

**FABRICATION OF MULTI-CHANNEL I-V  
CURVE TRACER FOR SOLAR PV PANEL  
PERFORMANCE MEASUREMENT**

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**FABRICATION OF MULTI-CHANNEL I-V CURVE TRACER FOR SOLAR  
PV PANEL PERFORMANCE MEASUREMENT**

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**A project report submitted in partial fulfilment of the  
requirements for the award of Bachelor of Engineering  
Honours Electrical and Electronic Engineering**

**Lee Kong Chian Faculty of Engineering and Science  
Universiti Tunku Abdul Rahman**

**January 2019**

## DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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**APPROVAL FOR SUBMISSION**

I certify that this project report entitled “**FABRICATION OF MULTI-CHANNEL I-V CURVE TRACER FOR SOLAR PV PANEL PERFORMANCE MEASUREMENT**” was prepared by **ANG HAN CIN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering Honours Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : \_\_\_\_\_

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Date : \_\_\_\_\_

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## ABSTRACT

The weather condition in a tropical country has been changing frequently, therefore the performance of the solar PV panel will be strongly affected because of the solar irradiance that transmits directly to the solar PV panel. In a research and development phase for a product, that is a need to perform solar PV panels comparison test. However, the commercial I-V curve tracer is just able to measure the panels one by one, which imply that the comparison of performance between the panels will not be precise as the measurements of both panels are not taken simultaneously, during frequent changing environment. In order to measure the performance between the different solar PV panels simultaneously, a low complexity and low-cost multi-channel I-V curve tracer prototype was designed, fabricated and tested. In this project, the capacitor load is utilizing for charged by the solar PV panel. The tracer successfully traces the current and voltage for two PV panel in real-time operation. The data is logged via the Arduino board. Other than that, the schematic design and board design of the multi-channel I-V curve tracer was designed by EAGLE software and the fabrication process of the PCB board was shown in the results. An outdoor test was conducted with two different types of the PV panel with 20W and 5W for approving the performance of the proposed system. Furthermore, the tracer was calibrated with a commercial I-V curve tracer and the error is less than 1%. Last but not least, the recommendations were made so as to make an enhancement for the present prototype.

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**LIST OF SYMBOLS / ABBREVIATIONS**

PV	Photovoltaic
I	Ampere, A
V	Voltage, V
P	Power, W
PCB	Printed Circuit Board
EAGLE	Easily Applicable Graphical Layout Editor
$I_{sc}$	Short Circuit Current
$V_{oc}$	Open Circuit Voltage
CCM	Continuous Conduction Mode
DCM	Discontinuous Conduction Mode
LCD	Liquid-crystal Display
USB	Universal Serial Bus
I/O pin	Input Pin and Output Pin
UARTs	Universal Asynchronous Receiver-transmitter
ICSP	In-circuit Serial Programming
SD card	Secure Digital Card
FAT16/32	File Allocation Table 16 or 32 Bits
SPS	Samples Per Seconds
SDA	Data Line
SCL	Clock Line
$V_{GS}$	Gate to Source Voltage

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## CHAPTER 1

### INTRODUCTION

#### 1.1 General Introduction

There are numerous sorts of sustainable energy sources in the World, for example, solar energy, wind energy, water energy and so on. Among the sustainable energy sources, solar energy is generated by the light of the sun. The function of the Photovoltaic (PV) generation is used to trap solar energy with the goal that it considers as an active solar technology. PV generation has become more famous because it will only produce a little measure of greenhouse gases and also the clean energy source.

The PV panel is equipment that absorbs the daylight from the sun and using the PV cells converts the light into electricity making a major contribution to power the load. Each panel has its own current-voltage (I-V) and the power-voltage (P-V) characteristics, the curves would give helpful data with the goal that the expert can identify variation of the panel. Moreover, each panel has a distinct efficiency, this is because of the PV panel influenced by sunlight irradiance blocking obstacles, dirt or soil amassing, and climate change, for instance, rainy and cloudy day. Influence the effectiveness of the PV panel will likewise influence the characteristics of the curves.

There are different types of load are used to trace the I-V characteristic of the solar panel, for instance, resistive load, electronic load, and capacitor load. Capacitor load is the most accurate outcome for tracing the curves hence the capacitor load is used in this project (Brito et al., 2014). There is a measuring technique which measures the current and voltage from a short circuit to open circuit when the capacitor is fully charged condition. By using this measuring technique, the results will obtain in a short time and the outcome will be more precise.

In a tropical country like Malaysia, there are consists a lot of clouds that block the sunlight and avoid the sunlight link with frequent intermittency of solar irradiance and that is why performance comparison is very hard if the measurement is not done simultaneously. The aim of the project is to design and fabrication of multi-channel I-V curve tracers so that the users can analyze the condition of various PV panel at the same time by using multiple input tracer.

## **1.2 Importance of the Study**

Nowadays, the prototype for I-V curve tracer only able to measure a single panel and subsequently the cost is costly in the market. The function of the multi-channel I-V curve tracer is used to measure multi-channels of panel simultaneously. The purpose to fabricate the multi-channel I-V curve tracer is because of easy to compare between the conditions of the panels and save a lot of times by measuring one by one.

Next, the prototype of the multi-channel I-V curve tracer circuit has been constructed in the breadboard previously. In this project, the circuit was updated from breadboard to a printed circuit board (PCB). After updated become PCB board, the circuit was more safe and reliable to utilize.

## **1.3 Problem Statement**

The prototype of the multi-channel I-V curve tracer was constructed at the breadboard previously. However, it faced a lot of problems when doing an outdoor test. In order to solve this problem, the best ways are fabricate the circuit at the PCB board and solder the components at the board. Besides that, the overall process is spent too much time which is more than 15 minutes.

## **1.4 Aims and Objectives**

The aim of the project is to design and fabrication of multi-channel I-V curve tracers by using the software. This project is the second phase of the measurement device. A prototype of the multi-channel I-V curve tracer has been developed and tested. This project involving some hand on activities such as etching, soldering and testing the board.

Objectives of this project are:

1. To draw and design a multi-channel I-V curve tracer circuit by utilizing computer software.
2. To fabricate the PCB board of the multi-channel I-V curve tracer circuit.
3. To conduct an outdoor test of the fabricated circuit to get the performance measurement of the solar panel.

### 1.5 Scope and Limitation of the Study

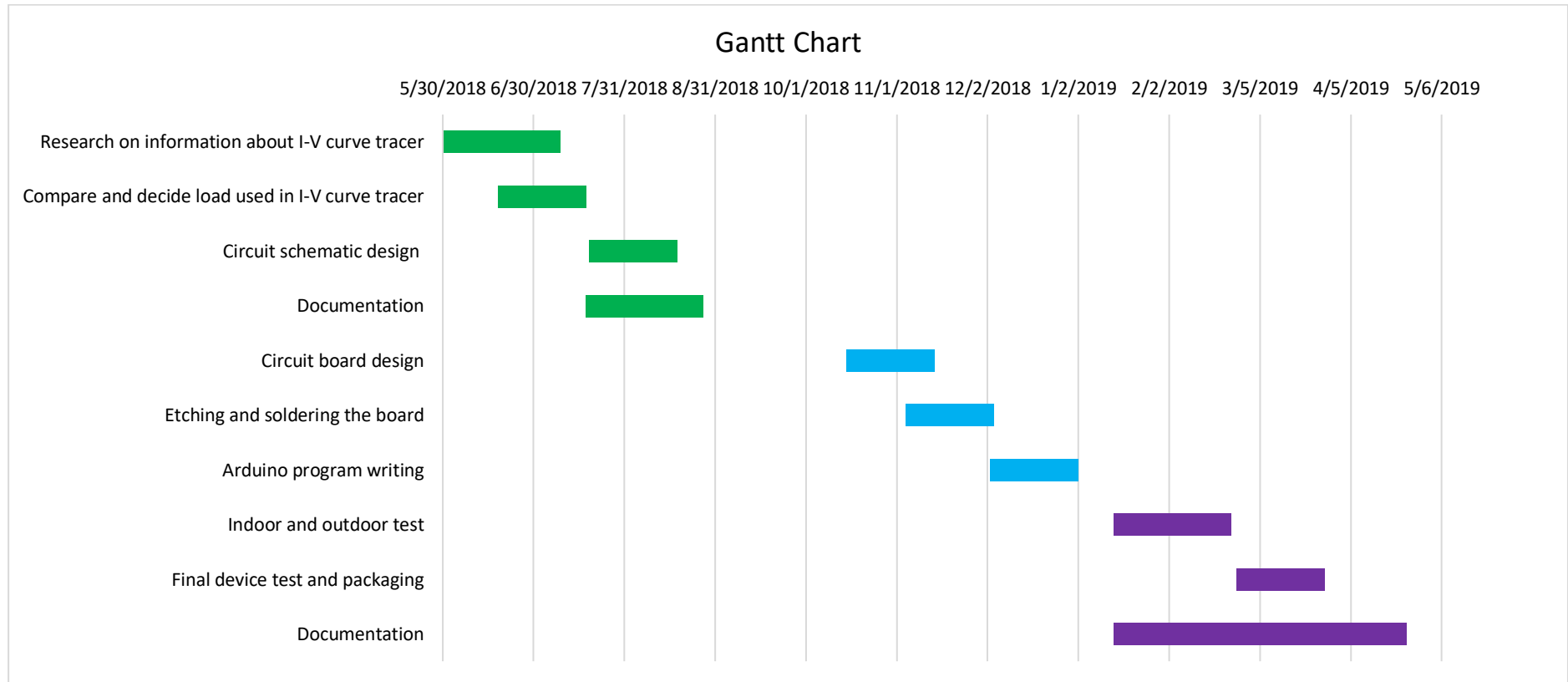
There are many different types of the PV panel that utilizes by the users and hence this project just only focuses on the PV panel with short-circuit current of 2A, the open-circuit voltage of 25V and maximum power up to 20W. Other than that, there are also many different types of computer software used for PCB design. EAGLE is one of the helpful programs used in this project for designing the PCB layout. Besides, this project will use an Arduino as a microcontroller connects to the circuit to collect data.

### 1.6 Project Schedule

Project schedule must be created before starting the project. Project schedule consists of the overall tasks timeliness and also the duration to complete the particular task. Table 1.1 shows the schedule of the project and the Gantt chart shown in Figure 1.1.

**Table 1.1: Project Schedule**

Task	Start Date	Duration (Days)
Research on information about I-V curve tracer	30-05-18	40
Compare and decide load used in I-V curve tracer	18-06-18	30
Circuit schematic design	19-07-18	30
Documentation	18-07-18	40
Circuit board design	15-10-18	30
Etching and soldering the board	04-11-18	30
Arduino program writing	03-12-18	30
Outdoor test	14-01-19	40
Final device test and packaging	25-02-19	30
Documentation	14-01-19	100



**Figure 1.1: Gantt Chart**

## **1.7 Contribution of the Study**

A multi-channel I-V curve tracer is not yet consisting in the market, so it considers as a new product. A multi-channel I-V curve tracer will able to assist the industry to obtain the measurements of the solar PV panel concurrently at the same weather condition and easy to do a PV panel performance comparison.

## **1.8 Outline of the Report**

There are a few chapters in this report, each chapter discusses or explains the respective topic and contents whereby to let the reader comprehend the structure or flow of the report. The short summaries for each chapter are written below.

### Chapter 1 Introduction

An introduction is briefly discussed about the purpose, background, aims, objective and scope of the overall project. Besides, the project schedule including activities and Gantt chart also discuss in this chapter.

### Chapter 2 Literature Review

A literature review will be focus on the related project's background and researches that have been done by other researchers before.

### Chapter 3 Methodology and Work Plan

A methodology will be discussed the concept and the method used in this project. The process flow of the project is presented in the block diagram and flowchart. Other than that, electronic components and computer software that used to implement in this project are also discussed in this chapter. Last, circuit design and explanations are discussed as well.

### Chapter 4 Results and Discussions

A result has briefly discussed the outcome or findings of the research while the discussion is interpreted the results in this project. The circuit schematic design, board design and the process of the fabrication of the PCB board are discussed in this chapter. Moreover, the numerical data that obtained are presented in table form and the graphs are plotted in the experimental results. Last, results compared with the theoretical results are also discussed in this chapter.

## Chapter 5 Conclusion and Recommendations for Future Work

A conclusion is to conclude the overall project and some recommendations will be suggested in this chapter as well as to enhance the present project.

## CHAPTER 2

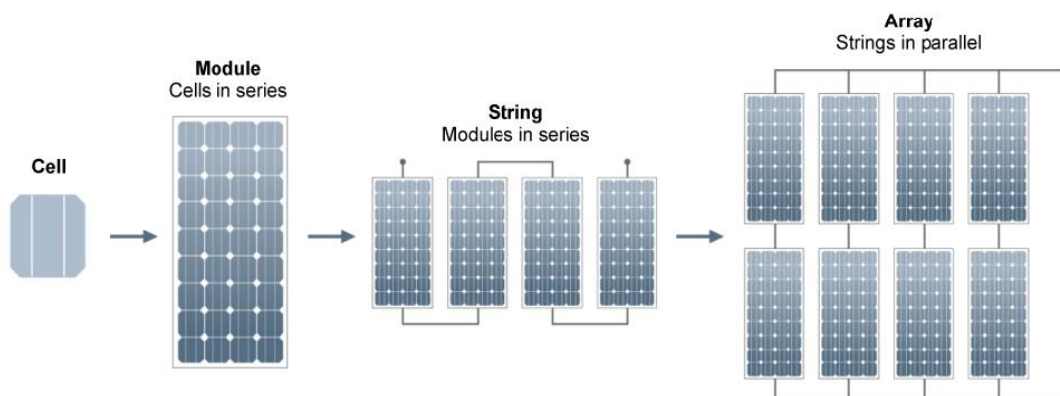
### LITERATURE REVIEW

#### 2.1 Introduction

In this chapter, the characteristic of the PV cell and the characteristic of the I-V curve will be discussed. Additionally, this chapter will also thoroughly analyzed the types of design an I-V curve tracer that had done by different researchers. Besides, the comparison between different loads for tracing the I-V curve will be discussed in this section too.

#### 2.2 Photovoltaic cell

Each solar panel consists of several photovoltaic cells that connected in series and also enable to connect together to form the string or array. A photovoltaic cell is a part of the semiconductor material and converts the light into electricity to power up the load. The semiconductor part of the photovoltaic cell is called a P-N junction and having three layers region, the thin top layer (n-type), the thick middle layer (depletion zone) and the thicker bottom layer (p-type). When there is a photon come from sunlight is absorbed by the PV cell, a hole and electron will be created in P-N junction. Inside the P-N junction, there is a current and voltage that form by electron will flow through the photovoltaic cell when the solar panel is connected to the load. The solar PV products from the solar cell to the solar array and the structure of the PV cell is illustrated in Figure 2.1 and 2.2.



**Figure 2.1: Solar PV Products - Solar Cell to Solar Array (admin\_yourhome, 2013)**

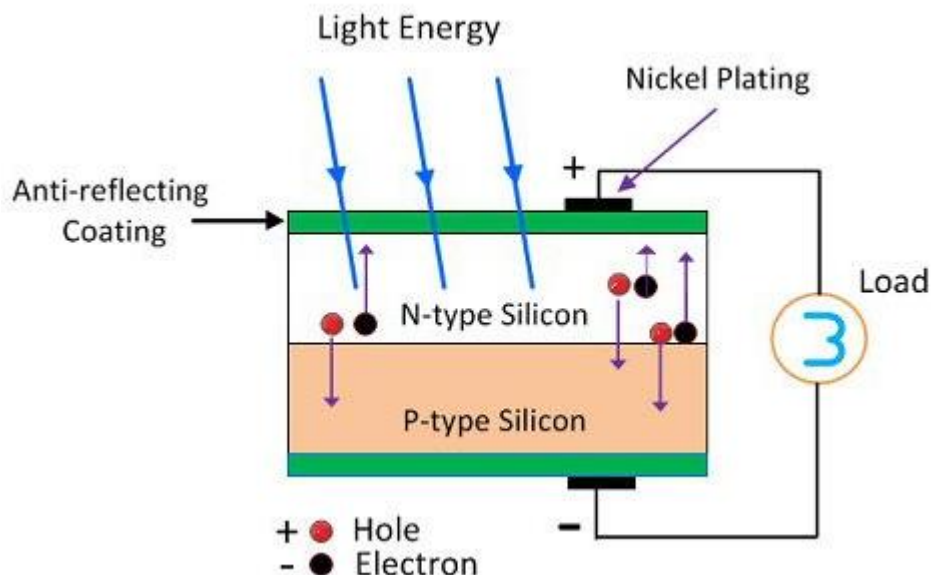


Figure 2.2: Basic Structure of Photovoltaic Cell (Anon, n.d.)

### 2.2.1 Photovoltaic Cell Characteristic

There is a common current-voltage characteristic that existing in each photovoltaic cell and the I-V curve will be plotted by these characteristics. By plotting the I-V curve, according to all the possible operating points of the solar panel under the condition of solar irradiance and temperature. Besides, the photovoltaic cell simply operates as a diode with a P-N junction when there is no sunlight transmit to the photovoltaic cell. A diode consists of 3 type various operation regions which are forward bias, reverse bias, and breakdown. The regions of the diode are shown in Figure 2.3.

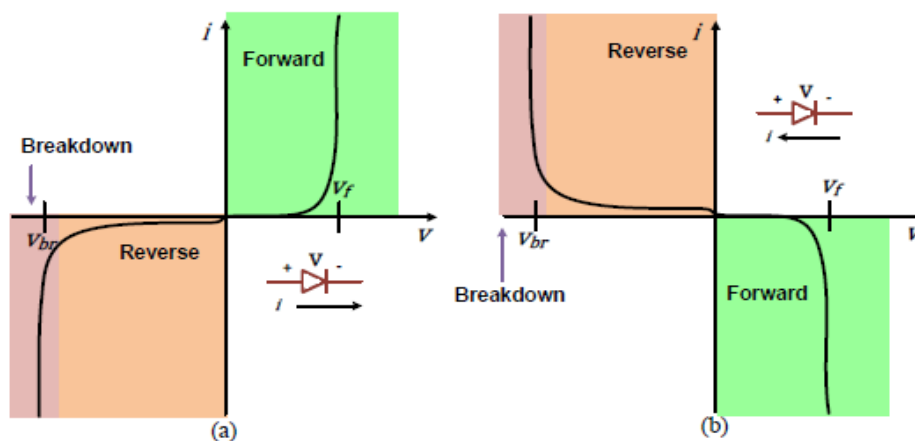
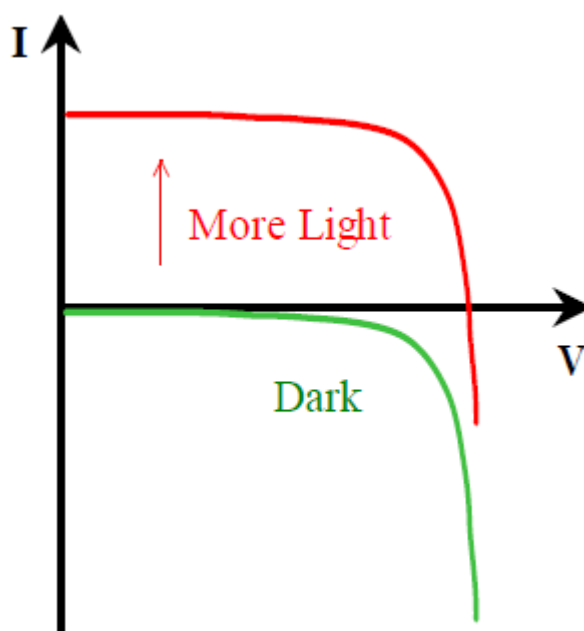


Figure 2.3: (a) Diode I-V curve (b) Diode I-V curve with Reverse Current Notation (Riley and Tolbert, 2015)

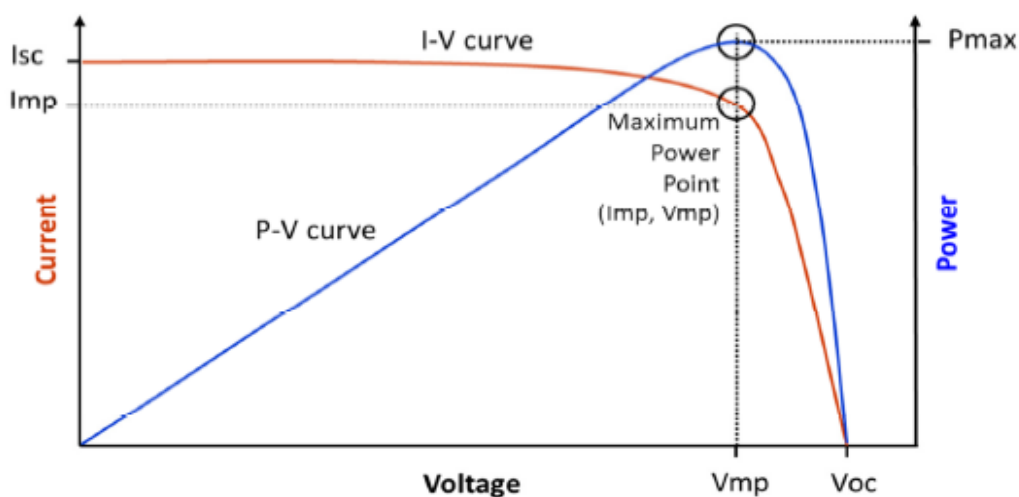


From Figure 2.3, it can be observed that in the photovoltaic cell the current flow through the diode is in opposite directions. When there is no solar irradiance to PV cell, the diode won't encounter the current flow through except if there is an external voltage applies to it. When there is direct sunlight to the photovoltaic cell, the I-V curve is moving up and hence the  $I_{sc}$  from photovoltaic cell is flowing to the load. PV cell's I-V curve from a dark condition to the bright condition is shown in Figure 2.4.



**Figure 2.4: I-V Curve of the PV Cell by Increasing the Incident Light (Voltage and Characterization, 1976)**

Normally the I-V curve will begin plotted from  $I_{sc}$  to  $V_{oc}$ . The  $I_{sc}$  will occur in the PV cell when the maximum current which is flow in the external resistance of zero value with the output voltage equal to zero. The  $V_{oc}$  will occur in the photovoltaic cell when the maximum voltage flow across the terminals of a photovoltaic cell with infinity load resistance and hence the output current become zero. Besides that, there is no power supply to the load when at the point of  $I_{sc}$  and  $V_{oc}$ . Along these two points, the maximum power point at a load with finite resistance will be obtained and correspondingly capable to plot the P-V curve. Figure 2.5 illustrates the I-V and P-V curve of the solar module.



**Figure 2.5: I-V and P-V curve of the Solar Module (Hernday, 2011)**

### 2.3 I-V Curve Tracer

I-V curve tracer is very useful equipment that utilizes to trace the current and voltage from the point of  $I_{sc}$  till  $V_{oc}$ . The I-V curve can be formed by plotting every single point in the curve due to every voltage point consists of its particular current value. Besides, it also can utilize to checking the undergoing solar PV's health and degradation effects. To form the I-V curve characteristics, the suitable device which is I-V curve tracer is chosen to obtain current and voltage information at the same time during the voltage variation.

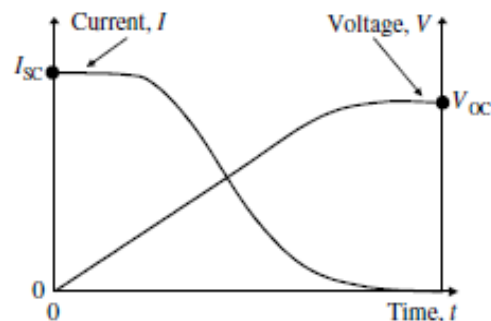
#### 2.3.1 Capacitor Load

Capacitor load is one of the types of method that used to construct the I-V curve tracer to trace the I-V curve of the solar panel. The measurement is performed within the period of capacitor charging from zero voltage to open circuit voltage,  $V_{oc}$ . The operating principle of the ideal capacitive load is explained as follow. First of all, the capacitor will initially discharge until the voltage inside the capacitor become zero voltage. During the charging process, the variation of the voltage will vary the current that flows through the capacitor so that the I-V curve can be traced (Brito et al., 2014).

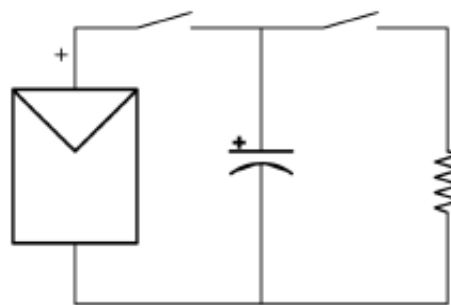
Next, the capacitor is in short circuit condition and the current value is the same as the PV panel short-circuit current. When a capacitor is connected to the panel, the current will flow through the capacitor and start to charge up the capacitor. Due to the characteristics of the capacitor, when the voltage of the capacitor is increased, the current flow through the capacitor will decrease until it fully charged (Muñoz and

Lorenzo, 2006). When the capacitor is fully charged, the current flow through the capacitor is 0A while at the same time the voltage across the capacitor reaches the open circuit voltage. The varying of the current and voltage values are used to construct the I-V curve (Erkaya et al., 2014). Evolution of the current and voltage waveform versus the time during the capacitor in the charging process is shown in Figure 2.6

Figure 2.7 illustrates the simple circuit of the capacitor load. The basic schematic diagram consists of a PV array, switches, capacitor, and power resistor. The function of the switch is used to connect the PV array to the load capacitor for charging process, while the other switch is used to connect the load capacitor to the power resistor for discharging process (Muñoz and Lorenzo, 2006). Both of the switches will open and closed simultaneously. When the first switch is closed then automatically the second switch will be opened and vice-versa. The switching process will control by the microcontroller (Brito et al., 2014).



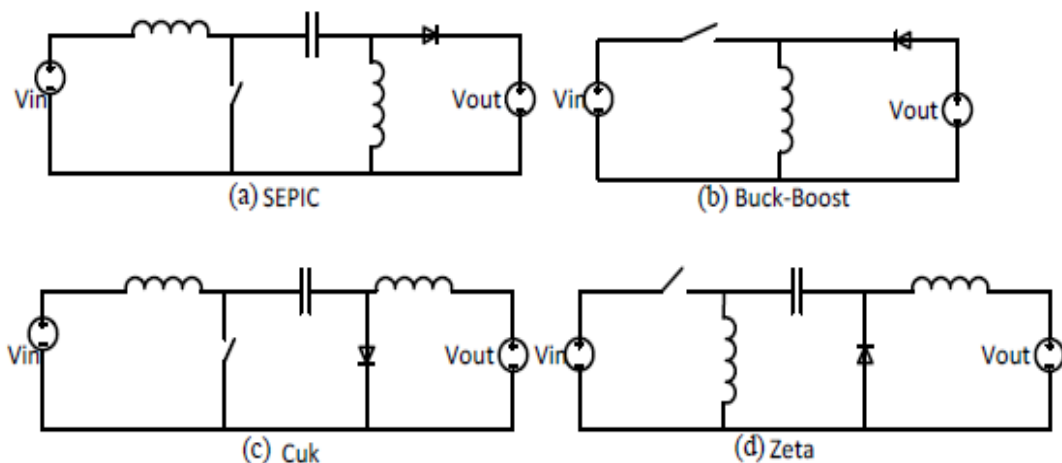
**Figure 2.6: Evolution of Current and Voltage Waveforms During the Charging Process (Muñoz and Lorenzo, 2006)**



**Figure 2.7: Basic Schematic Diagram of Capacitor Load (Erkaya et al., 2016)**

### 2.3.2 Electronic Load

Another type of load which is the electronic load, it also used for tracing the I-V curve characteristic. There are many researchers uses an electronic load such as DC-DC converters construct the I-V curve tracer. The ability that using the DC-DC converter is because it can trace the maximum power point of each PV module where there is an environment change (Riley and Tolbert, 2015). By changing the output voltage from the PV panel to the input of the DC-DC converter, it is able to retain the DC voltage output to the inverter side concurrently. The ability of the buck and boost the voltage is required so as to capture the complete I-V curve. The researchers also mentioned that the best application for capturing the I-V curve which is a switching converter (Duran, E., Galan, J., Sidrach-de-Cardona, M. & Andujar, 2007). There are many types of electronic load that had found by the researcher which are a buck-boost converter, Zeta, Cuk, and single-ended primary-inductor converter (SEPIC). The different types of converters are shown in Figure 2.8.



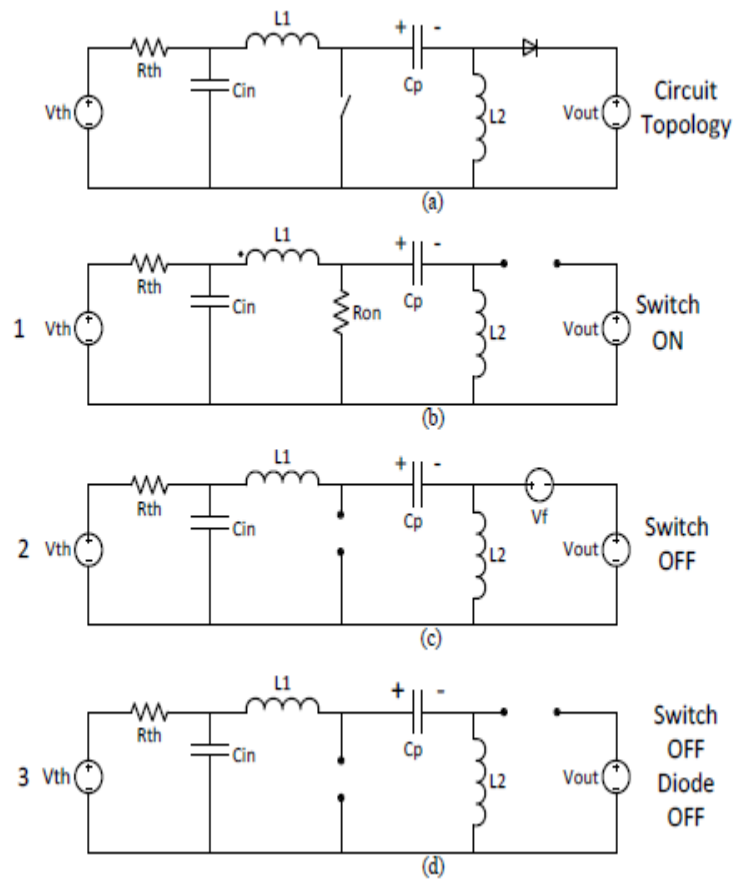
**Figure 2.8: Common Switching Converter to Perform an Ability of Buck and Boost (a) SEPIC (b) Buck-Boost (c) Cuk (d) Zeta (Riley and Tolbert, 2015)**

Zeta converter and buck-boost converter will cause the high noise issue during the tracing I-V curve because the switch is connected series to the input and it will produce the discontinuous current. Among these four converter, SEPIC converter gives the best impact for tracing the I-V curve, this is verified by (Duran, E., Galan, J., Sidrach-de-Cardona, M. & Andujar, 2007).

### 2.3.3 SEPIC Converter

The SEPIC converter is known as a non-inverting converter. Due to the ability of the buck and boost converter, the SEPIC converter will be capable to produce an increase, decrease or maintain the output voltage. According to the researcher (Sharp, 2014), mentioned that the SEPIC converter is able to deal with some issues. The operation of the Buck-Boost converter is inverting the voltage, while the Cuk converter is able to solve this issue by adding inductor and capacitor. Besides, other issues state that the Buck-Boost converter and Cuk converter's components will withstand a lot of electrical stress during the operation and hence it will be overheating the device. To prevent this issue from happening, the SEPIC converter is the only converter able to solve these issues.

According to the (Duran, E., Galan, J., Sidrach-de-Cardona, M. & Andujar, 2007), the researcher proves that by selecting a suitable value of load resistor able to let the SEPIC converter stay in continuous conduction mode (CCM) during tracing process. The reason to retain the converter in CCM is that it can be used for investigation and control purposes during operation. There are two states which are ON and OFF states when the converter is in CCM operation. Moreover, there are three different types of operation mode for DCM operation. In this topology, this is hard to display with conventional circuit analysis strategies, yet it ends up less difficult using the state averaging strategies. The different types of DCM operation mode are shown in Figure 2.9.



**Figure 2.9: SEPIC Topology and All Three Operation States (a) SEPIC Topology (b) Mode 1 Operation (c) Mode 2 Operation (d) Mode 3 Operation (Riley and Tolbert, 2015)**

### 2.3.4 Boost Converter

The boost converter is known as an electronic load that uses to boost up the low input voltage to high output voltage. The boost converter able to boost up the voltage is because it will vary the duty cycle so that the voltage flow can be controlled. MOSFET switch that use to vary the Pulse Width Modulation signal able to operate the converter as well and the operation of the converter also functioned in CCM (Lima et al., 2013). The relationship between the input voltage and the output voltage can be defined in the equation below:

$$V_{out} = \frac{1}{1-d} \times V_{in} \quad (1.1)$$

$$I_{out} = (1-d) \times I_{in} \quad (1.2)$$

where  $d$ , is the duty-cycle of the boost converter. The value of  $d$  can be determined by the ON state of the MOSFET and the switching period of the control signal. Recorded down the data for every single point of the duty cycle that control by the microcontroller which will increase from zero to a finite value. The recorded data will be used to plotted and construct the I-V curve. According to the (Lima et al., 2013), the researcher mentioned that an electronic load able to act as a variable resistive load. The equation below show that  $R_{in}$  able to be calculated by obtaining duty-cycle,  $d$  and also resistance at the output of the converter side,  $R_{out}$ .

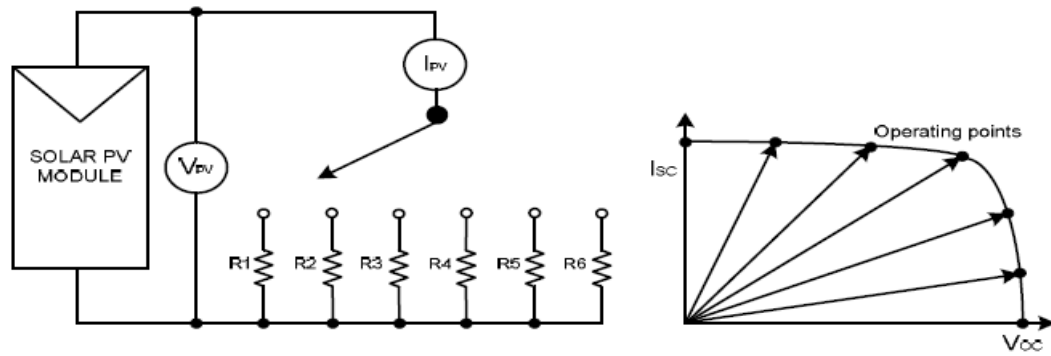
$$R_{in} = (1 - d)^2 \times R_{out} \quad (1.3)$$

### 2.3.5 Resistive Load

The resistive load also one of the types of method used to construct the I-V curve tracer. In a paper (Willoughby et al., 2014), the researcher had presented a straightforward reasonable and simple to create an instrument resistive load for tracing the I-V curve. 4017 microcontrollers will receive a clock pulse that sends by 555 astable oscillators and hence it will turn on the relay that connected to the different value of the resistors. By changing the value of the resistor from a minimum value to infinity, the output voltage from the PV panel can be traced from zero up to open circuit voltage,  $V_{oc}$ .

The researcher used the software, Labview to activate the MOSFETs that connected with a load resistor to capture the curves. For tracking the I-V and P-V characteristics, power MOSFETs act as a switch that used to vary the DC load. The MOSFETs that applied by (Willoughby, et al., 2014) was used to operate as a load that controlled by electronic and it moves along each point within the range of the I-V curve. After the process is done, the value of the  $I_{sc}$ ,  $V_{oc}$ , and the maximum power point will be obtained. Researcher claimed that resistive load cost the least expensive and easy to operate (Willoughby et al., 2014).

In this paper, the researcher used the resistor value from  $0.1\Omega$  to  $100\Omega$  to construct a resistive load tracer. The function of the MOSFETs is used to activate the relays that connected to the resistors and each different values of the resistor represented the operating points of the curve. From (Willoughby et al., 2014), the I-V curve was plotted by switching the different values of 6 resistors. Figure 2.10 illustrates the basic schematic diagram of the resistive load and the I-V curve measurement.



**Figure 2.10: Basic Schematic Diagram of Resistive Load and I-V curve measurement (Willoughby et al., 2014)**

#### 2.4 Comparison of Different Loads

The ability of the tracer is used to evaluate and also permits to foresee the conduct of the PV panel at various outside working conditions. If using a manually operating I-V curve tracer to obtain the information from the panel it will highly reduce the rate of I-V curve operating. The idea for capturing the I-V curve periodically can promote the ability to monitor the condition of the PV panel. Hence, an automatic data acquisition I-V tracer is required.

In order to achieve an automatic data acquisition, the resistive load cannot be chosen as a load is because to operate the resistive load need to adjust the value of a resistor from infinity to minimum value are discussed in the previous section. Besides, different types of electronic load also had discussed clearly in the previous section. From the paper (Erkaya et al., 2014), the researcher claimed that the electronic load is not really perfect and very unacceptable to use as an I-V curve tracer, this is because it will take a long time for tracing the I-V curve. There will be causing a large power sinking problem when used much time to capture the curve. Hence, an electronic load and resistive load are eliminated, instead of capacitive load is chosen in this project. Comparison between three different loads is shown in Table 2.1.



**Table 2.1: Comparison of Three Different Loads (Erkaya et al., 2014)**

<b>Resistive Load</b>	<b>Electronic Load</b>	<b>Capacitive Load</b>
Slowest	Faster	Fastest
Expensive	Less Expensive	Least Expensive
Heavy	Light (heavy resistor)	Lightest
Not scalable	Semi-scalable (resistor limitation)	Scalable (capacitor limitation)
Low Noise	High Noise	Low Noise

## 2.5 Summary

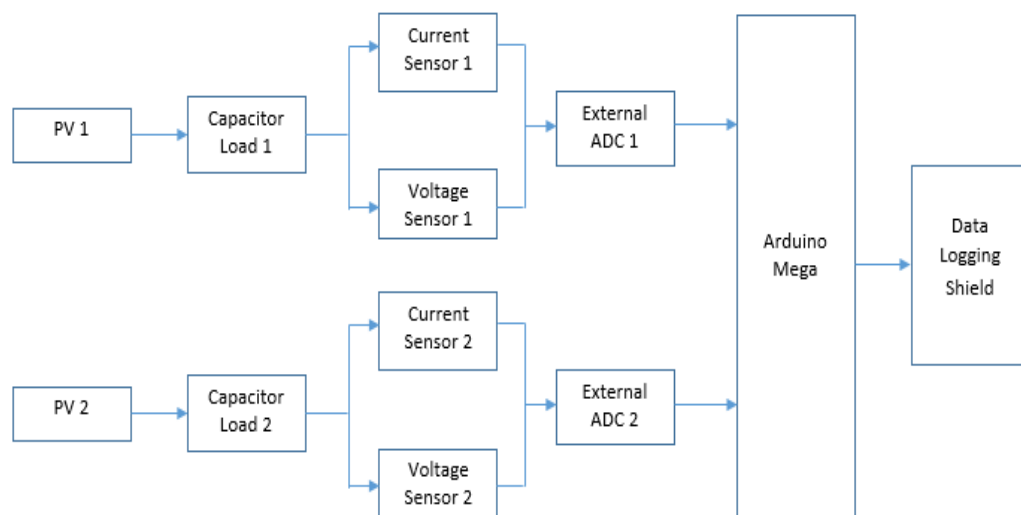
The photovoltaic cell in the PV panel and its characteristics are discussed in this chapter. Besides, there are various types of load to construct the I-V curve tracer has also been explained in this chapter. Types of load included the capacitor load, electronic load (SEPIC and boost converter) and a resistive load. Last, this chapter also discussed the comparison between three different loads.

## CHAPTER 3

### METHODOLOGY AND WORK PLAN

#### 3.1 Introduction

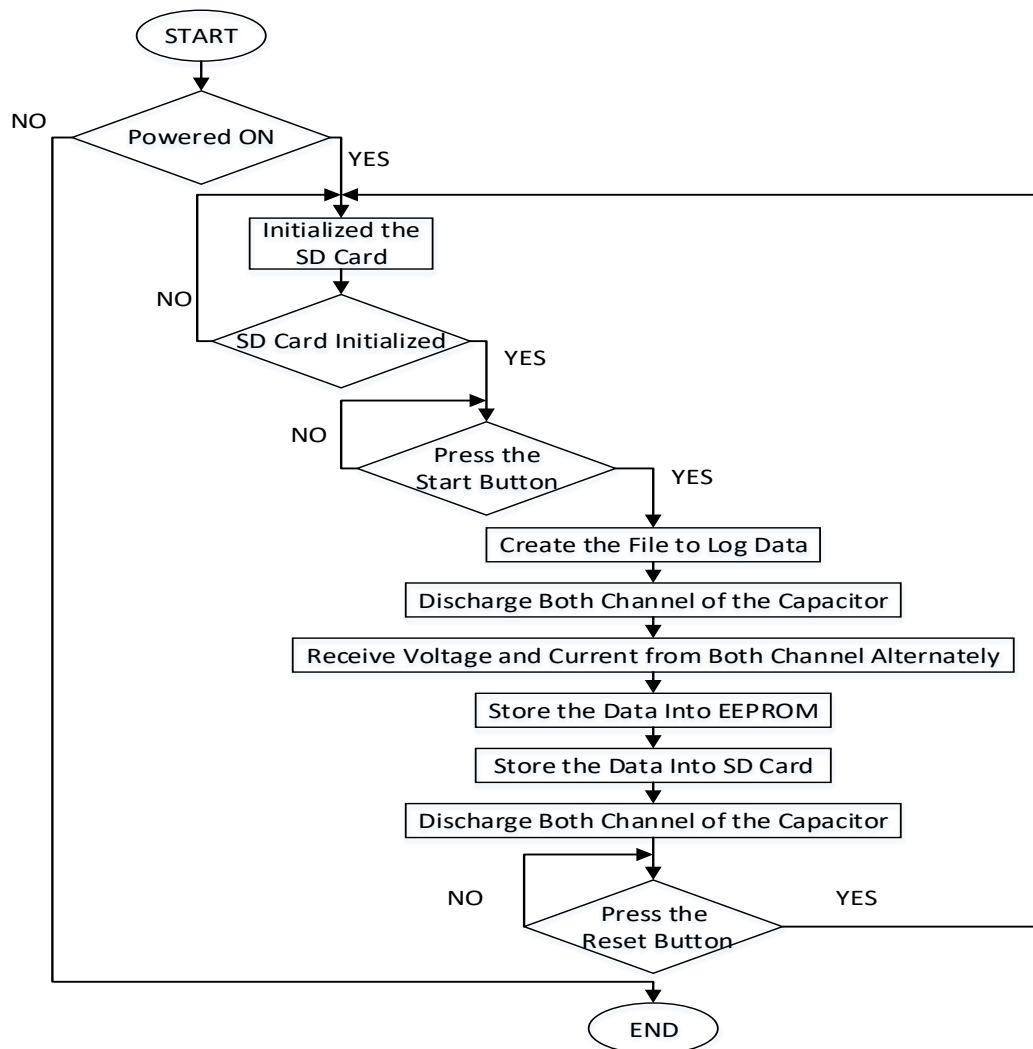
There are various types of load that used for tracing the I-V curve had been discussed. After a comparison between the different loads, the capacitor load is more suitable utilized to construct the I-V curve tracer. Therefore, the capacitor load has been chosen for this project. The skills and the ways that used to construct the I-V curve tracer will be discussed in this chapter. Additionally, this chapter will also thoroughly explain the components used in this project. In this project, the I-V curve tracer was designed in two separate inputs for the user to easily obtain the data within two different PV panels. The current sensor and voltage sensor is connected to the output of the solar panel. The reading that obtains by the sensor will send to the external ADC and then to Arduino. Last, the data that obtained will save in the Data logging shield. Figure 3.1 illustrates the basic block diagram of the multi-channel I-V curve tracer.



**Figure 3.1: Block Diagram of the Multi-channel I-V Curve Tracer**

### 3.2 The Process of I-V Curve Tracing

The I-V curve tracing consists of two inputs channel that allowed the user to obtain the data from two different PV panels. The output of the PV panel is connected to the current sensor and voltage sensor. When the powered is ON, the current sensor and voltage sensor will start to take the measurement and the capacitors are being to charge up. The measurement obtained by the sensors will be sent to the external 16 bits ADC for conversion. After that, the converted data will pass to Arduino Mega 2560 for processing via I2C. Every single point of the PV panel output will be sampled and store the data in the SD card that equipped on top of the Adafruit data logging shield. The SD card is able to remove and read by computer or laptop. The I-V curve can be plotted when the SD card is read. The process flowchart of the multi-channel I-V curve tracing is shown in Figure 3.2.



**Figure 3.2: Process Flowchart of the Multi-channel I-V Curve Tracing**

### 3.3 Materials Used

The electronic components used to construct the I-V curve tracer are shown in Table 3.1.

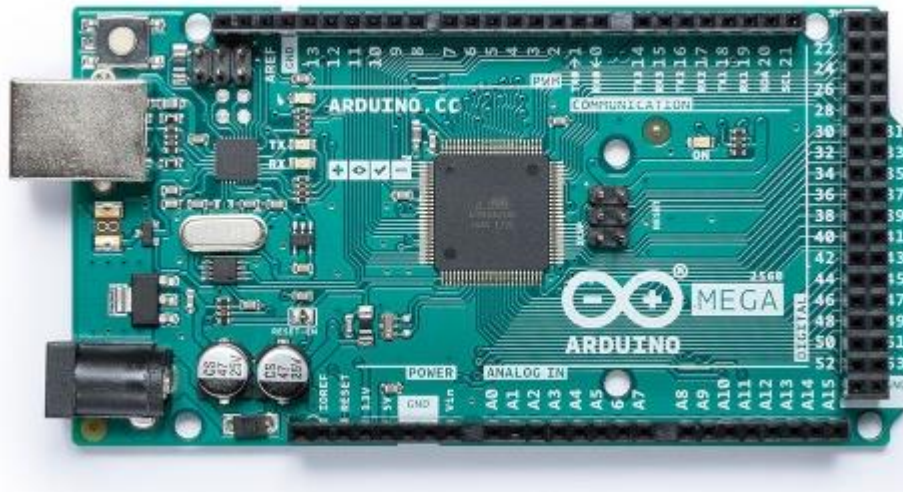
**Table 3.1: Component Used**

Component	Quantity
Arduino Mega 2560	1
Adafruit Data Logging Shield	1
ADC, ADS1115	2
Hall Effect Current Sensor, ACS712	2
LCD 16×8	2
MOSFET, IRF640N	4
MOSFET Gate Driver, TLP520	2
Variable Resistor, 10k $\Omega$	2
Resistor	
1k $\Omega$	4
330 $\Omega$	2
5W 100k $\Omega$	2
5W 10k $\Omega$	2
5W 750 $\Omega$	2
5W 510 $\Omega$	2
Capacitor	
0.1 $\mu$ F ceramic	2
0.1 $\mu$ F electrolytic	2
35W 6800 $\mu$ F	6

### 3.3.1 Arduino Mega 2560

Arduino is a sort of programmable microcontroller that provides a stage of electronic prototyping with equipment and programming which can be effectively modified and utilized. The special feature of the Arduino board is that it enables the user to do the interface between equipment promptly. It can deal with a different kind of equipment such as sensors, switch, LCD and so on. Besides that, there are sets of analog and digital inputs and outputs are outfitted at the board in order to interface the extension board or different circuit. The user can easily access the serial communications interfaces of the board by using the USB cable, which is utilized for loading the program from the laptop or computer.

Nowadays, there are many different kinds of Arduino board in the market. Distinctive sort of the Arduino board will perform in various applications. Arduino Mega 2560 is one of the kinds of Arduino board from the Arduino family. It provides more features and I/O pins compared to the Arduino Uno. Therefore, Arduino Mega is chosen to utilize in this project. The microcontroller of the Arduino Mega is ATmega2560. The length size of the board is 101.52mm and the width size is 53.3mm. Furthermore, the board consists of 54 digital I/O pins, 16 analog input pins, a reset button, a USB connection, 4 UARTs, a power jack, an ICSP header and a 16MHz crystal oscillator (Anon, n.d.). The Arduino Mega 2560 board is shown in Figure 3.2 and its specifications are shown in Table 3.3.



**Figure 3.3: Arduino Mega 2560 (Anon, n.d.)**

**Table 3.2: Specification of Arduino Mega 2560 (Anon, n.d.)**

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256KB of which 8KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
Length	101.52 mm
Width	53.3 mm
Weight	37 g

### 3.3.2 Adafruit Data Logging Shield

The operation of the data logging system is used to record or store the data obtained during tracing the I-V curve of the PV panel. Data logging shield will be utilized in this project is because Arduino Mega 2560 itself does not implement the data logging system. Therefore, the SD card that equipped at the data logging shield is used to store the data obtained. The Adafruit data logging shield is a circuit board that has been completely fabricated so that it can easily and perfectly fit on the top of the Arduino board to achieve an extra function.

The users enable to keep or store the data from the PV panel to any FAT16 or FAT32 formatted SD card in the data logging shield (Anon, n.d.). The data that stored in the SD card will allow the users enable to read and process the information for plotting the graph easily and the clearly recording time. Besides, Adafruit data logging shield also contains a Real Time Clock that can be synchronous with the present time and the time keeps running when there is no power supply connected to the Arduino board (Anon, n.d.). Due to this reason, the users do not need to reset the time every time when starting up the Arduino board. Moreover, the function of the Real Time Clock is very useful because the greater part of the data can be time-stamped with the time when the data is being recorded. Thusly, the users able to know the time of every single data is being recorded throughout the day after done collected the data. The Adafruit data logging shield is shown in Figure 3.4.



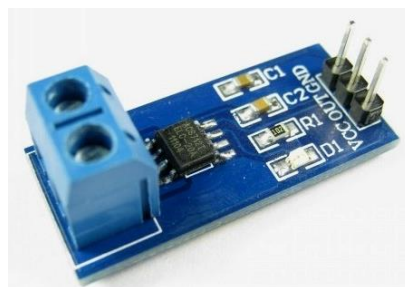
**Figure 3.4: Adafruit Data Logging Shield (Anon, n.d.)**

### 3.3.3 Sensors

Sensor plays an important role in this project because the Arduino board itself does not consist of any sensors so that the Arduino board unable to sense and interact with the external condition. By obtained the outcome, the sensor must connect to the Arduino board. There are many types of sensor in the market nowadays such as temperature sensor, ultrasonic sensor and so on. Since the current against voltage curve will be plotted as a result of this project after obtained the data. Thusly, there are two types of sensors are chosen in this project. First, a current sensor utilized to sense the current. Second, a voltage sensor utilized to sense the voltage output from the solar panel.

### 3.3.4 ACS712 Hall Effect Current Sensor

The operation of the current sensor is utilized to sense the current that passes through the wire or components. Besides that, the current sensor must be connected in series because current unable measured in parallel in order to avoid damage to the current sensor. The current sensor with model ACS712 is using the hall-effect basis. Commonly, the current sensor allows the user to sense the DC and AC current accurately. The sensor will work when there is a current pass through the copper conduction path inside the sensor and produce the magnetic field (Anon, n.d.). The magnetic field will be interpreted by Hall IC and convert into an output voltage. Hence, the sensor senses the input current and produce an output voltage. ACS712 current sensor able to sense the current within the range of  $\pm 20A$  and the sensitivity is  $100\text{ mV/A}$ . Thusly, the maximum output voltage of the sensor is  $2V$ . The ACS12ELCTR-20A-T is shown in Figure 3.5 and the specifications of ACS712 is shown in Table 3.3.



**Figure 3.5: ACS12ELCTR-20A-T Current Sensor (Anon, n.d.)**



**Table 3.3: Specifications of ACS712 (Anon, n.d.)**

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
<b>ELECTRICAL CHARACTERISTICS</b>						
Supply Voltage	$V_{CC}$		4.5	5.0	5.5	V
Supply Current	$I_{CC}$	$V_{CC} = 5.0$ V, output open	–	10	13	mA
Output Capacitance Load	$C_{LOAD}$	VIOUT to GND	–	–	10	nF
Output Resistive Load	$R_{LOAD}$	VIOUT to GND	4.7	–	–	k $\Omega$
Primary Conductor Resistance	$R_{PRIMARY}$	$T_A = 25^\circ\text{C}$	–	1.2	–	m $\Omega$
Rise Time	$t_r$	$I_P = I_P(\text{max})$ , $T_A = 25^\circ\text{C}$ , $C_{OUT} = \text{open}$	–	3.5	–	$\mu\text{s}$
Frequency Bandwidth	$f$	–3 dB, $T_A = 25^\circ\text{C}$ ; $I_P$ is 10 A peak-to-peak	–	80	–	kHz
Nonlinearity	$E_{LIN}$	Over full range of $I_P$	–	1.5	–	%
Symmetry	$E_{SYM}$	Over full range of $I_P$	98	100	102	%
Zero Current Output Voltage	$V_{IOUT(0)}$	Bidirectional; $I_P = 0$ A, $T_A = 25^\circ\text{C}$	–	$V_{CC} \times 0.5$	–	V
Power-On Time	$t_{PO}$	Output reaches 90% of steady-state level, $T_J = 25^\circ\text{C}$ , 20 A present on leadframe	–	35	–	$\mu\text{s}$
Magnetic Coupling <sup>2</sup>			–	12	–	G/A
Internal Filter Resistance <sup>3</sup>	$R_{F(INT)}$			1.7		k $\Omega$

### 3.3.5 Voltage Sensor

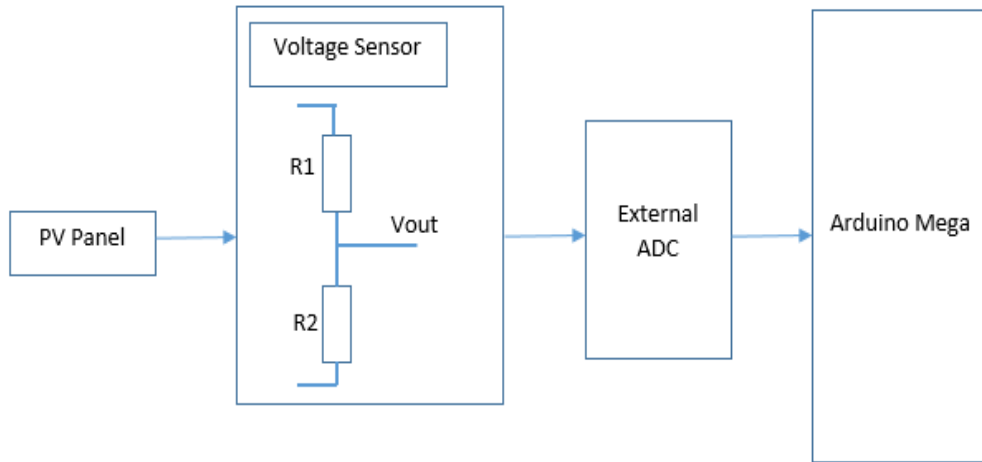
The operation of the voltage sensor is utilized to sense the voltage across the resistor or any components. Figure 3.6 showed that the output voltage of the PV panel will enter the voltage sensor, send the data to the external ADC, ADS1115 and then to Arduino. Since the voltage output from the PV panel is 25V and the enormous voltage will damage the external ADC if the voltage did not scale down because external ADC only can accept the DC voltage range from -0.3V up to 5.5V. In order to scale down the output voltage, the voltage divider as a voltage sensor is used in the circuit. The circuit of the voltage divider is constructed by connecting two resistors in series and get the output voltage that scaled down from between of the two resistors. Selecting the value of the resistors is important because the different value of the resistors will affect the input voltage of the external ADC.

In this project, the value of the resistors  $R_1 = 100k\Omega$  and  $R_2 = 10k\Omega$  have been selected to limit the output voltage of the voltage divider. The higher value of the resistance is chosen because there is a lower current flowing through and reduce the power losses in the voltage divider. The equation below shows the output voltage will be obtained when the input voltage from the PV panel enter the voltage divider. After obtained the data by external ADC, the data will send out to Arduino for convert back the voltage to the actual voltage by operate some arithmetic operation.

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \quad (2.1)$$

$$V_{out} = 21.6V \times \frac{10k}{100k + 10k}$$

$$V_{out} = 1.96V$$



**Figure 3.6: Block Diagram of Voltage Sensor to Arduino Mega**

### 3.3.6 Analog to Digital Converter

Arduino board itself consists of an analog to digital converter but only has 10 bits resolution, it will cause trouble in determining little changes of current during the measurement. This is due to the current sensor that able to measure the maximum current of 20A and the sensitivity is  $100mV/A$ , so that the maximum output from the sensor is 2V. This mean that the 10 bits ADC converter need to detect the enormous current within the range of 0 to 20A and this is not adequate bits to determine the changes in the large range of the current. To take care of this issue, an external ADC is utilized in this project.

An external ADC with model ADS1115 is used to increase the resolution of the converter outcome and obtained the measurement more precisely. It provides the 16 bits resolution with a sample range from  $8sps$  to  $860sps$ . Besides, it also able to communicate or connect to the Arduino board through I2C (protocol to enable multi-master and multi-slave communication). ADS1115 consists of four addresses in Figure 3.8 that allowed the user to set it by connecting the address pin (ADDR) to ground (GND), supply (VDD), SCL and SDA. Users are allowed to connect the maximum of four devices to ADS1115 through the same I2C path and using the same addresses. In

this project, there are two different addresses of ADS1115 are utilized to convert the two current measurement that come from two different of the PV panel. The ADC, ADS1115 converter is shown in Figure 3.7 and specifications are shown in Table 3.4.

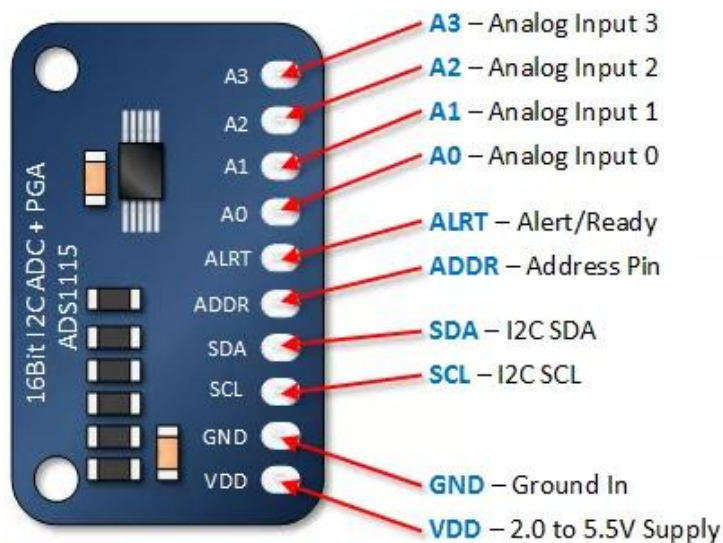


Figure 3.7: ADC, ADS1115 (Anon, n.d.)

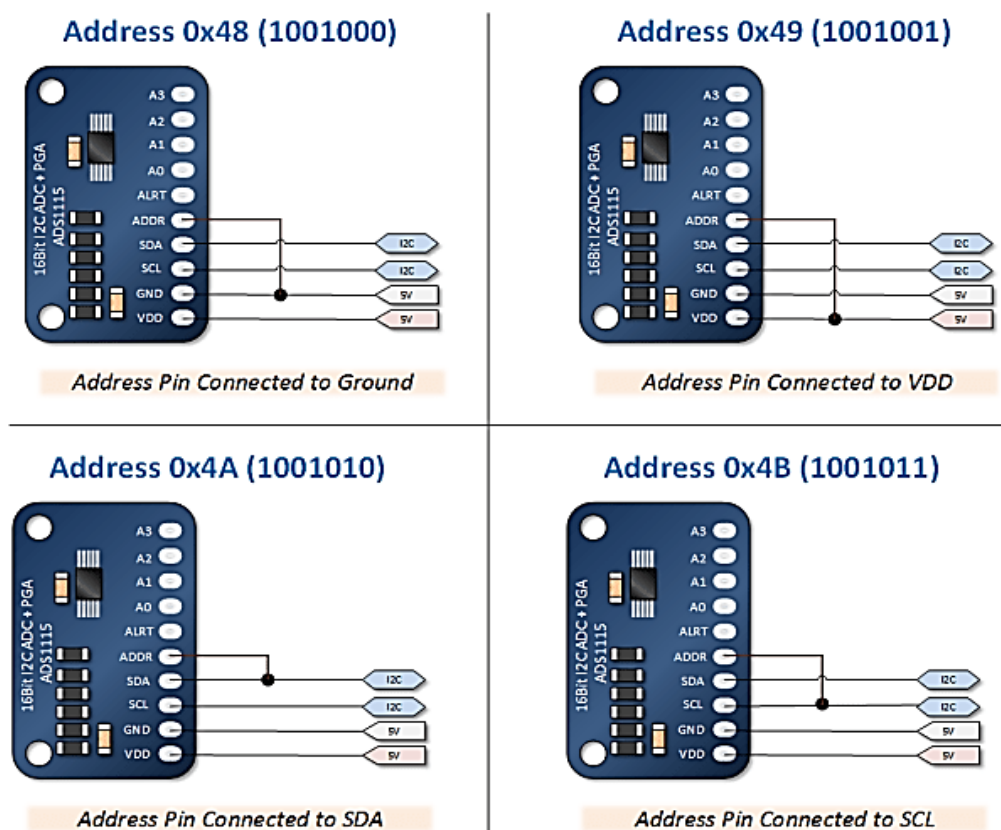


Figure 3.8: Four Addresses of the ADC, ADS1115 (Anon, n.d.)

**Table 3.4: Specifications of ADC, ADS1115 (Anon, n.d.)**

	ADS1113, ADS1114, ADS1115	UNIT
VDD to GND	-0.3 to +5.5	V
Analog input current	100, momentary	mA
Analog input current	10, continuous	mA
Analog input voltage to GND	-0.3 to VDD + 0.3	V
SDA, SCL, ADDR, ALERT/RDY voltage to GND	-0.5 to +5.5	V
Maximum junction temperature	+150	°C
Storage temperature range	-60 to +150	°C

### 3.4 Capacitive Load Sizing

There is various type of loads that utilized to trace the I-V curve have been discussed above, the capacitive load is chosen to utilize in this project. The reason that chooses the capacitor load is that it has the fastest response, low noise, least costly and the lightest because of the nonappearance of heavy resistor compared to others load. The formula of the capacitor charging time is shown below,

$$t_{charge} = 1.1 \times C_{load} \times \frac{V_{oc}}{I_{sc}} \quad (2.2)$$

where  $t_{charge}$  is the capacitor charging time,  $C_{load}$  is the value of the capacitor,  $V_{oc}$  is open-circuit voltage and  $I_{sc}$  is short-circuit current of the PV panel. In this project, the value of the capacitor is selected which is 3 pieces of  $6800\mu F$  and connected in parallel. The total of the capacitance is  $20.4mF$  and the formula of the total capacitance value that connected in parallel is shown below,

$$Total C_{load} = C_1 + C_2 + C_3 \quad (2.3)$$

In this project, a PV panel with  $V_{oc} = 21.6V$  and  $I_{sc} = 1.2A$  so that the charging time for the capacitor is  $403.92ms$ . Besides, solar insulation will affect the charging time of the capacitor. When the PV panel is under the half sun, the time taken to charge up the capacitor will be double. For an example, when the  $I_{sc}$  of the PV panel decrease become  $1A$ , then the  $t_{charge}$  will become  $484.70ms$ .

### 3.4.1 Capacitor Discharging Process

When the capacitor in the I-V curve tracer has been fully charged, the capacitor must be completely discharged first for the next charging process. The simple circuit had designed for the discharging process. When MOSFET between the PV panel outputs connected to the capacitor is opened, then the MOSFET between the capacitor connected to the resistor is closed for the discharging process. The discharging time of the capacitor is generally to be 5 times of the time constant of the RC circuit. The formula of the discharging time is shown below,

$$t_{discharge} \cong 5 \times RC \quad (2.4)$$

where  $t_{discharge}$  is the capacitor discharging time,  $R$  is the value of resistor and  $C$  is the value of the capacitor. Since the higher value of the capacitor is chosen which is  $20.4mF$ , in order to get the faster discharging time the value of the resistor must be smaller. Therefore, the resistor value is  $304\Omega$  so the discharging time is 31s.

### 3.5 Software Used

An Arduino IDE (Integrated Development Environment) is utilized in this project in order to write and compile the code to the Arduino board. The programming language that used to program the board is C or C++. Both of the programming languages is open-source. Therefore, the users are allowed to download or refer the free source code from the internet and use it. In such a way, the users will be easy to write the coding and upload the code to the Arduino board.

Besides, another computer software which is EAGLE also used in this project. It allowed the users to draw the schematic diagram of the circuit and also the board diagram of the circuit. There are many features are provided by EAGLE which are a component library, schematic editor, board editor and so on. In the component library, there are many types of components or devices that able to choose to design the circuit. If some of the components do not exist in the library, the users are allowed to design the new components by following the size or shape of the components. By using this useful software, the users can easily design a circuit board layout and route the circuit.

### 3.6 Circuit Schematic Design

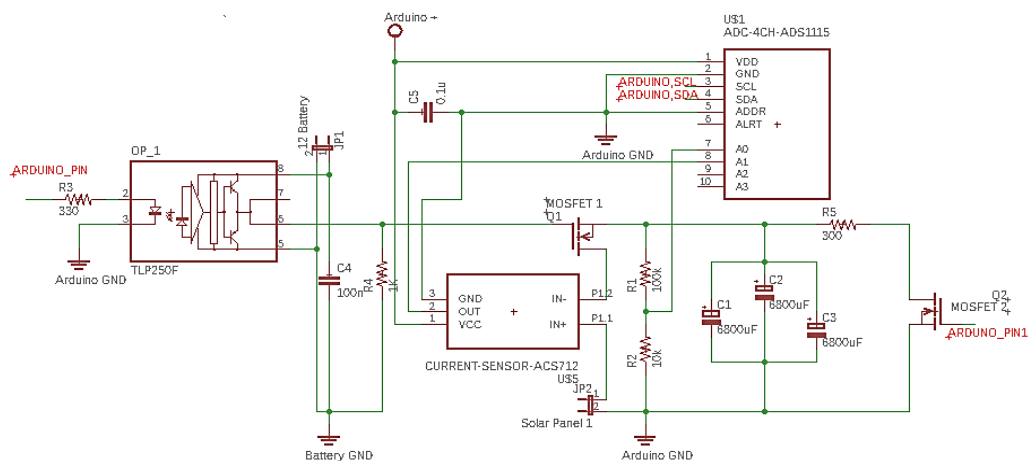
The circuit schematic design is shown in Figure 3.9, the circuit is designed by the components that collected that shown in Table 3.1. An optically isolated MOSFET driver, TLP250 is connected to the MOSFET 1 because MOSFET 1 is operated in high-side configuration. The high-side configuration in MOSFET means that the drain of the MOSFET is directly connected to the supply, while the source is connected to load and the load connected to ground. It also means that the current from the current sensor flow through the MOSFET 1 to the load and flow to ground. Besides, MOSFET 1 will not work it properly without using the MOSFET driver. For instance, the Arduino board provide the 5V to the gate of the MOSFET 1, MOSFET 1 will be switched ON and the voltage at the source will increase because of the load. In the meantime, the voltage at the gate will not be high enough to stay switching ON the MOSFET 1 due to the voltage drop at the load. To let the MOSFET 1 worked it properly, the  $V_{GS}$  must be greater than 5V and voltage from the digital I/O of the Arduino board is not sufficient to switch ON the MOSFET 1 in high-side configuration. Therefore, MOSFET driver, TLP250 is utilized to boost the voltage at the gate of MOSFET 1.

Moreover, there is a resistor,  $R_3$  which is  $330\Omega$  that connected to the input pin of the MOSFET driver. In order to protect the LED inside the MOSFET driver, the resistor,  $R_3$  is used to limit the voltage that come from the Arduino board. As mentioned before, to switch ON the MOSFET 1 the  $V_{GS}$  must greater than 5V so that MOSFET driver is connected to an external power source which is the 12V battery. There are consists of three different “grounds” in the high-side configurations circuit. The first ground is referred to the Arduino control signal, while the second ground referred to the external power source which is battery and the last ground is connected to the PV panel.

Figure 3.9 also shown that the output of the solar panel is connected to the current sensor, ACS712 in the series way. As mentioned above, to measure the current that passes through the circuit, the current sensor must connect in a series way. The MOSFET 1 will operate as a switch that allows or disallow the current flow through the load. MOSFET 1 is controlled by the signal from the Arduino board. Next, there is a voltage divider operate as a voltage sensor are constructed by two different values of the resistors which are  $R_1 = 100k\Omega$  and  $R_2 = 10k\Omega$  are connected parallel with the

capacitive load. The purpose to build the voltage divider is because of Arduino itself unable to sense the voltage more than 5V so that the voltage divider will scale down the voltage. In this project, there are three capacitors are connected in a parallel way so that the total capacitance is  $20.4mF$  referred to equation (2.3). An external ADC converter is used in this project to obtain the data from the current sensor and the voltage sensor. After that, the converted data will send to the Arduino board through I2C.

The resistor,  $R_5$  which is  $300\Omega$  is used for discharge the capacitors when the capacitors are full charged by PV panel. When the capacitors are fully charged, the Arduino board will send out the OFF signal to the MOSFET 1 to stop the charging process and send the signal ON to the MOSFET 2 to start the discharging process. Therefore, the MOSFET 2 is switched ON and let the capacitor discharge via the resistor. The voltage of the capacitors will pass through the resistor and discharge it until 0V, which mean that there are no more voltage is store inside the capacitors. After finished discharge the capacitors, which mean that it is ready for the next measurement.



**Figure 3.9: Circuit Schematic Design**

### 3.7 Summary

The materials used to construct the I-V curve tracing and the function of the components are discussed in this chapter. Besides, the process of the I-V curve tracer including the flowchart had also been discussed in this chapter. There are two types of software used in this project which is a C/C++ programming language and computer software “EAGLE”. Last, this chapter also explained the schematic design and the function of the circuit.

## CHAPTER 4

### RESULTS AND DISCUSSIONS

#### 4.1 Introduction

Steps to draw and create the schematic design and board design of the multi-channel I-V curve tracer by utilizing the computer software which is “EAGLE” will be discussed in this section. Besides that, this section will briefly go through the process of fabrication of the PCB board and hand on activities including soldering and drilling. The measurements obtained by the developed prototype was shown and discussed. Moreover, the comparison between the developed prototype and the commercial I-V curve tracer had been carried out and discussed.

#### 4.2 Schematic Design

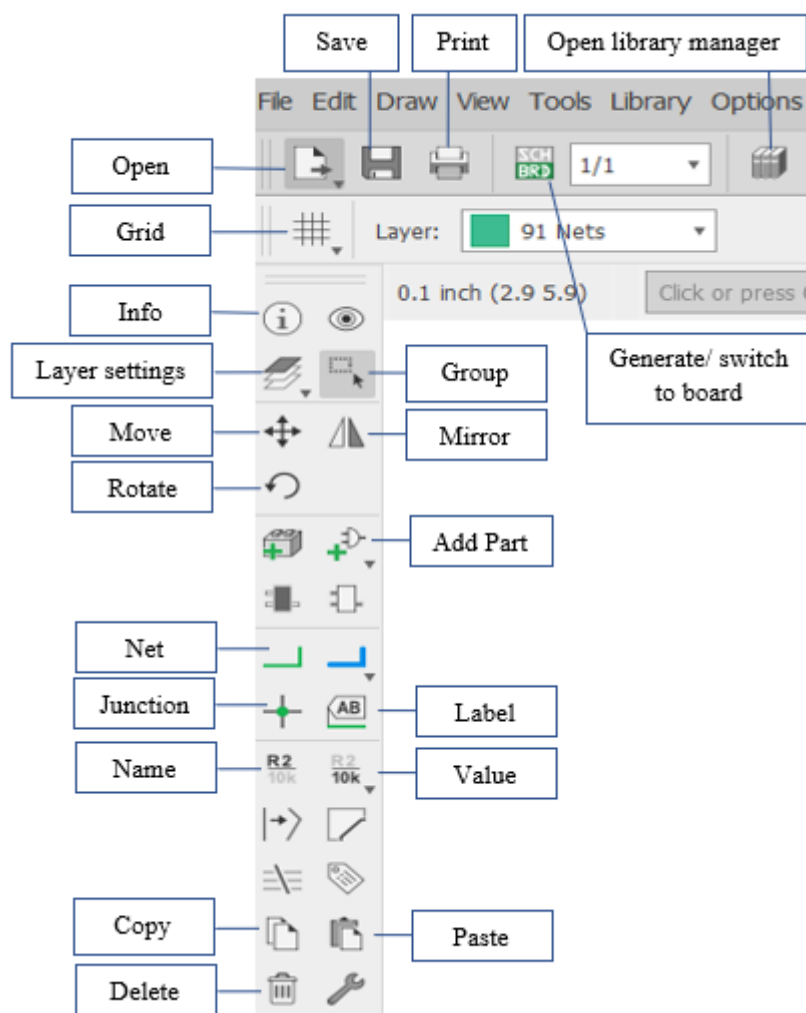
The schematic design is used to illustration that describes and determine the electrical connection between the different electrical components like resistors, capacitors, LCD and Integrated circuits IC. Besides, the specification of the connectivity and functionality between the different components that design inside the schematic diagram is easy to read and understand as well.

For creating the new schematic design file, first, start the EAGLE control panel application to create the new project and rename the project’s name. To open the schematic window, right-click the “*Project name > New > Schematic*”. After done open the schematic window, begin to design a schematic that defines the circuit’s components and their connections. Figure 4.1 shows the useful tools that use to draw the schematic diagram. For adding the components to the schematic window, select the “*Add Part*” to add it. Insert the name of the component at the “*Search*” bar and the details of the component will show out as well. After that, press “OK” and place the schematic of the component at the schematic window. Figure 4.2 shows the details including name, description, schematic symbol, board symbol and the size of the component. Some of the components do not exist in the library, the EAGLE software able to let the user create the new library for the components or find the library of the



component from the Internet. To add the library inside the library manager, click the “*Open Library Manager > In Use > Browse*” then select the library of the components.

After finish placed all the component that needed, the next process is to draw the wire by select the “*Net*” to link the end of the source pin of the component to the other components. The schematic design for the first channel and second channel I-V curve tracer are shown in Figure 4.3 and Figure 4.4. The schematic design for switch and LCD are shown in Figure 4.5.



**Figure 4.1: EAGLE’s Useful Tools for Schematic Design**

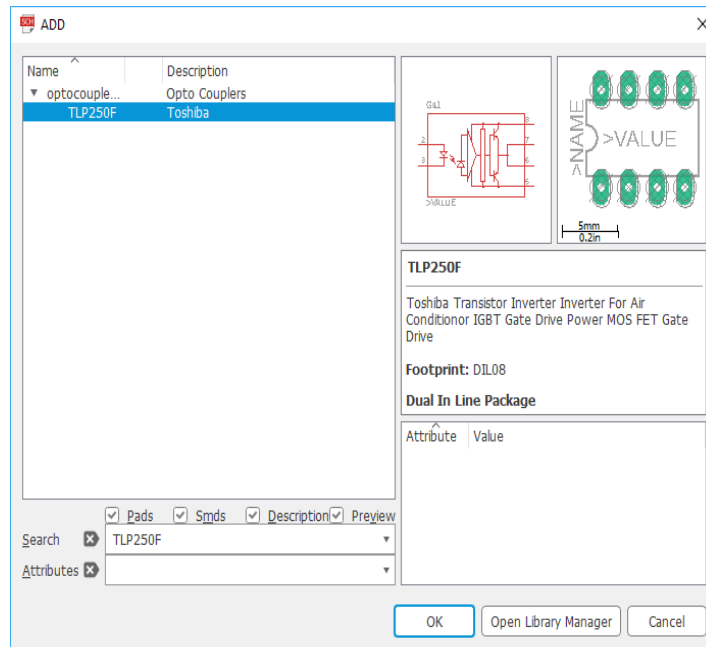


Figure 4.2: Details of the component

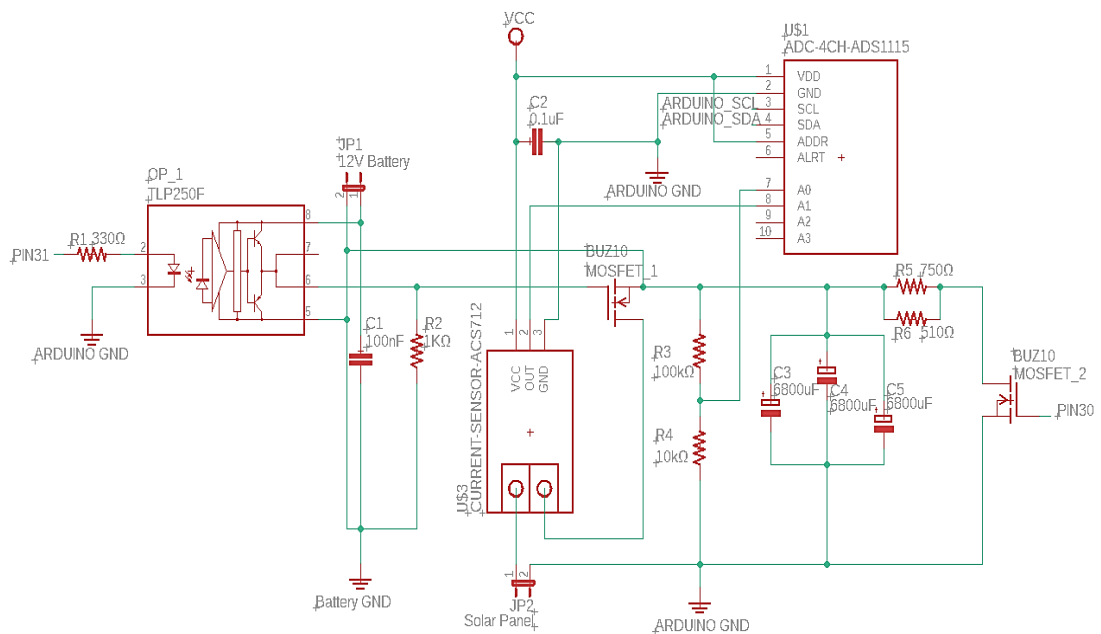
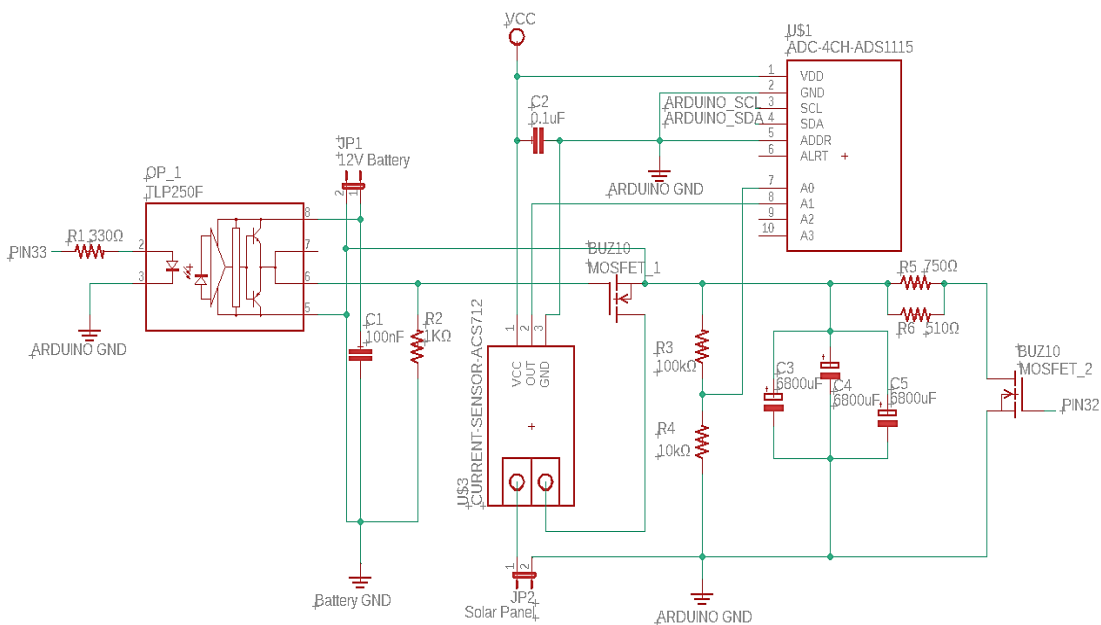
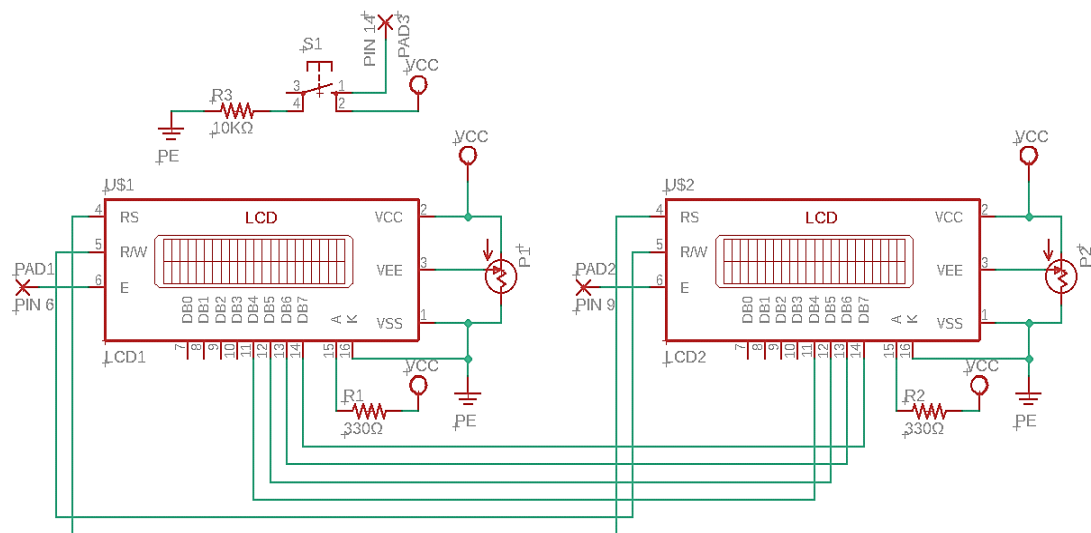


Figure 4.3: Circuit Schematic Design of First Channel I-V Curve Tracer



**Figure 4.4: Circuit Schematic Design of Second Channel I-V Curve Tracer**



**Figure 4.5: Circuit Schematic Design of LCD and Switch**

### 4.3 Board Design

The board design is used to demonstrate the location of the components and the traces of the components that connect it together on the PCB board by following the connection from the schematic design. Besides, the specification of the connectivity between the different components is complicated to read it compared to the schematic design.

For creating the board design, the schematic design must exist with the components and connectivity between the components, without the schematic design there will not be anything inside the board design and the user is not allowed to add any components at the board design, only able to add the components at the schematic design. After done connected all the components at the schematic design, click the “Generate/switch to board” and the board design page will pop up. At that time, all the components will be located on the left-hand side outside the box name “Dimension” which represent the area of the board or board outline that shown in Figure 4.6. Next, move all the components into the box and place it depends on how the components are connected. The board outline able to drag become larger if the dimension is not large enough to place all the components.

After done placed the components inside the “Dimension”, then used the “Route” tool to link the component together by following the yellow line known as the “Signal” tool while for the “Ripup” tool is used to delete the route. The EAGLE’s useful tools for board design is shown in Figure 4.7. Before starting to route the circuit, make sure that the layer is set to “16 Bottom” because the default of the layer is “1 Top”. For layer “16 Bottom” means that the copper route will locate under the PCB board while the layer “1 Top” the copper route will show on top of the PCB board. Besides that, the width of the trace is an important part when designing the board design. If all of the traces are design in the narrow width, it will be going to produce some heat when there is an electricity pass through the copper traces and some of the traces will be broken connection after etching the board. The best way to diminish the heat is to manipulate the width of the trace become wider, when the trace becomes wider there is also another advantage which is electricity will encounter the less resistance when passing through the circuit. In this project, the width of the route for normal power is 0.032 inch while for the high power is 0.056 inch. The via for normal power is set to 0.076 inches (Diameter) and 0.032 inches (Drill) while for the high

power is set to 0.08 inches (Diameter) and 0.04 inches (Drill). The function of the via is used to connect one PCB board to the other PCB board or connect one component to the other component at the same board when the route can't directly connect to the component.

Other than that, the angle of the trace also one of the important parts for designing the board. If the board is designed with a group of the right-angle trace, the outer edge of the trace will become narrower compared to the standard trace width and also sometime will get incompletely etch after done etched the board subsequently it will cause the short-circuit on board. Therefore, the 45-degree angle trace is used to design the PCB board in this project. This will create out the good-looking PCB layouts and effectively remove all the copper on board. The design of the angle trace is shown in Figure 4.8. Next, create a ground plane when finish connects all the signal by using "Route". For create the ground plane, select the "Polygon" tool, layer change to "16 Bottom", width is 0.032 inch and the isolate is 0.05 inch, then left-clicking to draw the polygon around the whole board. Named the polygon's name as "GND" after finished draw the polygon. The next step is to calculate and visible the ground plane by select the "Ratsnest" tool. The polygon's drawing and the ground plane after click the "Ratsnet" tool are shown in Figure 4.9. Last, click the "Print", printer select "Print to File (PDF)", options select "Black" and "Solid" then click "OK", the board layout will save in the PDF file. The board design for the first channel and second channel I-V curve tracer are shown in Figure 4.10 and Figure 4.11. The board design for switch and LCD are shown in Figure 4.12.



Figure 4.6: Board Design's Window

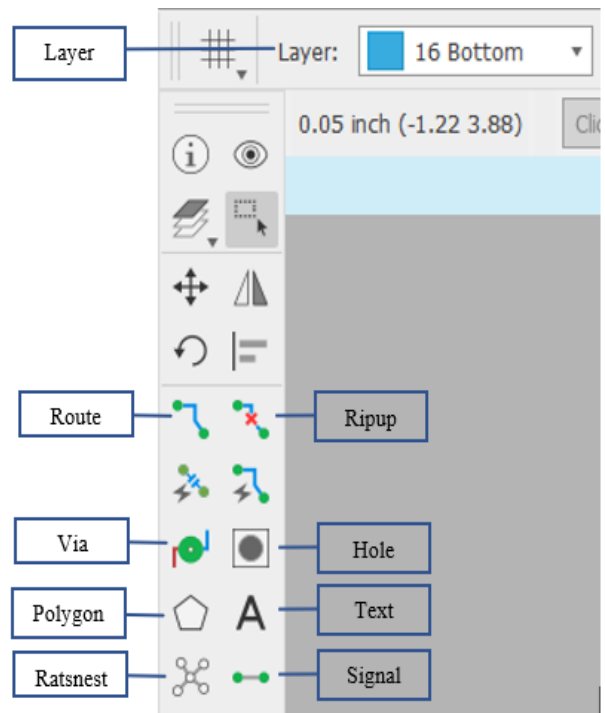


Figure 4.7: EAGLE's Useful Tools for Board Design

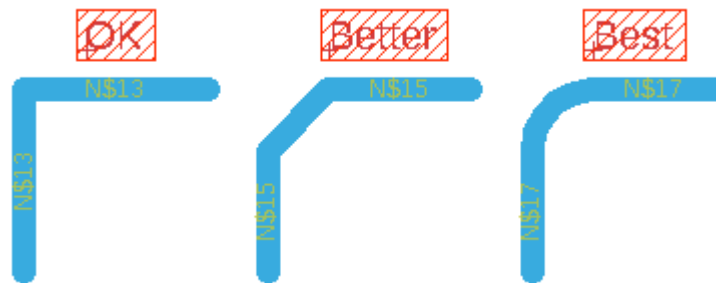


Figure 4.8: Design of the Angle Trace

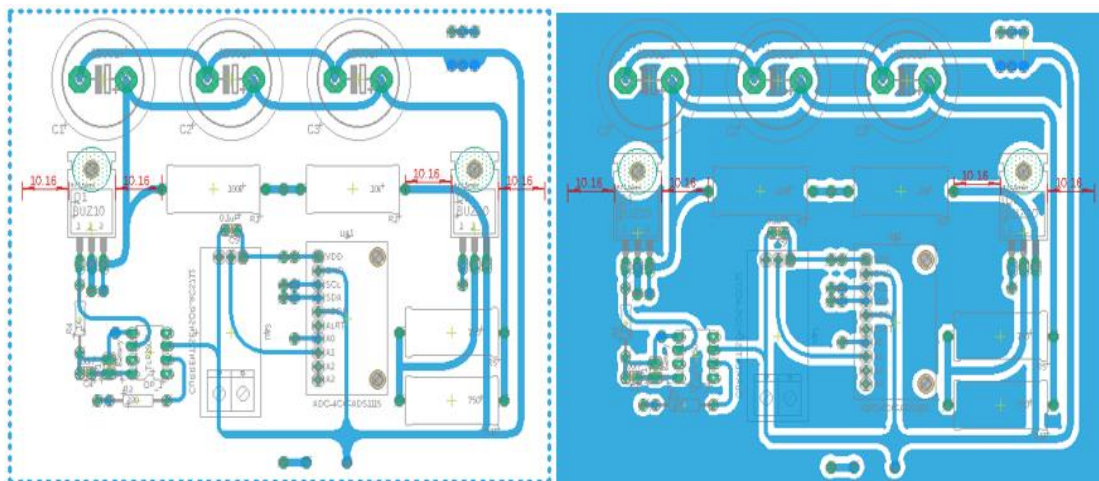
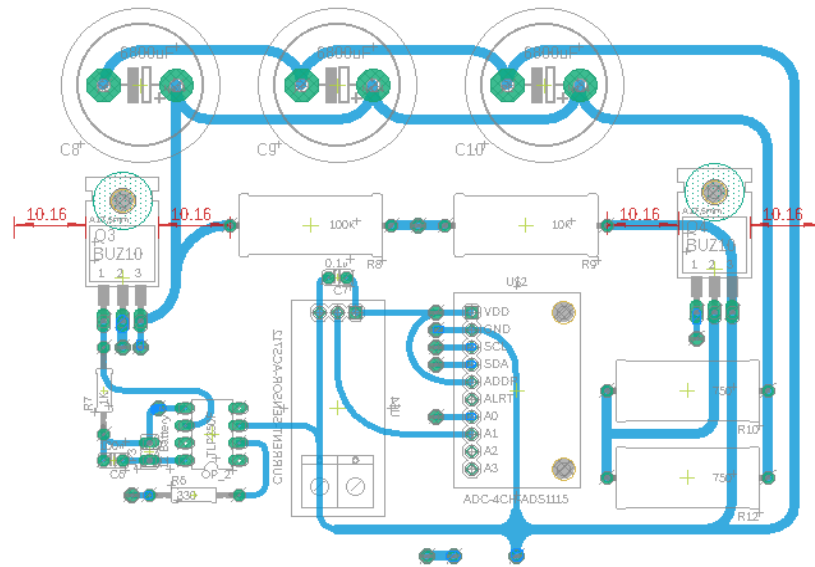
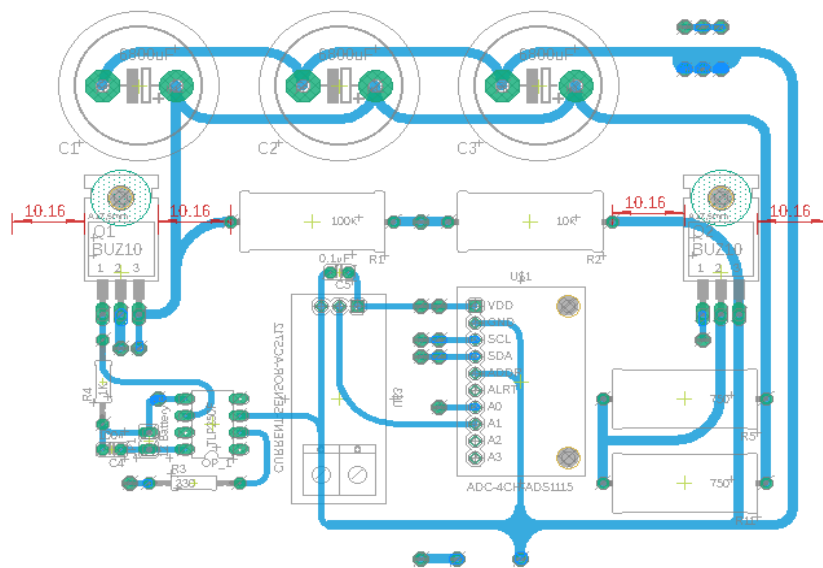


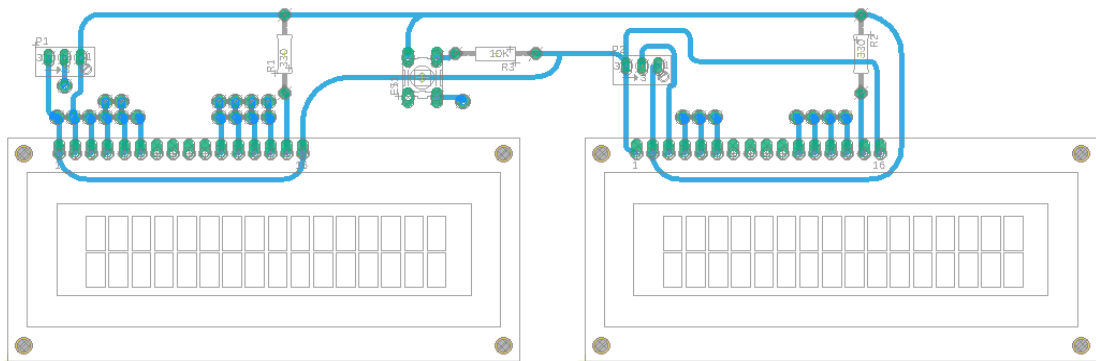
Figure 4.9: Polygon's Drawing and the Ground Plane



**Figure 4.10: Circuit Board Design of First Channel I-V Curve Tracer**



**Figure 4.11: Circuit Board Design of Second Channel I-V Curve Tracer**

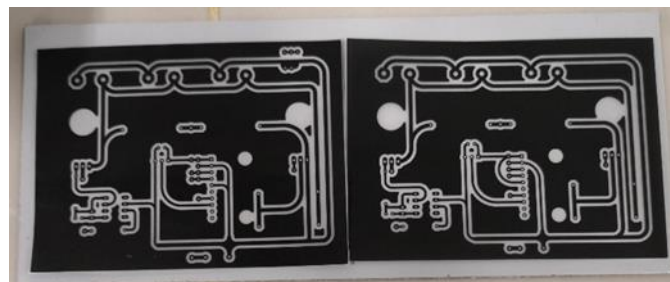


**Figure 4.12: Circuit Board Design of LCD and Switch**

#### 4.4 The Process of Fabrication of the PCB Board

When finished design the board layout of the project, print out the mask on a tracing paper and ready to fabricate the board. First of all, the lab coat, gloves, and eye protection must be worn before entering the etching lab. Place the printed mask on top of the board to measure it that illustrate in Figure 4.13 then use the board cutter to cut out the board. Turn off the fluorescent light, and open the yellow light bulb when peeling off the first layer of the photoresist and place it in a preheated lamination machine that shown in Figure 4.14.

Before closing the cover of the machine, align the printed mask with the photoresist laminated PCB then closed the cover. Switch on the power and expose it to ultraviolet light for 30 seconds. After that, prepared the 80ml of sodium chloride and 200ml of pure water measured by the beaker and mix it together at the plastic basin. After done mixed the liquid together, switch on the etching tank for 5 minutes to warm the ferric chloride which is preinstalled in the tank. Meanwhile, take out the board from the machine, remove the printed mask, place the board into the basin and slowly agitate with the mixed liquid until the desired pattern is shown on the PCB. When the desired pattern is shown, place the board into the provided net and immersed the net into the acid etching tank. The acid etching tank is shown in Figure 4.15. Monitor the PCB for every 5 minutes to check whether all the copper is etched away. Once the etching process complete, take out the board from the net and rinsed with the pure water. Dry the PCB board and proceed with the drilling process. After done drilled all the holes with the drilling machine, then able start to solder the components on top of the board.



**Figure 4.13: A Mask on Top of the Board.**





**Figure 4.14: Place a Mask and the Board in a Preheated Lamination Machine**

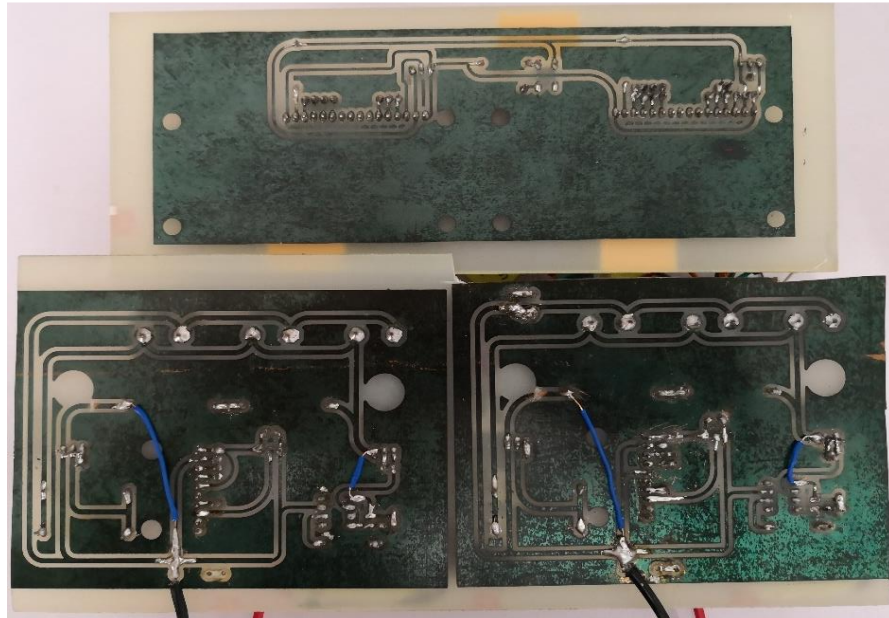


**Figure 4.15: Acid Etching Tank**

#### **4.5 Soldering Process**

Before started the soldering process, prepared the soldering iron with stand, solder, wire strippers, cutter, and desoldering pump. First of all, plugged the three-pin socket of the soldering iron into a wall outlet, turned on the power and let the soldering iron heating up a few seconds. While waiting for soldering iron to heat up, placed the smaller size of the components such as a resistor, MOSFET driver and push button at the front side of the fabricated board. After heating up the soldering iron, cleaned up the soldering iron with the sponge and melted the solder at the bottom side of the fabricated board with the components. When the melting solder was stuck it on the copper pad of the board hence remove the soldering iron and solder together. After that, used the cutter to remove the legs of the components.

Next, placed the larger size of the components and soldered all the components. A wire stripper was used to remove the rubber insulation of the wire while the desoldering pump was used to remove the solder easily when mistake soldered on the fabricated board. After finished soldered all the components, the soldering iron was cleaned up by sponge, turned off the power and unplug the socket from the wall outlet. Figure 4.16 shows the fabricated board and the components were soldered on the fabricated board.

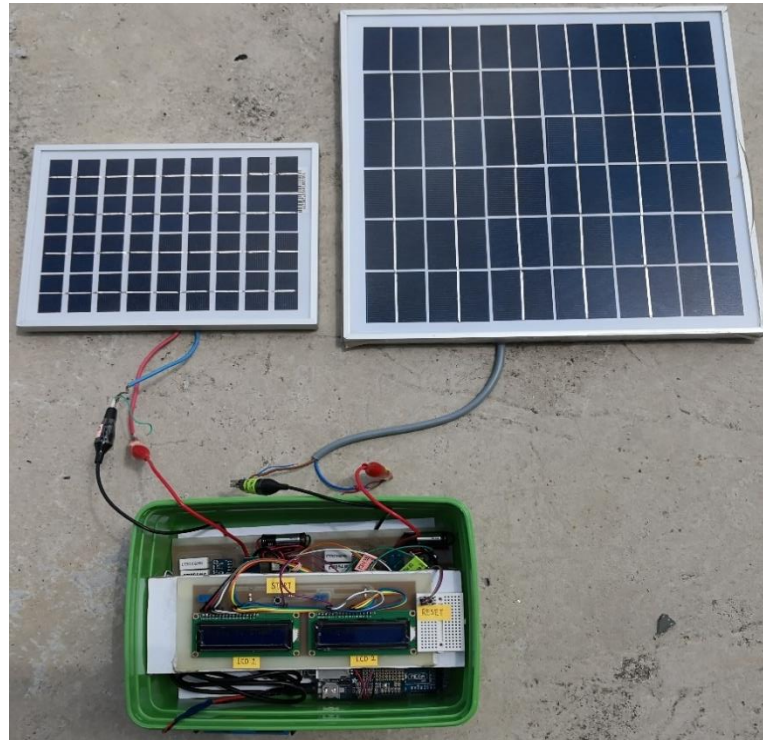


**Figure 4.16: Fabricated Board and Soldered the Components at the Bottom Side of the Board.**

#### **4.6 Experimental Results**

A prototype of the multi-channel I-V curve tracer with the capacitive load had been developed after completed the fabrication of the board and solder the components to the PCB board. The developed prototype and the finalized packaging are shown in Figure 4.17. The prototype can be power up by the laptop and also the portable battery supply, it can be easier and more convenient for the outdoor test when using the portable battery supply. There are two sets of the crocodile clips are provided to let the user connect it to the two different PV panel and the reading can be observed on both LCD as well.

There were two different types of the solar panel were tested at outdoor. Figure 4.18 shows the specification of two different types of solar panels. After the measurement, the measured data will be stored into the SD card and the data is used to plot the IV curve to determine the performance of the PV panel.



**Figure 4.17: Prototype of the Multi-channel I-V Curve Tracer**

<b>Type</b>	<b>Solar panel</b>	Maximum Power(Pmax)	20W ±3%
<b>Model</b>	<b>SP5-36B</b>	Voltage at Pmax(Vmp)	17.5V
<b>Maximum Power</b>	<b>5Watt</b>	Current at Pmax(Im <sub>p</sub> )	1.14A
<b>Maximum-Power Voltage</b>	<b>18V</b>	Open-Circuit Voltage(Voc)	21.6V
<b>Maximum-Power Current</b>	<b>0.277A</b>	Short-Circuit Current(Isc)	1.20A
<b>Open-circuit volage</b>	<b>21.6V</b>	Maximum System Voltage	1000VDC
<b>Shot-circuit current</b>	<b>0.305A</b>	Fuse Rating	10A
<b>Tolerance: -3%/+3%</b>		Operating Temperature	-40°C ~ +85°C
		Nominal Operating Cell Temp ( NOCT)	44.5 ± 2°C
		Minimun Field Wiring	12AWG
		Cell Technology	Poly-si
		Application Class	A

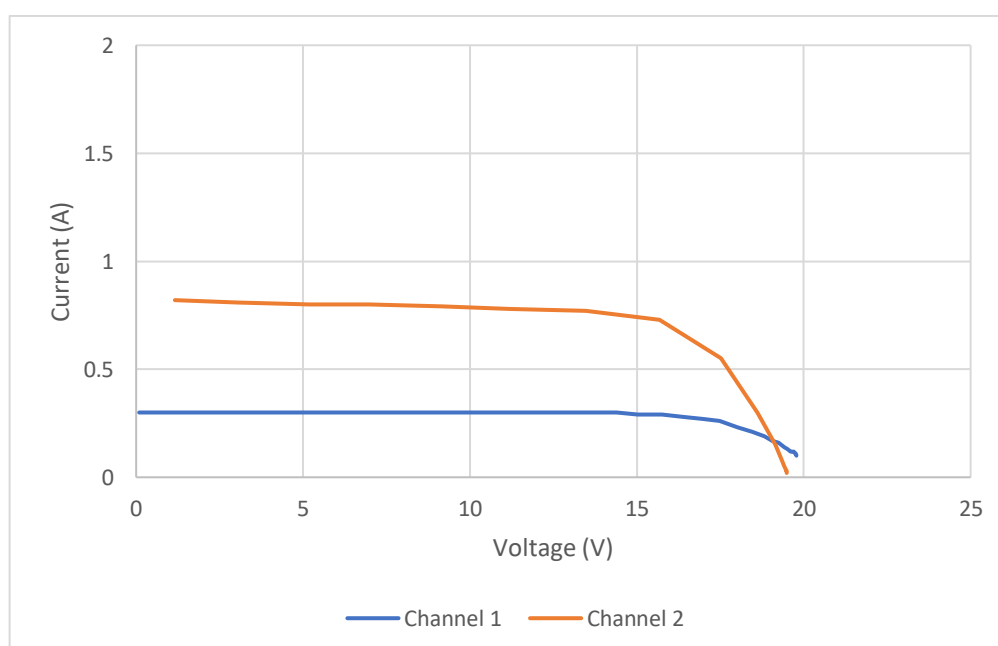
**Figure 4.18: Specification of the Solar Panel.**

The main objective of this project was to construct a device that can let the user obtain multiple solar panel performance measurements. The tests were conducted by connecting a solar panel with  $V_{oc} = 21.6V$ ,  $I_{sc} = 0.305A$  at channel 1 while the others solar panel with  $V_{oc} = 21.6V$ ,  $I_{sc} = 1.2A$  was connected to the channel 2. The data measured simultaneously by channel 1 and channel 2 were saved into the SD card was shown in Table 4.1. Inside the SD card, the file had recorded the timestamp, voltages and currents measurement taken in both channels with two different specification of the PV panel. Besides, the I-V curve corresponding to Table 4.1 was shown in Figure 4.19.

**Table 4.1: Two Channels Measurement of Prototype**

Timestamp	Voltage (1)	Current (1)	Voltage (2)	Current (2)
22-02-19 11:01	0.09	0.3	1.16	0.82
22-02-19 11:01	0.7	0.3	3.04	0.81
22-02-19 11:01	1.4	0.3	5.19	0.8
22-02-19 11:01	2	0.3	6.98	0.8
22-02-19 11:01	2.73	0.3	9.15	0.79
22-02-19 11:01	3.42	0.3	11.18	0.78
22-02-19 11:01	4.22	0.3	13.47	0.77
22-02-19 11:01	5.01	0.3	15.68	0.73
22-02-19 11:01	5.79	0.3	17.52	0.55
22-02-19 11:01	6.57	0.3	18.62	0.3
22-02-19 11:01	7.34	0.3	19.14	0.15
22-02-19 11:01	8.11	0.3	19.34	0.08
22-02-19 11:01	8.78	0.3	19.42	0.05
22-02-19 11:01	9.5	0.3	19.46	0.04
22-02-19 11:01	10.23	0.3	19.48	0.03
22-02-19 11:01	10.95	0.3	19.49	0.03
22-02-19 11:01	11.67	0.3	19.49	0.02
22-02-19 11:01	12.28	0.3	19.49	0.02
22-02-19 11:01	12.99	0.3	19.5	0.02
22-02-19 11:01	13.7	0.3	19.5	0.02
22-02-19 11:01	14.4	0.3	19.5	0.02
22-02-19 11:01	15.03	0.29	19.5	0.02
22-02-19 11:01	15.75	0.29	19.5	0.02
22-02-19 11:01	16.45	0.28	19.5	0.02
22-02-19 11:01	17.01	0.27	19.5	0.02
22-02-19 11:01	17.48	0.26	19.5	0.02
22-02-19 11:01	18.02	0.23	19.5	0.02
22-02-19 11:01	18.46	0.21	19.5	0.02
22-02-19 11:01	18.82	0.19	19.5	0.02
22-02-19 11:01	19.06	0.17	19.51	0.02

22-02-19 11:01	19.25	0.16	19.51	0.02
22-02-19 11:01	19.42	0.14	19.51	0.02
22-02-19 11:01	19.52	0.13	19.51	0.02
22-02-19 11:01	19.61	0.12	19.51	0.02
22-02-19 11:01	19.67	0.12	19.51	0.02
22-02-19 11:01	19.71	0.12	19.51	0.02
22-02-19 11:01	19.75	0.11	19.51	0.02
22-02-19 11:01	19.77	0.11	19.51	0.02
22-02-19 11:01	19.78	0.1	19.51	0.02



**Figure 4.19: I-V Curve Measurements in Channel 1 and Channel 2**

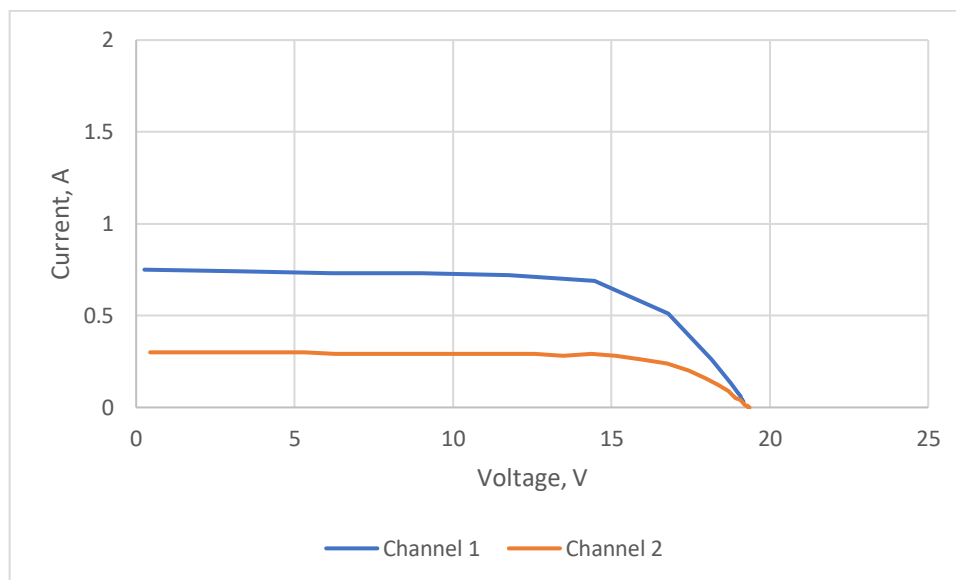
From the table above, we able to calculate the maximum power point to find out the performance of the solar panel. The maximum power point in channel 1 was  $4.61W$  while the maximum power point in channel 2 was  $11.45W$ , so the PV panel in channel 2 contain a higher maximum power point. From the graph above, we also noticed that the I-V curve of the channel 2 is higher than channel 1, it means that PV panel at channel 1 contain a lower current and power compared to PV panel at channel 2. Hence, we can conclude that the PV panel performance measurement of the channel 2 is better than the channel 1.

The other tests were also conducted by exchanged the PV panel which means that a PV panel with  $V_{oc} = 21.6V$ ,  $I_{sc} = 1.2A$  at channel 1 while the others PV panel with  $V_{oc} = 21.6V$ ,  $I_{sc} = 0.305A$  was connected to the channel 2. The data measurements were shown in Table 4.2 and the I-V curve corresponding to Table 4.2 was shown in Figure 4.20.

**Table 4.2: Two Channels Measurement of Prototype**

Timestamp	Voltage (1)	Current (1)	Voltage (2)	Current (2)
10-03-19 13:03	0.26	0.75	0.44	0.3
10-03-19 13:03	3.26	0.74	1.43	0.3
10-03-19 13:03	6.17	0.73	2.42	0.3
10-03-19 13:03	9	0.73	3.39	0.3
10-03-19 13:03	11.77	0.72	4.35	0.3
10-03-19 13:03	14.46	0.69	5.31	0.3
10-03-19 13:03	16.79	0.51	6.26	0.29
10-03-19 13:03	18.17	0.26	7.2	0.29
10-03-19 13:03	18.77	0.13	8.14	0.29
10-03-19 13:03	18.99	0.08	8.99	0.29
10-03-19 13:03	19.08	0.06	9.87	0.29
10-03-19 13:03	19.12	0.04	10.76	0.29
10-03-19 13:03	19.14	0.04	11.67	0.29
10-03-19 13:03	19.15	0.03	12.57	0.29
10-03-19 13:03	19.15	0.03	13.47	0.28
10-03-19 13:03	19.16	0.03	14.37	0.29
10-03-19 13:03	19.16	0.03	15.13	0.28
10-03-19 13:03	19.16	0.03	15.98	0.26
10-03-19 13:03	19.16	0.03	16.76	0.24
10-03-19 13:03	19.16	0.03	17.43	0.2
10-03-19 13:03	19.16	0.03	17.97	0.16
10-03-19 13:03	19.17	0.03	18.39	0.12
10-03-19 13:03	19.17	0.03	18.7	0.09
10-03-19 13:03	19.17	0.03	18.92	0.05

10-03-19 13:03	19.17	0.03	19.07	0.04
10-03-19 13:03	19.17	0.03	19.18	0.02
10-03-19 13:03	19.17	0.03	19.24	0.01
10-03-19 13:03	19.17	0.03	19.29	0.01
10-03-19 13:03	19.17	0.03	19.32	0



**Figure 4.20: I-V Curve Measurements in Channel 1 and Channel 2**

From the graph above, the graph shows that the I-V curve of the channel 1 was higher than channel 2. The maximum power point in channel 1 was  $9.97W$  while the maximum power point in channel 2 was  $4.24W$ , so the PV panel in channel 1 contain a higher maximum power point. Therefore, we can conclude that the PV panel performance measurement of the channel 1 is better than the channel 2. From Figure 4.19 and 4.20, we notice that the test by exchanged the PV panel connected with the different channels able to work without any problem.

#### 4.7 Results Comparison

In order to check the accurateness of the prototype, a comparison between prototype and commercialized I-V curve tracer had been made. Figure 4.21 shows the PV analyzer PROVA 210. Table 4.3 shows the data measurement measured by the prototype and the PV panel with  $V_{oc} = 21.6V$ ,  $I_{sc} = 1.2A$  was connected in channel 1. Figure 4.22 shows the comparison between PROVA 210 and prototype in channel 1.



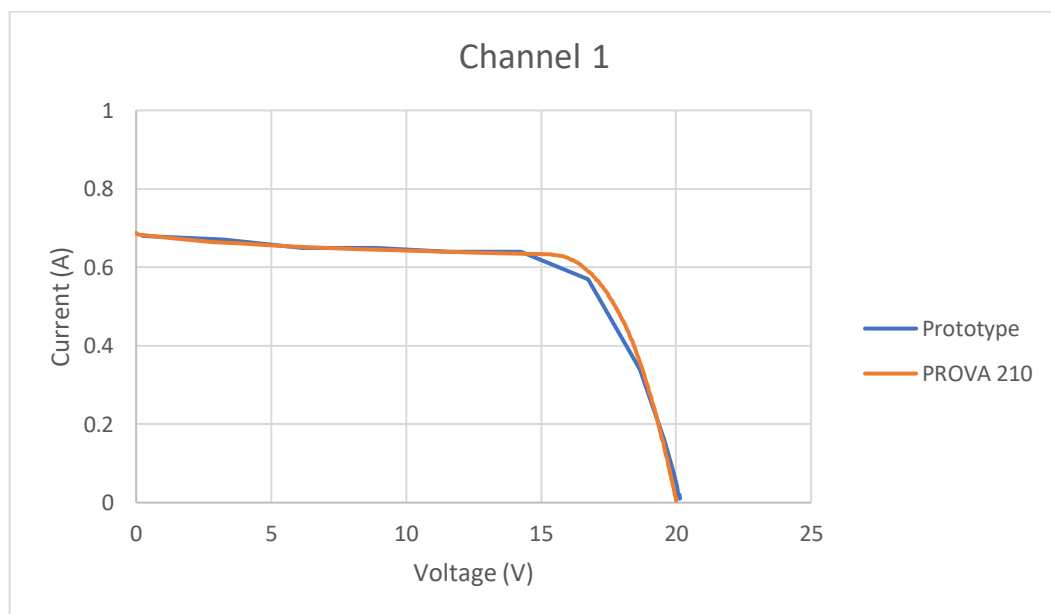
**Figure 4.21: PV Analyzer PROVA 210**

**Table 4.3: Voltage and Current Measured by Using Prototype in Channel 1**

Timestamp	Voltage (1)	Current (1)
22-03-19 11:11	0.24	0.68
22-03-19 11:11	3.25	0.67
22-03-19 11:11	6.14	0.65
22-03-19 11:11	8.84	0.65
22-03-19 11:11	11.58	0.64
22-03-19 11:11	14.26	0.64
22-03-19 11:11	16.74	0.57
22-03-19 11:11	18.66	0.34
22-03-19 11:11	19.56	0.16
22-03-19 11:11	19.9	0.08
22-03-19 11:11	20.03	0.04
22-03-19 11:11	20.07	0.03
22-03-19 11:11	20.09	0.02



22-03-19 11:11	20.11	0.02
22-03-19 11:11	20.11	0.02
22-03-19 11:11	20.12	0.02
22-03-19 11:11	20.12	0.02
22-03-19 11:11	20.12	0.02
22-03-19 11:11	20.12	0.02
22-03-19 11:11	20.12	0.02
22-03-19 11:11	20.12	0.02
22-03-19 11:11	20.12	0.02
22-03-19 11:11	20.13	0.01



**Figure 4.22: Comparison Between PROVA 210 and Prototype in Channel 1**

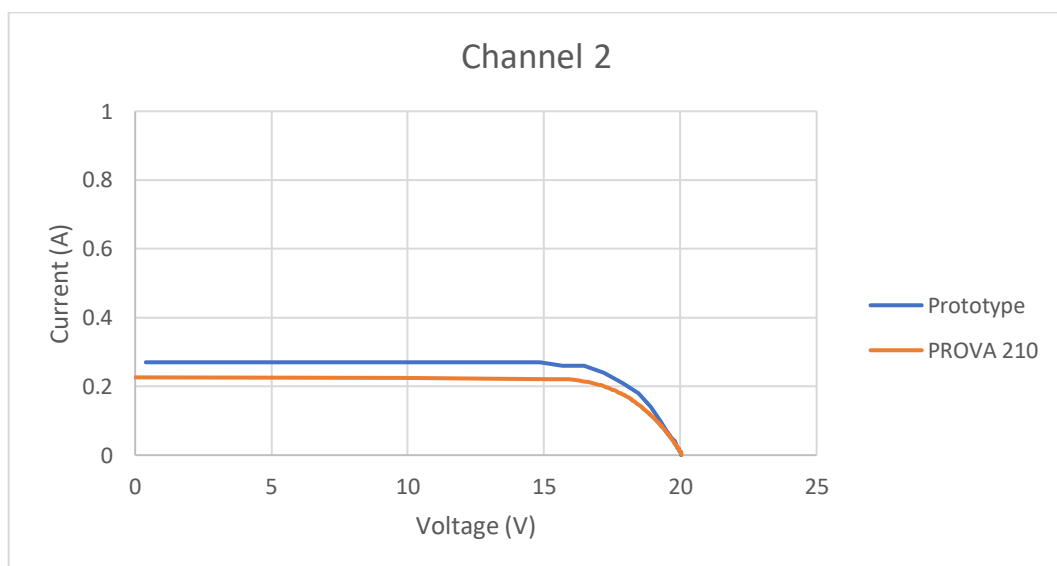
From the graphs above, we able to notice that the  $I_{sc}$  that taken by prototype was same while the  $V_{oc}$  that taken by prototype was slightly higher compared to the commercialized I-V curve tracer. The  $I_{sc}$  obtained from prototype was 0.68A while the  $I_{sc}$  obtained from PROVA 210 was 0.6876A, so the percentage error was 1.11%. The  $V_{oc}$  of the prototype was 20.13V while the  $V_{oc}$  of the PROVA 210 was 20.004V, so the percentage error was 0.63%. Other than that, the appearance of the I-V curve from the prototype was almost similar to the I-V curve that taken by commercialized I-V curve tracer.

Next, other types of the PV panel with  $V_{oc} = 21.6V$ ,  $I_{sc} = 0.305A$  also had been tested by commercialized I-V curve tracer and the prototype in channel 2. Table 4.4 shows the data measurement measured by the prototype in channel 2. Figure 4.23 shows the comparison between PROVA 210 and prototype in channel 2.

**Table 4.4: Voltage and Current Measured by Using Prototype in Channel 2**

Timestamp	Voltage (2)	Current (2)
22-03-19 11:11	0.39	0.27
22-03-19 11:11	1.4	0.27
22-03-19 11:11	2.39	0.27
22-03-19 11:11	3.33	0.27
22-03-19 11:11	4.31	0.27
22-03-19 11:11	5.28	0.27
22-03-19 11:11	6.2	0.27
22-03-19 11:11	7.16	0.27
22-03-19 11:11	8.07	0.27
22-03-19 11:11	8.94	0.27
22-03-19 11:11	9.8	0.27
22-03-19 11:11	10.66	0.27
22-03-19 11:11	11.51	0.27
22-03-19 11:11	12.35	0.27
22-03-19 11:11	13.19	0.27
22-03-19 11:11	14.02	0.27
22-03-19 11:11	14.85	0.27
22-03-19 11:11	15.68	0.26
22-03-19 11:11	16.48	0.26
22-03-19 11:11	17.2	0.24
22-03-19 11:11	17.88	0.21
22-03-19 11:11	18.46	0.18
22-03-19 11:11	18.91	0.14
22-03-19 11:11	19.26	0.1
22-03-19 11:11	19.51	0.07

22-03-19 11:11	19.69	0.05
22-03-19 11:11	19.81	0.04
22-03-19 11:11	19.89	0.02
22-03-19 11:11	19.94	0.02
22-03-19 11:11	19.97	0.01
22-03-19 11:11	20	0.01
22-03-19 11:11	20.02	0.01
22-03-19 11:11	20.03	0



**Figure 4.23: Comparison Between PROVA 210 and Prototype in Channel 2**

From the graphs above, we able to notice that the current and the power output that measured by the prototype was relatively higher compared to the commercialized I-V curve tracer. Besides that, the  $V_{oc}$  that taken by prototype was almost the same compared to the commercialized I-V curve tracer but there was an error for current measurement. The  $I_{sc}$  obtained by prototype was 0.27A while the  $I_{sc}$  obtained by PROVA 210 was 0.2262A, so the percentage error was around 20%. The  $V_{oc}$  that obtained by prototype was 20.03V while the  $V_{oc}$  of the PROVA 210 was 20.035V, so the percentage error was 0.02%. Since the percentage error of the current in channel 2 was high, the current sensor in channel 2 might have some defect. Due to the offset voltage of the current sensor was not stable so it will influence the measurement because the value of the offset voltage was used in Arduino programming for an arithmetic operation to obtain the current data.

## CHAPTER 5

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

In summary, there are three of the objectives of this project were successfully met. A multi-channel I-V curve tracer circuit was designed by the computer software “EAGLE” and the capacitor load was used to charge by the solar PV panel. Besides that, the schematic circuit was converted into board design and the circuit was fabricated on the PCB board as well. A multi-channel I-V curve tracer was developed and an outdoor test was conducted to get the performance measurement of the solar panel. The tracer was succeeded trace the current and voltage for two PV panel in real-time operation. The data was logged into SD card via the Arduino board. The prototype that constructed at the PCB board become safer when conducting an outdoor test and the overall process including charging and discharging the capacitor was less 2 minutes.

The author gained a lot of knowledge on the design of the schematic circuit and board circuit by utilizing the EAGLE software. Some hand on skills gained by the author when fabricating the PCB board including etching, drilling and soldering the PCB board. Moreover, an Arduino microcontroller programming skill also gained by the author in this project. This including to function the multi-channel data reading, create the log file with the real-time clock, charging and discharging the capacitor and log the data from Arduino into EEPROM and then to SD card. Other than that, the author also learned how to utilize the PV analyzer PROVA 210 to measure the PV panel and copy out the data to do a comparison with the prototype. After the comparison, the tracer was calibrated with a commercial I-V curve tracer and the error is less than 1%, but there was an error measurement of current in channel 2. Last but not least, the author gained the experiences of solving problems and troubleshooting issues that met in this project.

## 5.2 Recommendations for Future Work

A dual channel I-V curve tracer was constructed in this project utilized to measure the performance of the PV panel with the short-circuit current of 2A, the open-circuit voltage of 25V and the maximum power up to 20W. For measuring a higher specification of the PV panel, the charging time will become shorter compared with the lower specification of the PV panel, so there are not enough sample points to plot the I-V curve by utilizing the low rating voltage and capacitance. By implementing more capacitors with higher rating voltage and higher capacitance, the charging time will become longer and this will obtain more sample points of the curve. Hence, the user enables to get the accurate I-V curve for higher specification of PV panel.

Besides that, the WiFi module can be installed in the device, the module is used to access the WiFi network so that the data measurement able to upload to the cloud storage when there is internet access. Cloud storage is convenient to use and also offers greater adaptability. When the data are uploaded to the cloud storage, the user will be easier to observe the live data and easier to make a comparison between the PV panel at any location that has internet access.

Moreover, the temperature sensor and the solar irradiance sensor also can be added in the device for the measurement, so that the user will know the temperature and irradiance when conducting a test. Therefore, it will become more alike to the commercialized I-V curve tracer. Nowadays, there are a lot of electronic products are constructed by the surface mounted board, hence the prototype also able to upgrade it to the surface mount board. This will save a lot of space because the components are smaller than the thru-hole components and also eliminates the drilling process for thru-hole components. Therefore, the size of the prototype will become smaller and more convenient to carry around.

Lastly, when there is a zero current that passes through the ACS712 current sensor which means that the output voltage as known as offset voltage is half of the voltage supply. For example, when the current sensor is powered by 5V, hence the offset voltage will be 2.5V at 0A. If the supply voltage drops to 4.85V then the offset voltage will be 2.425V. The value of the offset voltage will be used in the Arduino programming to do some arithmetic and obtain the current data. Therefore, build a 5V voltage regulator for each current sensor and using an AC/DC adaptor to power up the Arduino board to avoid the offset voltage inconsistent and error when collecting data.

## REFERENCES

- admin\_yourhome, 2013, *Photovoltaic systems* [Online]. Available at: <http://www.yourhome.gov.au/energy/photovoltaic-systems> [Accessed: 7 July 2018].
- Anon, *ACS712 Current Sensor* [Online]. Available at: <http://embedded-lab.com/blog/a-brief-overview-of-allegro-ac712-current-sensor-part-1/> [Accessed: 4 August 2018].
- Anon, ads1115.pdf. Available at: <https://cdn-shop.adafruit.com/datasheets/ads1115.pdf> [Accessed: 10 August 2018].
- Anon, *Arduino ADS1115 ADC* [Online]. Available at: <http://henrysbench.capnfatz.com/henrys-bench/arduino-voltage-measurements/arduino-ads1115-module-getting-started-tutorial/> [Accessed: 10 August 2018].
- Anon, *Arduino Mega 2560 Rev3* [Online]. Available at: <https://store.arduino.cc/usa/arduino-mega-2560-rev3> [Accessed: 1 August 2018].
- Anon, *Data Logger Shield* [Online]. Available at: <https://hobbycomponents.com/shields/587-data-logger-shield> [Accessed: 3 August 2018].
- Anon, *Photovoltaic or Solar Cell Definition, Construction, Working &* [Online]. Available at: <https://circuitglobe.com/photovoltaic-or-solar-cell.html> [Accessed: 23 June 2018].
- Brito, E.M. da S., Antonio, A. da S., Cupertino, A.F. and Pereira, H.A., 2014. Characterization of Solar Panel Using Capacitive Load. *2014 11th IEEE/IAS International Conference on Industry Applications*, pp.1–7.
- Duran, E., Galan, J., Sidrach-de-Cardona, M. & Andujar, J. M., 2007. A New Application of the Buck-Boost-Derived Converters to Obtain the I-V Curve of Photovoltaic Modules. *Power Electronics Specialists Conference*, pp.413–417.
- Erkaya, Y., Flory, I. and Marsillac, S.X., 2014. Development of a String Level I-V Curve Tracer. *2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*, pp. 3104–3107.
- Erkaya, Y., Moses, P. and Marsillac, S., 2016. On-site characterization of PV modules using a portable, MOSFET-based capacitive load. *June 2016 IEEE*, pp. 3119–3122.
- Hernday, P., 2011. Field Applications for I-V Curve Tracers. *SolarPro*, (4.5).
- Lima, N.N. et al., 2013. Low Complexity System for Real-time Determination of Current-Voltage Characteristic of PV Modules and Strings. *Applied Power Electronics Conference and Exposition (APEC)*, March 2013 IEEE, pp. 2817–2823.

Muñoz, J. and Lorenzo, E., 2006. Capacitive Load Based on IGBTs for on-site Characterization of PV Arrays. *Solar Energy*, 80(11), pp.1489–1497.

Riley, C.W. and Tolbert, L.M., 2015. An Autonomous Online I-V tracer for PV Monitoring Applications. *IEEE Power and Energy Society General Meeting*, 2015–Septe.

Sharp, G., 2014. Sepic Converter Design and Operation, s.l.: degree, WPI .

Willoughby, A.A., Omotosho, T. V. and Aizebeokhai, A.P., 2014. A Simple Resistive Load I-V Curve Tracer for Monitoring photovoltaic module characteristics. *IREC 2014 - 5th International Renewable Energy Congress*, pp.1–6.

## APPENDICES

### APPENDIX A: Arduino Programming

```

#include <SD.h>
#include <LiquidCrystal.h>
#include <SPI.h>
#include <Wire.h>
#include <Adafruit_ADS1015.h>
#include <RTCLib.h>
#include <EEPROM.h>
#include <EEPROMAnything.h>

Adafruit_ADS1115 ads1(0x49);
//define address of external ADC, ads1115 VDD channel 1
Adafruit_ADS1115 ads2(0x48);
//define address of external ADC, ads1115 GND channel 2
LiquidCrystal lcd1(8, 7, 6, 5, 4, 3, 2); //define pin for LCD 1
LiquidCrystal lcd2(8, 7, 9, 5, 4, 3, 2); //define pin for LCD 2
RTC_DS1307 RTC; //define the Real Time Clock object
File dataFile; //define data logging file
const int chipSelect = 10; //chip select 10 for Data Shield on Mega
byte logMode = 0; //to check logMode
const int button = 14; //START button
int16_t adc0, adc1, adc2, adc3;
// read from the ADC, have a 16-bit integer as a result
int currentAddress = 0; //declare address of EEPROM in Arduino
int Rratio = 11;
float offvoltage1 = 2.465;
float offvoltage2 = 2.476;
float readSensor1, readSensor2;
// use to monitor the voltage of capacitor while discharging
char timestamp [30];

```



```

struct{
  float Voltage1 = 0.0;
  float Current1 = 0.0;
  float Voltage2 = 0.0;
  float Current2 = 0.0;
} IV;

void dateTime(uint16_t* date, uint16_t* time) {
  DateTime now = RTC.now();
  sprintf(timestamp, "%02d:%02d:%02d %02d/%02d/%02d \n",
now.hour(),now.minute(),now.second(),now.month(),now.day(),now.year()-2000);
  // return date using FAT_DATE macro to format fields
  *date = FAT_DATE(now.year(), now.month(), now.day());
  // return time using FAT_TIME macro to format fields
  *time = FAT_TIME(now.hour(), now.minute(), now.second());
}

void setup() {
  pinMode(30, OUTPUT); // to turn on discharge mosfet1 in first set of IV tracer
  pinMode(31, OUTPUT); // to turn on charge mosfet1 in first set of IV tracer
  pinMode(32, OUTPUT); // to turn on discharge mosfet2 in second set of IV tracer
  pinMode(33, OUTPUT); // to turn on charge mosfet2 in second set of IV tracer

  //to make sure all mosfets are OFF at the beginning
  digitalWrite(30, LOW);
  digitalWrite(31, LOW);
  digitalWrite(32, LOW);
  digitalWrite(33, LOW);
  Serial.begin (9600);
  ads1.begin();
  ads2.begin();
  lcd1.begin(16, 2);
  lcd2.begin(16, 2);
}

```

```
pinMode(button, INPUT); //button as input at pin 14
lcd1.print("Welcome!");
delay(500);
lcd1.clear();
lcd2.print("Standby...");
lcd2.clear();
Serial.print("Initializing SD card...");
lcd1.print("Initializing ");
lcd1.setCursor(0, 1);
lcd1.print("SD card...");
delay(500);
lcd1.clear();
pinMode(53, OUTPUT); //set 53 as output for MEGA

//check if the card is present and initialized
while (!SD.begin(10, 11, 12, 13)) {
  Serial.println("Card not insert or failed!");
  lcd1.print("Card not insert");
  lcd1.setCursor(0, 1);
  lcd1.print("or failed!");
  delay(500);
  lcd1.clear();
}
Serial.println("Card initialized!");
lcd1.print("Card ");
lcd1.setCursor(0, 1);
lcd1.print("initialized!");
delay(500);
lcd1.clear();
}
```

```
void loop() {
  if (digitalRead(button) == HIGH) {
    logMode = 1; //button pressed
  }else {
    logMode = 0; //button not pressed
  }
  if (logMode == 0) {
    lcd1.print("Press to START...");
    lcd2.print("Standby...");
    delay(100);
    lcd1.clear();
    lcd2.clear();
  }else
    datalog(); //if pressed, go to datalog
}

void datalog() {
  logMode = 1;
  do {
    //open file to log data
    Serial.println("Opening file...");
    lcd1.print("Opening File...");
    delay(500);
    lcd1.clear();
    char filename[] = "LOGGER00.CSV";
    for (uint8_t i = 0; i < 100; i++) {
      filename[6] = i / 10 + '0';
      filename[7] = i % 10 + '0';
      if (!SD.exists(filename)) {
        //only open a new file if it doesn't exist
        dataFile = SD.open(filename, FILE_WRITE);
        break; //leave the loop.
      }
    }
  }
}
```

```

//kickstart the Real Time Clock
Wire.begin();
RTC.begin();
if (!RTC.begin()) {
  Serial.println("RTC failed");
}
// set date time callback function
SdFile::dateTimeCallback(dateTime);
DateTime now = RTC.now();
sprintf(timestamp, "%02d:%02d:%02d %02d/%02d/%02d \n",
now.hour(),now.minute(),now.second(),now.month(),now.day(),now.year()-2000);
Serial.print(timestamp);

if (!dataFile) {
  Serial.println("Error opening file!");
  lcd1.print("Error opening ");
  lcd1.setCursor(0, 1);
  lcd1.print("file!");
  delay(500);
}else {
  Serial.println("Logging to:");
  Serial.println(filename);
  lcd1.print("Logging to:");
  lcd1.setCursor(0, 1);
  lcd1.print(filename);
  delay(1000);
  lcd1.clear();
}
//print the header
dataFile.println("Timestamp,Voltage(1),Current(1),Voltage(2),Current(2)");

```

```
// discharge the capacitor
digitalWrite(30, HIGH);
digitalWrite(31, LOW);
digitalWrite(32, HIGH);
digitalWrite(33, LOW);
readSensor1 = ads1.readADC_SingleEnded(0)* 0.1875E-3 * Rratio;
readSensor2 = ads2.readADC_SingleEnded(0)* 0.1875E-3 * Rratio;

while ((readSensor1 > 0.02) || (readSensor2 > 0.02)){
  readSensor1 = ads1.readADC_SingleEnded(0)* 0.1875E-3 * Rratio;
  readSensor2 = ads2.readADC_SingleEnded(0)* 0.1875E-3 * Rratio;
  if (readSensor1 > 133)
    readSensor1=0.00;
  if (readSensor2 > 133)
    readSensor2=0.00;
  lcd1.clear();
  lcd2.clear();
  lcd1.setCursor (0,0);
  lcd1.print ("Discharging...");
  lcd2.setCursor (0,0);
  lcd2.print (readSensor1);
  lcd2.print (" V");
  lcd2.setCursor (0,1);
  lcd2.print (readSensor2);
  lcd2.print (" V");
  delay(500);
}
lcd1.clear();
lcd2.clear();
lcd1.setCursor (0,0);
lcd1.print ("Done!");
delay(500);
```

```

digitalWrite (30, LOW);
digitalWrite (31, LOW);
digitalWrite (32, LOW);
digitalWrite (33, LOW);
adc0 = ads1.readADC_SingleEnded(0);
//read voltage at the 1st channel of external ADC, ADS1115 from 1st IV tracer input
adc1 = ads1.readADC_SingleEnded(1);
//read current at the 2nd channel of external ADC, ADS1115 from 1st IV tracer input
adc2 = ads2.readADC_SingleEnded(0);
//read voltage at the 1st channel of external ADC, ADS1115 from 2nd IV tracer input
adc3 = ads2.readADC_SingleEnded(1);
//read current at the 2nd channel of external ADC, ADS1115 from 2nd IV tracer input
IV.Voltage1 = (adc0 * 0.1875E-3) * Rratio;
// scale factor of ADC is 0.1875 mV per bit
IV.Current1 = (adc1 * 0.1875E-3 - offvoltage1)/100E-3 ;
// scale factor of ADC is 0.1875 mV per bit, the sensitivity is 100 mV per Amp
IV.Voltage2 = (adc2 * 0.1875E-3) * Rratio;
//scale factor of ADC is 0.1875 mV per bit
IV.Current2 = (adc3 * 0.1875E-3 - offvoltage2)/100E-3 ;
// scale factor of ADC is 0.1875 mV per bit, the sensitivity is 100 mV per Amp

lcd1.setCursor (0,0);
lcd1.print ("Start");
lcd1.setCursor (0,1);
lcd1.print ("Charging...");
delay(500);
lcd1.clear();
lcd1.setCursor (0,0);
lcd1.print(IV.Voltage1);
lcd1.print("V");
lcd1.setCursor (0,1);
lcd1.print (IV.Current1);
lcd1.print("A");

```

```

lcd2.setCursor (0,0);
lcd2.print(IV.Voltage2);
lcd2.print("V");
lcd2.setCursor (0,1);
lcd2.print (IV.Current2);
lcd2.print("A");
delay (500);

//charging the capacitor
digitalWrite (30, LOW);
digitalWrite (31, HIGH);
digitalWrite (32, LOW);
digitalWrite (33, HIGH);

for (int i=0; i<60; i++) {
  adc0 = ads1.readADC_SingleEnded(0);
  //read voltage at the 1st channel of external ADC, ADS1115 from 1st IV tracer input
  adc1 = ads1.readADC_SingleEnded(1);
  //read current at the 2nd channel of external ADC, ADS1115 from 1st IV tracer input
  adc2 = ads2.readADC_SingleEnded(0);
  //read voltage at the 1st channel of external ADC, ADS1115 from 2nd IV tracer input
  adc3 = ads2.readADC_SingleEnded(1);
  //read current at the 2nd channel of external ADC, ADS1115 from 2nd IV tracer input
  IV.Voltage1 = (adc0 * 0.1875E-3) * Rratio;
  // scale factor of ADC is 0.1875 mV per bit
  IV.Current1 = (adc1 * 0.1875E-3 - offvoltage1)/100E-3 ;
  // scale factor of ADC is 0.1875 mV per bit, the sensitivity is 100 mV per Amp
  IV.Voltage2 = (adc2 * 0.1875E-3) * Rratio;
  //scale factor of ADC is 0.1875 mV per bit
  IV.Current2 = (adc3 * 0.1875E-3 - offvoltage2)/100E-3 ;
  // scale factor of ADC is 0.1875 mV per bit, the sensitivity is 100 mV per Amp

```

```

EEPROM_writeAnything (currentAddress, IV); //store everything into EEPROM
currentAddress = currentAddress + 16;
// increment the EEPROM address ie. 1 value = 4 bytes, 4 values = 16 bytes
}

```

```

digitalWrite (30, LOW);
digitalWrite (31, LOW);
digitalWrite (32, LOW);
digitalWrite (33, LOW);
//reset the EEPROM address and store everything in EEPROM into SD card
currentAddress = 0;

```

```

for (int i=0; i<60; i++){
  EEPROM_readAnything(currentAddress, IV);
  //DATA LOGGING
  DateTime now;
  // fetch the time
  now = RTC.now();
  // log time
  dataFile.print(now.year(), DEC);
  dataFile.print("/");
  dataFile.print(now.month(), DEC);
  dataFile.print("/");
  dataFile.print(now.day(), DEC);
  dataFile.print(" ");
  dataFile.print(now.hour(), DEC);
  dataFile.print(":");
  dataFile.print(now.minute(), DEC);
  dataFile.print(":");
  dataFile.print(now.second(), DEC);
  dataFile.print(",");
  Serial.print(now.year(), DEC);
  Serial.print("/");

```



```
Serial.print(now.month(), DEC);
Serial.print("/");
Serial.print(now.day(), DEC);
Serial.print(" ");
Serial.print(now.hour(), DEC);
Serial.print(":");
Serial.print(now.minute(), DEC);
Serial.print(":");
Serial.print(now.second(), DEC);
Serial.println("");

//log sensor values
dataFile.print(IV.Voltage1);
dataFile.print(",");
dataFile.print(IV.Current1);
dataFile.print(",");
dataFile.print(IV.Voltage2);
dataFile.print(",");
dataFile.print(IV.Current2);
dataFile.println("");

//DISPLAY IN SERIAL MONITOR
Serial.print("VOLTAGE(1) : ");
Serial.print(IV.Voltage1);
Serial.println(" Volt");
Serial.print("CURRENT(1) :");
Serial.print(IV.Current1);
Serial.println(" Amps");
Serial.print("VOLTAGE(2) : ");
Serial.print(IV.Voltage2);
Serial.println(" Volt");
Serial.print("CURRENT(2) :");
Serial.print(IV.Current2);
```

```

Serial.println(" Amps");
Serial.println(""); // print the next sets of parameter after a blank line

lcd1.setCursor (0,0);
lcd1.print(IV.Voltage1);
lcd1.print("V");
lcd1.setCursor (0,1);
lcd1.print (IV.Current1);
lcd1.print("A");
lcd2.setCursor (0,0);
lcd2.print(IV.Voltage2);
lcd2.print("V");
lcd2.setCursor (0,1);
lcd2.print (IV.Current2);
lcd2.print("A");
currentAddress = currentAddress + 16;
dataFile.flush();
}
delay (500);

// discharge the capacitor
digitalWrite(30, HIGH);
digitalWrite(31, LOW);
digitalWrite(32, HIGH);
digitalWrite(33, LOW);
readSensor1 = ads1.readADC_SingleEnded(0)* 0.1875E-3 * Rratio;
readSensor2 = ads2.readADC_SingleEnded(0)* 0.1875E-3 * Rratio;

while ((readSensor1> 0.02) || (readSensor2> 0.02)){
  readSensor1 = ads1.readADC_SingleEnded(0)* 0.1875E-3 * Rratio;
  readSensor2 = ads2.readADC_SingleEnded(0)* 0.1875E-3 * Rratio;
if (readSensor1 > 133)
  readSensor1=0.00;

```

```
if (readSensor2 > 133)
  readSensor2=0.00;

  lcd1.clear();
  lcd2.clear();
  lcd1.setCursor (0,0);
  lcd1.print ("Discharging...");
  lcd2.setCursor (0,0);
  lcd2.print (readSensor1);
  lcd2.print (" V");
  lcd2.setCursor (0,1);
  lcd2.print (readSensor2);
  lcd2.print (" V");
  delay(500);
}
lcd1.clear();
lcd2.clear();
lcd1.setCursor (0,0);
lcd1.print ("Done!");
delay(500);

digitalWrite (30, LOW);
digitalWrite (31, LOW);
digitalWrite (32, LOW);
digitalWrite (33, LOW);
lcd1.clear();
lcd2.clear();
lcd1.setCursor (0,0);
lcd1.print ("Press the RESET");
lcd1.setCursor (0,1);
lcd1.print ("Button for");
lcd2.setCursor (0,0);
lcd2.print ("Next Measurement");
```

```
if (digitalRead(button) == HIGH) {  
  logMode = 0;  
}else {  
  logMode = 1;  
}  
delay (5UL*60UL*1000UL); // (minutes*seconds*milliseconds)  
lcd1.clear();  
lcd2.clear();  
}while (logMode == 1);  
}
```