Battery Management System for Traffic Monitoring Application

By

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHD IZZUDDIN BIN MOHD NOOR

Abstract

In a stand-alone photovoltaic application, power storage has been a common problem in many system that are currently implemented. This is primarily caused by insufficient management of the battery storage where proper charging and discharging are not practiced. Therefore, this project aims to develop a battery management system that could oversee the charging and discharging of the batteries in a traffic monitoring application to provide continuous power supply. The power consumption of the system were studied based on the existing system and the data obtained is used to design the battery management system. The battery management system will utterly improve the operation of the traffic monitoring system and other stand-alone photovoltaic applications thus making them more reliable.

ACKNOWLEDEMENT

The process of writing a dissertation is long and arduous, and it is certainly not done singlehandedly. First and foremost, I would like to express my utmost gratitude to Allah swt. for His blessing and guidance. Without Him, none could be achieved throughout the project. I would also like to express my appreciation to both my parents that have been my inspiration to complete this project.

I would certainly be remiss to not mention and sincerely thank Dr Azrina Abd Aziz and Dr Balbir Singh Mahinder Singh. Without their help, advice, expertise and encouragement, this research and dissertation would not have happened.

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CHAPTER 1
INTRODUCTION

1.1 Background Study

In recent years, there has been an increase in the number of vehicles in Malaysia. It has been recorded that there are approximately 23 million vehicles on the streets in Malaysia as of 31 December 2012 [1]. This leads to traffic congestion on highways. Thus, there is a need for traffic scheduling and planning so that the congestion can be reduced. By doing this, drivers could opt for alternative route to avoid congestion. This is important as Malaysia's total population has increased to 30.6 million peoples as of January 2015 [2]. The increase in population will lead to the increase in the number of vehicles in the future.

The traffic scheduling and planning must be done based on the data collected by using real-time traffic monitoring system. There are traffic monitoring systems available currently, but their operations are not sustainable due to several factors:-

- Access to grid power
- Delayed broadcast
- Network coverage
- Security of the system

In Malaysia context, real traffic monitoring system has been implemented in many parts of Malaysia's highways. A study on 22 June 2015 on the live traffic monitoring system [3] showed that approximately 28% of the cameras set-up along the routes of Kuala Lumpur city center were not functioning. Further study on PLUS-North highway and PLUS-South highway showed 35% and 6% of the cameras installed along the highway respectively, did not function. One of the reasons contributing to this failure is contributed by the lack of energy provided by the power source.

Many traffic monitoring systems use off-grid power supply that takes advantage of solar energy. In systems that utilize photovoltaic application, lead acid battery is the most common storage technology used due to its maturity, great availability and low cost. However, the lifetime of the batteries are much shorter between those described in the manufacturer's data and those experienced in real application. This is caused by repeated deep discharged and no optimal charge and discharge cycles thus damaging the batteries which affects the system as a whole.

This project aims to optimize the lifetime of the system by developing the battery management system. This project is a collaboration effort established between UTP and KreatifApps [4] a company based in Cyberjaya, Malaysia, that provides live traffic flow information to users around Klang Valley area.

1.2 Problem statement

Most traffic monitoring systems installed on highway rely on the batteries charged by the solar panel to operate continuously. However, these systems do not have sufficient management incorporated to the system to protect the batteries from repeated deep discharge and over charging.

As a result, the lifetime of the batteries are shortened which impacts the performance, reliability and the cost of the system. Therefore, there is a need to develop a battery management system to optimize the use of the batteries making the overall system more reliable and cost effective.

1.3 Objectives

The objectives of this project are:

- To study the power consumption of an existing traffic monitoring system.
- To develop a battery management system for the traffic monitoring application.
- To validate and test the proposed battery management system.

1.4 Scope of study

The scope of this project is limited to the design of a battery management system for the use of traffic application. Thus, adequate knowledge on the power consumption of the system and photovoltaic based electricity generating system are needed. Apart from this, understanding the solar geometry and the nature of solar radiation are also required. The orientation and optimum tilt angle of the photovoltaic module will be determined in order to improve the energy efficiency of the system. The power system must also adhere to the specific requirements of the application in particular, the size, weight and robustness of the whole system must be taken into account. The power consumption of the existing system, will be monitored and computed to determine the electrochemical storage capacity.

1.5 Significance of study

The study will give better knowledge on how to design a battery management system for traffic monitoring applications thus improving the system applications as a whole by providing optimal charging and discharging to the batteries. This will increase the system reliability and minimize maintenance making the system cost effective.

At the end of the project, the findings on the development of battery management techniques can be implemented on other energy system with photovoltaic based solar electricity generator.

CHAPTER 2
LITERATURE REVIEW

2. TRAFFIC SCHEDULING AND PLANNING

Due to the rapid urbanization, the road traffic systems are becoming more complex, as the number of road intersections and vehicles are increasing especially in urban area causing road congestion. The need of traffic monitoring system is paramount to reduce the traffic congestion.

2.1 Traffic Monitoring System

Traffic monitoring system, which is also known as Intelligent Transportation System (ITS), aims to provide traffic management services for different modes of transport. This will enable numerous users to be well informed and make better, more coordinated use of transport network [5]

Figure 1: ITIS monitoring center [6].

In Malaysia, Integrated Transport Information System (ITIS) shown in Figure 1 is responsible for traffic management system in Klang Valley area [6] while PLUS Malaysia Berhad (PMB) has its Traffic Monitoring Centre (TMC) to monitor all its highways [7].

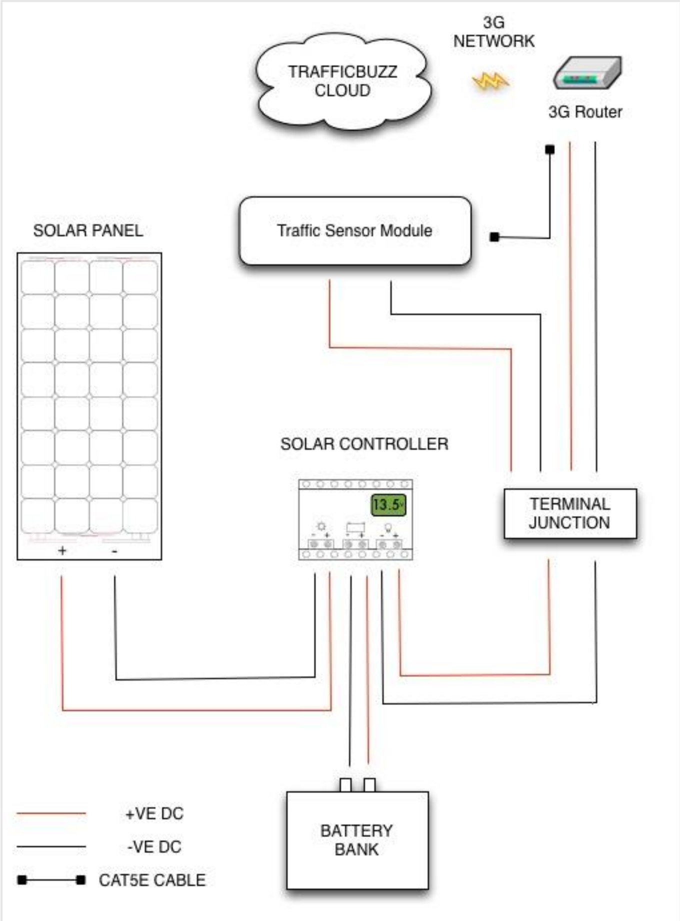

Figure 2: Solar powered traffic monitoring system.

Figure 2 shows the architecture of the solar powered traffic monitoring system used in this project which is based on the actual traffic monitoring system architecture provided by KreatifApps [4]. In general, the system uses the solar panel as a power generator. The generated power is stored in an electrochemical storage (battery) and used as a power supply for the traffic monitoring system.

2.2 Traffic Monitoring System Implementation Challenges

For any technologies, there are limitations. To implement the traffic monitoring system, sensors need to be installed in strategic places. This is to provide the sensors a good field of view while maintaining their safety from possible theft or vandalism.

With the ever expanding routes being constructed, more and more traffic sensors are being deployed to locations which are usually remote. This limits the system's access to grid power supply. Thus, most traffic sensors rely on electrochemical storage as a power source which would enable them to run for limited amount of time depending on their respective power consumption.

To extend the limited operating time for the sensors, photovoltaic electricity generator (solar module) are commonly used to recharge its electrochemical storage. Though it is reliable, the photovoltaic electricity generator could only generate electricity during the day in the presence of the solar radiation which is affected by intermittent weather.

2.3 Traffic Monitoring Modules

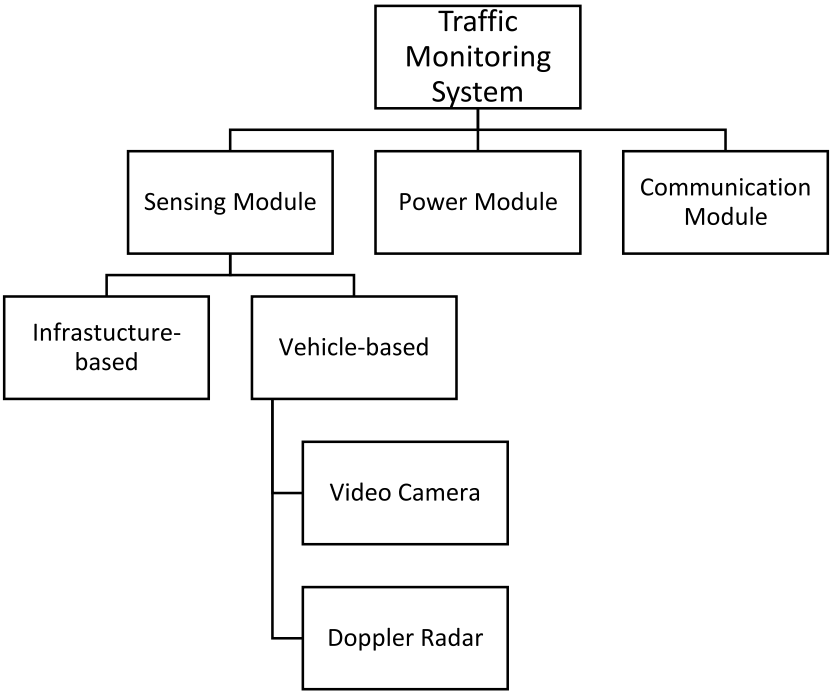

Figure 3: Modules of traffic monitoring system.

As shown in Figure 3, each traffic monitoring system consists of three main modules which are (1) the sensing module, consisting of sensors that are installed at strategic location along the road that could determine the traffic volume on the roads; (2) the power module, either on-grid or off-grid; and (3) the communication module, providing the capabilities for the system to send collected data to the monitoring center, road users or servers.

2.3.1 Sensing Module

The sensing module usually consists of infrastructure-based and vehicle-based network system. Infrastructure-based sensors are made to be indestructible as this devices are embedded or installed in the road or its surrounding such as traffic posts and buildings while vehicle-based sensors uses electronic beacons that are installed on poles or billboards. For this project, a combination of two vehicle-based sensors are used which are Doppler radar sensor and video camera.

A. Infrastructure-based sensors

This type of sensor is commonly used and installed in roadbed. An example is induction loop which functions as a vehicle counter by detecting vehicles that pass the magnetic field loop. Application of induction loop can be seen in Figure 4 [8]. Additional features include length estimation, speed estimation, vehicle recognition and distance between two vehicles [9].

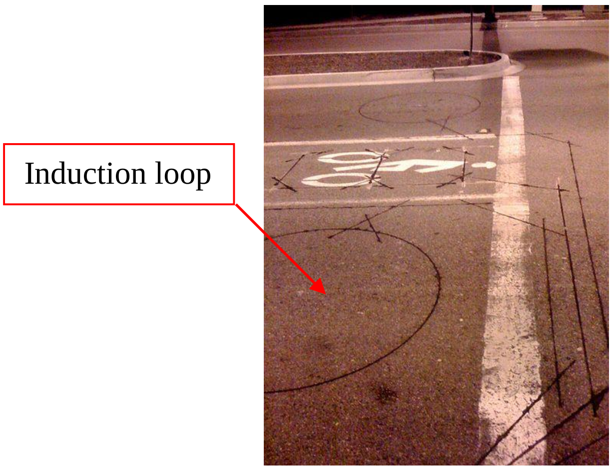

Figure 4: Induction loop installed in the road [8].

B. Vehicle-based sensors

Vehicle-based sensors use intelligent electronic beacons together with modern microchip, Radio Frequency Identification (RFID) and telecommunication and information technology for identification communication in infrastructure-to-vehicle and vehicle-to-infrastructure deployment [9].

i. Video Camera

Video camera is used for vehicle detection as shown in Figure 5 [10]. Detection is done by processors that analyses the image being fed to it and detect any characteristic changes. Initial configuration is needed to “train” the processor on the background image baseline. This is implemented in automatic incident detection and traffic-flow measurement [9].

Figure 5: Video camera installed on pole [10].

ii. Doppler Radar Sensor

This sensor utilizes Doppler effect to measure the velocity of moving vehicles. Figure 6 shows the operation of Doppler radar sensor by emitting a microwave signal towards the desired moving vehicle and analyzing the variation of the returned signal. Other application of Doppler radar includes the detection of vehicle presence, measurement of volume and length of vehicles [11].

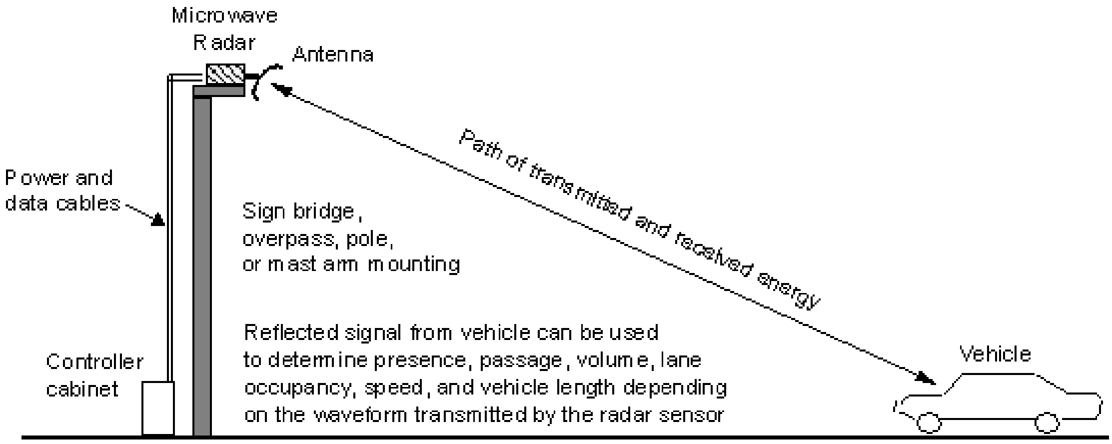

Figure 6: Doppler radar operation [11].

2.3.2 Power Module

The idea of solar system is to harness the sun's energy to generate electricity using concentrating solar power (CSP) and solar photovoltaic (PV) systems and hot water using solar thermal systems. As it is technically well proven, numerous systems have been installed all over the world in the last few decades [12]. The focus of this project is to use solar photovoltaic system for flexible power source for the traffic monitoring system. Most traffic monitoring systems rely on solar photovoltaic system to provide power source because of limited access to on-grid power supply. An example could be seen in Figure 7 [13].

Figure 7: Traffic sensor installed with photovoltaic module [13].

A. Solar Photovoltaic System

Solar energy or solar photovoltaic (PV) electricity generation is recognized as an unblemished energy source, with huge potential, significant to the growing concerns for global warming due to greenhouse effect and gradual diminish of fossil fuels [14], [15]. Solar energy is converted directly to electricity in a solar photovoltaic (PV) systems. PV system consists of semiconductor devices called PV cell that absorbs solar energy and converts it into direct-current (DC) electricity. This PV cells are then interconnected as a PV module which is then combined with sets of application-dependent system components (e.g. batteries, electrical components, inverters, and mounting system) to form a PV system [15]. The power output produced by PV modules are affected by its ***panel's mounting angle, solar geometry, PV material, solar irradiation, temperature and weather*** [16]. Therefore, it is important to consider all these factors in the study to optimize the solar photovoltaic system used in this project.

i. Photovoltaic Material

Photovoltaic materials can be classified into crystalline or thin film and they are evaluated based on two criteria: economics and efficiency. Crystalline cells are essentially silica-based materials that has been melted and crystallized. Liquidized semiconductor material deposited onto glass, plastic or stainless steel substrate are done to produce thin film cells. Table 1 provides the advantages and disadvantages of different types of PV sells. In this project, monocrystalline PV cell is used for its high efficiency and it requires less space since the traffic monitoring system will be mounted on an electric pole.

Table 1: Photovoltaic advantage and disadvantage [17], [18].

Type of PV Cell	Advantage	Disadvantage
Monocrystalline	• High efficiency • Requires less space • Long life span	• High cost • Efficient in warm weather • Circuit may break due to shading
Polycrystalline	• Low cost • Easily manufactured • Long life span	• Low efficiency • Requires more space
Thin Film	• Flexible • Easily manufactured • High heat tolerance	• Requires more space • Low efficiency • Short life span

ii. Solar Irradiation

Solar irradiance has large effect to the performance of solar module. Solar irradiance is defined as the density of radiation energy absorbed by the solar module over its area. Geographically, Malaysia is situated between 1° and 7° in the northern hemisphere close to the equator and longitudes 100° and 104° [19]. With the sun movement from North to South, Malaysia has an average 12 hours of moderate daily sunlight for which the Peninsular Malaysia and East Malaysia with an overall area of 329,847 km^2 procure between 4.21 kWh/m^2 and 5.56 kWh/m^2 average daily solar irradiation each year. The top most daily solar irradiation is during the month of August and November with an estimate of 6.8 kWh/m^2 per day. Plentiful solar irradiation is due to Malaysia tropical climate with an average of 1643 kWh/m^2 solar irradiance annually [21-22].

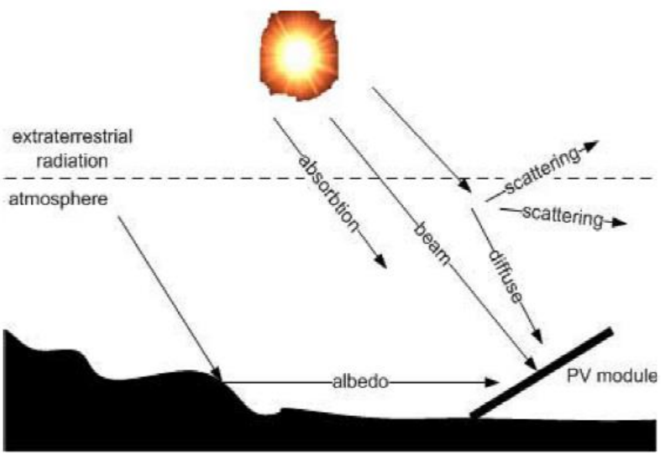

Figure 8: Solar radiation in earth's atmosphere [22].

Figure 8 shows solar radiation enters earth's atmosphere [22]. The global irradiance, I_G, on a module perpendicular to the sun's ray can be computed using

$$I_G = 1.1 \cdot I_D \quad , \tag{1}$$

where I_D is the intensity on a plane perpendicular to the sun's ray.

iii. Solar Geometry

For relatively every 365 days, the earth goes through elliptical revolution around the sun with a 360° rotation on its axis each day. Thus, the sun's position varies from each day to the next thus it is important to know the sun path of specific location [23]. This can be seen in Figure 9 [24].

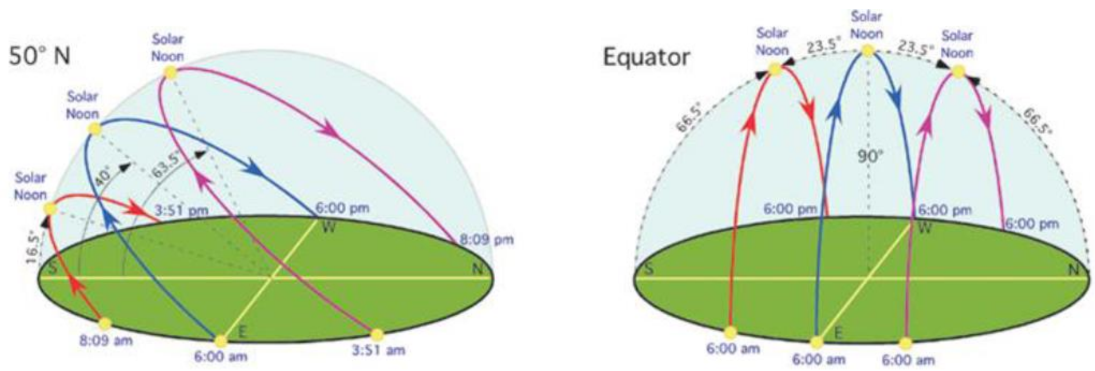

Figure 9: Sun path [24].

From the sun's trajectory, it is imperative that to achieve maximum energy generation the photovoltaic module's incident angle must be perpendicular to the incident radiation as shown in Figure 10 [23].

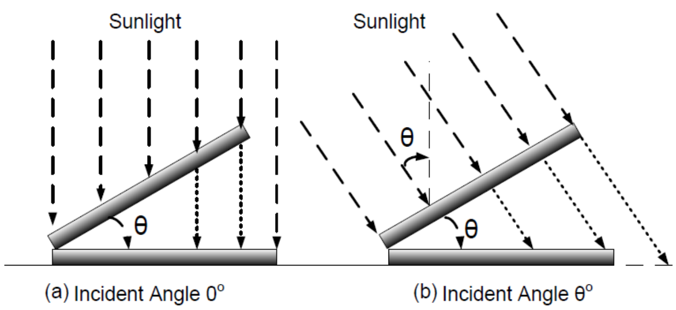

Figure 10: (a) Effective area with incidence angle 0° and sunlight's angle of incidence. (b) Fixed collector optimized mounting angle with incidence angle θ°.

The equations related to the incident angle or tilt angle, θ, are:

$$S_{horinzontal} = S_{incident} \sin \propto \quad (2)$$

$$S_{module} = S_{incident} \sin(\propto + \theta) \quad (3)$$

where α is the elevation angle and θ is the tilt angle of the module measured from the horizontal.

iv. Electrochemical Storage

Comparison on electrochemical storage technologies is shown in Table 2. Valve-regulated lead-acid is the primary choice for energy storage in photovoltaic application due to its high availability and cost effective thus ruling out other type of electrochemical storage which requires high production cost.

Table 2: Electrochemical storage technologies [25].

Technology	Advantages	Disadvantages
Flooded Lead-Acid	• Cost effective • Mature technology • Relatively efficient	• Low energy density • Cycle life depends on battery design and operational strategies when deeply discharged • High maintenance • Environmentally hazardous materials
Valve-Regulated Lead-Acid	• Cost effective • Mature technology	• Traditionally have not cycled well • Have not met rated life expectancies
NiCd	• Good energy density • Excellent power delivery • Low maintenance	• Moderately expensive • “Memory effect” • Environmentally hazardous materials
NiMH	• Good energy density • Low environment impact • Good cycle life	• Expensive
Li-ion	• High energy density • High efficiency	• High production cost • Scale-up proving difficult due to safety concerns
Na/S	• High energy density • Long cycle life when deeply discharged • Low maintenance • Integrated thermal and environmental management	• Relatively high cost • Requires powered thermal management (heaters) • Environmentally hazardous materials

v. Solar Charge Controller

A charge controller is essential in an energy system to make sure the system energy storage is properly charged. The function of the charge controller is to block reverse current thus preventing the energy storage from overcharging. Some charge controller includes additional features such as energy storage over discharged prevention, electrical overload prevention, and battery status and power flow display [26]. There are two types of charge controller available in the market which are the normal Pulse Width Modulation (PWM) types and the Maximum Power Point Tracking (MPPT) which have the ability to match the energy output of a PV module to the storage voltage to assure maximum charge.

Table 3: PWM vs MPPT comparison [27].

	PWM Charge Controller	MPPT Charge Controller
Array Voltage	• PV array and battery voltages should match	• PV array voltage can be higher than battery voltage
Battery Voltage	• Operate at battery voltage so it performs well in warm temperatures and when the battery is almost full	• Operates above battery voltage so it can provide "boost in cold temperatures and when the battery is low
System Size	• Typically recommended for use in smaller systems where MPPT benefits are minimal	• ≈ 150W- 200W or higher to take advantage of MPPT benefits
Off-Grid or Grid-Tie	• Must use off-grid PV modules typically with Vmp ≈ 17 to 18Volts for every 12V nominal battery charge	• Enables the use of lower cost/grid-tie PV modules helping bring down the overall PV system cost
Array Sizing Method	• PV array sized in Amps (based on current produced when PV array is operating at battery voltage)	• PV array sized in Watts (based on the Controller Max. Charging current x Battery Voltage)

Table 3 compares the PWM charge controller and MPPT charge controller with respect to their features [27]. In this project, MPPT charge controller is used due to its ability to provide maximum charge to ensure uninterrupted power supply for the traffic monitoring system.

2.3.3 Communication Module

Since most traffic monitoring systems are installed far from its monitoring center, each of these systems is usually equipped with wireless communication module to give the ability for one-way and two-way communication between the traffic monitoring system and the monitoring center.

There are many types of wireless communication technologies applicable depending on the communication range. For this project, general packet radio service (GPRS) is used to send data retrieved from the traffic sensors to the monitoring center.

GPRS is chosen as it is a well-established method for long-range communication and there are available services from local communication service providers using second (2G) and third (3G) generation system.

2.4 Battery Management System

A battery management system is incorporated in electronic systems that utilize rechargeable batteries to oversee the charging and discharging of the batteries in order to prevent the batteries from operating over the set limits of their Safe Operating Area. Other functions include battery state monitoring, battery’s environment control and data acquisition.

In this project, the battery management system is used to prolong the life span of the batteries by prohibiting (1) under-voltage, over discharged, deep discharged and over-voltage that can cause ***sulfation*** and (2) over-voltage, over charge and trickle charge that can cause ***gassing***.

2.4.1 Sulfation

Sulfation of lead-acid batteries occurs when the batteries are discharged for a long period of time or deeply discharged, or left uncharged for extended period of time after being discharged. This is common in systems that utilize photovoltaic application where the batteries are not being charged or sufficiently charged due to low solar radiation. If this happens, the lead sulfate crystals deposits on the plate will harden. This prohibits the batteries from being charged thus reducing their battery capacities. Sulfation also increases the batteries internal resistance resulting in longer charging time and less efficient and in complete charging [28-29]. Figure 11 shows sulfated plate of a lead-acid battery.

Figure 11: Sulfated Anode positive terminal plate at right side [29].

2.4.2 Gassing

When excessive charging is applied, gassing will occur where large amount of hydrogen and oxygen are produced by electrolysis. This would decrease the amount of electrolyte in the batteries when the gasses are vented from the battery or internal explosion as the gasses are explosive [28-29]. Figure 12 shows lead-acid battery damaged b\y internal explosion.

Figure 12: Exploded lead-acid battery [29].

CHAPTER 3
METHODOLOGY

3. PROJECT METHODOLOGY

This chapter focuses on two tasks: (1) the development of the method to study the power consumption of actual traffic monitoring system and (2) design of battery management technique for the energy source of the traffic monitoring system. Figure 13 shows the project activities to implement the above-mentioned tasks.

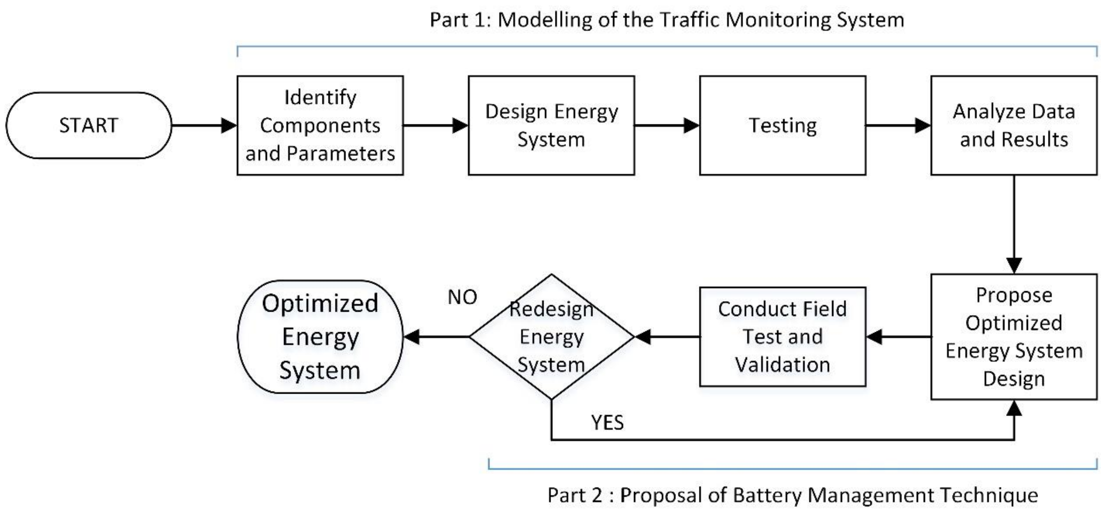

Figure 13: Flow chart of the project.

3.1 Traffic Monitoring System Architecture

Figure 14 shows the architecture of the traffic monitoring system used by the company KreatifApps [4], where the left side of the figure is the architecture of the traffic monitoring system implemented in practice while on the right side of the figure is similar system used for this project but its traffic sensor module and 3G router were modeled as load using a fan. In order to develop the similar architecture, the specification provided by KreatiffApps [4] was used for the load. Table 4 gives the details of this specifications.

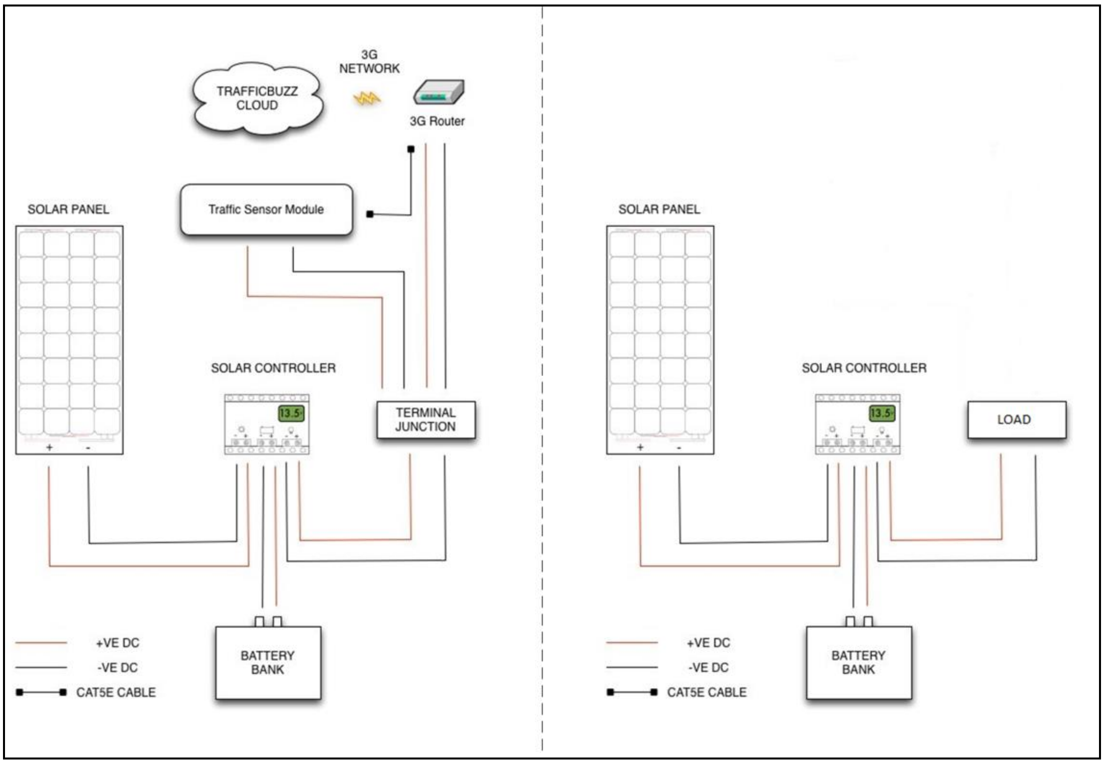

Figure 14: Architecture of the traffic monitoring system implemented in practice (left) and modeled architecture of the traffic monitoring system for the experiment.

Table 4: Specification of Modeled Load

Equipment	Specification
Traffic Sensor Module	• Traffic Counter, Vehicle Classification and Image Sensor • Supply voltage: 12VDC (Nominal) • Power consumption: 1.1 Watt (Typical), 2.2 Watt (Max)
3G Router	• Supply voltage: 12VDC (Nominal) • Power consumption: 3.48 Watt (Typical) • Maximum operation temperature: +70°C

The operation of this system is expected to be 24 hours a day. However, due to limited battery capacity of 18 AH (Ampere-Hour) 12VDC, the traffic monitoring system could only last for 18 hours. It is important to prolong the lifetime of the battery to provide uninterrupted power supply as the system runs solely on the battery

3.2 Experimental Set-up for Part 1

Experiment was set-up to study the solar irradiance and its effects on the power produced by the solar panel, and the power consumed by the load. This is important to determine how long would the power source of the system last during the actual deployment on the highway.

To optimize the system, the data related to power being consumed and generated must be obtained. Thus, the power consumed by the traffic sensor is measured to better estimate the optimized storage capacity for the electrochemical storage to support the system. The power generated from the photovoltaic module is calculated by

$$P = I \cdot V \tag{4}$$

where I is current and V is voltage.

This calculation is then done on the solar irradiance to observe and understand the relationship between the amount of solar irradiance received and the amount of power that could be generated by the solar photovoltaic module.

Figure 15 shows the power parameters are monitored using monitoring software.

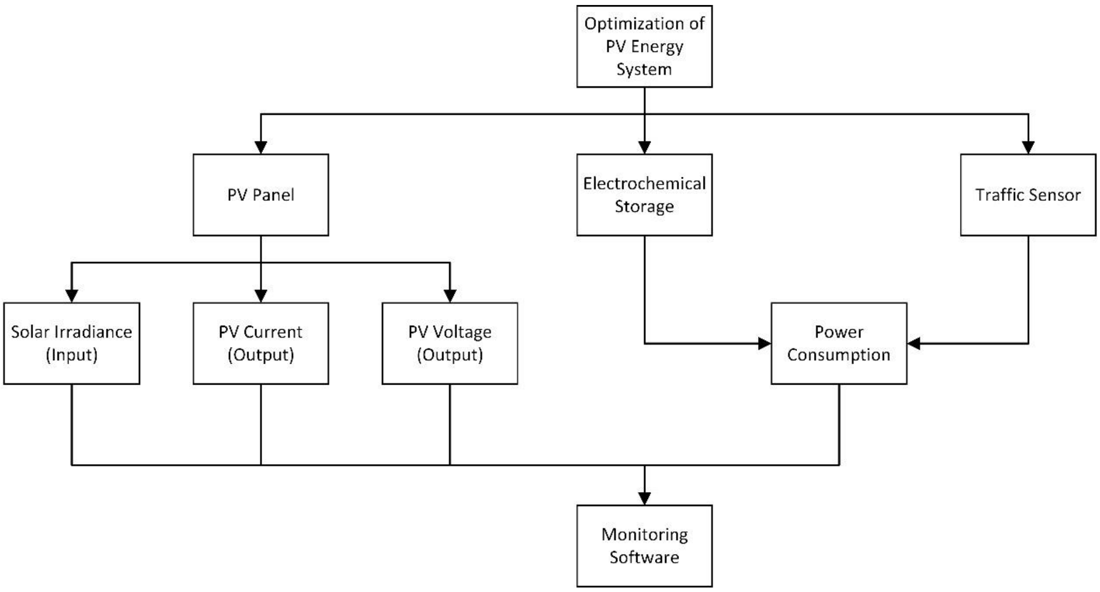

Figure 15: Power parameters monitored using monitoring software.

3.2.1 Performance Parameters

- **Solar Irradiance.** Solar irradiance is collected by the PV panel and converted into DC power supply. Higher amount of solar irradiance will produce higher amount of DC power supply.
- **Power Produced.** The power produced is calculated from the voltage and current output of the PV panel. The voltage and current output varies depending on the amount of solar irradiance available and will be stored in the electrochemical storage (battery).
- **Power Consumed.** The power consumed is calculated from the voltage and current input from the battery to the load. The voltage and current input varies according to the number of load connected to the system and their specification respectively.

3.2.2 Equipment Set-up

The equipment and circuit connection are provided in Figure 16. The description of this set-up will be discussed in this section. Table 5 briefly explains the functions of each equipment.

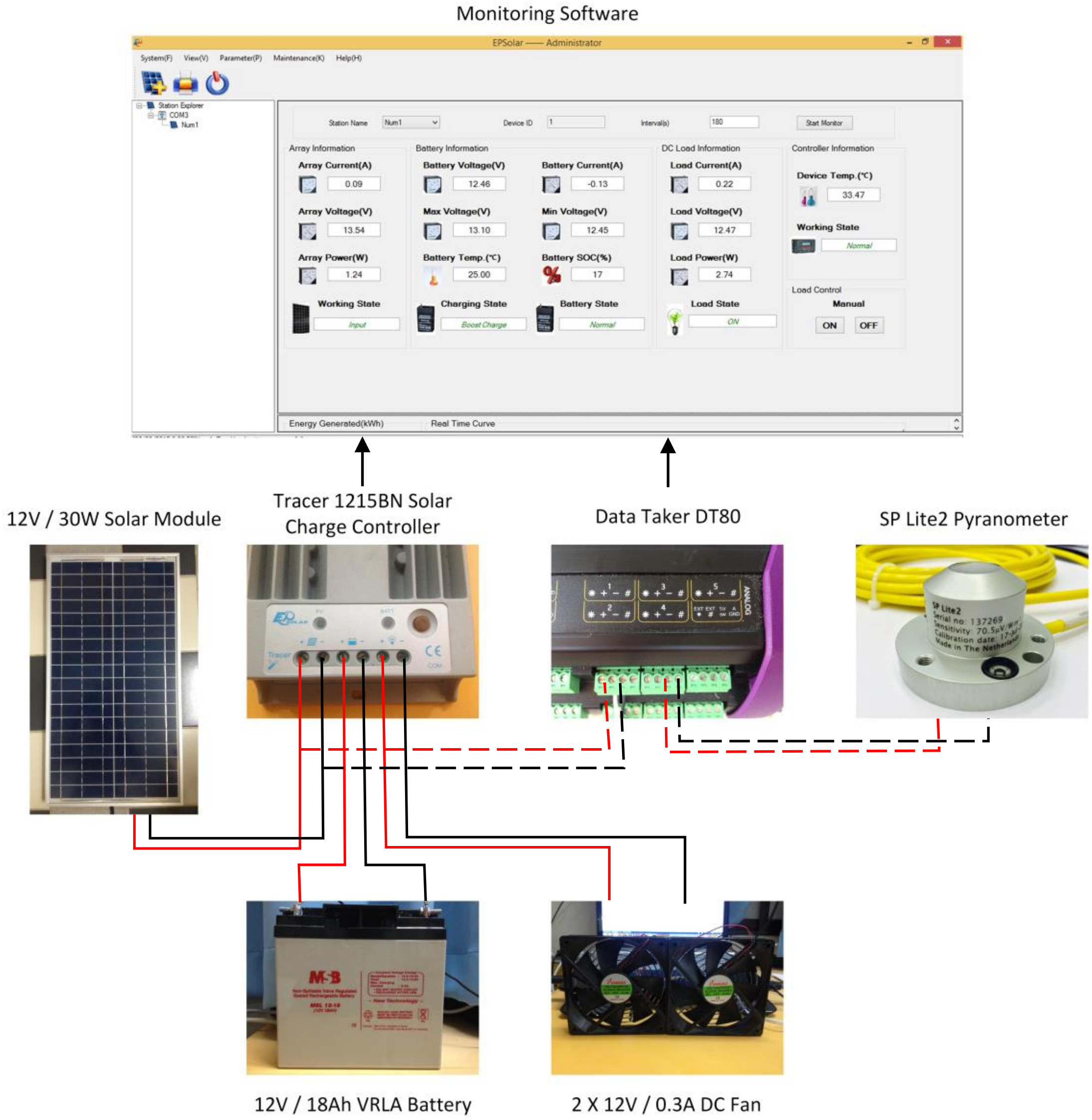

Figure 16: Equipment set up.

Table 5 : Functions of equipment used

Equipment	Function
Monitoring Software	Monitor and record performance parameters
Solar Module	Convert solar energy into DC power
Tracer 1215BN Solar Charge Controller	To control the charging and discharging of the battery
Data Taker DT80	Record the power parameters (V, I)
SP Lite2 Pyranometer	Solar irradiance sensor
VRLA Battery	Power source for the system
DC Fan	Modeled load

A. Monitoring software

In this project, two monitoring software are used to measure and record the parameters required which are Solar Station Monitor and Data Taker DT80. Table 6 shows the parameters monitored by both software.

Table 6: Parameters monitored by monitoring software

Monitoring Software	Parameters
Solar Station Monitor	• Array Current, Array Voltage, Array Power • Battery Voltage, Battery Current • Load Current, Load Voltage
Data Taker DT80	• Array Voltage • Solar Irradiance

i. Solar Station Monitor

Solar Station Monitor is a product application provided by Beijing Epsolar Technology Co., Ltd. [30] for their product consumers to monitor a system installed.

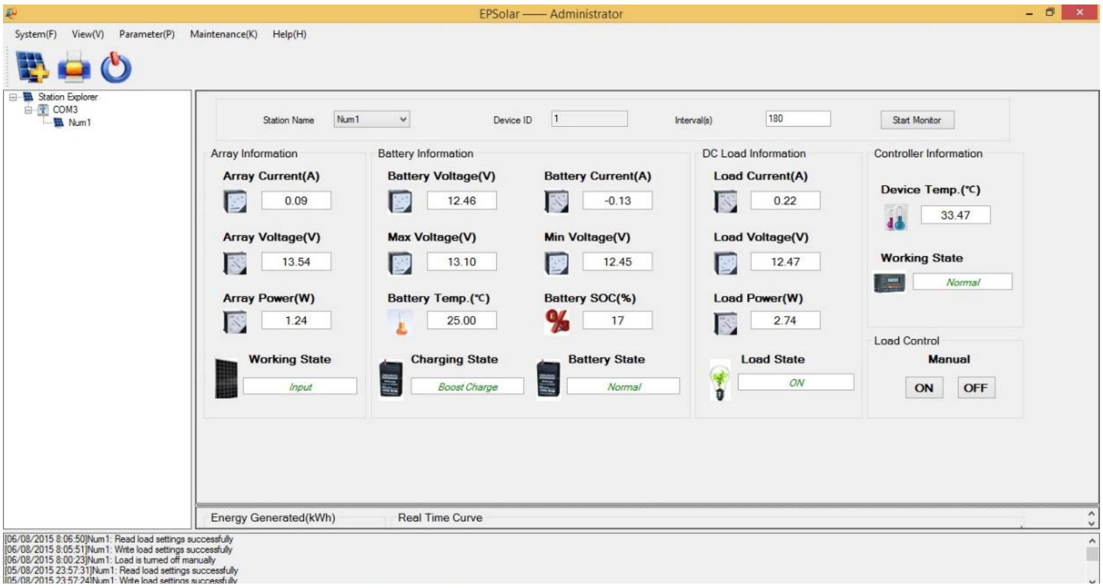

Figure 17: Solar Station Monitor software interface.

The software displays two basic information which are Current (Amps) and Voltage (Volt) for solar array, battery and system load while for Power (Watt), only solar array and system load will be displayed. Extra information displayed are battery's State of Charge (SOC), Temperature (for battery and device) and State (for working, charging, battery state and load). For this software to be able to monitor the system as shown in Figure 17, it is connected from the Tracer 1215BN solar charge controller seen in Figure 18 to a laptop.

Figure 18: Ethernet port output to be connected to a laptop.

ii. Data Taker DT80

Data Taker DT80 is a data logging instrument to measure and record a wide variety of quantities and values in real world practice.

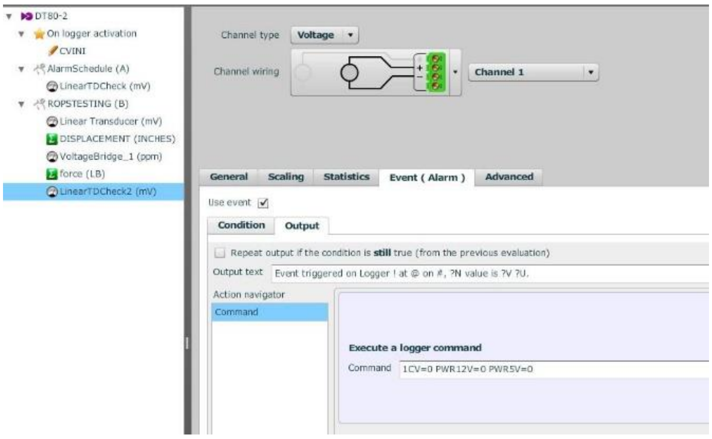

Figure 19: Data Taker software interface

From the software interface shown in Figure 19, the Data Taker DT80 can be configured to record different parameters such as voltage, current, solar radiance and temperature. The recorded data then can be exported in Excel form. To acquire data of the parameters, the system is connected to the Data Taker DT80 inputs which can be seen in Figure 20.

Figure 20: Data Taker digital and analog input

B. Solar Irradiance

The solar irradiance varies from day to day depending on the solar geometry of the location. To measure the solar irradiance, a SP Lite2 pyranometer is used. This device is designed to measure the solar irradiance on a plane surface with a field of view of 180° [31]. For the purpose of measuring the solar irradiance, the sensor is placed on a window awning which can be seen in Figure 21 and positioned precisely to avoid the solar panel being covered by the shadow of the upper awning. The output of the sensor is directly connected to the Data Taker DT80 input to be recorded.

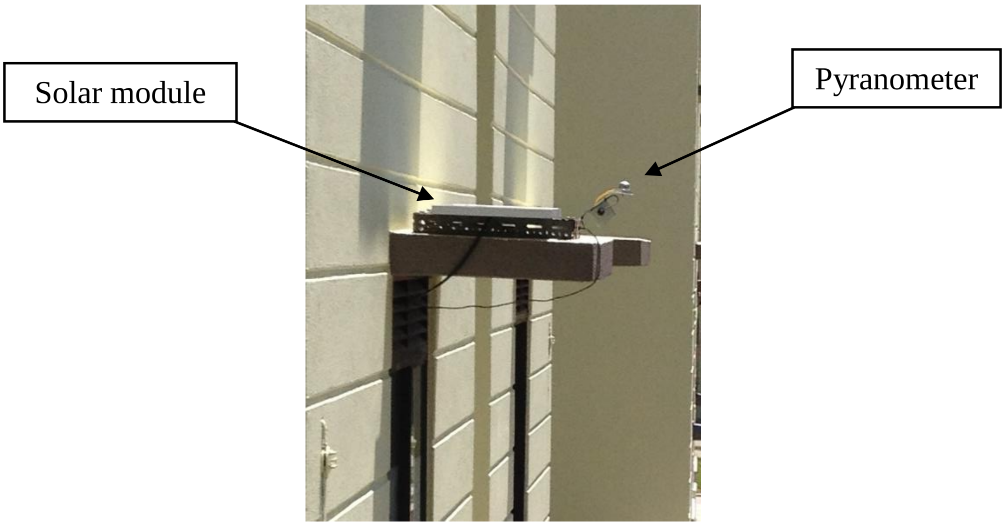

Figure 21: Pyranometer and solar module placed on a window awning.

C. Solar Array Output

Output of a photovoltaic module are the current and voltage. This could be measured by using analog amp meter and volt meter or a digital multi-meter. To obtain the value of generated power, the ampere and voltage are multiplied. To test the system, a 12Volt solar module with rated power of 30Watt is used. With direct sunlight, the solar module has a rated voltage of 17.5Volt and rated current of 1.72Amps. The photovoltaic module is set up with the pyranometer as shown in Figure 20. The module is connected to the solar charge controller and Data Taker DT80 to monitor the voltage and current output.

D. Power consumption

Figure 22: 12V/0.3A DC Fan.

The load is firstly determined. This could be obtained by looking at the load's power rating label. If only amperage and voltage are shown, these two values are multiplied to obtain the wattage. The wattage obtained is the power needed per hour, with base unit, Watt-Hour (Wh).

$$Power = Voltage \cdot Current \tag{5}$$

To better estimate the power consumption, the wattage is multiplied with 1.5, which is known as fudge factor. This is to compensate other losses such as interconnection and wiring losses and charging and discharging losses [32].

$$Power = 1.5 \cdot Voltage \cdot Current \tag{6}$$

For testing purpose, two DC fans rated at 12 Volt / 0.3 Amps shown in Figure 22 are used to represent the power consumption of the traffic sensor and communication module as the load of the system. The power consumption of the solar charge controller is also included and considered as self-consumption.

Table 7: Power consumption comparison

Load \ Power Consumption	Actual System (Wh)	Test System (Wh)
1 x Traffic Sensor Module	2.2 (Max)	-
1 x Communication Module	3.48 (Typical)	-
1 x Solar Charge Controller	0.6	0.6
2 x DC Fan	-	7.2
Total	6.28	7.8
Estimated Total (1.5xTotal)	9.42	11.7

E. Electrochemical Storage Capacity

To calculate the minimum capacity for the electrochemical storage, equation 7 is used

$$\begin{aligned} &Minimum\ battery\ capacity \\ &\quad = 2 \cdot Load\ WattHours \cdot Running\ Hours\ per\ Day \\ &\quad \cdot Days\ worth\ of\ Energy \end{aligned} \tag{7}$$

Therefore, the minimum battery capacity for the actual system described in Table 7 with estimated total power consumption is

$$\begin{aligned} Minimum\ battery\ capacity &= 2 \cdot 9.42 WattHours \cdot 24 hours \cdot 2 days \\ &= 904.32\ \mathrm{WattHours} \\ &\cong 904\ \mathrm{WattHours} \end{aligned} \tag{8}$$

For the test system, a Valve – Regulated Lead Acid (VRLA) battery shown in Figure 23 is used with a 12 Volt rated voltage and 18 AmpHours capacity. This means that the power capability of the battery equals to 216 WattHour.

Figure 23: 12V / 18Ah Valve – Regulated Lead Acid.

Since the value of WattHour for the battery is known, the running hours for the system can be calculated using:

$$Total\ running\ hours : \frac{Total\ Battery\ Capacity\ (Wh)}{Total\ Power\ Consumption\ (Wh)} \tag{9}$$

For the actual system with estimated total power consumption:

$$\begin{aligned} Total\ running\ hours\ &= \frac{216\ WattHours}{9.42\ WattHours} \\ &= 22.92\ hours \\ &\cong\ 23\ hours \end{aligned} \tag{10}$$

For the test system with estimated total power consumption:

$$\begin{aligned} Total\ running\ hours\ &= \frac{216\ WattHours}{11.7\ WattHours} \\ &= 18.46\ hours \\ &\cong\ 18\ hours \end{aligned} \tag{11}$$

The calculations are summarized in Table 8

Table 8: Summarized calculation for battery capacity and total running hours

	Actual System	Test System
Minimum Battery Capacity	904 WattHours	-
Experiment Battery Capacity	216 WattHours	216 WattHours
Total Running Time base on Experiment Battery Capacity	23 Hours	18 Hours

3.3 Experimental Set-up for Part 2

Experiment is set-up to design a battery management circuit for the power source of the traffic monitoring system. This circuit is designed based on the study done in Part 1 which provided the estimated value of the power generated and power consumed by the system.

To design the circuit, the necessary requirements and specifications are first determined. The parameters are then decided in order to meet the criteria of the requirements and specifications determined. Finally, appropriate components are chosen to acquire those parameters. All decision done will be discussed in the following sub-sections.

3.3.1 Design Features

When designing, specifications must be determined to have a better prospect on how to design the optimization circuit for the power source of the traffic monitoring system.

- **Low Voltage Disconnect.** The optimization circuit should be incooperated with a low voltage disconnect circuit where the battery will be disconnected from the load when the voltage reading of the battery goes below the threshold value. This will enable the battery management circuit to prevent the battery from under-voltage, over discharge and deep discharge. When discharged more than 50% of the battery capacity or left in discharged state for a long period of time, sulfation will develop on the battery's plate that will hinder the battery's ability to charge. If this happens, the battery needs to be replaced with a new battery.

- **High Voltage Disconnect.** The optimization circuit should also include a high voltage disconnect circuit. This will disconnect the battery from the solar charge controller when the voltage reading of the battery goes above the threshold value. By doing this, the optimization circuit is able to prevent the battery from over-voltage, over charge and trickle charge. When the battery is excessively charged, gassing will occur where hydrogen and oxygen is produced by electrolysis. From the accumulated hydrogen and oxygen, the battery might explode due to high pressure or internal explosion.

- **Over-current Protection.** Over-current protection circuit is essential part of the optimization circuit. This will not just protect the components of each circuit but the whole traffic monitoring system itself. The lead-acid battery has the ability to conduct constant amount of high current. Thus, when high current flows through the protection circuit, it will disconnect the battery from the whole system. This will prevent any possible damage to the components of the traffic monitoring system.

- **Two Days Battery Capacity.** In Part 1, it is observed that the total capacity of the battery is insufficient for the traffic monitoring system to run continuously for more than two days. Thus, a two battery setup is proposed for the circuit to increase the total battery capacity for the traffic monitoring system. For this, the circuit should be able to control the charging and discharging of both batteries in order to lengthen their life cycle by alternatively charging and discharging between both of the batteries. This is to slowly deplete its charge cycle while lengthening its life cycle.

3.3.2 Design Requirements

The proper application require the system to meet the following requirement

a) **Sufficient Battery Capacity.** As the proposed optimization circuit requires two batteries, it is essential for both batteries to have sufficient amount of battery capacity. Each battery must be able to provide enough power supply for the traffic monitoring system to run for more than 24 hour without any power interruption before the transition between the two batteries occurs. For this, each battery should have at least two days or more worth of total battery capacity.

b) **Proper ventilation for the system.** The batteries should be charged at a temperature of approximately 25°C. If the temperature of the surroundings or storage is higher than 25°C, proper ventilation should be provided or lower voltage threshold should be set to prevent overcharging.

3.3.3 Performance Parameters

- **Battery Voltage.** The voltage reading of the battery is obtained as reference to decide if the battery is fully discharged or fully charged.
- **Load Current.** The current reading is measured and used to approximate the power consumed by the load.
- **Power Produced.** The power produced is calculated from the voltage and current output of the PV panel. The voltage and current output varies depending on the amount of solar irradiance that are available and will be stored in the electrochemical storage (battery).

3.3.4 Design of Battery Management Circuit

The design of the circuit is based on the requirements and specifications that have been determined and are implemented in stages. Each stage is then integrated with each other and assembled as a prototype. Figure 24 shows how the optimization circuit is integrated to the modelled architecture of the traffic monitoring system.

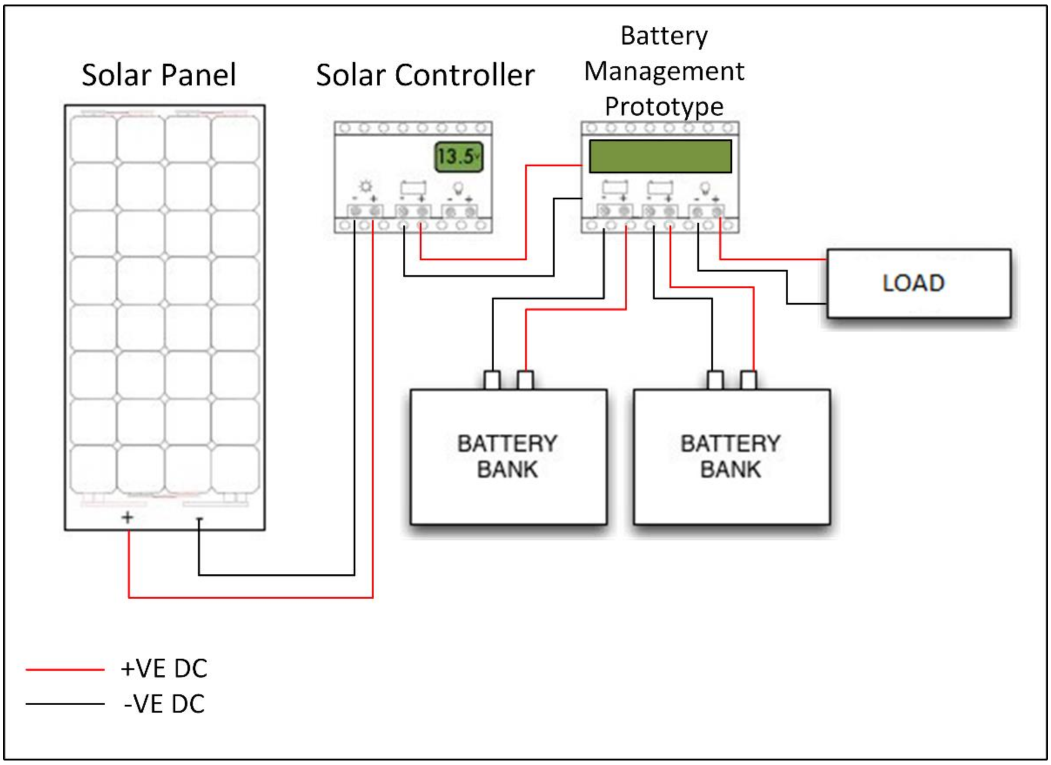

Figure 24: Modelled architecture of the traffic monitoring system architecture integrated with battery management prototype.

Battery management circuit is incoorperated with two type of circuit which is (1) low voltage disconnect circuit and (2) high voltage disconnect circuit.

A. Low voltage disconnect circuit

A low voltage disconnect circuit is used to automatically disconnect the connections between the load and the battery when the battery voltage falls below the threshold value. This will prevent the batteries from being over discharged or deeply discharged.

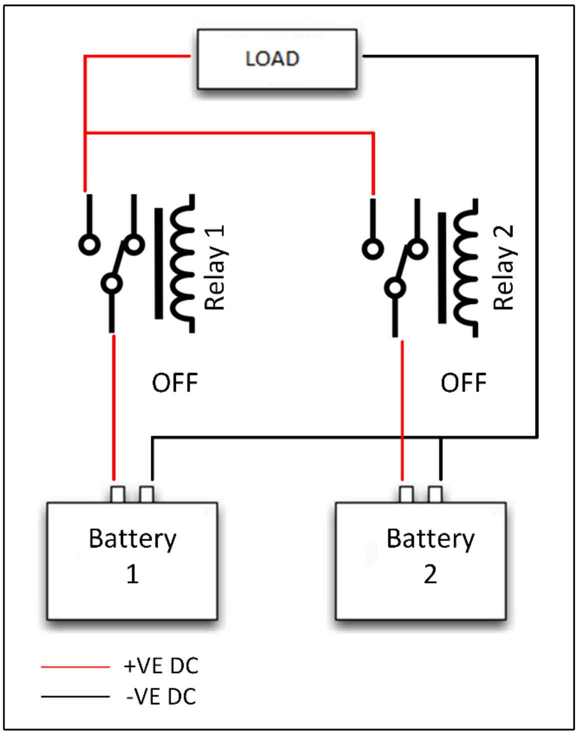

Figure 25: Low voltage disconnect circuit in Mode 0.

Figure 25 shows the low voltage disconnect circuit in its Mode 0. This mode is the initial state when the system is first start up and when both batteries have the voltage reading below the threshold value. In this mode, both Relay 1 and Relay 2 will not be triggered.

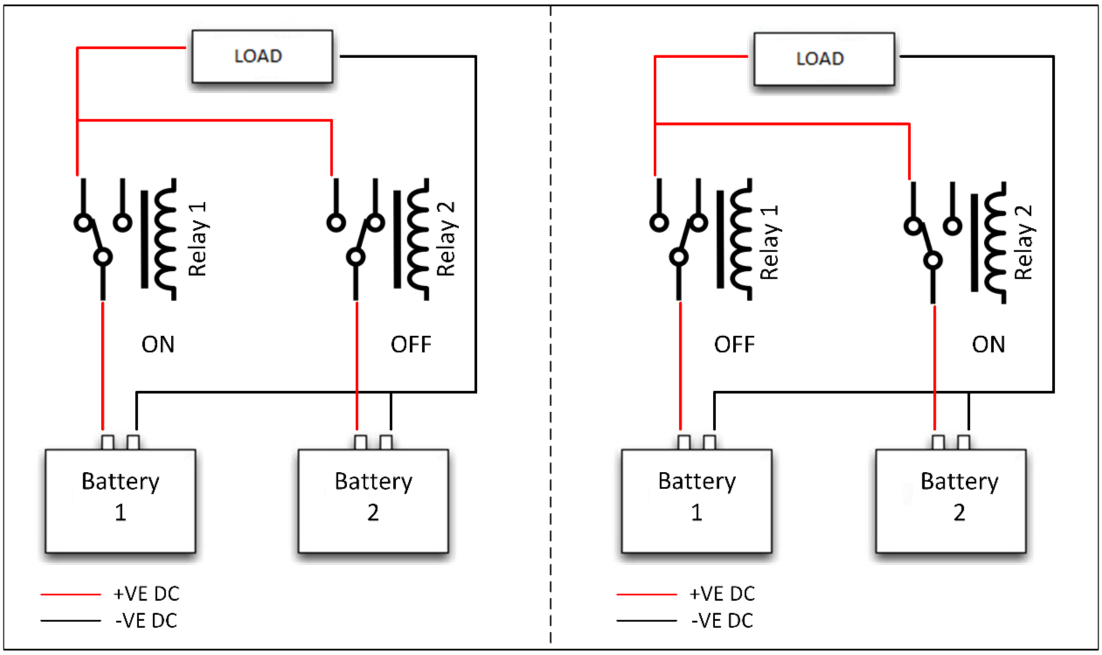

Figure 26: Low voltage disconnect circuit in Mode 1 (left) and Mode 2 (right).

From Figure 26, there are two modes of configuration for the low voltage disconnect circuit: (1) Mode 1 on the left of Figure 25 where Relay 1 is ON and Relay 2 is OFF; and (2) Mode 2 where Relay 1 is OFF and Relay 2 is ON. Mode 1 is triggered when the voltage reading of battery 1 is higher than the threshold value and the battery 2 is being charged while Mode 2 is triggered when the voltage reading of battery 2 is higher than the threshold value and battery 1 is being charged.

The threshold for the low voltage disconnect circuit is set at 12 Volt.

B. High voltage disconnect circuit

High voltage disconnect functions by automatically disconnecting the battery from the solar charge controller when the voltage reading of the battery goes higher than the threshold value. This is to avoid over charging and trickle charging of the batteries.

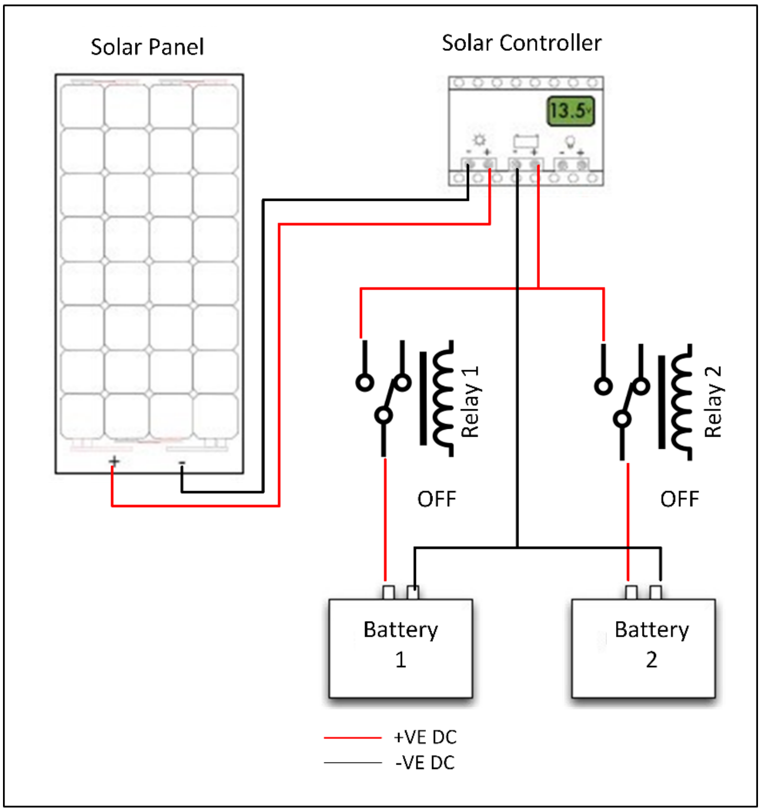

Figure 27: High voltage disconnect circuit in Mode 0.

In Figure 27 shows the circuit in Mode 0, where both Relay 1 and Relay 2 are not triggered. This is because Mode 0 is triggered during the initial startup of the system and when both batteries have voltage reading above the threshold value.

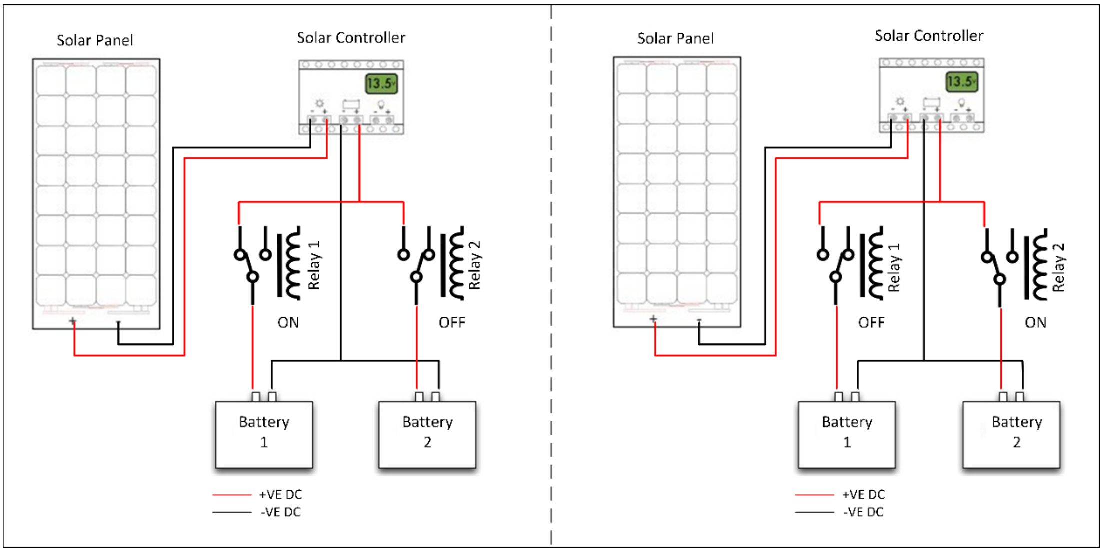

Figure 28: High voltage disconnect circuit in Mode 1 (left) and Mode 2 (right).

From Figure 28, there are two modes of configuration for the high voltage disconnect circuit: (1) Mode 1 on the left of Figure 28 where Relay 1 is ON and Relay 2 is OFF; and (2) Mode 2 where Relay 1 is OFF and Relay 2 is ON. Mode 1 is triggered when the voltage reading of battery 1 is lower than the threshold value and the battery 2 is being used by the load while Mode 2 is triggered when the voltage reading of battery 2 is lower than the threshold value and battery 1 is being used by the load.

The threshold for the high voltage disconnect circuit is set at 14 Volt.

C. Integrated Battery Management Circuit

The low voltage disconnect circuit and high voltage disconnect circuit are both integrated together to form the battery management circuit. At start up, both circuits will be in Mode 0 where both circuits are not triggered. This is shown in Figure 29.

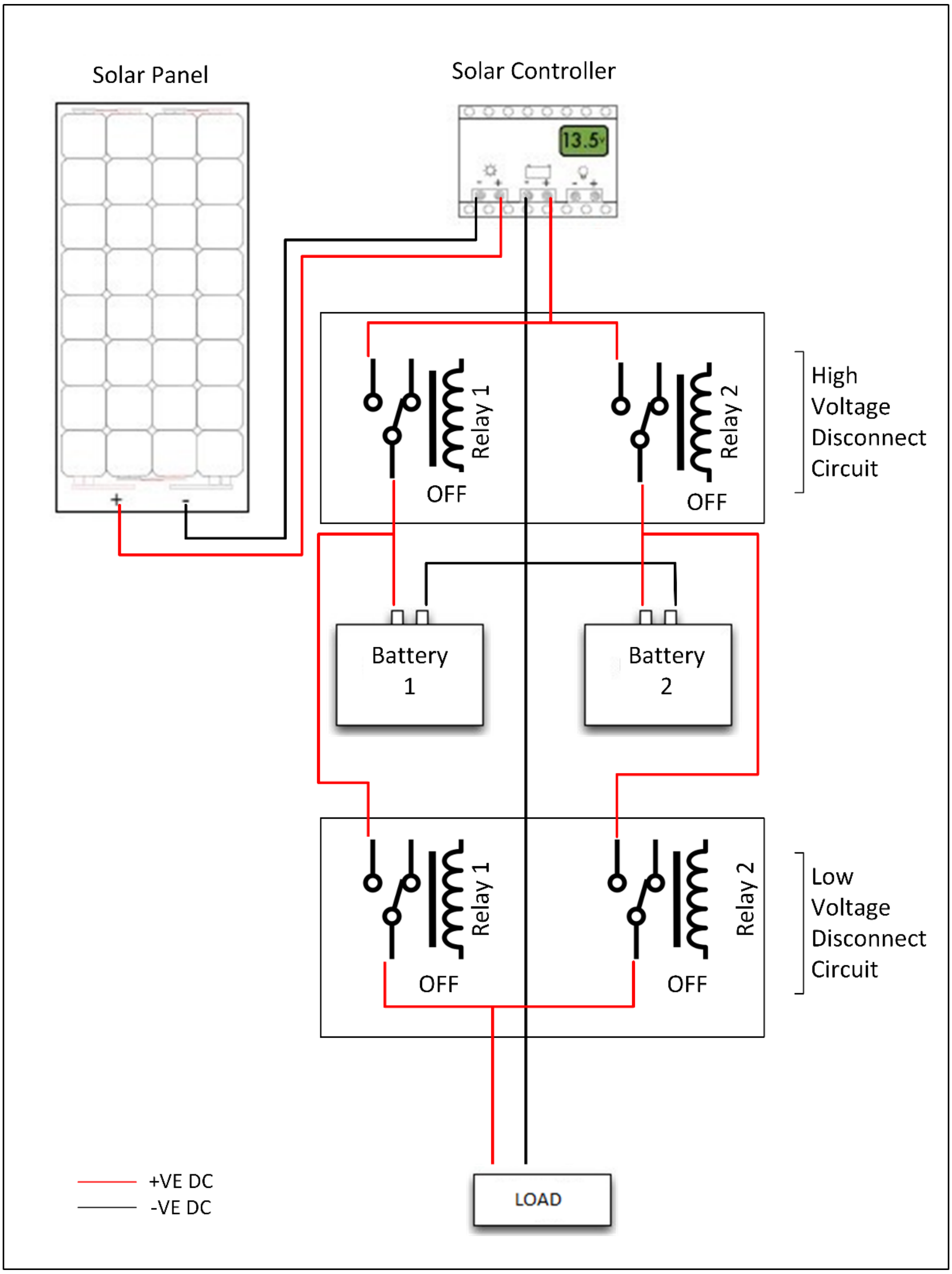

Figure 29: Low voltage disconnect circuit and high voltage disconnect circuit both in Mode 0.

While in operation, both circuits will be triggered in different mode respectively. Figure 30 shows the high voltage disconnect circuit in Mode 1 and low voltage disconnect circuit in Mode 2 while Figure 31 shows the low voltage disconnect circuit in Mode 1 and the high voltage disconnect circuit in Mode 2.

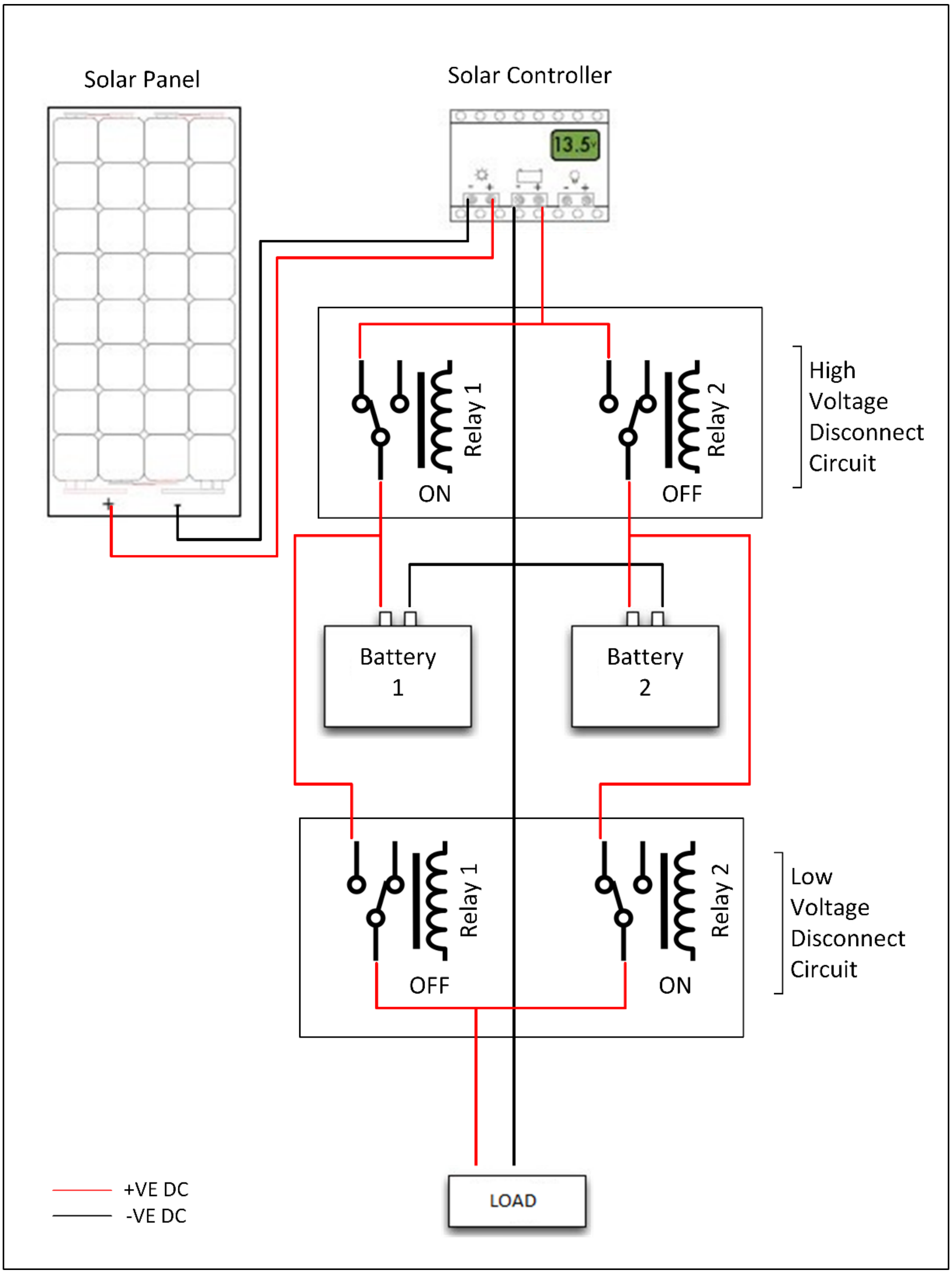

Figure 30: High voltage disconnect circuit in Mode 1 and low voltage disconnect circuit in Mode 2

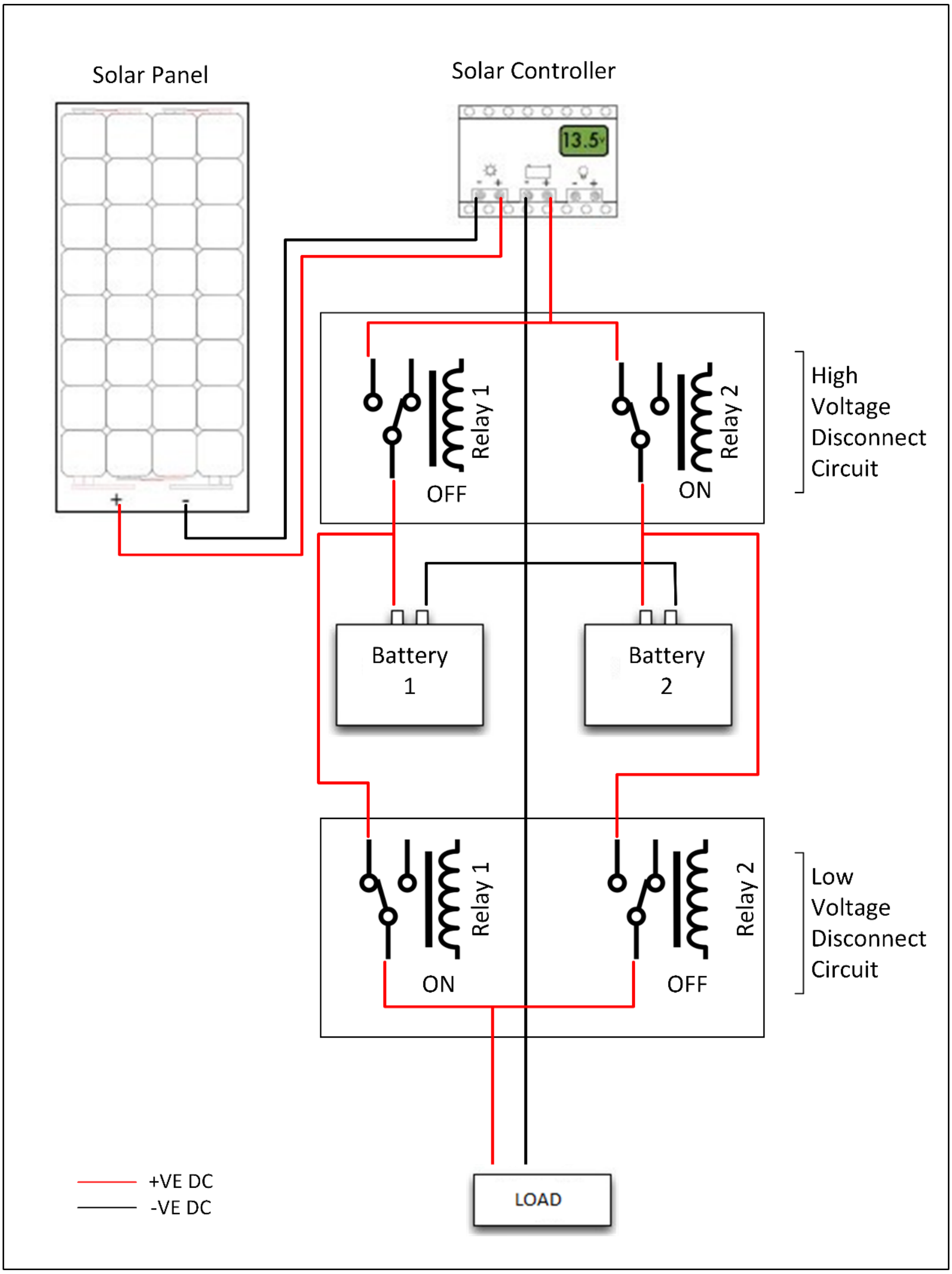

Figure 31: Low voltage disconnect circuit in Mode 1 and high voltage disconnect circuit in Mode 2.

The final design of the battery management circuit is shown in Figure 32 where all the components such as ***the microcontroller, voltage sensors, current sensors and the Real Time Clock (RTC)*** are included.

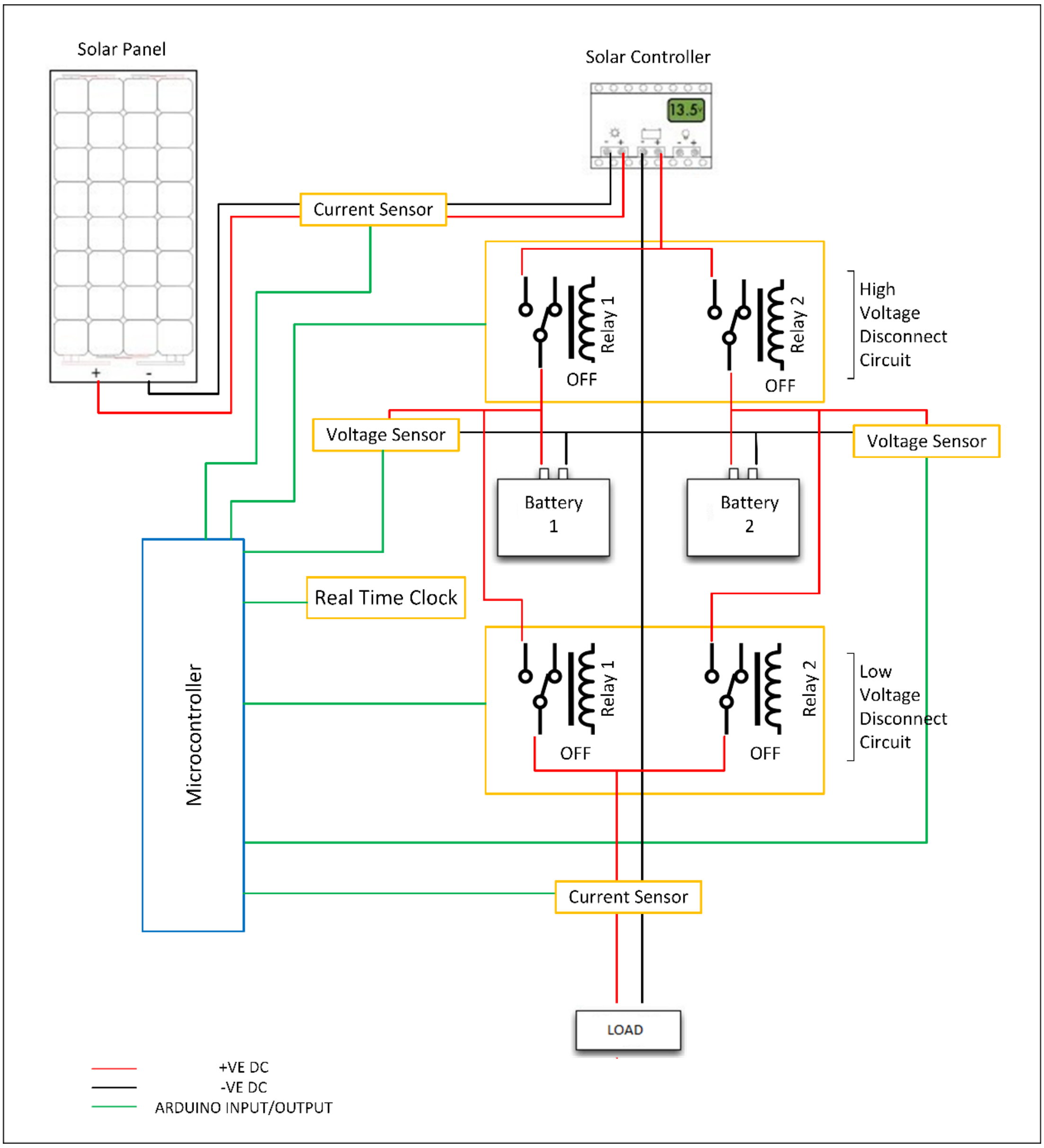

Figure 32: The design of battery management circuit.

3.4 Gantt Chart

The timeline of this project is shown in the Gantt chart in this section describing the activities of the project.

Gantt chart for FYP 1

Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Title Selection	■	■												
Preliminary Research & Literature Review		■	■	■	■	■								
Submission of Extended Report						♦								
Learning Basic for Data Taker							■	■						
Field Test							■	■	■	■	■	■		
Proposal Defend								♦						
Obtain Optimized Energy System												♦		
Prepare Interim Report											■	■	■	■
Submission of Interim Draft Report													♦	
Submission of Interim Report														♦

♦ Key Milestone ■ Process

Gantt chart for FYP 2

Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Design of Battery Management Circuit	■	■	■	■	■	■	■	■	■	■	■			
Submission of Progress Report							♦							
Propose Optimize Design for The System										♦				
Lab Test on the Battery Management Circuit								■	■	■	■			
Pre-Sedex											♦			
Submission of Draft Final Report												♦		
Submission of Dissertation													♦	
Submission of Technical Report													♦	
Viva														♦
Submission of Project Dissertation														♦

♦ Key Milestone ■ Process

CHAPTER 4

RESULTS AND DISCUSSION

PART 1

Two experiments were set up and left running to investigate the power consumption and sustainability of the system.

(1) The time range of the data being recorded for the first experiment were 8:00AM to 6:00PM. The parameter taken was solar irradiance which is recorded in Figure 33.

(2) The time range of the data being recorded for the second experiment were 9:30AM to 9:30PM and 9:30PM to 9:30AM. Three parameters were taken which are voltage, current and power. The readings for voltage, current, and power for solar array, battery and system load are represented in red line, green line and blue line respectively. The result is recorded in Figures 34 to Figure 42.

1. Solar Irradiance

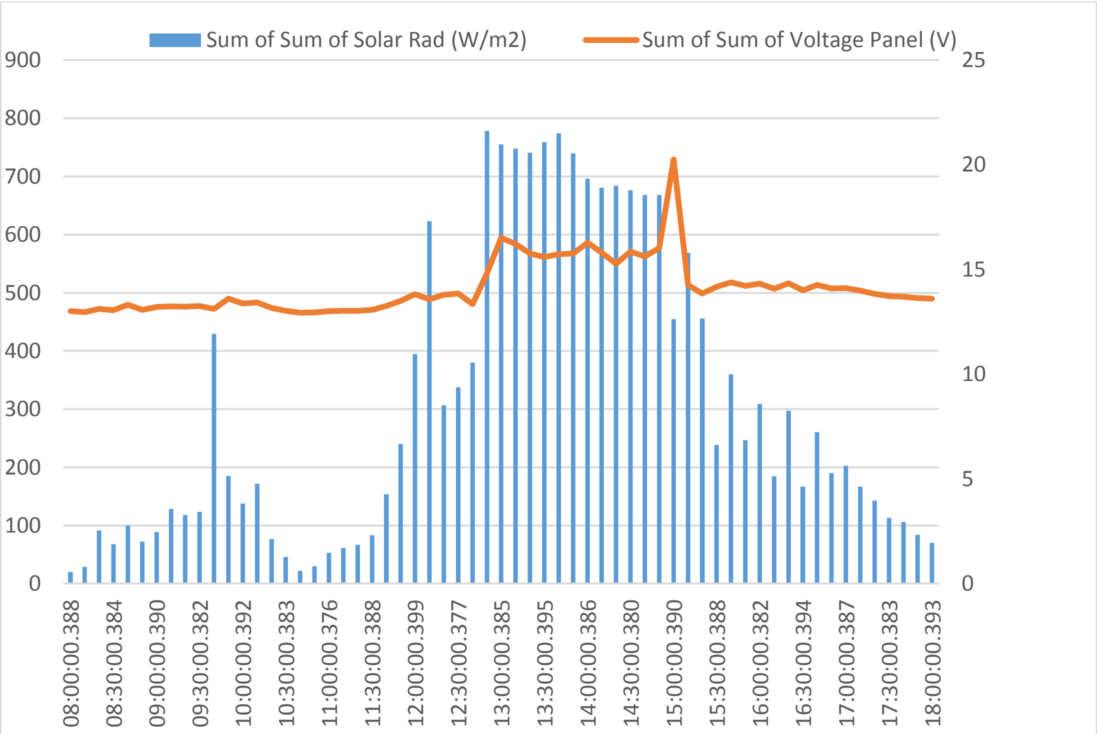

Figure 33: Solar radiance reading on 6/8/15 from 8:00AM to 6:00PM

The SP Lite2 pyranometer was set up from 8:00AM to 6:00PM to measure the solar radiation using the DataTaker DT80. Theoretically, the solar radiation should have a smooth increase from sunrise and reached its maximum at noon before it slowly decreases until sunset. This was not correctly reflected from the readings obtained shown in Figure 33 due to intermittent weather during the day of testing.

From the readings, it was observed that the solar radiance was at maximum during noon time from 12PM to 2PM when the sun was directly above with a maximum value of 778 Watt/meter^2. During this period of time, the solar module generated the highest value of power which can be seen in Figure 40 and Figure 42. Since the solar module needs 1000 Watt/meter^2 to generate its rated power, 30 Watt, it can be concluded that the solar module could not generate its rated power capacity due to insufficient amount of solar radiation.

2. Voltage

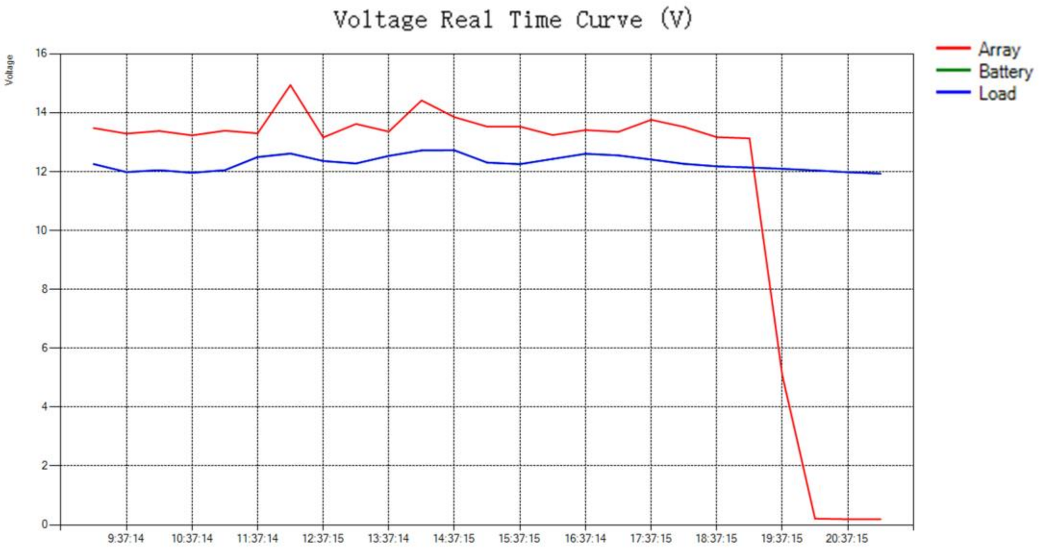

Figure 34: Voltage reading on 9/8/15 from 9:30AM to 9:30PM.

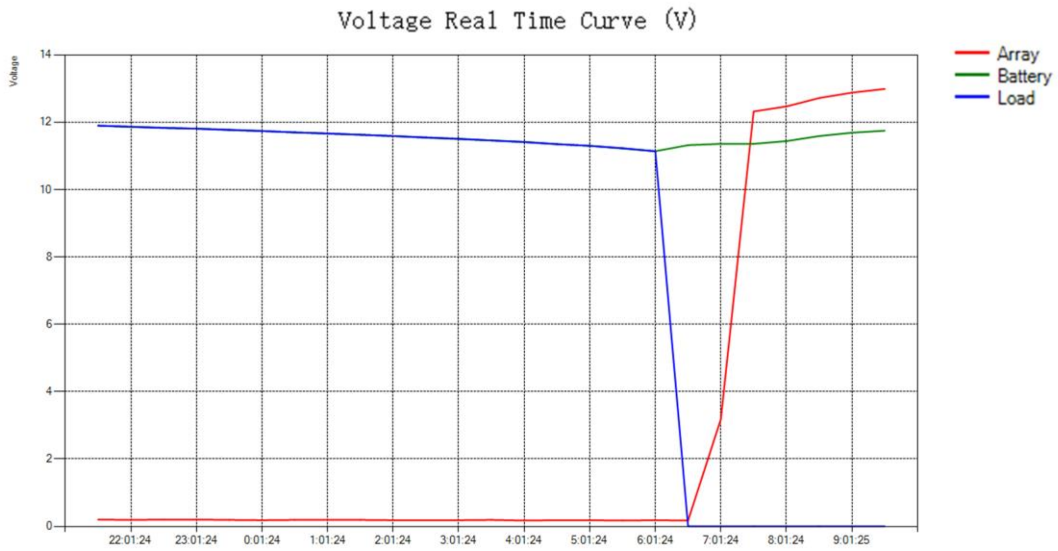

Figure 35: Voltage reading on 9/8/15 from 9:30PM to 9:30AM.

The voltage of the solar array recorded is the voltage reading generated by the solar module. The solar module generated voltage at estimated time, 7:00AM and stop generating at 7:00PM. The voltage reading of the solar module remains consistent at 13 Volt but fluctuates several times. This may due to the large amount of solar radiation it receives at noon.

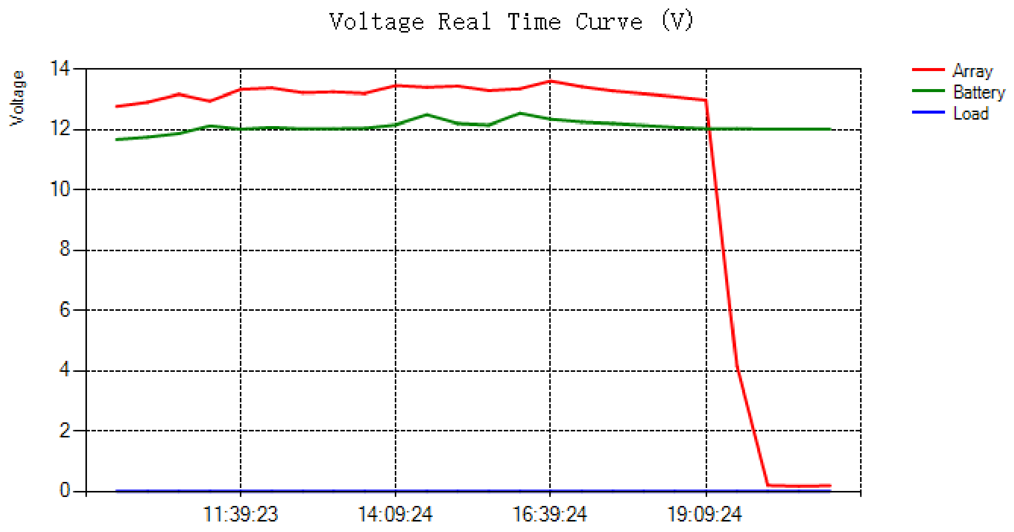

Figure 36: Voltage reading on 10/8/15 from 9:30AM to 9:30PM.

Voltage readings for battery and system load were the same which was 12 Volt as both the battery and the load were rated at 12 Volt. The readings remained consistent at 12 Volt until the load was turn off where the reading drop to 0 Volt which is seen in Figure

35 and Figure 36. This is because the solar charge controller had detected that its battery was overly discharged thus the load was cut off.

3. Current

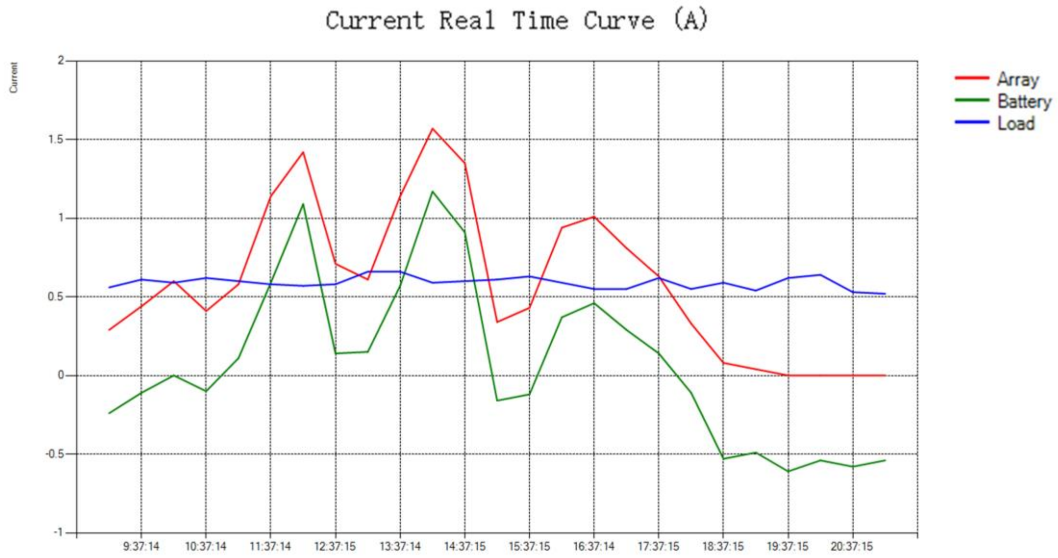

Figure 37: Current reading on 9/8/15 from 9:30AM to 9:30PM.

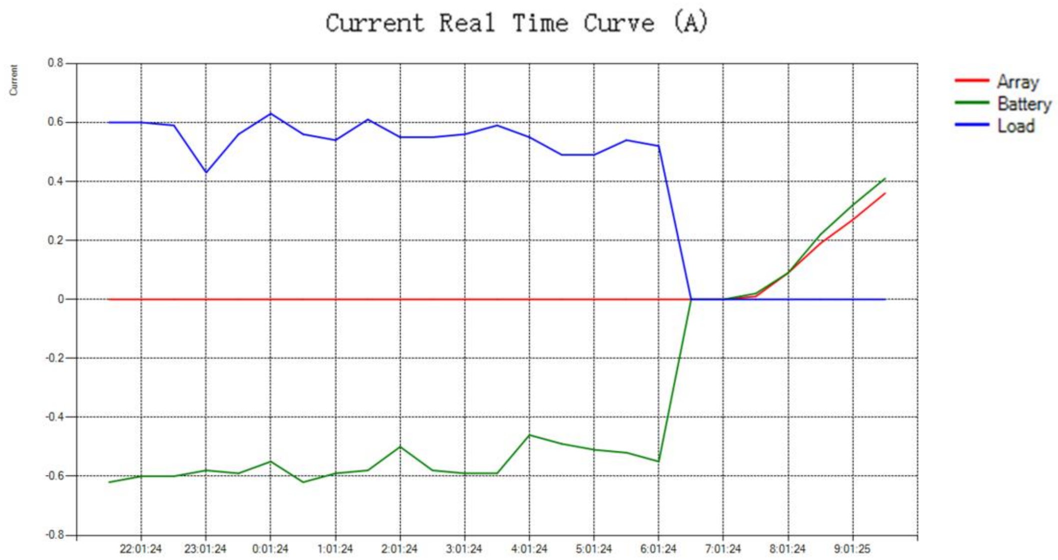

Figure 38: Current reading on 9/8/15 from 9:30PM to 9:30AM.

The system load current input equals to 0.6 Amps. The reading remains the same until the load is cut off by the solar charge controller where the current reading is 0 Amps. This means no current is being supplied to the load. For solar array, the current readings varies from time to time because the current generated depends on the amount of solar radiation it receives during day time while at night time the reading is 0 Amps which shows there is no current being generated.

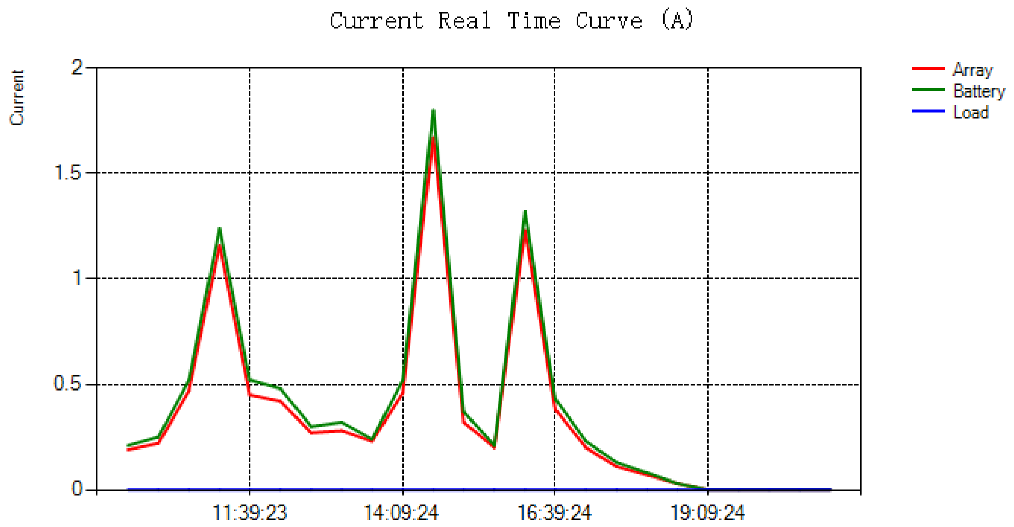

Figure 39: Current reading on 10/8/15 from 9:30AM to 9:30PM.

The readings for the battery is calculated as:

$$Current_{Battery} = Current_{Array} - Current_{Load} \tag{12}$$

For example, when the load is cut off as shown in Figure 39, the value of the battery current is equals to the solar array current where the value is positive which indicates that the battery is being charged by the solar module.

At night time where the solar array is cut off, the current reading of battery is seen as negative value. This shows that the current is being discharged by the battery and supplied to the load where the value is positive. This is depicted in Figure 38.

While in Figure 37, both the load and the solar array are connected which means that the battery is being charged by the solar module and discharged to supply the load. Thus the shape of the graph in the figure for the battery is almost the same as solar array but has a different value.

4. Power

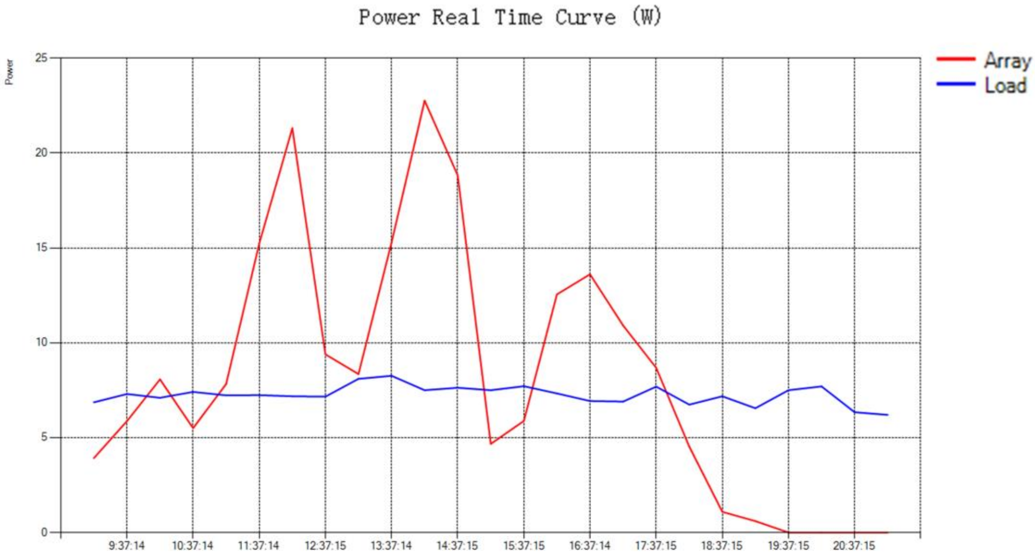

Figure 40: Power reading on 9/8/15 from 9:30AM to 9:30PM.

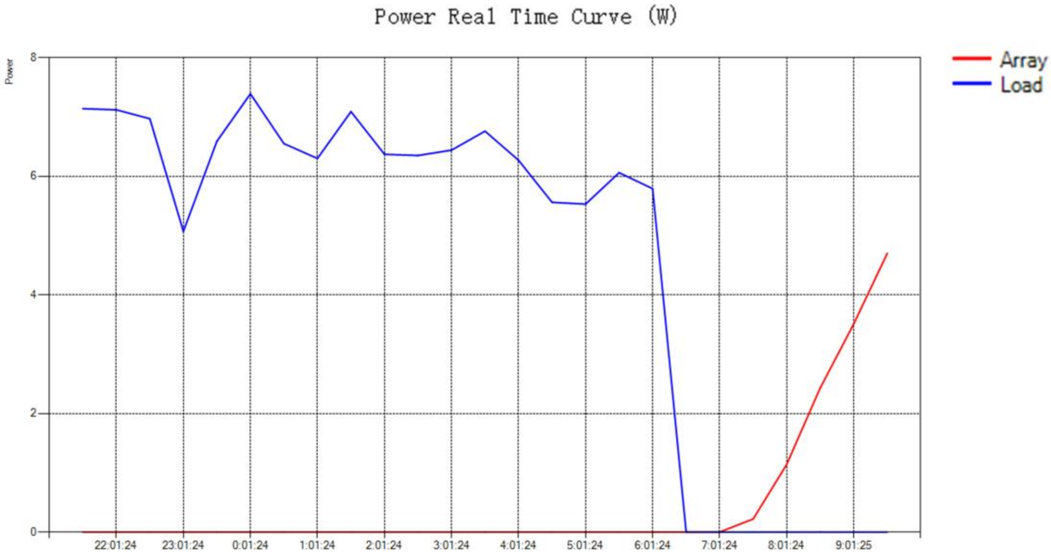

Figure 41: Power reading on 9/8/15 from 9:30PM to 9:30AM.

In the monitoring system, only solar array and system load power readings are monitored. In Figure 40 and Figure 42, the system load readings are approximately 7 Watt which equals to the power consumption of the 2 DC fan connected to the solar charge controller. This is true since the solar charge controller only monitors the load power consumption and not its self-consumption. The 0 Watt readings are due to the load being cut off by the solar charge controller.

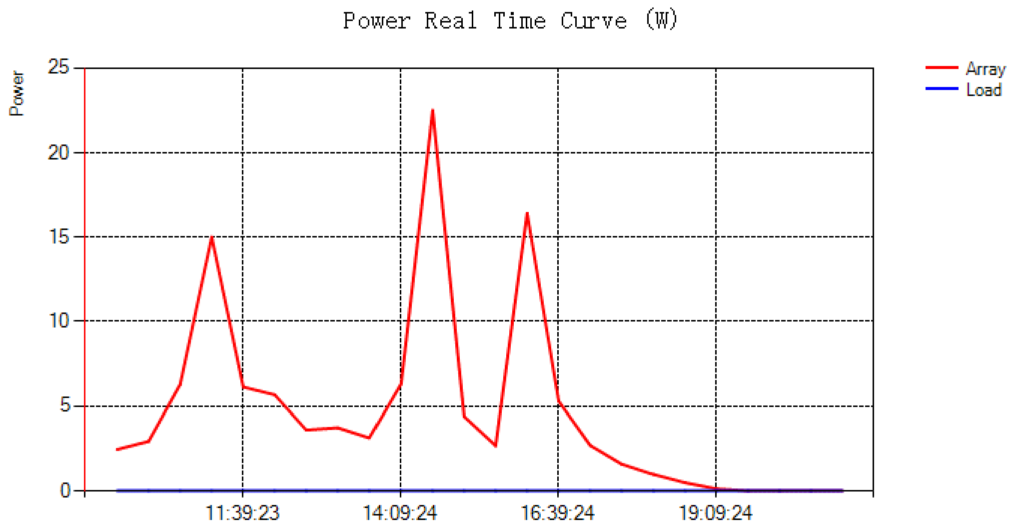

Figure 42: Power reading on 10/8/15 from 9:30AM to 9:30PM.

In Figure 40 to Figure 42 of power readings, it is observed that the value of the readings is inconsistent throughout the day while it remains 0 during the night. This is because the solar module can only generate power during the day in the presence of solar radiation. But due to the different amount of solar radiation it receives, thus the power generated is inconsistent.

Based on Figure 40 and Figure 42, it was observed that the power generated is maximum around noon from 12PM to 2PM when the sun is directly above with a maximum value of 23 Watt. With a rated power of 30 Watt, the solar module was not generating power at full capacity. This maybe because the solar module is not set up with the optimum tilt angle.

5. Conclusion

In conclusion, the power generation is not reaching its full capacity resulting in the battery not being able to be fully charged. As seen in all the readings obtained, the system were running from 9:30AM on 9th August 2015 until 6:30AM on 10th August 2015 which equals to 21 hours of running time. This validate the calculation of the estimated running hours of the test system which is 18 hours with an additional 3 hours provided by the solar charging.

PART 2

Part 2 presents the proposed design of battery management circuit. Two experiments were conducted in the laboratory which are (1) simulation on the battery management circuit and (2) validation on the battery management circuit voltage and current readings.

1. Simulation on battery management circuit

The first experiment uses a DC power supply unit to simulate the setup of two lead-acid battery connected to the supply input of the battery management circuit. The conditions tested are shown in the Table 9.

Table 9: Conditions tested on the battery management circuit

Voltage		Mode	
Battery 1	Battery 2	High Voltage Disconnect Circuit	Low Voltage Disconnect Circuit
High	High	0	1
Low	High	1	2
High	Low	2	1
Low	Low	1	0

The High voltage condition is when the voltage reading of the battery is above the threshold value which is 14 Volt while the Low voltage condition is when the voltage reading is below the threshold value which is 12 V.

The results are recorded in Figure 43 to Figure 50 according to the sequence of conditions in the above table. In all figures, the high voltage disconnected circuit is the two relays on the right while the low voltage disconnect circuit are the two relays on the left. The red LED indicator turns on indicates that the relay is being turned ON.

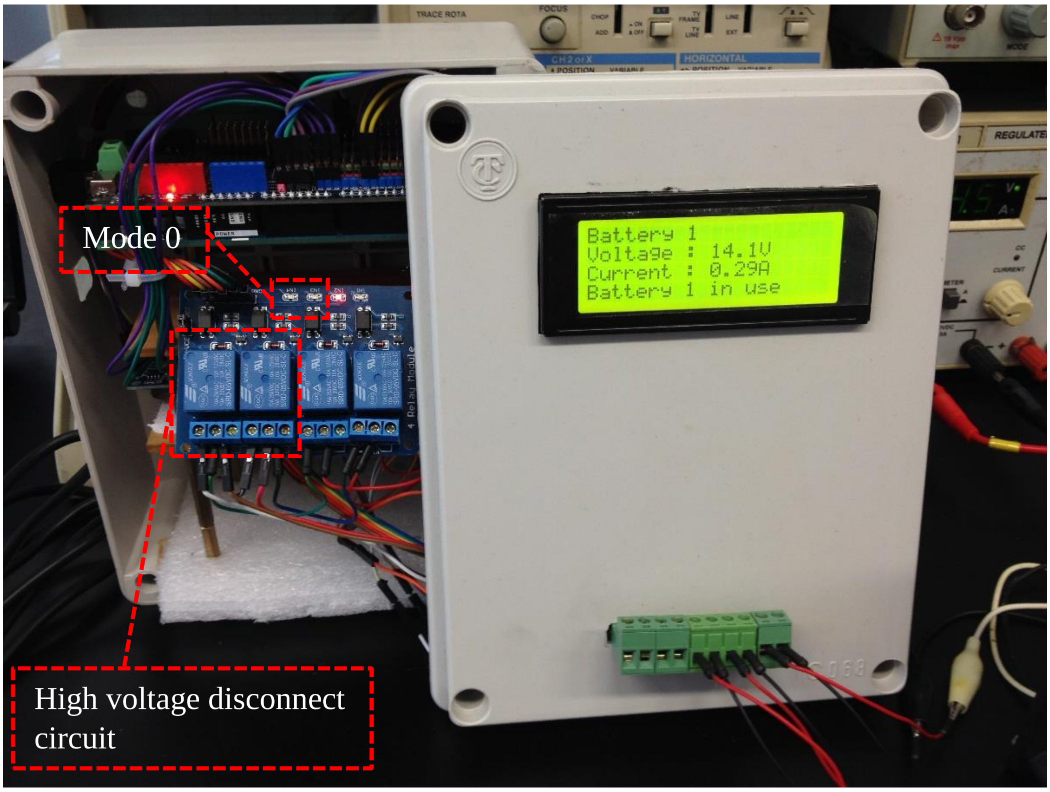

Figure 43: High voltage disconnect circuit in Mode 0 and low voltage disconnect circuit in Mode 1.

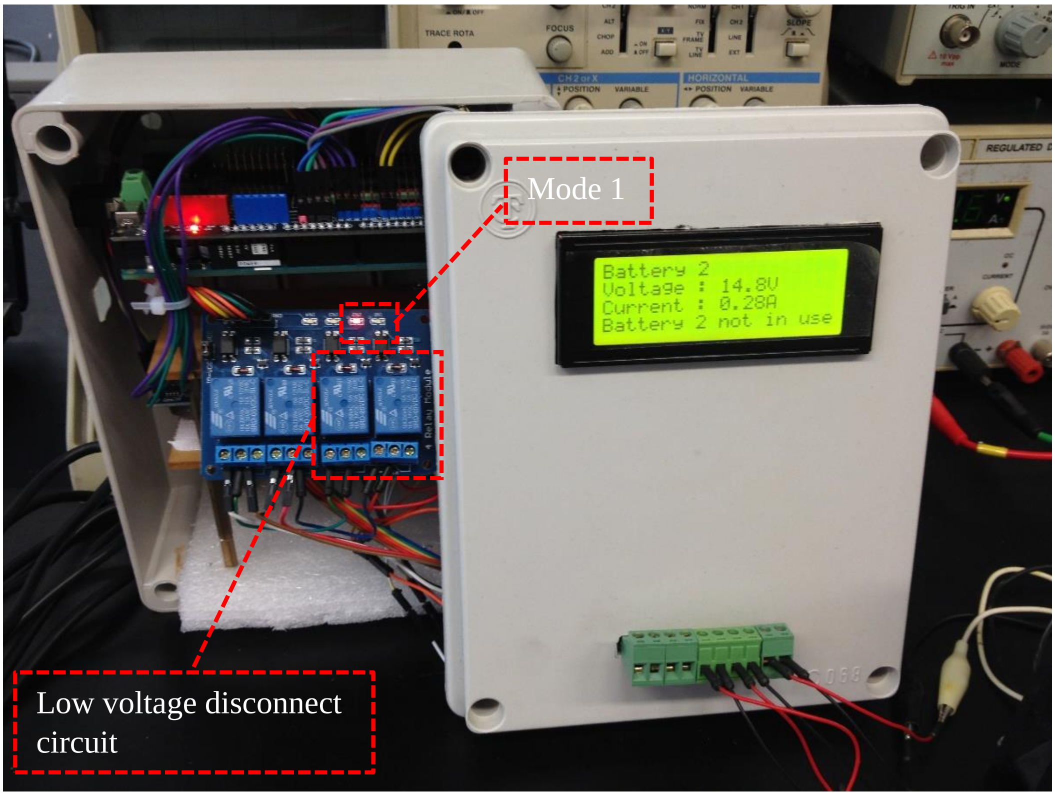

Figure 44: High voltage disconnect circuit in Mode 0 and low voltage disconnect circuit in Mode 1.

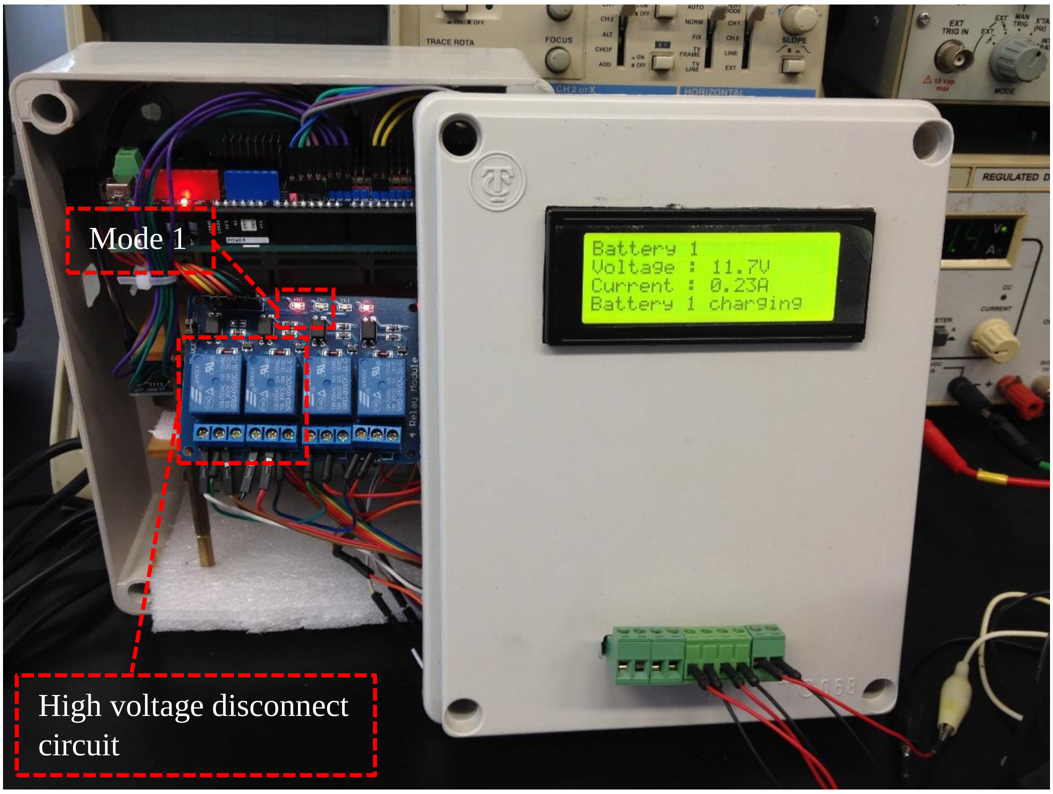

Figure 45: High voltage disconnect circuit in Mode 1 and low voltage disconnect circuit in Mode 2.

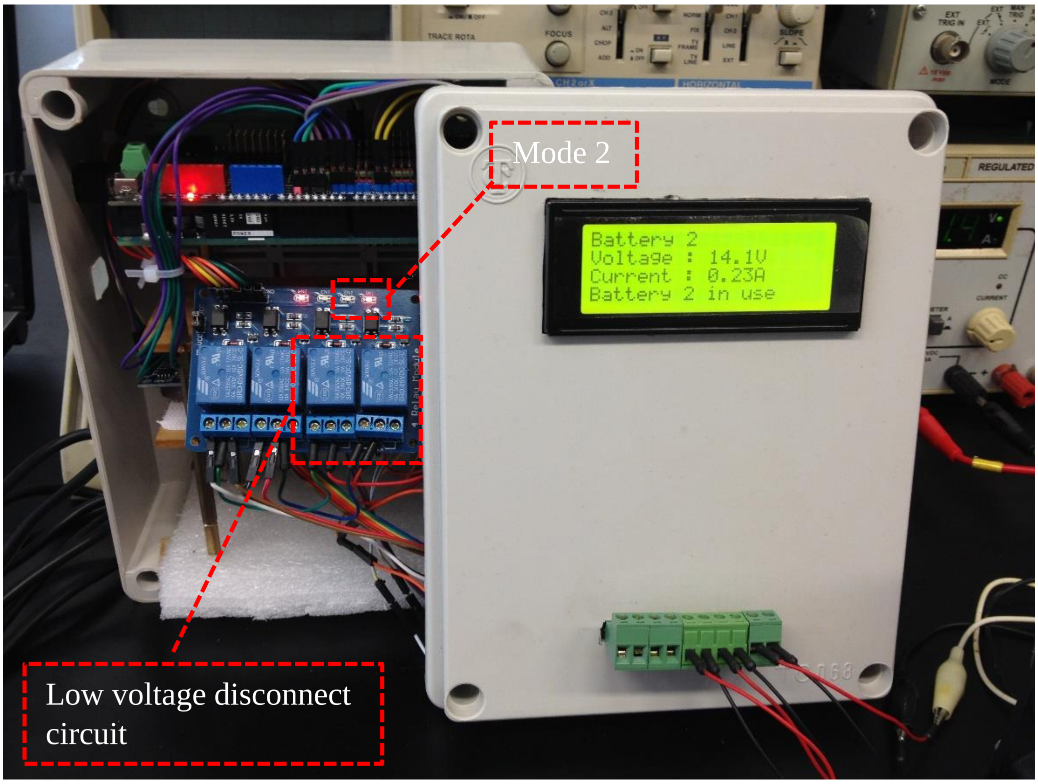

Figure 46: High voltage disconnect circuit in Mode 1 and low voltage disconnect circuit in Mode 2.

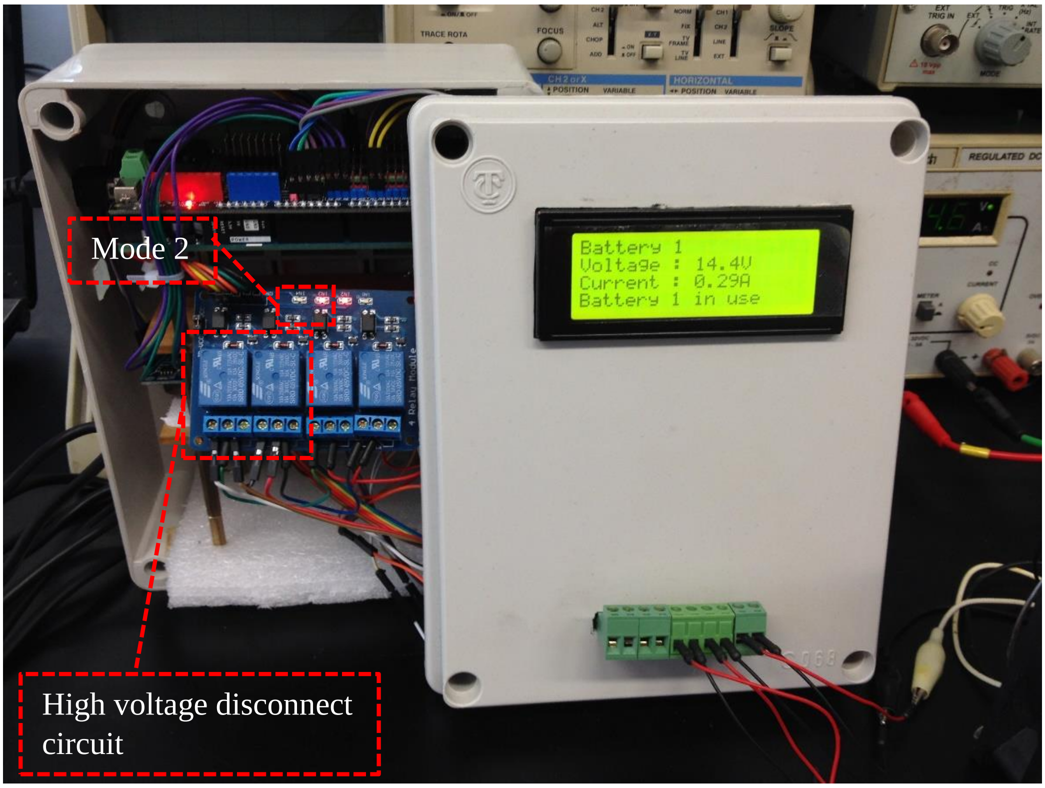

Figure 47: High voltage disconnect circuit in Mode 2 and low voltage disconnect circuit in Mode 1.

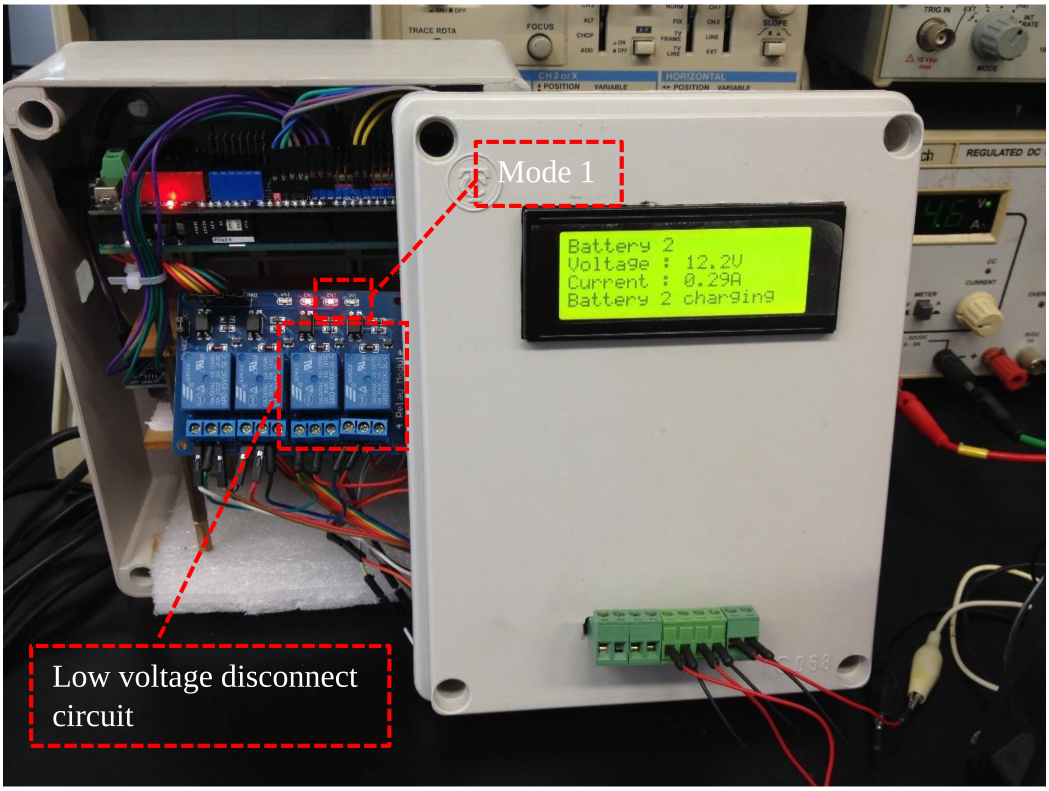

Figure 48: High voltage disconnect circuit in Mode 2 and low voltage disconnect circuit in Mode 1.

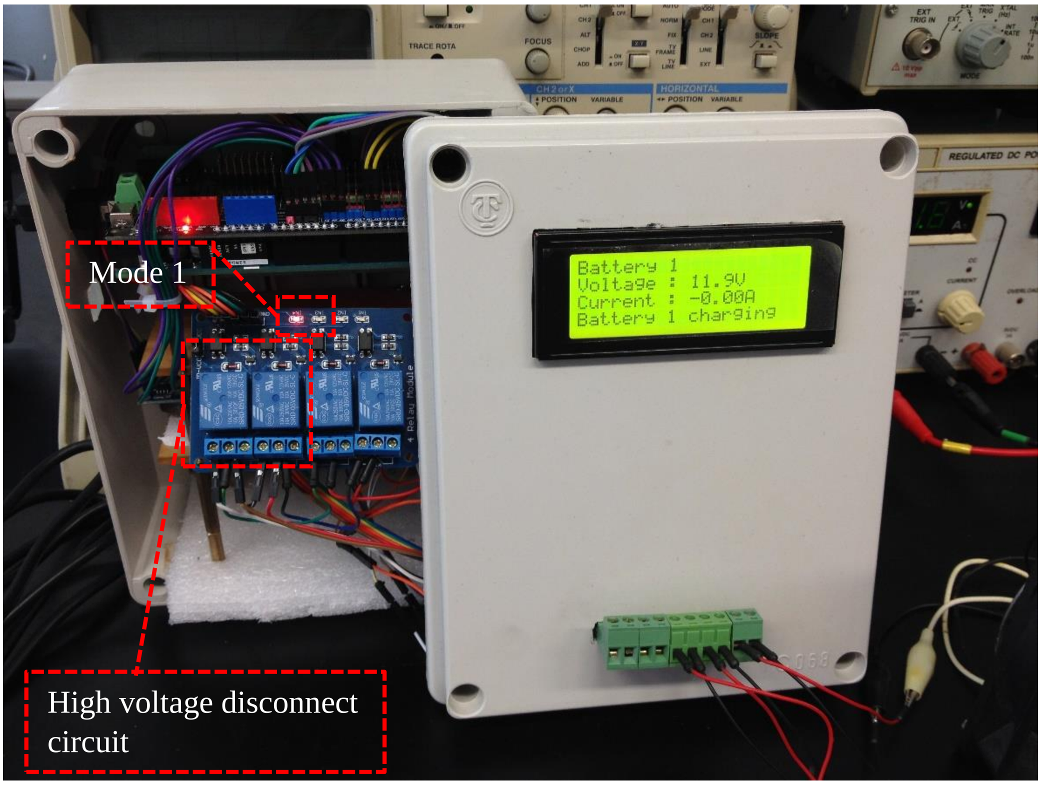

Figure 49: High voltage disconnect circuit in Mode 1 and low voltage disconnect circuit in Mode 0.

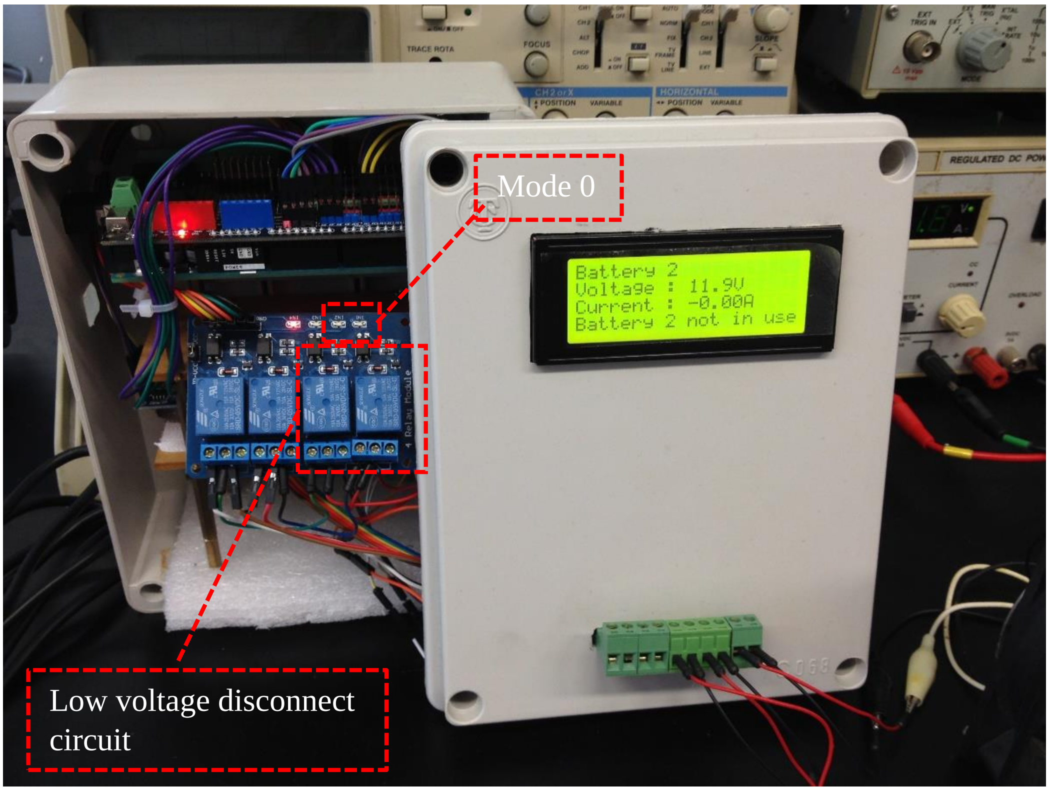

Figure 50: High voltage disconnect circuit in Mode 1 and low voltage disconnect circuit in Mode 0.

2. Validate voltage and current readings

The second experiment used a DC power supply to test the voltage readings and current readings of the battery management circuit for its accuracy.

- **Voltage Reading.** For the voltage readings, the DC power supply voltage outputs were set-up as 14.2 Volt each as shown in Figure 51. The readings were taken and recorded in Table 10 to Table 11. Figure 52 and Figure 53 show the battery management circuit with and without the load connected.

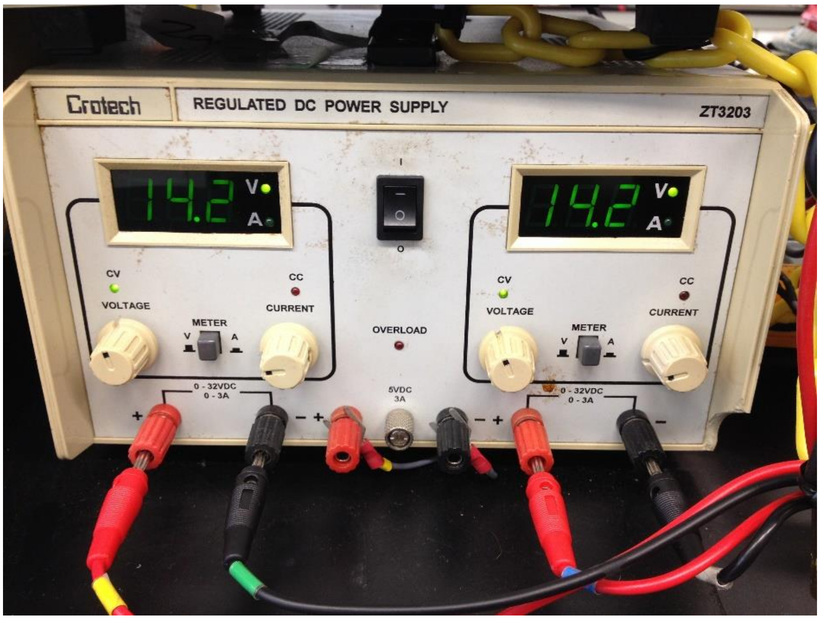

Figure 51: DC power supply voltage set at 14.2 Volt.

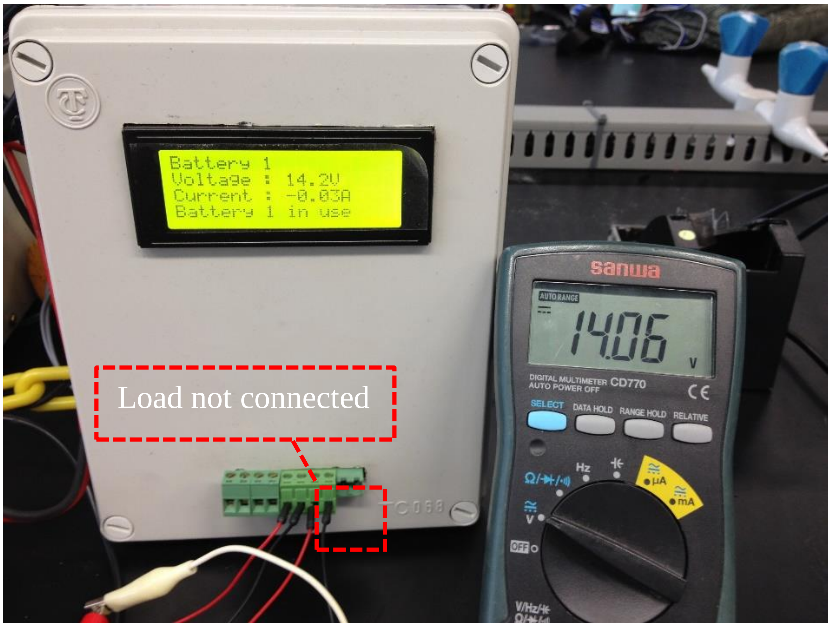

Figure 52: Voltage reading without load connected.

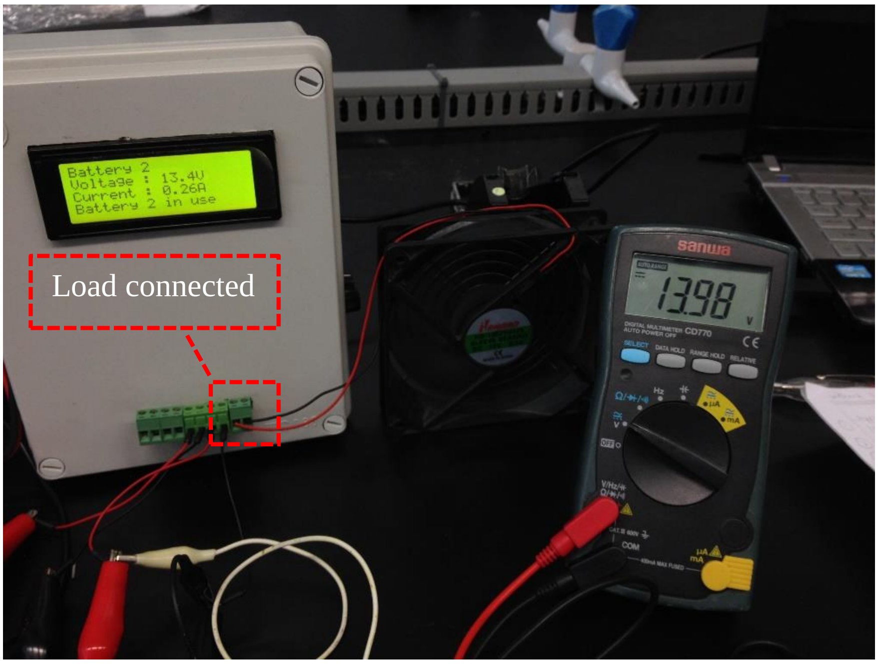

Figure 53: Voltage reading with load connected.

Table 10: Voltage readings without load connected.

	Battery 1			Battery 2		
No.	DC Power supply	Battery Management Circuit	Multimeter	DC Power supply	Battery Management Circuit	Multimeter
1	14.2 V	14.2 V	14.06 V	14.2 V	14.2 V	14.03 V
2	14.2 V	14.2 V	14.06 V	14.2 V	14.2 V	14.03 V
3	14.2 V	14.2 V	14.06 V	14.2 V	14.2 V	14.03 V
4	14.2 V	14.2 V	14.06 V	14.2 V	14.2 V	14.03 V
5	14.2 V	14.2 V	14.06 V	14.2 V	14.2 V	14.03 V

Table 11: Voltage readings with load connected.

	Battery 1			Battery 2		
No.	DC Power supply	Battery Management Circuit	Multimeter	DC Power supply	Battery Management Circuit	Multimeter
1	14.2 V	13.1 V	13.80 V	14.2 V	13.6 V	13.99 V
2	14.2 V	13.1 V	13.75 V	14.2 V	13.4 V	13.99 V
3	14.2 V	13.2 V	13.68 V	14.2 V	13.5 V	13.99 V
4	14.2 V	13.3 V	13.71 V	14.2 V	13.4 V	13.99 V
5	14.2 V	13.3 V	13.66 V	14.2 V	13.6 V	13.99 V

It can be seen in both Table 10 and Table 11 that the readings are almost consistent without large difference between each readings. This is because for each readings, the battery management circuit takes ten voltage readings and computes the total average of those readings thus providing more accurate readings.

The difference seen in the readings between the voltage readings with the load connected and the voltage readings without the load connected are approximately 1 volt. This is due to the voltage drop when the load is connected to the circuit.

- **Current Reading.** For the current reading, the DC power supply will give a current output base on the load that it is connected to. Thus, the reading can be obtained from the display of the DC power supply shown in Figure 54.

Just as the voltage readings, the battery management circuit takes ten current readings and computes the total average of the readings. These readings are taken and recorded in Table 12.

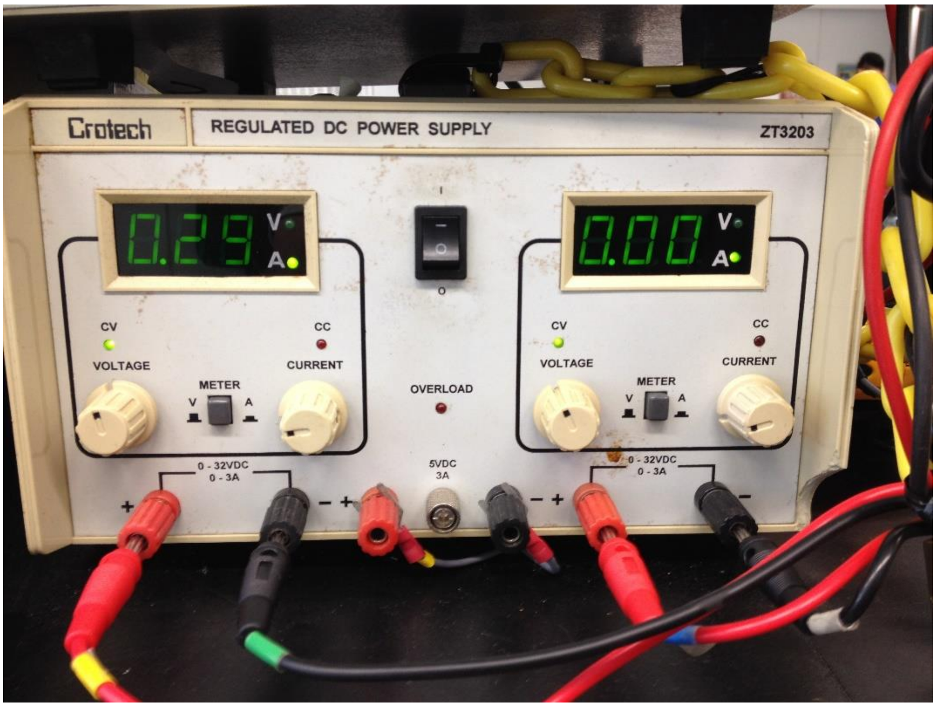

Figure 54: DC power supply current reading.

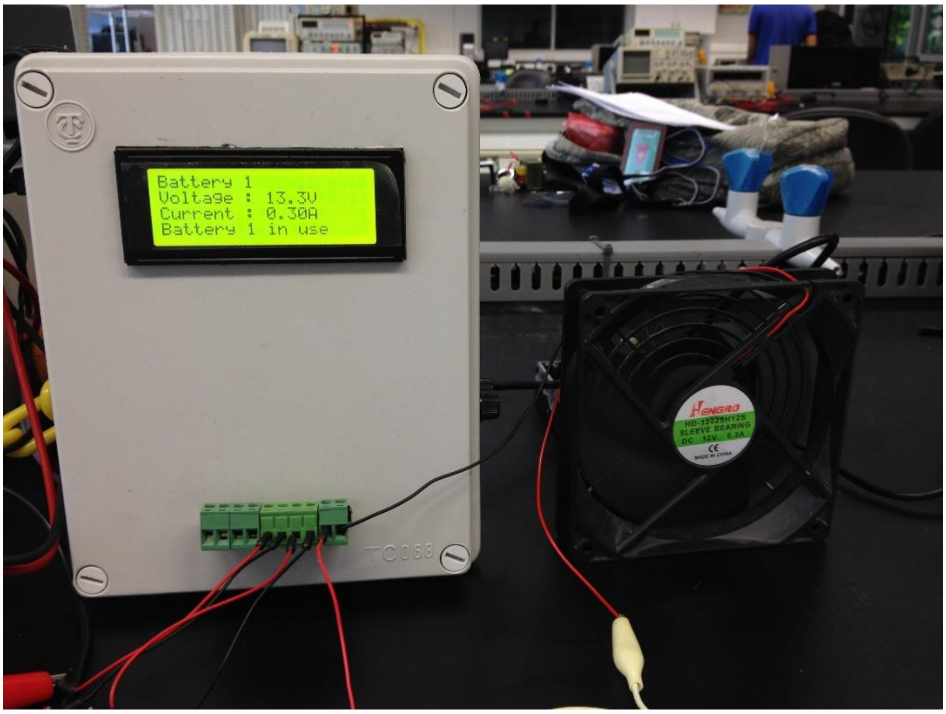

Figure 55: Battery management circuit current reading.

Table 12: Current readings

	DC Power Supply	Battery Management Circuit
1	0.29 A	0.24 A
2	0.29 A	0.29 A
3	0.29 A	0.23 A
4	0.29 A	0.26 A
5	0.29 A	0.28 A

The current readings obtained by the battery management circuit are significantly accurate with an offset of 0.05 A. This readings can be made more accurate by using better current sensor.

3. Conclusion

The battery management circuit is able to automate the decision in choosing the mode for charging and the mode for discharging of the batteries. This would improve the traffic monitoring system as a whole and increases its reliability when it is implemented on the highways.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

In this project, the power consumption has been studied in the first part of the project where rigorous experiments had been conducted. This experiment where built similar to the existing traffic monitoring system based on the specification given by the company. It is shown that the system could only last for 21 hours thus the current system did not meet the requirement of the company which requires 48 running hours.

For the second part of the project, a battery management system was built with the ability to automate the decision of charging and discharging the batteries in the proposed system design. The system consists of (1) a microcontroller which oversee the charging and discharging of the batteries, (2) relay module that act as the low voltage disconnect circuit and high voltage disconnect circuit, (3) voltage and current sensors to measure the voltage and current that contributes to the decision making, and (4) a Real Time Clock module that enables the microcontroller to monitor the system based on time.

Lastly, further improvement on the system could be made by using a smaller and cheaper microcontroller for the system. This will make the size of the system much smaller and more cost effective. In addition, a field test should be conducted to further improve the design of the battery management system when it is implemented to the existing system.

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