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FINAL REPORT

LOW IRRADIATION CONCENTRATOR EFFECTS ON THE PHOTOVOLTAIC PANELS' PERFORMANCE

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LOW IRRADIATION CONCENTRATOR EFFECTS ON THE PHOTOVOLTAIC PANELS' PERFORMANCE

by

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LIST OF ABBREVIATIONS

MWT	*Metallisation Wrap-through*
EWT	*Emitter Wrap-through*
BJ	*Back-junction*
IBC	*Interdigitated Back Contact*
HIT	*Hetero-junction with Intrinsic Thin Layer*
US $	*United State Dollar*
RM	*Ringgit Malaysia*
PID	*Potential Induced Degradation*
LCPV	*Low Concentrated Photovoltaic*
HCPV	*High Concentrated Photovoltaic*
IDE	*Integrated Development Environment*
PWM	*Pulse Width Modulator*
SRAM	*Static Random Access Memory*
EEPROM	*Electrically Erasable Programmable Read-only Memory*
USB	*Universal Serial Bus*
VCC	*Voltage at Common Collector*
OUT	*Output*
GND	*Ground*

FF	*Fill Factor*

IMPAK PENUMPU IRADIASI RENDAH KE ATAS KEBERKESANAN SEL-SEL FOTOVOLTAIK

ABSTRAK

Sel-sel fotovoltaic telah menjadi salah satu penjana kuasa yang sering digunapakai dan mudah di era urban ini, di mana penjana-penjana kuasa yang mengunakan sumber tidak boleh diguna semula akan di tinggalkan dan disisihkan kerana kekurangan sumber. Objektif projek ini adalah untuk menyarankan peningkatan ke atas system jana kuasa di rumah untuk mencapai ketepatan yang lebih tinggi dengan memasang penumpu ke dalam system tersebut. Objektif lain bagi projek ini adalah untuk menetukan panel solar yang manakah yang terbaik antara yang berada di pasaran sekarang ini. Dengan mengkaji panel solar mana yang terbaik dan kesan penumpu ke atas panel fotovoltaik, pembelian dan pemasangan system solar yang terbaik dapat dilakukan di rumah. Data arus, voltan, suhu dan luminance cahaya telah direkod dan catat di dalam projek ini. Data yang telah disusun dan dipersembahkan dalam rajah dan juga lengkungan I-V dan P-V membantu untuk membuat konklusi. Keputusan akhir menunjukkan bahawa panel HIT adalah yang paling wajar berbanding yang lain dan penumpu memang memberi kesan terhadap kebolehan panel-panel solar tersebut.

LOW IRRADIATION CONCENTRATOR EFFECTS ON THE PHOTOVOLTAIC CELLS' PERFORMANCE

ABSTRACT

Photovoltaic cells have been one of the most used and convenient power generations in the urbanisation world where nowadays the resources that have been used as power generations is coming to an era where it will dried out and desolated. One of the objectives of this project is to make improvement to the existing power generations at home to get a higher efficiency of the solar panels by installing concentrators to its' systems. The other objective of the project is to investigate the best solar panels in the market nowadays. By investigating which one is the best among the popular solar panels and the effects of concentrator on photovoltaic panels, it can ease the purchasing and installation of the best systems at home. In the project, data of current, voltage, temperature and light luminance are measured and recorded. Tabulating and presenting the data in tables and also I-V and P-V curves can ease the conclusion making. The final results show that HIT is the desirable among all other 4 solar panels and the concentrators does have effects on the solar panels performance.

CHAPTER 1

INTRODUCTION

1.1 Background

Solar energy have been a popular electricity generation nowadays, due to the awareness of sustainability in human in this era of urbanization, thus mankind need to use more reusable resources compared to non-reusable one. Also compared to other reusable resources, solar energy are more efficient and can be collect anywhere around the world. This is compared to wind energy that needed strong wind to generate electricity and hydropower plant that would run out of electricity generation if dry season happen in certain area.

The photovoltaic actually absorbs the solar energy in the form of light and then convert them into a form of direct current. Solar energy generation depends on several variables to produce a good and steady flow of electricity. Which are type of photovoltaic cells, light intensity and thermal energy absorb by the solar panel. The type of photovoltaic cells that commonly being used are Polycrystalline Silicon, Mono-crystalline Silicon, Back contact, Amorphous and Hybrid [1]. In this project, only 4 types of photovoltaic solar panels are used which are mono-crystalline, polycrystalline, back contact and hetero-junction with intrinsic thin layer.

Firstly, the characteristics of the mono-crystalline silicon panels are that they are made of cylindrical crystal silicon from molten silicon. They are then cut into slices and shaped into hexagon. Mono-crystalline cells are one of the most efficient silicon type cells *with a rating of 13% to 16%. It is also known to be cells with space efficient advantage because the panels yield more power per unit. It also performed better in low light intensity that polycrystalline and can operate in cold conditions. On the other hand, they are more expensive in cost and time consuming to produce[1].*

Meanwhile for the polycrystalline silicon panels, they are made of molten silicon that is cooled under controlled conditions in a mould. Then they are sets irregularly into multi-crystal form before cut into slices. An extra feature for the polycrystalline cells are that it is coated with anti-reflective coating to ensure maximum absorption of light. Their efficiency is less than mono-crystalline with just 12% to 16%. To be compared in price, it is less expensive than mono-crystalline[1].

Next, for the back contact panels, it is like moving all or part of the front contact grid to rear of the panels or devices. The main characteristic is that it has higher efficiency due to reduction of shading on the front of the cells. There are 3 common type of back contact cells which are the metallisation wrap-through (MWT), emitter wrap-through (EWT) and back-junction (BJ) cell structures[2]. In the journal [2], it is stated that the metallisation wrap-through (MWT) are the most closely linked to the conventional cell structures.

Last but not least is the hetero-junction with intrinsic thin layer panels. This hetero-junction with intrinsic thin layer (HIT) panel was first used by Sanyo in 1992. There are 2 different type of semiconductor materials which are a-Si:H and c-Si that creates a pn-junction. It also contains an undoped "intrinsic" amorphous Si layers in between the p and n type materials with the thickness of a-Si:H layer that is less than 20 nm. The efficiencies are said to be up to 22% [24].

1.2 Problem Statements

Discovering the use of solar energy as one of the most eco-friendly source on Earth was a good discovery by human. Not like other sources which are not renewable, solar energy could not run out of resources. Which make them most likely to be used as power generation. But nowadays there are many types of solar panels that is sold in the market, which make us ask which one is the best of all. Also, as we picked the best solar panels, how else can it's power generation can be increased. Thus the idea of installing reflectors is made. But do the reflectors really have impact on the solar panels' performance.

1.3 Objectives

1. *To investigate the effects of low irradiation concentrator on various type of photovoltaic solar panels.*
2. *To compare the performance of poly-crystalline, mono-crystalline, back contact and hetero-junction with intrinsic thin layer photovoltaic solar panels under concentrator.*

1.4 Project Scope

This project is basically about testing and taking the reading from the solar panels to be compared to each other. The method that will be used in this project for the low irradiation concentrator is as below:

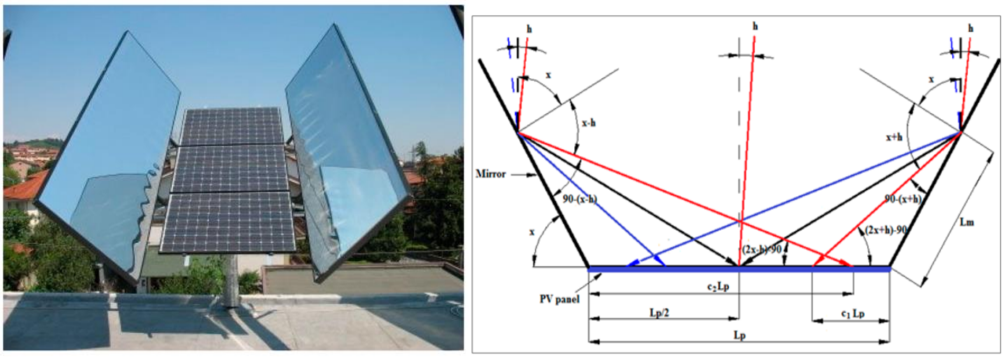

Figure 1: Simple type of concentrator (Left) and angle of the reflected rays from the sun (Right).

The solar panels that are being used are mono-crystalline silicon, polycrystalline silicon, back-contact and hetero-junction with intrinsic thin layer panels. The performance of the cells were measured and compared throughout the project. Also Arduino Nano is used to ease the measurement along-side with the solar charger, thermocouple and current sensor module.

1.5 Thesis Organisation

This thesis contains 5 main chapters. The first chapter mainly discuss basic information on the title of the project, problems that this project trying to encounter, objectives of the project and the project's scope. Next, in chapter two, the works that have been published which have relation with this project are discussed. Each and every components are mentioned here in chapter two.

Chapter three focused on the methods that will be used to obtain measurements and readings. Also the components and its' specifications are discussed. The readings and measurements are then used in chapter four to tabulate and present it as the results and topics for the discussion. Lastly, in chapter five, the results and discussions are combined and sum up to make the conclusion. Also the possible ways to improve this project are the discussed as the future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter covers the literature review of this project. This review covers in depth several photovoltaic technologies, their performance as well as low concentrator technologies for photovoltaic. However the concentrators that is commonly used are well-known of it's high in installation and maintenance values. These include the state of the art photovoltaic technologies such as Interdigitated Back Contact (IBC), Hetero-junction with Intrinsic Thin Layer (HIT), Pearl, Thin Film and Multi-junction solar panels.

2.2 Solar Panels

Solar panels work as the energy conversion from a solar energy to an electrical energy. In other words, it actually captures the photons in the sunlight and let them push the electrons of the atoms' bond, which basically generates electricity. Nowadays, they come in many types and sizes of well-known brands. Now every company that produced solar panels are racing to invent more efficient solar panels. They change the way it is made, they replace the materials inside the cells and also they introduced ways to make the panels be more efficient. Each and every one of them has their own advantages and disadvantages. Though there are many other types of solar cells in the market nowadays but these are among the most common solar panels which are mono-crystalline silicon, poly crystalline silicon, back contact, hybrid, amorphous silicon, thin film and also the technologies mention earlier such as IBC, HIT, Pearl, Thin Film and Multi-junction solar panels.

2.2.1 Mono-crystalline Silicon Solar Panel

Basically, this type of silicon solar panel is made up of primary silicon crystals. The procedure to make mono-crystalline silicon panels starts with a cylindrical crystal of silicon that is cut into thin-hexagonal layer which then fit together on the solar panels [1]. These mono-crystalline silicon panels have the efficiency up to 25% as wafers and 21.5% as thin film [3]. In the normal form, the mono-crystalline silicon solar panels have the efficiency of 15% to 19%. In addition, these type of solar panels are known to perform better in low light conditions compared to polycrystalline as well as it live longer than them [1]. This type of solar panels usually being sold with the rate of US $ 0.3 per Watt up to US $ 2.5 per Watt (from the alibaba.com website) and RM 389 to RM1050 for 80 Watt to 100 Watt (from the lelong.my website).

2.2.2 Polycrystalline Silicon Solar Panel

Composed primarily of silicon crystals same as mono-crystalline, but the molten silicon is inserted into a cast to get the shaped before cooled down in a mould. Then the sliced molten silicon are sets irregularly into multi-crystal form thus giving it the sparkled appearance [1]. The efficiency is said to be around 15% to 17% [4]. Compared to mono-crystalline silicon, polycrystalline silicon are simpler in procedure of making and also used less cost. Marketing price for polycrystalline nowadays are around RM200 for 50 Watts of power production (from the lelong.my website) and around RM599 for a 100 Watts(from the scomart.com website).

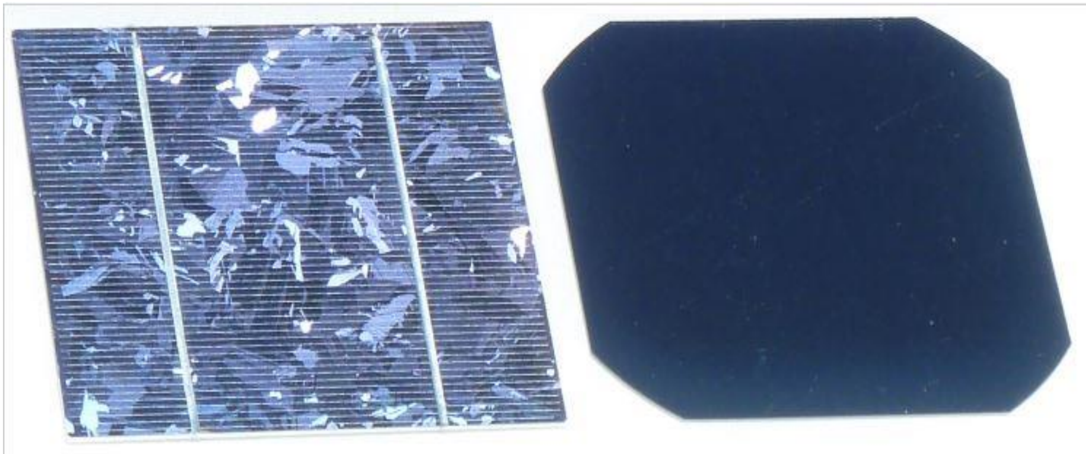

Figure 2.1 : Polycrystalline silicon cells on the left and mono-crystalline silicon cells on the right [1].

2.2.3 Interdigitated Back Contact Solar Panel

The main part of the mechanical structure of back contact cells are made up of silicon. Emitter part is located on the top or front of the surface. As extraction point, a metal grid is used in each of the silicon regions. Some back contact solar panels are built-in with a solid copper foundation, which virtually impervious to the corrosion and cracking of the panels. The back contact sells are expected to have the efficiency of 22% and above in large area scale [2]. In some cases and design, 27.6% of efficiency was measured from their system [5]. IBC are proven to work and delivers power in real-live condition such as cloudy day, low light and also high temperature conditions.

Figure 2.2 : The interdigitated back contact panel.

2.2.4 Hetero-junction with Intrinsic Thin Layer

HIT solar panels generate electricity simultaneously on the front and also on the back. The combination of the additional light on the back and the light taken up by the front of the panels contributes to higher power generations and efficiencies. The presence of the thin intrinsic layer of amorphous actually will balance the electrons and holes mobility thus reducing the loss of electron while it is moving towards the surface of the panel. This also elongated the depletion region of the electrons and holes of the panels.

HIT panels are proven to be more efficient in high temperature conditions due to its very low temperature coefficient that is -0.29%/^{o}C. This solar panel also is Potential Induced Degradation (PID) free. PID is an event or phenomenon where photovoltaic panels experience stray currents. This will make the solar panels degrade faster thus making them to not works at their best performance during their lifetime. The effect may cause power loss up to 19%.

Figure 2.3 : The hetero-junction with intrinsic thin layer panel.

2.2.5 Thin Film

Thin film solar panels are also one of the most popular energy generations in this new era. Their efficiencies are proven to achieve for about 7 to 16 %. Various type semi-conducting materials are stacked on top of each other to create the thin films. For various types of solar applications, thin films usually used with different photovoltaic substances. Thin films have the abilities to withstand high heat and also shading effects. Furthermore, thin films technologies are said to be relatively cheaper compared to other crystalline modules. Although thin films itself have advantages to attract customer, but there are 2 major flaws that are to be highlighted here which are space consuming and short lifespan.

Figure 2.4 : Thin film technologies composed of non-crystalline silicon deposited on a flexible material.

2.3 Concentrator

Concentrators are usually consists of one or more tilting mirror sets up to increase the performance or energy absorption of a certain solar panels. The tilting mirror normally comes in flat-plane and also in parabolic shaped. There are many configurations and types of concentrator nowadays, not only in the power generation industries but also homemade concentrator. These concentrators are basically invented to overcome the shading or low irradiation problems. In addition, concentrators are useful as a power generation booster during normal condition.

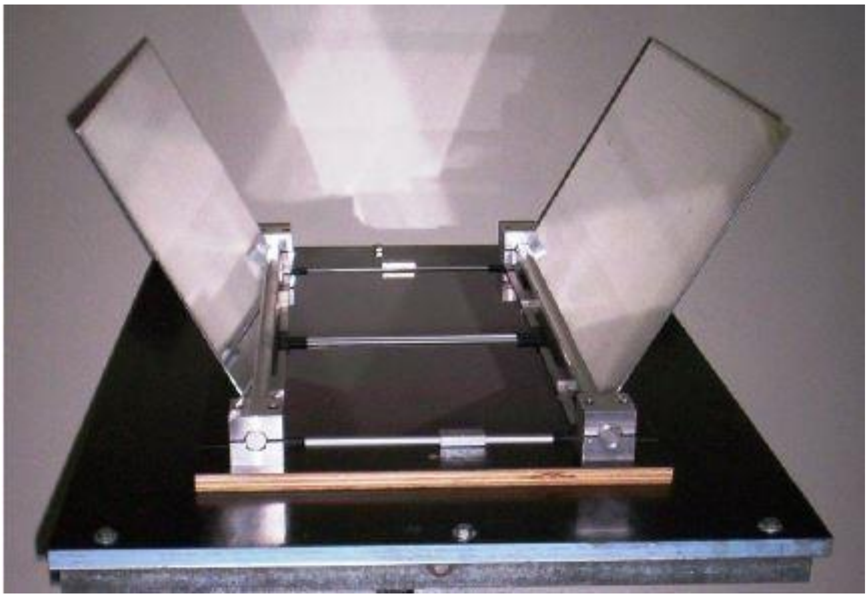

Figure 2.5 : A simple configuration of reflectors with 2 flat-plane mirror [6].

One of the concentrator is low concentrated photovoltaic (LCPV). It is easier compared to high concentrated photovoltaic (HCPV) in terms of costs, high tracker tolerances, reduced installation precision and passive heat sinks . It is also said to have an increased in output of 35% and above.

Also there is mirror based concentrator, this type of concentrator are in the group of low concentrator technologies. A mirror based concentrator usually concentrates for about 1 to 10 suns. Normally the construction of mirror based concentrator is simple and robust.

Figure 2.6 : Twin Reflector on both side of the panels.

Next is Fresnel reflectors. They are made of many thin, flat mirror strips acting as the concentrator of sunlight towards a tube with working fluid. Compared to the parabolic reflectors, Fresnel reflectors are flat, which capture more sunlight with same amount of space and also less in costs.

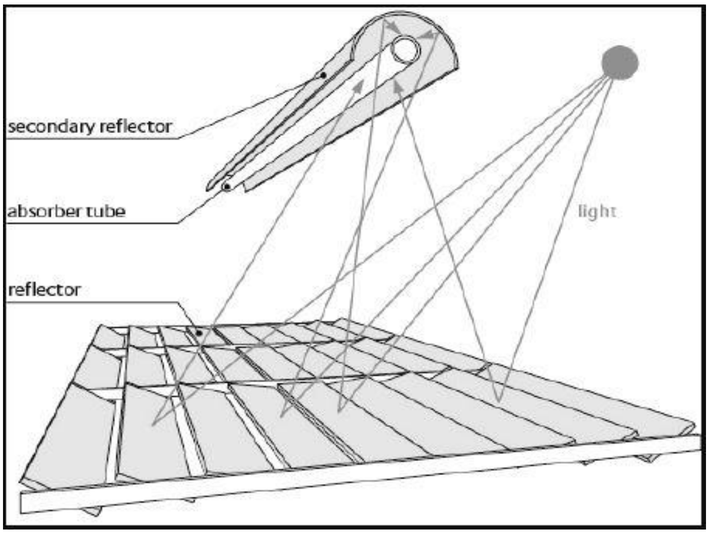

Figure 2.7 : Fresnel reflectors animated overview of how it absorb sunlight [7].

Other than that parabolic trough type is also well known nowadays. The configuration consists of linear parabolic reflectors arranged so that they concentrate light onto a receiver positioned directly above the middle point of the parabolic mirror. The receiver is a tube containing fluid, mostly molten salt. The molten is heated through the process and then act as the heating source for a power generation system.

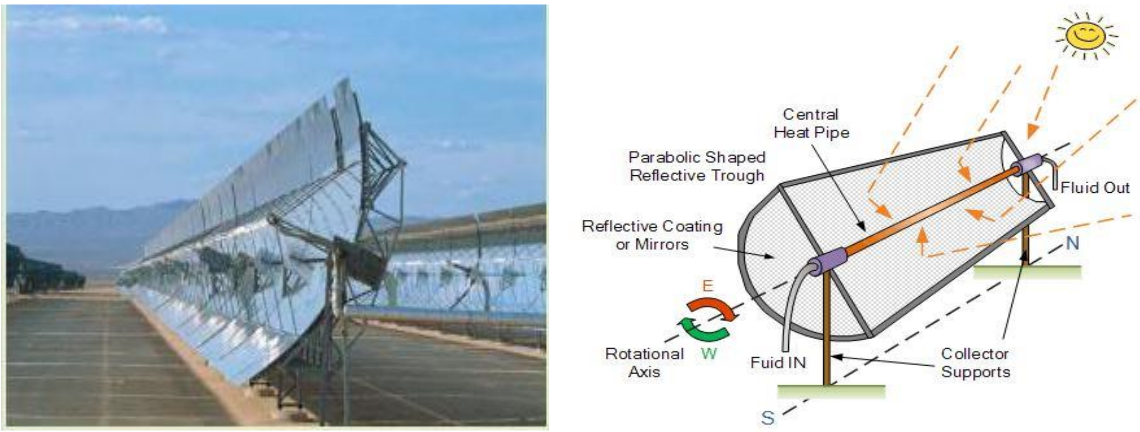

Figure 2.8 : A parabolic reflector (left) and the animated parabolic reflector and how it works (right) [8].

Last but not least is the dish Stirling. It is also known as the dish engine. This system consists of a stand-alone parabolic reflector that concentrates light onto a receiver that is positioned at the focal point of the parabolic mirrors. The reflector tracks the Sun.

Figure 2.9 : A dish Stirling reflector [6].

2.4 Solar Module Arduino

From their main websites, Arduino is open-source electronics platform that is easy and simple in both hardware and software. It is also said to be a way to make a certain project be more interactive. The products consists of boards for many features such as entry level, enhanced, internet of things, educational, wearable and also 3 dimensional printings. The software parts are mainly about the Arduino Integrated Development Environment (IDE) where you can control the system by giving them orders in code form. In this project, the Arduino Nano are used, alongside with current sensor, thermocouple and solar charger.

2.5 Summary

This chapter consists of theoretical background of the system. Three types of solar panels will be used to compare their characteristics with the presence of simple flat mirror reflectors. The Arduino part is the crucial part because it act as the brain of the system as it control the whole systems. These backgrounds are important before proceeding to Chapter 3. Chapter 3 will discusses more about implementing the needed and right hardware and software. Most of the techniques and theories from this chapter will be used in the next chapter in the development process.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter highlight the methodology of this project. First and foremost, the main objective of this project is to study the effects of low-irradiation concentrator to the performance of selected solar panels and also to differentiate their very own characteristics. Basically this project will be using three selected types of solar panels which are mono-crystalline silicon, polycrystalline silicon and back/rear contact solar panel. Basic Arduino solar module circuit are used to collect and measure the data and needed information. Later, the variables such as current, voltage, temperature and light luminance are measured and recorded. Thus ease in the plotting of the I-V and P-V curve which is used to determine and distinguish the characteristics of the panels among themselves.

3.2 Project Implementation Flow

The required steps for the designing and implementing of the proposed system are shown in a proper sequence as seen in **Figure 3.1** . *The flow chart is referred as a guideline throughout the project.*

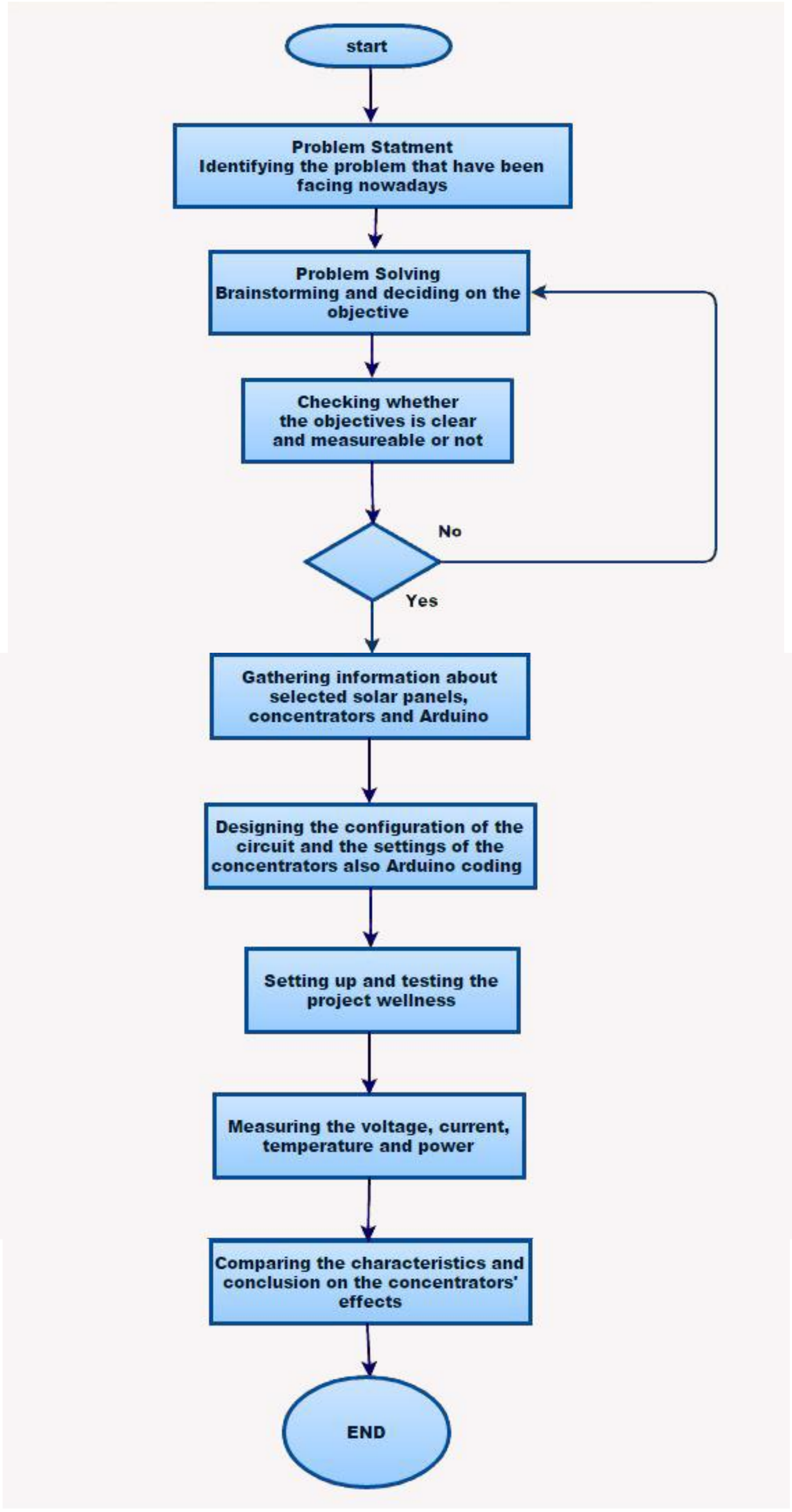

Figure 3.1 : Flowchart of the project from objectives to conclusion.

3.3 Project Requirement

In this section, all the rated values and specified items that are being used throughout the project.

3.3.1 Solar Panels

The solar panels that are being used in this project are mono-crystalline silicon cells, polycrystalline silicon cells and hetero-junction with intrinsic thin layer cells. The cells specifications are as shown in **Table 3.1, Table 3.2, Table 3.3 and Table 3.4** *below.*

Solar Module PM75 Mono-crystalline Silicon Panels

Table 3.1 : Specification of the solar module PM75 mono-crystalline silicon panels.

Maximum Power Rating, P_{max} (Wp)	*75 Watt*
Minimum Power Rating, P_{min} (Wp)	*73 Watt*
Rated Current, I_{MPP} (A)	*4.32 Ampere*
Rated Voltage, V_{MPP} (V)	*17.2 Volts*
Short Circuit Current, I_{SC} (A)	*4.87 Ampere*
Open Circuit Voltage, V_{OC} (V)	*21.6 Volts*
Dimension (cm^2)	*875 mm X 660mm*

BP Solar Polycrystalline Silicon Panels – BP 275$_F$

Table 3.2 : Rated values of the BP solar polycrystalline silicon panels – BP 275$_F$.

Nominal Peak Power, P_{max}	*75 Watt*
Minimum Power, P_{min}	*71.25 Watt*
Peak Power Voltage, V_{mp}	*17 Volts*
Peak Power Current, I_{mp}	*4.45 Ampere*
Short Circuit Current, I_{SC}	*4.45 Ampere*
Open Circuit Voltage, V_{OC}	*21.40 Volts*

Sunpower SPR-327NE-WHT-D Interdigitated Back Contact

Table 3.3: Specification of the Sunpower Interdigitated Back Contact panels.

Peak Power , P_{max}	*327 Watt*
Voltage , V_{mp}	*54.7 Volts*
Current , I_{mp}	*5.98 Ampere*
Open Circuit Voltage , V_{OC}	*64.9 Volts*
Short Circuit Current , I_{SC}	*6.46 Ampere*
Maximum Series Fuse	*20 Ampere*

Panasonic Hetero-junction with Intrinsic Thin Layer

Table 3.4 : Specification of the Panasonic hetero-junction with intrinsic thin layer panels.

Max. Power, P_{max} (W)	*240 Watt*
Max. Power Voltage, V_{mp} (V)	*43.6 Volts*
Max. Power Current, I_{mp} (A)	*5.51 Ampere*
Open Circuit Voltage, V_{OC} (V)	*52.4 Volts*
Short Circuit Current, I_{SC} (A)	*5.85 Ampere*
Maximum System Voltage	*1000 Volts*
Minimum P_{max}	*228 Watts*
Max. Overcurrent Rating (A)	*15 Ampere*
Dimension	*1580mm*798mm*

3.3.2 Arduino Nano

Arduino Nano is set to be the brain of the project's configuration. As the project's measurement and reading are based and controlled by the Arduino itself. Also to be able to control the subunits, the Arduino needed to be provided with coding to ensure it works based on what needed.

Arduino Nano operates under the input voltage in the range of 5 - 12 Volts. Contains 14 pins on board including 6 pulse width modulator (PWM) output and 6 analogue input pins. It also uses ATmega328 as the microcontroller with flash memory of 32KB, 2KB of SRAM and 1KB EEPROM. It has 16MHz of clock speed[9].

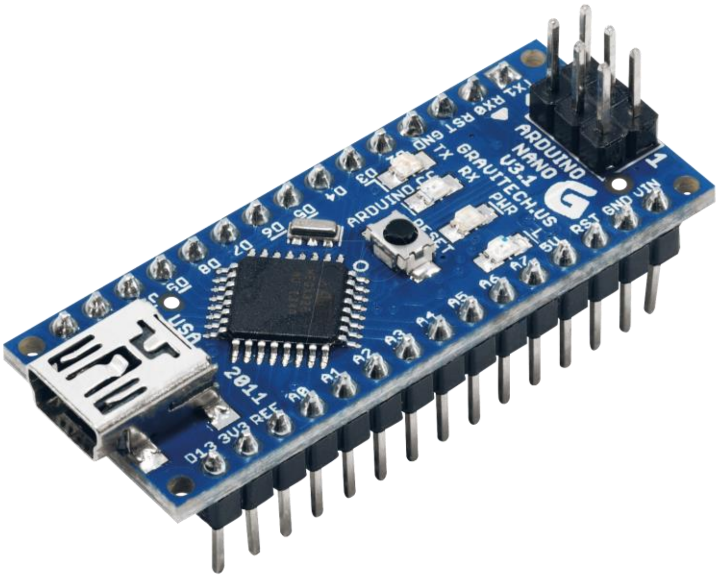

Figure 3.2 : The upper view of the Arduino Nano where all the pins and its name can be seen [9].

3.3.3 Thermocouple

Thermocouple type k with Sainsmart MAX6675 module are used in this project. The temperature range are said to be around 0°C ~ 1024°C. With the size of 15mm X 25mm, the thermocouple works in the range of 3.0 V ~ 5.5 V and 50mA.

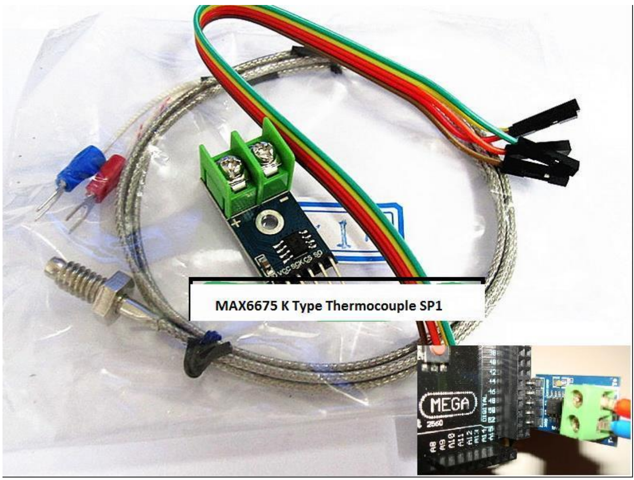

Figure 3.3 : Thermocouple type K for Arduino with it's probe [10].

3.3.4 Current Sensor

Current sensor is used to measure the current that flow through its' module and let it readable by the Arduino. The ACS712 sensor is used in this project scope with the ampere range of 5A. The power supply for this module is 5 Volts. The analogue output is 185mV/A (miliVotls per Ampere). The output voltage are halves of the VCC (VCC/2) only when there is no current detected [11].

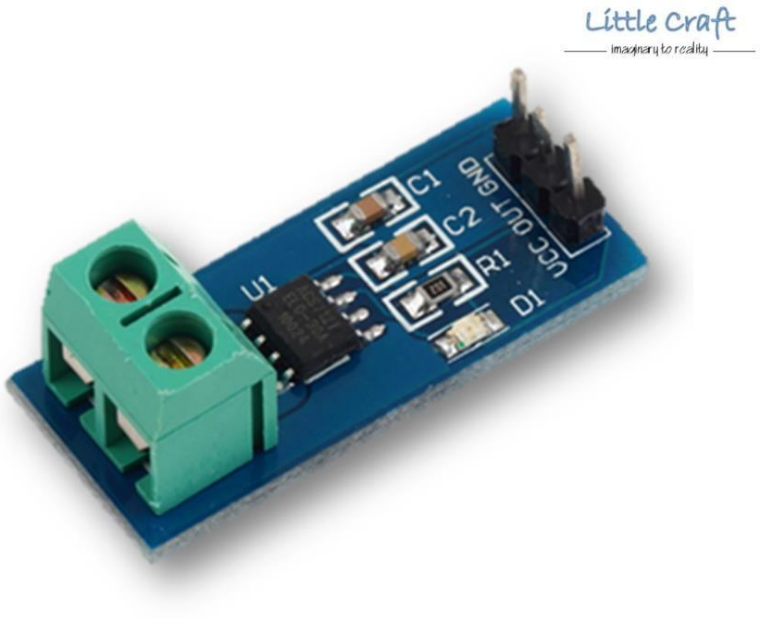

Figure 3.4 : The current sensor overview, left side is from the detector and the right side connected to the Arduino [11].

3.3.5 Concentrator

The term concentrator in this project refers to a basic configuration of 2 flat-plane mirror placed at both, left and right, side of the panels. The mirrors are held up in place by a homemade frame made up of aluminium profile. The frame is designed to be able to adjust the mirror angle from the ground to 30^o, 45^o *and* 60^o.

$$W \sin(\phi - 2\alpha) = R \sin \alpha \, , \; G = 1 + \cos 2\alpha \, . \qquad (1)$$

α & ϕ – *The angles of the sunlight*

W – Panels' width

R – Reflectors' size

G – Gain of the output

By referring to the equation above, α & ϕ *are the angles between the outside of the mirrors and the ground. The configuration of the mirror on the frame is as follows:*

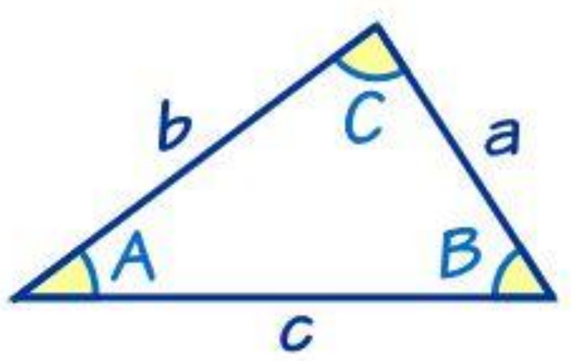

Figure 3.5 : The diagram that is used to solve the angle of the inclined mirror from the ground [12].