DESIGN AND DEVELOPMENT OF SINGLE-AXIS SOLAR TRACKING SYSTEM USING MICROCONTROLLER

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DESIGN AND DEVELOPMENT OF SINGLE-AXIS SOLAR TRACKING SYSTEM USING MICROCONTROLLER

by

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LIST OF ABBREVIATIONS

PV	Photovoltaic
LDR	Light Dependent Resistor
Hz	Hertz
lx	Lux
A	Ampere
V	Voltage
W	Watt
W/m^2	Watt Per Square Meter
^oC	Degree Celcius
AD	Analog Digital
DC	Direct Current
AC	Alternating Current
SD Card	Secure Digital Card
USB	Universal Serial Bus
STC	Standard Test Conditions

REKA BENTUK DAN PEMBANGUNAN SISTEM PENJEJAK SURIA SATU PAKSI MENGGUNAKAN PENGAWAL MIKRO

ABSTRAK

Penggunaan panel suria semakin meningkat sejak tahun-tahun kebelakangan ini kerana fungsinya menukarkan tenaga suria kepada tenaga elektrik. Sistem penjejak suria memainkan peranan penting untuk meningkatkan pengeluaran tenaga daripada panel suria. Dalam projek ini, sistem penjejak suria satu paksi telah direka bentuk dan dibangunkan untuk digunakan bersama peranti pv suria silikon. Dengan penjejak suria, ia akan menjana lebih banyak tenaga kerana dapat mengekalkan permukaan panel serenjang dengan cahaya matahari. Oleh itu, arah matahari dan kedudukan panel solar adalah penting. Projek ini membincangkan reka bentuk dan perkembangan penjejak suria yang mempunyai satu paksi kebebasan. Untuk penjejak ini, Perintang Bergantung Cahaya digunakan untuk mengesan kedudukan matahari. Untuk menganalisis prestasi panel suria, sensor telah digunakan untuk mengukur parameter panel. Operasi ini dikawal oleh pengawal mikro Arduino. Prestasi panel suria telah dianalisis berdasarkan dua keadaan iaitu bersama dengan sistem penjejakan suria dan pada kedudukan tetap. Kesimpulannya, sistem ini menghasilkan lebih banyak tenaga antara 18% sehingga 31% berbanding panel solar konvensional yang tidak menggunakan sistem penjejak kerana sistem ini meningkatkan kecekapan panel kerana panel tersebut terdedah kepada cahaya matahari beradiasi tinggi. Sistem ini merupakan teknologi yang dapat memberikan impak yang baik kepada setiap pengguna yang ingin prestasi panel suria pada keadaan optimum.

DESIGN AND DEVELOPMENT OF SINGLE-AXIS SOLAR TRACKING SYSTEM USING MICROCONTROLLER

ABSTRACT

The solar panel has been used increasingly in the recent years in converting the solar energy into electrical energy. Solar tracking system plays an important role in increasing the energy output of the solar panel. In this project, single-axis solar tracking systems have been designed and develop to be used with silicon photovoltaic device. With solar tracking, it will become possible to generate more energy since the solar panel can maintain a perpendicular profile to the light intensity of the sun. Thus, the tracking of the sun and positioning of the solar panel is important. This project discusses the design and develops of the solar tracking that has a single axis of freedom. For this tracker, Light Dependant Resistor is used to detect the position of the sun. To analyse the performance, sensors are used to measure the important parameters. This operation is controlled by an Arduino microcontroller. The performance of the solar panel is being analysed based on two conditions which are with the solar tracking system and pv panel at fixed position. As a result, this tracker system produces 18%-31% more output energy than conventional solar panels which do not use the tracking system because this system increases the efficiency of the panel since the panel is exposed to the light concentration of light from the sun. This system is the technology able to give a good impact to every consumer who is concerned to keep the performance of the solar panel at optimum level.

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, the world demand for energy is increasing proportionally with the world population. This problem will lead to shortage of fossil fuel, natural gas and coal sources in the future. Because of this problem, renewable energy has become an interesting topic for researchers, engineers and investors all around the world to provide an affordable and reliable source of energy for humanity. The type of renewable energy that getting attention included are solar energy, wind energy, thermal energy, hydropower and bioenergy. Among those types of energy, solar energy is considered as one of the main energy resources. This is because solar energy is clean and available in abundance and inexhaustible.

Solar energy is the energy where electricity is produced from solar panels by derived the sun rays into electrical current in the photovoltaic (PV) cells [1]. The effect of light on electrolytic cells or PV effect was discovered in 1839 by Becquerel [2]. However, even using solar energy, the efficiency of cell is limited because the challenge to harvest the energy. The challenging process of solar energy is to maximise the output produced by the PV cells which don’t receive a maximum amount of radiation of solar. This shows that there I still room for improvement. It is important to identify a solution to improve the efficiency of the solar panels.

A solar tracking system is the best example to explain the devices that orient the solar panel toward the sun. By using a solar tracking system, it can minimise the angle of incidence between the solar panels and the incoming light. At the same time, this system will maximise the electrical output produced by the PV cells.

The purpose of this project is to design and develop the single axis solar tracking system with microcontroller. This project consists of hardware and software application. In this project also include two parts which are electrical and mechanical parts. Both of this part will be designed by considering the performance, cost and efficiency. Single axis solar tracking system is one of the types of the solar tracker. Single axis solar tracking system is involves only one path of the sun. It will rotate the solar panel from east to west following the movement of the sun. Thus, the performance of the solar panel will increase the concentration of the sunlight because the sunlight is perpendicular to the solar cells.

1.2 PROBLEM STATEMENT

The performance of the solar power is related to the amount of the electricity that it can produce. The amount of the power generated depends on the temperature and the solar radiation intensity on the solar panel [3]. The intensity of solar radiation will affect the azimuth angle and zenith angle which both angles influence the incident of sunlight on the solar panel [4]. As a result, solar power will produce at the highest level of energy only when the sun is at the optimum angle toward to the solar panel.

Furthermore, most of the solar panel is installed securely which means it is at fixed position and does not follow the movement of the sun. Fixed solar panel will only produce highest output when the system reached its optimum levels. The performance of this system is not impressive and not efficient because it produced low output power. In order to generate maximum power output, the number of the solar panel is increased.

However, this solution uses a lot of space to place the solar panel and will increase the cost to harvest the solar energy.

1.3 OBJECTIVES

The objectives of this project are:

1. To design a single-axis solar tracking system using microcontroller that constantly tracking the sun during daytime.

2. To develop a solar tracking system that maximise the power output from the solar panel.

3. To test and evaluate the performance of the single axis solar tracking system using microcontroller.

1.4 PROJECT SCOPE

The scope of this project is designing and developing a single axis solar tracking system. The performance of the solar panel will be analysed based on two conditions which are with a single axis solar tracker and at the fixed position. This solar tracking system will let the solar panel to move only in horizontal axis. In this project, the measurement of the important parameters for the solar panel such as temperature, light intensity, voltage, current and power will be done by the sensor system. All the data measured will be saved on the SD card using a microcontroller named Arduino Uno.

1.5 PROJECT CONTRIBUTION

This project is done to design and develop a single axis solar tracking system. Since the world is working toward energy efficiency, the single axis solar tracking system will give the benefit to the solar energy industry. With this system, the solar panel arises to extract maximum solar energy. Besides that, this tracking system will provide more time to get available maximum power and produce greater capacity hours a day. Thus, there is no solar radiation can be waste compared to fixed solar panel installation. By using solar energy, it can reduce rapidly environmental damage and will contribute to green energy which can reduce the global warming. Other than that, since this project involves design and development process, the design can be simplified first before constructing the solar tracker and save the cost of the tracking system.

1.6 PROJECT OUTLINE

This report is organised into three chapters. The first chapter is the introduction that covers the background of the project, problem statement, objectives and project scope.

Chapter 2 covers the literature review of the project which includes the research made about the requirement and the components needed for the single axis solar tracking system. This chapter also discussed the fundamental knowledge about the efficiency of the solar energy.

Chapter 3 presents the project methodologies. All of the steps and the method implemented to carry out in this project are described in the form of flowchart and explanations. Hardware, software and algorithm were included in the design.

Chapter 4 presents the results and discussions. Results for the estimations and experiment from chapter 3 are provided in this chapter. Discussion s of the results is also presented in this chapter.

Chapter 5 concludes the whole project from the beginning to the end of the project. This chapter states the successiveness of the project, the limitation of the project and the recommendation for the future to improve this project further.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A solar tracking system is a device used to orient the solar panel toward the sun. The position of the sun is varied with time of day as the sun moves across their path. By using this system, solar energy can be generated at the optimum level as they are pointed directly to the sun. These trackers improve the efficiency of the solar energy system by maximising the output produced by the solar panel

PV systems or solar energy system is the one great primary sources of clean, abundant and inexhaustible energy that only provides alternative energy resources but also improves environmental pollution. Sunlight has two components, the direct beam that carries about 90% of the solar energy and diffuse sunlight that carries the remainder [5]. This system is possible because of the phenomenon called photovoltaic effect. The Photovoltaic effect occurred when the semiconductor undergoes the process of the conversion from solar energy to direct current electricity.

This chapter will be focusing on the engineering and practical aspects of the project such as the principle of solar cell, technique of solar tracking, solar tracking system and other factors that affect the efficiency and performance of solar panel. The information obtained here based on the thesis, journals and articles. Decision making in this project was made based on information in this chapter.

2.2 SOLAR RADIATION

Solar radiation is the energy released by the Sun. This radiation is the most abundant energy available on earth. Solar radiation also used to produce electricity which is known as photovoltaic solar energy. In northern of peninsular Malaysia, the monthly average amount of daily solar radiation is in between 4000 W/m^2 to 5000 W/m^2 [6]. Solar radiation measurement will be used to estimate the efficiency of the system from heating load. Figure 2.1 show the monthly average value of solar radiance in April 2011.

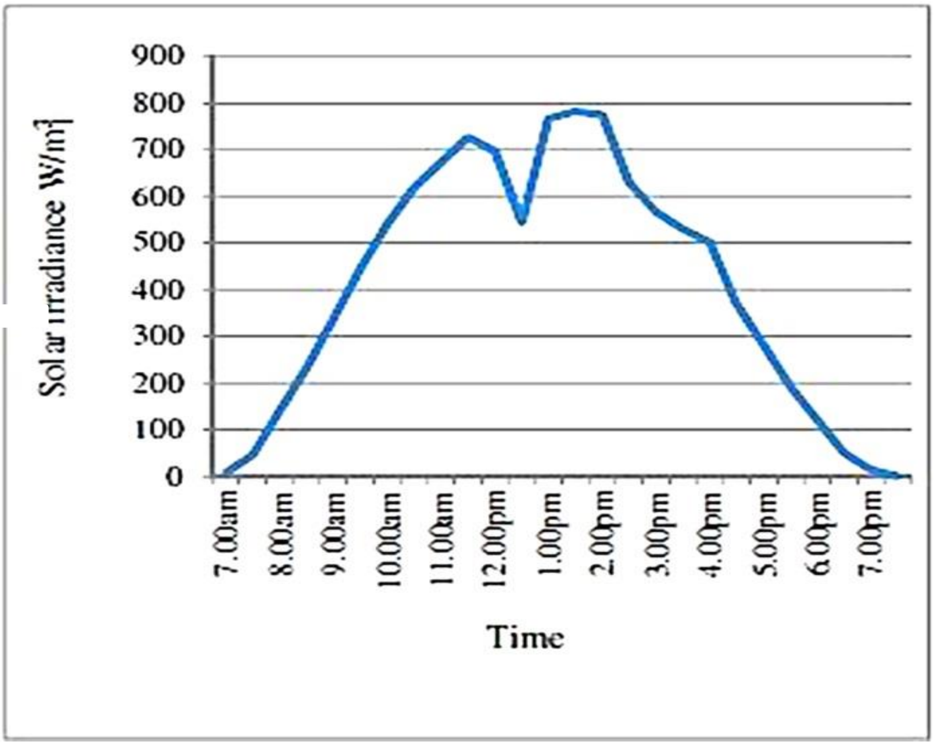


Figure 2.1: Monthly average of solar radiance [6]

Solar radiation can be categorise into three, such as direct solar radiation, reflected solar radiation and diffuse solar radiation [7]. Direct solar radiation is the type of radiation where the radiation reached surface of the earth directly from the sun without going through reflections and absorptions. Radiation from the sun that has been reflected by any surface is called reflected solar radiation. Lastly, diffuse solar radiation is the radiation reached surface of the earth but has been scattered by particles in the atmosphere.

2.3 PHOTOVOLTAIC EFFECT

A PV cell or solar cell is made up of semiconductor materials that convert solar energy to direct current electricity. In the material of semiconductor, the excitation range of energy is separated by a band gap. Band gap in this effect can be divided into two, which are valence band and conduction band. A valence band is generally occupied with electron of the material atoms while the conduction band is mostly empty. The amount of energy will be similar to the band gap when the electron is excited. Then the electron will jump to the conduction band and create a pair of electron-hole.

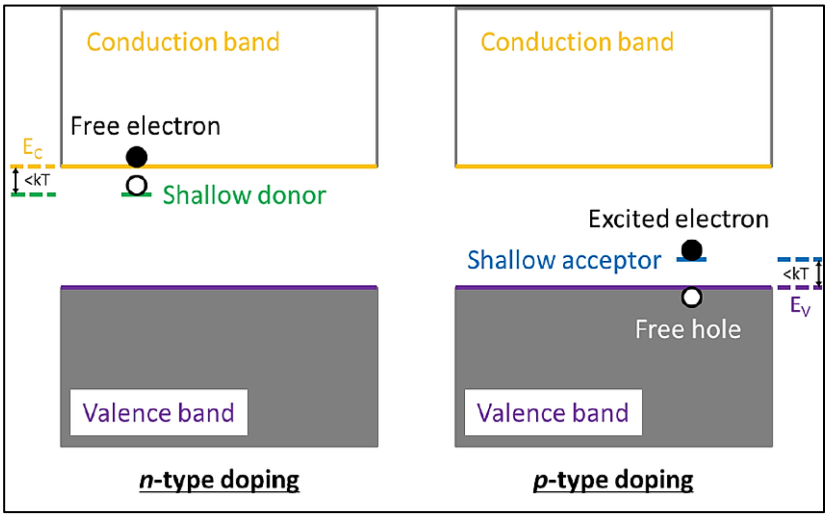


Figure 2.2: Excited doped semiconductor [8]

Based on Figure 2.2, its show that P-type semiconductor is lack of electrons in the covalence bond and N-type semiconductor has extra electrons from donor. By combined the P-type and N-type together, it will produce P-N junction. In a P-N junction, the holes from the P-type will diffuse to the N-side and vice versa for N side electrons. These will create a depletion region between both sides. In the depletion region, there is negative charged part of P-type and positive charge part of N-type. If the solar cell exposed to the photons of the sunlight, pairs of electron-hole are created in the depletion region and created an electric direct current, as shown in Figure 2.3.

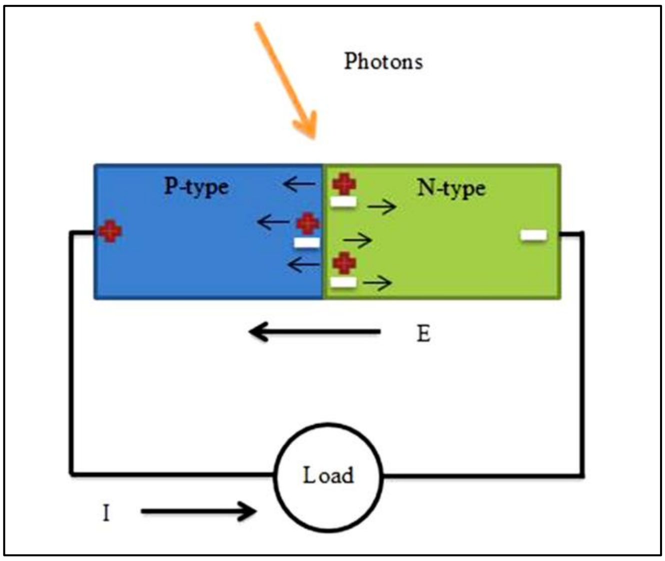


Figure 2.3: Schematic diagram of solar cell when an external circuit was connected to a P-N junction

2.4 EFFICIENCY OF SOLAR CELLS

This section will explain the details on the types of the solar cells that are available in the market. There are many types of the solar cells such as mono-crystalline silicon cells, poly-crystalline silicon cells, amorphous silicon cells and other types of cells. Crystalline silicon (c-Si) solar cells are the first generation of solar cell. Besides that, amorphous silicon (a-Si), copper indium gallium diselenide (CIGS), cadmium telluride (CdTe) and organic semiconductors are the second and third generation of solar cell [11]. Table 2.1 show that the efficiency of different solar cells.

Table 2.1: Efficiencies of different solar cells [9, 10, 11]

Solar cell materials	**Efficiency, η (%)**
Mono c-Si	25.0
Poly c-Si	20.4
a-Si	10.1
CIGS	20.3
CdTe	18.3
Organic semiconductors	10.7

Based on Table 2.1, mono-crystalline silicon the most efficient solar cell while organic semiconductors are the less efficient solar cell compared to the others. The efficiency is the most important parameter used to compare the performance of the solar cells.

The efficiency of is the product of output energy produced by solar panel over the input energy from the sun. Normally, this parameter is depending on the temperature of the solar cell, light intensity and incident angle of the sunlight. The efficiency of solar cells also can be defined as:

$$\eta = \frac{P_m}{E\,A_c} \qquad [12]$$

where, η = efficiency

P_m = maximum power point (W)

E = input of light irradiance (W/m^2)

A_c = surface area of the solar cell (m^2)

2.5 FACTOR THAT AFFECT THE EFFICIENCY OF SOLAR PANEL

The efficiency of the solar panel is referring to the amount of electrical power which is converted from solar energy. There are many different factors that affect the rate of efficiency of solar panel such as temperature, light intensity, incidence angle and shading.

2.5.1 TEMPERATURE

The efficiency of the solar panel is decreased when the temperature increases. The band gap of the semiconductor is reducing as the temperature rise. Under STC, when the temperature increases, the efficiency of the panel will drop about 0.40% - 0.50% [13]. This phenomenon will affect the parameters of the material such as open-circuit voltage, V_{OC} and short-circuit current, I_{SC}.

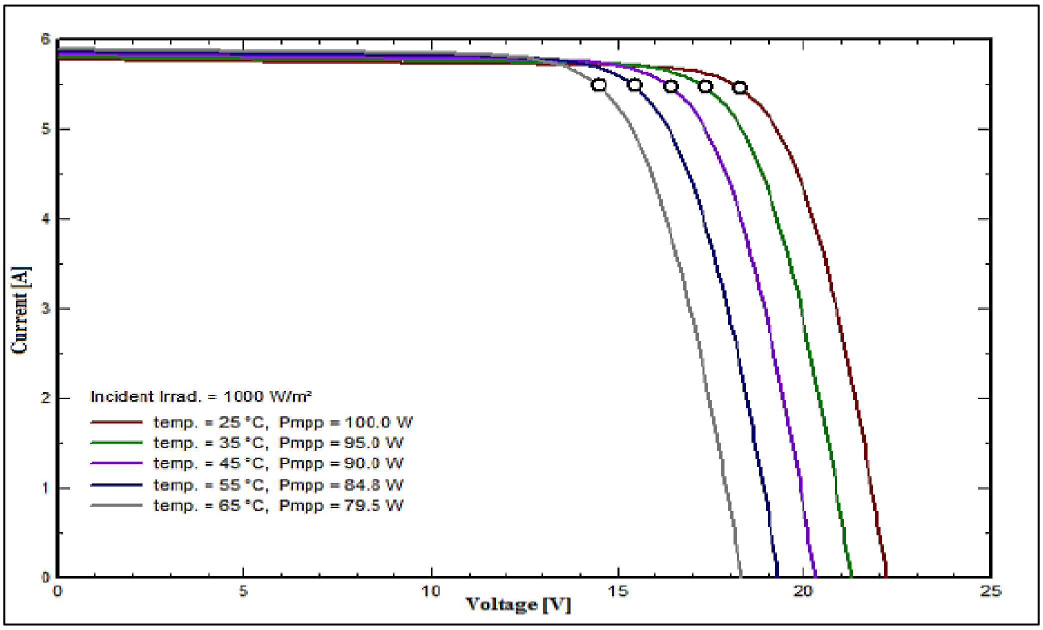


Figure 2.4: The effect of temperature on IV characteristics of solar cell [13]

From Figure 2.4, is shown that when the temperature increases, the short-circuit current will increase slightly while the major changes in open-circuit voltage.

2.5.2 LIGHT INTENSITY

The changing of the sunlight intensity on a solar cell will change all the parameters which include the efficiency, the short circuit current, the open circuit and the impact of series and also the shunt resistances. Therefore, the increase or decrease of the light intensity will affect the amount of output power generated from the solar panel.

.The luminous flux or the power of the sunlight is the parameters that commonly used to measure the light intensity of the sun [14]. A unit of luminous flux is lux (lx) and a unit of the power of sunlight is Watt per square meter (W/m^2). Table 2.2 shows the range of sunlight intensity in the unit of lux.

Table 2.2: Range of the sunlight intensity

Time of day	Luminous flux (lux)
Sunrise or sunset	300 – 500 lx
Overcast day	1000 lx
Daylight	10000 – 25000 lx
Direct sunlight	32000 – 130000 lx

2.5.3 INCIDENCE ANGLE

The efficiency of solar panel will increase if the panel is always facing the sun. The solar radiation is the highest at optimal incidence angle [15]. The angle of incidence for the horizontal surface is also known as the zenith angle. Zenith angle is the angle between the vertical axis and the sun. This angle is the product of 90^{o} minus the angle of the sun from the horizontal surface. In order to minimize the incident of light intensity on the solar panel, the solar panel must face perpendicular to the sun. Therefore, this will improve the efficiency of the solar energy.

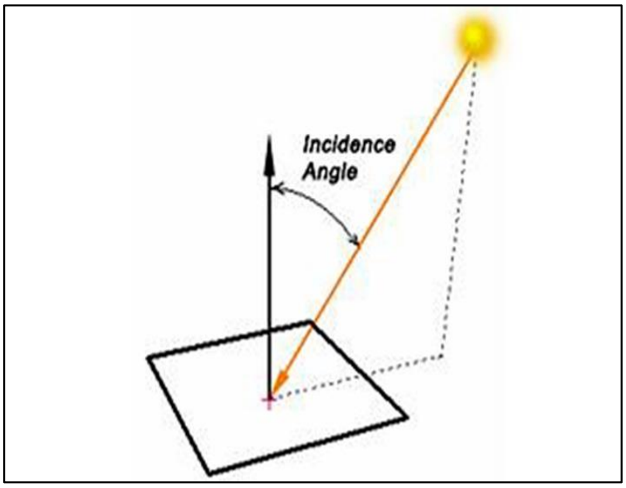


Figure 2.5: Angle of incidence [16]

2.5.4 SHADING

To maximize the efficiency of the solar panel, it should be located at a place where no shadow will interrupt the function of the solar panel. Even small part of shadow appears on the solar panel, it can result in a huge effect on the final output. The efficiency of the solar panel can reduce by up to 50% due to dust on the surface of solar panel [17]. When the solar radiation is higher, the effect of dust is reduced. Thus, to obtain the highest efficiency, the surface of the solar must be clean and free from dust.

2.6 ROTATION OF THE EARTH

Earth is the third planet in the solar system and turning around the sun. There are two motions of the earth which are rotation and revolution. The earth revolves around the sun and also rotates on its axis from west to east. The axis of the earth is passing through from the North Pole to the South Pole. This motion is responsible for the occurrence of the day and night which a solar day is. The sidereal of the completed rotation is 23 hours and 56 minutes. Therefore, the difference of the rotation takes about 4 minutes for every 1^o longitudes and this is due to the changing of the earth position toward to the sun [18].

Based on Figure 2.6, prime meridian is one of the longitudes and used as a reference point for world timing. Prime meridian is located at Greenwich in England and separates the longitudes into two parts which are west longitudes and east longitudes [14]. An equator is the located in the middle of the earth and divides the planet into two parts which are north hemisphere and south hemisphere.

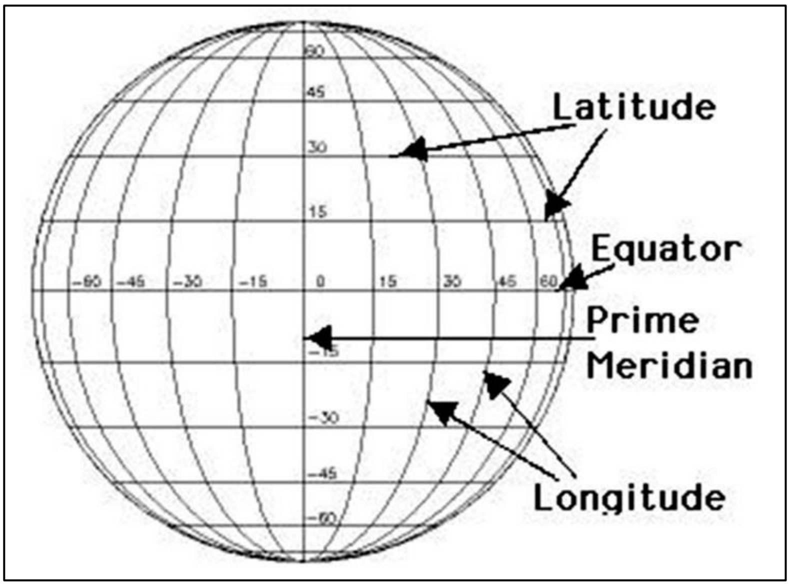


Figure 2.6: The earth's grid system [19]

2.7 TYPES OF SOLAR TRACKING SYSTEM

In solar tracking systems, solar panels are mounted on a structure which moves to track the movement of the sun throughout the day. There are three types of solar tracking system:

i. Active solar trackers

ii. Passive solar trackers

iii. Chronological solar trackers

These methods can be configuring either as a single-axis tracking system or dual axis tracking system.

2.7.1 ACTIVE SOLAR TRACKERS

In active tracking, the position of the sun in the sky during the day is continuously determined by sensors. The sensors will send the signal to the linear actuator or motor to move the tracker system. Thus, this makes the solar panels will always follow and face the sun throughout the day [20]. This type of tracker is mostly accurate except on very cloudy days when it is for the sensor to detect the higher intensity of light and position on the sun. So, the system will not track the position of the sun due to a low light intensity.

2.7.2 PASSIVE SOLAR TRACKERS

For passive tracking, the system will move in response to an imbalance in pressure between two points at the tracker. The imbalance in pressure is caused by the solar heat that created gas pressure on a low boiling point of the gas fluid which then moves the structure [20].

The advantage of the passive tracker is that the tracking technique does not require a controller but this tracker is slow in response and it's vulnerable to wind gusts. Unlike active tracking, this technique is not accurate because it depends on the temperature of the solar panel.

2.7.3 CHRONOLOGICAL SOLAR TRACKERS

The last part of the solar tracking techniques is the chronological tracking. The chronological tracking is the tracker uses a timer based tracking technique which will move the structure at a fixed rate throughout the day. The theory for chronological tracking technique is that the sun moves across the sky at a fixed rate. The actuator or motor is programmed to continuously rotate at the slow rate of 15 degrees per hour [20]. The disadvantage of the tracker is it consumed a lot of power and it has a problem to track the sun on a very cloudy day.

2.8 SOLAR TRACKING SYSTEM

Generally, there are two main groups that categorize the solar trackers:

i. Single axis tracking system

ii. Dual axis tracking system

2.8.1 SINGLE AXIS SOLAR TRACKING SYSTEM

A single axis solar tracking system follows the movement of the sun from east to west by rotating the structure along the vertical axis. The solar panels are usually tilted at a fixed angle corresponding to the latitude of the location. Furthermore, the use of single axis tracking can increase the electricity yield by as much as 27% to 32% [21]. Thus, a single axis tracking system can give a greater output power compared to a static solar panel.

This tracker can either have a horizontal axis or a vertical axis. It makes the system less complicated and less expensive than a double axis solar tracker. In addition, it is optimal to balances the performance with long-term reliability, high durability and minimal maintenance. The DC motor and gears control the movement of the solar tracker in order to optimize the utilization of the solar energy.

Based on Figure 2.7, it shows an example of horizontal single axis tracker. The horizontal type is used in regions near the equator where during noon; the sun is at its highest altitude in the sky while the vertical single axis tracker in Figure 2.8 is used mostly in high latitudes where the sun does not reach its highest altitude in the sky.

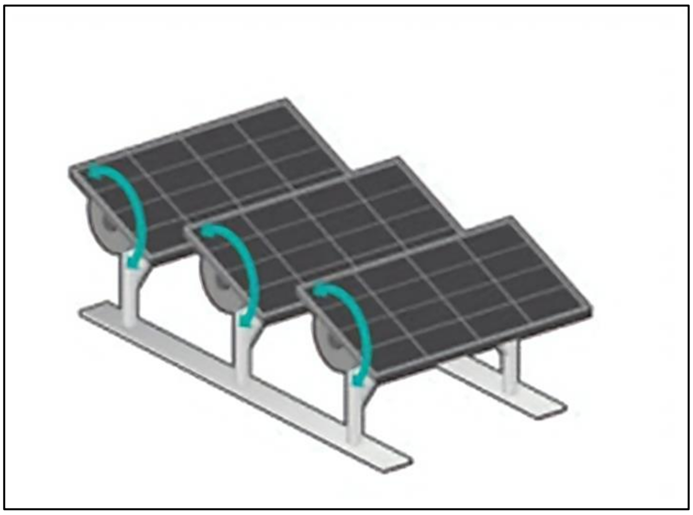


Figure 2.7: Horizontal single axis tracker [22]

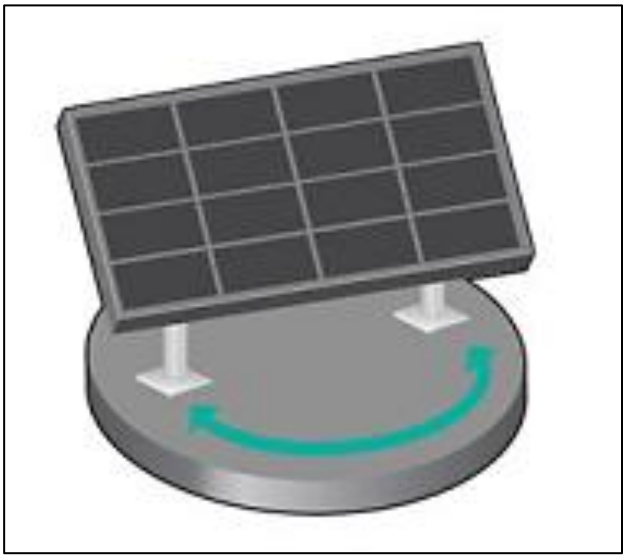


Figure 2.8: Vertical single axis tracker [22]

2.8.2 DUAL AXIS SOLAR TRACKING SYSTEM

The dual axis tracking system has two degrees of freedom that act as axes of rotation. Both axes are horizontal axis and vertical axis. This means that the panel can move from east to west and north to south direction for minimum absorption of sunlight. Two linear actuators or two motors were mounted on perpendicular axes and even aligned in a certain direction. In some design, both motors could not move at the same time. The horizontal axis and vertical axis are typically normal to each other. The primary axis is the one that is fixed with respect to the ground. The secondary axis is the one referenced to the primary axis.

The dual axis tracking system is used to improve the efficiency of the solar panel compared to the single axis solar tracker. The dual axis capability is essential since solar panels need to track the sun in a three-dimensional space using both azimuth and elevation drives [5]. Thus, by using dual axis tracking system it can increase the electricity output as much as 35% to 40% [21].

Figure 2.9: Dual axis solar tracking system [22]

2.9 SUMMARY

Briefly, the second chapter of this research project is mainly focusing on the concepts that need to be emphasizing in conducting the project. It is very important to analyse all the requirement need to design and develop a single axis solar tracking system. Besides that, this chapter is essential especially in understanding the interrelation between solar tracker system and other specification that has been discussed in this chapter that needs to be used to achieve the maximum result at the end of this research project.

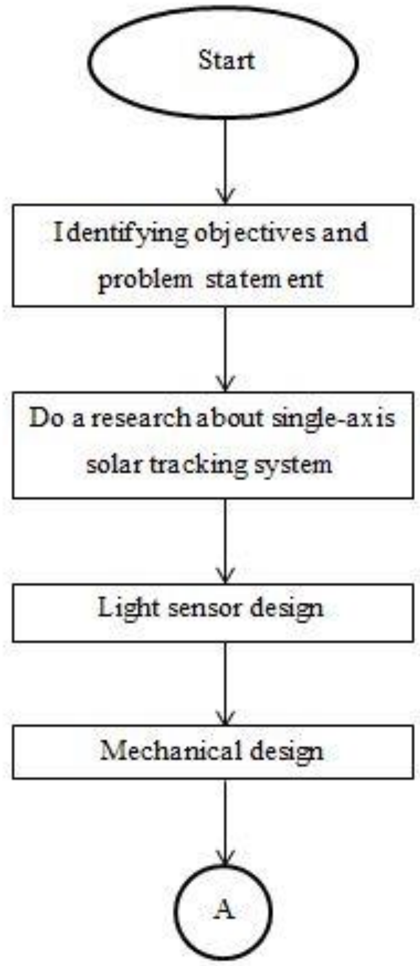
CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will be discussing about the methodology that has been taken in order to solve the problem that has been discussed in Chapter 2. In this chapter also will be explain in details about the flow of the project, system design, software development, sensor, project testing and the method applied.

As shown in Figure 3.1 below, a flow chart illustrates the planning of this project.



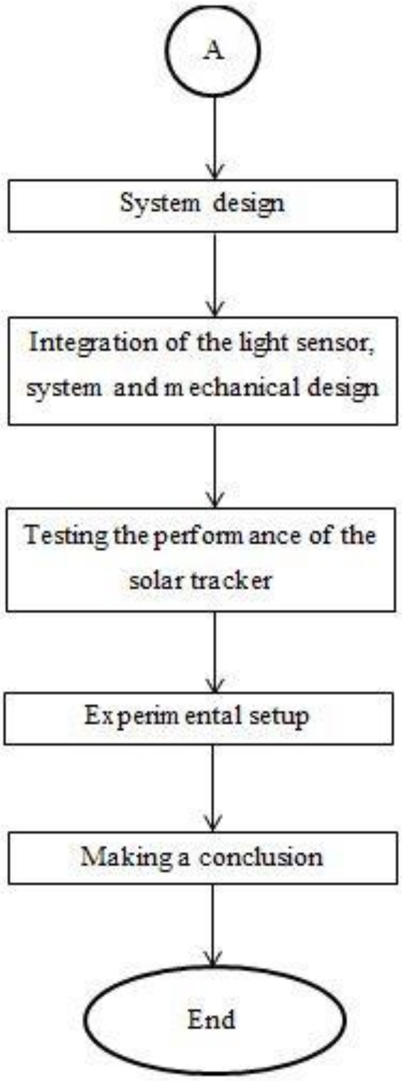


Figure 3.1: Flowchart for the design and development of the project

3.2 LIGHT SENSOR DESIGN

3.2.1 LIGHT DEPENDENT RESISTOR

Light dependent resistor (LDR) or photo resistor is the simplest and low cost light sensor available in market. The light dependent resistor is a sensitive light sensor that the resistance will change depending on the light intensity that falls upon it. There are two types of the LDR which are gallium arsenide (GaAs) and cadmium sulphide (CdS). In this project, two cadmium sulphide photoresistor is used to sense the light.

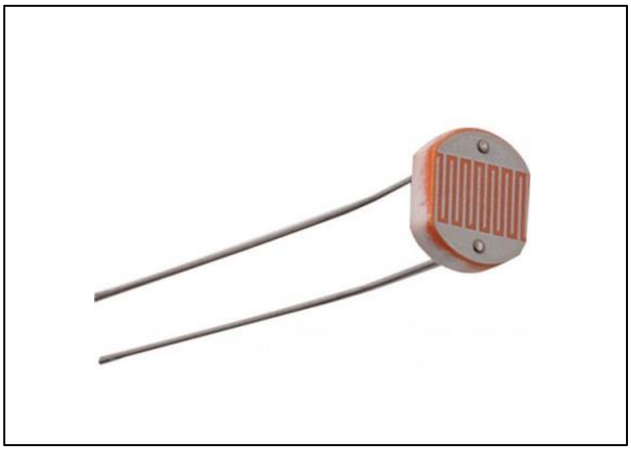


Figure 3.2: Light dependent resistor that used for the light sensor system [23]

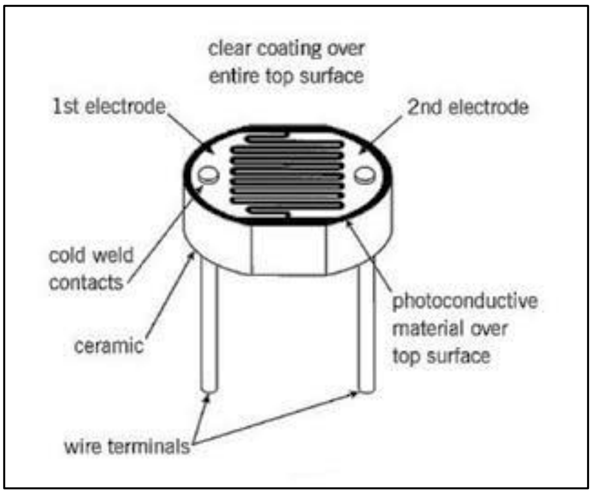


Figure 3.3: Construction of LDR [24]

The LDR is a passive sensor which the amount of the light intensity toward is inversely proportional to the resistance. This characteristic is a suitable for uses for the solar tracker based on its light saturation resistance and its dark resistance.

Typically, the LDR resistance is very high but resistance will drops dramatically when they are illuminated with light. This is because the resistance of LDR is high when the light intensity is low and vice versa. Figure 3.3show the construction of LDR.

In this project, a light sensor system is used to generate corresponding analog output by measuring the light intensity from the sun. This analog output value then will be converted to a digital output by the microcontroller. In order to get maximum light intensity from the sun, this sensor will compare the light intensity so it can move the solar panel on the horizontal axis. To utilize the LDR, 10 kΩ was placed in series with the LDR. A voltage divider was formed and the output from the divider was obtained. The divider was supplied with 5V to LDR and ground the remaining end of the resistor. The output voltage from the divider is converted to the digital value using ADC module of the microcontroller. The resistance of LDR was measured under several conditions such as bright light, dark light and average light conditions. The results of measurement and the voltage divider circuit are shown below.

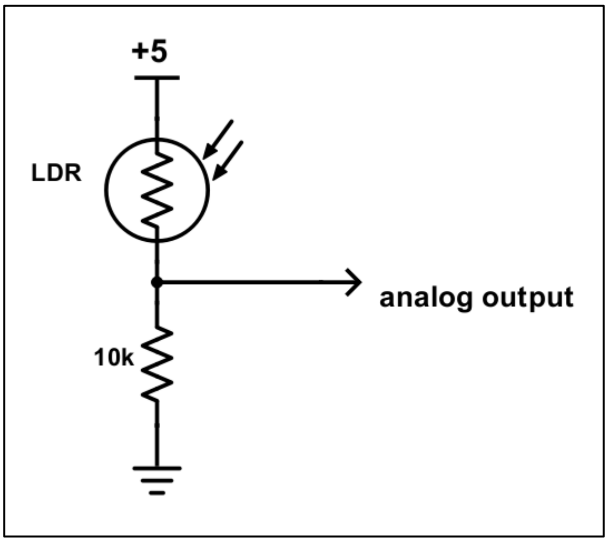


Figure 3.4: Schematic diagram of voltage divider