

DC - DC CHARGE CONTROLLER FOR A SMALL PV SYSTEM

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UNIVERSITI MALAYSIA PAHANG

DC - DC CHARGE CONTROLLER FOR A SMALL PV SYSTEM

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This thesis is submitted as partial fulfilment of the requirements for the award of the Bachelor of Electrical Engineering (Hons.) (Power Systems)

Faculty of Electrical & Electronics Engineering
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Specially dedicated to my beloved family and my fellow friends for their
endless encouragement

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ABSTRACT

Nowadays, renewable energy such as solar power has become important to generate electricity and the solar power system can be installed at homes. In conjunction with the aforementioned points, solar power system is continuously improved by researchers around the world, who focused to attain the best design, in order to maximize the efficiency of solar power system. In this project, battery charging controller has been integrated and implemented towards the small scale solar panel system to achieve the best battery charging applications. This project utilized a battery charging in the form of intelligent controller method. The hardware system includes of Arduino UNO microcontroller as a main controller and temperature sensor (LM35) for sensing the maximum intensity of humidity. Initially, the application of the battery that is charged by the solar panel needs a battery charging controller so that it can control the battery from exceeding the maximum charging and discharging level to protect the battery from get damage. As in solar power system, charge controller is the heart of the system and design to protect the rechargeable battery. Apart from that, the energy from the battery can be used to drive a small load which is connected to the solar panel. The amount of the energy input generates by the PV panel is regarding to the weather. In conclusion, the application of the charge controller system delivers a convenient output power for a 12 volt system.

ABSTRAK

Pada masa kini, tenaga boleh diperbaharui seperti tenaga solar telah menjadi penting untuk menjana tenaga elektrik dan sistem kuasa solar ini boleh dipasang di kediaman rumah. Bersempena dengan apa yang dinyatakan di atas, sistem kuasa solar sentiasa dipertingkatkan oleh penyelidik di seluruh dunia, yang memberi tumpuan untuk mencapai reka bentuk yang terbaik, untuk memaksimumkan kecekapan sistem kuasa solar. Dalam projek ini, bateri pengawal pengecasan telah diintegrasikan dan dilaksanakan ke arah sistem panel solar yang kecil untuk mencapai bateri yang baik bagi mengecas aplikasi. Projek ini menggunakan bateri mengecas dalam bentuk kaedah pengawal pintar. Sistem perkakasan termasuk Arduino UNO mikropengawal sebagai pengawal dan alat sensor suhu (LM35) untuk mengesan sebarang maksimum kelembapan. Pada mulanya, penggunaan bateri yang dikenakan oleh panel solar memerlukan bateri pengecas pengawal supaya ia boleh mengawal bateri daripada melebihi had pengecasan maksimum dan menyahcas pada tahap ditentukan untuk melindungi bateri daripada kerosakan. Seperti dalam sistem kuasa solar, nadi system itu adalah pengawal pengecas dan reka bentuk untuk melindungi bateri boleh dicas semula. Selain itu, tenaga daripada bateri boleh digunakan untuk memacu alat elektronik yang bersaiz kecil yang bersambung pada panel solar. Jumlah input tenaga yang dijana oleh panel PV adalah merujuk kepada cuaca itu sendiri. Kesimpulannya, penggunaan sistem pengawal caj memberikan tenaga pada kadar yang bersesuaian untuk kuasa keluaran sistem 12 volt.

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LIST OF SYMBOLS AND ABBREVIATIONS

PWM	-	Pulse Width Modulation
ADC	-	Analog Digital Converter
SoC	-	State of Charge
PV	-	Photovoltaic
LCD	-	Liquidcrystal Display
LED	-	Light Emmiting Diode
AH	-	Amp Hour
MPPT	-	Maximum Power Point Tracker
LVD	-	Low Voltage Disconnect
PCB	-	Printed Circuit Board
TVS	-	Transient Voltage Suppression

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter describes the characteristics and the background of the project, the problem statement of the project, objectives of the overall project and scope which are related regarding to the development of the dc – dc charge controller for a 12-volt system.

1.2 Background of Project

Nowadays, source of energy like fossil fuel such as coal energy, natural gas energy, nuclear energy, harvest energy and etc. have a significantly been contributing to the development and utilization of industrial society. Electrical power generation operation based on renewable energy sources begun to dominant in fulfilling the demand of electric energy. Diminishing of fossil fuel are expected to finish up within the next hundred years from this present. Renewable energy is energy that generated from the mother nature comes from the surroundings that are continuously

replenished. Sunlight, wind, water, geothermal heat, and biomass are the sources of energy that are constantly renewed.

Amongst the renewable energy, solar energy is the way more effective and efficient energy to produce electricity. For certain countries, where warm climate shows dominant, solar energy is assessed as one of the predominant energy resources.

Throughout the renewable energy technology, technology using solar is also the fastest growing based on the factors like primary source is continually costless after the assembly, accessible, plentiful, non-polluting, and clean. Solar radiation is the yield in term of quantity that solar energy fall on a solar PV panel for a period of time, called as solar irradiation. Generally solar radiation is made up of a combination of three includes direct, diffused and reflected radiation as shown in Figure 1.1. There is shortage in the limitation of solar radiation when it is cloudy and wet weather, where the solar PV panel not able to receive enough sun radiation to produce the electricity.

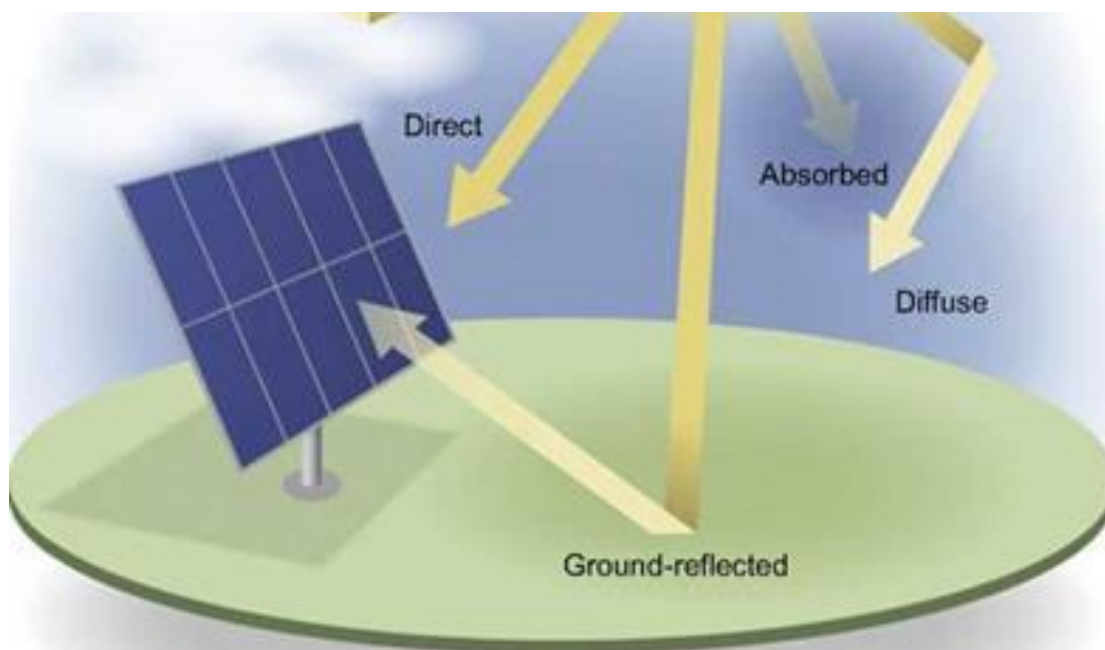


Figure 1.1 Components of Solar Radiation

When the energy harvest from a solar panel, electric energy is kept to store in a rechargeable battery form. Energy in the battery is reusable for other appliances purpose. In practice, solar panel is paired with a lead acid battery for many manufacturers for use as storage device.

The problem of a lead acid battery is having a low lifetime and to receive the maximum storage amount from a solar panel. Battery consists of plates which enclosed in a plastic battery case and submersed in an electrolyte a mix of water and sulfuric acid. Lead acid battery not generate voltage on their own, they only store the energy from another source. A typical 12-volt battery used fully charged will generate a total voltage of 12.6-volts. Discharging a lead acid battery below 10.5-volts will severely damage it.

To solve this problem, many manufacturers have been prevent the cause by develop and implement a battery charging controller. Battery charging controller or a solar charge controller is designed to protect the rechargeable battery while maintain the proper charging voltage on the battery. As input voltage of solar panel rises, battery charging controller regulates the charge and store into the battery. The efficiency of battery production is accommodating by battery charging controller.

1.3 Background of Problem

At present, to have a good production of battery storage is comparatively low. There is some lack of efficiency of storage capability and the operating energy consumption while battery operated. In such a way the issue or utilization of rechargeable battery has evolved. Hence to solve, a battery charging controller is introduced. Generally battery that is charged by a solar panel needs a battery charging controller so that it can control the battery from exceeding the maximum charging and discharging level to protect the battery from get damage. Overcharging which cause plate corrosion, gassing and loss of liquid. Deep discharging which might cause permanent damage to the battery and loss of capacity. If happen at prolonged time it can affect the internal system and shorten battery lifetime

Towards that preventing, charge controller will change the way of charging state when there is increment or decrement on battery storage intensity. The important to understand about rechargeable lead acid battery is that a charger with a output voltage do not properly recharge or maintain the battery. Proper recharging requires a intelligent charging control system which vary charging voltage based on state of charge.

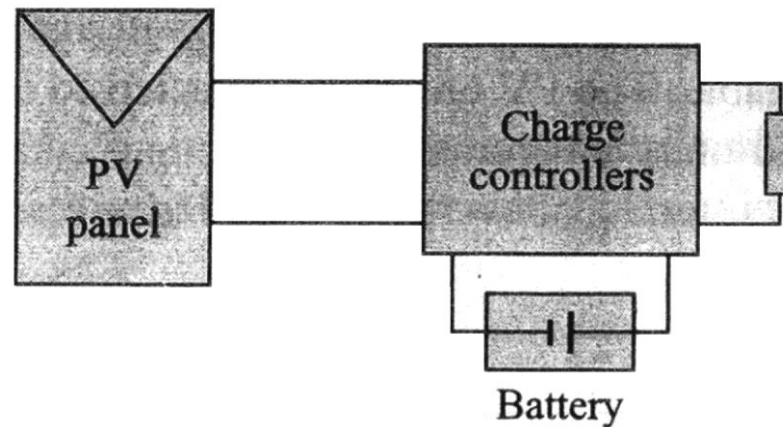


Figure 1.2 Solar Power System

1.4 Objectives

A battery charging controller is important in term of effectiveness utilization of a solar power system. This project has a main objective to develop a dc – dc charge controller for a small 12-volt PV system. In the application, the recharge battery receive the exact amount of energy to maintain a proper charging thus the whole system is depending on the charge controller which is placed between a solar panel and a battery. The system can shows the indicator lights for state of charge and charging percentage in the Liquid Crystal Display (LCD). It explains the Pulse Width Modulation (PWM) in operation. When it reached the regulation set point of battery voltage, PWM algorithm will slowly reduce the charging current yet charging is still continuous until desired maximum battery voltage.

1.5 Scope

There are two major parts to be fulfill in the design specification of the project includes hardware and software. The hardware parts consist of charge controller itself, solar panel, lead acid battery storage, the microcontroller, temperature sensor, LCD, and led indicator. Microcontroller used is Arduino Uno which all the source code is programed in the software. In software part also includes a programming for temperature sensor and all the algorithm refers to the charging process.

1.6 Thesis Outline

This thesis are organized in chapters. In first chapter, describes the overview that notify about introduction and overview of the whole project includes with the objectives, scope of project and problem statement. Chapter 2 reviews about literature review on the project, includes PV panel, connections, technology modeling, design controller, circuit schematic, microcontroller, battery storage, source code program, and related works by researchers.

For chapter 3, mainly focus on the development of the hardware and software of the project. The main components whole process are describe in detail. The program and circuit design development and hardware implementation. In chapter 4, detail on the testing, results of the experiment and observation such as voltage output, indicators parameters, and load response. For chapter 5, conclusion and recommendation for further work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter summarizes the study and research that carry out from related project which involves the study of various types of PV panel, battery, microcontroller and the overall working parts regarding the project.

2.2 Solar Energy

Musse Mohamud Ahmed and Marizan Sulaiman [1] have proposed the application of solar energy for remote and urban areas as the potential in wide range where solar energy source is cost free and clean energy. The overall project is discussed as below.

2.2.1 Concepts of Solar Radiation

Solar radiation is produced by the sun that has three way output which are direct radiation, diffuse radiation, and reflection radiation. Term of direct radiation means that solar irradiation that has not scattered until it reached the PV panel surface. About 90% of solar power energy is carry by direct radiation and the remainder is carry by diffuse and reflection diffusion when it comes to a bright day.

A diffuse radiation is a radiation which hit through a cloud towards the solar PV panel, means that the sun light was going to the filtration. While reflected radiation is the incidents comes from the direct radiation and diffuse radiation that has been reflected by an object nor the earth. All types of these radiations is known as global radiation on a solar PV panel.

2.2.2 Overview of Solar PV Panel

A solar PV panel is also called as solar module, photovoltaic (PV) module or photovoltaic (PV) panel. A solar PV panel is actually a fragment of photovoltaic cells. Generally, on communication satellites, the solar PV panel occupies a large area of surface providing a large flat surface over antennas mounted side. A substantial photovoltaic system to harvest and supply electricity for commercial and residential usage is another application scenario. Theoretically, all solar PV panel output produces a dc power under a controlled environment. Depends to the total area of the solar PV panel can determines the efficiency, thus determine the total output power. As an example, 32 % efficient 230 watt panel has twice the area of a 16 % efficient 230 watt panel. Large amount of electricity can be harvest if many solar PV panel are used in a single array connection. A solar system, generally it consists of array of

solar PV panel, an inverter, a battery with controller, and sometimes a solar tracker with wiring connections.

Photovoltaic cells are a thin semiconductor layer specially designed, two terminals which are positive and negative at both different sides. From the sun, light strikes the solar PV panels, electrons are extract from the atoms that strikes into semiconductor cells. Further, when electrical conductor is applied to the both terminals, forming a complete electrical circuit which is the electrons are stored forming electric current as in Figure 2.1 below. To generate power, it is necessary to attach all solar cells together to form PV array. Stated that electrical output of solar PV panel is proportional to the solar irradiation quantity and it is highest when directly though facing the sun.

The output current of panel are depends on three aspect, first is the amount of light strikes on the solar PV panel, the second aspect is regarding to the size of surface area covered, and the third aspect is referring to the voltage that array is operated. In other hand, operating voltage for PV is always closely related on the load require. Therefore, the third aspect is emphasized more in this project which is load has to receive a proper or precisely amount from the PV. So that the system is well operated, the overall systems have to be compatible.

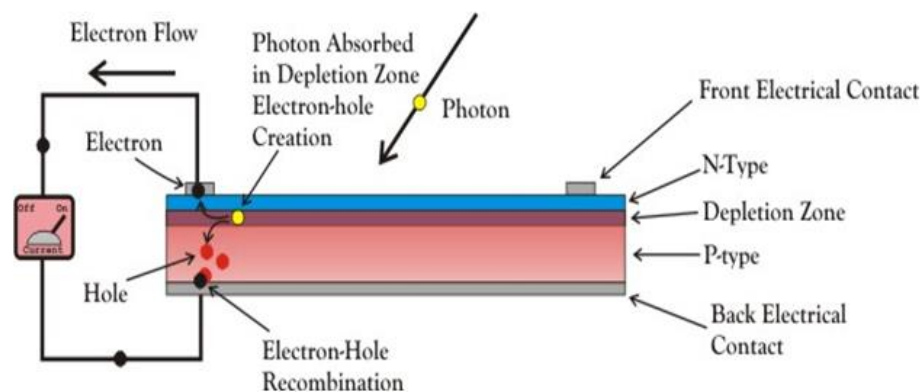


Figure 2.1 Basic Operation of Solar Cell

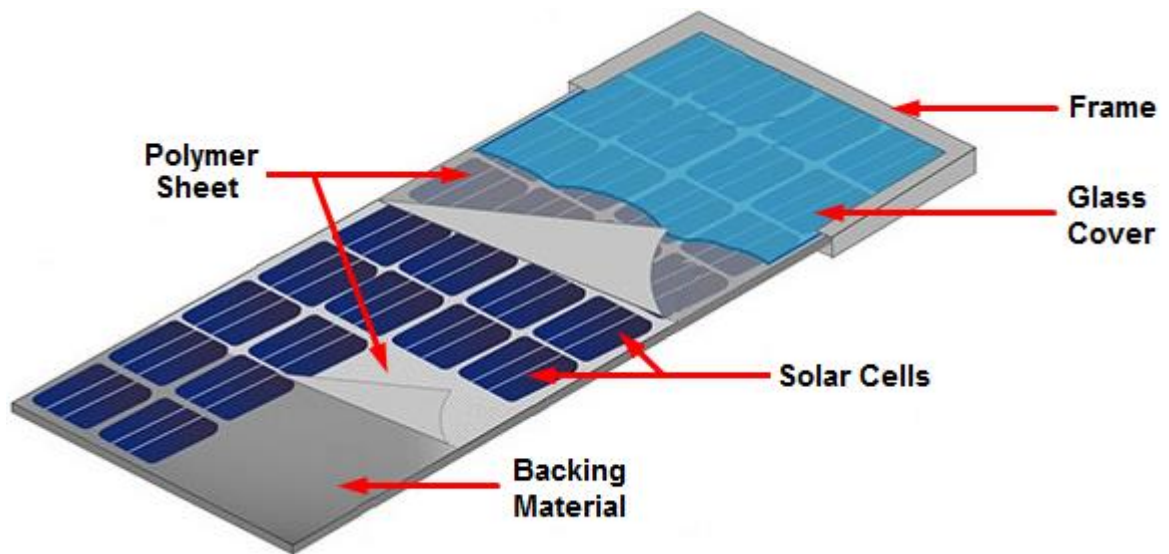


Figure 2.2 Structure of Solar Module

2.2.3 Type of Solar PV Panel

Types of solar PV panel is listed in four different type :

- i. Poly-crystalline (p-Si)
- ii. Mono-crystalline (m-Si)
- iii. Amorphous Silicon (a-Si)
- iv. Ribbon Silicon

These difference types (i), (ii) and (iv) are wafer based manufacturing. In other word, this three approaches are self-supporting wafers of approximate 300 μm thick are fabricated and then soldered together forming a module. A thin film approaches are module based. Meanwhile, (iii) panel substrate is coated with desired layers and a

laser scribe which is used to represent individual cells. Poly-crystalline produce highest power output compared to amorphous silicon and mono-crystalline.

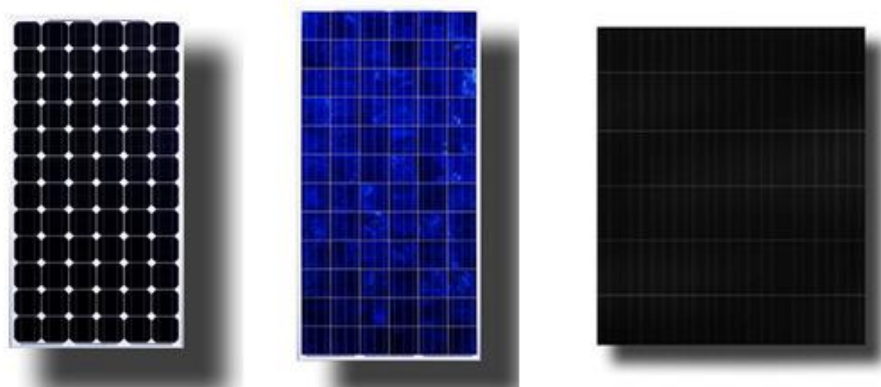


Figure 2.3 Silicon Photovoltaic Module

2.3 Application of Battery Storage

Battery is great importance usage in a power system because it gives the disposal in storing a small quantity of energy for the last decade. Massimo Ceraolo have discussed with much detail on analyzing the battery behavior, besides releasing the facts on the internal phenomena of the battery [2]. Based on this project, the storage properties in lead acid battery is easily to be used and familiar with the solar power system.

2.3.1 Concept of Battery Construction

The usage of lead acid batteries has been comprehensive in power system. All lead acid batteries consist of flat lead plates that immersed in an electrolyte. The

design have two lead plates of positive plate and a negative plate that be made by sponge lead with separator in between. The outer of the battery are enclosed in a plastic case and the plates are all submersed in an electrolyte consisting of water and sulfuric acid. Initially, to produce a voltage battery must receive a charge voltage for at least 2.1-volt from any source. Purpose manufacturer of battery is only to store a charge from another source. Basic sizes of the battery, refers to the battery plates and amount of electrolyte which describes the amount of charge lead acid battery can store. Storage capacity is describe in amp hour (AH) which also called as rating of a battery. Figure 2.4 below shows six single 2.1-volt cells are connected in series to create a typical 12-volt battery. Thus, total voltage for fully charged is 12.6-volt.

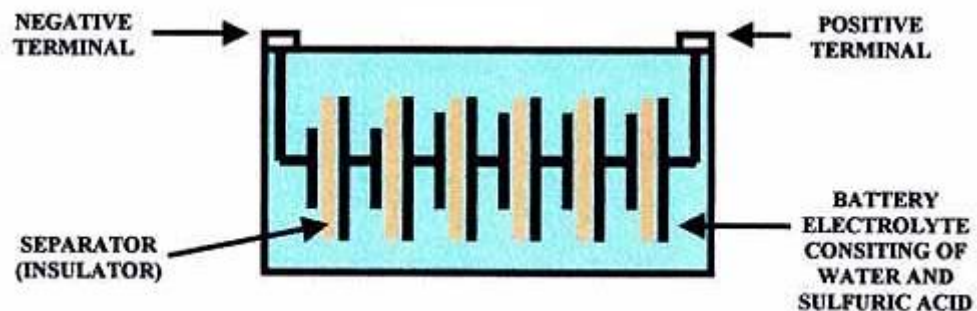


Figure 2.4 Basic Lead Acid Battery Construction

2.3.2 Discharge Cycle

In the beginning, when the load is connected to the battery, process of chemical reaction take place between a sulfuric acid and lead plates in the battery thus produce the electricity to light the load, etc. light bulb. The fully charge battery voltage starting to discharged. At the plates, another chemical reaction take place, positive and negative plates begins to be coat with a substance called lead sulfate. This process is normal during a discharge cycle. While discharging continuous, lead

sulfate coats and covered the plates until full, at this point battery voltage begin to decrease from fully charged state.

As the battery is fully discharged, the plate are almost all covered with a lead sulfate and voltage has drop to 10.5-volts. Discharging voltage below 10.5-volts will severely damage the battery. However, lead sulfate is a soft material, it can be vanish back into a lead and sulfuric acid. Once the state is fully discharged, connect immediately with a battery charger, it can cause the lead sulfate from becoming a hard crystals form. Therefore, always recharge the battery soon as possible to prevent loss in capacity.

2.3.3 Charging Cycle

An intelligent charging system is based on battery state of charge. A proper charge needs an intelligent system. A battery with 12-volt has to be charge using a charger with a higher voltage. During a battery recharge cycle, a lead sulfate starting to disappear and recover to lead and sulfuric acid. Once the battery level reach to 90% of fully charge, voltage supply to the battery is reduced from 14.4 to 13.6-volts, this feature can reduce the gassing and water loss in the battery. In addition, battery that reach low state of charge the voltage supply to the battery will automatically change the operation to the boost mode charging process. While the boost mode increase the supply voltage to 14.4-volts. Then when the battery voltage level reach the 90%, the charge voltage reduce back to 13.6-volts until the battery voltage is fully charge.

2.4 Application of Charger Controller

Basically, there are two basic methods exist in order to controls or regulates the charging process of the battery from solar panels, which are series and shunt regulation. Each method have basic performance and applicability, Steve Harrington and James Dunlop have states the following description of the two basic methods and variations of methods [3]. One of the familiar series regulation methods that constantly used in solar power system is Pulse Width Modulation control.

2.4.1 Basic Concept

A charge controller is a device of voltage or current regulator that prevent battery from overcharging. Voltage that regulates coming from the solar panels brings a voltage or current to a batteries. Basically most solar panel rating 12-volt supply an output of 16 to 20-volt, if no regulation on the batteries it will be damaged. Any panels are not specific made out to just 12-volts output. If so, panels only can provide the energy under a perfect condition or full sun. Unfortunately, panels have to gives an extra voltage more than just 12-volt, thus if the sun is low in the sky, or having a heavy haze, cloud cover, or high temperature, some output still can be provided from the panels. Basic fully charge for a 12-volt battery is about 12.7-volt at rest, so panels output needs more power for any worst case condition.

2.4.2 Working Principle

A charge controller can regulate for 16 to 20 volts of solar panels output voltage and regarding to what condition of battery at the time. The regulation of battery are vary from 10.5 to 14.6, regarding to the state of charge of the battery, type of battery, battery temperature, and state of the controller. In manufacturer, charge controller comes in all sizes, features and shapes. Charge controller also have algorithm of charge controls which is consist of 3 general types, etc. 1 or 2 stage controls, 3 stage or PWM, and maximum power point tracking (MPPT). Simple 1 or 2 stage controls is always rely on relays or shunt transistors to make control of the voltage. The system concept is to short or disconnect any power from the battery when a certain voltage reached. For 3 stage or PWM, it is industry standard that essential for a solar system. But it is still occasionally have shunt, relay and other few components.

For maximum power point tracking (MPPT), it is a such ultimate in controllers. It is approximately comes with efficiencies of 94% to 98% , furthermore it can save considerable money for a large system as they initiate about 10 to 30 % more power for the battery. Usually a controller have some features like indicator, either a simple LED, or digital meter indicator. The purpose of such indicator are to let the user knew that it is powered and getting some kind of charge. Some controllers are also designed to have a low voltage disconnect (LVD) settings. It is usually embedded for a small loads for example small appliances and lights. Main objective of the low voltage disconnect, is to turn off the load terminal from getting continuous supply, thus battery are maintained and not getting any over discharged. Any typical small loads, low voltage disconnect is a corresponding system. Depending on the controller rating, it can only drive for a small load.

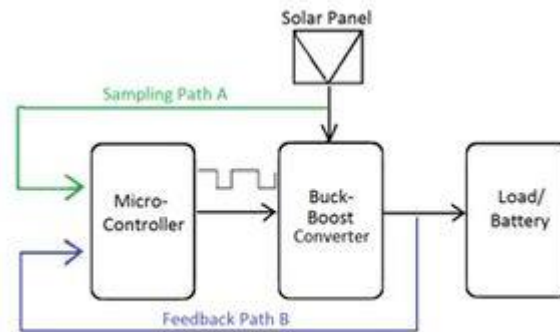


Figure 2.5 Working Principle of Charge Controller

2.5 Pulse Width Modulation (PWM) Control

There are a few controllers that use this application algorithm. PWM is famed with method of float charging. It sends out a fast series of a short charging pulses to the battery. The application is constantly refers to the state of charge on the battery to counter how fast the pulses, and the duration of the pulses. In a fully charge mode, the operation is ticked every seconds and sends a short pulse. In a discharge mode, pulses are longer and almost continuous. The controller reviews the state of charge on the battery along with the pulses and adjusts each time.

In PWM the signal is digital square wave, and the frequency is constant the same but the duty cycle can be vary between 0 and 100%. For the simples PWM mode, there is a timer which is repeated counts from 0 until 255. Output will turn on as the timer is at 0, and turns off as the timer matches the output compare register. In this case, the higher output compare register is set, the higher duty cycle might be. It is called as Fast PWM Mode. The output compare register is associated with timer is set then the timer is match with the output compare register value, and reset at 0.

PWM signal may generate with resolution of 16 bits in order to give signal to switching mosfet.

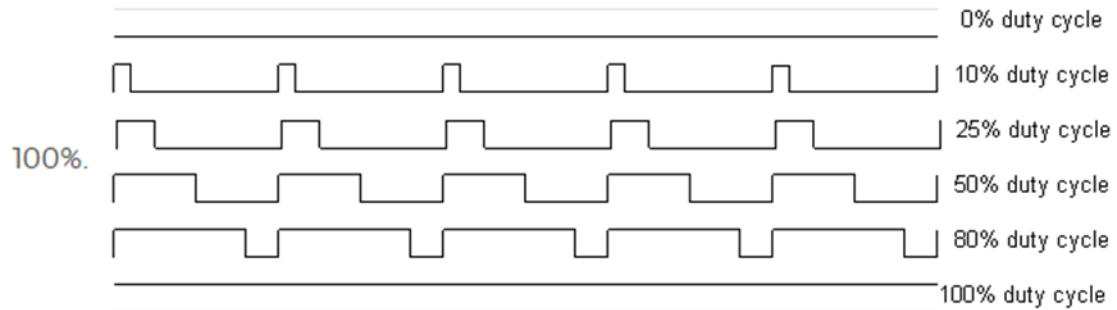


Figure 2.6 Duty Cycle Form

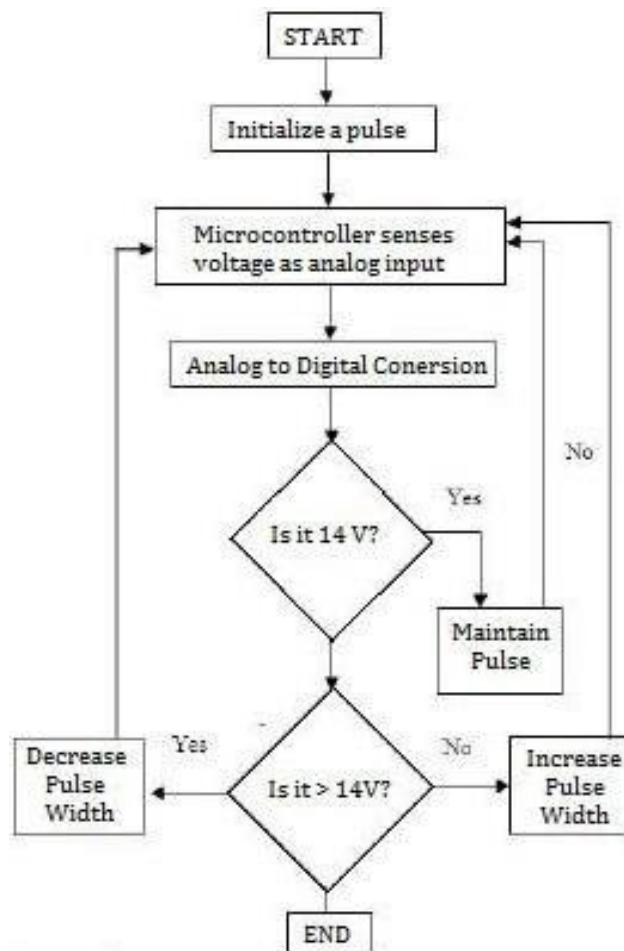


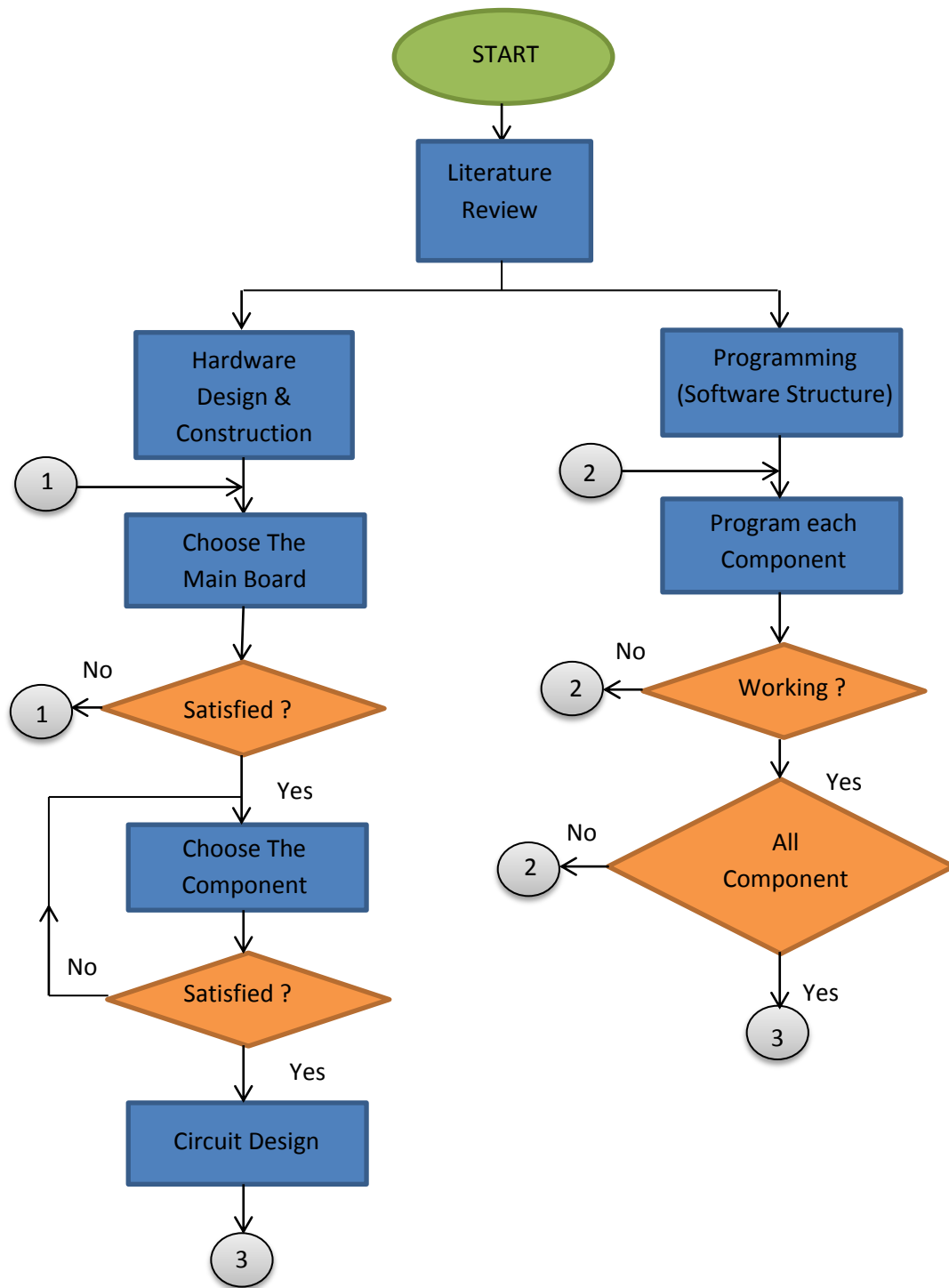
Figure 2.7 Flowchart of Working Principle

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter emphasizes on the overall project implementations and testing procedures along the year. It can be clarify into six parts, includes project overview process, main function of charge controller, preliminary experiment, circuit design, hardware development process, and software development process. In the project overview, one clarifying flowchart that shows the project structure that be held through the beginning. The main function of the programming system states clearly in this chapter along with the preliminary experiment. Researched on the design and methodology has results circuit with 12-volt system operating software. Lastly, hardware and software were conducted.



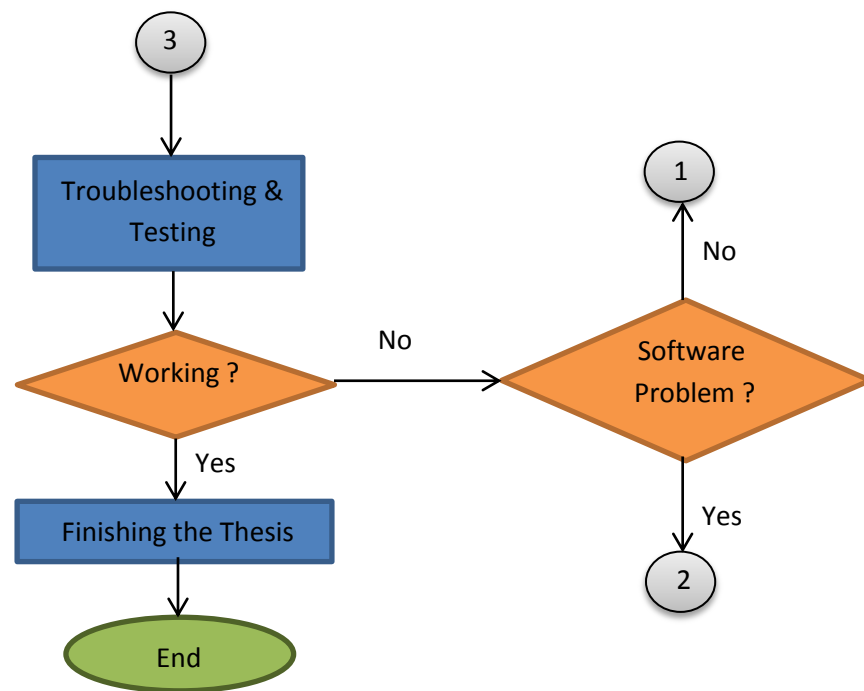


Figure 3.1 Overall Flowchart of the Program

The flowchart shows in Figure 3.1 is to clarifying the clear look for the overall system procedures. All the peripheral component hardware and software procedure that included in the project are stated according to the order, starts from the literature review until the finishing of the thesis.

3.2 Project Overview

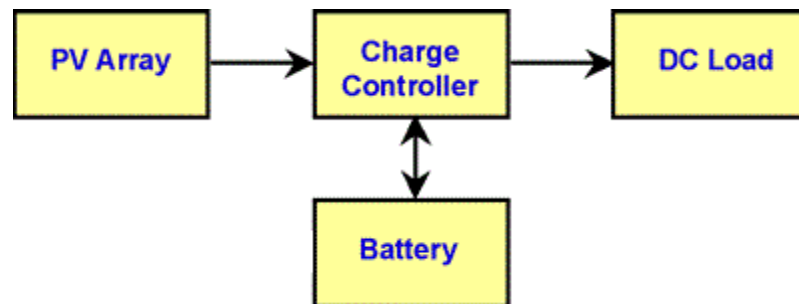


Figure 3.2 Project Block Diagram

Figure 3.2 illustrates the block diagram of the overall system regarding the project. The block diagram shows the main part of the operation process. A charge controller is a voltage regulator that is placed between the solar panel and the battery storage input, and additional dc load is also connected as a powered electric device. The system has two voltage sensors which operate simultaneously to detect voltage output of solar panel and the battery, then the signal is sent into the microcontroller as the voltage reading has been sensed.

The microcontroller receives signal from the sensors and processes them. As the signal is sent through the analog ports, the pulses are the output of the microcontroller. The pulses are based on the state of charge of battery usage at the time being. In the meantime, the dc load device is being powered. The charging process of the battery is maintained by the help of the charge controller, thus the system is efficient. The charge controller regulates the voltage output as the battery receives a suitable input and matches with the energy storage capacity.

3.3 Main Function of Charge Controller

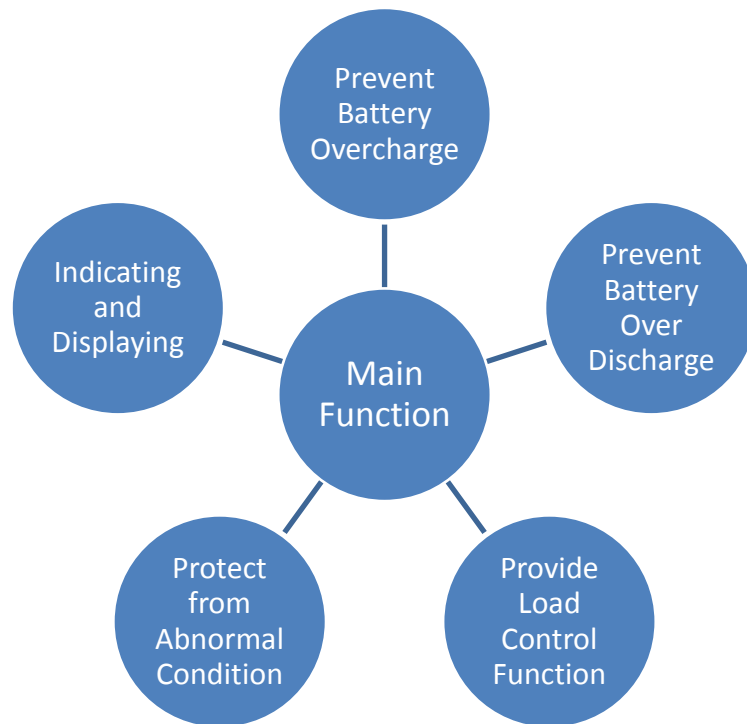


Figure 3.3 Illustration of The Main Function

Based on Figure 3.3, the solar charge controller taking care of the following points. The ability to prevent a battery from overcharge is implemented when the limit supplied voltage is sent to the battery when it becomes fully charged. It can be show in `charge_cycle()` code. To prevent from battery over discharge, load is disconnected from the battery which reach a low state of charge. It can be show in `load_control()` code. The circuit are protected from a situation includes of lightning, overvoltage, overcurrent, and short circuit. There are also indicator and display like lcd display and led display which indicate the various parameters in the circuit.

3.4 Preliminary Experiment

By using the Proteus (ISIS) software, there is a libraries that can create a prototype of this project in the software. By designing all sorts of the component and placed in one, output and input based, the result has shown the circuitry is running correctly. Which mean, the circuit design for the charge controller has be proven by the simulation.

3.5 Circuit Design

The project of solar charge controller with an intelligent operation system consists of a Arduino UNO microcontroller board, a temperature sensor (LM35), and two voltage sensors. A PWM algorithm based controller is applied in the system in the Arduino programming. The overall solar system can be referred as in Figure 3.3. The aim of this circuit design is to have a maintain power consumption for the battery and supply load from a small PV system.

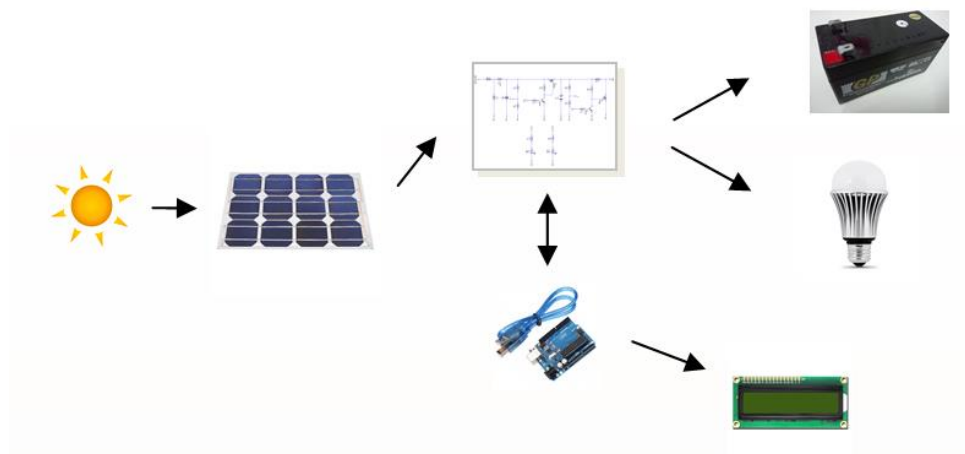


Figure 3.4 A Solar Charge Controller Overall System

The heart of the charge controller circuit is the Arduino UNO microcontroller board. The arduino board senses the voltage output of the solar panel and voltage level of the battery storage. According to the voltages it decides on how to charge the system battery and the load control.

The amount of current that charged is decided by comparing the difference between battery voltage and the charge set point voltage. This controller uses two stages charging algorithm. By referring to the charging algorithm, it sent a fixed frequency PWM signal to the solar PV panel side p-MOSFET. The PWM signal has a frequency default about 490.20Hz, and the duty cycle from 0 to 100% that is adjusted by the error signal. In the other side, the controller sent a HIGH or LOW command to the p-MOSFET at the load referring to the battery voltage.

3.5.1 Controller Circuit Design

Basically, by referring to the main objective, the project is to design the circuit of a solar system which is DC to DC converter (buck boost converter), to convey the output helps to maintained the battery operation. However, with the connection of solar panel, battery, and load, this project only focuses on the charging controller circuit design. In this project, controller will consists of an Arduino UNO board together with the integrated temperature sensor, and voltage sensors.

3.5.1.1 Solar Panel

A solar panel is a power system appliance that act as a receiver or collector of a sunlight energy power, then the light that strikes the surface panel change the energy power from light into electrical form. This energy produced is a clean energy, thus it makes mono-crystalline solar PV panel is chosen and used in this project. It has a longevity, no installation cost, efficient, clean energy from environment, produce more electricity, and etc. The solar panel rating is about 5 watt as shown in Table 3.1.

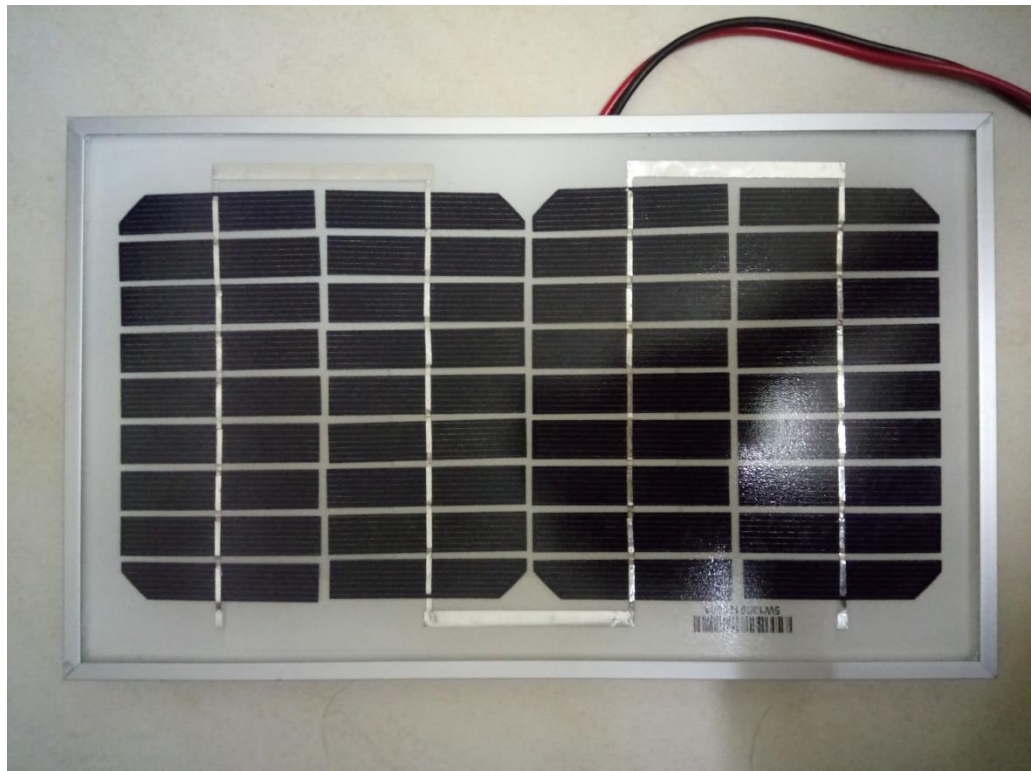



Figure 3.5 5W Mono-crystalline Panel

Table 3.1 Solar PV Panel Specification

 JOB Solar Energy Sdn Bhd	
Model Number	CHN5-36M
Rated Maximum Power	(Pmax) 5W
Current at Pmax	(Imp) 0.29A
Voltage at Pmax	(Vmp) 18.1V
Short-Circuit Current	(Isc) 0.31A
Open-Circuit Voltage	(Voc) 22.35V
Dimensions	290*175*17(mm)
Maximum System Voltage	1000VDC
Cell Technology	Mono SI
All technical data at standard test condition AM= 1.5 E= 1000W/m ² Tc=25°C	
Warning/Electrical Hazard This module produce electricity when exposed to light. Follow all applicable electrical safety precautions. Only qualified personnel should install or perform maintenance work on these modules. Be aware of dangerous high DC voltage when connecting modules. Do not damage or scratch the rear surface of the modules Do not handle or install modules when they are wet. Follow the battery manufacturer's recommendations if batteries are used with modules.	

3.5.1.2 Arduino UNO R3

The Arduino UNO R3 microcontroller board is based on microcontroller chip ATmega328. The construction consist of 14 bi-directional digital input and output pins, six pins of it is PWM output, six analog input pins, ICSP header and a reset button. The Arduino UNO R3 also can be powered by the power jack supply and USB connection cable. Figure 3.5 and Figure 3.6 shows the Arduino UNO R3 microcontroller board manufacturer and board pins location. Table 3.2 shows the overall specification of microcontroller board.

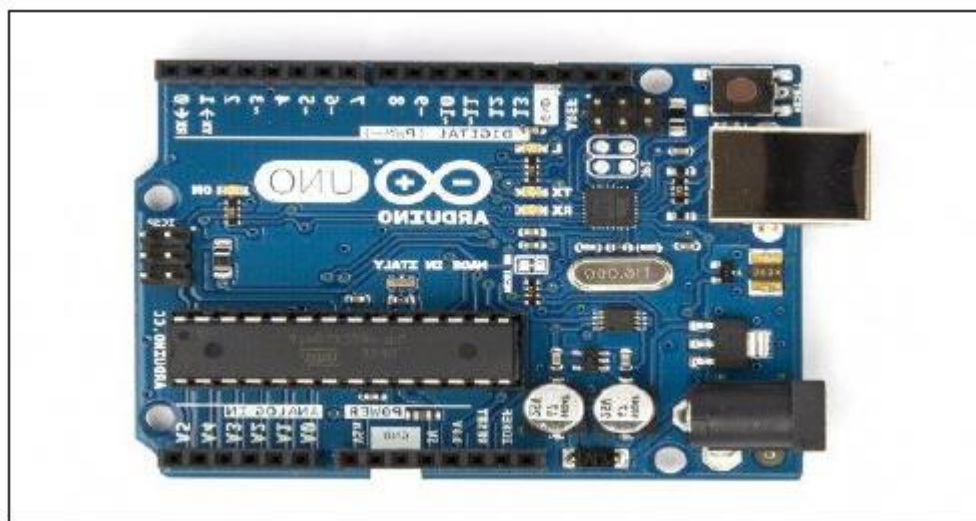


Figure 3.6 Arduino UNO R3 Microcontroller Board

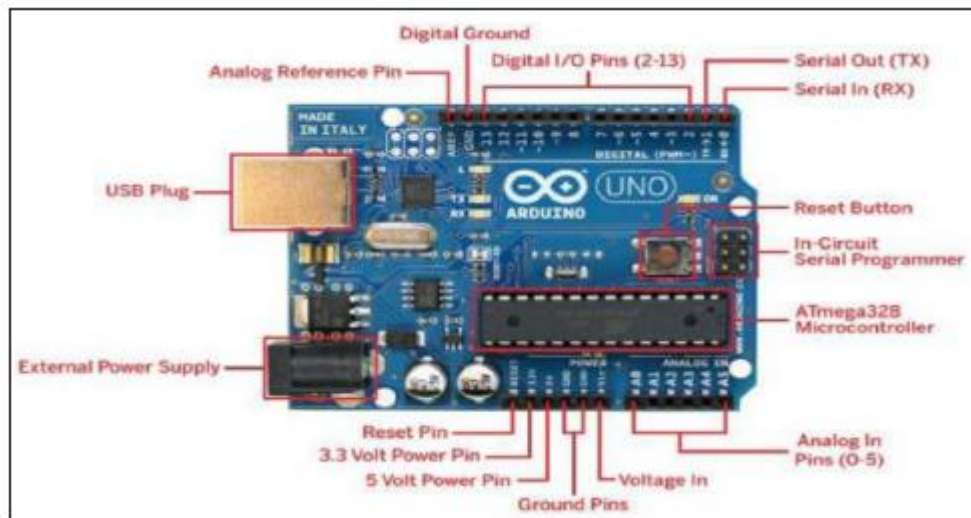


Figure 3.7 Arduino UNO R3 Microcontroller Pin Diagram

Table 3.2 Specification of Arduino UNO R3 Microcontroller

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which ^ provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1KB
Clock Speed	16 MHz
Length	68.6 mm
Width	53.4 mm
Weight	25 g

3.5.1.3 Temperature Sensor (LM35)

The LM35 is a component temperature device with output voltage proportional to the Centigrade temperature used to sense room temperature. It does not require any external calibration or trimming to provide typical accuracy at a room temperature. It has a low impedance, linear output, and precise calibration makes the device circuitry very easy. In the programming, temperature value is used in the calculation of a charge set point of the battery management. LM35 has been designed with the features of :

- i. Calibrated directly in Celsius
- ii. Linear $+10\text{mV}/^{\circ}\text{C}$ scale factor
- iii. Ensured accuracy at 25°C
- iv. Rated for full -55°C to 150°C range
- v. Suitable for remote application
- vi. Low cost due to Wafer-Level-Trimming
- vii. Operates from 4 V to 30 V
- viii. Less than $60\text{ }\mu\text{A}$ current drain
- ix. Low self – heating, 0.08°C in still air
- x. Non-linearity only $\pm 1/4^{\circ}\text{C}$ typical
- xi. Low-impedance output, 0.1 ohm for 1-mA load



Figure 3.8 LM35

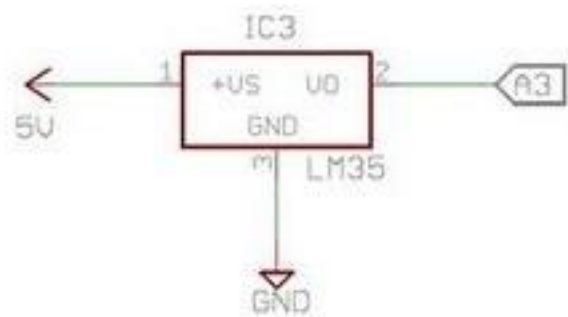


Figure 3.9 Connection of LM35

3.5.1.4 Voltage Sensor

The circuit for a charge controller possess two sensing voltage, which is one at the solar panel side and one at the load side. Actually the method is by using a voltage divider, where resistor 20 k and 100 k are used. After the voltage sense, the signal is sent to the analog pin A0 and A1 PWM. As Arduino UNO only receive 5 V input, the voltage divider is necessary.

The output voltage of solar is calculated according to the voltage divider equation,

$$V_{out} = V_{solar} \times \frac{R_2}{R_1 + R_2} \quad (3.1)$$

The output voltage of battery is calculated according to the voltage divider equation,

$$V_{out} = V_{batt} \times \frac{R_4}{R_3 + R_4} \quad (3.2)$$

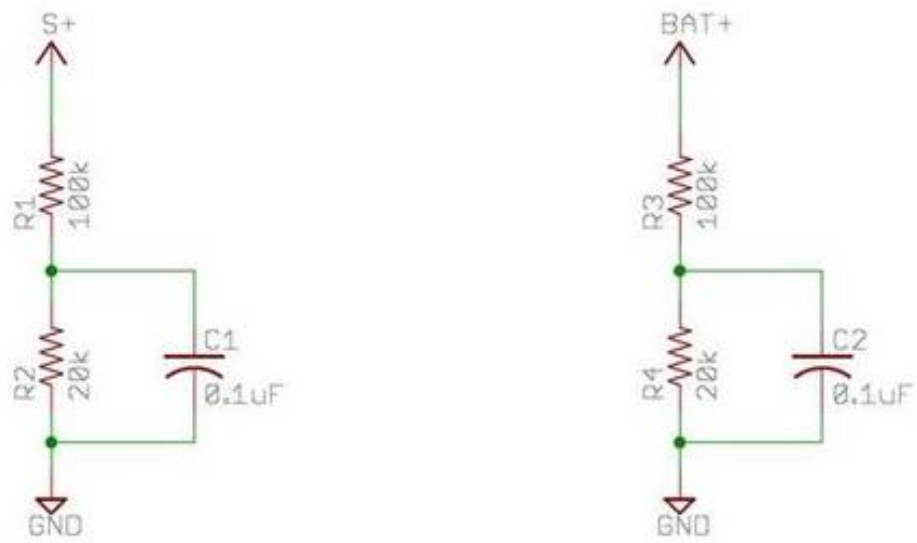


Figure 3.10 Voltage Divider Circuit

3.5.1.5 Transistor

Transistor is a semiconductor device for amplify or switch electronic signal. In most integrated circuit, transistor is constantly used as a switching device. In the circuit, transistor T1 and T2 is functions as a driver for the p-MOSFET.



Figure 3.11 Transistor (2N3904)

3.5.1.6 P-MOSFET

There are various type of MOSFET in the field, it is a type of transistor which used as the same as a transistor terminology as a switching device. Integrated circuit includes microprocessor or memory devices in power electronic can have a very large amount of integrated MOSFET on the device, it provide basic function of switching. MOSFET technology has been built as a faster semiconductor types of silicon based transistor.

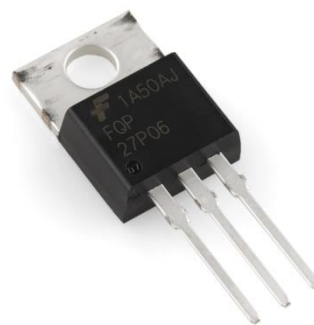


Figure 3.12 P-MOSFET (IRF9540)

To turn on a p-MOSFET, a positive voltage, V_s is apply to the source of the MOSFET and a negative voltage is apply to the gate terminal. A threshold voltage across the drain-source region has to be lower than the gate negative voltage, so that current will be allowed to flow through the source-drain. Therefore, the MOSFET is fully function as ON mode operation. Generally, in this controller circuit design, the MOSFET prevent power comes out from the solar panel to interconnected directly with the battery. The switching control by a PWM signal from Arduino UNO R3 has on the gate MOSFET. The moment MOSFET is turn on, the voltage enter to the battery and charging process begins. The second MOSFET, switch on the load connectivity with the circuit.

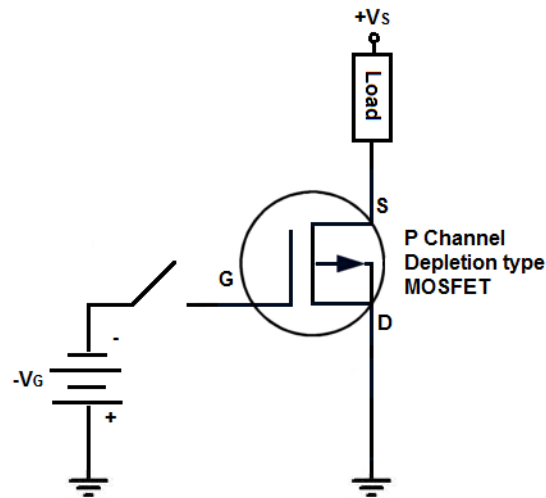


Figure 3.13 Schematic Circuit of p-MOSFET

3.5.1.7 Protection Component

i. TVS diode

These diodes are solid state pn junction devices specifically designed for protection of sensitive components from damage, effects of transient voltage. Its fast response time and low clamping voltage make them suitable for any protection for sensitive components and semiconductor device. TVS diodes are normally placed in parallel to the protected circuit. It acts as a high impedance in a normal operating condition, when the voltage exceeds the rating of a normal operation, TVS diodes provide a low impedance path for transient current. Thus the transient current is diverted away from the protected circuit through a TVS diode. After the threat passes, the device returns to operating at a normal operation, TVS diode returns to a high impedance.



Figure 3.14 TVS Diode (P6KE36CA)

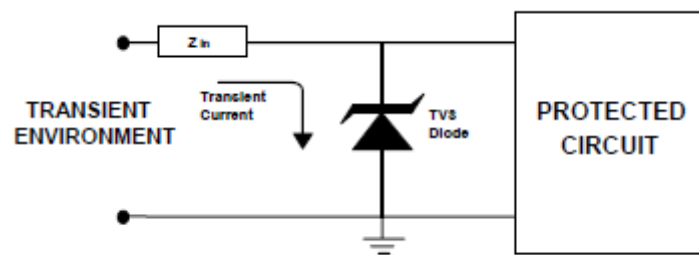


Figure 3.15 TVS Diode Example

ii. Power Diode

Power diode is a semiconductors that act as a reverse polarity protection in the circuit for a solar panel. It can handle a large amount of current, thus the reverse current flow protection is managed by installed a power diode.



Figure 3.16 Power Diode (MBR2045)

iii. Fuses

Over current and over load protection is implemented at end of the terminal. A 10 amp fuses are used at the both end connection of solar panel and load terminal.



Figure 3.17 10 Amp Fuse

3.5.1.8 Indicators

There are two indicators used to be display in this project. The features for both indicators are described as below :

i. Liquidcrystal Display

To display solar panel voltage, battery storage voltage, temperature Celsius, and state of charge, a 20x4 LCD is used. The purpose of displayed parameter on the LCD is to indicate and monitor all the system voltage.

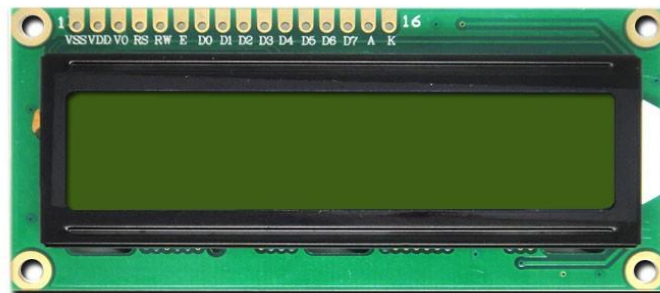


Figure 3.18 20x4 LCD

ii. LEDs

Important parameter that defines the power content in the battery storage is the state of charge. State of charge indicates the remaining charge stored in the battery. The different color of RGY LED is used.

Battery LED :

RED – Voltage is low

YELLOW – Voltage is healthy

GREEN – Fully Charged

Load LED :

GREEN (ON) – Connected

GREEN (OFF) – Not Connected

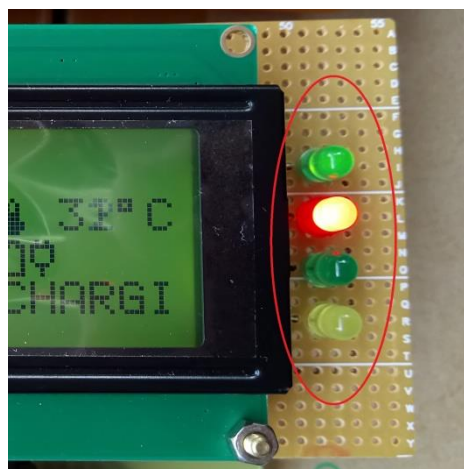


Figure 3.19 LED Indicator

3.6 Hardware Development

Figure 3.21 shows a printed circuit board (PCB) which is made in UMP laboratory. The PCB is then integrated with all components of the charge controller and become a complete solar charge controller as in 3D visualizer Figure 3.20. Arduino UNO R3 microprocessor, LCD, LED, solar PV panel, 9W LED load, and 12V lead acid battery are connected with the board.

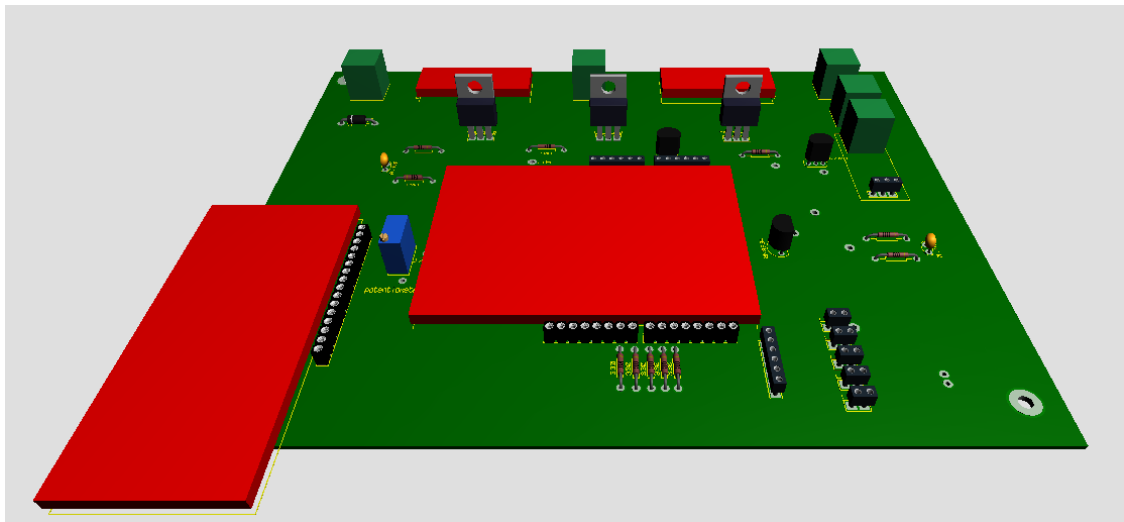


Figure 3.20 3D Visualizer of PCB

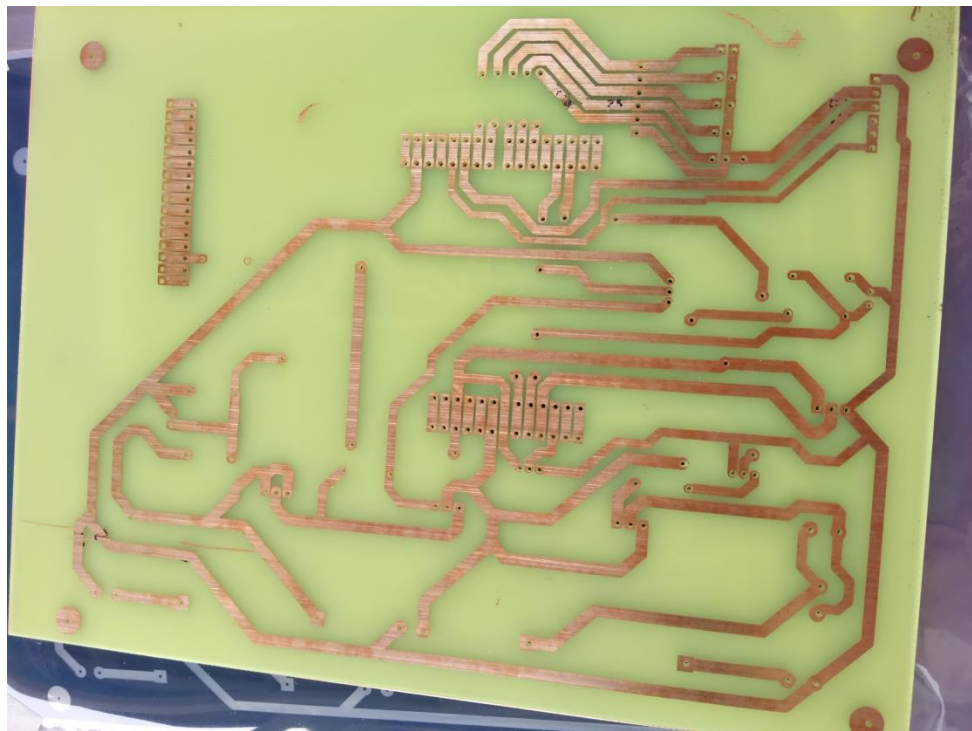


Figure 3.21 Printed Circuit Board (PCB)

Figure 3.22 shows the breadboard testing on the LCD connection. The connection of LCD with Arduino UNO R3 microprocessor pins is shown in Appendix 1. A variable resistor is used in the connection of LCD pins in order to get backlight of the LCD.

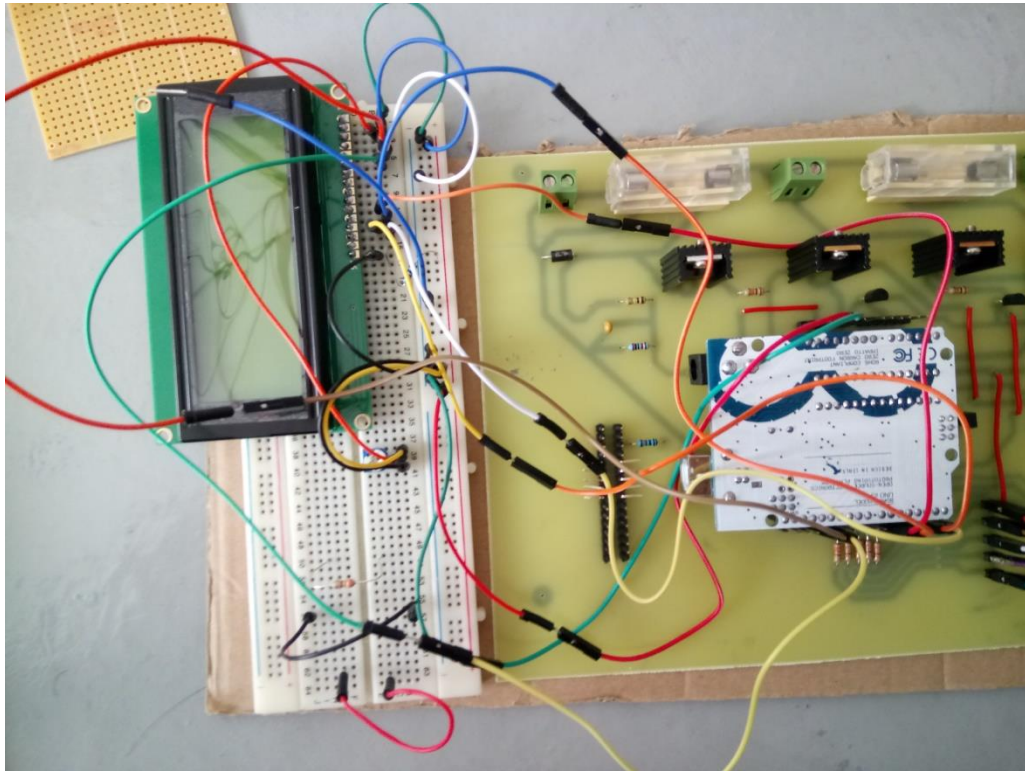


Figure 3.22 LCD Testing on the Breadboard

The installation of indicators are made by combining both of the LCD and LED on a small donut board, and mounted above of the PCB. The hardware becomes one as all the parts are connected together. Figure 3.23 shows the process of uploading a program into the Arduino UNO R3. Figure 3.24 below is the complete system of the solar charge controller.

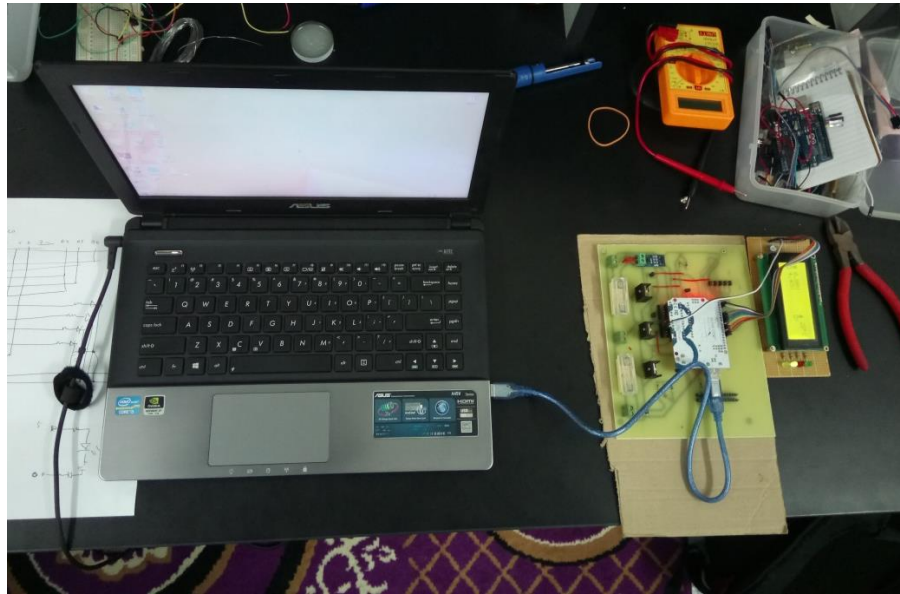


Figure 3.23 Uploading Program into Arduino UNO R3

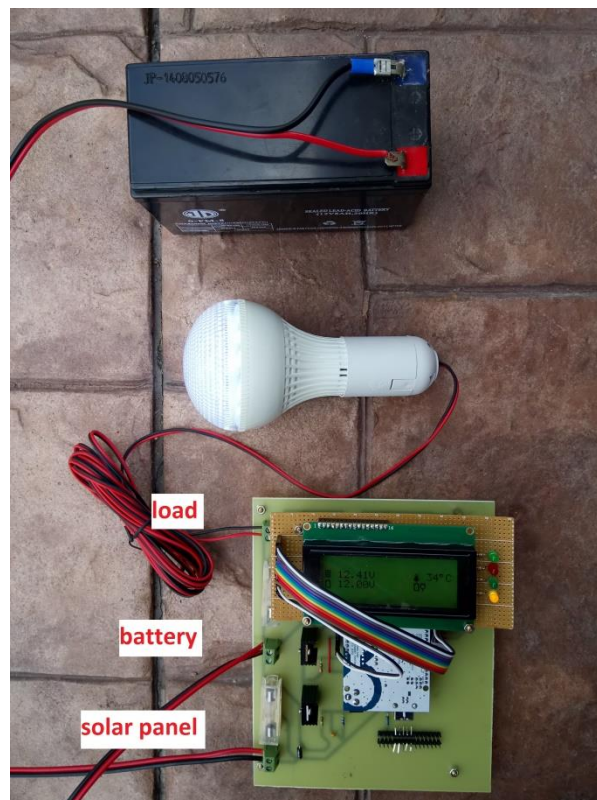


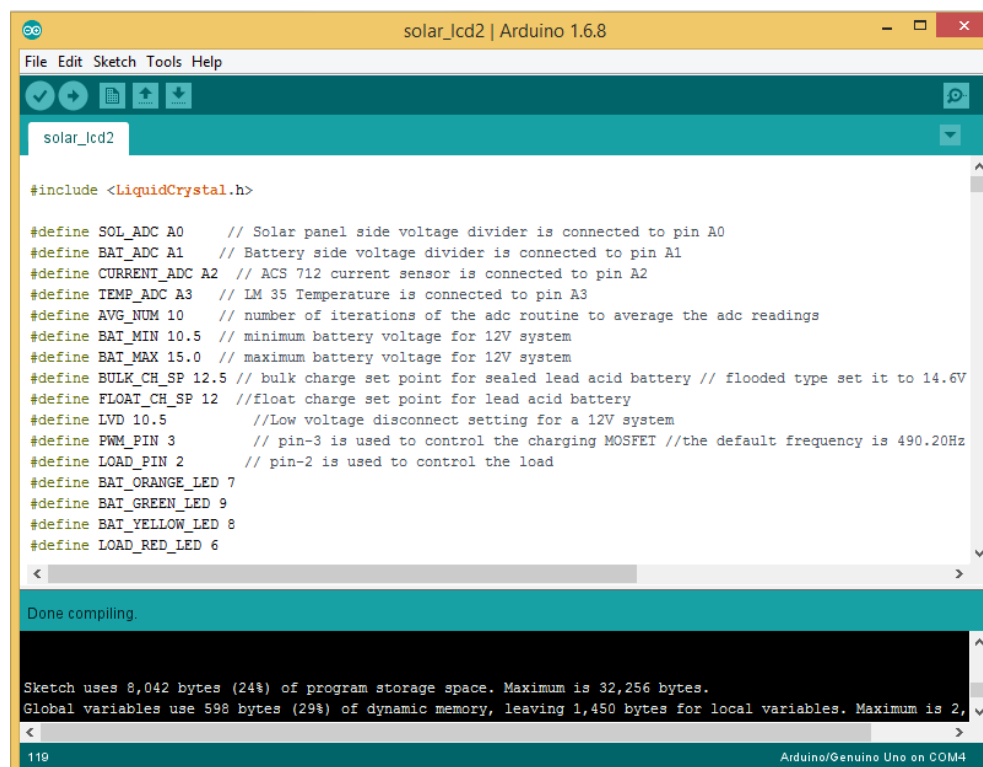
Figure 3.24 Complete Solar Power System

3.7 Software Development

In software development, the important part is constructing the algorithm of the programming as how the desire process. Apart process of hardware, software part is important, all the programming is written and compile in a Arduino software, starts from the declaration until the end of the program.

3.7.1 Charging Algorithm

The charging process has 2 stages, which is bulk and float process. Flowchart below shows the clear illustration of the process. Bulk mode is a preset maximum constant current energy (amp) supplied to the battery as no error/PWM. Generally, at the bulk stage, battery voltage gradually increasing until it reached the float stage. Then floating indicate any error from the solar voltage and battery voltage, thus the charging voltage is reduce gradually until the storage is fully charged.



```

solar_lcd2 | Arduino 1.6.8
File Edit Sketch Tools Help

solar_lcd2

#include <LiquidCrystal.h>

#define SOL_ADC A0      // Solar panel side voltage divider is connected to pin A0
#define BAT_ADC A1      // Battery side voltage divider is connected to pin A1
#define CURRENT_ADC A2  // ACS 712 current sensor is connected to pin A2
#define TEMP_ADC A3     // LM 35 Temperature is connected to pin A3
#define AVG_NUM 10      // number of iterations of the adc routine to average the adc readings
#define BAT_MIN 10.5    // minimum battery voltage for 12V system
#define BAT_MAX 15.0    // maximum battery voltage for 12V system
#define BULK_CH_SP 12.5 // bulk charge set point for sealed lead acid battery // flooded type set it to 14.6V
#define FLOAT_CH_SP 12 // float charge set point for lead acid battery
#define LVD 10.5        // Low voltage disconnect setting for a 12V system
#define PWM_PIN 3       // pin-3 is used to control the charging MOSFET //the default frequency is 490.20Hz
#define LOAD_PIN 2      // pin-2 is used to control the load
#define BAT_ORANGE_LED 7
#define BAT_GREEN_LED 9
#define BAT_YELLOW_LED 8
#define LOAD_RED_LED 6

Done compiling.

Sketch uses 8,042 bytes (24%) of program storage space. Maximum is 32,256 bytes.
Global variables use 598 bytes (29%) of dynamic memory, leaving 1,450 bytes for local variables. Maximum is 2,
119 Arduino/Genuino Uno on COM4

```

Figure 3.25 Declaration of parameter

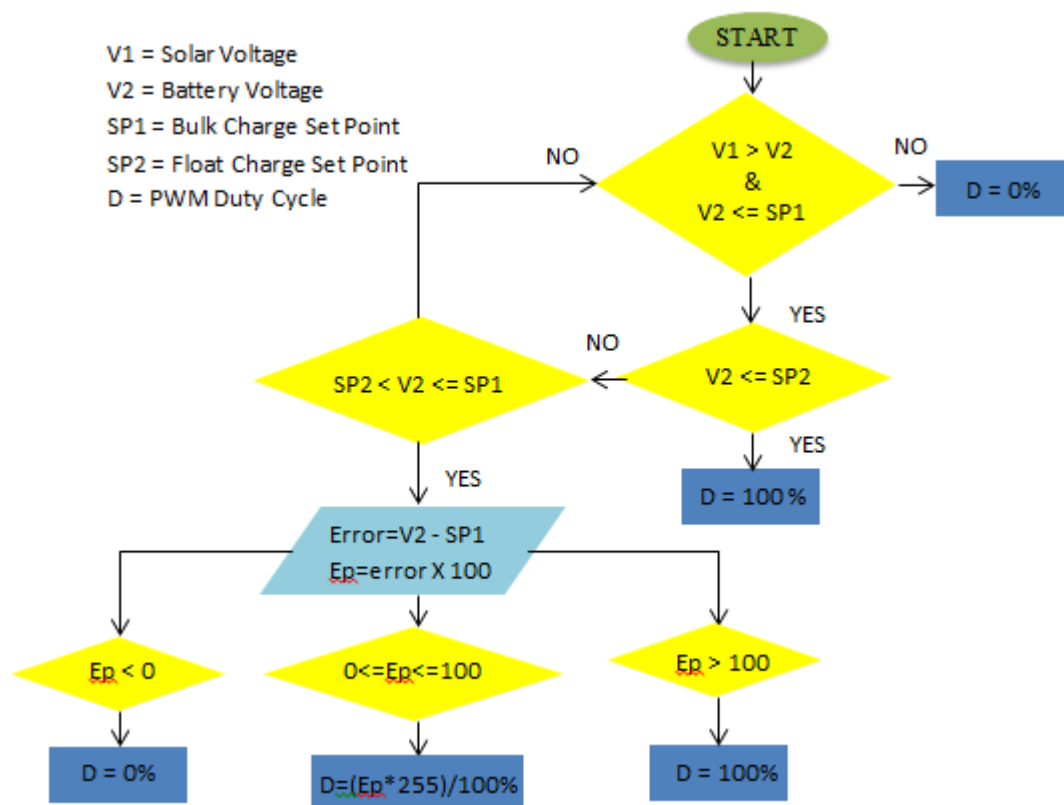


Figure 3.26 Flowchart of the Programming

3.7.2 Declaration of the Analog Digital Converter (ADC)

The analog output from the solar, battery, and LM35 is sent to the microcontroller and have to convert into a digital form to be execute. The coding is shown in Figure 3.27 below.

```

//5V = ADC value 1024 => 1 ADC value = (5/1024)Volt= 0.0048828Volt
// Vout=Vin*R2/(R1+R2) => Vin = Vout*(R1+R2)/R2    R1=100 and R2=20
solar_volt = read_adc(SOL_ADC) * 0.00488 * (120 / 20);
bat_volt   = read_adc(BAT_ADC) * 0.00488 * (120 / 20);
temperature = read_adc(TEMP_ADC) * 0.00488 * 100;

```

Figure 3.27 ADC coding

3.7.3 Calculation of Charge Set Point

Charge set point is one important parameter, where the preset voltage is determine by the value. Both bulk charge set point and float charge set point are be affected by the temperature changing. If the temperature is above the room temperature, charge set point should be reduced, whereas if the temperature is below the room temperature, charge set point should be increased. Figure 3.28 shows the calculation of the charge set point.

```

{
temp_change = temperature - 25.0; // 25deg cel is taken as standard room temperature
// temperature compensation = -5mv/degC/Cell
// If temperature is above the room temp ;Charge set point should reduced
// If temperature is bellow the room temp ;Charge set point should increased
if (system_volt == 12)
{
    bulk_charge_sp = BULK_CH_SP - (0.030 * temp_change) ;
    float_charge_sp = FLOAT_CH_SP - (0.030 * temp_change) ;
    lvd = LVD;
}
}

```

Figure 3.28 Charge Set Point Calculation

3.7.4 PWM Duty Cycle

In order to have enough supplied current for the battery, transistor which act as a driver will be connected to the PWM pins D2, D3 of the Arduino UNO R3 microcontroller. PWM is used to give pulses for the charge set point.

```

if (solar_volt > bat_volt && bat_volt <= bulk_charge_sp)
{

    if (bat_volt <= float_charge_sp) // charging start
    {
        charge_status = 1; // indicate the charger is in BULK mode
        duty = 252.45;
        analogWrite(PWM_PIN, duty); // 99 % duty cycle // rapid charging
    }
else if (bat_volt > float_charge_sp && bat_volt <= bulk_charge_sp)
{
    charge_status = 2; // indicate the charger is in FLOAT mode
    error = (bulk_charge_sp - bat_volt); // duty cycle reduced when the battery voltage a
    Ep = error * 100 ; //Ep= error* Kp // Assume Kp=100

    if (Ep < 0) //overcharge (voltage battery higher than Bulk setpoint)
    {
        Ep = 0;
    }
else if (Ep > 100) //error>1V. battery voltage lower than 12V. So max charging voltage
{
    Ep = 100;
}

else if (Ep > 0 && Ep <= 100) // regulating
{
    duty = (Ep * 255) / 100;
}
analogWrite(PWM_PIN, duty);

```

Figure 3.29 PWM Duty Cycle Code

3.7.5 Load Control Setting

To automatically connect and disconnect load, load control is program in the microcontroller. Main purpose of load control program is to disconnect the load from battery to keep save from deep discharging. The condition of the load where the connection will cut off is when the battery voltage is lower than the low voltage disconnect (LVD) setting.

```
if (bat_volt > lvd) // check if battery is healthy
{
    load_status = 1;
    digitalWrite(LOAD_PIN, HIGH); // load is ON
}
else if (bat_volt < lvd)
{
    load_status = 0;
    digitalWrite(LOAD_PIN, LOW); //load is OFF
```

Figure 3.30 Load Control Program

3.7.6 Battery Led Indication

Battery state of charge is indicates by sets of led with different colors. Figure 3.31 clarifying a clear look for the overall illustration of condition. The program includes three condition of state of charge, low voltage, healthy voltage, and fully charged etc.

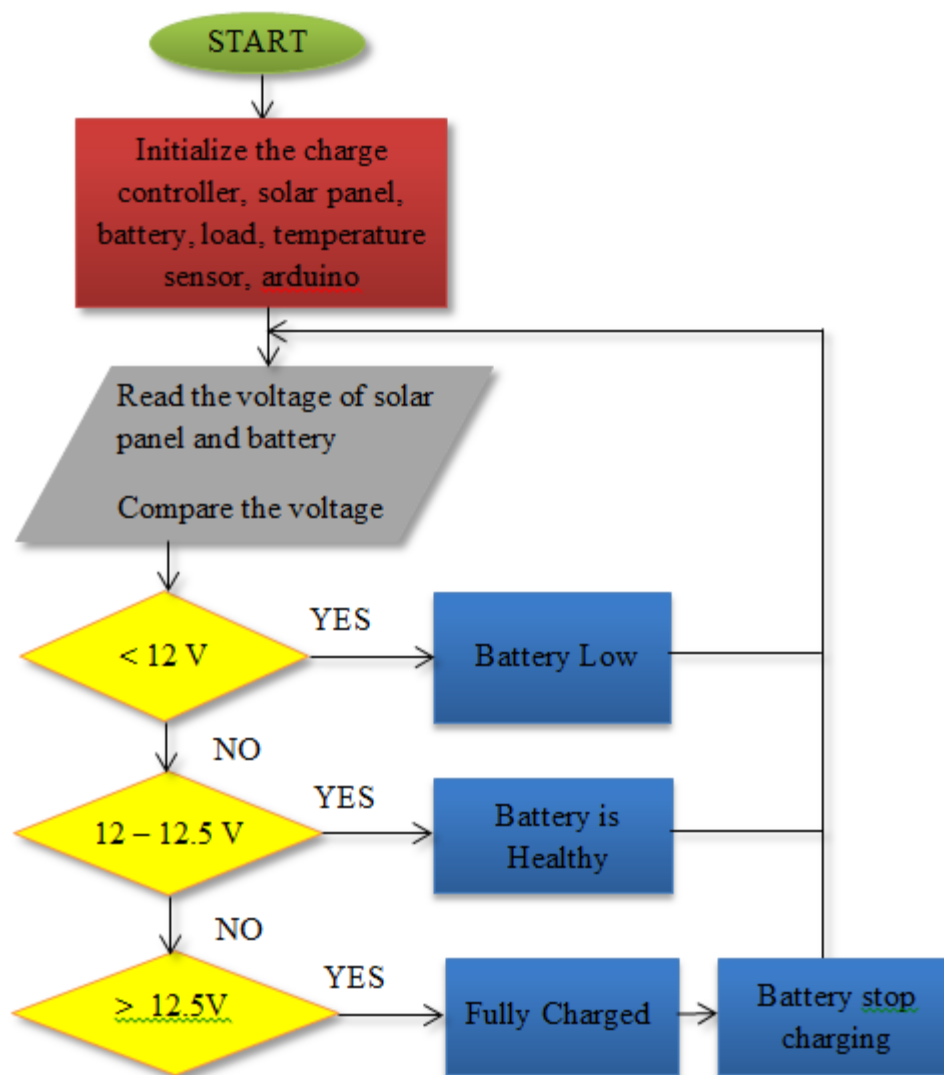


Figure 3.31 Flowchart for Battery Led Indication

```

if ( (bat_volt >= system_volt) && ( bat_volt < bulk_charge_sp))
{
    leds_off_all();
    digitalWrite(BAT_YELLOW_LED,HIGH); // battery voltage is healthy
}
else if (bat_volt >= bulk_charge_sp)
{
    leds_off_all();
    digitalWrite(BAT_GREEN_LED, HIGH); //battery is fully charged
}
else if (bat_volt < system_volt)
{
    leds_off_all();
    digitalWrite(BAT_RED_LED, HIGH); // battery voltage low
}

```

Figure 3.32 Battery Led Indicator Programming

3.7.7 The Schematic Circuit

The schematic circuit for the whole project is tested by using Proteus (ISIS) software. The attachment for the circuit can be obtained in the Appendix.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, discussion is emphasizes on findings in the experimental results. The results collected from the experiment is explained more clearly and demonstrated in figures. The objective and project scope of the project are presented and analyzed from the output of the system, either the method of intelligent charging controller is efficient for the 12-volt battery system.

4.2 Results and Discussions

The results of the project that can be presented are the state of charge of the LED display that displayed in the charge controller, and values of the parameters in LCD display. As mentions in previous chapter, the LED shows various colors which indicate each state of charge. Besides that, LCD readings also indicates that the battery voltage is stop charging as the voltage reached 12.36 volt, means that the battery is fully charged as the current is no longer been supplied. LCD display also shows the condition of state of charge, either bulk or float states.

Figure 4.1, Figure 4.2, and Figure 4.3 indicates each state of charge in the operation. Besides battery status, the highest LED on the charge controller indicates load device is connected. The outputs notify a reader using LED indicator that shows every status of charge set point and state of charge of the battery. In Figure 4.1, battery voltage gives reading 11.92 volt below 12 volt, inform that it is category as a voltage low, where red LED is light up. Whereas in Figure 4.2, battery voltage gives reading 12 volt precisely, inform that it is category as a healthy voltage condition, where yellow LED is light up. Lastly, in Figure 4.3 battery voltage gives reading 12.36 volt, which inform that it is category as a fully charged condition, where green LED is light up. Battery terminal is disconnecting simultaneously from current supply.

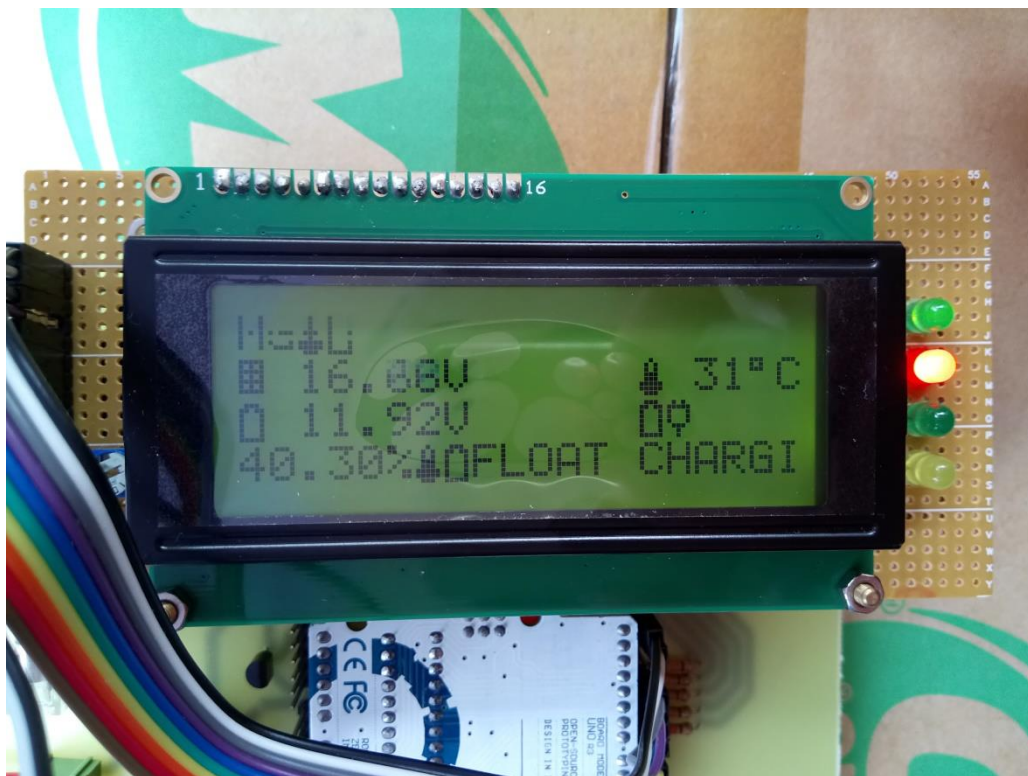


Figure 4.1 Voltage is Low Red LED Display

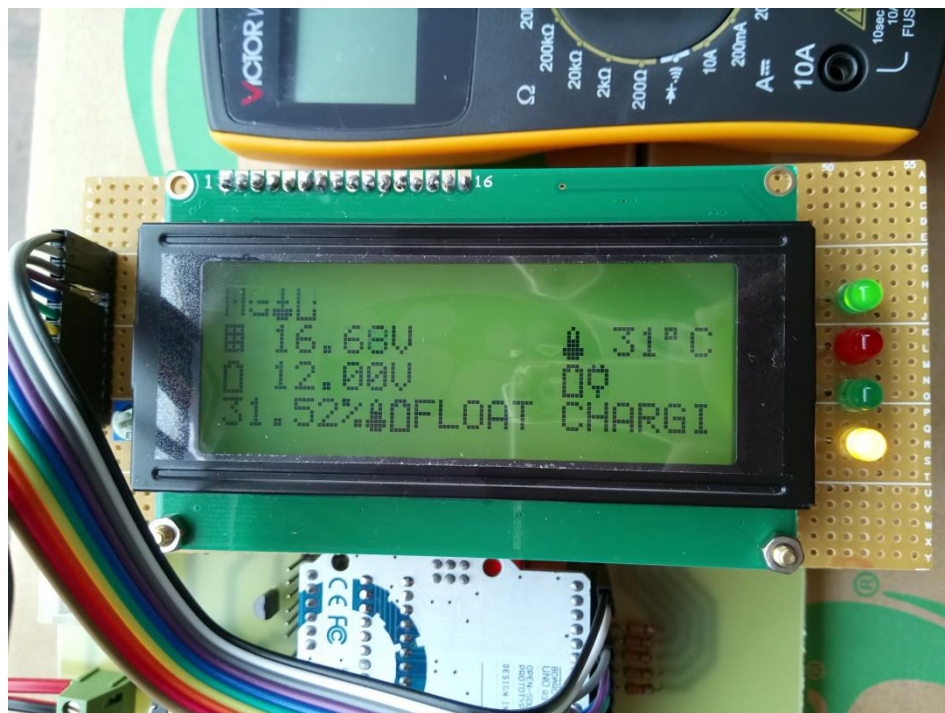


Figure 4.2 Voltage is Healthy Yellow LED Display

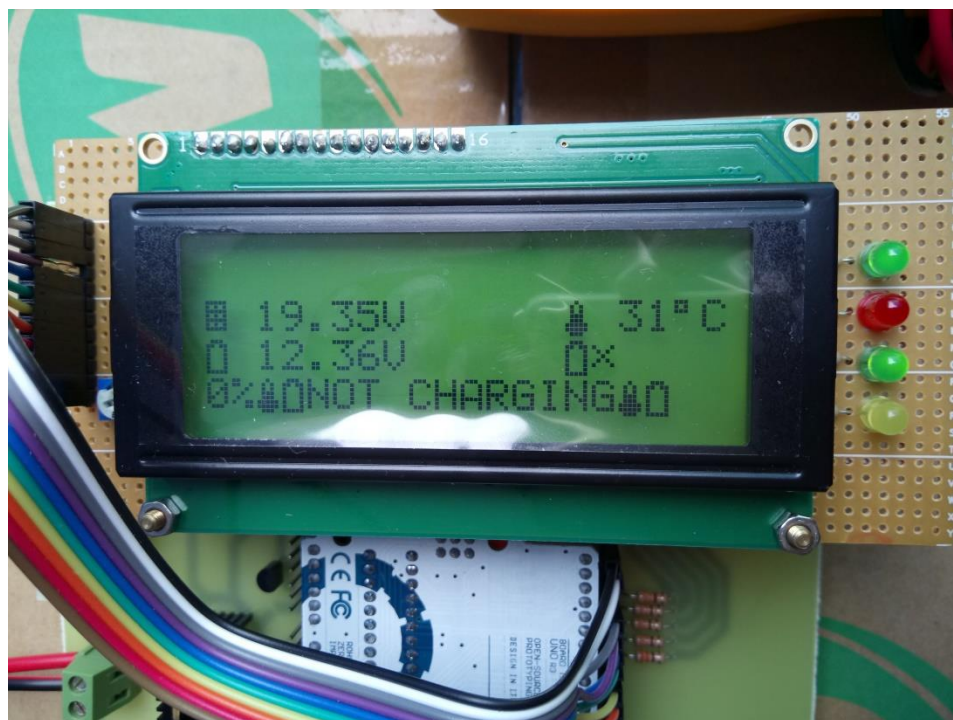


Figure 4.3 Fully Charge Green LED Display

Initially, status in LCD states that bulk charging process is taking place, after a certain point battery voltage reach 11.86 volt, status bulk charging is changed to float charging mode. Float point charge is about 11.86 volt due to the safety precaution calculation in the programming that relate to the room temperature, whereas exact float charge set point should be 12 volt. It is the same as the bulk point charge where the voltage should be at 12.5 volt, but the system precaution change it to 12.36 volt. Thus, the indicator is purposed to facilitate and ease the reading of the output.

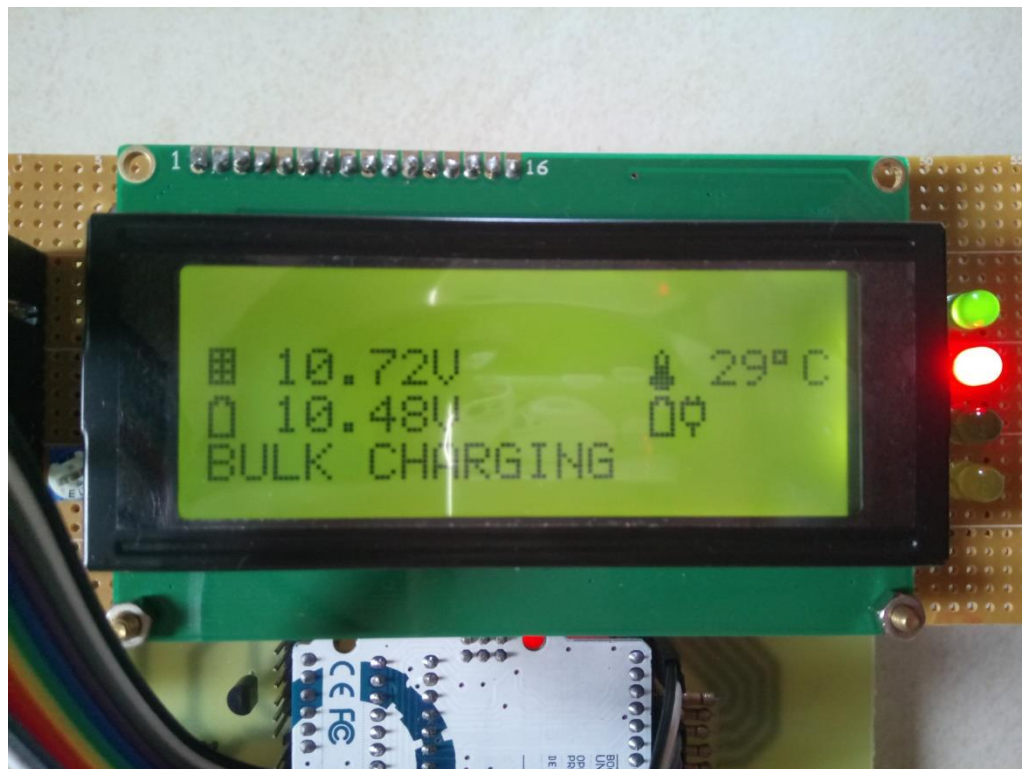


Figure 4.4 Bulk Charging Operation

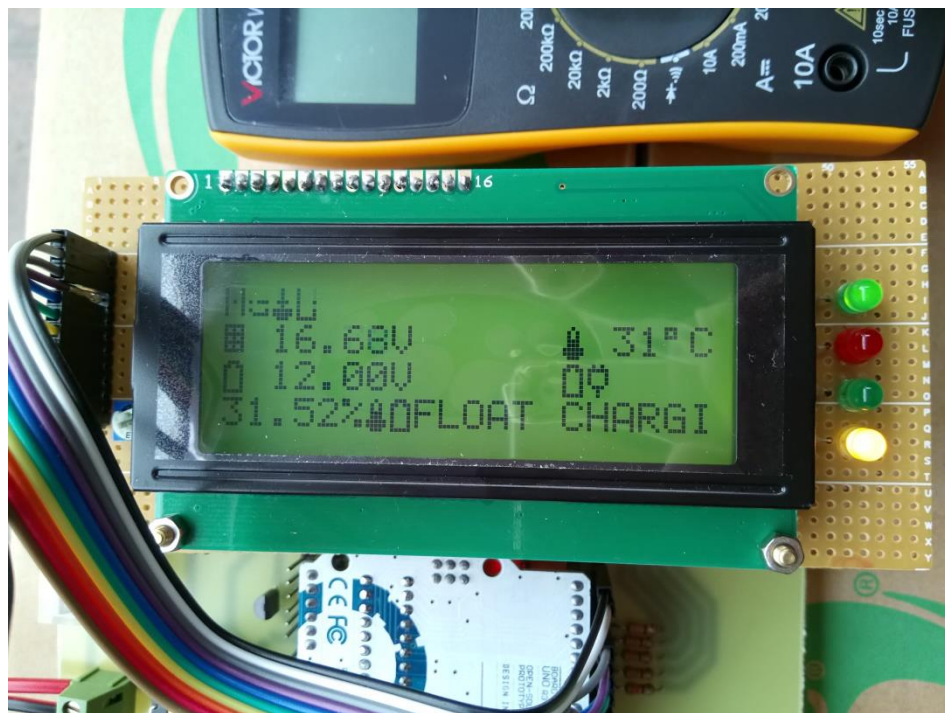


Figure 4.5 Float Charging Operation

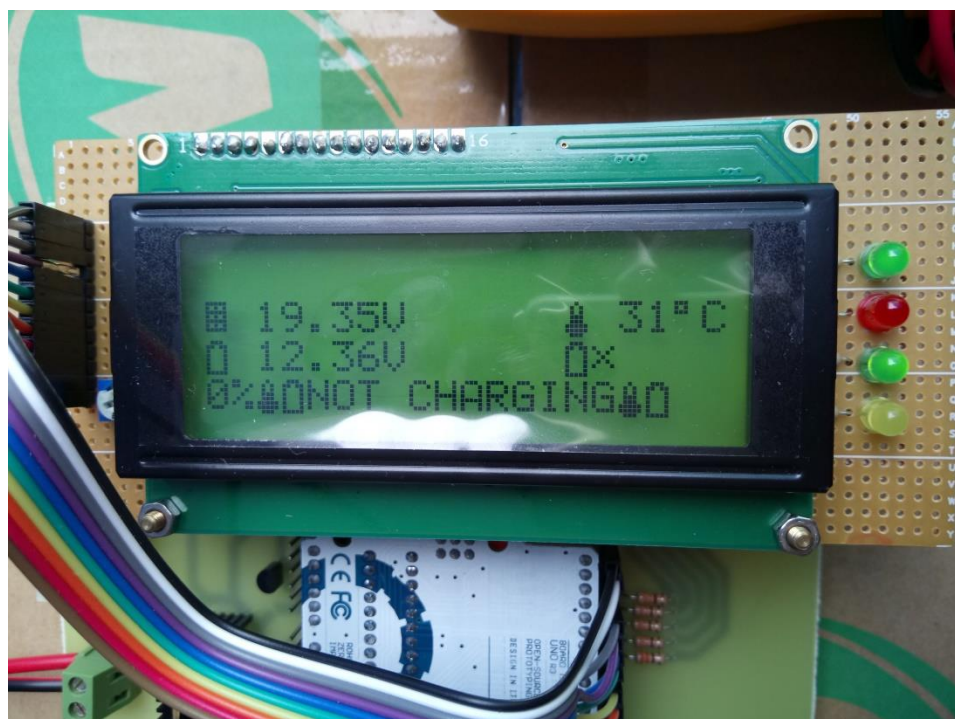


Figure 4.6 Not Charging (Fully Charged) Operation

The experiment setup was conducted throughout a daytime in 24 November 2016. The weather was kept on changing and uncertain because of a heavy rain, and cloudy day appears. It was carried out by collecting the output from solar energy, battery voltage, room temperature, and state of charge parameters. Therefore, all the data were recorded and tabulated as shown in Table 4.1. The main parameters in the recorded experiment were the lead acid battery voltage and the percentage of the charging process executes (duty cycle). As a whole, Figure 4.7 to Figure 4.10 respectively shows the output power from different criteria.

Table 4.1 Experiment Results for All Parameters

NO	TIME	SOLAR	BATTERY	PERCENTAGE	TEMPERATURE
1	8.25	12.03	11.50	100.00	29.00
2	8.30	12.03	11.68	100.00	29.00
3	8.35	12.12	11.74	100.00	30.00
4	8.45	12.15	11.77	100.00	30.00
5	8.48	12.18	11.80	100.00	30.00
6	8.50	12.21	11.83	100.00	30.00
7	8.54	15.27	11.86	100.00	31.00
8	8.56	15.66	11.86	49.16	30.00
9	8.58	16.60	11.89	43.23	31.00
10	9.01	16.53	11.92	40.30	31.00
11	9.04	16.58	11.95	37.38	31.00
12	9.09	16.88	11.98	34.45	32.00
13	9.31	16.81	12.00	31.52	31.00
14	9.40	17.38	12.03	25.59	32.00
15	9.55	17.53	12.06	22.88	32.00
16	10.30	17.80	12.09	22.66	32.00
17	11.00	17.53	12.12	21.56	29.00
18	1.20	17.36	12.15	20.36	28.00
19	1.58	17.66	12.18	19.95	28.00
20	2.40	18.01	12.21	11.02	32.00
21	3.06	18.01	12.21	8.02	32.00
22	3.55	18.16	12.25	5.30	30.00
23	4.28	19.16	12.30	2.03	30.00
24	5.15	19.35	12.36	0.00	30.00

PV Voltage Criteria

The graph illustrates the PV Voltage Criteria over time. The voltage starts at 12.00V at 8:25 and remains constant until 8:50. It then rises to 15.00V by 8:54 and continues to rise to 19.50V by 5:15.

Time	PV Voltage
8.25	12.00
8.30	12.00
8.35	12.00
8.45	12.00
8.48	12.00
8.50	12.00
8.54	15.00
8.56	15.50
8.58	16.50
9.01	16.50
9.04	16.50
9.09	16.80
9.31	16.80
9.40	17.50
9.55	17.50
10.30	17.80
11.00	17.50
1.20	17.20
1.58	17.80
2.40	18.00
3.06	18.00
3.55	18.20
4.28	19.20
5.15	19.50

Figure 4.8 PV Voltage against Time

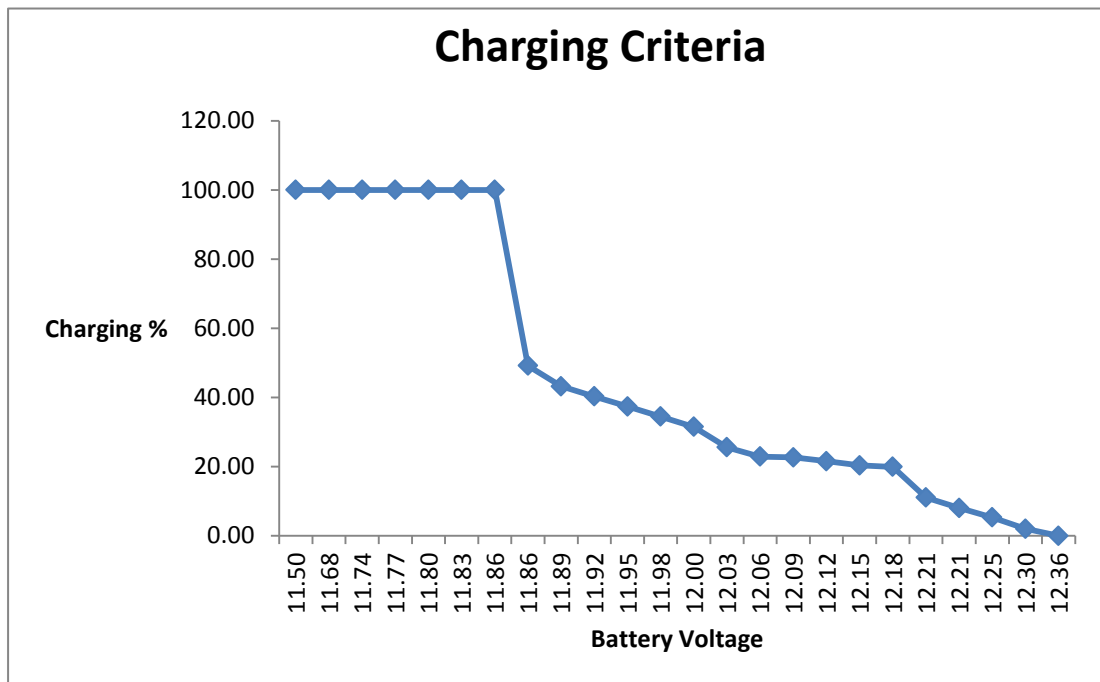


Figure 4.9 Charging Percentage against Battery Voltage

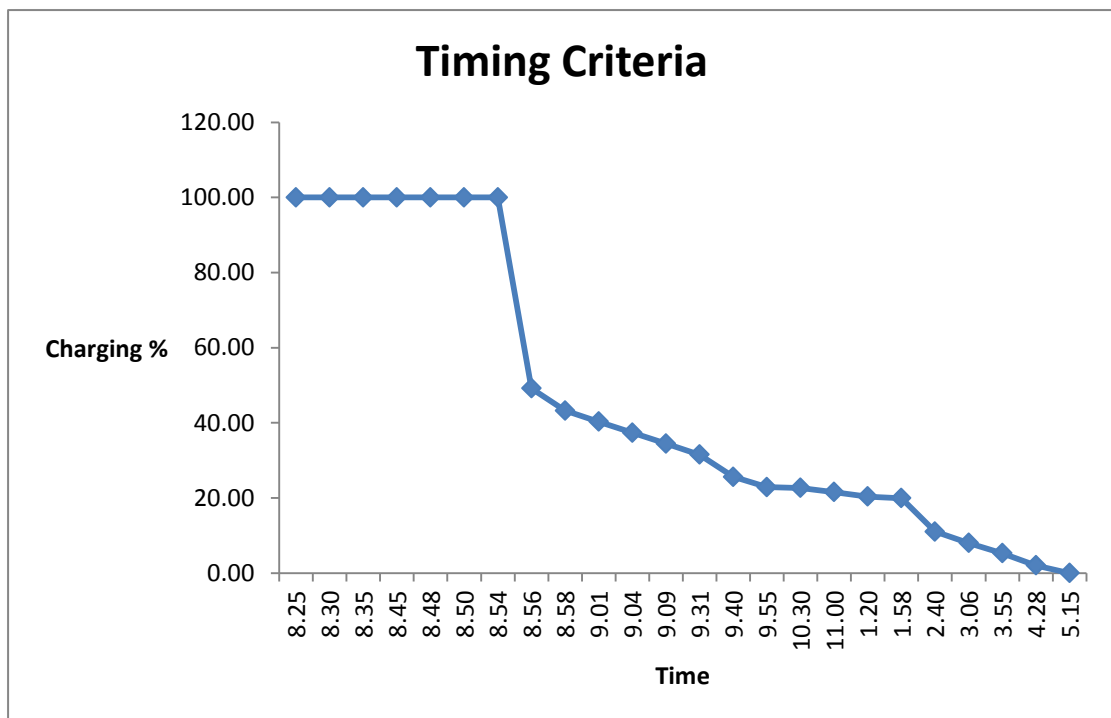


Figure 4.10 Charging Percentage against Time









	08	09	10	11	12	13	14	15
								
Suhu (°C)	26°	26°	27°	28°	29°	28°	28°	29°
RealFeel®	32°	34°	34°	37°	38°	37°	33°	35°
Angin (km/j)	6 BL	7 BL	7 BBL	9 BBL	9 BBL	9 BBL	11 BBL	11 BBL

Figure 4.11 AccuWeather.com Weather Meteorology

The experiment was conducted starting early in the morning from 8.25am – 5.15pm. From the data collected in AccuWeather.com, the meteorology specialist stated that the weather that day was rainy and cloudy most of the time, but solar panel still functioning as the radiation was still there. By referring the first graph, temperature criteria is related to the surrounding circumstances, it is fluctuate from 29°C to 32°C respectively. The temperature can tells that the humidity at the place were moist at the meantime, although the PV panel reading was incrementally rising.

In the second graph shows that relation of the solar panel and time, as in the graph it tells the radiation that solar panel received from the sun was promisingly increases. This is due to cloudy weather in the morning and slowly sunny in the afternoon. Therefore, graph result shows total radiation of solar panel incrementally rising, which is from 12.03 volt to 19.35 volt. By considering the bad weather and low radiation of sunlight, duration for a lead acid battery charging process was longer and finished the charging process late in the afternoon. The weather has a great influence for the time taken process.

In the third graph, the relation shows charging percentage and battery voltage. The purposed of the graph is actually to clarify the overall efficiency of the battery charge controller. Both main important parameter shows the output where the initial charging % maintain at a uniform 100% proper value starting from 11.5 – 11.86 volt then suddenly drop to 49.16%. This is due to changing process of a charge set point, where bulk charging (< 12 -volt) process changed to float charging (≥ 12 -volt) process. The change occurs when the battery reached 11.86 volt. After a period of time, decrement in percentage of float charging shows until 0%, where the lead acid battery was fully charged. The illustration of the graph indicates that each bulk charging process occurs from 11.5 – 11.86 volt, whereas float charging process occurs from 11.86 – 12.36 volt respectively.

Lastly in the fourth graph, it shows the relation between a charging percentage against time. The timeframe indicates the time taken for initial charging percent was rapidly moved, and after a two hours later the time taken for a charging percent moving at a slow pace. Means that, the closer the battery voltage from the fully charge state, the slower the charging rates. Hence, the efficiency of charging percentage proved that the method used in this project is a success. The intelligent battery charge controller system was built.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Solar power system is one of the best alternative renewable energy that has availability and cost effectiveness. A solar charge controller system with an intelligent method is about the battery to be charged with efficient amount of current input. However, there are some issues regarding the charging process, where the battery state is exposed to many problems. The problem could be like battery gassing, plate corrosion, or loss of liquid. Therefore, the system will be a best solution to the problem of having an inefficient battery charging process.

This system utilized a PWM algorithm control to give a uniform pulses that trigger the controller so that proper charging will be carried out. Implementing this PWM system control will ensure the problem solving. In order to get a proper charging process, voltage divider is used to sense every voltage condition of solar panel and battery. This voltage divider continuously monitors the voltage level and data are sent to the Arduino UNO R3 microcontroller board.

Since the voltage and the current output that produce by solar panel are not properly sent, the bulk charge set point and float charge set point setting be used. The duty cycle of charge set point initially sending a full power or boost mode signal, in other word battery received a maximum amount of energy. While the battery is being charged, a load control setting also supplies the energy for a 12 volt small electronic system. At one point, boost mode bulk charging is substituted with a float charge set point.

The various pulses are transmitted from PWM to regulate the appropriate amount of current into the battery, where the intensity of current is maximized efficiently. To be ease, the amount of current is defined as charging percentage. Starting from 100 percent duty cycle it drops until zero percent duty cycle, where the charging is totally full.

Float charge set point operates in decrement charging percentage as the fully charged state get closer. A conclusion can be made by the experiment, the closer the battery voltage from the fully charge state, the slower the charging rates. In other word, battery received a minimum amount of energy. The methodology which consist 2 stages of charge set point helps to maintain the battery, thus the project is a success.

Apart from that, solar charge controller is also embedded with the function where all parameters are demonstrated by indicator. The indicator represents of LED and LCD display respectively. All devices in manufacturer basically equipped with indicator that intended to facilitate, either positive or negative position. In conclusion, the objectives are achieved, where the system generates solar voltage output delivered to the battery charging scheme has maintained the battery. The system results a high efficiency of solar power system.

5.2 Future Recommendations

Despite achieving the project objectives, improvement is requiring to enhance the application works. There are several recommendation for future works planning based on the performance. Firstly, future planning for a charging cycle, an ideal charging procedure for a charging algorithm can be increase by adding ‘absorption charge set point’. The basic idea for the absorption charge set point is when the absorption stage enters, the charging current maintain the battery voltage for one hour, by holding the voltage constantly, overheating and over gassing can be avoided. Absorption stage can be implemented in between bulk stage and float stage.

In this project, Arduino is powered by the power jack supply and USB connection cable. To overcome this, a regulator or buck boost converter can be implemented externally. A direct voltage from battery through a regulator to the pin Vin in Arduino microcontroller board. Meaning that, the Arduino is powered by the battery itself.

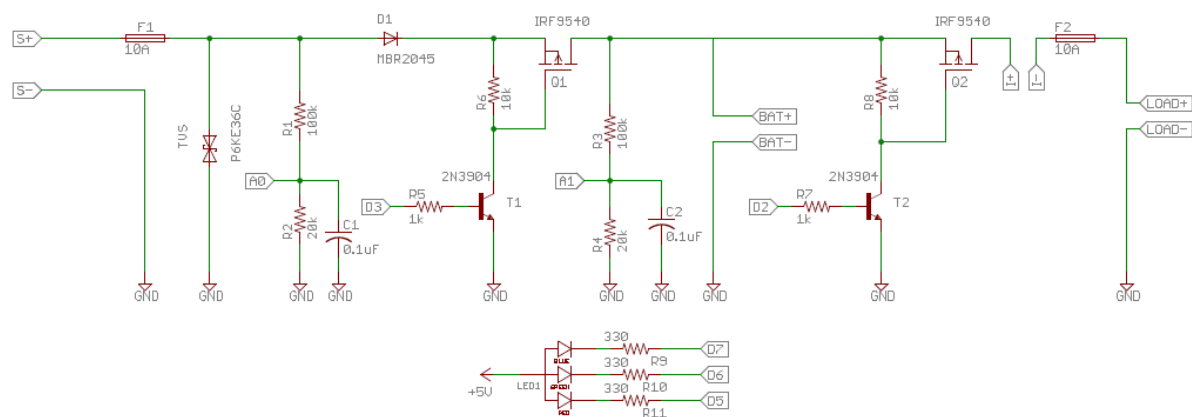
Other than that, to make a solar power system be more intelligent, invent a solar tracking controller device. The performance of solar panel will gradually increase as the tracker point the solar panel directly towards the sun. Lastly, probably a solar power system should have a remote data logging, such as Bluetooth or infrared interface or computer interface.

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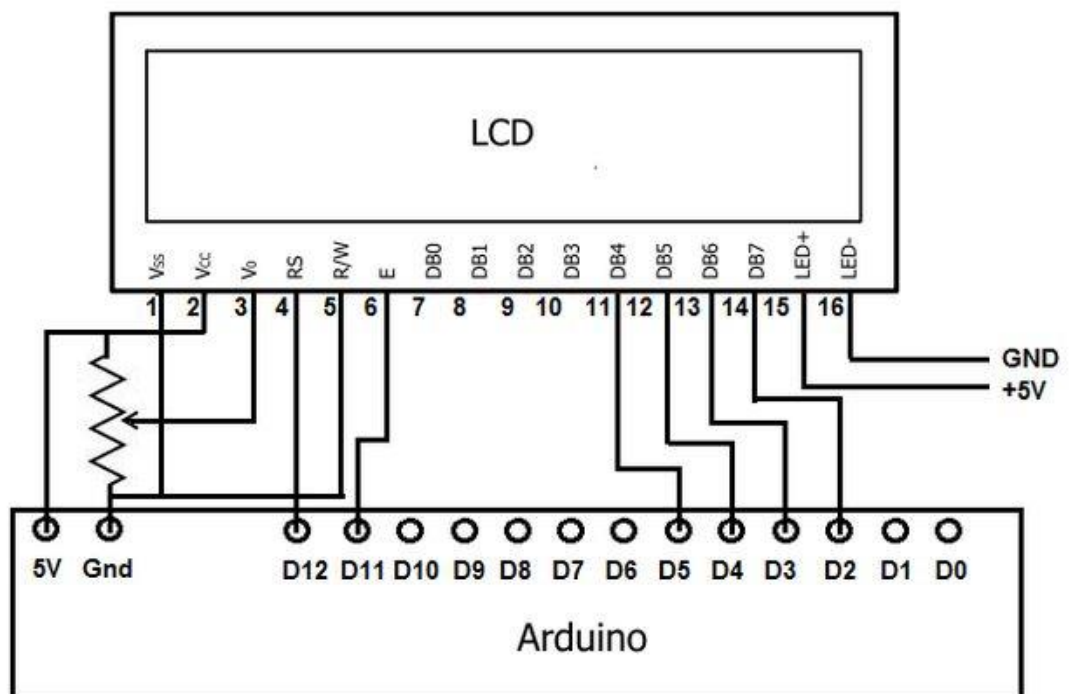
APPENDIX B

Main Circuit Schematic Diagram



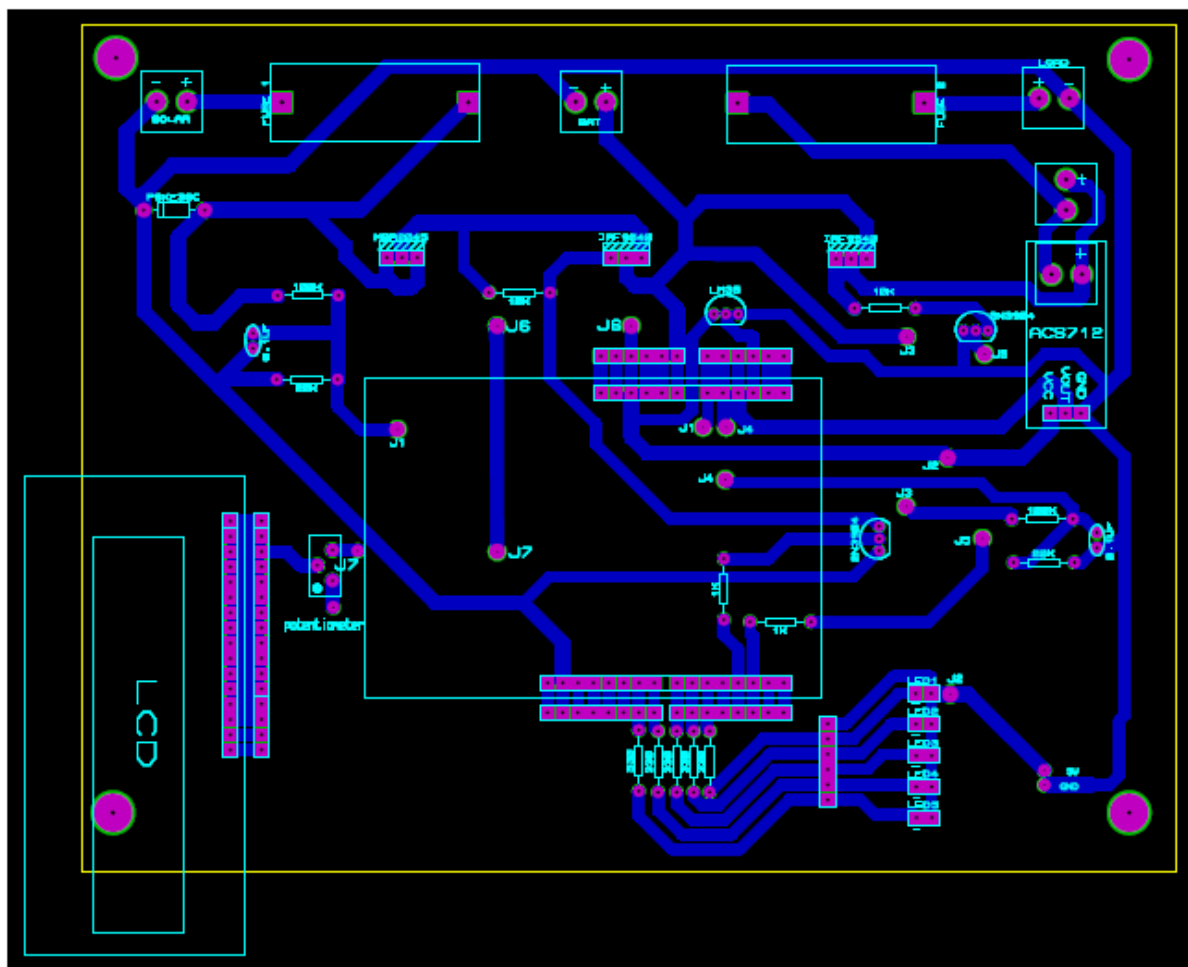
APPENDIX C

LCD Schematic Diagram



APPENDIX D

PCB Schematic Diagram



APPENDIX E

Source Code

```
#include <LiquidCrystal.h>

#define SOL_ADC A0    // Solar panel side voltage divider is connected to pin A0
#define BAT_ADC A1    // Battery side voltage divider is connected to pin A1
#define CURRENT_ADC A2 // ACS 712 current sensor is connected to pin A2
#define TEMP_ADC A3   // LM 35 Temperature is connected to pin A3
#define AVG_NUM 10    // number of iterations of the adc routine to average
#define BAT_MIN 10.5  // minimum battery voltage for 12V system
#define BAT_MAX 15.0  // maximum battery voltage for 12V system
#define BULK_CH_SP 12.5 // bulk charge set point for sealed lead acid battery
#define FLOAT_CH_SP 12 //float charge set point for lead acid battery
#define LVD 10.5      //Low voltage disconnect setting for a 12V system
#define PWM_PIN 3      // pin-3 is used to control the charging MOSFET
#define LOAD_PIN 2     // pin-2 is used to control the load
#define BAT_ORANGE_LED 7
#define BAT_GREEN_LED 9
#define BAT_YELLOW_LED 8
#define LOAD_RED_LED 6
```

////////DECLARATION OF ALL BIT MAP ARRAY FOR FONTS////////

byte solar[8] = //icon for solar panel

```
{
    0b11111, 0b10101, 0b11111, 0b10101, 0b11111, 0b10101, 0b11111, 0b00000
};
```

byte battery[8] = //icon for battery

```
{
    0b01110, 0b11011, 0b10001, 0b10001, 0b10001, 0b10001, 0b10001, 0b11111
};
```

byte energy[8] = // icon for power

```
{
    0b00010, 0b00100, 0b01000, 0b11111, 0b00010, 0b00100, 0b01000, 0b00000
};
```

byte temp[8] = //icon for termometer

```
{
    0b00100, 0b01010, 0b01010, 0b01110, 0b01110, 0b11111, 0b11111, 0b01110
};
```

byte charge[8] = // icon for battery charge

```
{
    0b01010, 0b11111, 0b10001, 0b10001, 0b10001, 0b01110, 0b00100, 0b00100,
};
```

byte not_charge[8] =

```
{
    0b00000, 0b10001, 0b01010, 0b00100, 0b01010, 0b10001, 0b00000, 0b00000,
};
```

//////////DECLARATION OF ALL GLOBAL VARIABLES//////////

```
float solar_volt = 0;
float bat_volt = 0;
float load_current = 0;
int temperature = 0;
int temp_change = 0;
float system_volt = 0;
float bulk_charge_sp = 0;
float float_charge_sp = 0;
float charge_status = 0;
float load_status = 0;
float error = 0;
float Ep = 0;
int duty = 0;
float lvd;
float msec = 0;
float last_msec = 0;
float elapsed_msec = 0;
float elapsed_time = 0;
float ampSecs = 0;
float ampHours = 0;
float watts = 0;
float wattSecs = 0;
float wattHours = 0;
```

```
int mVperAmp = 66;
int RawValue= 0;
int ACSoffset = 2500;
double Voltage = 0;
double Amps = 0;
```

```
LiquidCrystal lcd(12, 11, 5, 4, 1, 0);
```



```
//***** MAIN PROGRAM START *****
```

```
void setup()
```

```
{
```

```
    pinMode(BAT_ORANGE_LED, OUTPUT);
```

```
    pinMode(BAT_GREEN_LED, OUTPUT);
```

```
    pinMode(BAT_YELLOW_LED, OUTPUT);
```

```
    pinMode(LOAD_RED_LED, OUTPUT);
```

```
    pinMode(PWM_PIN, OUTPUT);
```

```
    pinMode(LOAD_PIN, OUTPUT);
```

```
    digitalWrite(PWM_PIN, LOW); // default value of pwm duty cycle
```

```
    digitalWrite(LOAD_PIN, LOW); // default load state is OFF
```

```
    lcd.begin(20, 4);
```

```
    //lcd.backlight();
```

```
    lcd.createChar(1, solar);
```

```
    lcd.createChar(2, battery);
```

```
    lcd.createChar(3, energy);
```

```
    lcd.createChar(5, temp);
```

```
    lcd.createChar(6, charge);
```

```
    lcd.createChar(7, not_charge);
```

```
}
```

```
void loop()
```

```
{
```

```
    read_data();
```

```
    system_voltage();
```

```
    setpoint();
```

```
    charge_cycle();
```

```
    load_control();
```

```
    led_indication();
```

```
    lcd_display();
```

```
}
```

```
    /// READS AND AVERAGES THE ANALOG INPUTS (SOLAR  
VOLTAGE,BATTERY VOLTAGE)/////
```

```
int read_adc(int adc_parameter)
```

```
{
```

```
    int sum = 0;
```

```
    int sample ;
```

```
    for (int i = 0; i < AVG_NUM; i++)
```

```
    { // loop through reading raw adc values AVG_NUM number of times
```

```
        sample = analogRead(adc_parameter); // read the input pin
```

```
        sum += sample; // store sum for averaging
```

```
        delayMicroseconds(50); // pauses for 50 microseconds
```

```
    }
```

```
    return (sum / AVG_NUM);
```

```
}
```

```
//////////////////////////////////READ THE DATA//////////////////////////////////
```

```
void read_data(void)
{
  //5V = ADC value 1024 => 1 ADC value = (5/1024)Volt= 0.0048828Volt
  // Vout=Vin*R2/(R1+R2) => Vin = Vout*(R1+R2)/R2  R1=100 and R2=20
  solar_volt = read_adc(SOL_ADC) * 0.00488 * (120 / 20);
  bat_volt  = read_adc(BAT_ADC) * 0.00488 * (120 / 20);
  temperature = read_adc(TEMP_ADC) * 0.00488 * 100;
  //load_current = (read_adc(CURRENT_ADC) * .0488 - 25);
  RawValue = analogRead(CURRENT_ADC);
  Voltage = (RawValue / 1024.0) * 5000; // Gets you mV
  load_current = (0.12*Voltage/2.42);//((Voltage - ACSoffset) / mVperAmp);
}
```

```
//////////////////////////////////PRINT DATA IN SERIAL MONITOR//////////////////////////////////
```

```
void print_data(void)
{
  delay(100);
  Serial.print("Solar Panel Voltage: ");
  Serial.print(solar_volt);
  Serial.println("V");
  Serial.print("Battery Voltage: ");
  Serial.print(bat_volt);
  Serial.println("V");
  Serial.print("System Voltage: ");
  Serial.print(system_volt);
  Serial.println("V");
  Serial.print("Charge Set Point:");
  Serial.println(bulk_charge_sp);
}
```

```

Serial.print("Temperature:");
Serial.print(temperature);
Serial.println("C");
Serial.print("Load Current: ");
Serial.print(load_current);
Serial.println("A");
Serial.print("Power: ");
Serial.print(watts);
Serial.println("W");
Serial.print("Energy: ");
Serial.print(wattHours);
Serial.println("WH");
Serial.print("Duty Cycle :");
if (charge_status == 1)
{
    Serial.println("99%");
    Serial.println("BULK CHARGING");
}
else if (charge_status == 2)
{
    Serial.print(Ep);
    Serial.println("%");
    Serial.println("FLOAT CHARGING");
}
else
{
    Serial.println("0%");
    Serial.println("NOT CHARGING");
}
if (load_status == 1)
{
    Serial.println("LOAD IS CONNECTED");
}
else

```

```

{
    Serial.println("LOAD IS DISCONNECTED");
}

Serial.println("*****");
}

////////////////////////////////SYSTEM VOLTAGE AUTO DETECT //////////////////////////////////

void system_voltage(void)
{
    if ((bat_volt > BAT_MIN) && (bat_volt < BAT_MAX))
    {
        system_volt = 12;
    }

    else if ((bat_volt > BAT_MIN / 2 ) && (bat_volt < BAT_MAX / 2))
    {
        system_volt = 6;
    }

}

////////////////////////////////CHARGE SET POINT //////////////////////////////////

void setpoint(void)
{
    temp_change = temperature - 25.0; // 25deg cel is taken as standard room
    temperature
    // temperature compensation = -5mv/degC/Cell
    // If temperature is above the room temp ;Charge set point should reduced
    // If temperature is bellow the room temp ;Charge set point should increased

```

```

if (system_volt == 12)
{
    bulk_charge_sp = BULK_CH_SP - (0.030 * temp_change) ;
    float_charge_sp = FLOAT_CH_SP - (0.030 * temp_change) ;
    lvd = LVD;
}

else if (system_volt == 6)
{
    bulk_charge_sp = (BULK_CH_SP / 2) - (0.015 * temp_change) ;
    float_charge_sp = (FLOAT_CH_SP / 2) - (0.015 * temp_change) ;
    lvd = LVD / 2;
}

}

//////////////////////////////////PWM CHARGE CYCLE @500 HZ ////////////////////////////////////

void charge_cycle(void)
{
    if (solar_volt > bat_volt && bat_volt <= bulk_charge_sp)
    {

        if (bat_volt <= float_charge_sp) // charging start
        {
            charge_status = 1; // indicate the charger is in BULK mode
            duty = 252.45;
            analogWrite(PWM_PIN, duty); // 99 % duty cycle // rapid charging

        }
        else if (bat_volt > float_charge_sp && bat_volt <= bulk_charge_sp)
        {

```

```

charge_status = 2; // indicate the charger is in FLOAT mode
error = (bulk_charge_sp - bat_volt);    // duty cycle reduced when the battery
voltage approaches the charge set point
Ep = error * 100 ; //Ep= error* Kp // Assume Kp=100

if (Ep < 0)      //overcharge (voltage battery higher than Bulk setpoint
{
    Ep = 0;
}
else if (Ep > 100)      //error>1V. battery voltage lower than 12V. So max
charging voltage
{
    Ep = 100;

}

else if (Ep > 0 && Ep <= 100) // regulating
{
    duty = (Ep * 255) / 100;
}
analogWrite(PWM_PIN, duty);
}
}
else
{
    charge_status = 0; // indicate the charger is OFF
    duty = 0;
    analogWrite(PWM_PIN, duty);
}
}

```

////////////////////////////////LOAD CONTROL////////////////////////////////

```
void load_control()
```

```

{
  if (solar_volt < 5 )
  {
    if (bat_volt > lvd) // check if battery is healthy
    {
      load_status = 1;
      digitalWrite(LOAD_PIN, HIGH); // load is ON
    }
    else if (bat_volt < lvd)
    {
      load_status = 0;
      digitalWrite(LOAD_PIN, LOW); //load is OFF
    }
  }
  else
  {
    load_status = 0;
    digitalWrite(LOAD_PIN, LOW);
  }
}

```

//////////////////////////////////LED INDICATION//////////////////////////////////

```

void led_indication(void)
{
  battery_led();      //Battery status led indication
  load_led();         //Load led indication
}

```

//////////////////////////////////BATTERY LED INDICATION//////////////////////////////////

```

void battery_led(void)

```



```

{

if ( (bat_volt >= system_volt) && ( bat_volt < bulk_charge_sp))
{
    leds_off_all();
    digitalWrite(BAT_GREEN_LED,HIGH); // battery voltage is healthy
}
else if (bat_volt >= bulk_charge_sp)
{
    leds_off_all();
    digitalWrite(BAT_YELLOW_LED, HIGH); //battery is fully charged
}
else if (bat_volt < system_volt)
{
    leds_off_all();
    digitalWrite(BAT_ORANGE_LED, HIGH); // battery voltage low
}
}

```

//////////////////////////////////LOAD LED INDICATION//////////////////////////////////

```

void load_led()
{
    if (load_status == 1)
    {
        digitalWrite(LOAD_RED_LED,LOW);
    }
    else if (load_status == 0)
    {
        digitalWrite(LOAD_RED_LED,HIGH);
    }
}

```

```
////////////////////// TURN OFF ALL THE LED//////////////////////
```

```
void leds_off_all(void)
{

    digitalWrite(BAT_ORANGE_LED, LOW);
    digitalWrite(BAT_GREEN_LED, LOW);
    digitalWrite(BAT_YELLOW_LED, LOW);
    digitalWrite(Load_RED_LED, LOW);

}
```

```
////////////////////// LCD DISPLAY//////////////////////
```

```
void lcd_display()
{

    lcd.setCursor(0, 1);
    lcd.write(1);
    lcd.setCursor(2, 1);
    lcd.print(solar_volt);
    lcd.print("V");
    lcd.setCursor(14, 1);
    lcd.write(5);
    lcd.setCursor(16, 1);
    lcd.print(temperature);
    lcd.write(0b11011111);
    lcd.print("C");
    lcd.setCursor(0, 2);
    lcd.write(2);
    lcd.setCursor(2, 2);
```

```
lcd.print(bat_volt);
lcd.print("V");
lcd.setCursor(14, 2);
lcd.write(2);
if((charge_status==1) | (charge_status== 2))
{
lcd.write(6);
}
else
{
lcd.write(7);
}
lcd.setCursor(0,3);
if (charge_status==1)
{
Serial.println("99%");
lcd.print("BULK CHARGING");
}
else if (charge_status==2)
{
lcd.print(Ep);
lcd.println("%");
lcd.println("FLOAT CHARGING");
}
else
{
lcd.println("0%");
lcd.println("NOT CHARGING");
}
}
```