure 2.11: Throttle Potentiometer

2.7 Working Principle of Differential Gear

The differential gear was first invented in China, in the third century A.D. After turning a car the outside wheel has to turn faster than the inside one in order to cover the greater distance. That is why two wheels are not driven at a same speed. So we need a differential gear. A car differential is a place halfway between the wheels, on either the front or both axes.

2.7.1 Main Mechanisms:

Wheels receive power from the motor via drive shaft. The power receiving wheels which make the vehicle move forward are called the drive wheels.

The main function of the differential gear is to allow the drive wheels to turn at different Rpm while receiving power from the engine. The main characteristics of differential is

- To aim the engine power at wheels.
- To transmit the power to the wheels while allowing them to rotate at differential speeds.

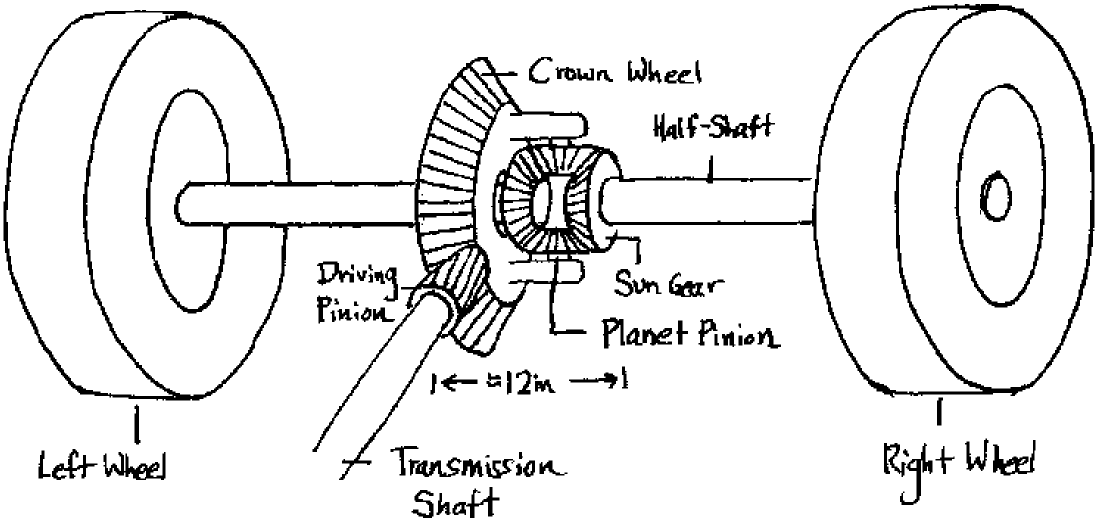


Figure 2.12: Differential Gear

The left wheel has to travel more distance compared to the right wheel. The wheels are connected using a soil shaft. The wheels would have to slip to accomplish the turn. The mechanism in a differential allows left and right wheels to turn at different Rpm, while transferring power to both the wheels.

2.7.2 Differential Parts

There are three types of gear available:

1) Pinion drive gear: Transfers power from the drive shaft to the ring gear
2) Ring gear: Transfers power to the differential case assembly
3) Side/Spider gears**:** Helps both wheels to turn independently while turning.

Differential case assembly: Holds the ring gear and other components that drive the real axle.

2.7.3 Power Flow

First drive shaft spins the pinion gear. Pinion gear turns the larger ring gear. Ring gear attached to differential case. Hence it rotates with ring gear. Then differential case spins the sun gears which are attached to the axles. Axles transfer power to the wheels.

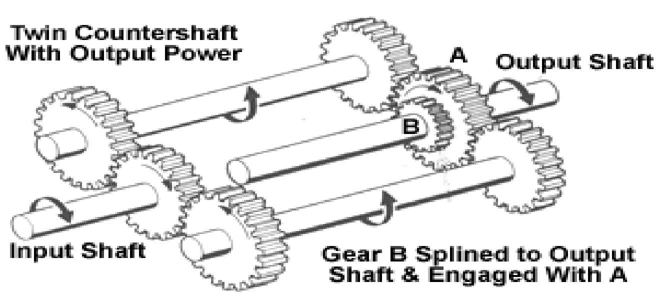


Figure 2.13: Power flow diagram

Function:

- Transfer power from drive shaft to the wheels
- Provides final gear reduction
- Splits amount of torque going to each wheels
- Allow the wheels to rotate at different speeds in turns

2.7.4 Hypoid Gears

Most of the modern differentials have hypoid gears. Pinion gear sits offset, lowered from the ring gear. It has more contact area compared to the other gear pairs and will make sure that the operating gear is smooth.

Its advantage is to improve gear life and reduces gear noise.

2.7.5 Other Functions of Differential Gear:

Apart from allowing the wheels to rotate at different Rpm differential has two more function.

1) Speed reduction: This is achieved by using ring gear which having at most 4-5 times numbers of teeth as a pinion gear. Such huge gear ratio will bring down the speed of the ring gear. Since the power flow at the pinion and ring gear are the same, such a speed reduction will result in a high torque multiplication.

2) To turn the power direction by 90 degree.

Differential problems:

Bearings: (humming sound gets louder with higher speeds)

Solutions:

- Lift the vehicle on the hoist.

- Put it in gear and spin the wheels at approx. 50 Km/hr.

- Use a stethoscope to listen for a humming sound by the carrier bearings and the pinion bearings.

2.7.6 Ring and Pinion problems:

- If backlash between ring gear and pinion gear is too great, a clunking sound can be produced, especially when an automatic transmission is shifted into gear.
- Lack of service or low fluid can cause this problem.
- Will show up as whining or howling noise that changes when going from acceleration to deceleration.

Also there is a situation where one wheel of the vehicle is on the surface with good traction and other wheel in the slippery track. In this case a standard differential will send the majority to the slippery wheel.

2.8 Working Principle of Combination Switch

A comfortable bodily condition is needed for the driver while driving. This does not just include the work of hand and feet but the work for the fingers too. After controlling the steering, pedals and shifter by using hands and legs, the controlling of the combination switch is needed to be done by the fingers and it needs to be reached easily from the driver. The combination switch is the unit which stays behind the steering wheel. From there the lights are controlled and the window wipers. Turning the headlights on and off, actuating the headlights' high beam function and getting the turn signal lights working are the main three works which are easily handled by the usage of the combination switch.

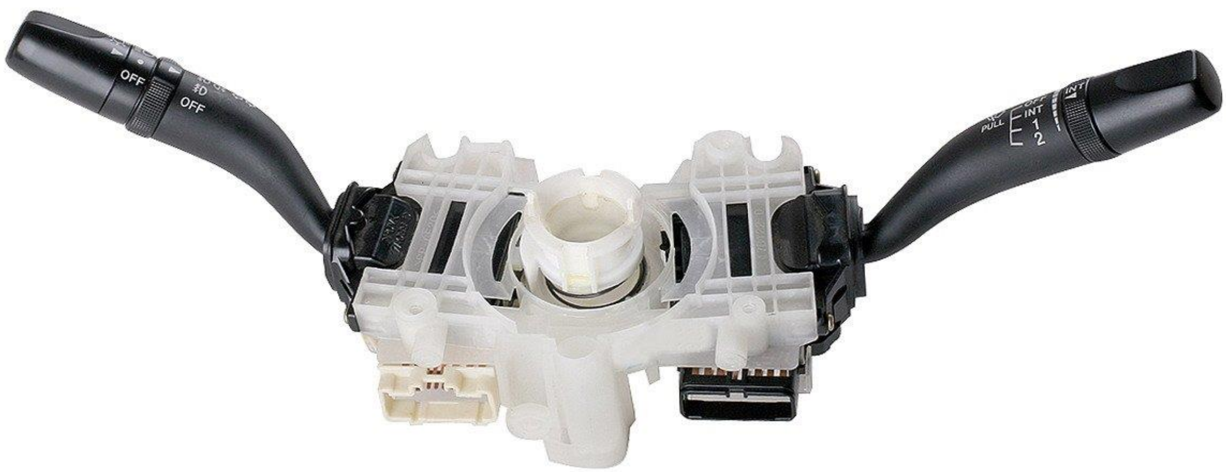


Figure 2.14: High quality Mitsubishi combination switch

Figure 2.15: Side view of the combination switch used in the car

There are six steps to install a combination switch inside the car and the main equipments which are needed to do so are:

1) New combination switch

2) Screwdriver

3) Wrench set

4) Steering wheel puller (optional)

And the required six steps are:

1) Preparing the car for installation: Before installing the combination switch in a car at first the car's battery's negative cable needs to be disconnected from the terminal.

2)Locating the combination switch.

3)Removing the old combination switch: The steering wheel is needed to be removed for reaching the panel of the switch. The screws on both of the cover found on the upper and lower part of the steering column are needed to be unscrewed. Then the three screws are to be removed from the switch's assembly. Then, the wires which connect the combination switch to the car's electric system are needed to be disconnected by getting a hold of the switch assembly. After disconnecting both the switches are needed to be removed from the frame.

4)Installing the new combination switch: The new combination switch needs to be connected by taking a note with respect which wire is connected where to avoid wiring problems for later and these wires are attached by using the three retaining screws removed earlier. Next the upper and lower covers are needed to be refasten.

5)Reassembling all the parts removed.

6)Testing the new combination switch: It is of course needed to be checked whether the new combination switch is acting properly or not.

The most important thing which is controlled by the combination switch is the functioning of different lights. The kinds of lights that are used in the solar car are very simple and necessary. Different kinds of globules have been used in the car for the different purposes of the lightings. The base of the tubular "trim" lights are of blade sort with couple contacts, plastic or glass wedge or double wire circles. Because of their characteristic of releasing under vibration the "screw-base" lights are never used. Dismal globules are used for signal lights with inside or outside hued lenses. For an experience of better driving the indicators and all the other kind of lights are used in the car and the total electrical system that the car consists was tested in the lab as well.

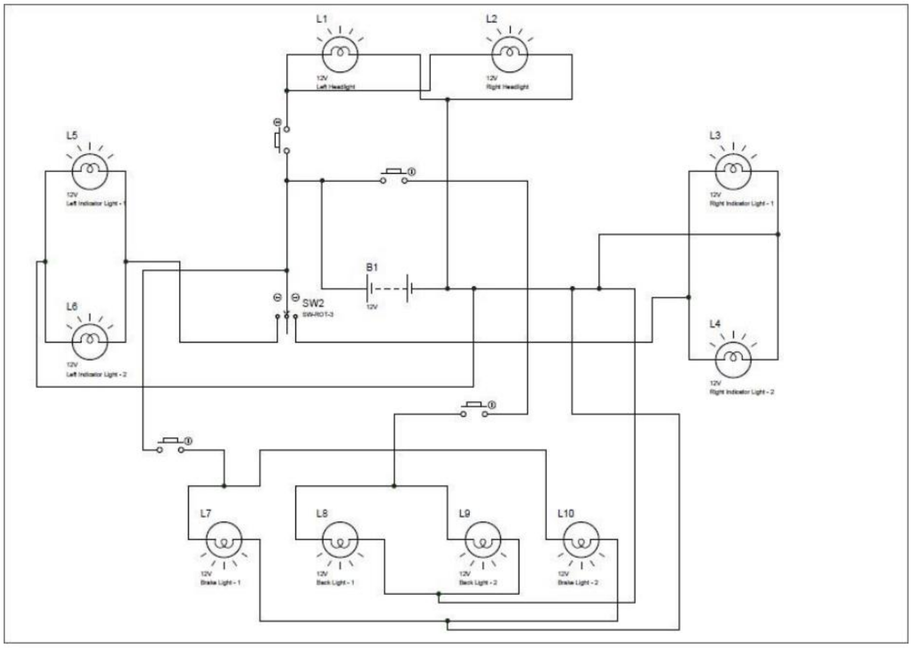


Figure: Testing diagram of the lighting system .

Chapter 3: Data Analysis and Results

3.1: Solar Charging

3.1.1 Solar Panel/Photovotaic Terminology:

1) Solar Cell**:** A p-n junction type device which converts light energy or photons to electricity by recombining electrons and protons.
2) Module: The smallest complete,environmentally protected assembly of solar cels and other components designed to generate dc power under light.
3) Panel: A group of modulesconnected together in compact form for using it as a installable unit.
4) Short-Circuit Current of PV Cell (I_{SC}): The current that flows through the solar cell when the voltage across is zero. The short circuit current is is due to generation of current or collection of light generated carriers. Short-circuit curent may depend on the area of the solar cell, the number of photons, the spectrum of the incident light, the optical properties, the collection probability.

3.1.2 System Model

Photovoltaic Cell Model

The mathemetical model of photovoltaic cell is deduced by the p-n junction's characteristics similar diode. It is usually represented by a current source (I_{SC}), connected with a diode,a series resistance(R_S). The current source generates a current which is proportional to the amount of light fell on the cell. There is a parallel resistance (R_P) in the model which is shown to represent the small leakage current. (Singh, A, & Kumar, 2015)

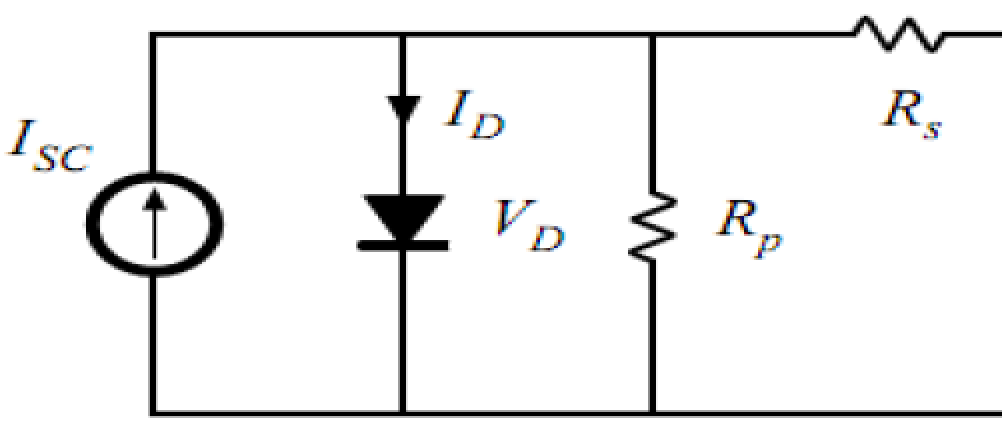


Figure 3.1: Photovoltaic Cell Model

For the photovoltaic cell current is generated by,

$$I_{SC} - I_D - \frac{V_D}{R_P} - I_{PV} = 0$$

Where,

I_{SC}= Short-Circuit Current.

I_D=Diode current.

V_D=Diode Voltage.

I_{PV}=Photovoltaic/Photon Current.

The diode current (I_D)equation is given by,

$$I_D = I_O(e^{\frac{V_D}{V_T}} - 1)$$

Where,

I_O=Dark Saturation Current.,V_T=Thermal Voltage.

Hence the voltage of the pv cell yields to,

$$V_{PV} = V_D - R_S.I_{PV}$$

3.1.3Battery Model:

The widespread energy storage technology is lead acid battery for its advantages, availability, cost efficiency and reliability. The battery modeling has been done later to establish its SOC. (Semaoui, Arab, Bacha, & Azoui, 2013)

The SOC is usually determined usually by,

$$SOC(t) = \frac{C_{sta}(t)}{C_{nom}(t)}$$

Where,

C_{sta}=Instantaneous Capacity, C_{nom}=Nominal capacity which is varying by the ageing effect.

3.1.4 Battery Charging

In charge mode, the instantaneous SOC is estimated by the ampere-hour flown into the battery. The battery state of charge is estimated by,

$$SOC(t+1) = SOC(t) + \frac{\Sigma\left(I_{batt}(t) - I_{gas}\right)\Delta t}{C_{nom}}$$

Where,

SOC(t) and SOC(t+1) are the battery SOC at time t and t+1 respectively. $I_{batt}(t)$ is the battery current and I_{gas} represents te battery loss. Δt is the time interval and C_{nom} is the nomial capacity in ampere hour. (Koutroulis & Kalaitzakis, 2004)

3.1.5 Experiment on Charging a Lead-Acid Battery by Solar Panels.

Apparatus:

- 5 Lead Acid Batteries (12V each in series)
- 5 Solar Panels (21.2V each in series)
- Charge Controller
- Wires
- Multi Meter
- Ammeter etc.

Circuit Diagram:

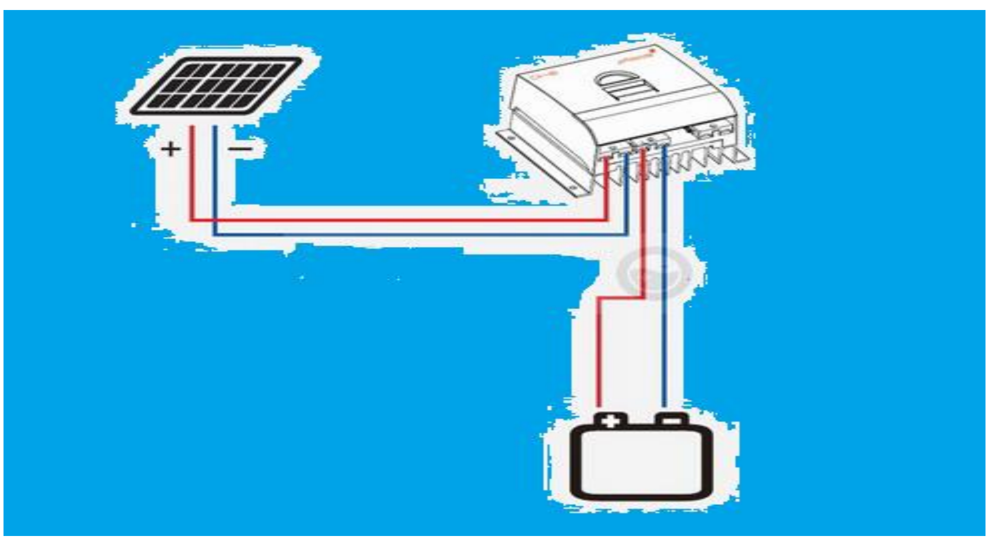


Figure 3.2: Circuit Diagram of Battery Charging by Solar Panel

Data Analysis of Solar Charging:

Primarily the battery voltage was 60.6 and from there on we started charging. We chose Δt=10 minutes.

The acquired data was analyzed to retrieve Panel and Battery voltage-time, current time characteristics

Battery Voltage Characteristics:

The following graphs show the battery voltage charecteristics on a day to day basis.

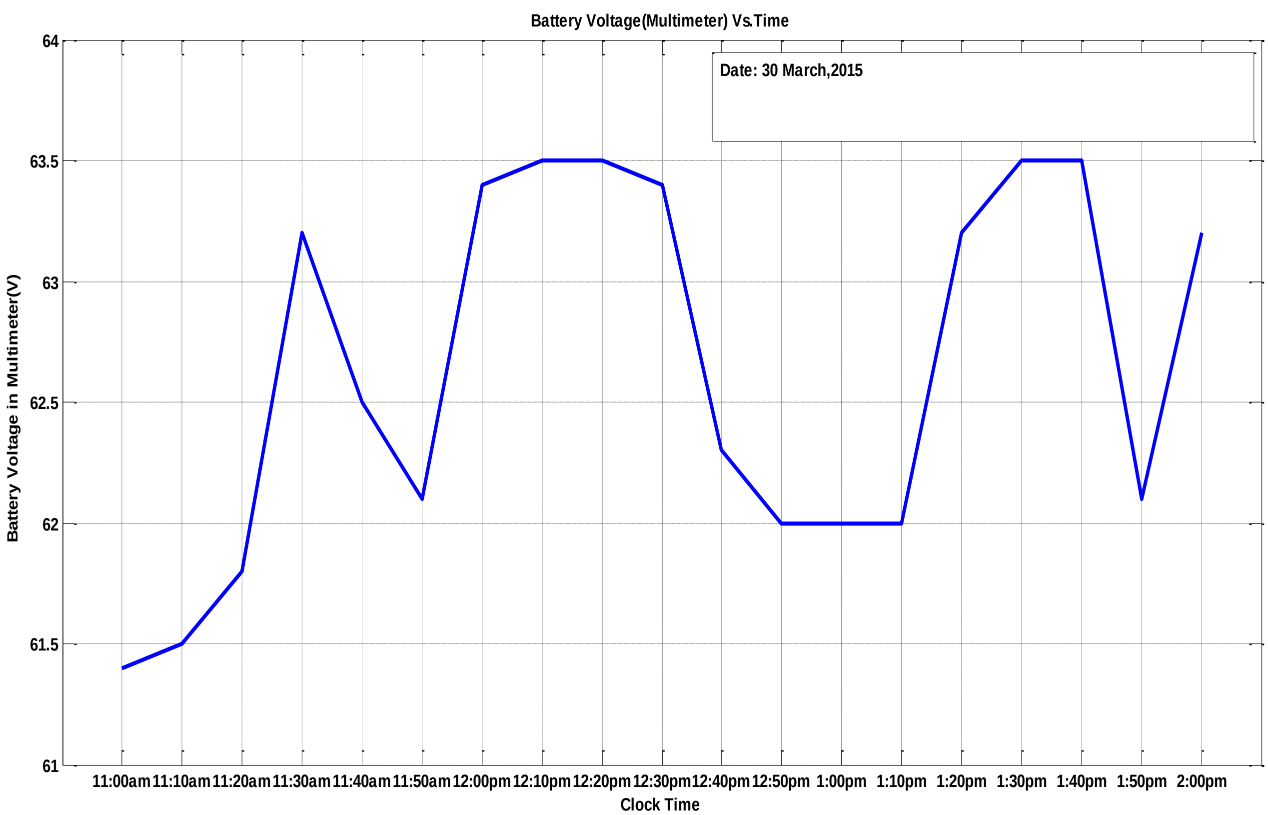


Figure 3.3: Solar Charging Battery Voltage vs. Time (30 March, 2015)

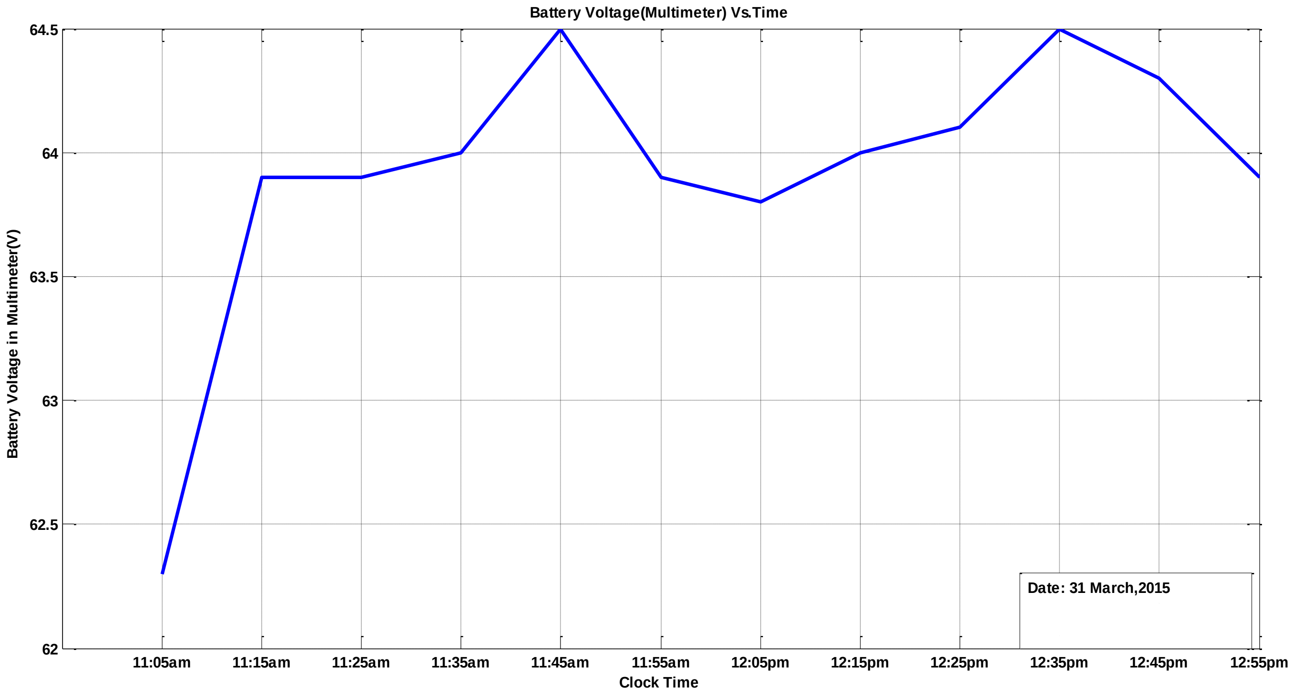


Figure 3.4: Solar Charging Battery Voltage vs. Time (30 March,2015)

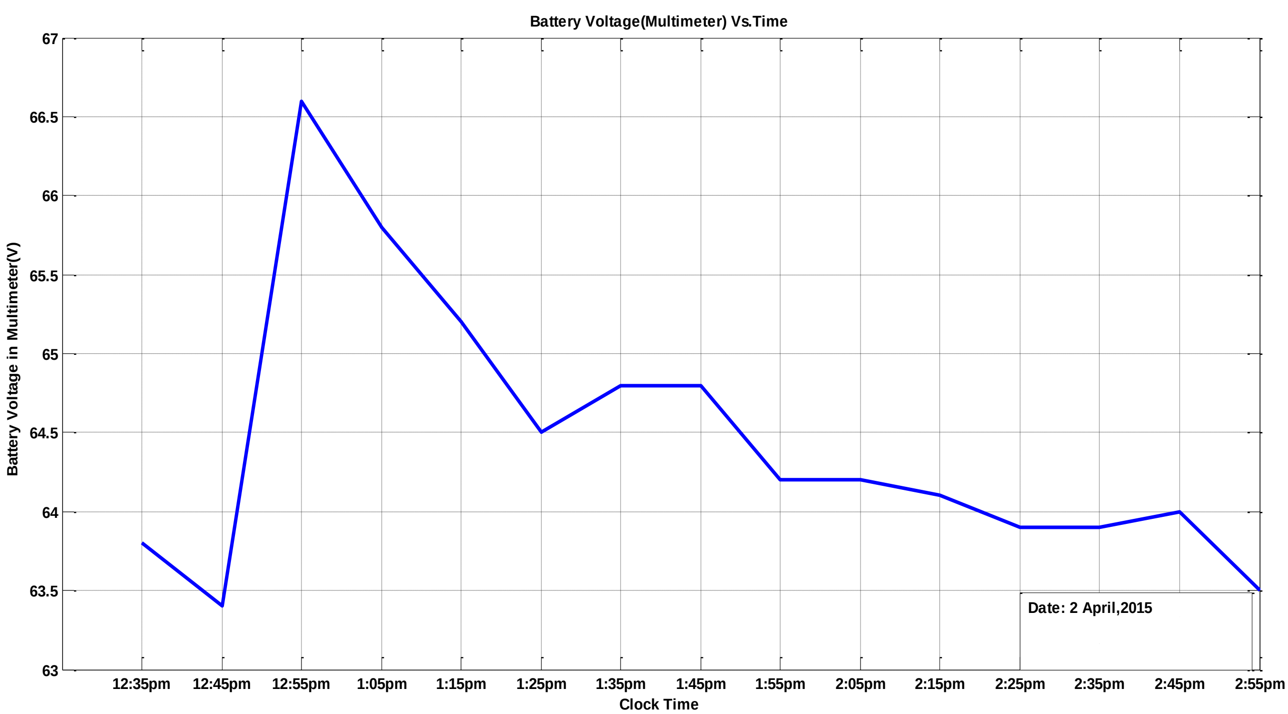


Figure 3.5: Solar Charging Battery Voltage vs. Time (2 April, 2015)

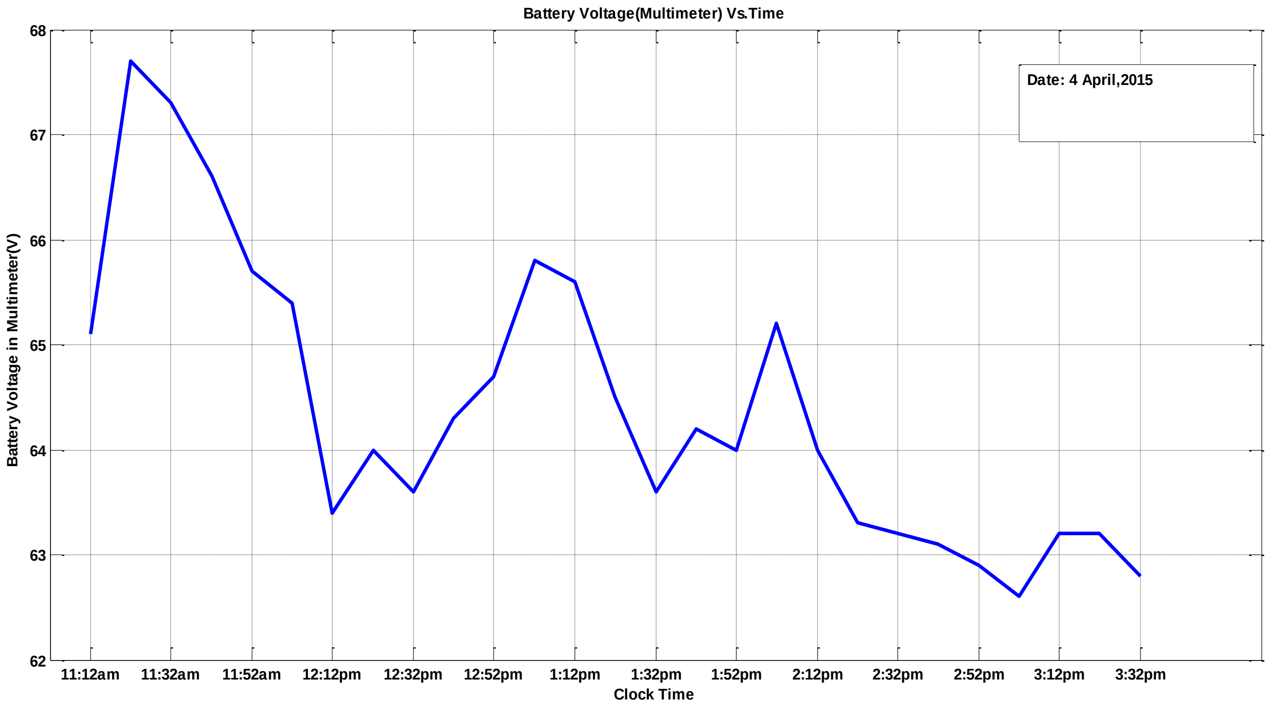


Figure 3.6: Solar Charging Battery Voltage vs. Time (4 April, 2015)

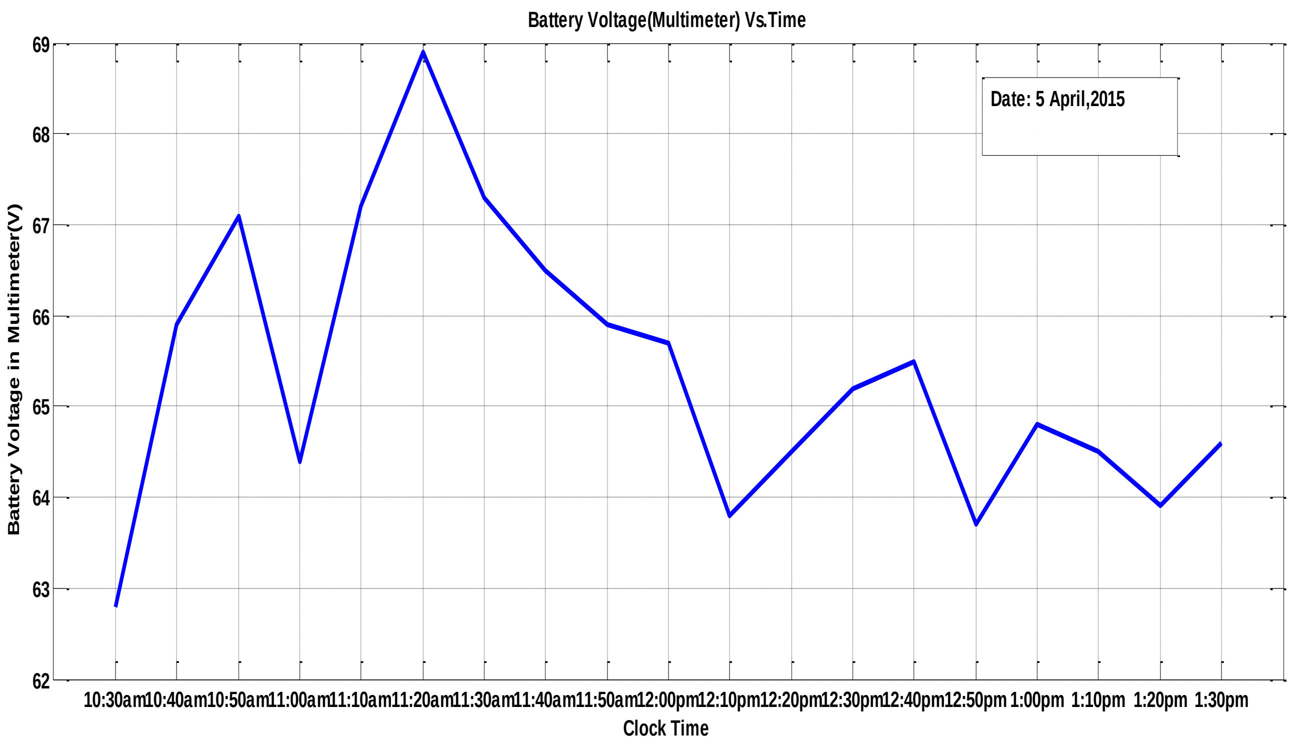


Figure 3.7: Solar Charging Battery Voltage vs. Time (5 April, 2015)

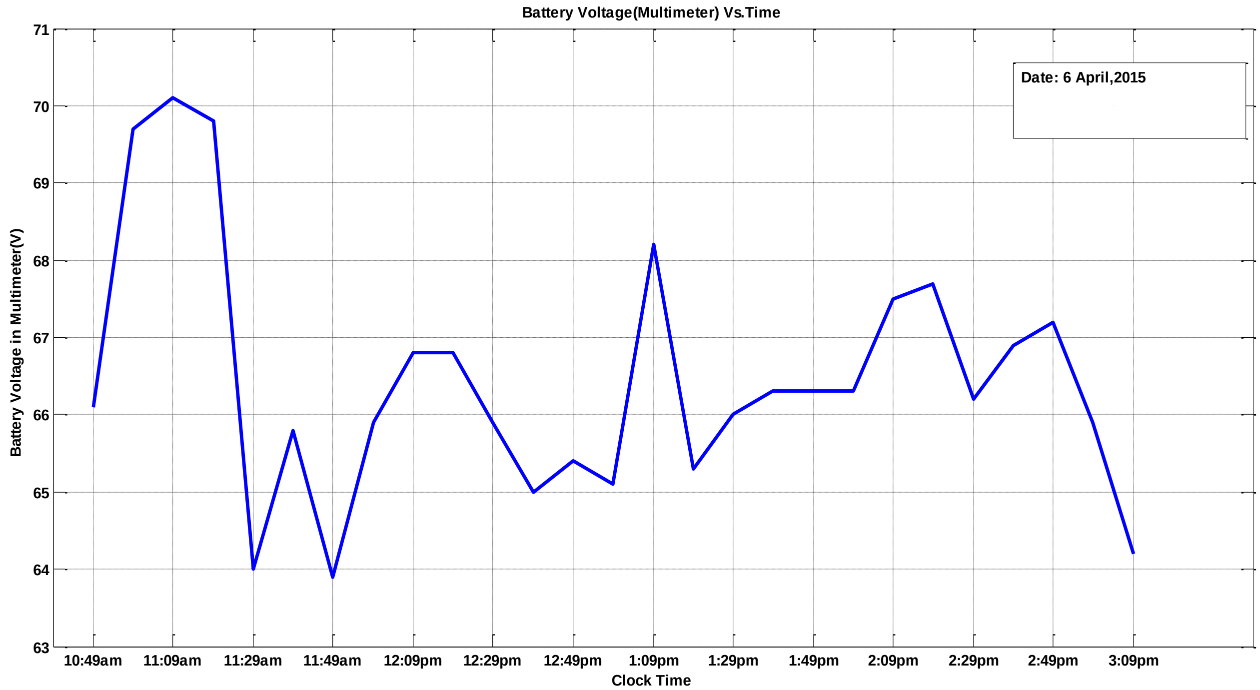


Figure 3.8: Solar Charging Battery Voltage vs. Time (6 April, 2015)

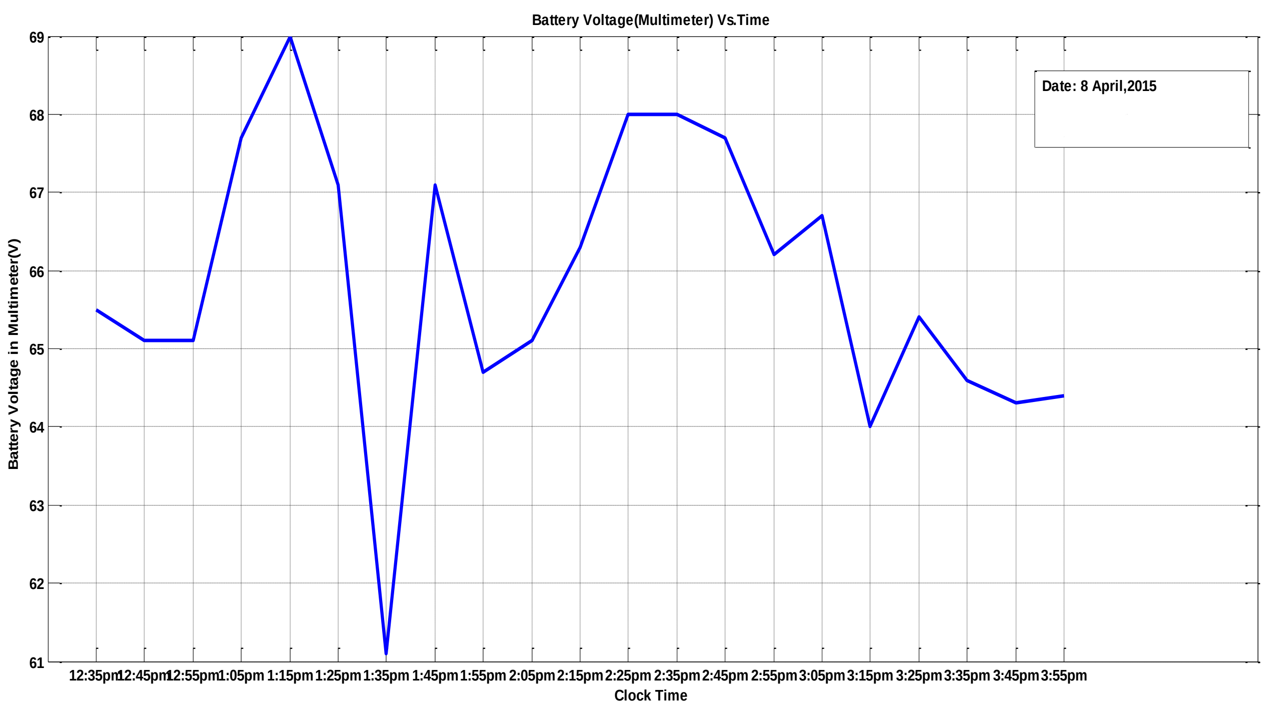


Figure 3.9: Solar Charging Battery Voltage vs. Time (8 April, 2015)

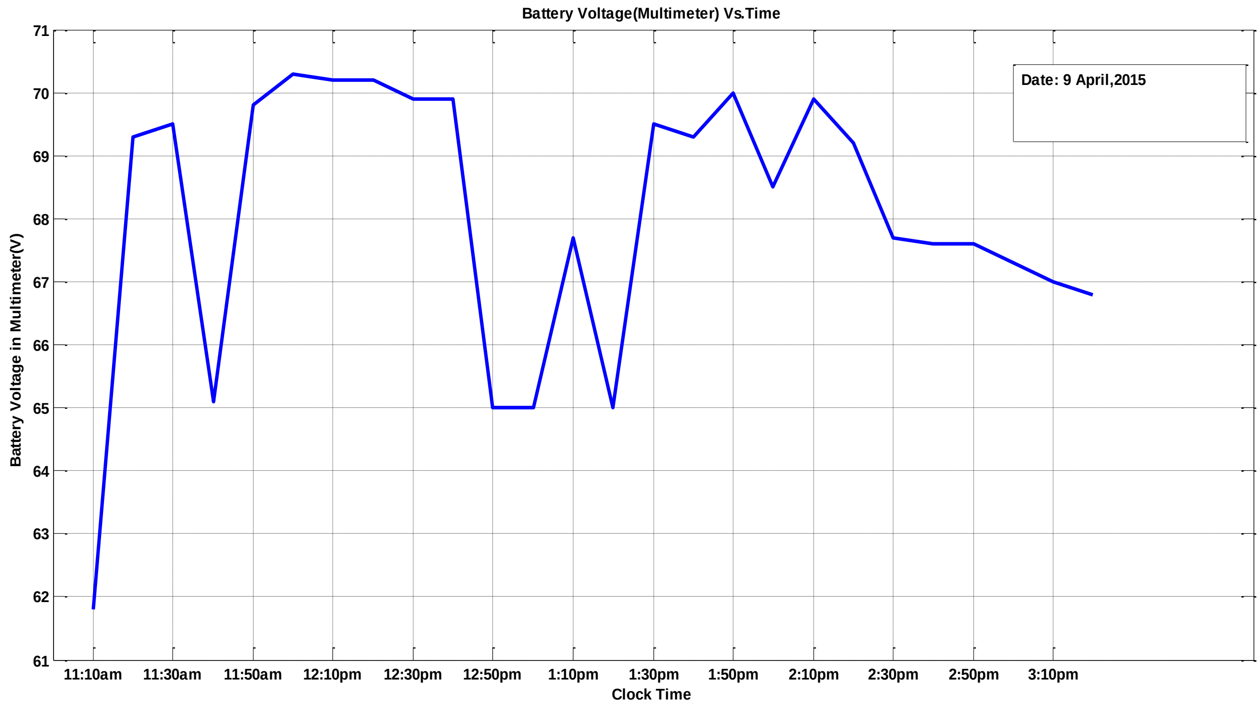


Figure 3.10: Solar Charging Battery Voltage vs. Time (9 April, 2015)

Panel Voltage Characteristics:

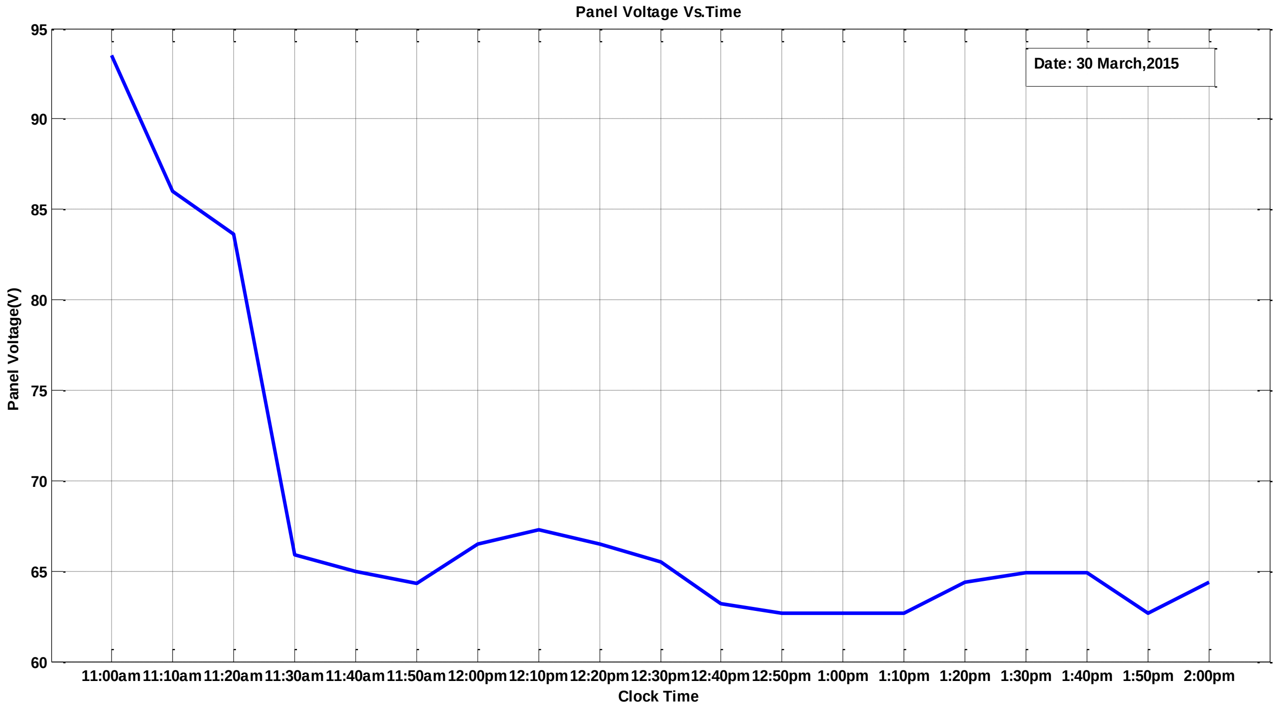


Figure 3.11: Solar Charging Panel Voltage vs. Time (30 March, 2015)

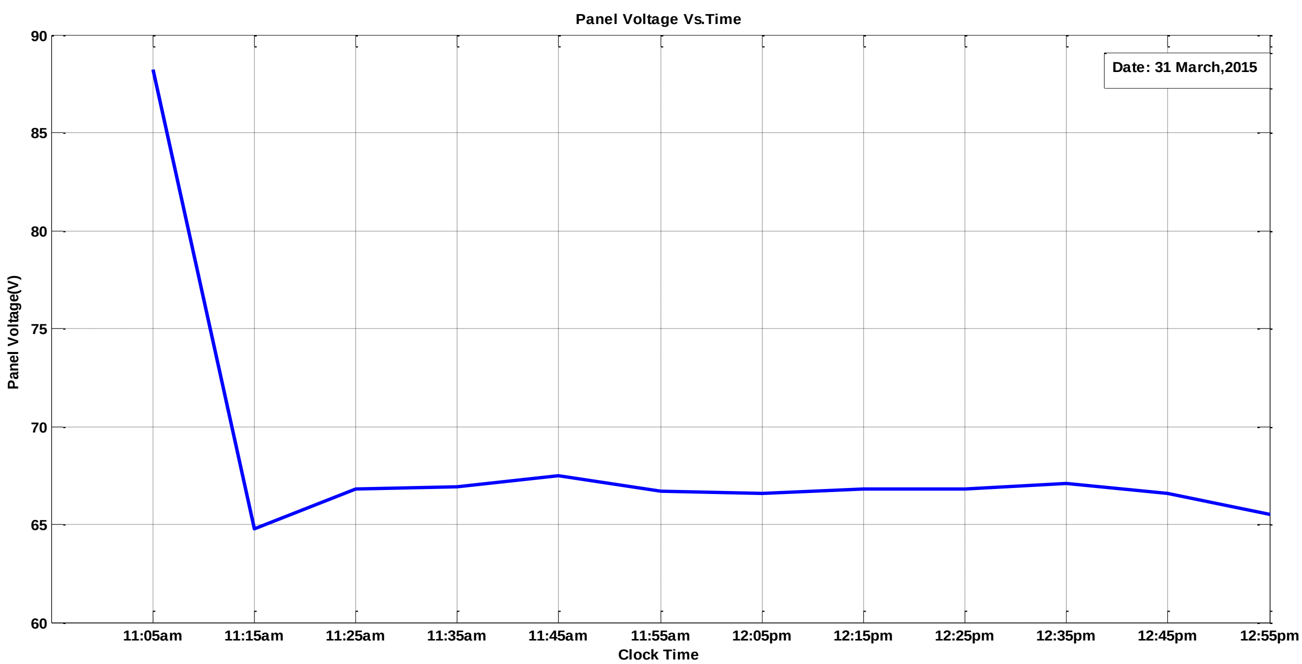


Figure 3.12: Solar Charging Panel Voltage vs. Time (31 March, 2015)

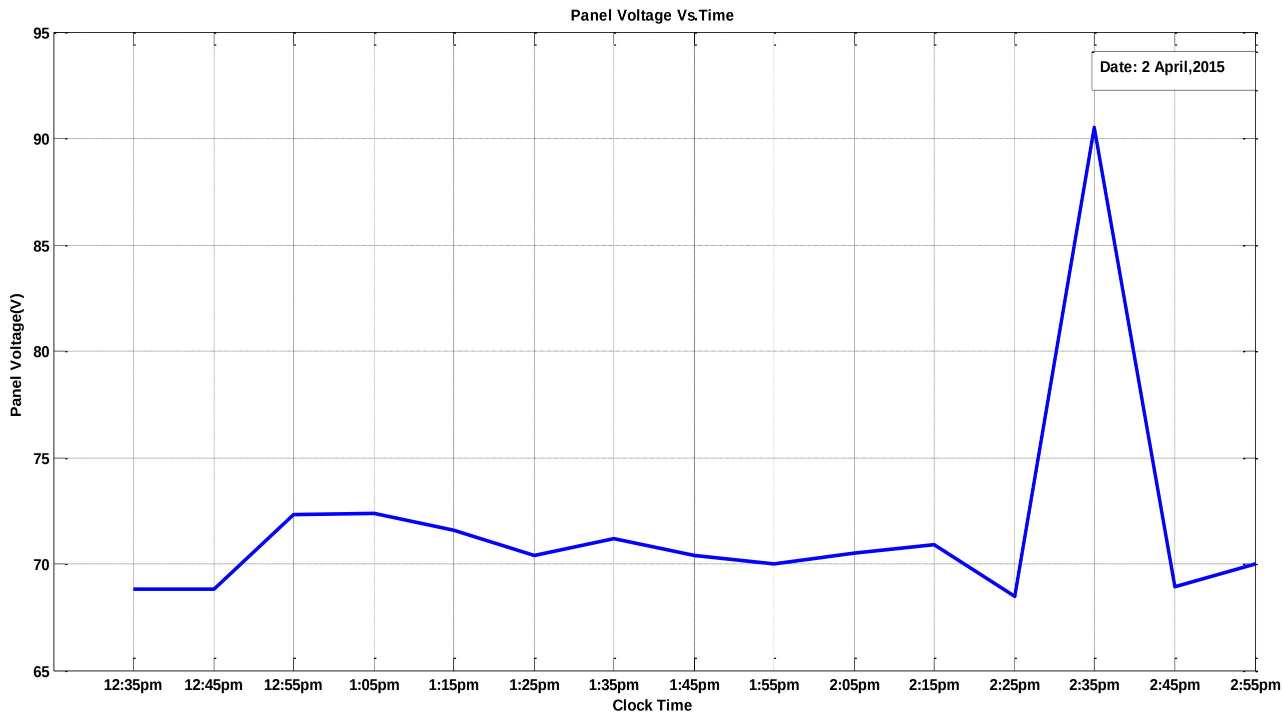


Figure 3.13: Solar Charging Panel Voltage vs. Time (2 April, 2015)

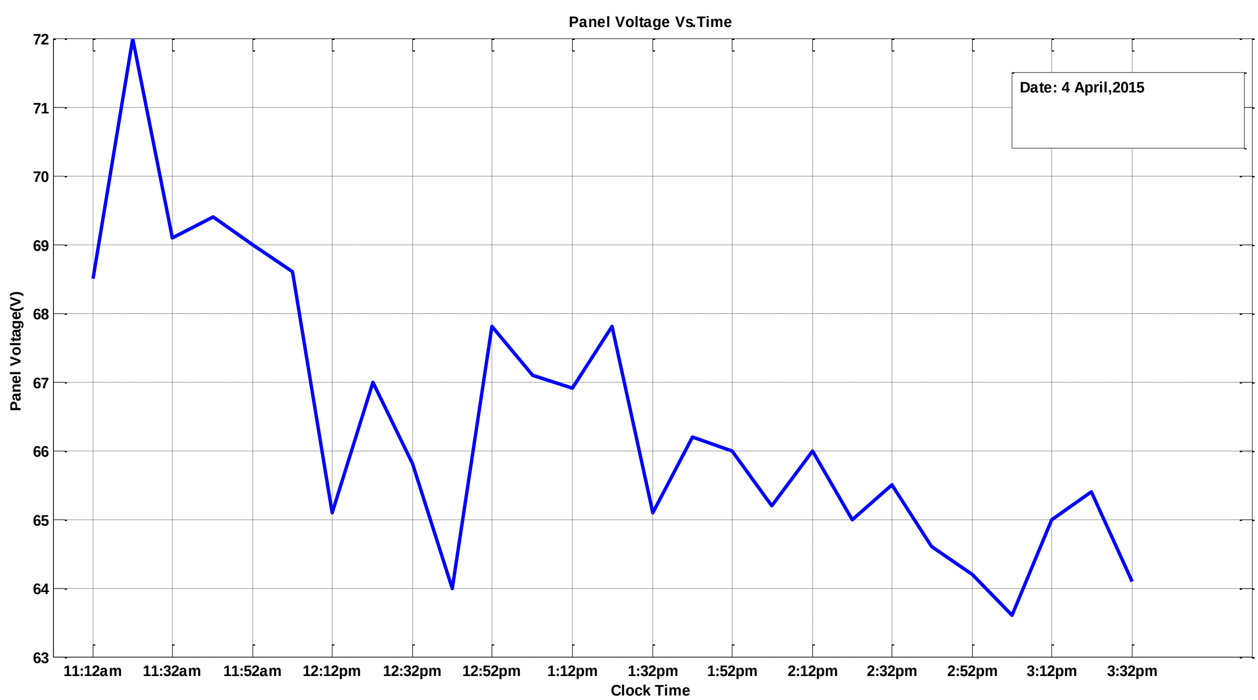


Figure 3.14: Solar Charging Panel Voltage vs. Time (4 April, 2015)

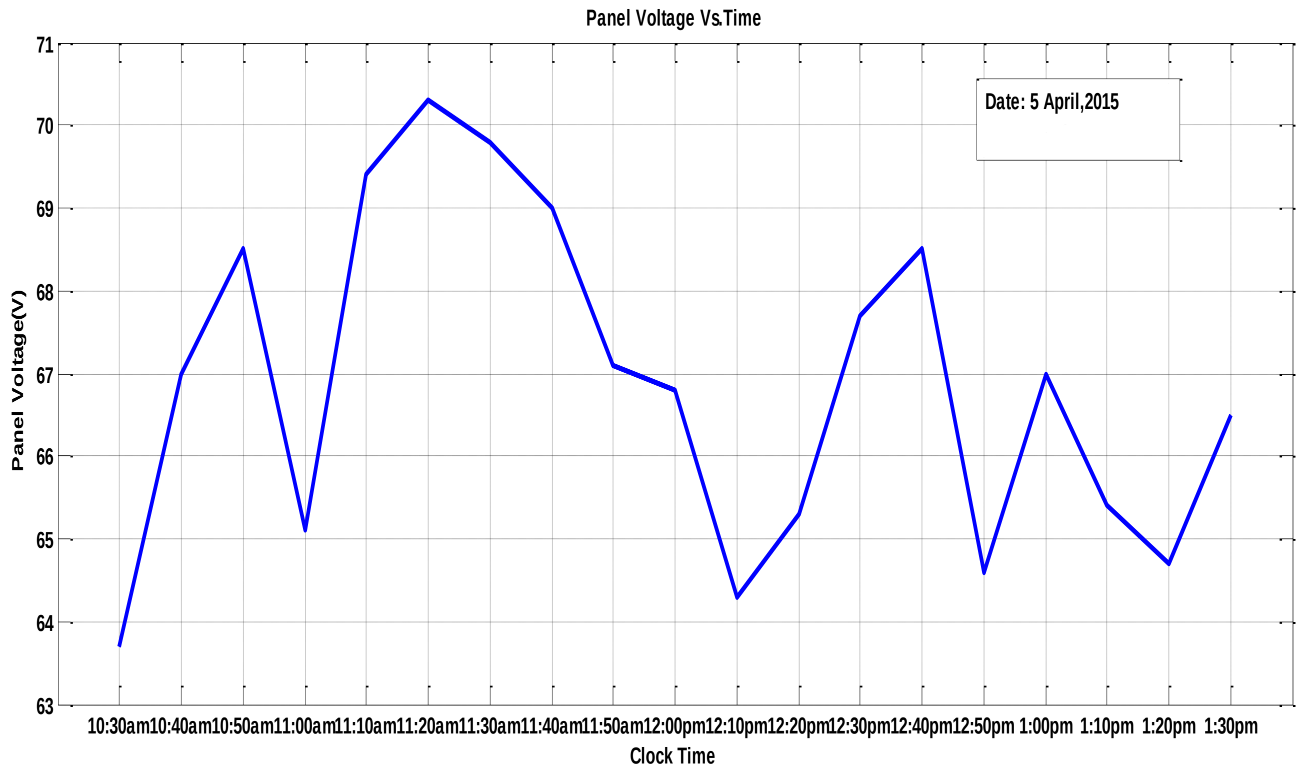


Figure 3.15: Solar Charging Panel Voltage vs. Time (5 April, 2015)

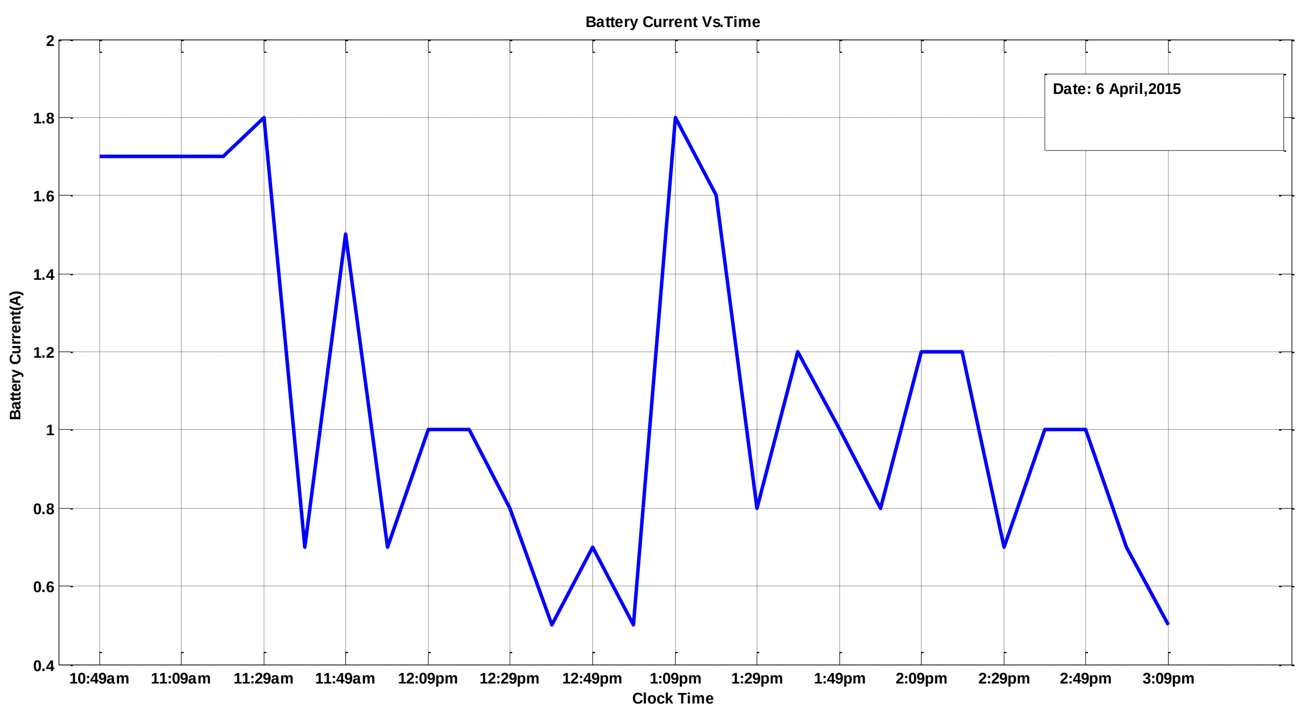


Figure 3.16: Solar Charging Panel Voltage vs. Time (6 April, 2015)

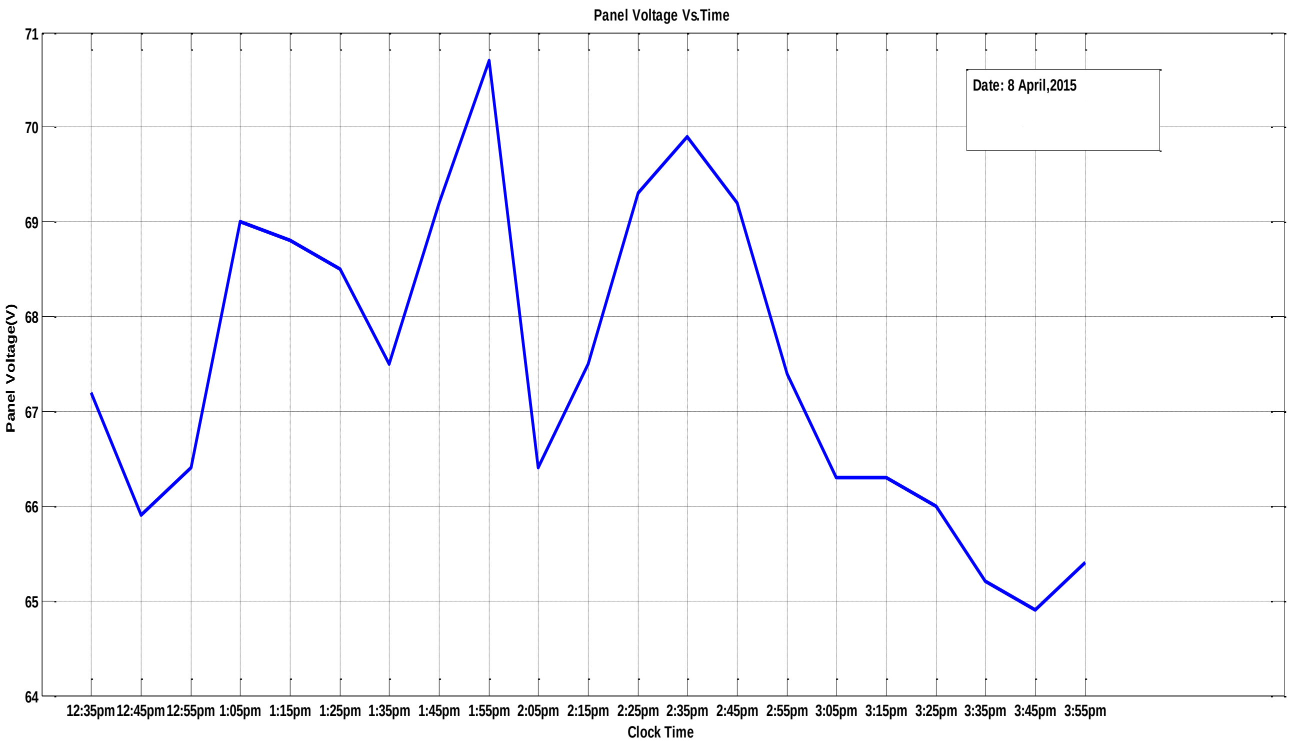


Figure 3.17: Solar Charging Panel Voltage vs. Time (8 April, 2015)

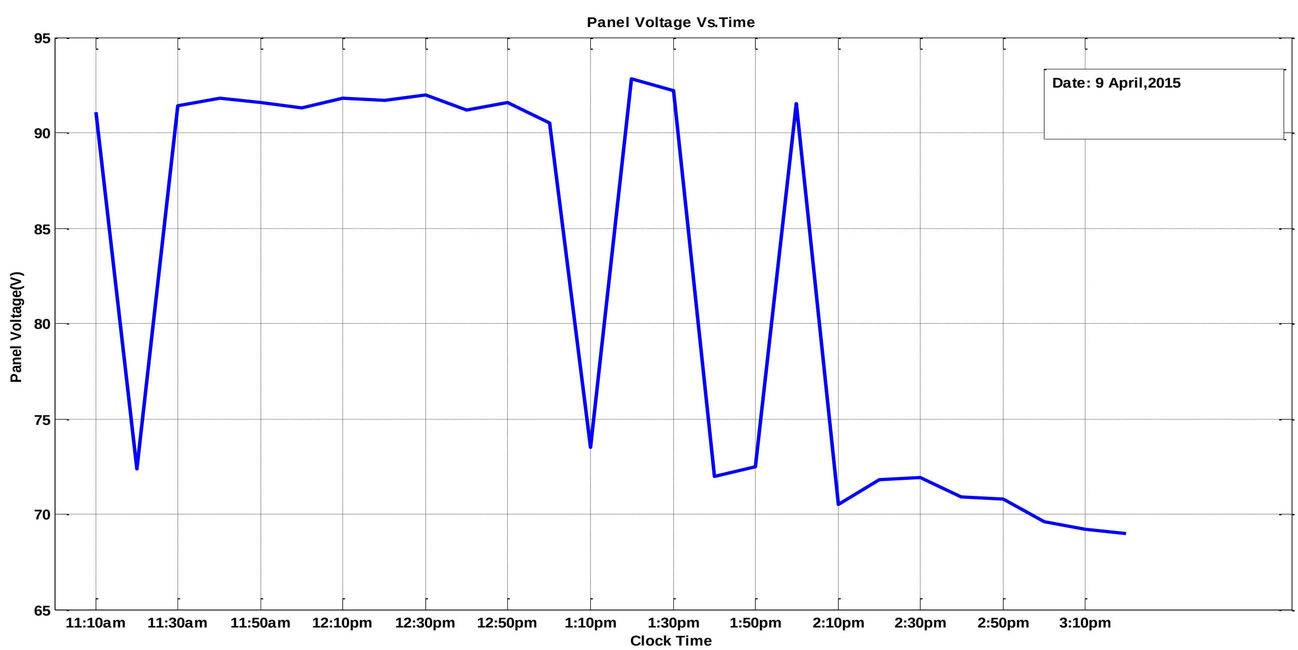


Figure 3.18: Solar Charging Panel Voltage vs. Time (9 April, 2015)

Battery Current Characteristics:

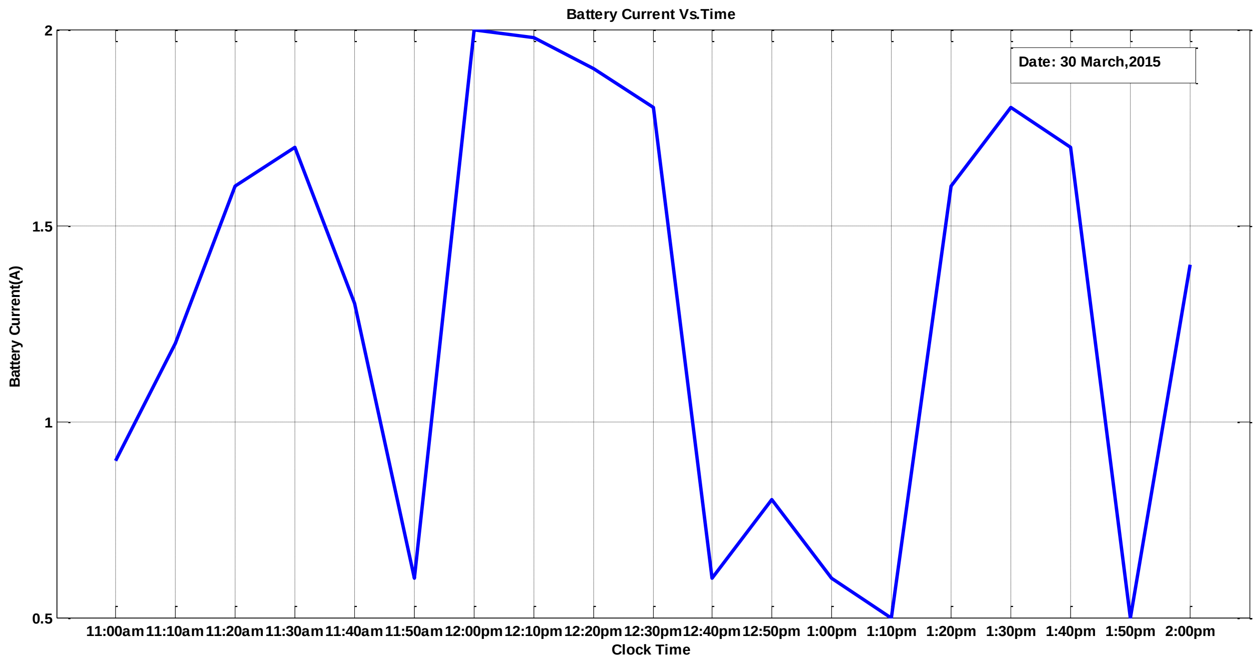


Figure 3.19: Solar Charging Battery Current vs. Time (30 March, 2015)

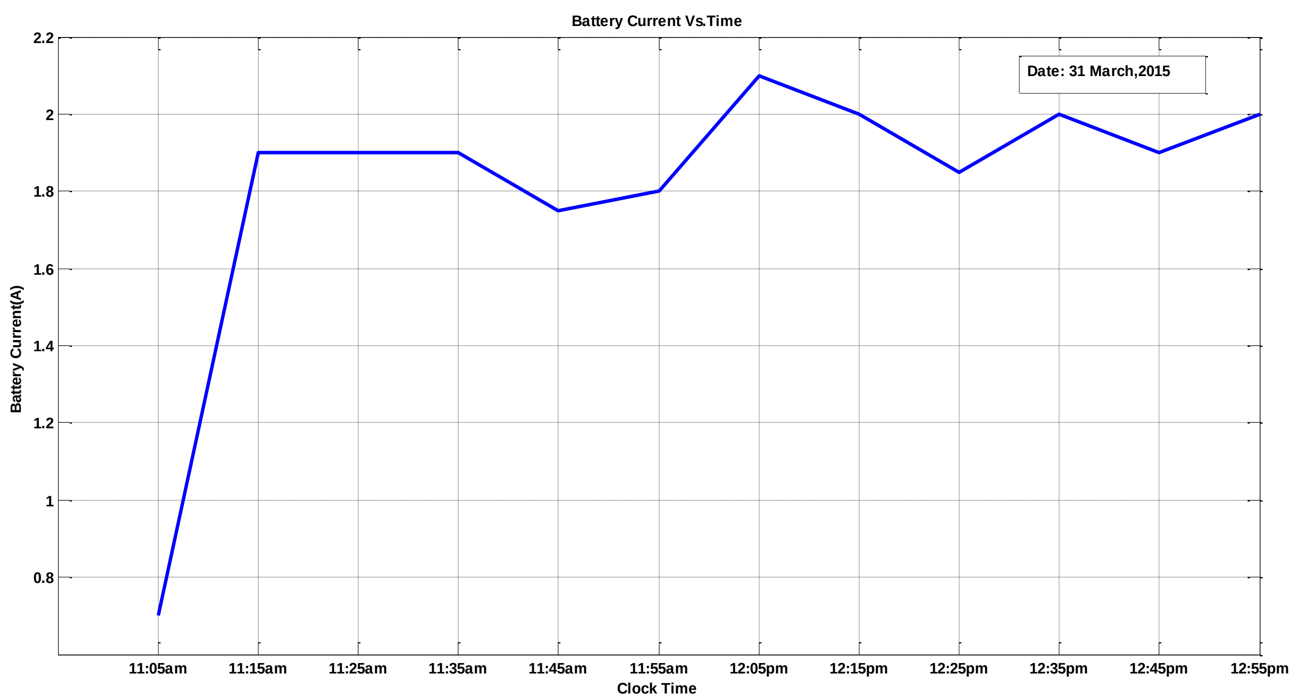


Figure 3.20: Solar Charging Battery Current vs. Time (31 March, 2015)

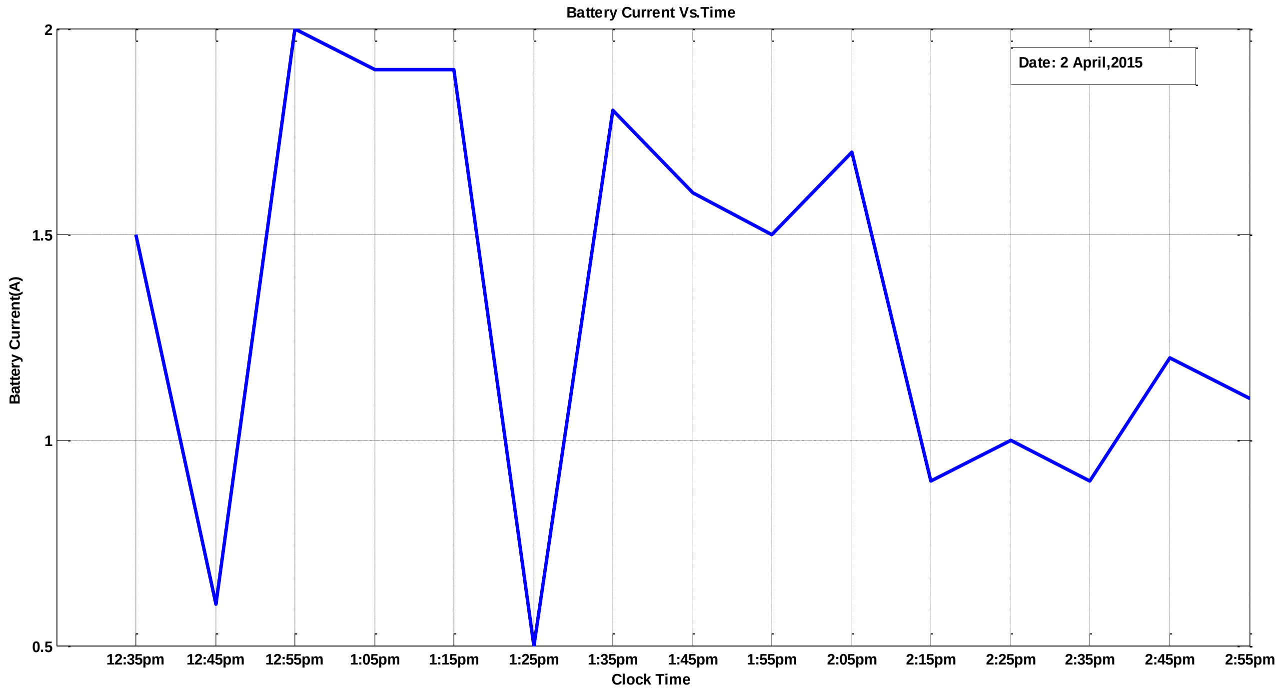


Figure 3.21: Solar Charging Battery Current vs. Time (2 April, 2015)

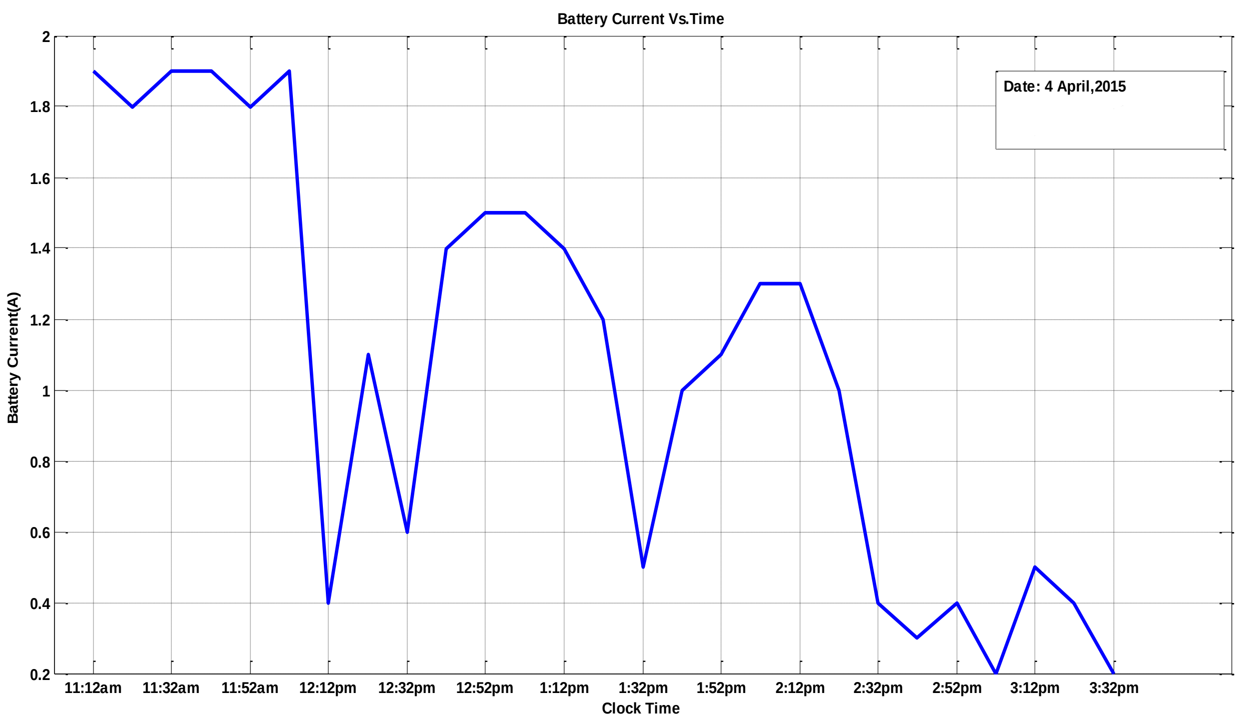


Figure 3.22: Solar Charging Battery Current vs. Time (4 April, 2015)

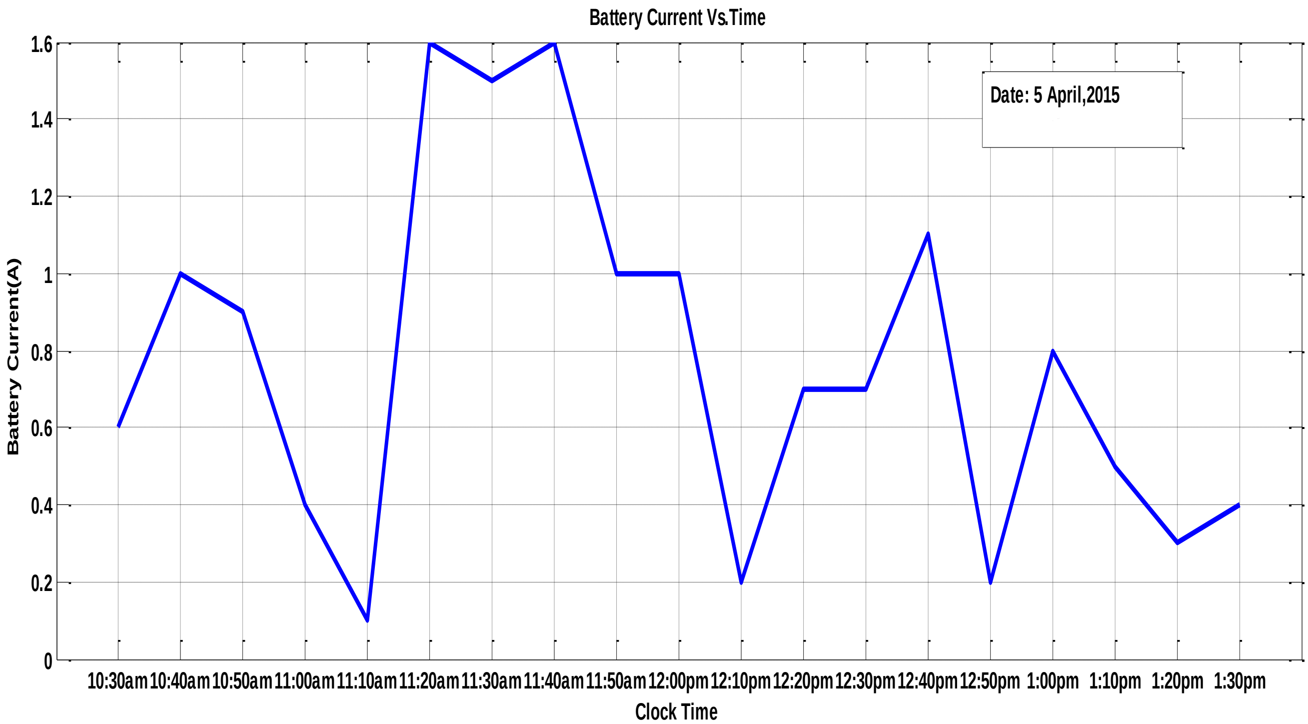


Figure 3.23: Solar Charging Battery Current vs. Time (5 April, 2015)

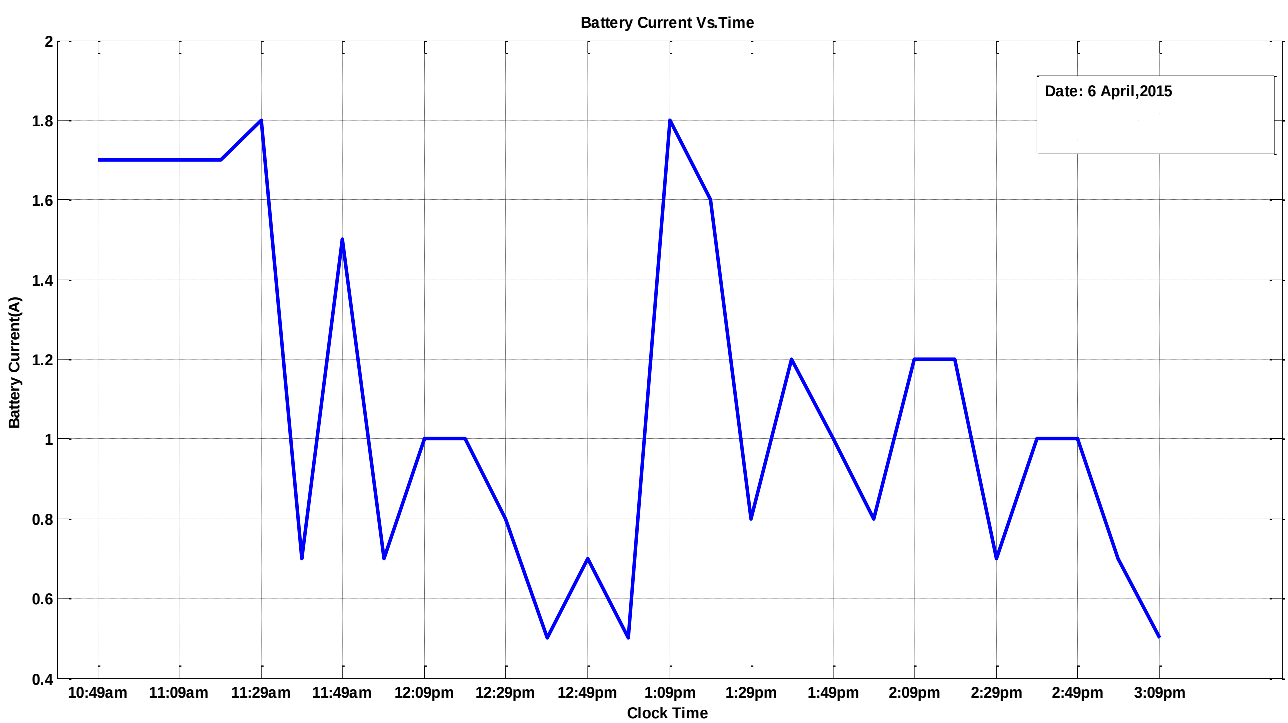


Figure 3.24: Solar Charging Battery Current vs. Time (6 April, 2015)

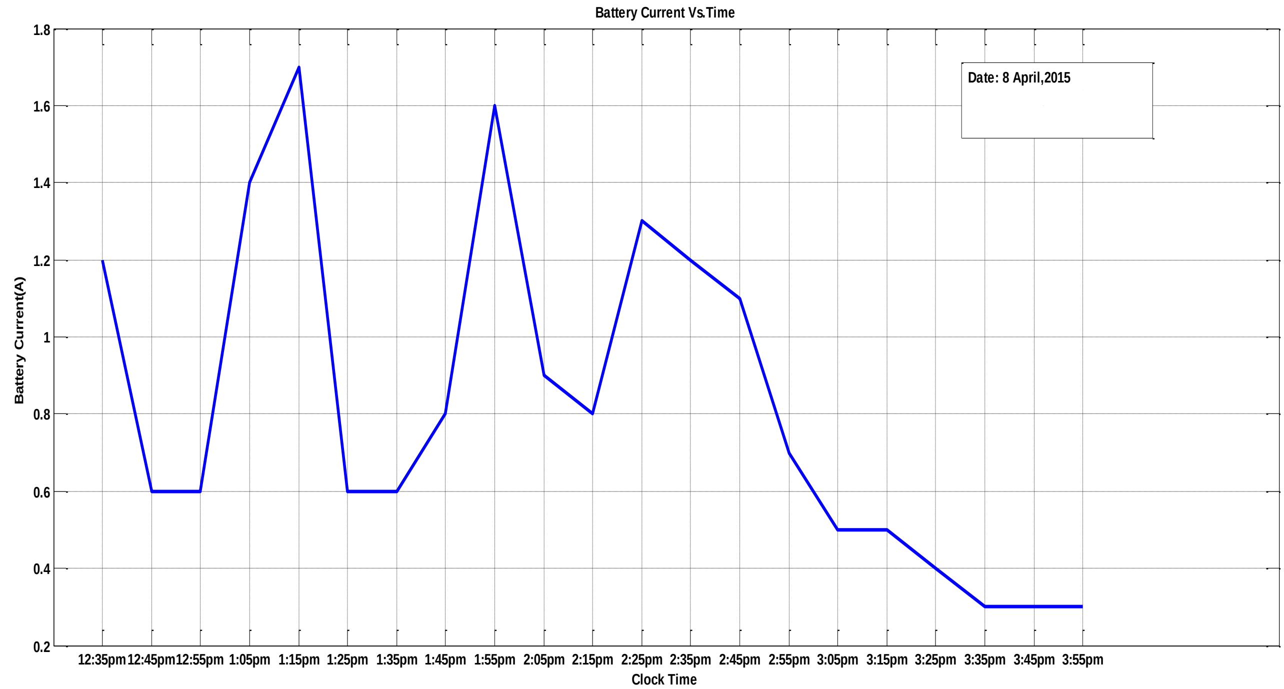


Figure 3.25: Solar Charging Battery Current vs. Time (8 April, 2015)

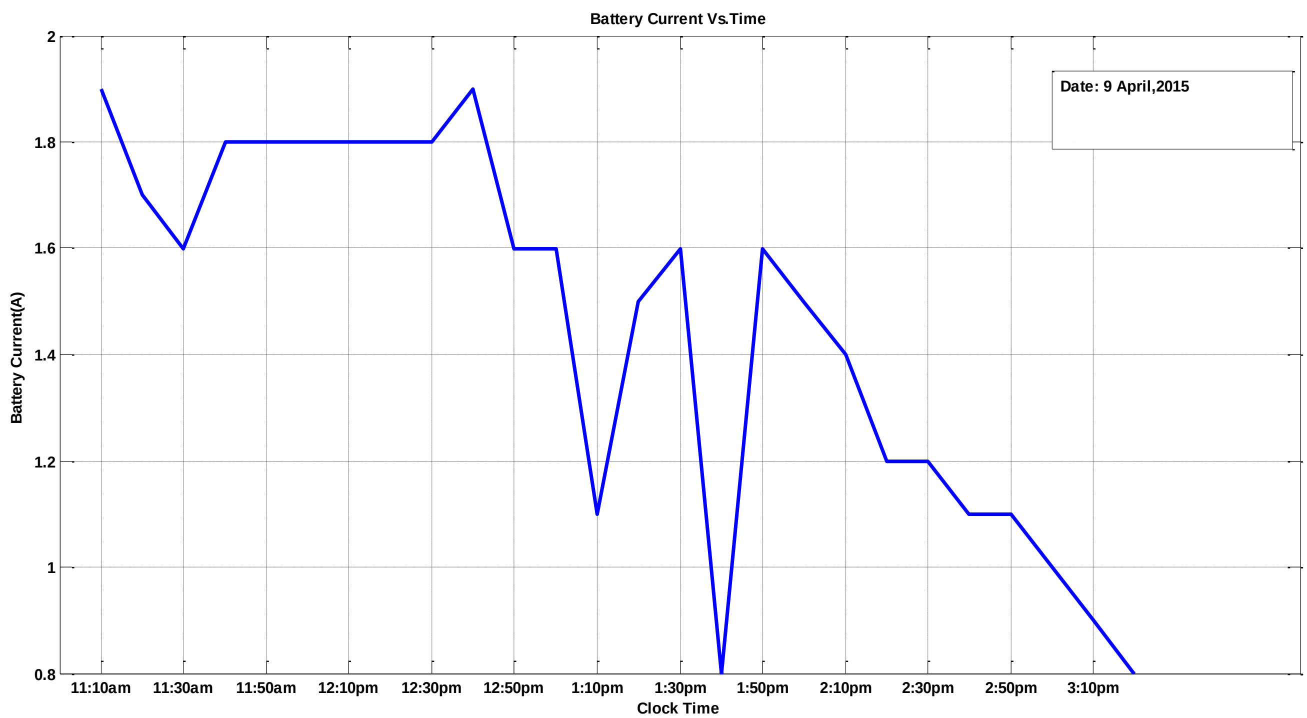


Figure 3.26: Solar Charging Battery Current vs. Time (9 April, 2015)

Result:

A charging curve was generated from battery current-time curve. It was also integrated to find total charge for the specific day.

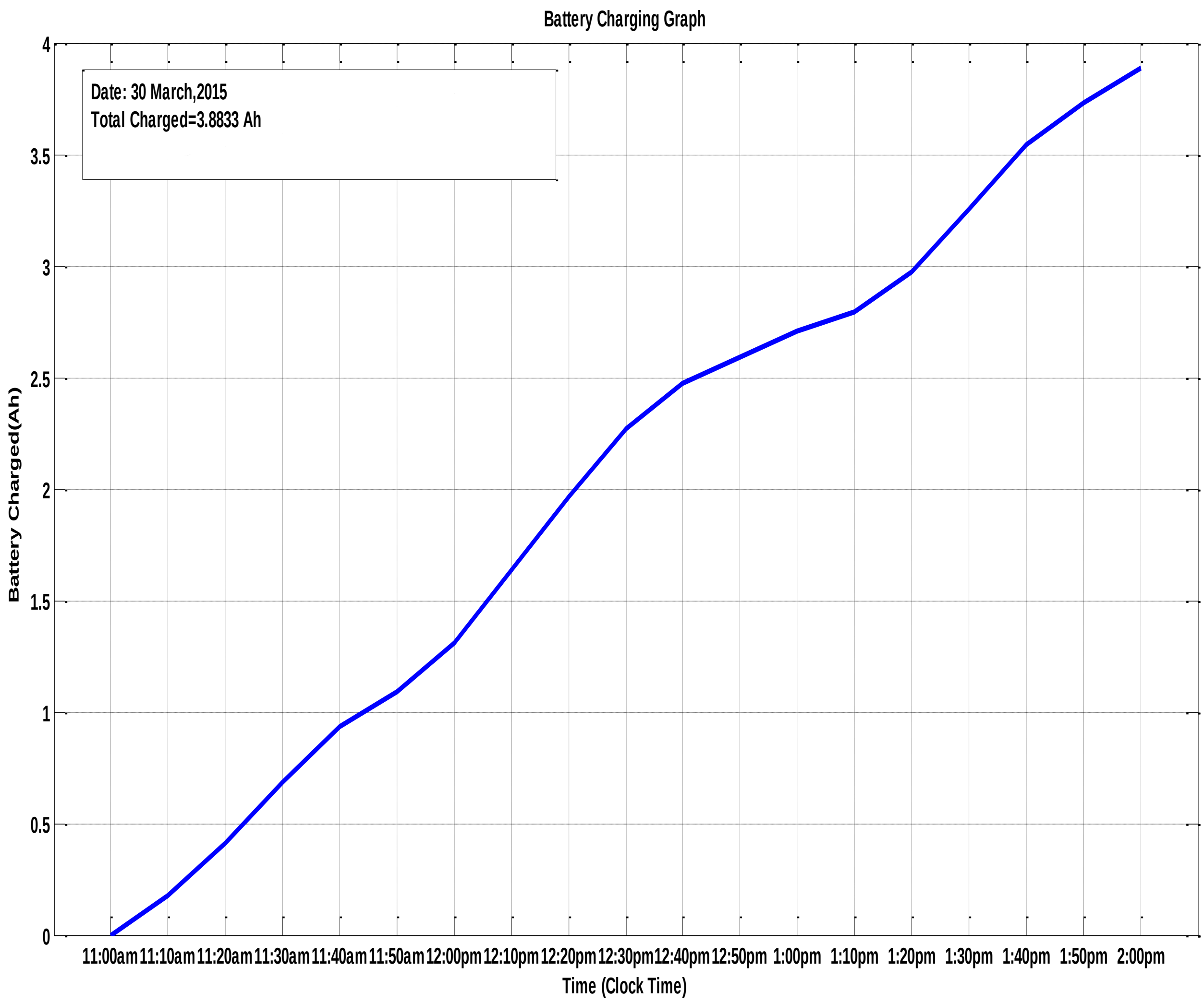


Figure 3.27: Battery charged on 30 March, 2015

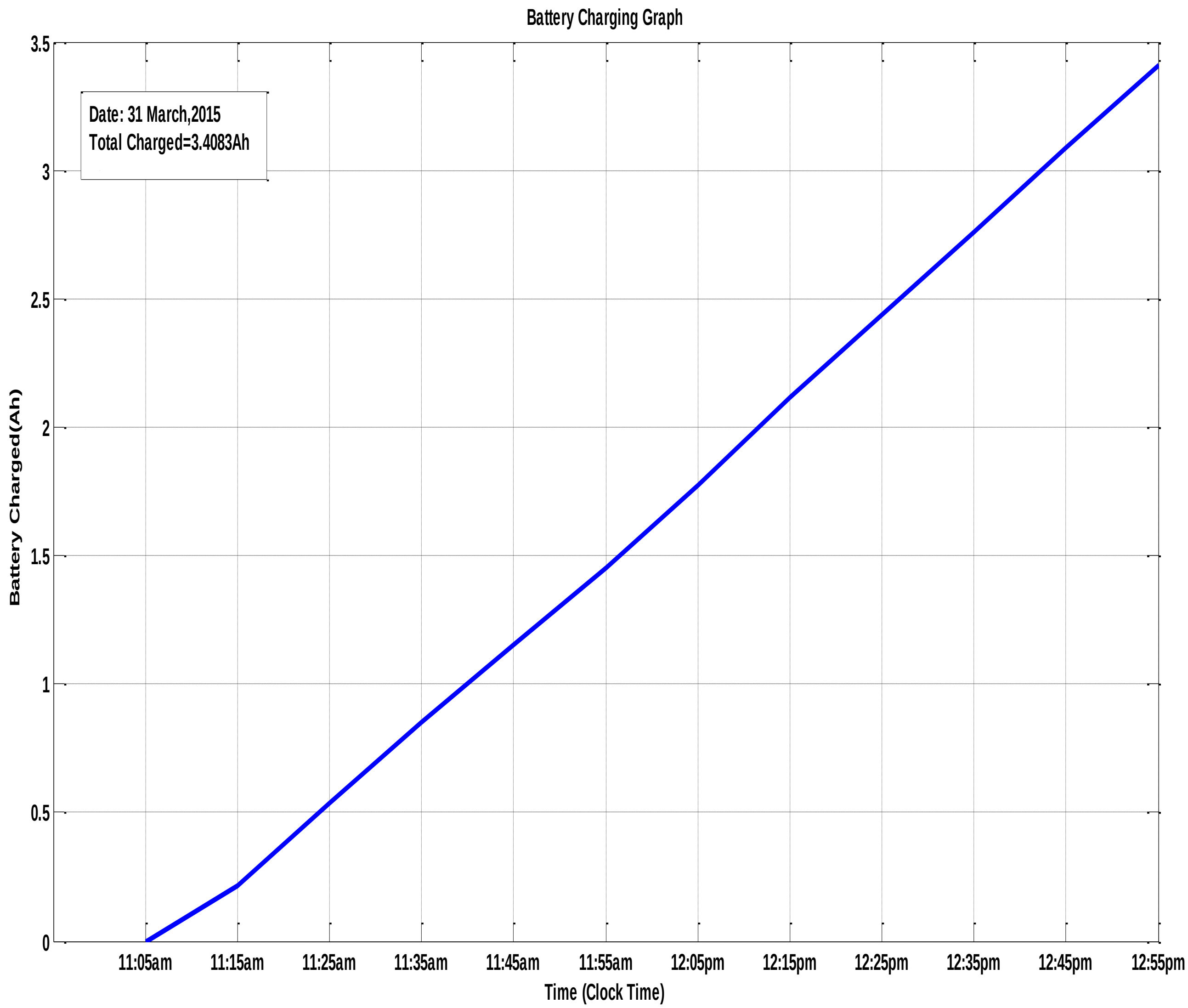


Figure 3.28: Battery charged on 31 March, 2015

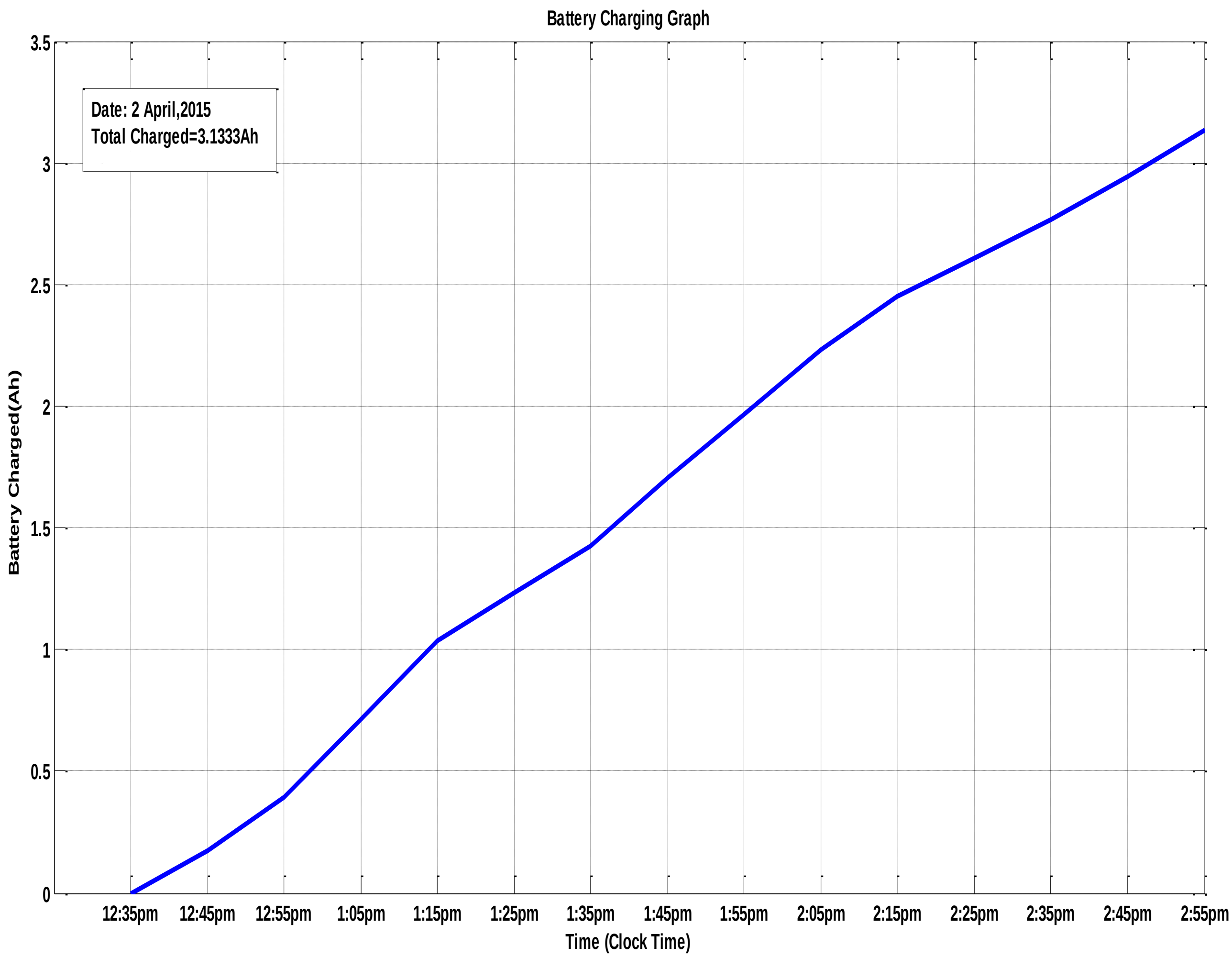


Figure 3.29: Battery charged on 2 April, 2015

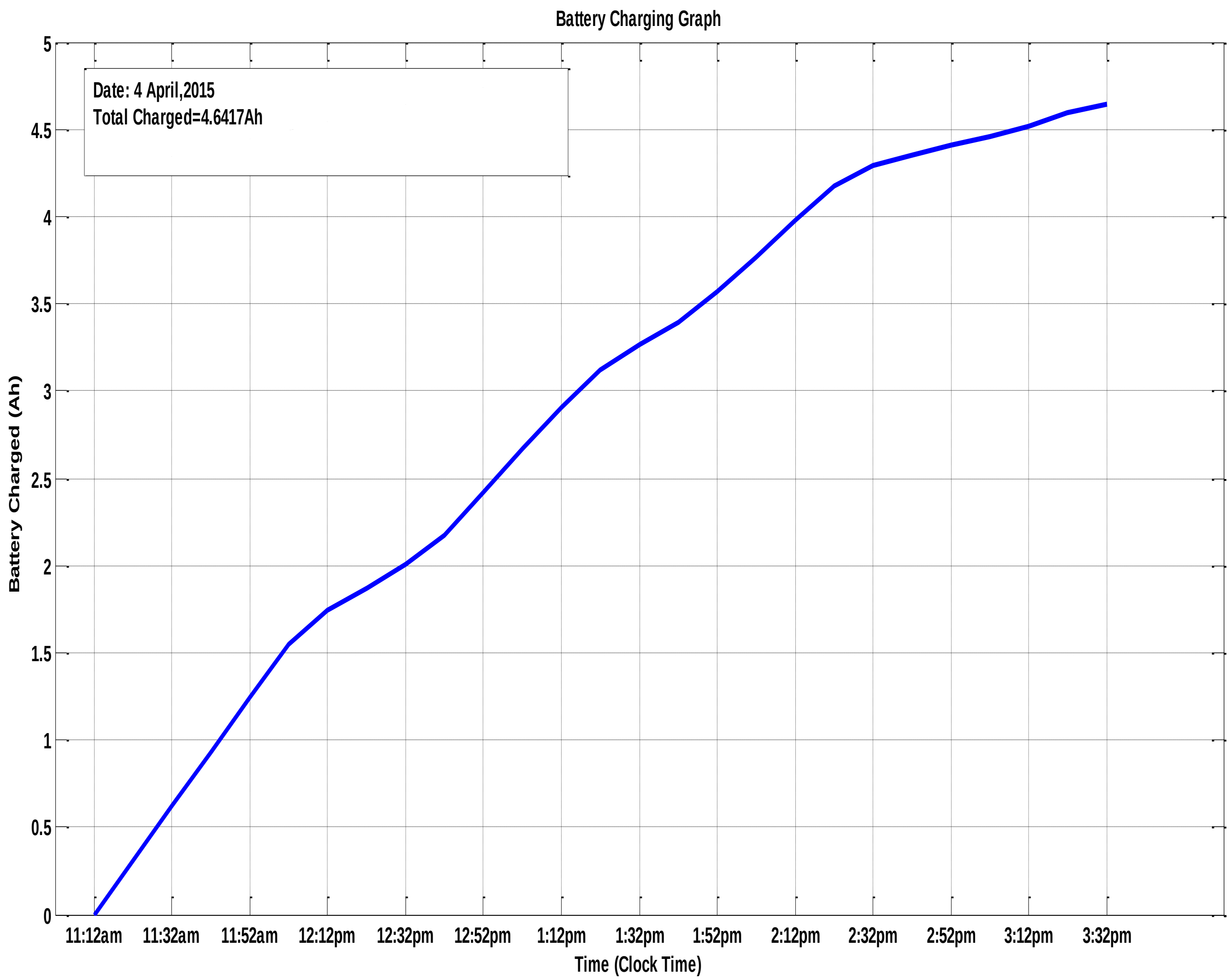


Figure 3.30: Battery charged on 4 April, 2015

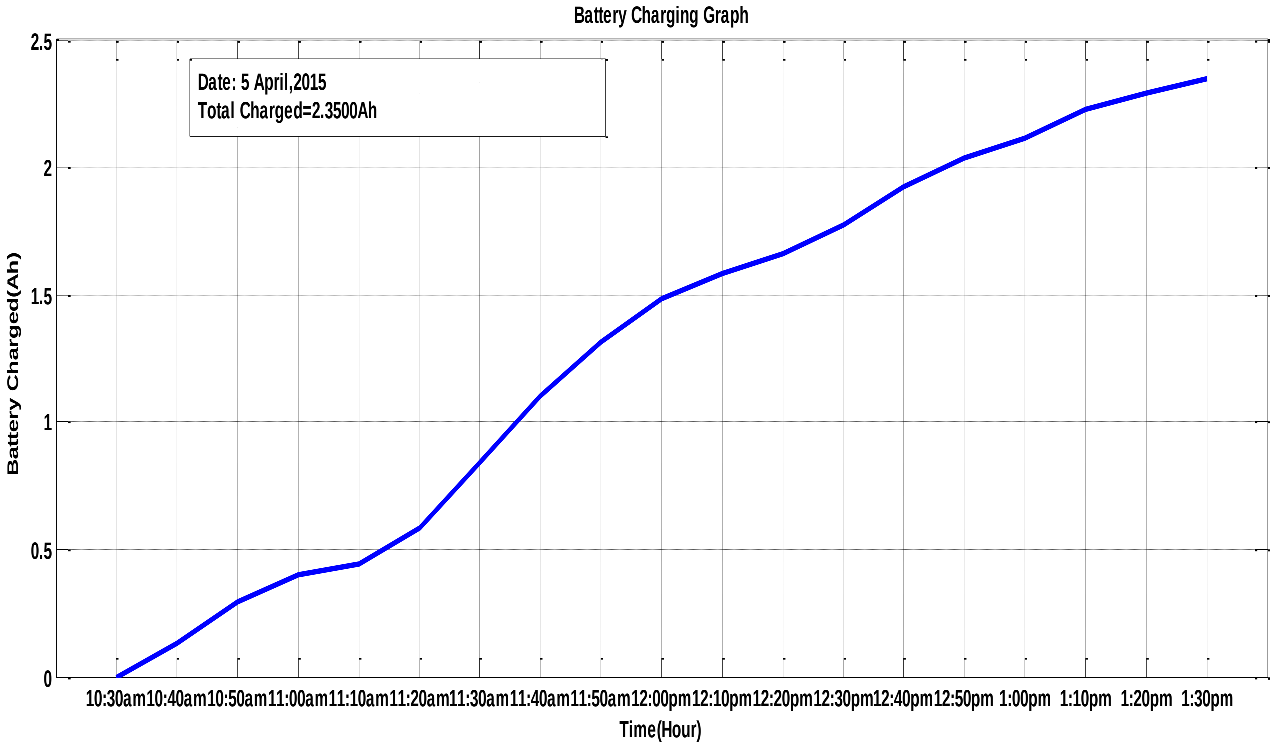


Figure 3.31: Battery charged on 5 April, 2015

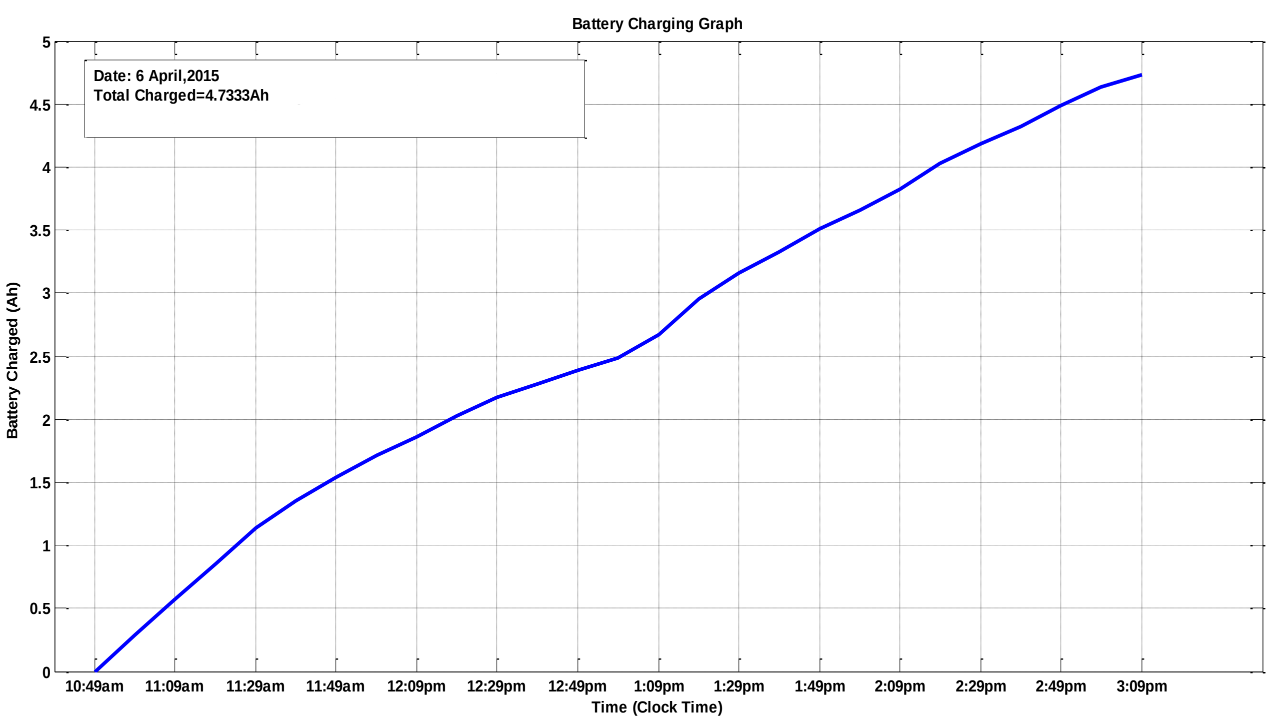


Figure 3.32: Battery charged on 6 April, 2015

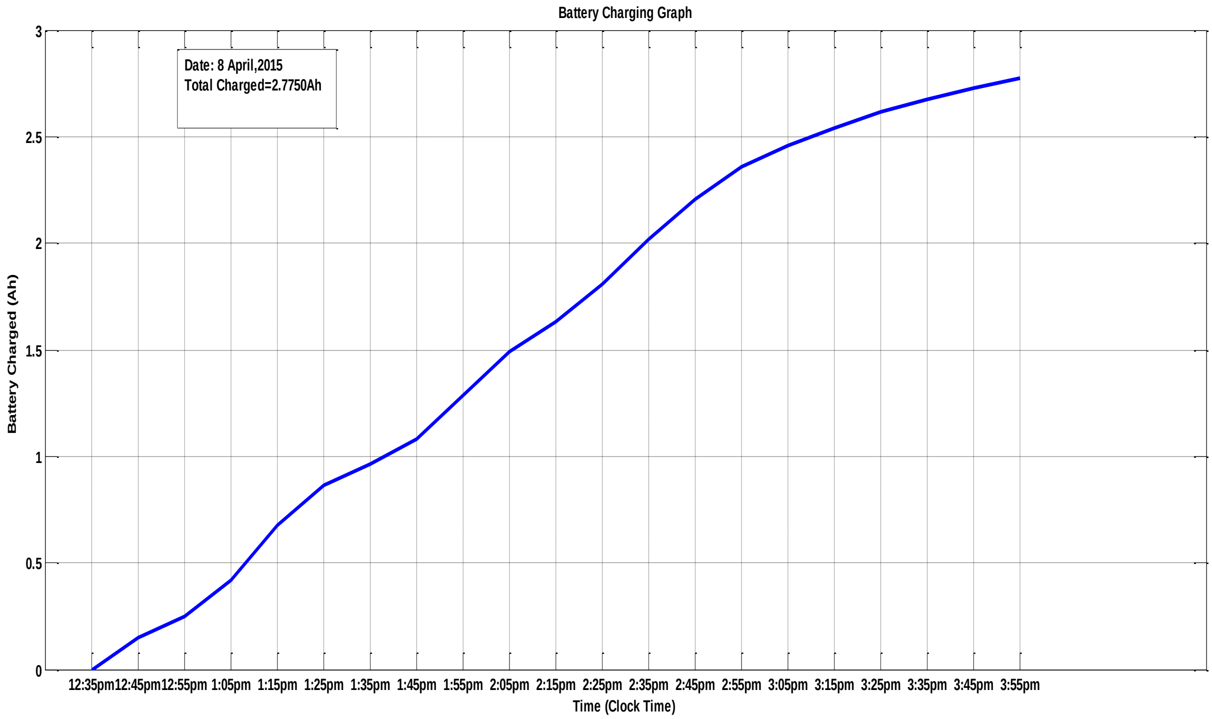


Figure 3.33: Battery charged on 8 April, 2015

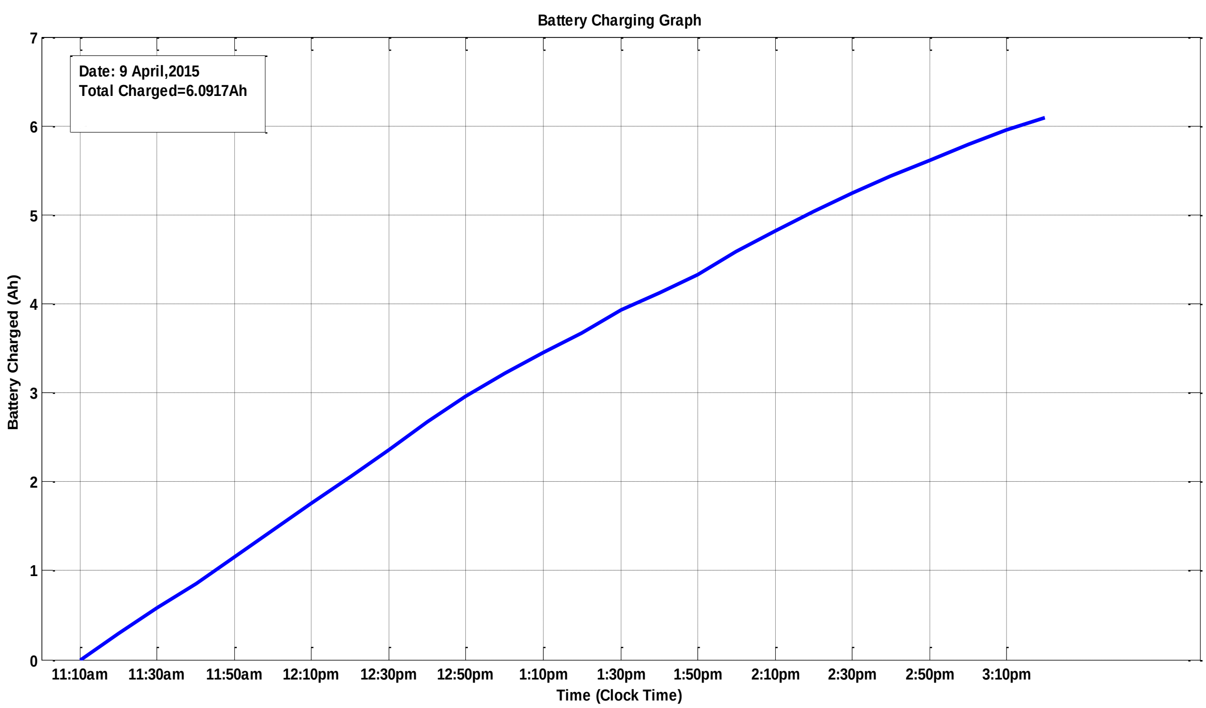


Figure 3.34: Battery charged on 9 April, 2015

Result:

Assuming the whole charging process continuous we find the total charge graph as,

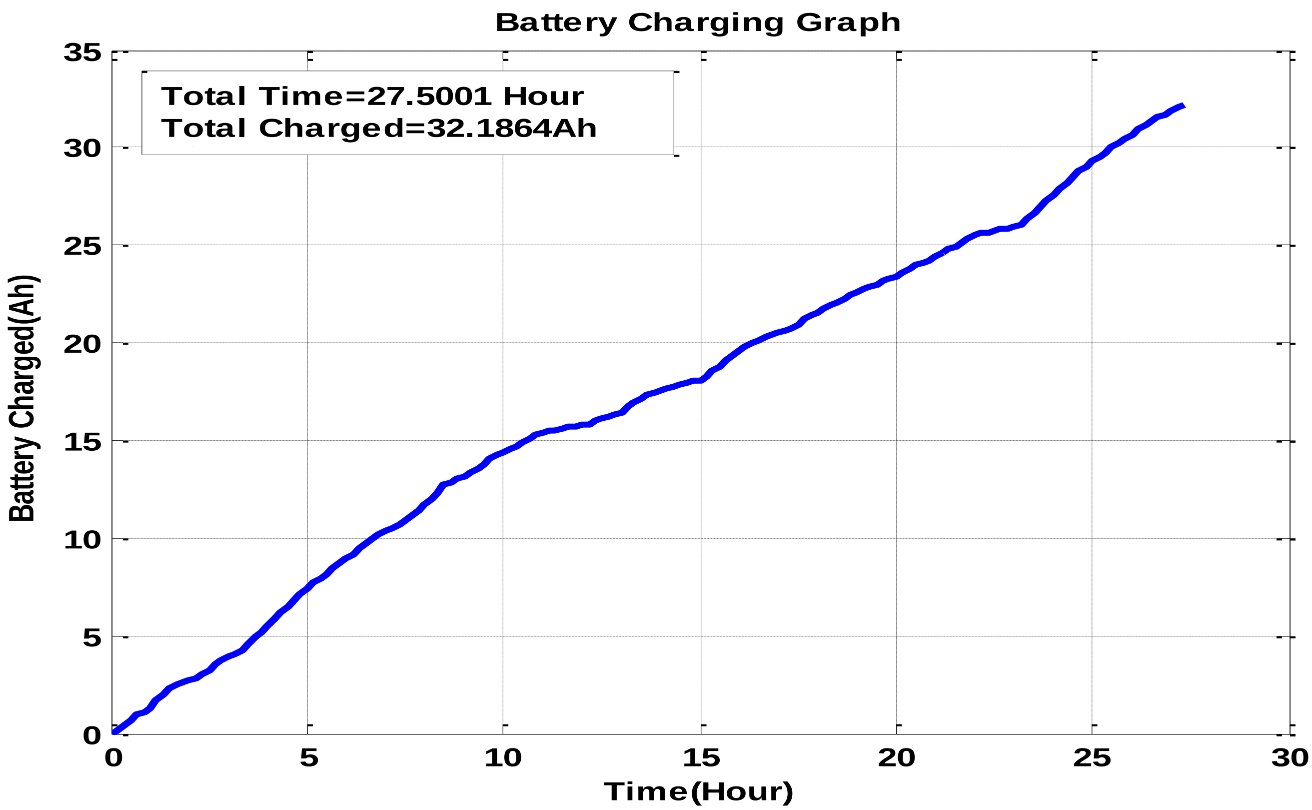


Figure 3.35: Total battery charged over time

We charged the 60.42 Ah battery unit for total of 27.5 hours up to 32.1864 Ah which is 53.27% of its SOC during the end of spring.

3.2 Battery Model

3.2.1 Battery Condition Parameters:

The following parameters are used to define the condition of battery. We have obtained the condition of our battery by analyzing the parameters in the battery modelling process.

1) State of Charge (SOC) (%): The state of charge charge is an expression of battery to represent the battery capacity in terms of percentage. A fully charged battery has 100% SOC and starts to decrease in a discharging process. The current integration over time is used to determine the SOC such as we have used 70Ah battery as 100% SOC.(Dunlop, 1997)

2) Depth of Discharge (DOD) (%):The percentage of battery capacity that has been withdrawn in discharging process expressed as a percentage of maximum capacity. Usually DOD 20% is referred as deep discharge and suggested to recharge for durability.(Dunlop, 1997)

3) Open Circuit Voltage(V_{OC}) (V):The open circuit voltage of battery is the voltage of battery that appears across the battery without any load connected to it in rest or steady state. The open circuit voltage of battery depends on battery state of charge (SOC), specific gravity of electrolyte and temparature. The open circuit voltage of battery is directly proportional to the SOC.

4) Terminal Voltage (V_t) (V):The voltage between the battery terminals with load connected to it is know as terminal voltage. The terminal voltage changes with SOC and charging or discharging current.

5) Voltage Drop (V_d) (V): The contact of electrolyte and battery plates creates a RC effect. Due to that RC effect there is a voltage drop of battery.

6) Internal Resistance(Ω):The resistance a battery has within itself is known as internal resistane of battery. The internal resistance of battery is usually different for charging and discharging state as well as SOC. Usuallly the internal resistance of lead acid battery goes up with discharge due to the change of specific gravity.Self discharge resistance drains the battery by the electroysis of water at high voltage and sllow leakage across the battery terminal at low voltage. The resistances associated with electrolyte resistance,plate resistance,fluid resistance in different charging and discharging level is known as

resistance for charging and discharging. When the battery is over charged or over discharged, the internal resistance is increased significantly due to electrolyte diffusion.

3.2.2 Methodology:

Battery model needs to have high fidelity for meaningful results. The literature review of different battery models such as Simple Battery Model, Thevenin Battery Model, Dynamic Battery Model, Copetti Model, Randle's Battery Model, Electrochemical Model, Electrical-Circuit Model, Analytical Model,Peukert's law, Rakhmatov and Vrudhula extension were done. Preferring a simple yet significant model that will help us to compare our result with the solar vehicle to understand the attribute we chose dynamic model as our experiment model. Then again, some electro chemical model were done for the electrolyte of battery.

3.2.3 Thevenin Battery Model with Dynamic Response:

The extention of Simple Battery Model and Thevenin Battery Model which takes account of the non-linear characteristics of the open circuilt volatage and the internal resistance.

The internal resistance, $R_{internal}$=k/SOC.

$$V_t = V_{OC} - \left(R_b + \frac{k}{SOC}\right) I$$

Varying Voltage and resistance with respect to SOC, the model provides the power value in watt which is given by the equation:

$$P = V_t * I$$

Where,
V_t= Terminal Voltage
I= Battery Current
The internal resistance of the battery can easily be obtained by measuring the open circuitvoltage (V_{OC}) and terminal voltage (V_t) using the following equation:

$$V_t = V_{OC} - IR_i$$

The open circuit voltage (V_{OC})is determined by the SOC which is dependent of the ampere-hour (Ah) of battery.

The battery model so far has been done without considering the capacitive effects of plates and dynamic response of battery. Incorporating the voltage drop (V_d) , we come up with a new equation.

$$V_t = V_{OC} - V_d - IR_i$$

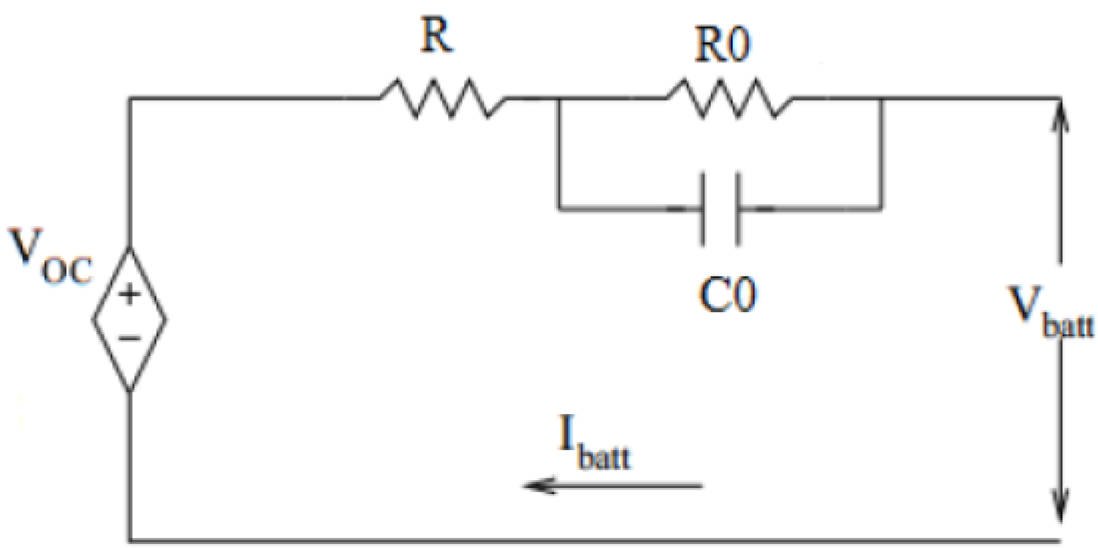


Figure 3.36: Thvenin Battery Model

The variation of the variable resistance (R) significantly changes the internal resistance. The internal resistance of battery also depends whether its charging or discharging. On other note we can say that,

$$V_{OC} - V_t = V_d + IR_i$$

The RC branch of the circuit is shown to figure out the capacitive behaviour of the battery plates. The voltage across $R_o$and $C_o$can be deuced by

$$V_{Ro} = i_{Ro}R_o$$

$$and, V_{Co} = \int i_{Co}dt + V_{initial}$$

$$where, V_{Ro} = V_{Co}$$

Taking derivatives with respect to time in both side we can obtain with

$$R_o\left(\frac{di_{R_o}}{dt}\right) = \frac{i_{C_o}}{C_o}$$

The Battery Current,I(t)=i_{Ro}+ i_{Co}.

$$\therefore R_oC_o\left(\frac{di_{R_o}}{dt}\right) = I(t) - i_{R_o}$$

$$\mathrm{I(t)} = R_oC_o\left(\frac{di_{R_o}}{dt}\right) + i_{R_o}$$

The RC branch resistance (R_o) varies substantially with the discharge current. (Fakham, Lu, & Francois , 2010)

3.2.4 Experimentof BatteryDischargingand DataAnalysis

Apparatus:

- DC Source
- Lead Acid Battery (60V,70Ah)
- Multimeter
- 2Rheostat
- Connecting Wires

Circuit Diagram:

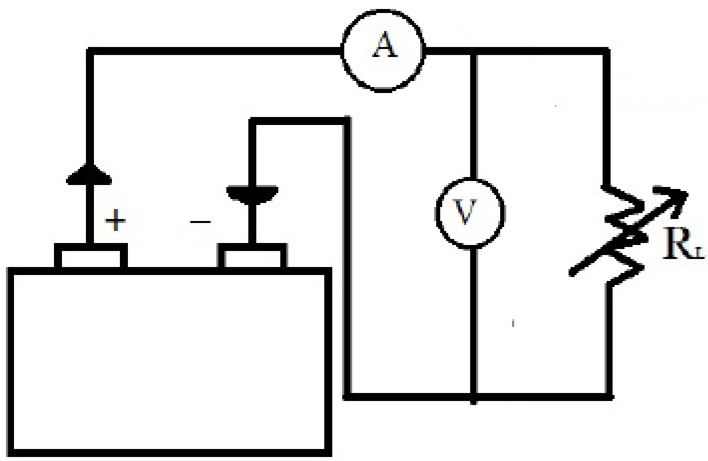


Figure 3.37: Battery Discharging Circuit Setup

Method:

The battery was discharged by 2 rheostats (15Ω each) keeping in mind the described battery model. Data of open circuit voltage (V_{OC}), terminal voltage (V_t), Battery Current (I) was measured. The current (I) was varied 2A to 5.5A each time and the change of terminal voltage (V_t) was obseved to find V_{OC} -V_t in every instant.Then, the data was plotted using MATLAB to understand the battery condition parameters with a simple equation.(Tariq, Sabbir, & Azad, 2014)

The raw data was fitted by linear regression to come up with an equation. The basic concept of line regression is, if n raw data points are to be used to predict a certain attribute; the equation is given by:

$$y = a_0 + a_1 x$$

Where, a_0 and a_1 are linear regression model constants.

The constants of linear regression model are deduced by minimizing the error of the model by:

$$a_1 = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}$$

and, $$a_0 = \frac{\sum_{i=1}^{n} y_i}{n} - a_1 \frac{\sum_{i=1}^{n} x_i}{n} = \bar{y} - a_1 \bar{x}$$

where in our analysis,

a_1=Internal Resistance ($R_{internal}$) of battery

a_0=Voltage Drop (V_d)

Result and Data Analysis:

The plotted curves by MATLAB below shows the V-I characteristics of battery for a specific SOC while it was being discharged. The battery current flow were taken in x-axis and difference of the $V_{OC}$and V_t were in y-axis so that we could come up with the slop as the internal resistance of battery and the constant as voltage drop.

The graphs below illustrate the data taken at the time of experiment.

V_{OC}-V_t Vs. Battery Current(I):

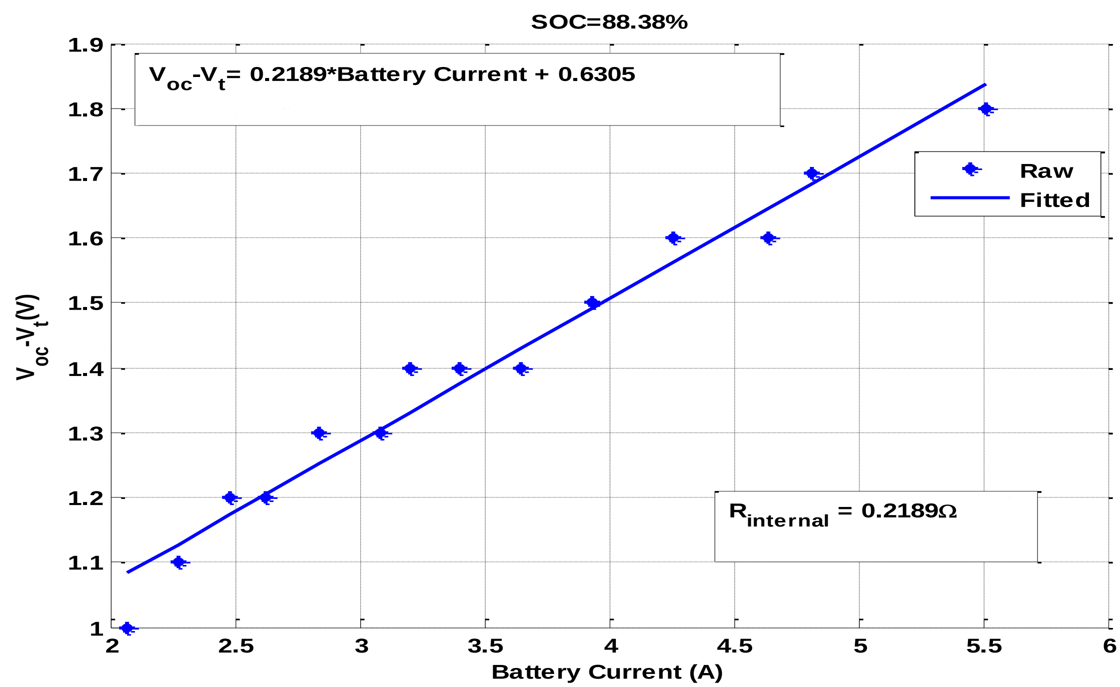


Figure 3.38:(V_{OC}- V_t)-I characteristics at 88.38% SOC

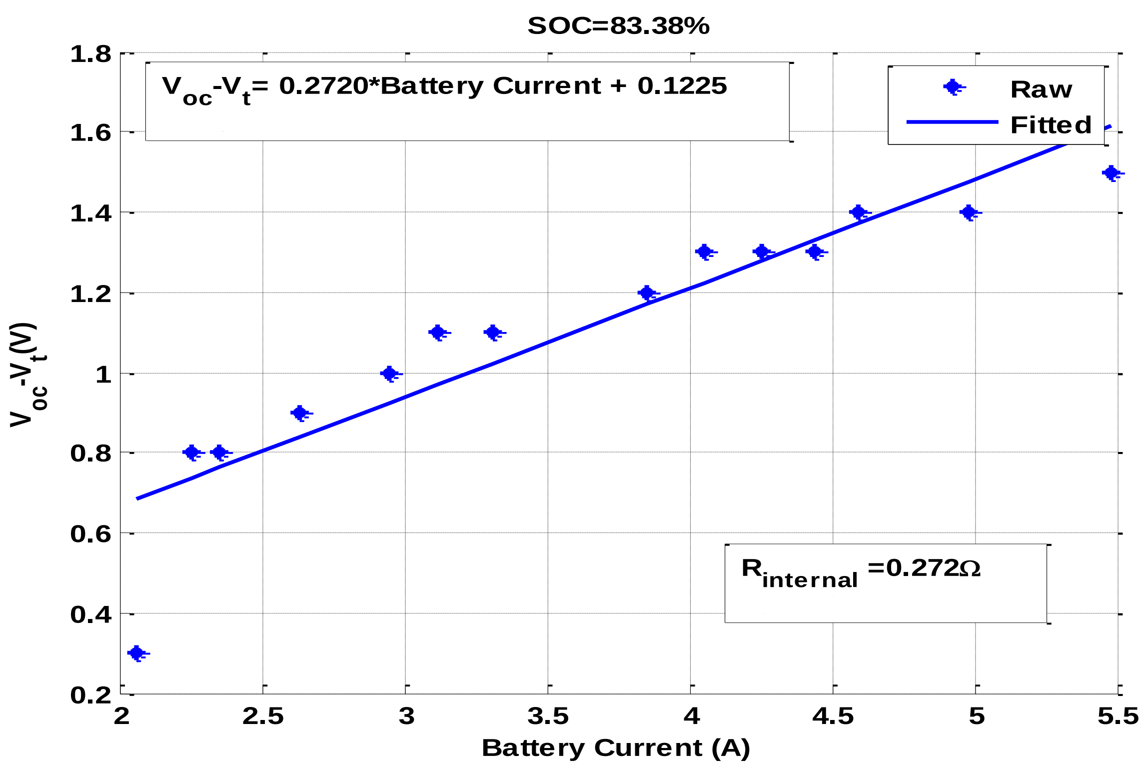


Figure 3.39:(V_{OC}- V_t)-I characteristics at 83.38% SOC

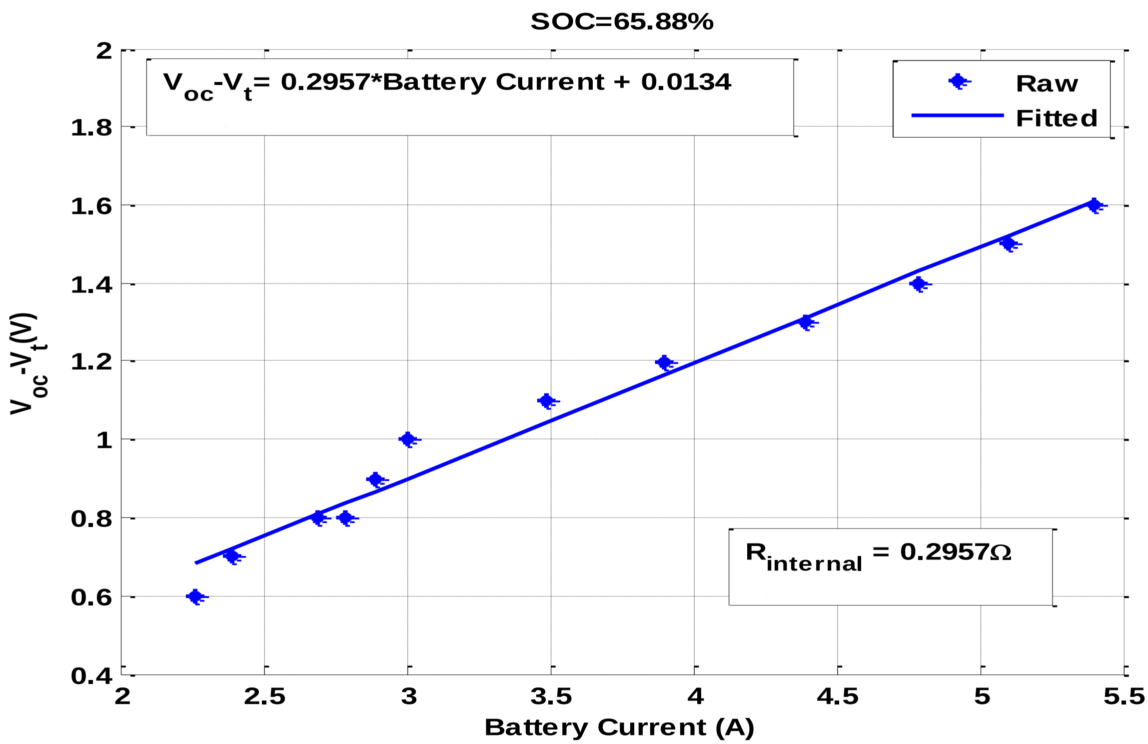


Figure3.40:(V_{OC}- V_t)-I characteristics at 65.88% SOC

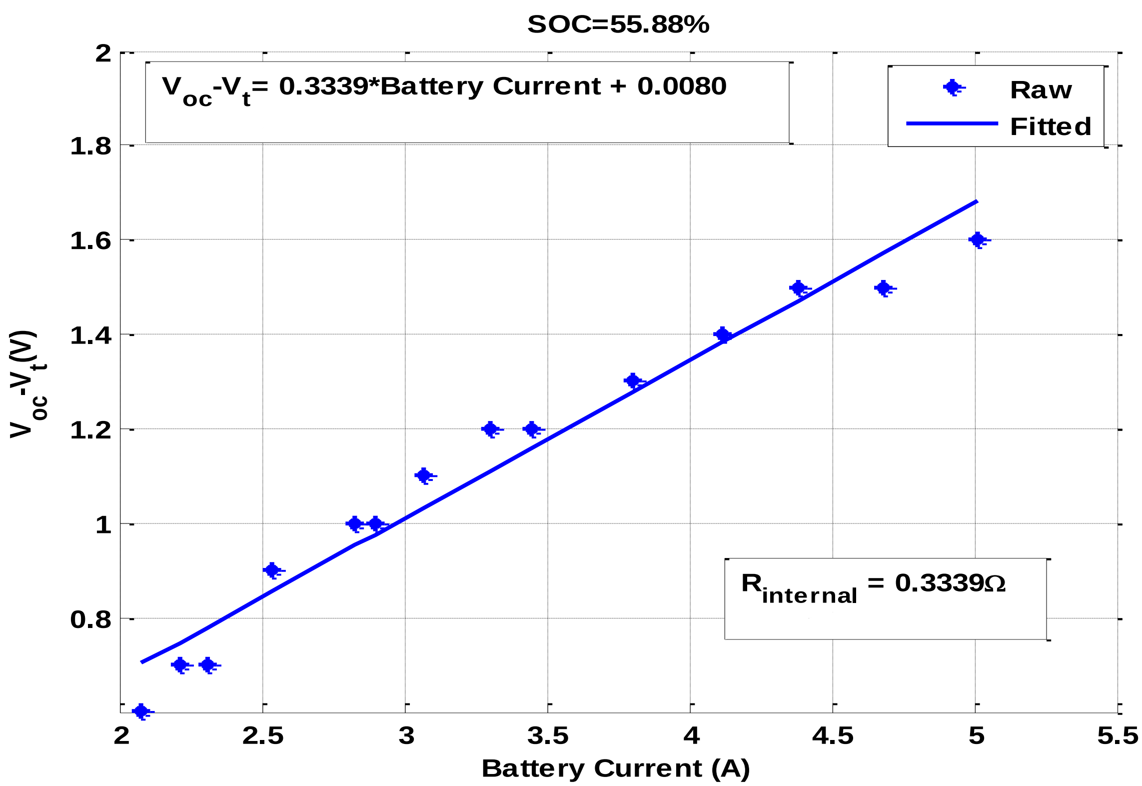


Figure 3.41:(V_{OC}- V_t)-I characteristics at 55.88% SOC

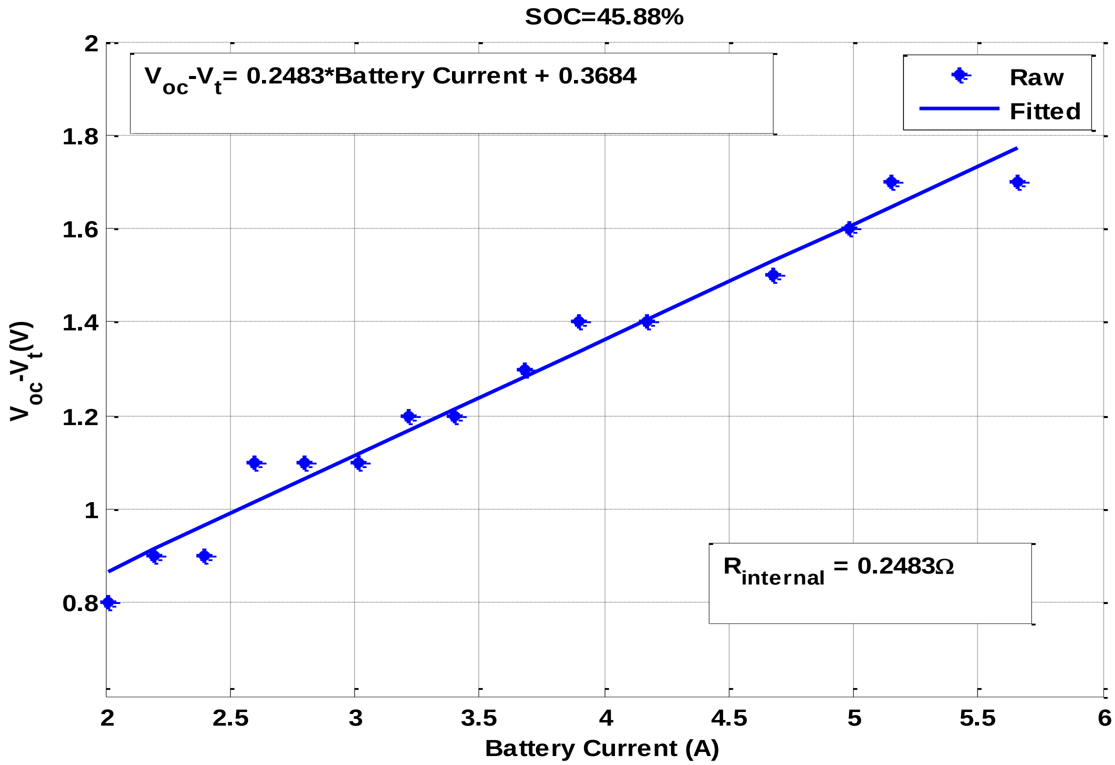


Figure 3.42:(V_{OC}- V_t)-I characteristics at 45.88% SOC

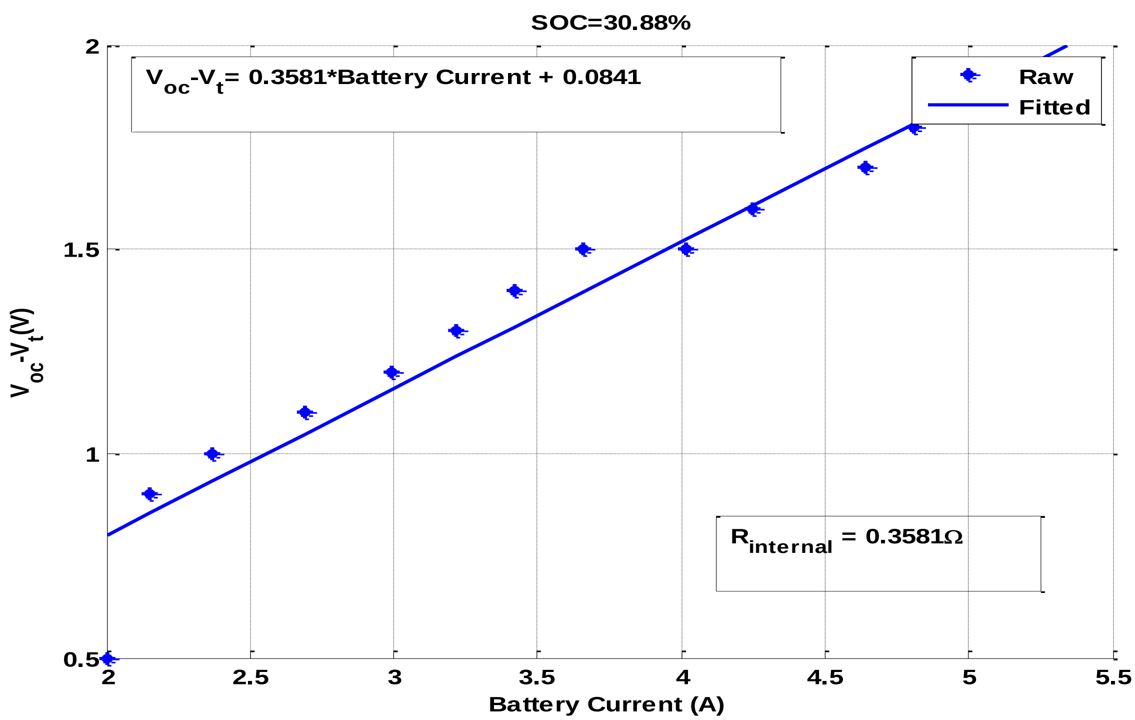


Figure 3.43:(V_{OC}- V_t)-I characteristics at 30.88% SOC

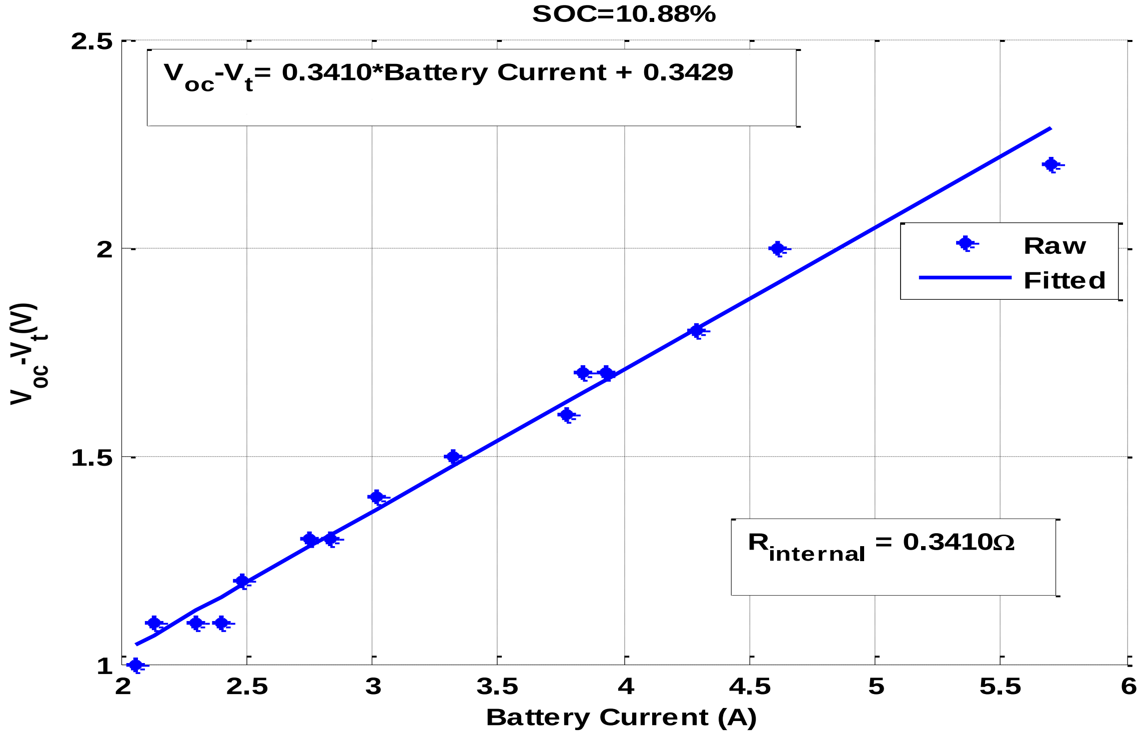


Figure 3.44:(V_{OC}- V_t)-I characteristics at 10.88% SOC

Result:

From the analyzed data plotted above we extracted the y-intercept and x-intercept and plotted those data again; against the percentage SOC to come up with the internal resistance ($R_{internal}$) value, voltage drop (V_d) and open circuit voltage (V_{OC}). At the same time, the relation between the deduced values was used to find its relationship with SOC.

Internal Resistance ($R_{internal}$):

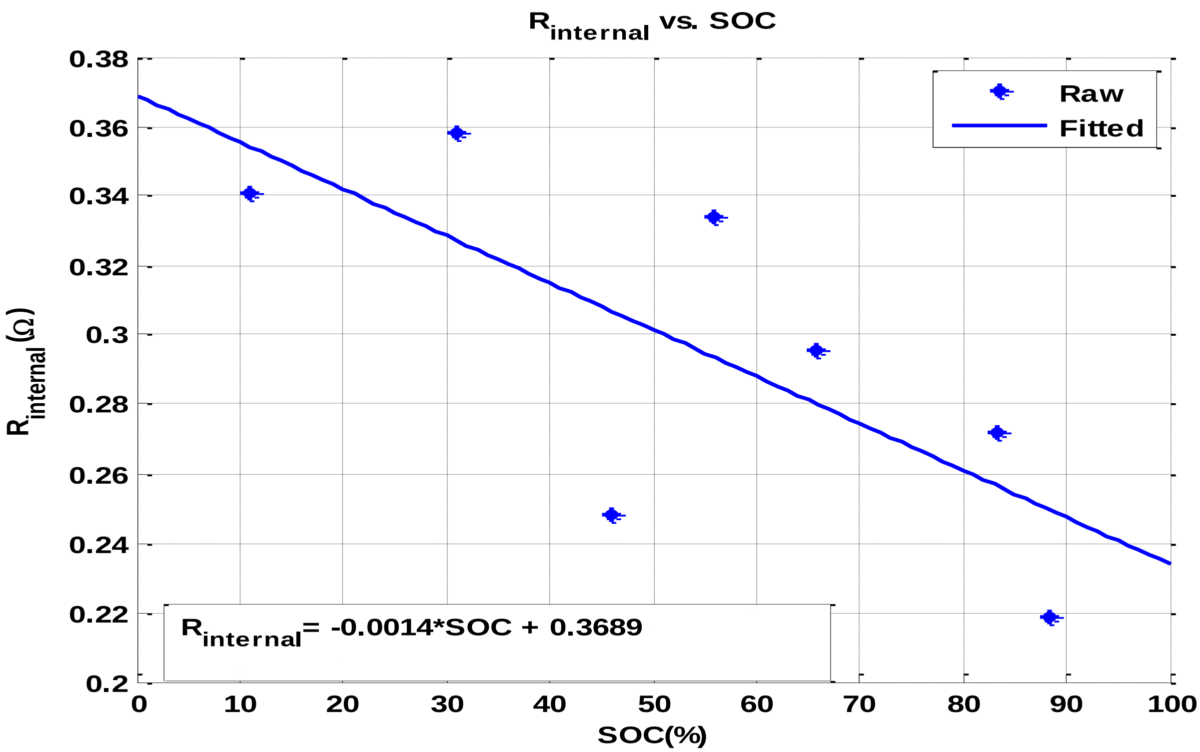


Figure 3.45: Varying Internal Resistance with SOC relationship

The line regression shows the relation of internal resistance ($R_{internal}$) with the percentage state of charge (SOC) with an equation,

$$R_{internal} = -0.0014 * SOC + 0.3629$$

We can now easily find the internal resistance for a specific SOC using this equation for further analysis when necessary.

Voltage Drop (V_d):

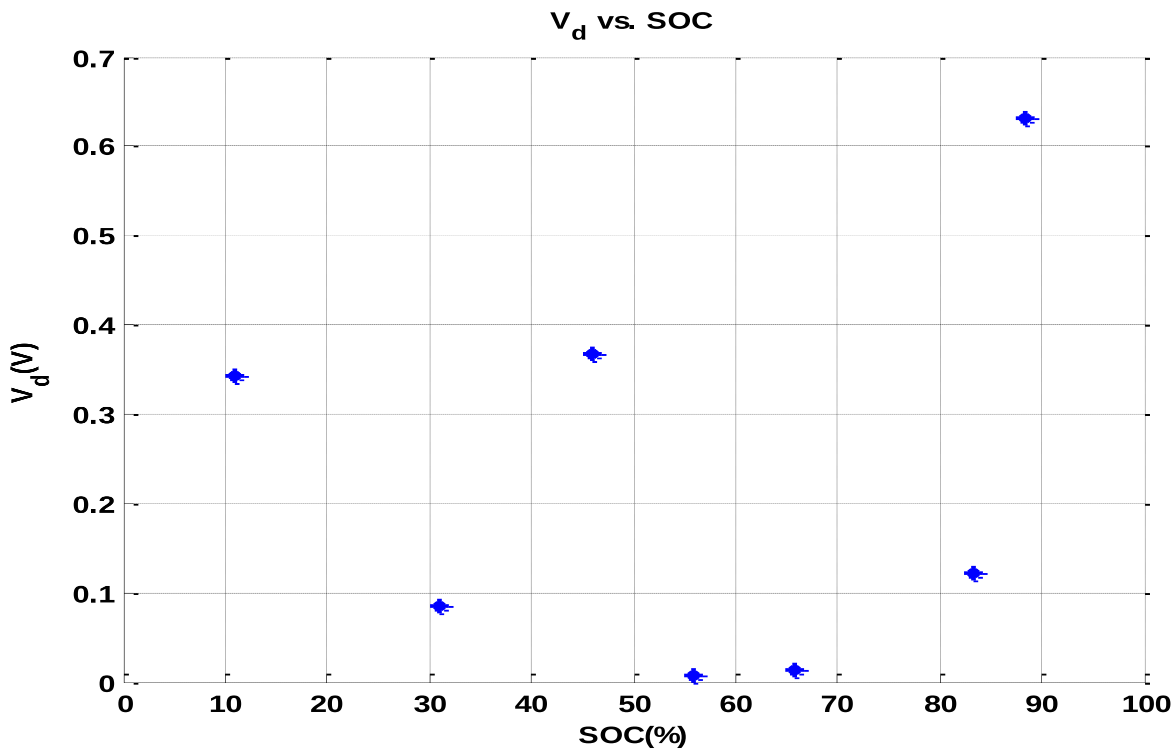


Figure 3.46: Varying Internal Resistance with SOC relationship

The above graph shows that the voltage drop (V_d) are scattered over the graph randomly. This set of data was not possible to be fitted in any equation; rather being random these data indicates the voltage drop (V_d) is constant over the percentage SOC.

3.3 Battery State of Charge Estimation

3.3.1 Battery Charging at Constant Current

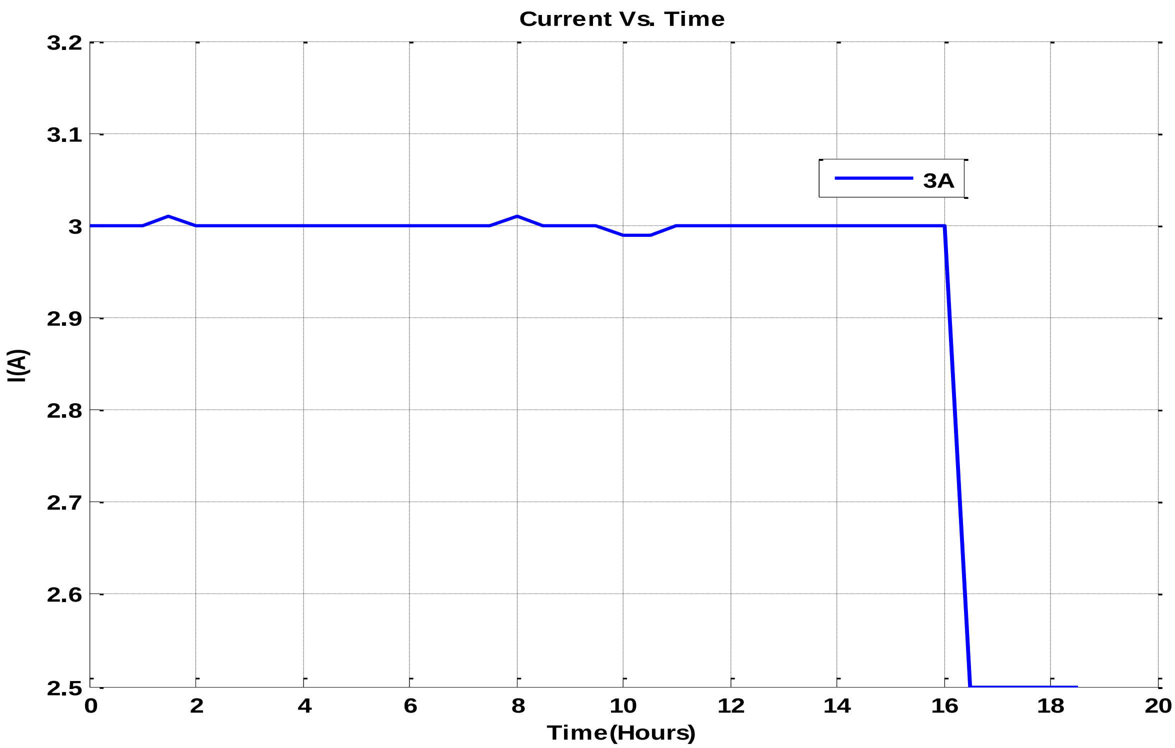


Figure 3.48: Battery charging at 3A current(constant)

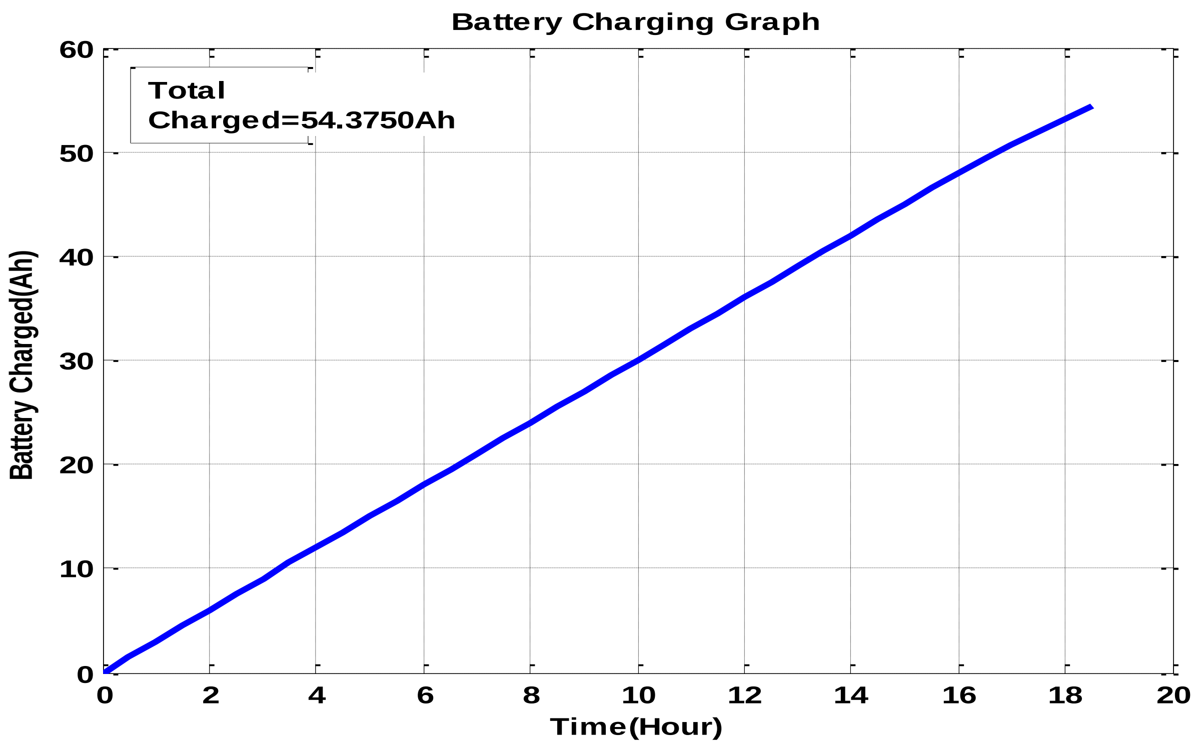


Figure 3.49: Battery charge

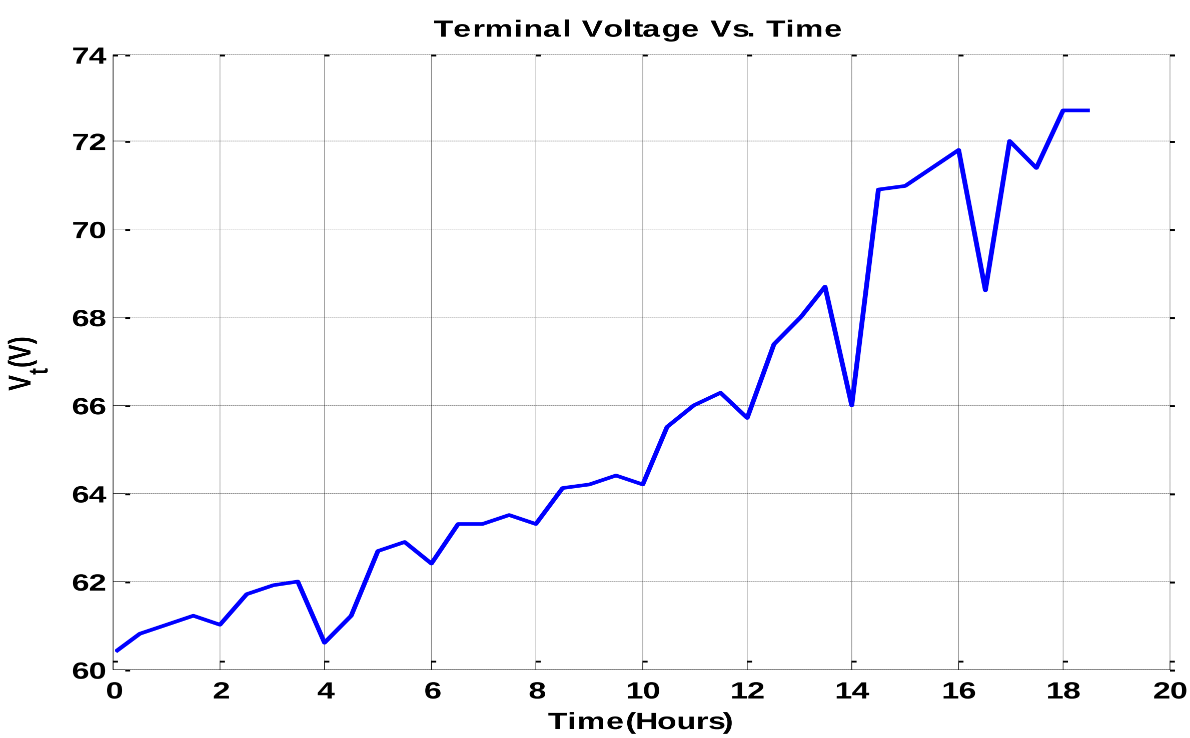


Figure 3.50: Terminal Voltage Vs. Time while charging

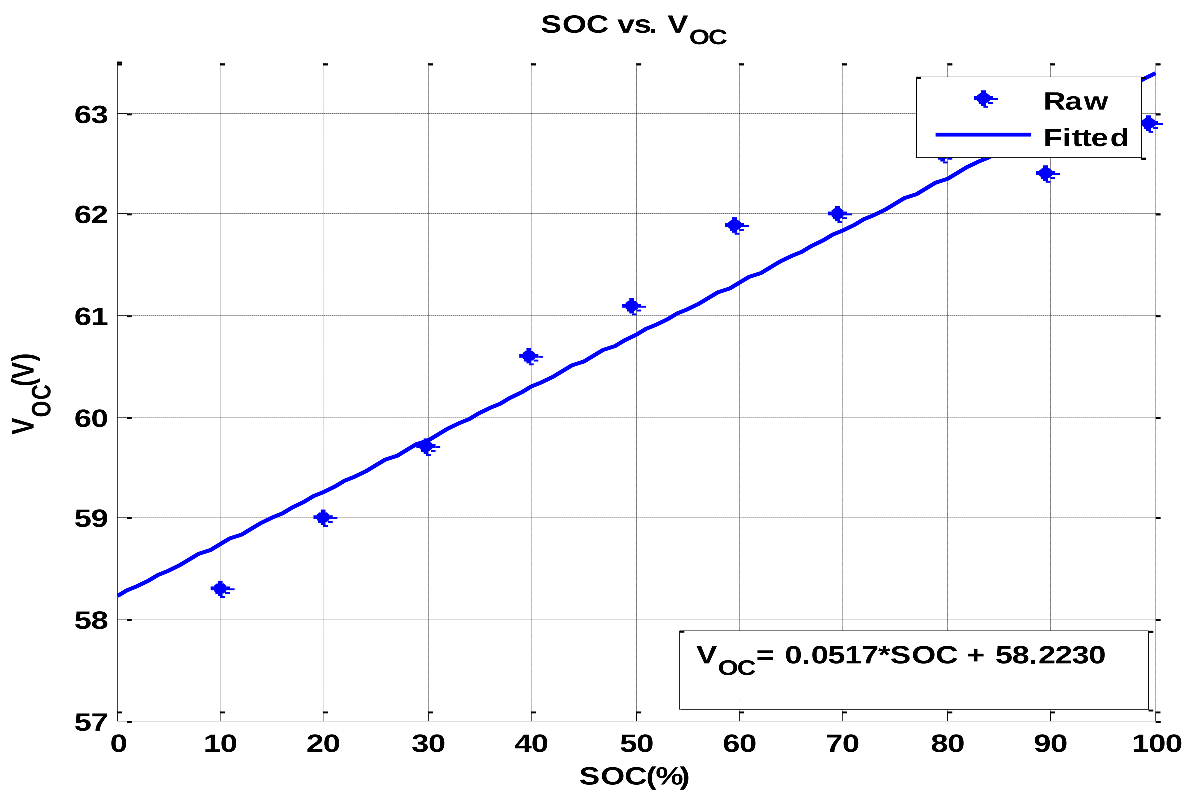


Figure 3.51: SOC Vs. V_{OC} while charging

3.3.2 Battery Discharging at Constant Current

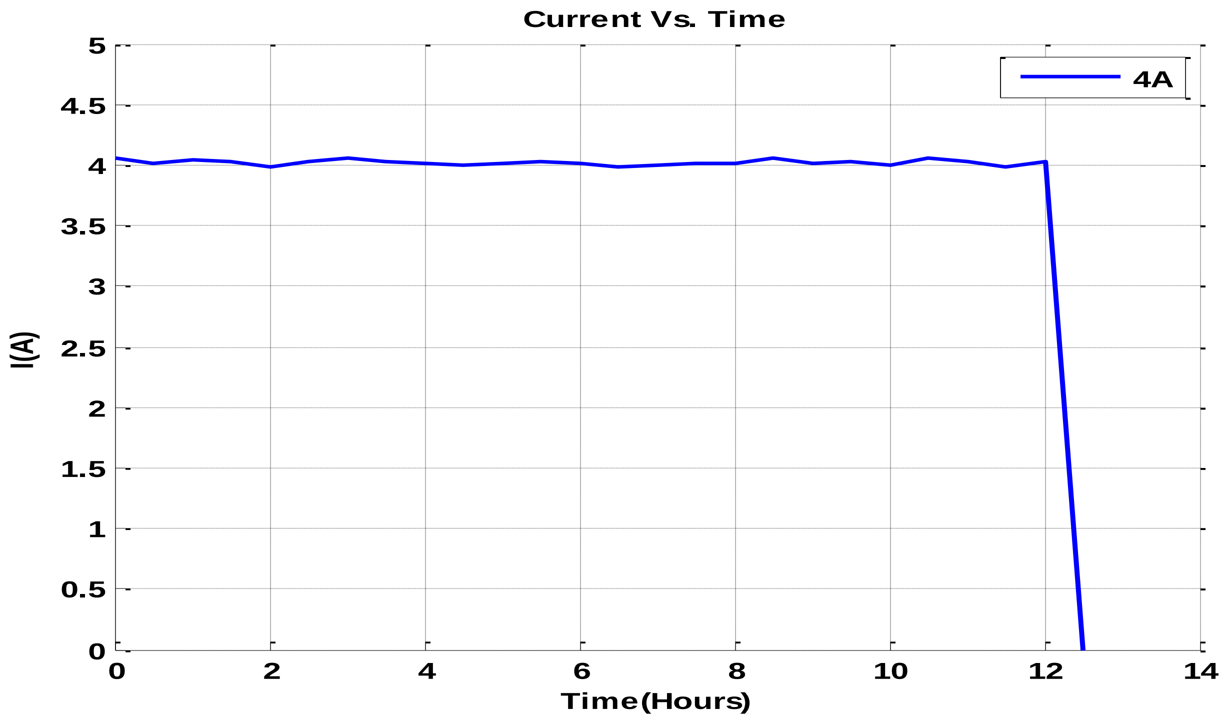


Figure 3.52: Battery discharging at constant current (4A)

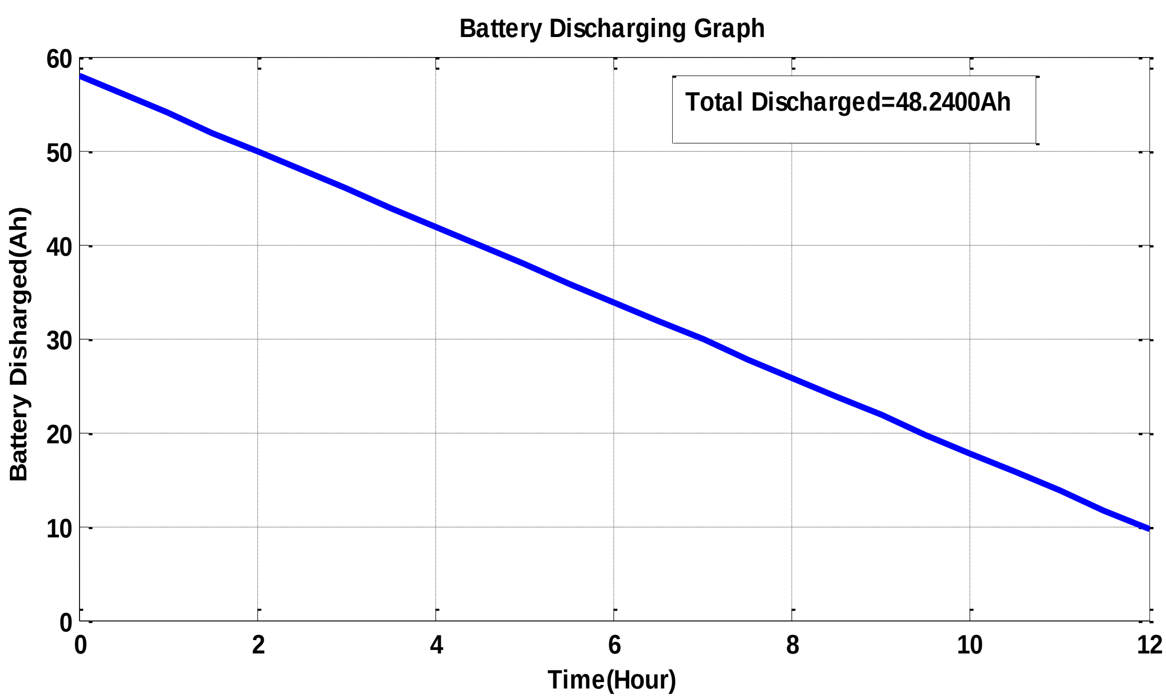


Figure 3.53: Battery discharge

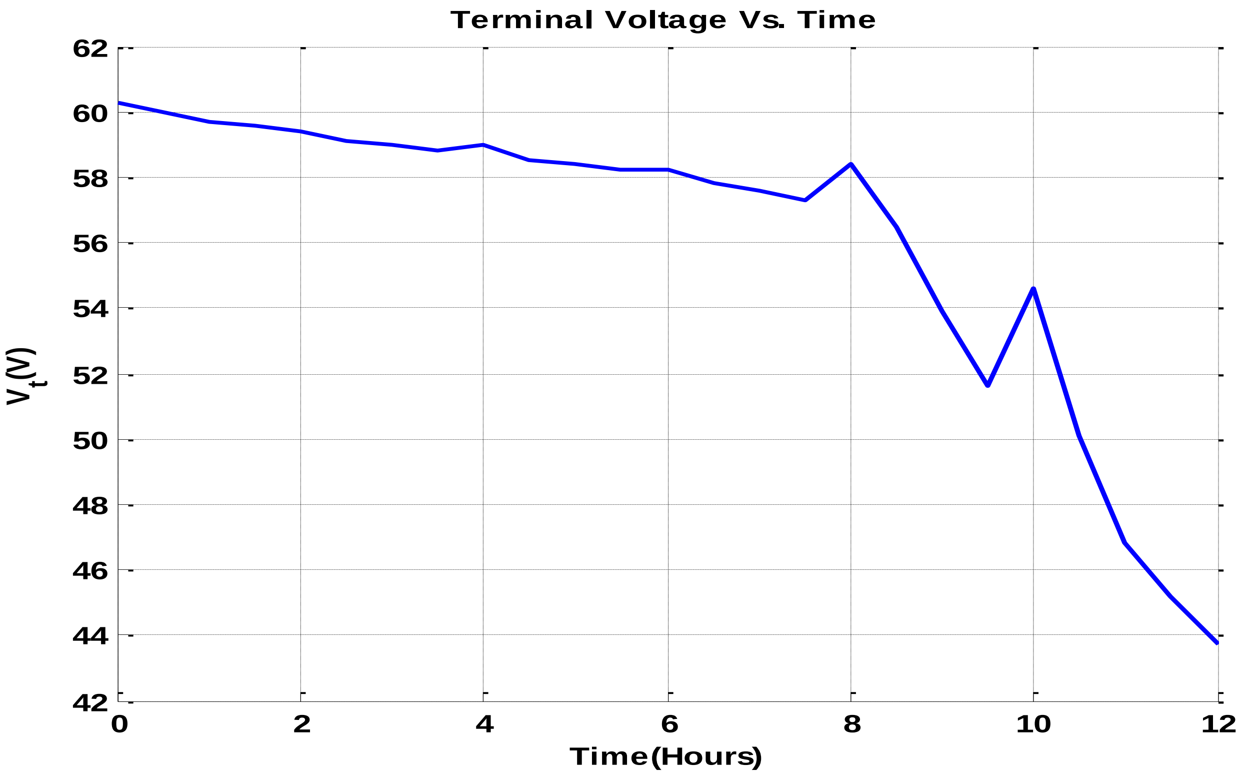


Figure 3.54: Terminal Voltage Vs. Time

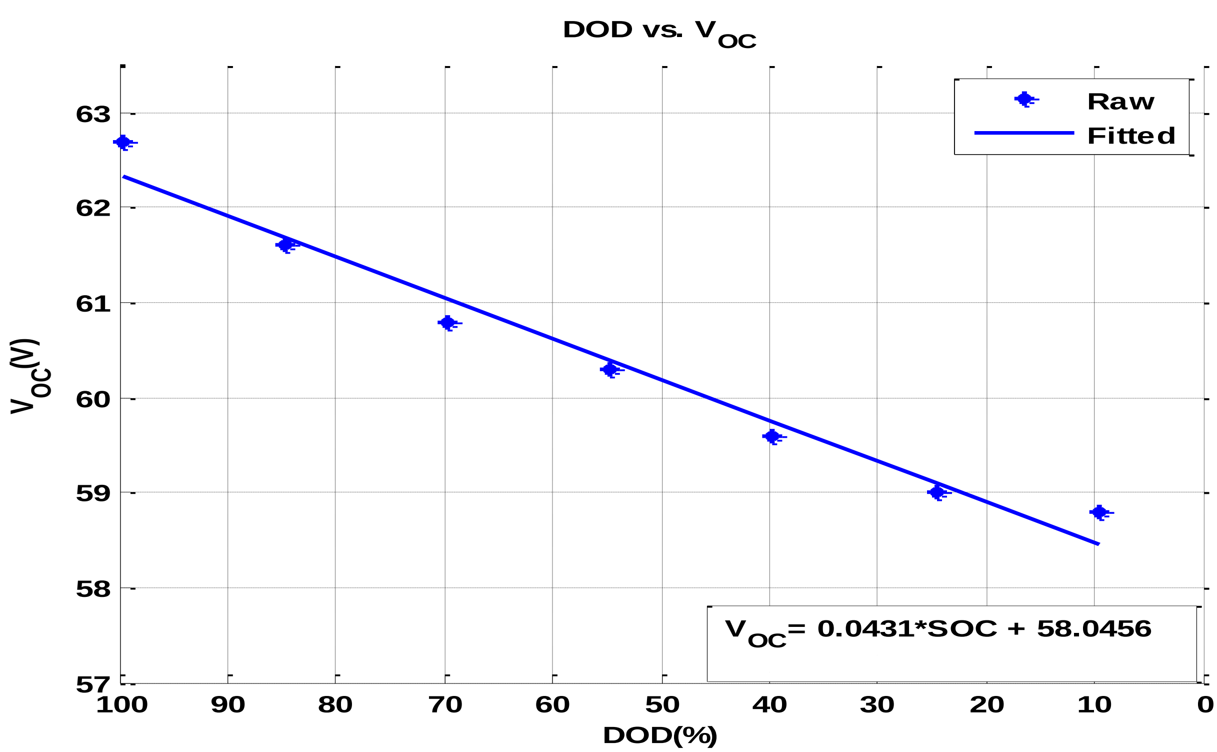


Figure 3.55: DOD Vs. V_{OC} while discharging

Result:

We charged the battery unit for total 18.5 hours at 3A current while storing 54.375Ah. After every 6 Ah charging we measured the V_{OC} to plot them with respect to SOC and after line regression we deduced the equation of V_{OC},

$$V_{OC}=0.0517*SOC+58.2230$$

After that we discharged the battery unit for total 12 hours at 4A current while discharging 48Ah. After every 8Ah discharging we measured the V_{OC} to plot with respect to SOC and after line regression we deduced the equation of V_{OC},

$$V_{OC} = 0.0431*SOC + 58.0456$$

Here the difference between the charge stored while charging and charge dissipated during discharging is due to the effect of charge efficiency of Lead-Acid Battery.

3.4 Battery Ageing Effect Based On Specific Gravity Test

3.4.1 Background

Specific Gravity:

Specific gravity is the most direct way to determine the state of charge (SOC) of battery. The ratio of weight of a solution to the weight of equal volume water at a specific temperature is called specific gravity. For electric vehicle where heavily cycled batteries are used needs a specific gravity of 1300 at standard temperature.

Gassing Effect:

The battery charging process leads to some side chemical reactions with the main reaction in the battery. The side reaction leads to produce hydrogen and oxygen gas by anode and cathode respectively. The gassing effect may occur for various reasons such as charging faster than nominal voltage rate, gassing current.

Specific Gravity during Recharging:

The specific gravity does not have a linear relationship with the amount of charge returned in Ampere-hour (Ah). There is no gassing effect at the early stage of charge to mix with electrolyte. The heavier acid being released from anodes will lie in the bottom of the cell container. In this case, the hydrometer reading will not give the true specific gravity or state of charge.

Specific Gravity Chart:

A new battery usually has the following specific gravity at standard temperature given in the table below:

SOC(%)	Specific Gravity	Open Circuit Voltage(V_{OC})		
		2V	12V	60V
100%	1265	2.10	12.65	63.25
75%	1225	2.08	12.45	62.25
50%	1190	2.04	12.24	61.2
25%	1155	2.01	12.06	60.3
0%	1120	1.98	11.89	59.45

Table 3.1 :BCI (Battery Council International) standard for SOC estimation.(Buchmann)

The hydrometer test needs to be corrected when it is not done in standard temperature (25^{o}).

For every 3F above 77 F or 1.5^{o}C above 25^{o}C, 100 points need to be added with hydrometer reading.

Moreover, the cell voltage can be obtained by,

$$Cell\ Open\ Circuit\ Voltage = \frac{Specific\ Gravity}{1000} + 0.845$$

Battery Ageing:

The process of battery losing its capacity with the number of cycles is known as battery ageing. A new battery of full capacity starts to fade its performance over time.

3.4.2 Estimation of Specific Gravity and State of Charge:

Methodology:

The specific gravity test complies the concentration of acid in battery with the state of charge (SOC). The discharging process consumes the active material and the concentration of acid decreases so does the SOC.(Samolyk & Sobczak, 2013)

In loaded condition, the reaction of the battery plates with the electrolyte will cause an internal loss of charge because of the chemical reaction and the current of the load. The additive effect due to battery aging and discharge current can be obtained. Furthermore, the electrochemical theory is used to obtain the internal loss of battery. Using these features, the SOC of battery can be accurately calculated by the following electrochemical model.

Electrochemical Model:

The electrochemical model takes in consideration of the chemical energy being converted into electrical energy by a redox reaction expressed generally as

$$aA + ne \leftrightarrow cC$$

The other electrode will have the same kind of reaction

$$bB - ne \leftrightarrow dD$$

Hence, the entire reaction of the battery is the summation of the two reactions

$$aA + bB \leftrightarrow cC + dD$$

In lead acid battery,

$$Pb + PbO_2 + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2PbSO_4 + 2\,H_2O$$

The chemical energy converted into electrical energy is deduced by,

$$\Delta G = -nFE^0$$

Where,

F= Faradays Constant (96,487 kgm^2/As^3).

E^o= EMF of the battery.

The Nernst Equation of lead acid battery is

$$E = E^0 - \frac{GT}{nF} \ln \frac{H_2SO_4}{H_2O}$$

Where,

G=Gas Constant

T=Temperature of the battery

Usually the chemical energy is supposed to convert fully into electrical energy but the gassing effect exhibitsresistance which dissipates a part of the energy.

$$C_R = \frac{I}{nFAK[\frac{C_O}{C_R}\exp\frac{-\alpha nFE^0}{GT} - \exp\frac{(1-\alpha)nFE^0}{GT}]}$$

This equation relates the concentration of sulfuric acid to determine its specific gravity and relate with SOC.(SHIAO, SU, YANG, & HUNG)

Here,

C_o=Concentration of oxidation agent.

C_R=Concentration of reduction agent.

A=Surface Area of electrode.

α =Transfer Factor.

η= E-E^o

K= Ratio of forward and reverse reaction constants.

3.4.3 Experiment on Electrochemical Model to Determine Battery Health and Battery Ageing

Apparatus:

- Hydrometer
- Multi meter

Procedure:

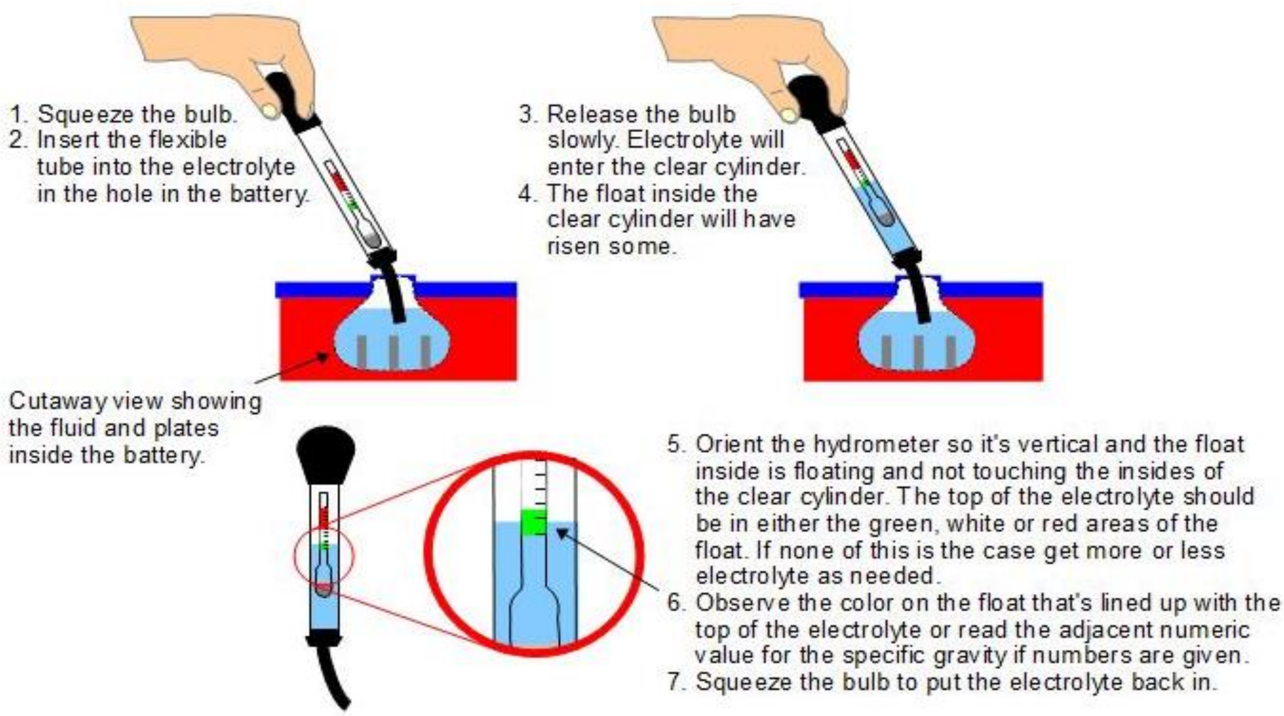


Figure 3.56: Specific Gravity Test Procedure.

(How to use a hydrometer to measure specific gravity)

3.4.4 Data Analysis and Result

Experiment 1:

Cell Comparison of Specific Gravity:

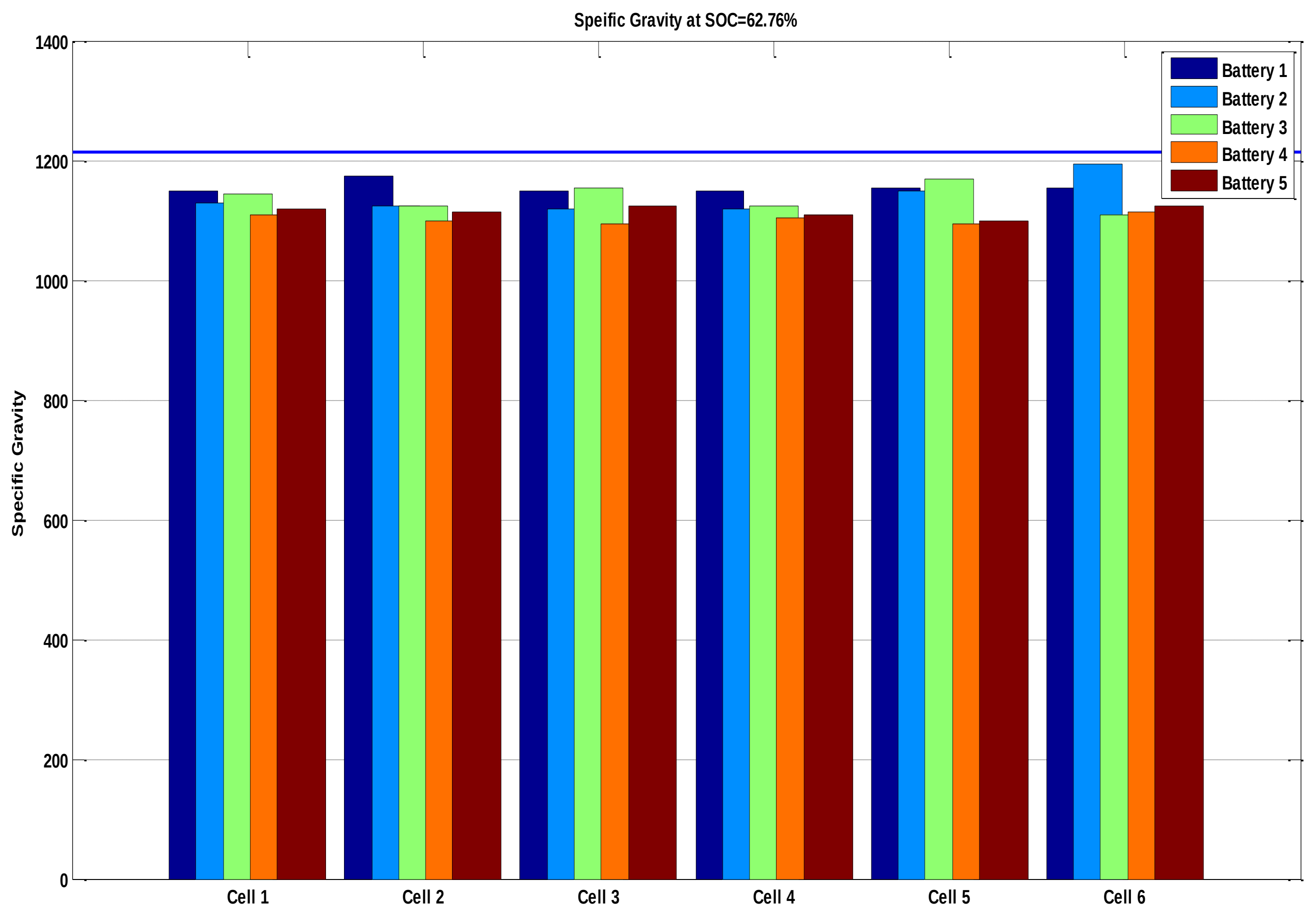


Figure 3.57: Specific Gravity of Battery Cells at SOC 62.76%

Battery Comparison of Specific Gravity:

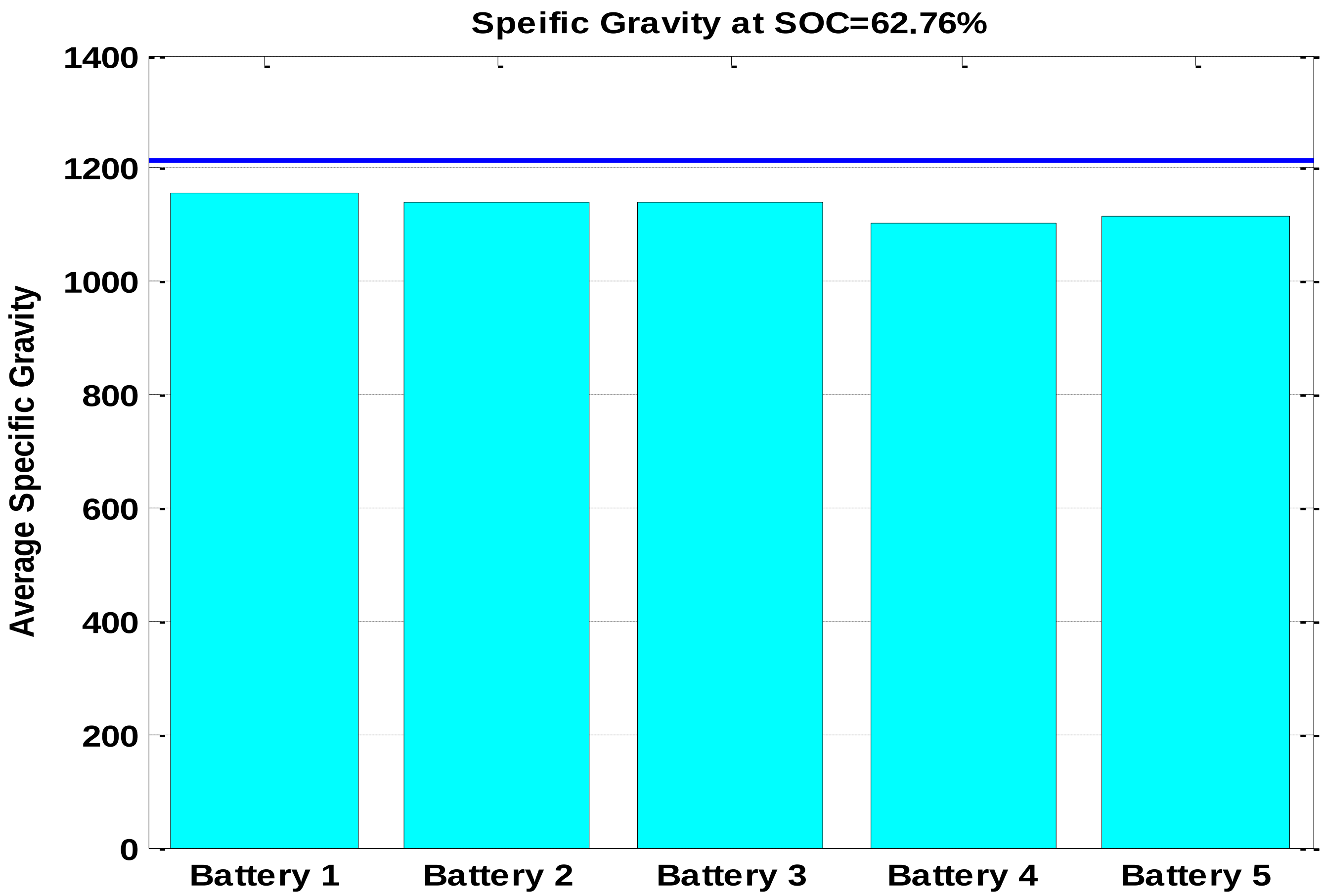


Figure 3.58: AverageSpecific Gravity of Battery Cells at SOC 62.76%

The benchmark of each battery cell's specific gravity at 62.76% SOC is supposed to be 1213. The battery cells of every battery did not reach to the benchmark as it is supposed to.The open circuit voltage shows to be 59.27V as per specific gravity calculation but the test was done at 62.4V.The error occurred due to battery ageing.

Experiment 2:

Cell Comparison of Specific Gravity:

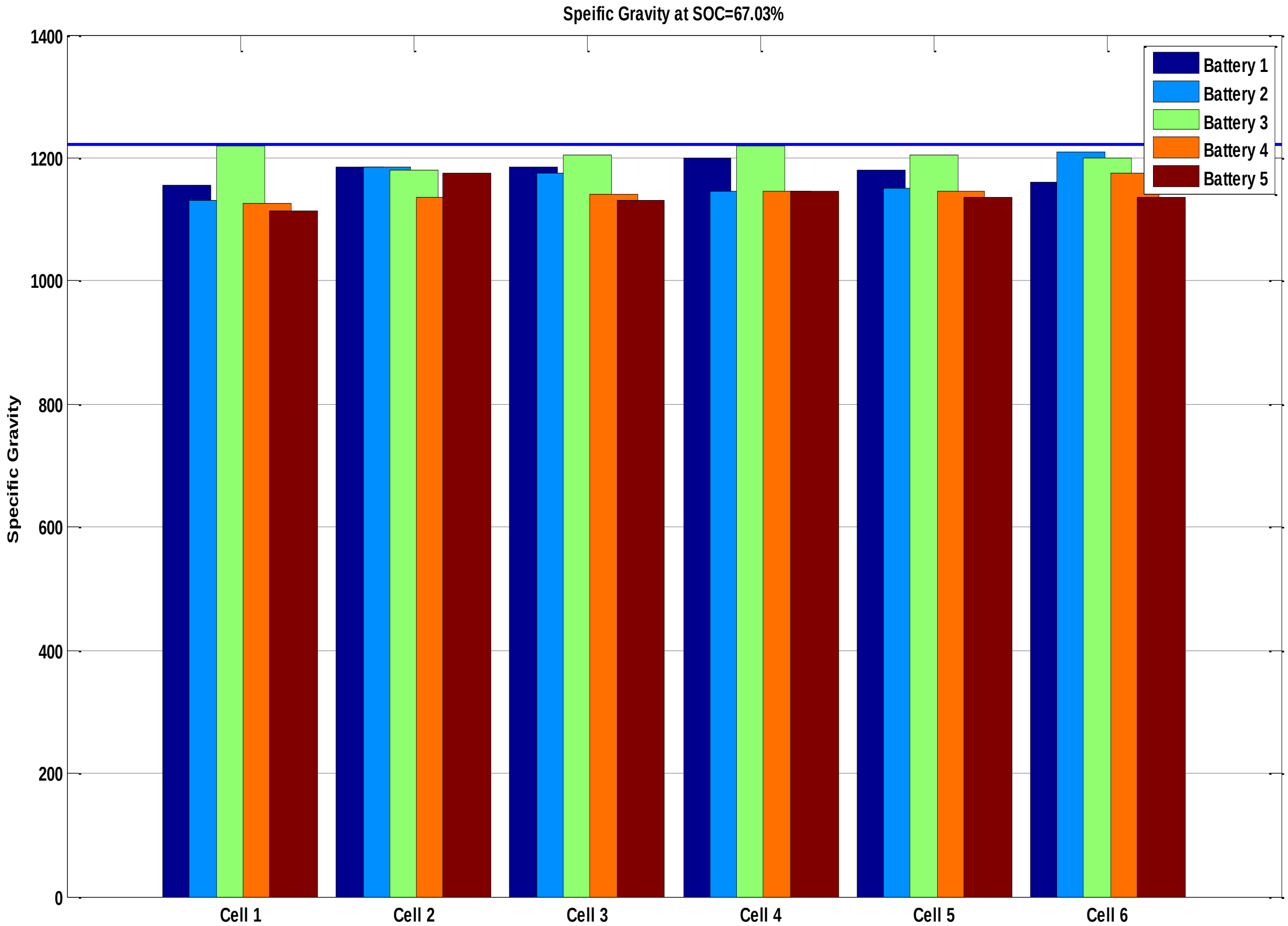


Figure 3.59: Specific Gravity of Battery Cells at SOC 67.03%

Battery Comparison of Specific Gravity:

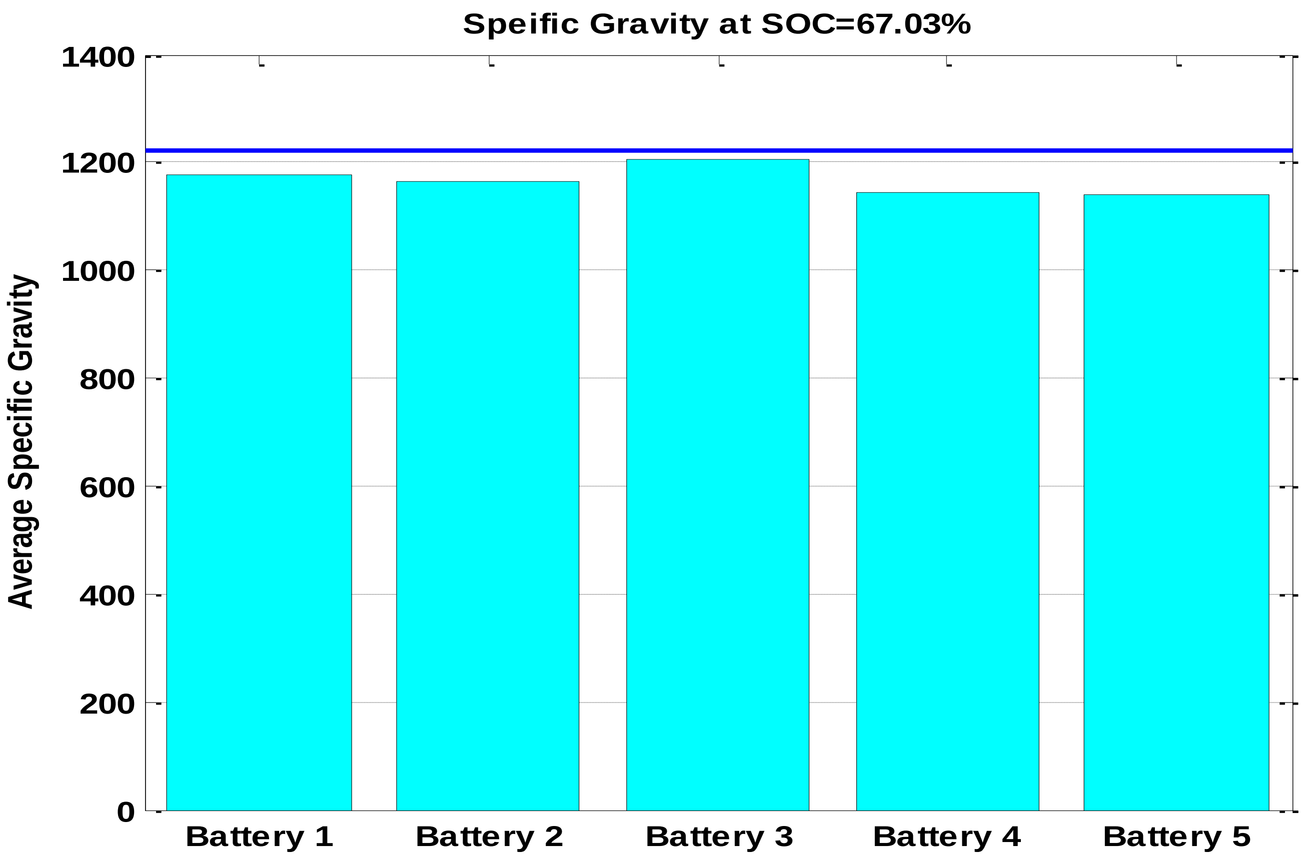


Figure 3.60: Average Specific Gravity of Battery Cells at SOC 67.03%

The batteries were charged and the SOC was increased almost 4.27%. Following the same procedure, the specific gravity value was extracted. This time also the battery cells and average specific gravity could not reach to the standard value of 1223. The extracted battery voltage was 60.34 where it was supposed to be 62.6.

Battery Comparison of Average Specific Gravity with increased SOC:

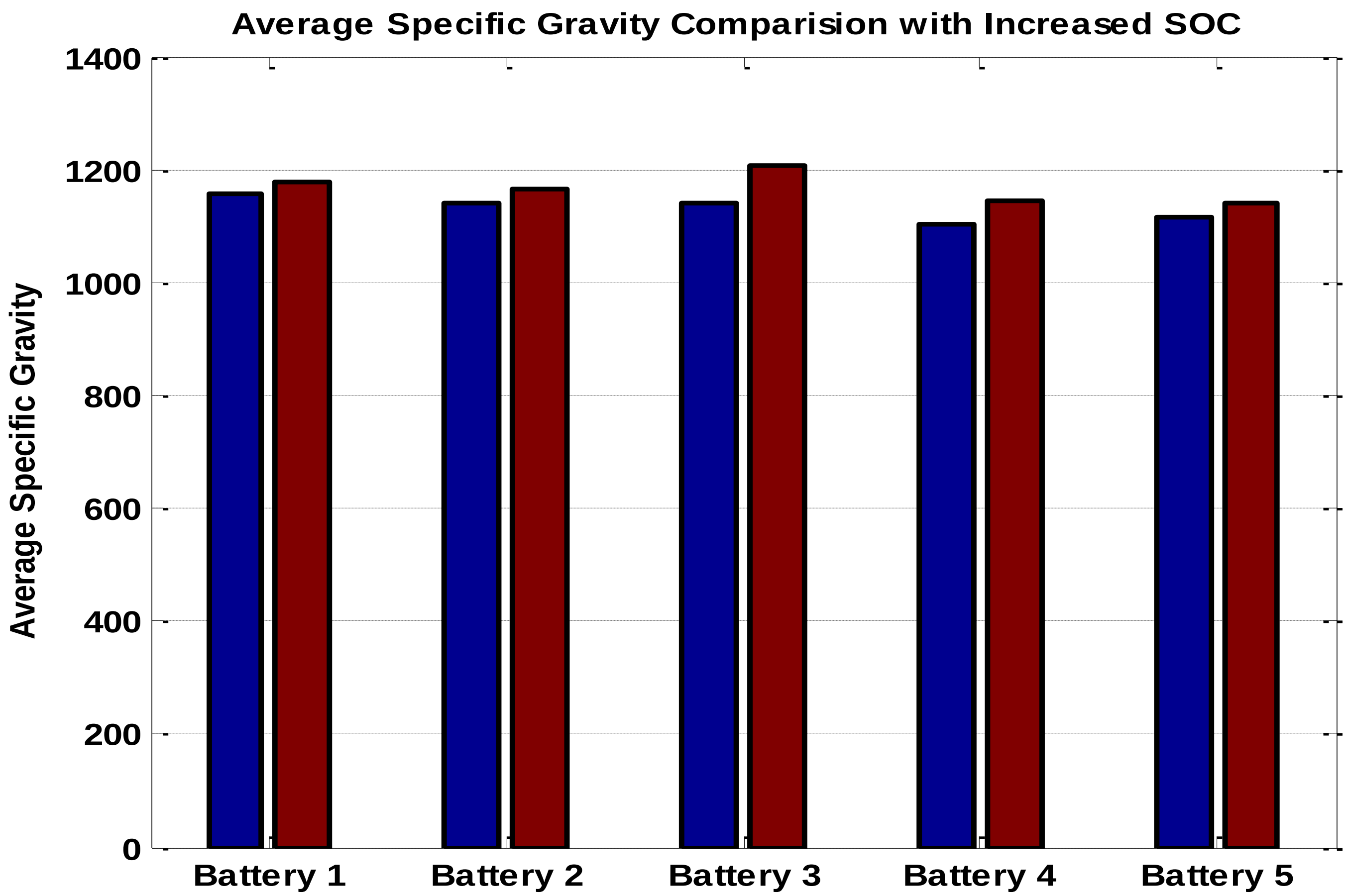


Figure 3.61: Average Specific Gravity with increased SOC

Batteries with increasing SOC also tend to have increment in their average specific gravity. The experiment data also tend to increase the specific gravity with SOC but it could not reach to the optimum value it was supposed to be. The value not being able to reach optimum level proves that their capacity is reduced due to battery ageing.

3.5 Electromagnetic Interferences (EMI)

Electric Vehicles (EV) are promising replacements for vehicles running on combustion engine.

One problem that naturally results from making an EV is Electromagnetic Interferences from different components like the motor, Batteries and wires carrying high current. This EMI can hamper the operations of various electronic components present in the car. This paper looks into experiments done to show the presence of EMI in an EV, as well as, several methods to eliminate or lower the effects of EMI in an EV.

What is EMI?

Electromagnetic interference is the radio frequency that causes disruption in any electronic devices near a magnetic field.

Possible Sources of EMI in an EV

1) Motor
2) Battery
3) Wiring
4) Motor Controller
5) Charge controller

High voltage and high electrical currents in the cables between the batteries, the converter and the motor generate strong magnetic and electric fields. This causes interference with other equipments in the vehicle

Background

While implementing different meters in the EV, irregular readings were obtained when the accelerator was applied. Similarly all the meters showed irregular readings when the horn was pressed. The presence of EMI was hypothesized and experiments were conducted to show the presence of EMI in the EV which may have caused the unusual readings obtained from the meters.

Experiment

An experiment was conducted to detect the presence of EMI in the EV while in no-load condition. No load condition was achieved by raising the back wheels on a jack. The speed, current and the magnetic field inside the car was measured while one person stepped on the accelerator. The readings were taken simultaneously at 10s intervals. The speed was calculated from RPM measured using a tachometer pointed at the wheel. The current in the wire connecting the batteries was measured using a clamp meter. The magnetic field inside the car was measured using a magnetometer app in the phone.

Results

The experiment conducted inside the EV showed increased magnetic field strength when the accelerator was pressed. The magnetic field was particularly high near the batteries of the EV. The following graphs were obtained from the Experiment conducted on the EV in No-load condition.

Figure 3.62 is a graph of Magnetic field strength vs. Current.

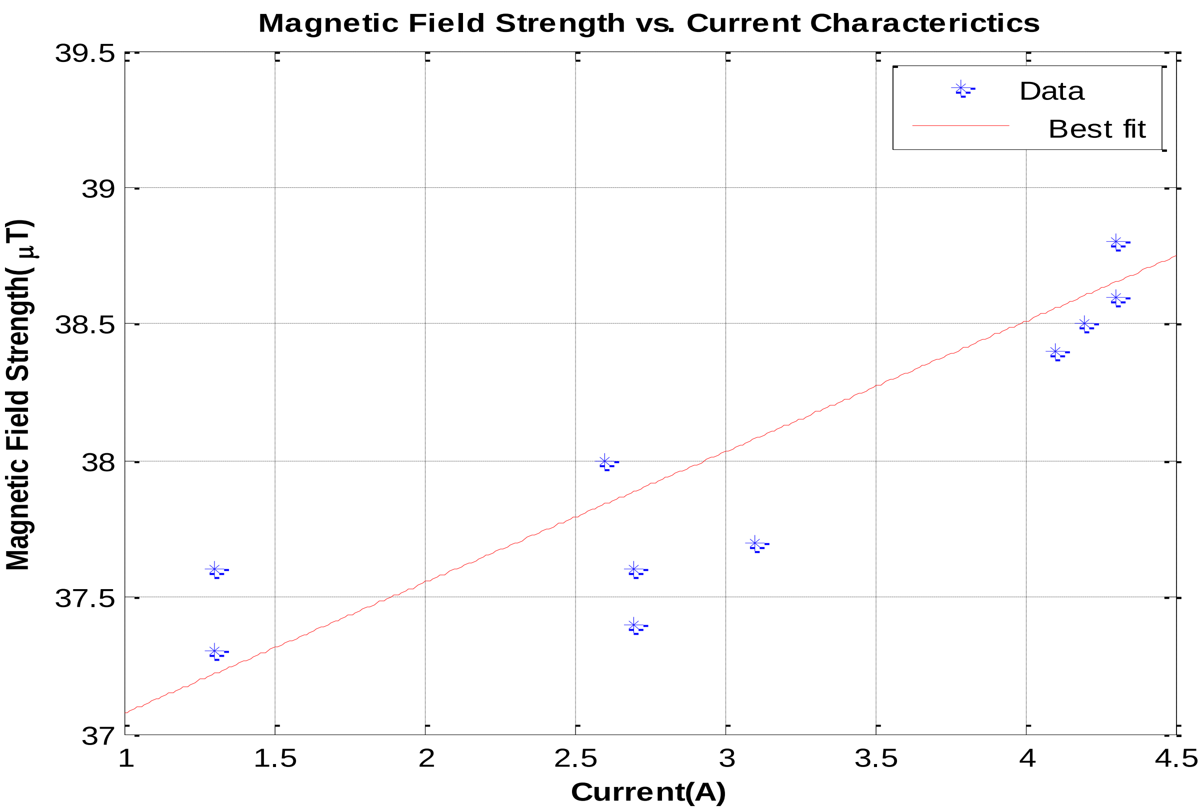


Figure 3.62: Magnetic Field Strength vs. Current

Figure 3.62 shows an overall increase in Magnetic Field strength as the current increases.

Figure 3.63 is a graph of Magnetic field strength against velocity obtained from three sets of data.

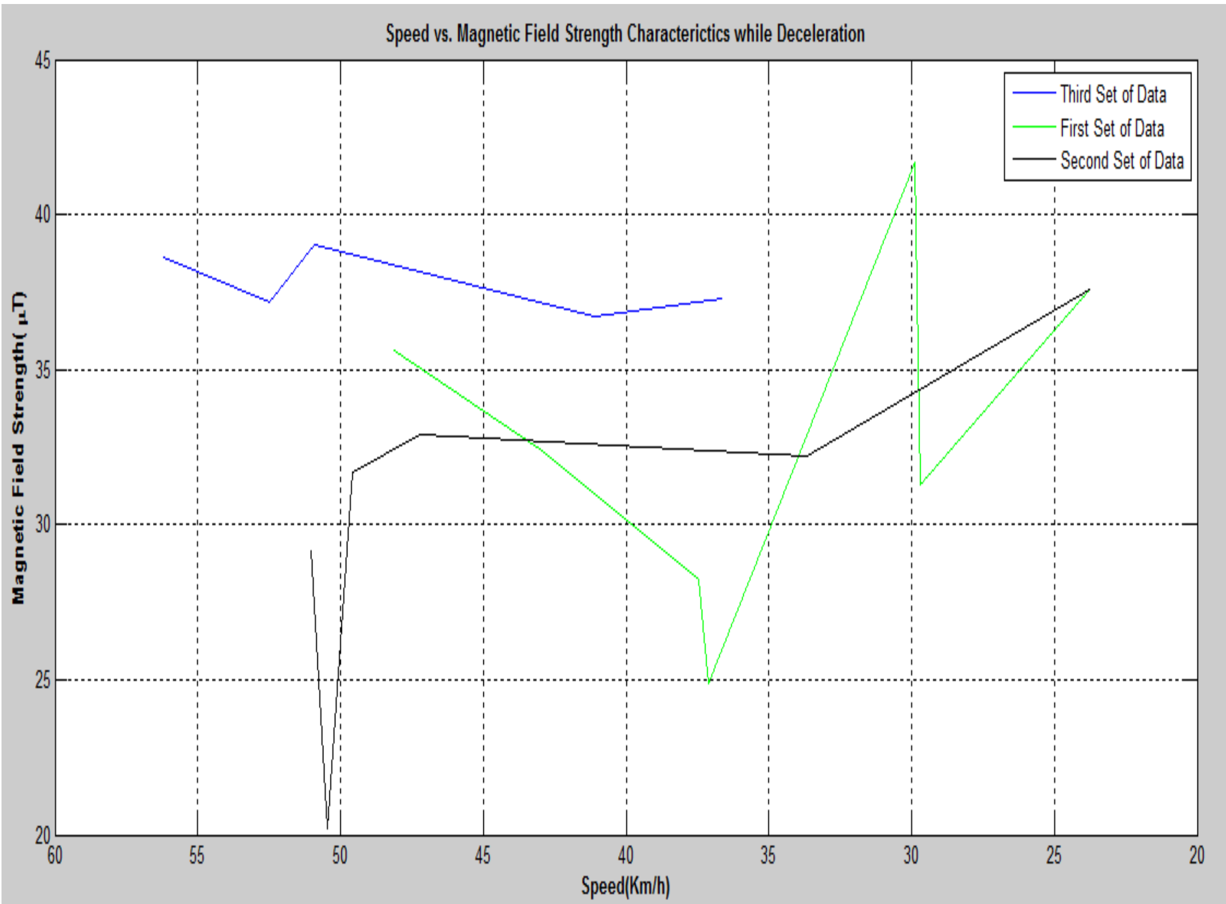


Figure 3.63: Magnetic Field Strength Vs. Velocity

The graph in Figure 3.63 shows no conclusive relationship between the speed of the wheels and the magnetic field strength produced inside the EV

Solutions

1) The possible sources of EMI, the battery and the motor can be kept inside a Faraday's cage. This process is called shielding. The Faraday's cage is a cage made of wire mesh that reduces the effects of EMI.

2) The wiring in the entire EV can be replaced with high voltage cables or coaxial cables, these are cables with built in shielding. This might lower EMI caused from current flowing through the wire.

Cross-section through a coaxial cable showing shielding and other layers

Figure 3.64: Coaxial Cable

3) Spraying the inside of the body of devices used in the EV with metallic paint might lower the effect of EMI. The possible sources can also be put in a box and the inside can be sprayed with metallic paint.

4) Delfingen has developed Nu-Guard EMI-HV which is used in the high voltage wire harness applications in electric and hybrid vehicles. It is made of copper and PET monofilament. The copper is braided to make it more effective to higher electromagnetic shielding. Nu-Guard EMI-HVis usually assembled directly over the high power cables and grounded to the vehicle.

EMI is one of the major obstacles that consumers might face inside an EV. Further Experiments should be conducted to find more about EMI in an EV especially while it is been run in full load condition. More experiments can also be conducted in controlled environments with more sophisticated instruments to get more accurate results.

3.6 Performance Analysis

The field tests on the Solar Electric Vehicle were done on a location near TB gate in Mohakhali. We selected a secluded road around a field. We calculated the length of one lap around the field and drove many laps around it to acquire the necessary data. Each lap around the field was found to be 545 m. We connected a voltmeter to the batteries to get continuous voltages and used a clamp meter to measure the current flowing from the batteries to the motor. We also used GPS to measure the speed of the car with reasonable accuracy.

3.6.1 Field Test without Interval (day 1)

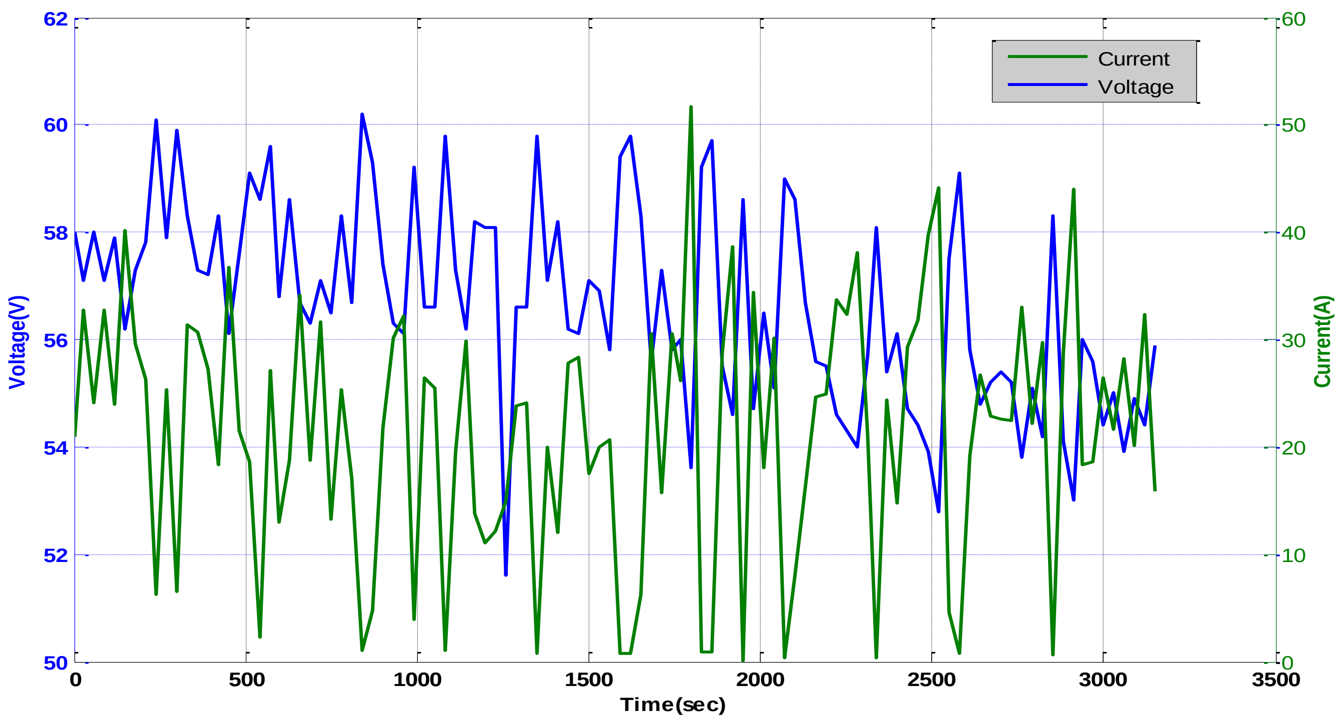


Figure 3.65: Voltage and Current trend in 1st Field Test

3.6.2 Field Test with Interval (day 2)

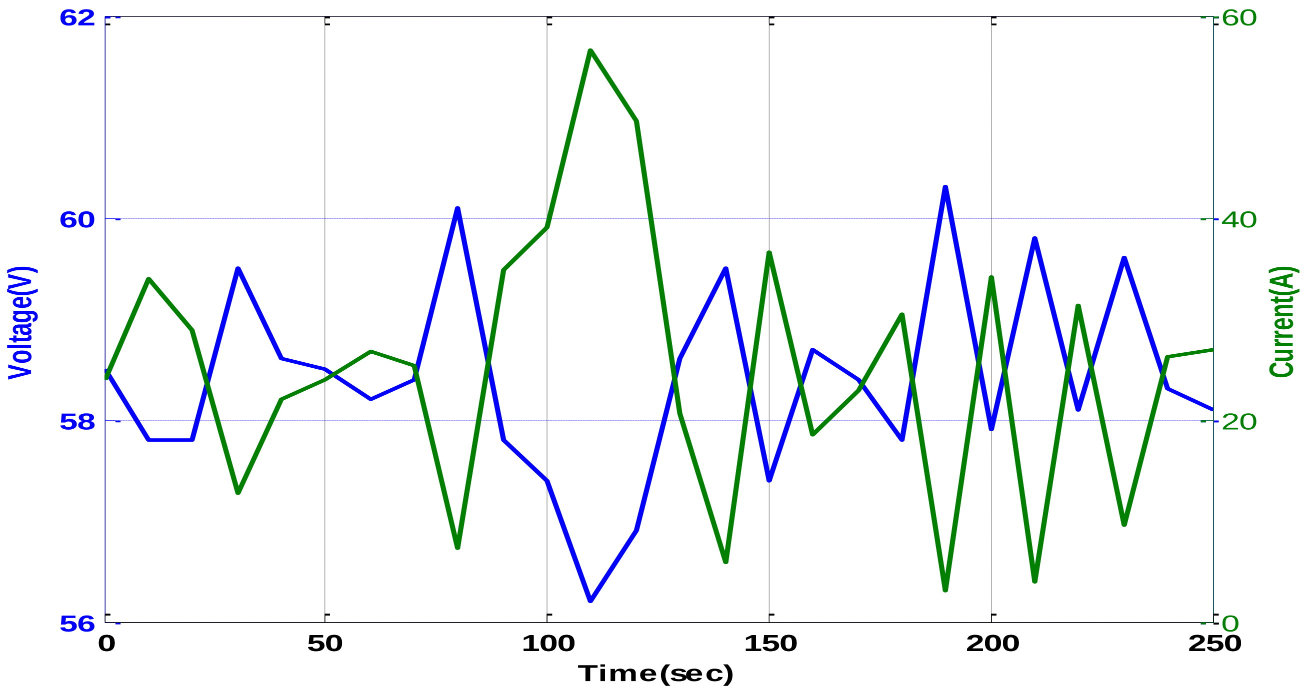


Figure 3.66: Voltage and Current trend of in Lap 1

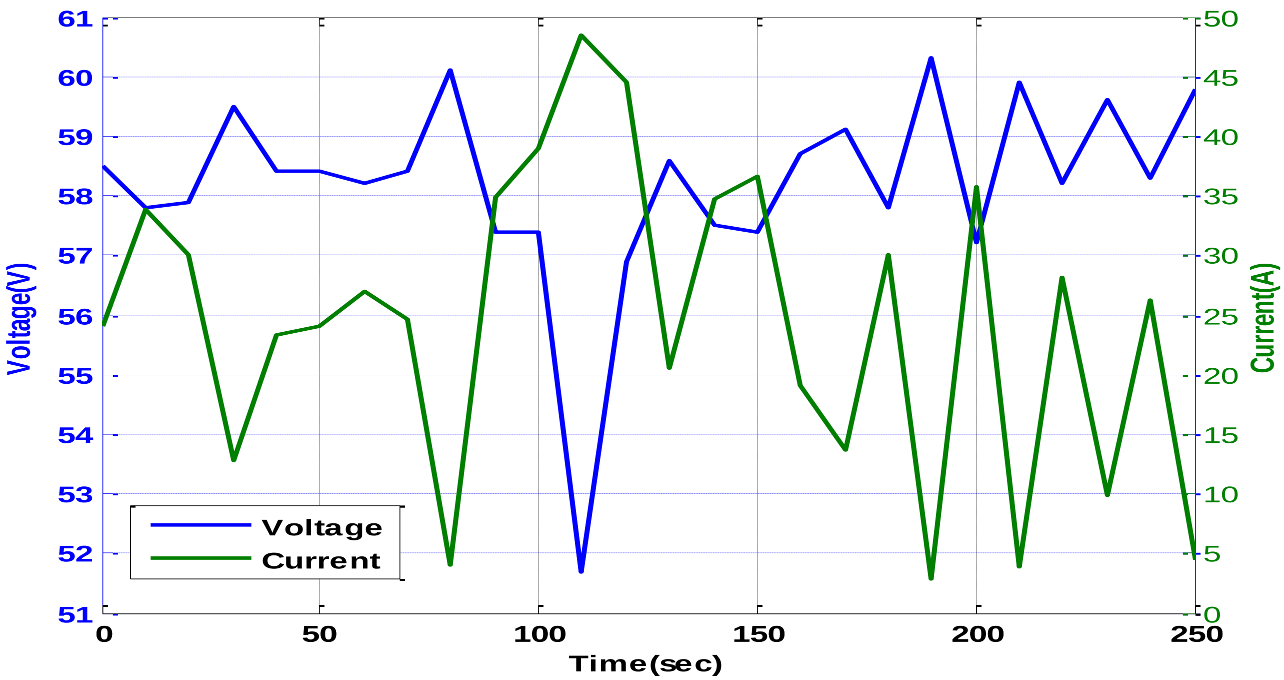


Figure 3.67: Voltage and Current trend in Lap 2

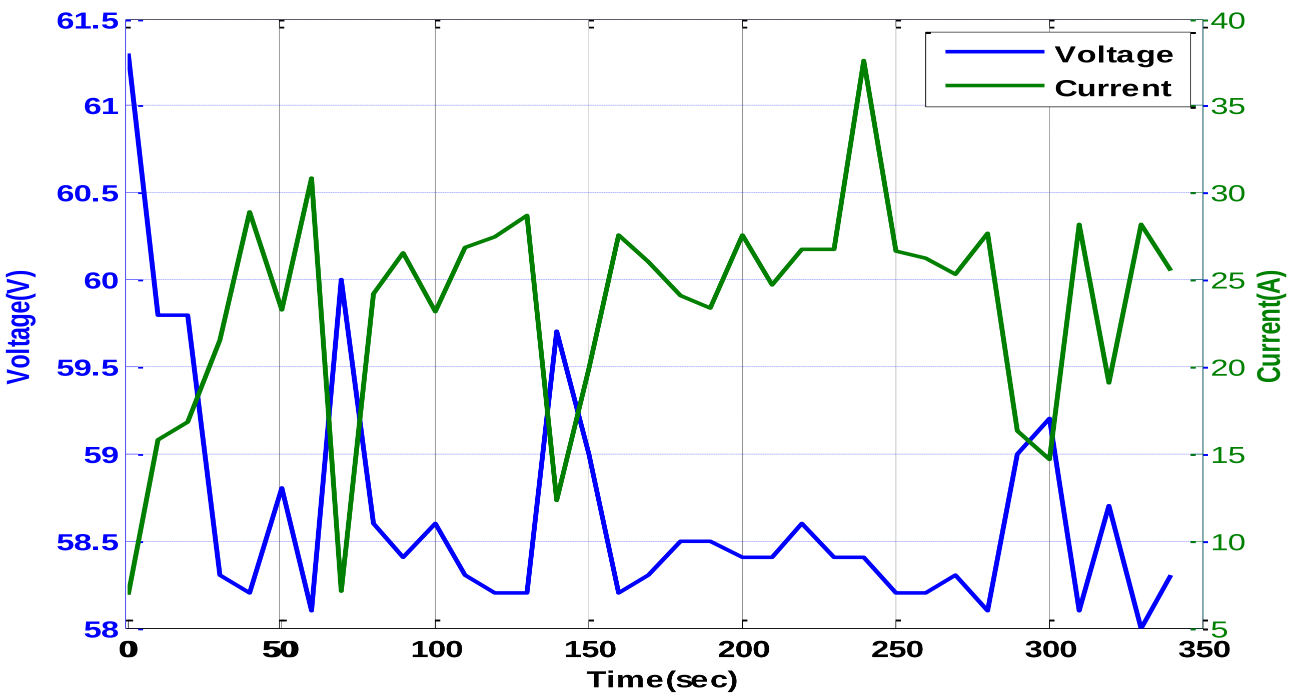


Figure 3.68: Voltage and Current trend in Lap 3

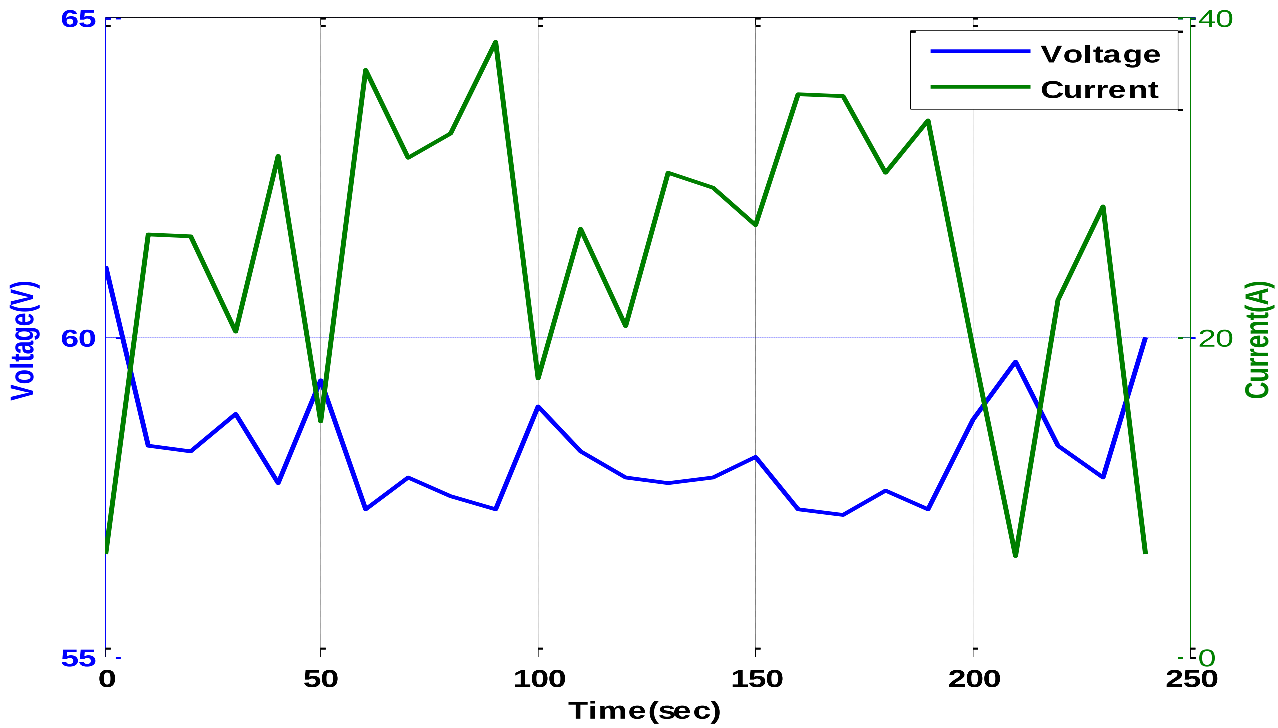


Figure 3.69: Voltage and Current trend in Lap 4

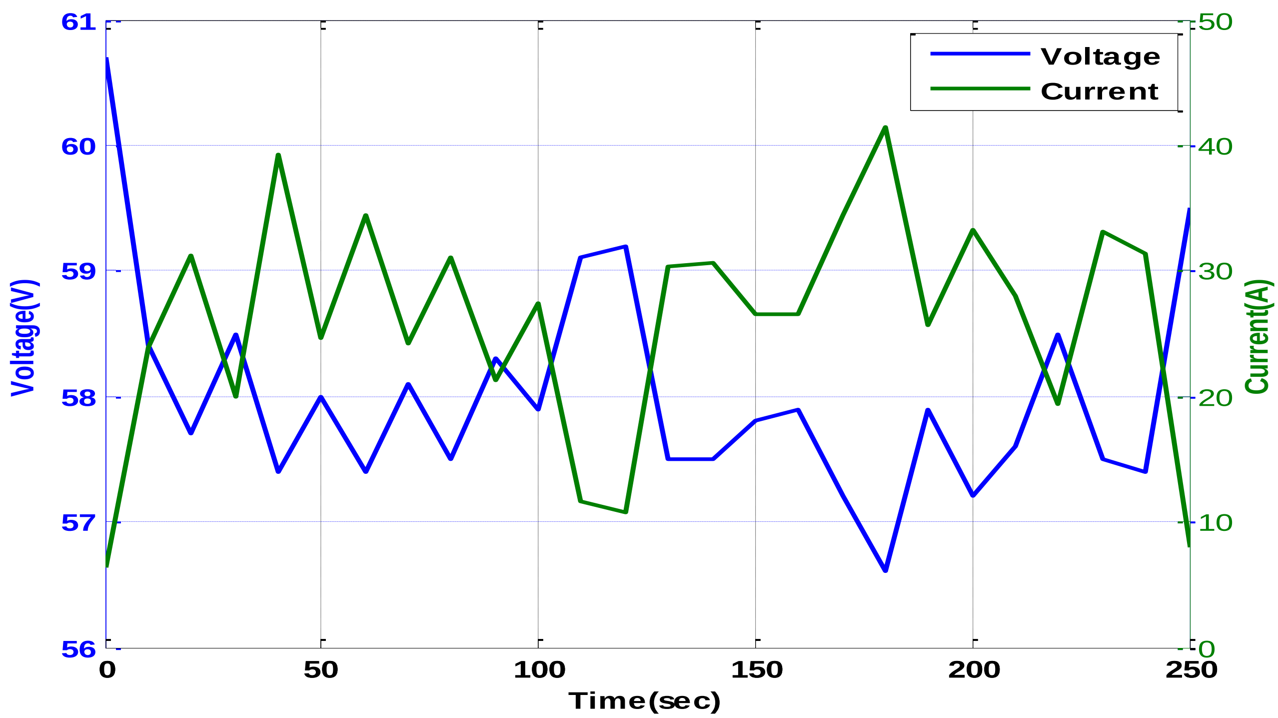


Figure 3.70: Voltage and Current trend in Lap 5

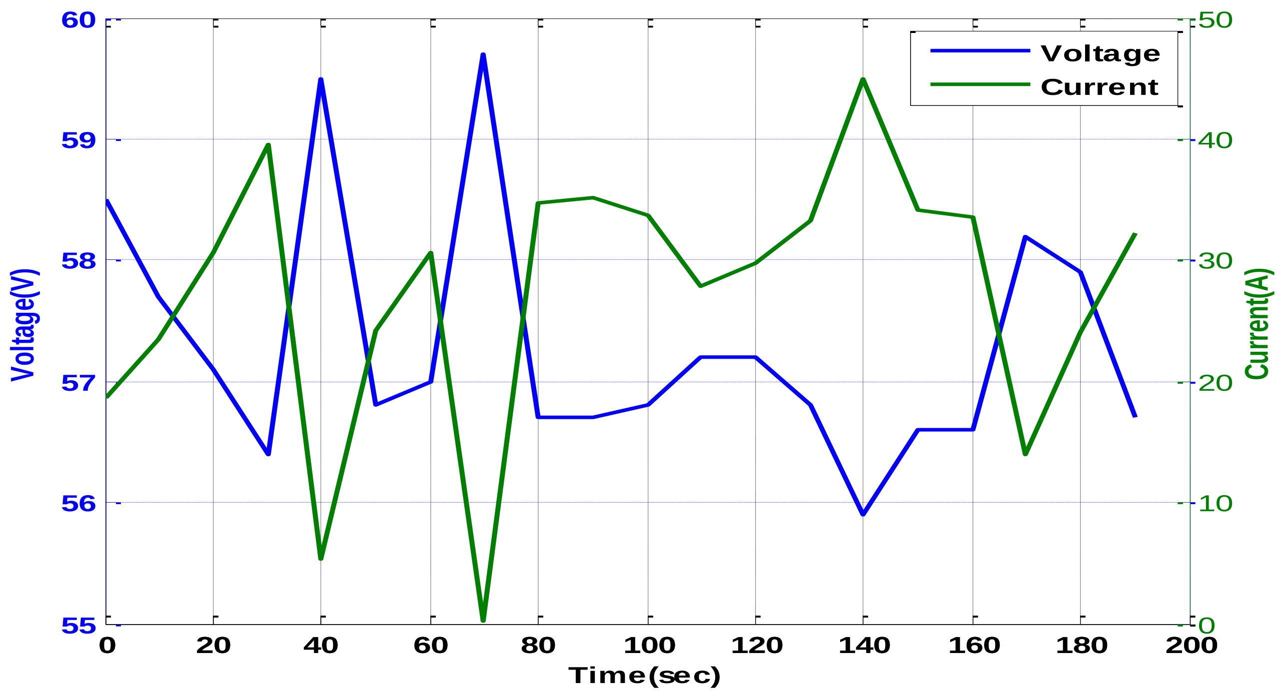


Figure 3.71: Voltage and Current trend in Lap 6

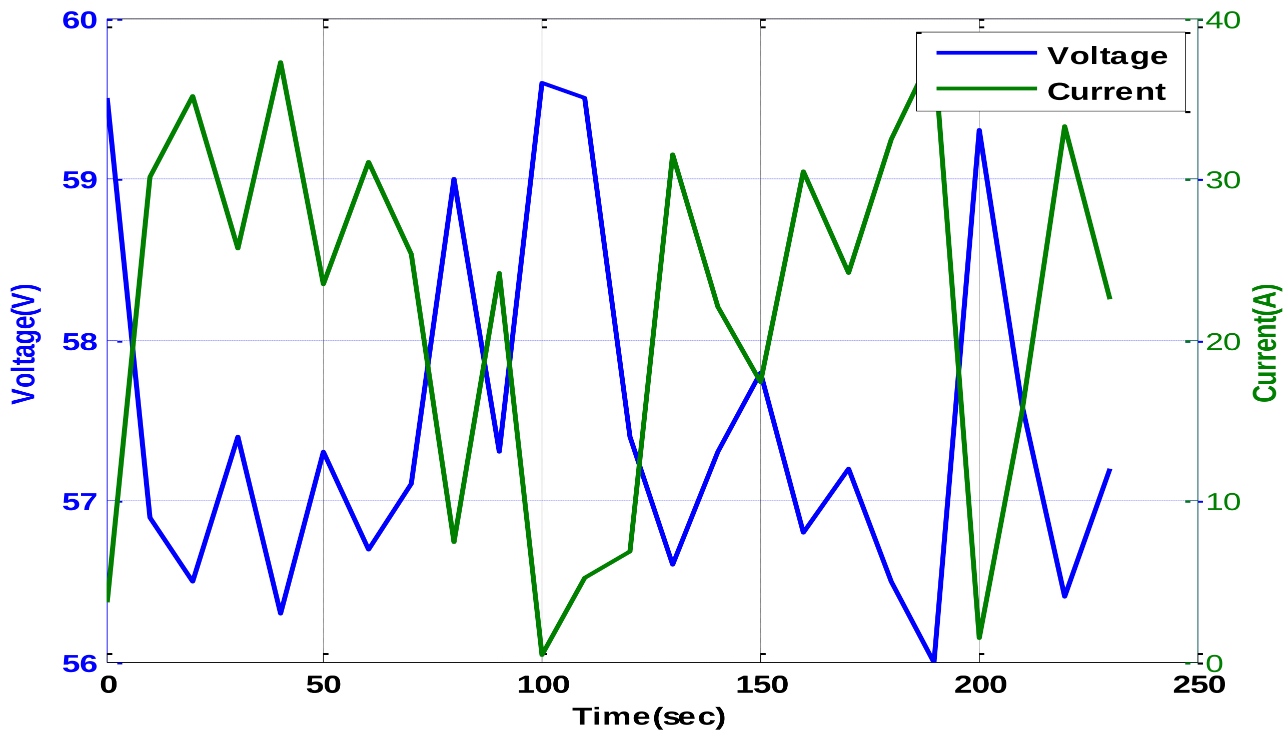


Figure 3.72: Voltage and Current trend in Lap 7

3.6.3 Analysis of Field Test Data

DAY 1 (without break)

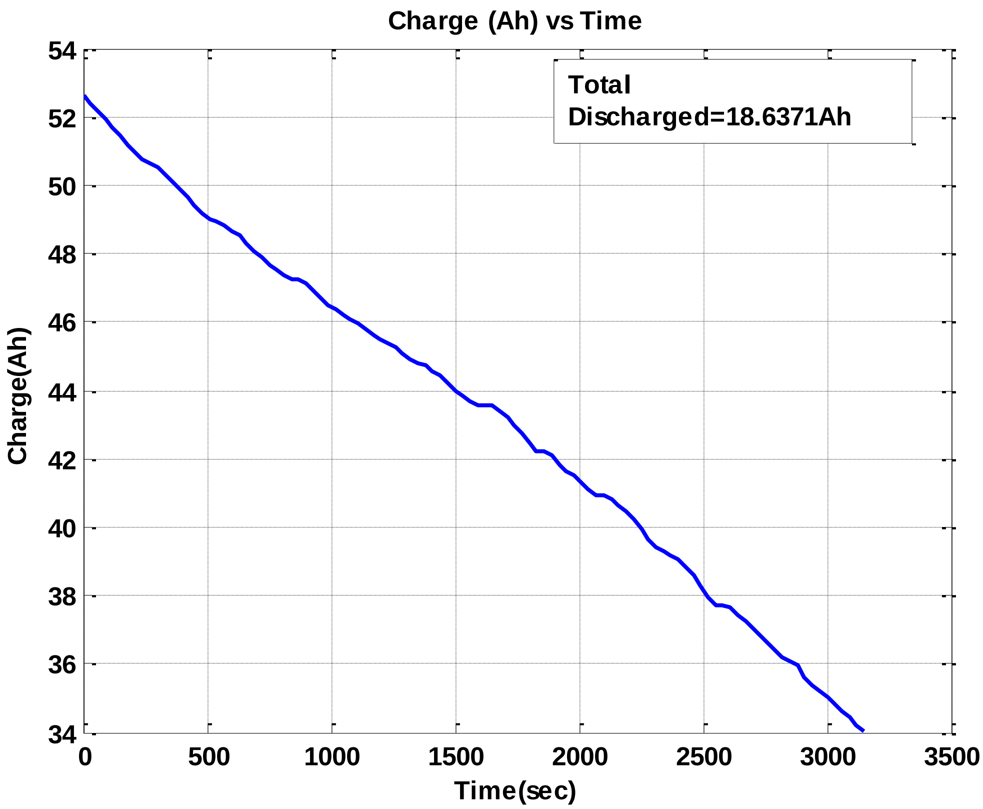


Figure 3.73: Battery discharge in field test without interval

Day 2 (with breaks)

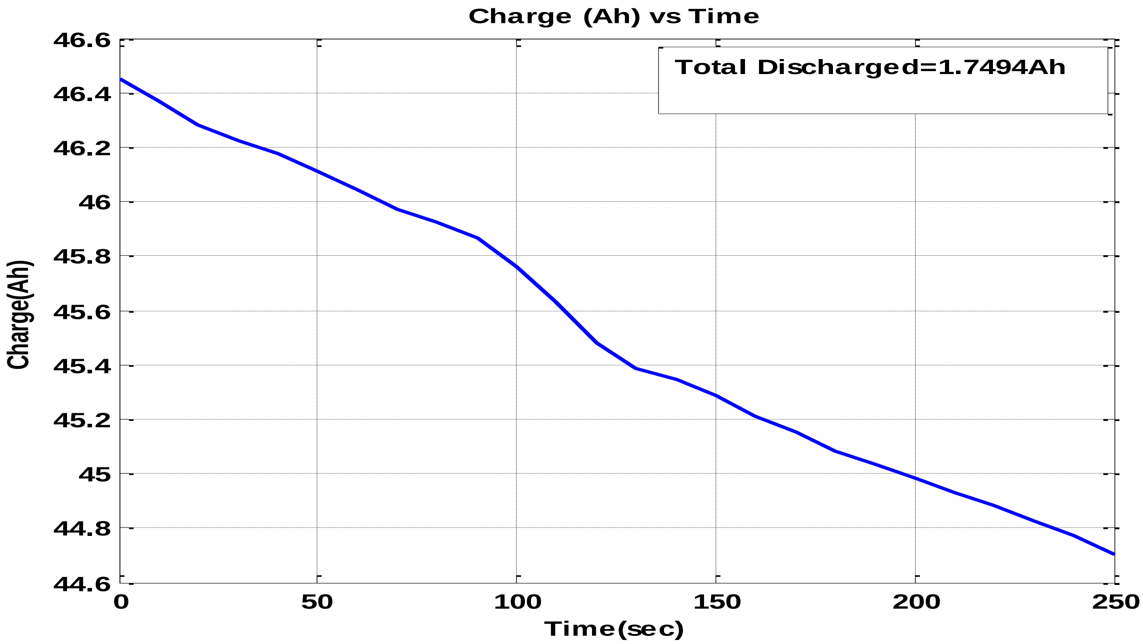


Figure 3.74: Battery discharge in lap 1 of field test

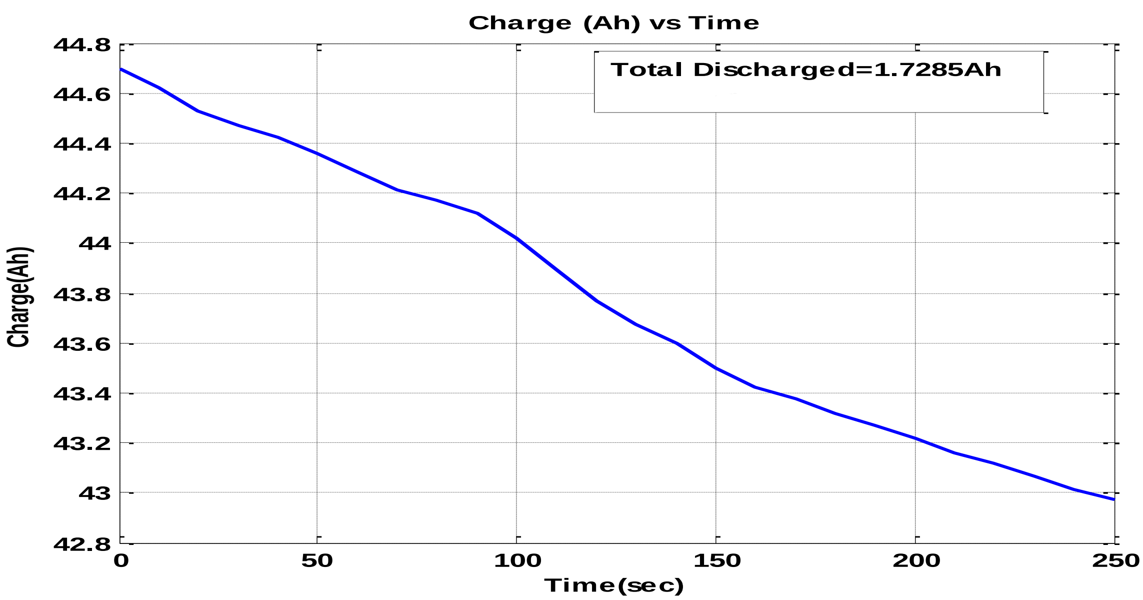


Figure 3.75: Battery discharge in lap 2 of field test

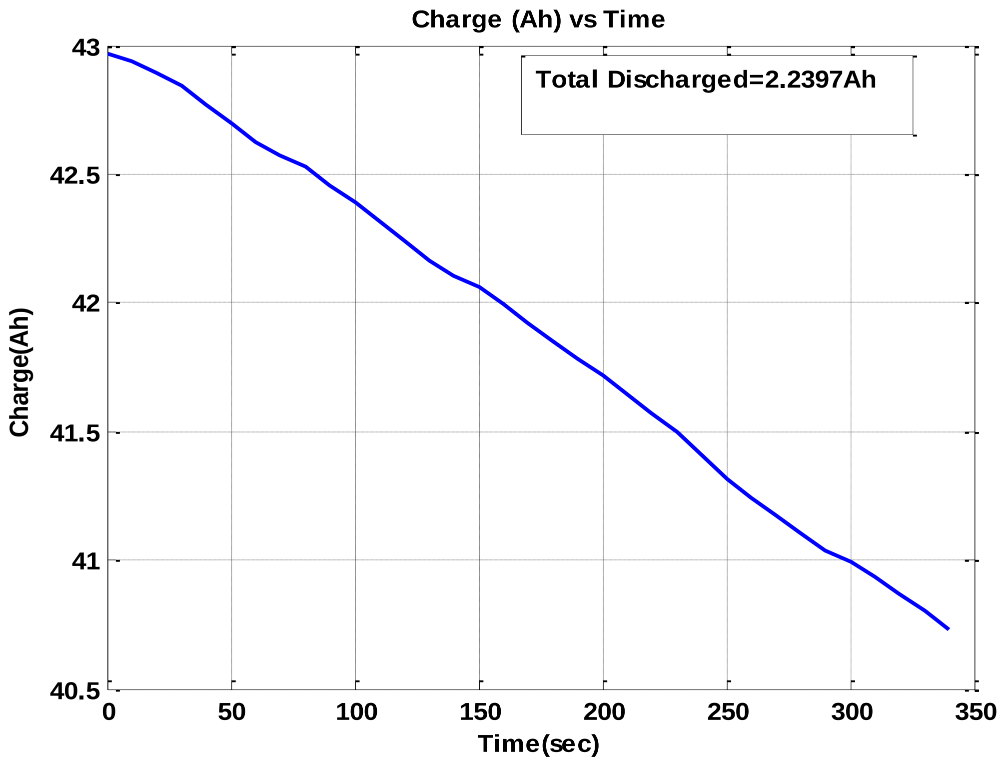


Figure 3.76: Battery discharge in lap 3 of field test

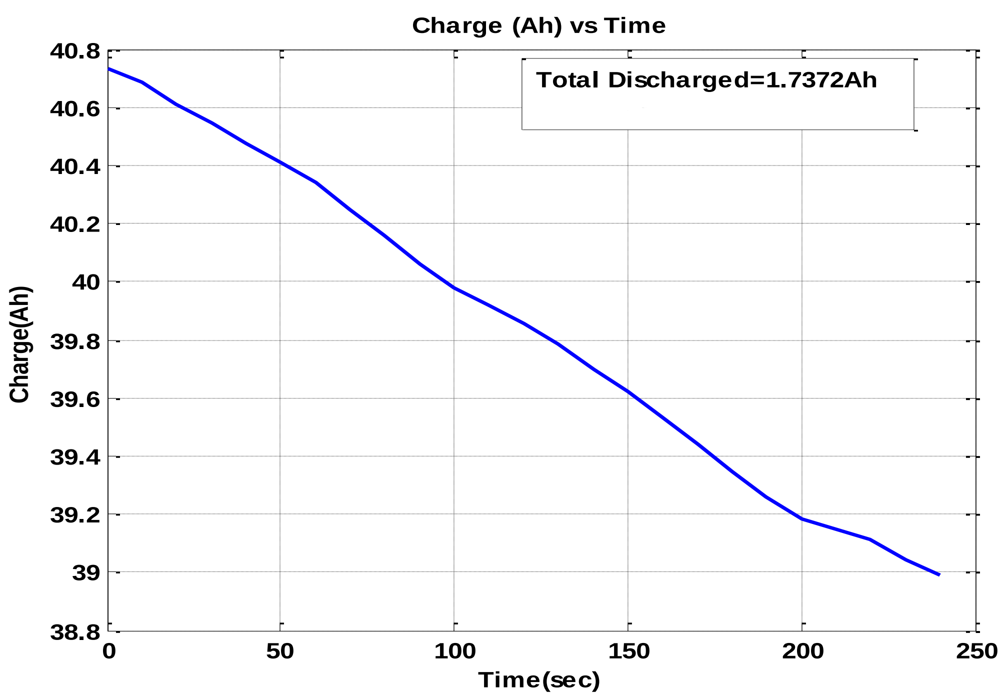


Figure 3.77: Battery discharge in lap 4 of field test

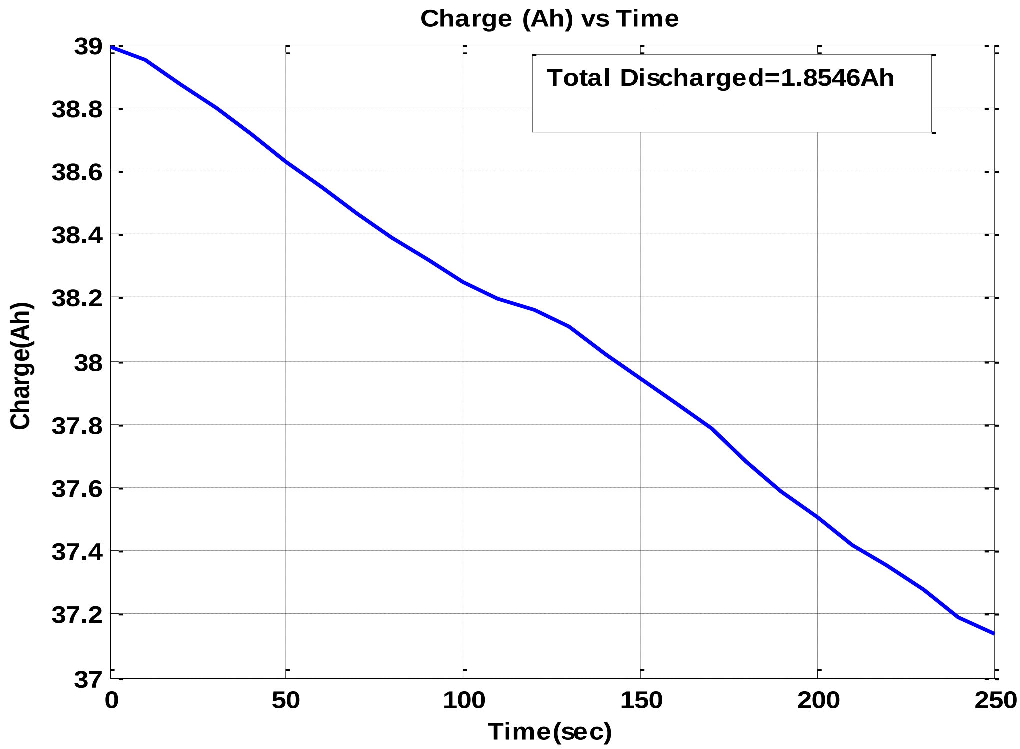


Figure 3.78: Battery discharge in lap 5 of field test

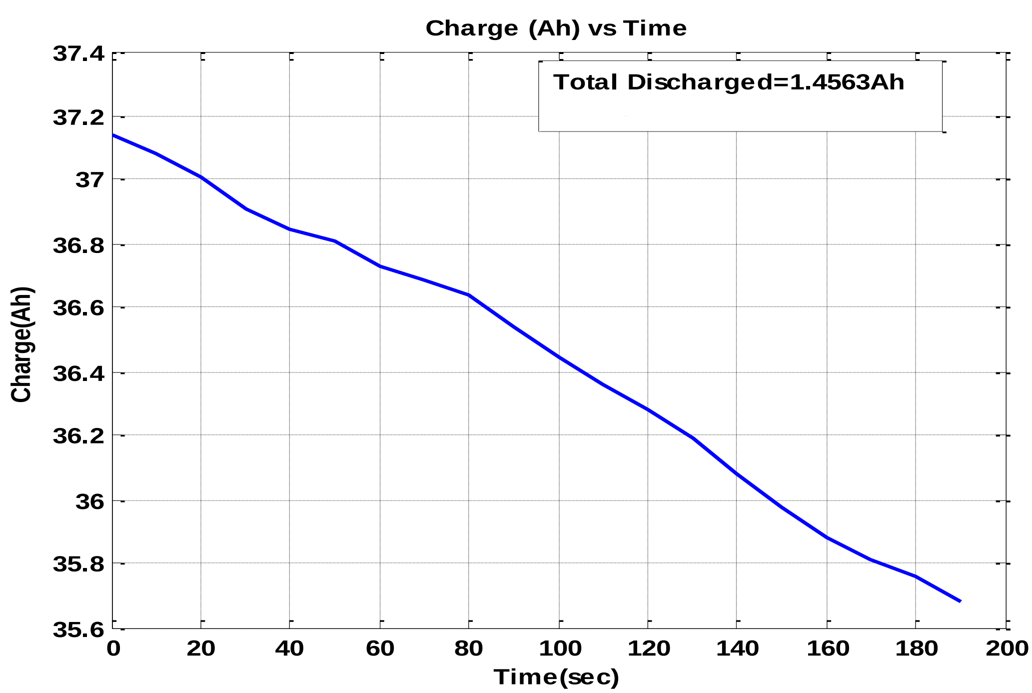


Figure 3.79: Battery discharge in lap 6 of field test

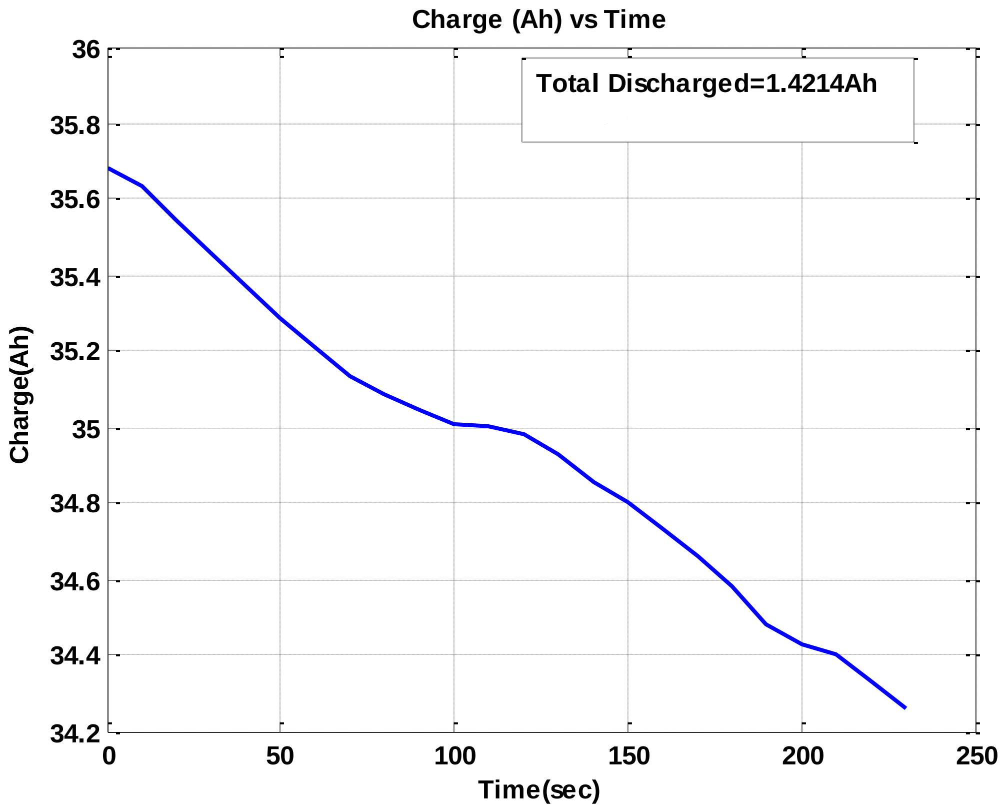


Figure 3.80: Battery discharge in lap 7 of field test

3.6.4 Result of field tests

We conducted two days of successful field tests in an effort to find the various parameters of the Solar Electric Vehicle. In day 1 we ran continuously for 13 laps and to and fro our University to our designated location. On day 2 we completed 7 laps stopping the car for approximately 10 minutes after every 2 laps. From the data and graphs of these two days we were able to determine various aspects of the car.

Day 1 (without any breaks):

Total distance travelled = 8.375 km

Total time = 0.875 hours

Total discharge (Figure: 3.73) =18.6371Ah

Range of the car = 23.974 km

If we consider the initial and final Voc and using our battery discharge model (Figure: 3.55) to deduce the discharge from day 1 we get the following result:

Initial Voc = 62.3V

Final Voc = 59.8 V

Total discharge = 30.381Ah

Range of the car = 14.7 km

Day 2 (with breaks):

Total distance covered = 3.815km

Total time = 0.4847 hours

Total discharge (Figure: 3.74-3.80) = 12.1871Ah

Total travelling range of car based on day 2 data = 16.7 km

Considering the initial and final Voc and using our battery model (Figure: 3.55) to calculate the total discharge from day 2 we get the following results:

Initial Voc = 61.8V

Final Voc = 60.7V

Total discharge = 13.325Ah

Travelling range of the car = 15.26 km

On day 2 we took breaks at regular intervals and allowed the motor to cool down between laps. We also recalibrated the Clamp meter before each lap and hence got much more reliable data on day 2. So we were able to achieve similar ‘maximum range’ from discharge-time graph as well as using our battery model. The range of the vehicle is however, much less than our estimated 32km. This decrease in range can be attributed to decrease in our battery capacity as well as to the fact that our motors appears to be drawing current much higher than its rated value.

Chapter 4: Vehicle Performance at a Glimpse

The data and calculation of our research implies that, the shortest day length in Bangladesh is 10.5 hours and longest day length is 13.5 hours. From our solar charging experiment, we can deduce that we can 12.3Ah and 15.8 Ah charge the battery from solar respectively in the shortest day and longest day length. For summer days, as the sunlight intensity is much more than a gloomy day we can harness 2 times higher energy from solar.

Through our experiments done for the test drives it is found that the total travelling range with a full charged battery unit is 16.7km,while our maximum speed was detected as 25km/h which was measured using an android application named "Speedometer" .

Chapter 5: Limitations and future work

We were determined to create the Solar Electric Vehicle using parts and components available in Bangladesh. We also faced some obstacles using different tools and apparatus that were not appropriate for our experiments. Below are some limitations of our thesis.

Motor:

Limitation: The motor used for our thesis, though appropriate based on the fact that it has high initial torque, is still underpowered. Any practical car running on the streets should achieve a speed of at least 60Km/h, whereas we can only manage less than half of that.

Future work: We would need a motor of around 4 KW to achieve a reasonable speed that a vehicle must have; however the maximum powered motor available in the market now is 1.1 KW.

Limitations: The motor we are using is Series Wound as a result regenerative braking cannot be developed based on this motor.

Future work: Replacing the motor with Shunt DC motor would enable the development of regenerative braking as the armature and field windings are in parallel.

Batteries:

Limitations: The lead acid batteries we used, only have charge of 70Ah and are much too heavy that makes the vehicle too heavy.

Future work: Implementing Li-ion or Li-Polymer batteries could reduce the weight; these batteries also stores more charge that would drastically increase the range of the car, making it more feasible.

Meters:

Limitations: Some of our experiments may have yielded unreasonable data due to unavailability of appropriate meters.

Future works: We believe we could have found much more reasonable data from our “Field Test” if we had access to high current ammeters instead of clamp meters. The effects of EMI in full load conditions also could not be measured due to the lack of magneto-meters.

EMI:

Limitations: The Speedo-meter we developed could not be implemented due to the presence of strong EMI; hence the maximum speed of the vehicle could not be measured accurately.

Future work: Using coaxial cables as our power cables and by shielding the motor and the batteries, we can significantly reduce the effects of EMI.

Charge controller:

Limitations: The charge controller for solar charging is not equipped with ‘Maximum Power Point Tracking’ (MPPT), as a result it consumes a significant amount of the charge obtained from the panels.

Future work: The charge controllers can be replaced with MPPT charge controllers.

Chapter 5: Conclusions

Electric Vehicles are what everyone is going to turn to in the near future as mode of transportation due to its low cost and polluting effect. The Solar Electric Vehicle that we have developed cannot be practically charged only by the solar power and has to take a fraction of its charge from the grid. As the electricity in our country is not produced from renewable sources, we cannot claim that the Solar Electric Vehicle is completely green. If, however, we can establish several Solar Power Stations and charge the vehicles from those stations, it can be completely emission less. Developing such system would drastically improve air quality, which is especially important here as the air pollution level of Dhaka city has reached an alarming level and one of the major contributors to this is the transport sector. Time is now ripe to make this issue our top priority. Our work on development and analysis of the Solar Electric Vehicle will, hopefully, be a giant leap towards achieving that goal.

Bibliography

Ahmed, S., Zenan, A. H., & Rahman, M. (2014). A Two-Seater Light-Weight Solar Powered Clean Car: Preliminary Design and Economic Analysis. *Developments in Renewable Energy Technology (ICDRET)* (pp. 1-7). Dhaka: IEEE.

Ahmmed, & Tanvir, K. (2010). Air Pollution Aspects of Dhaka City. *Proc. of International Conference on Environmental Aspects of Bangladesh (ICEAB10),*, (pp. 129-131). Japan.

Alphonse, I., Thilagar, D. S., & Singh, F. B. (2012). Design of Solar Powered BLDC Motor Driven Electric Vehicle. *NTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH*, *2*(3).

Balamurugan, T., & Manoharan, S. (2013). OPTIMAL DESIGN AND CONTROL OF SOLAR/ELECTRIC/REDUCED FUEL CONSUMPTION(IC ENGINE) HYBRID POWERED VEHICLE (SEFPHV) TECHNOLOGY. *International Journal of Renewable Energy Technology Research*, *2*(5), 151-169.

Buchmann, I. (n.d.). *How to Measure State-of-charge*. Retrieved from Battery University: http://batteryuniversity.com/learn/article/how_to_measure_state_of_charge

Bangladesh 4th most polluted in world. (2015, March 8). Retrieved from The Daily Star: http://www.thedailystar.net/bangladesh-4th-most-polluted-in-world-23348

Casacca, M., & Salameh, Z. (1992). Determination of Lead-Acid Battery Capacity Via Mathematical Modeling Techniques. *IEEE Transactions on Energy Conversion*, *7*(3), 442-446.

Ceraolo, M. (2000). New dynamical models of lead-acid batteries. *Power Systems, IEEE Transactions on (Volume:15 , Issue: 4)*, 1184 - 1190.

Chaturvedi, A., Kushwaha, K., Kashyap, P., & Navani, D. J. (2015). Solar Powered Vehicle. *International Journal of Electrical and Electronics Research*, *3*.

Dunlop, J. P. (1997). *Batteries and Charge Control in Stand-Alone Photovoltaic Systems-Fundamentals and Application.* Florida: Florida Solar Energy Center.

Fakham, H., Lu, D., & Francois , B. (2010). Power Control Design of a Battery Charger in a Hybrid Active PV Generator for Load-Following Applications. *Industrial Electronics, IEEE Transactions on, 58*(1), 85-94.

How to use a hydrometer to measure specific gravity. (n.d.). Retrieved from rimstar.org: http://rimstar.org/renewnrg/measure_battery_electrolyte_specific_gravity_with_hydrometer.htm

Jackey, R. (2007). *A Simple, Effective Lead-Acid Battery Modeling Process forElectrical System Component Selection.* The MathWorks, Inc.

Khatun, K., Chowdhury, R., Kabir, M. S., & Sarker, S. (2013). *System Design and Circuit Implementation of a solar powered car.* Bachelor Thesis, BRAC University, Electrical & Electronic Engineering, Dhaka.

Koutroulis, E., & Kalaitzakis, K. (2004, March). Novel battery charging regulation system for photovoltaic application. *IEE Proceedings-Electrical Power Appliances, 151*(2), 191-197.

Mahadi, M. (n.d.). Air Pollution In Dhaka City. Khulna.

Michael, D. (2010). Global Energy Modeling – A Biophysical Approach. *World Energy Congress*, Issue 2.4.

Rahman, S. q. (2009). *Fuel consumption of transport sector:how the people of Dhaka City will be moving in the future?* Jahangirnagar University, Urban and Regional Planning.

Samolyk, M. M., & Sobczak, J. (2013). *Development of an algorithm forestimating Lead-Acid Battery State of Charge and State of Health.* Blekinge Institute of Technology, Electrical Engineering. Valhallavägen: Blekinge Institute of Technology.

Semaoui, S., Arab, A. H., Bacha, S., & Azoui, B. (2013). Optimal sizing of a stand-alone photovoltaice system with energy management in isolated areas. *Energy Procedia*, 358-368.

SHIAO, Y.-S., SU, D.-T., YANG, J.-L., & HUNG, R.-W. (n.d.). Electrochemistry Theorem Based State-of-Charge Estimation of the Lead Acid Batteries for Electric Vehicles. *WSEAS TRANSACTIONS on SYSTEMS, 7*(10), 1092-1103.

Singh, P., A, S., & Kumar, P. (2015, Jan-June). BATTERY (Ni-Cd) CHARGING ANALYSIS OF STAND- ALONE 300W SOLAR PHOTOVOLTAIC SYSTEM AT CONSTANT SOLAR INSOLATION. *International Journal of Electrical and Electronics Engineers, 7*(1), 310-317.

Su, Q., Zhang, G., Lai, J., Feng, S., & Shi, W. (2010). Green Solar Electric Vehicle Changing the Future Lifestyle of Human. 128-132. Shanghai.

Sun, Y.-H., Jou, H.-L., & Wu, J.-C. (2011). Aging Estimation Method for Lead-Acid Battery. *IEEE TRANSACTIONS ON ENERGY CONVERSION, 26*(1), 264-271.

Tariq, R., Sabbir, S., & Azad, S. A. (2014). *Dynamic Electrical Model of Sealed Lead-Acid Battery for EV Simulation.* BRAC University, Electrical and Electronic Engineering. Dhaka: BRAC University.

Thompson, D. (2005). *A Four Quadrant Adjustable Speed Drive For Series Wound DC Motors.* Bachelor's Thesis, UNIVERSITY OF SOUTHERN QUEENSLAND, Engineering and Surveying.

Tremblay, O., & Dessaint, L.-A. (2009). Experimental Validation of a Battery Dynamic Model for EV Applications. *World Electric Vehicle Journal, 3,* 289-298. Hybrid and Fuel Cell Electric Vehicle Symposium.

Wamborikar, Y. S., & Sinha, A. (2010). Solar Powered Vehicle. *Proceedings of the World Congress on Engineering and Computer Science.* San Francisco.