Faculty of Electrical Technology and Engineering

DEVELOPMENT OF SOLAR PV PERFORMANCE MEASUREMENT SYSTEM

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Bachelor of Electrical Engineering Technology with Honours

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DEVELOPMENT OF SOLAR PV PERFORMANCE MEASUREMENT SYSTEM

MOHAMAD ZAMRY AMIRUL BIN WASLI

A project report submitted
in partial fulfillment of the requirements for the degree of
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Sesi Pengajian : 2023/24

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I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours.

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DEDICATION

I dedicate my final year project to my family, whose love and support have been my continuous source of inspiration and motivation. I am grateful to my supervisor for his advice and knowledge, which has guided my academic career and motivated me to improve myself. I sincerely thank my friends and classmates for their support, hilarity, and shared challenging times. This project is a tribute to growth, learning, and determination, and I dedicate its completion to everyone who has supported my studies and helped me improve as a person and a student.

ABSTRACT

Due to various initiatives done by the government, solar photovoltaic (PV) installation is now a multi-million industry in Malaysia. In order to produce a system that is relatively maintenance free, it is crucial that the different components involved in the system is the most optimum specification as possible. To quantify the accuracy of the solar PV system especially the solar panel, a reliable performance measurement system is needed. The solar PV measurement system usually comes in terms of irradiance sensor, temperature sensor as well as voltage sensor and current sensor. These sensors are used to correctly assess the performance of the system so that the solar PV output can always be maintained at the desired level. The aforementioned sensors are usually quite expensive and comes separately in the market. Therefore, the objective of this project is to resolve this issue by attempting to combine the several measurement systems into a single system that will be more affordable, efficient, and user friendly. To do so, Proteus 8 software is used to simulate the operation of this Arduino Uno powered solar PV measurement system project in this semester. Three different irradiance and temperature situations are simulated which are set at minimum, average and maximum levels. The simulation results show a promising current and voltage readings which indicate a successful implementation of the measurement system. This project also has successful develop in form of hardware that combining various sensors utilizing Arduino Uno. To ensure this project give a precise and accurate measurement value, it is compared to commercial system and the data analysis show that the measurement value give an error in range of 7 % to 10 % which is quite good for this project. It is hoped that this project will be an outstanding cost-effective solution for solar PV performance measurement system in the future.

ABSTRAK

Disebabkan pelbagai inisiatif yang dilakukan oleh kerajaan, pemasangan solar photovoltaic (PV) kini menjadi industri berjuta-juta di Malaysia. Untuk menghasilkan sistem yang agak bebas penyelenggaraan, adalah penting bahawa komponen berbeza yang terlibat dalam sistem dengan spesifikasi yang paling optimum yang mungkin. Untuk mengukur ketepatan sistem PV solar terutamanya panel solar, sistem pengukuran prestasi yang boleh dipercayai diperlukan. Sistem pengukuran PV solar biasanya datang dari segi penderia sinaran, penderia suhu serta penderia voltan dan penderia arus. Penderia ini digunakan untuk menilai prestasi sistem dengan betul supaya output PV solar sentiasa boleh dikekalkan pada tahap yang dikehendaki. Sensor yang disebutkan di atas biasanya agak mahal dan datang secara berasingan di pasaran. Oleh itu, objektif projek ini adalah untuk menyelesaikan isu ini dengan cuba menggabungkan beberapa sistem pengukuran ke dalam satu sistem yang akan menjadi lebih berpatutan, cekap dan mesra pengguna. Untuk berbuat demikian, perisian Proteus 8 digunakan untuk mensimulasikan operasi projek sistem pengukuran PV solar berkuasa Arduino Uno ini pada semester ini. Tiga situasi iradian dan suhu berbeza disimulasikan yang ditetapkan pada tahap minimum, purata dan maksimum. Keputusan simulasi menunjukkan bacaan arus dan voltan yang menjanjikan yang menunjukkan kejayaan pelaksanaan sistem pengukuran. Projek ini juga telah berjaya dibangunkan dalam bentuk perkakasan yang menggabungkan pelbagai sensor menggunakan Arduino Uno. Bagi memastikan projek ini memberikan nilai ukuran yang tepat dan jitu, ia dibandingkan dengan sistem komersial dan analisis data menunjukkan nilai pengukuran tersebut memberikan ralat dalam julat 7 % hingga 10 % yang agak baik untuk projek ini. Diharapkan bahawa projek ini akan menjadi penyelesaian kos efektif yang luar biasa untuk sistem pengukuran prestasi PV solar pada masa hadapan.

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In the name of ALLAH S.W.T, the Most Beneficent, The Most Gracious and The Most Merciful. It is deepest sense gratitude of the almighty that give me strength and ability to complete this Final Year Project report.

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Finally, I would like to thank all my fellow colleagues and classmates, the faculty members, as well as other individuals who are not listed here for being co-operative and helpful. Without all of these amazing individuals and resources working together, this project would not have been achievable.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

V	-	Voltage
A	-	Ampere
MW	-	Megawatts
°C	-	Degree Celsius
mm	-	Millimeter
Vdc	-	Voltage Direct Current
Vac	-	Voltage Alternating Current
$\mathrm{W/m^2}$	-	Watt Per Meter Square
%	-	Percentage

LIST OF ABBREVIATIONS

PV	-	Photovoltaic
DC	-	Direct Current
VCC	-	Voltage Common Collector
GND	-	Ground
VSS	-	Voltage Source
VDD	-	Voltage Drain
LCD	-	Liquid Crystal Display
PWM	-	Pulse Width Modulation
AC	-	Alternating Current
$MPPT$	-	Maximum Power Point Tracking
$VRMS$	-	Root Mean Square Voltage
$HVAC$	-	Heating, Ventilation and Air Conditioning
IoT	-	The Internet of Things
$SPVPMS$	-	Solar PV Performance Measurement System

CHAPTER 1

INTRODUCTION

1.1 Background

In Malaysia, there are a few main issues to overcome in the energy sector. Concerns about environmental sustainability as well as global warming arise from how heavily the country depends on fossil fuels, especially natural gas and coal, for the production of power. Furthermore, due to the global energy crisis, where the requirement for energy sources such as coal is surpassing supply, there is risk in temporary pricing, with natural gas current prices hitting their highest point ever this year internationally [1]. Yet, Malaysia has not been particularly affected by the energy crisis. The government has been encouraging renewable energy resources, including solar and biomass, as well as putting energy efficiency policies into place to solve these challenges.

Renewable energy has advantages when compared to conventional energy. Wind, hydro, geothermal and solar power are renewable energy sources that are essentially sustainable and are not harmful to natural resources. It is helping to reduce greenhouse gas emissions, minimise the affects of global warming, and create an environment that is healthier and cleaner. Furthermore, considerable improvements in efficiency and cost have made renewable energy technology more competitive and financially realistic. For a number of reasons, solar energy has become the most popular renewable energy source.

Over the past ten years, the use of solar energy has significantly expanded over by 68%, making it the fastest-growing source of electricity and outpacing the growth of all other renewables, according to the Solar Energy Industries Association (SEIA) [2]. Sunlight is an abundant renewable energy source that is available to varied degrees all around the earth. Due to its accessibility, solar energy is a practical choice for many communities, including those that lack equipped electrical infrastructure or are in rural areas. Solar panels are also ideal for a variety of uses from residential rooftops to large-scale solar farms, and are very simple to install and maintain. Solar energy is becoming more and more accessible and competitive on the market because to reducing solar panel prices and advances in technology.

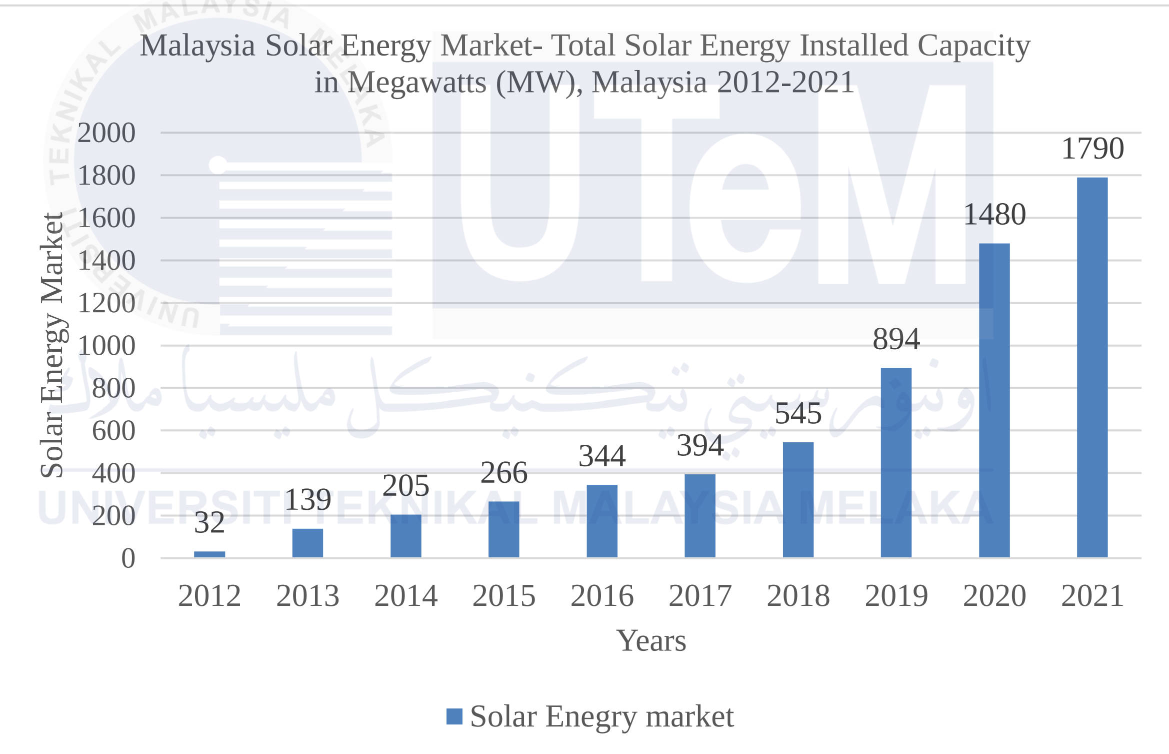


Figure 1.1 Statistic of total solar energy installed capacity in Megawatts [3]

According to the following graph, the total installed solar energy capacity in Malaysia has increased by years in a direct proportion during the previous nine years, from 2012 to 2021. Only 32MW of solar energy was installed in 2012. By 2021, the installation of solar energy has expand by as much as 1980MW due to a move towards cleaner energy due to a greater awareness of the environmental effects of conventional fossil fuel-based energy sources.

Measuring the effectiveness of solar systems is crucial since solar energy is growing in the renewable energy industry and becoming an important economic generator. First, performance monitoring makes it possible to evaluate the effectiveness and productivity of solar panels and related parts. These measurements offer important insights into the overall condition and effectiveness of the system by monitoring variables including voltage, current, temperature, and irradiance. Voltage and current measurements assist in keeping track of the system's electrical characteristics, ensuring that it is performing at its best and identifying any problems like bad connections, wiring difficulties, or device failures. Because solar panels are sensitive to temperature variations and too much heat might shorten their lifespan, temperature monitoring is important. System operators can discover shading concerns, panel alignment challenges, or impediments that can obstruct ideal solar energy output by monitoring irradiance levels. Together, these parameters offer a thorough insight of the system's operation, enabling quick maintaining, troubleshooting, and optimisation to guarantee optimal energy production and overall system effectiveness.

1.2 Problem Statement

As previously said, it is crucial to assess the solar system's performance to understand its efficiency and productivity. Voltage, current, temperature, and irradiance are the usual measurement variables. Pyranometers are usually used to measure irradiance, and market prices for these instruments are quite high. Furthermore, a lot of equipment is needed to measure these parameters, such voltmeters to measure voltage, ammeters to measure current, and thermometers to detect temperature. If you lack one of these tools, you'll have to acquire them individually, which may be a bit bothersome. Improvements in technology have made it considerably simpler to merge all of those measurement devices into a single measuring equipment. Since this equipment combines all of the tools needed to test the factors mentioned above, it is certain to be affordable, effective, and simple to use.

1.3 Project Objective

The aim of building a solar measurement performance system is to accurately monitor, assess the performance of solar panel and determine the durability as well as effectiveness of the solar system, the objective are as follow:

a) To simulate the solar PV performance measurement system using Proteus 8 Professional.

b) To develop a hardware of solar measurement system consisting of various type of sensors interface with Arduino UNO to measure a different parameter like irradiance, temperature, voltage and current.

c) To analyze the performance of solar panel and environment in terms of irradiance, temperature, current and voltage by using this measurement system.

1.4 Scope of Project

The scope of this project are as follows:

a) Limit to measure voltage, current, temperature and irradiance.

b) Voltage sensor is used to measure input of dc voltage in range between 0V to 25V. The DC voltage detection range is between 0.02445 to 25V. The input of positive terminal is connected to VCC while GND is connected to negative pole.

c) Current is detected or measure by ACS712ELC-20A current sensor. This sensor was operated with 5V power supply and can measured plus and minus 20A, with corresponding analog output 100mV/A.

d) Temperature sensor LM35 is use to measure temperature. The operating voltage for this sensor is between 4V to 30V and able to measure ambient temperatures between in range of -55°C and +150°C. The accuracy of this sensor is plus minus 0.5°C.

e) Solar cell polycrystalline 5V 40mA and monocrystalline 5V 60mA is part of a reference cell to measure irradiance.

f) Solar panel polycrystalline 300W and monocrystalline 300W is to be measure. Both have a dimension of 1640 x 992 x 35 mm.

g) LCD display that is use is the standard 16X2 LCD character module. VSS is connected to ground and VDD to 5V positive power.

h) All of the sensor and LCD is connected to Microcontroller Atmega 328 with operating input voltage 5V. This microcontroller also has 14 digital outputs pins which is 6 out of 14 pins provide PWM outputs and has 6 analog inputs.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A review of research and development efforts associated with the measurement of various parameters related to solar photovoltaic (PV) systems is provided by a literature review of solar PV measurement systems. The necessity for precise measurement and monitoring of system performance is becoming more and more crucial as solar PV technology obtains mainstream acceptance. This study of the literature examines the many techniques and technologies employed to gauge vital performance indicators such solar radiation, PV module temperature, DC current and voltage, and generation of AC power. The paper also discusses the many sensors, data collection systems, and monitoring platforms that are used to gather and process data from solar PV systems. This literature review tries to identify gaps in current knowledge and potential for future research and development efforts targeted at enhancing the performance and dependability of solar PV systems by looking at the research and development activities that are now being conducted in this area.

2.2 Background of Solar PV System

For the system to work at its best and produce the expected quantity of energy, it is important for the solar PV system performance to be measured and monitored. Sensors used in solar PV measuring systems generally gather and analyses data on a variety of parameters, including solar irradiance, temperature, voltage, and current. It is possible to optimize and troubleshoot the system using the measuring system's useful information on the system's performance. Aside from that, solar PV measurement systems are employed to check that the system complies with legal requirements and to track its environmental impact. The creation of precise and dependable measuring methods is becoming more crucial for the solar industry as the use of solar PV systems grows.

2.2.1 History of Solar PV System

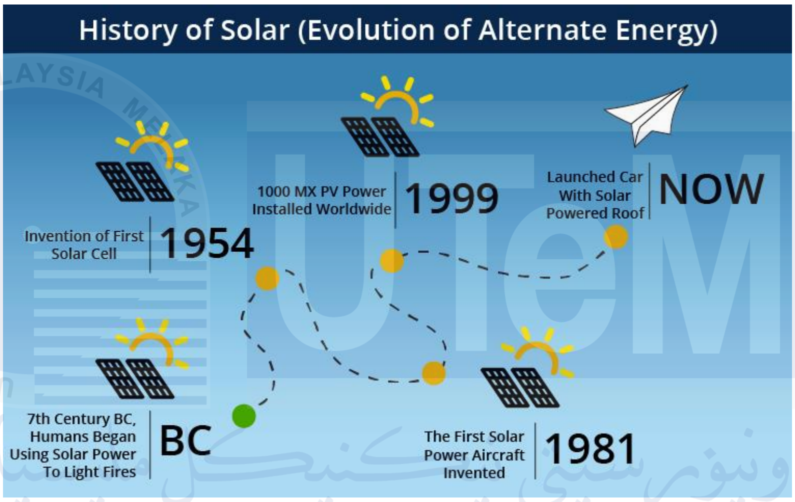


Figure 2.1 History of Solar PV system [4]

Solar panels, commonly referred to as photovoltaic (PV) panels, which have the ability to be utilized to generate energy through the photovoltaic effect and convert them into heat [5]. Monocrystalline, polycrystalline, thin film, heterojunction with intrinsic thin layer (HIT), and other types of solar panels are available. Take a quick trip to the year of 1883, where Charles Fritts known as an American invertor that created the first solar cell by coating selenium with an extremely thin layer of gold [6]. Fritts wanted to create a machine that could turn sunlight directly into electricity because he recognized the possibility of using it as a sustainable and clean source of energy.

The basic elements of solar panels, photovoltaic cells are converting the sun rays into electrical current. Photovoltaic cells are placed between several layers of semiconducting elements, such as silicon. Each layer's separate electrical properties gain energy and form an electric field when sunlight photons touch it. Solar panels may be employed in a variety of settings, such as private residences, public buildings, and utility-scale systems. They may be mounted on building facades, ground-mounted arrays, or roofs. Electricity is produced by solar panels and utilized to power buildings such as houses, offices, schools, and hospitals. They are also used to offer off-grid power in rural regions, as well as to power electronics, charge batteries, and other things.

2.2.2 Concept of Solar PV Power Generation

Using solar panels consisting of photovoltaic cells, solar PV (photovoltaic) power generating turns sunlight into energy [7]. These cells' semiconducting components, often silicon, absorb sunlight and transform it into direct current (DC) power. Any acceptable surface where they can receive the most sunshine exposure, such as roofs, open fields, or other suitable locations, is where the solar panels are put. When photons from sunlight knock electrons into a higher energy state, a flow of electricity results. This is how solar panels produce electricity. As we know in Malaysia, there have four types of solar system that actually work such as grid-connected system, off-grid residential solar system, hybrid solar and direct current solar systems [8].

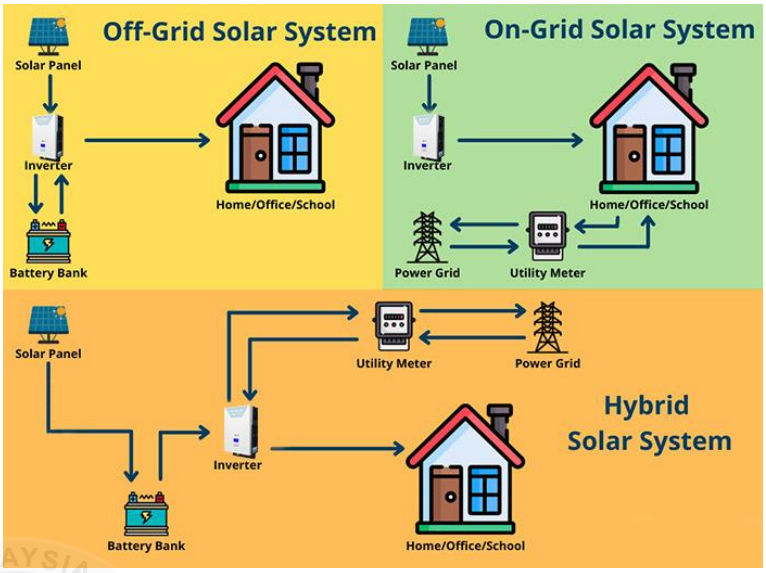


Figure 2.2 Types of Solar System [9]

As shown in Figure 2.2 above, the first type of solar system is hybrid solar, sometimes referred to as grid-connected solar with energy storage. Off-grid household solar systems can be compared to it since they virtually resemble one another. This approach offers users cost savings for hybrid solar. This is due to the fact that if the battery has energy stored in it, it will use that energy rather than the electricity from the grid. The cost of this technology is higher same as off-grid, which is one drawback. This is due to the fact that you must constantly update the batteries in order to prevent it from becoming worn out.

The system that sees the most used is the Grid-Connected System. It has connections to the home electrical system and the surrounding grid. Any extra power is returned to the grid. This approach is great since it requires little maintenance because it needs fewer equipment and its running costs are low. While only requiring one conversion, which is to direct current, a solar system is more effective because it is very efficient with direct current.

Furthermore, in order to install this solar system, we must calculate and understand the solar design. The solar design can be determined the panel size and quantity that may be used then it can be calculated using the step below:

Step 1: Know the how energy is being generated.

Step 2: Determine the Peak Sun Hour at the location that want to install solar PV

Step 3: Know the system efficiency (%)

Step 4: Calculate by using formula to know the power

Energy ÷ Peak Sun Hour ÷ System Efficiency

Step 5: To know the amount of solar panel needed, divide the amount that we get in step 4 by the power of solar panel.

Besides, when we want to install solar PV, another aspect that we must know in order to determine the solar panel is in good condition or not is by testing it open-circuit voltage (Voc) and short-circuit current (Isc).

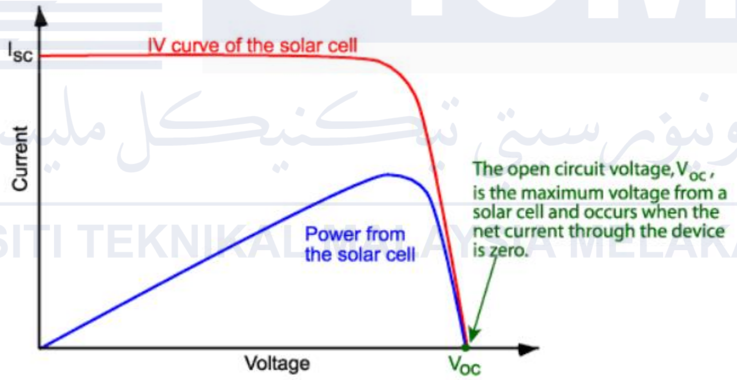


Figure 2.3 IV curve of Open-Circuit Voltage [10]

The maximum voltage which is obtained through a solar panel is known as the open-circuit voltage, or Voc. This value of Voc is occurs at zero current and can be measured using a multimeter by connecting it in parallel with a solar panel. Meanwhile, the short-circuit current is measured by connecting a multimeter in series with a solar panel and equals the current flowing through the solar cell while the voltage across it is zero [10]. Refer equation (2.1) to calculate the open circuit voltage:

$$Voc = \frac{nkT}{q}(\frac{IL}{Io} + 1) \tag{2.1}$$

Where:

Dark Saturation Current, Io,

Light Generated Current, IL,

Ideality Factor, n =1,

Temperature, T,

Open Circuit Voltage, Voc.

An inverter is then used to change the direct current (DC) power produced by the solar panels into alternating current (AC) electricity. The AC power may be utilized to run buildings, companies, and factories, or it can be returned to the grid for use by others. The fact that solar PV power generation uses a sustainable energy source and emits no harmful emissions or pollutants is one of its main benefits. In addition, solar PV systems have a long lifespan and few maintenance needs, making them an affordable source of power in the long run.

2.2.3 Component of Solar PV System

In order to capture sunlight and turn it into energy, a solar photovoltaic (PV) system needs a number of crucial components that operate together. Basically made up of photovoltaic cells that produce direct current (DC) when exposed to sunlight, solar panels are its central component. Thus, this part will cover the components that needed in solar PV system.

2.2.3.1 Solar Panel

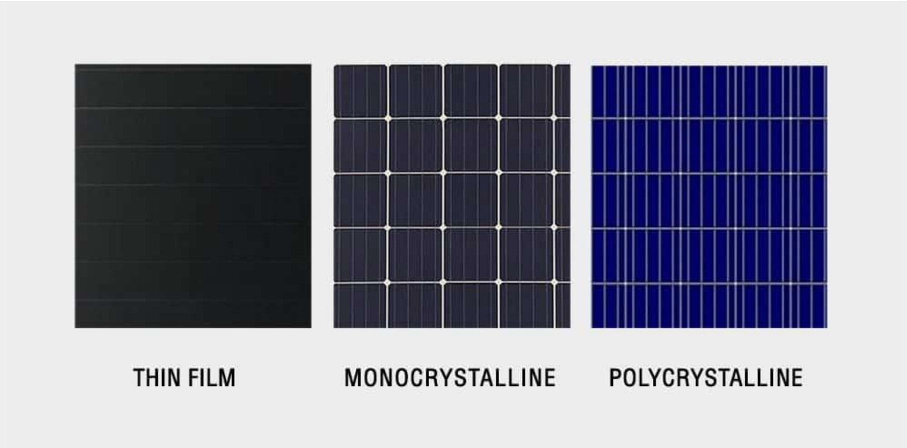


Figure 2.4 Types of Solar Panel [11]

Figure above show that Monocrystalline, polycrystalline, and thin-film solar panels are the three primary varieties on the market. Here is an overview and comparison of each kind:

i. Solar panels composed of a single silicon crystal, or monocrystalline, are more efficient than other forms of solar panels. Due to their consistent black color and rounded edges, they are easily identified. Due to their higher efficiency rate, monocrystalline panels are more expensive and work best in applications with constrained space [11].

ii. Polycrystalline solar panels, which are made of several silicon crystals, are less effective than monocrystalline ones. The square edges and blue color of these things make them simple to identify. Although polycrystalline panels are less expensive than monocrystalline ones, they also require more space to produce the same amount of power.

iii. Thin-film solar panels are the least efficient of the three types of solar panel. Amorphous silicon, cadmium telluride, copper indium gallium selenide, and other materials are among those that can be used to create this solar panel. They have a consistent look and are adaptable, making them simple to identify.

Compared to monocrystalline and polycrystalline panels, thin-film panels are less costly, but they also take up more area per unit of energy produced.

2.2.3.2 Solar Inverter

Alternating current (AC) is created by inverters using DC energy from a solar array or battery bank. Figure 2.5 below show that inverter also come up with various type of inverter which is hybrid, grid-connected and stand-alone inverter. They come in a wide range of sizes and may be used to power DC loads including lights, fans, pumps, motors, and specialized machinery [12].To imitate the waveforms of AC power, inverters transform the DC current using a technique known as pulse-width modulation. This is accomplished by adjusting the DC electricity's voltage and frequency to coincide with the AC electricity's voltage and frequency.

Figure 2.5 Types of Solar Inverter [13]

String inverters and microinverters are the two major types of inverters used in solar power systems. Figure 2.6 below show the different between string inverter and micro inverter. Larger solar projects, where several solar panels are linked in series to form a string, employ string inverters. The entire string's DC power is subsequently converted into AC electricity via the inverter. On the other hand, microinverters are utilized in smaller solar systems, where each solar panel has a separate microinverter that transforms the DC power generated by the panel into AC electricity.

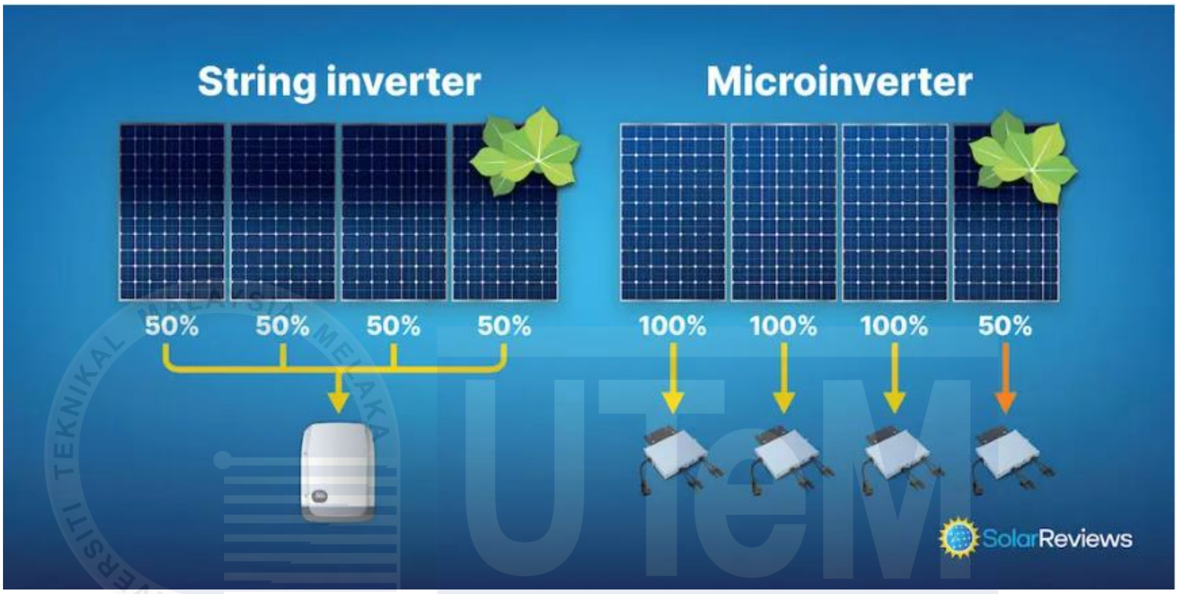


Figure 2.6 String and Micro Inverter [14]

Inverters not only convert DC electricity into AC electricity but also carry out other crucial tasks like tracking the maximum power point tracking (MPPT) of the solar panels. An MPPT, or electronic DC to DC converter, improves the PV array (solar panels) compatibility with the battery bank or utility grid. Briefly stated, to charge the batteries, they needed to convert solar panels higher DC output voltage (as well as some wind turbines output voltage) to the lower voltage [15].

2.2.3.3 Mounting Structure

A solar PV system's mounting framework for solar panels is a crucial part. Its main purpose is to offer a safe and secure platform for the installation of solar panels. The mounting framework is frequently constructed of metal, such as aluminum or steel, and is intended to handle the weight of the solar panels, wind loads, and other environmental conditions. Solar panel mounting systems are typically either roof-mounted or ground-mounted.

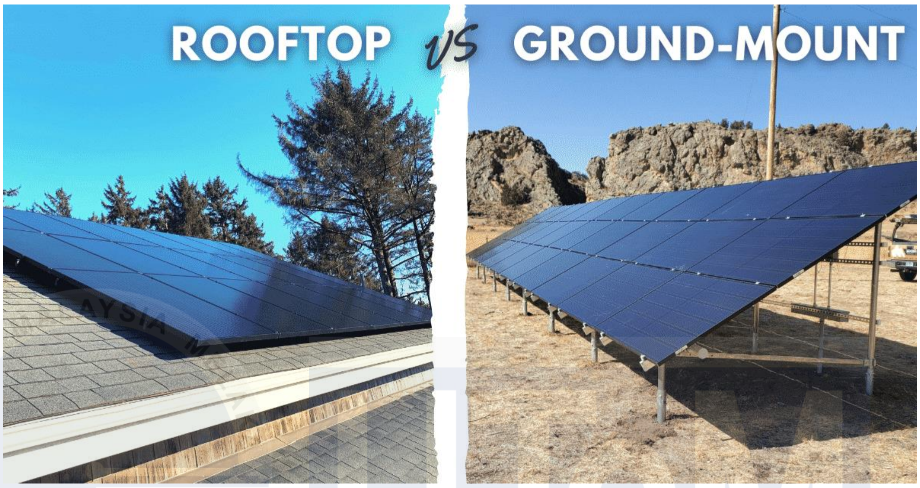


Figure 2.7 Example of Roof-mounted structure compare to Ground-mounted structure that uses in Solar PV System [16]

Roof-mounted structures are made to be fastened to the roof of a building, such a home or a business. Usually constructed from lightweight materials, they are meant to be mounted on sloped roofs. Depending on the roof angle and the required orientation for the solar panels, roof-mounted structures can be either flush-mounted or slanted. Although the number of cable lines in between of the solar panel array and the battery bank or inverter is frequently kept at the minimum number, they still need a rooftop access to avoid a risk of which causes leaking, thus the rooftop must be well sealed. You need to make sure that there are no trees or other structures casting shadows in the solar system's ideal airflow route if you're utilizing a roof-mounted structure for the best system efficiency [17].

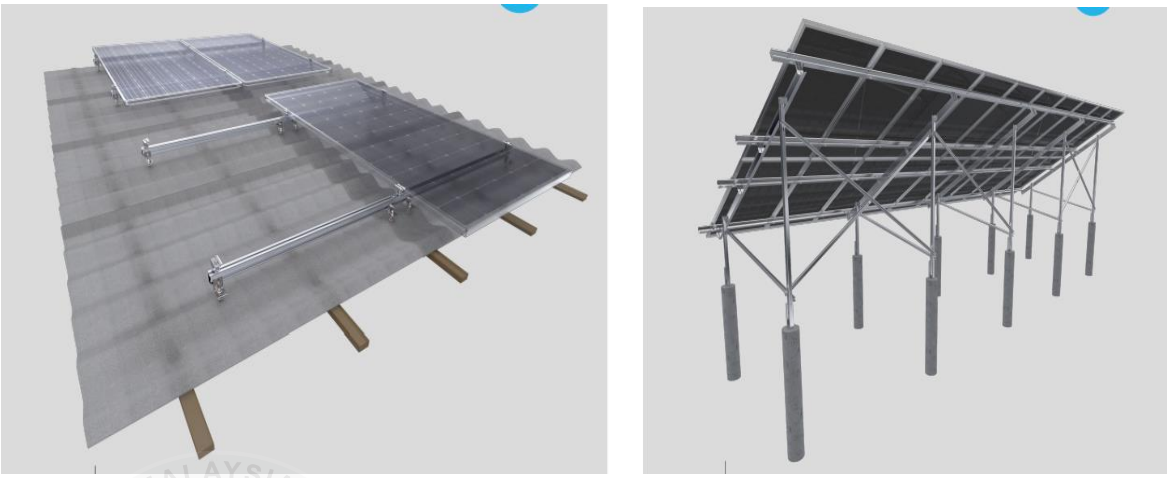


Figure 2.8 Left show the Roof-mounted structure design while on the right show the Ground-mounted structure design [18]

Structures that are ground-mounted are made to be put in place on the ground, usually in a sunny spot. Usually constructed of heaver materials like steel, they are intended to be fixed to the ground for stability as shown in figure 2.8. Depending on the required seasonal modifications and the preferred orientation for the solar panels, it can be permanent or adjustable. This structure needs a proper foundation configuration. Structures on the ground run the risk of being subject to vandalism, a buildup of dirt, leaves, and snow at the base of the array. As a result, ground-mounted racks should only be used in safe areas, especially those with stable surroundings [17].

The mounting structure aids in maximizing the efficiency of the solar PV system in addition to giving solar panels a safe base. The solar panels may be positioned at the best angle and direction for the greatest amount of sunshine exposure with the help of properly planned and built mounting structures. As a result, the solar PV systems total efficiency and energy production may rise.

2.2.3.4 Electrical Protection Equipment

An essential part of a solar PV system is electrical protection equipment that provides protection for the system against malfunctions or damage caused by electricity. The electrical components of the system are protected against deterioration by devices including fuses, circuit breakers, and surge protectors.

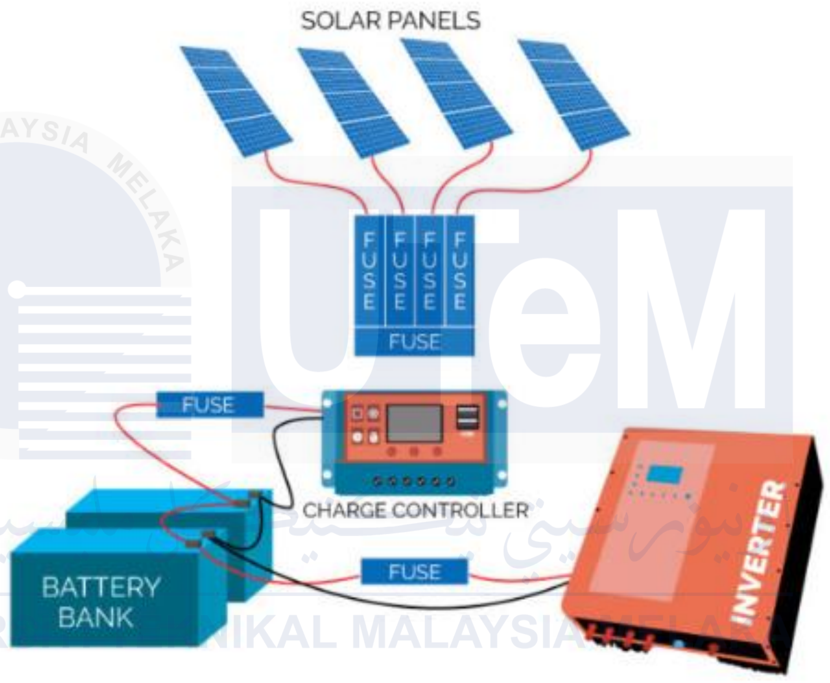


Figure 2.9 Connection of Solar Fuse in Solar System [19]

A type of fuse made specifically for solar power systems is known as a solar fuse. The solar equipment is shielded from potential short circuits, overloads, and overheating by this fuse [20]. In order to prevent harm to the system's electrical components, they are built to shut off the electrical circuit when the current running through it surpasses a specific threshold and connected as show in figure above.

Figure 2.10 Component that used as a protection equipment including DC circuit breaker and surge protectors [21]

The solar system cannot function without DC circuit breakers. A barrier between the panels and the alternating current is necessary for setup and regular maintenance [22]. DC circuit breakers are crucial for electrical safety. They are normally put in the solar PV system's electrical wiring and are made to trip if the circuit's current exceeds a certain limit.

Surge protectors are devices meant to protect against spikes in voltage and surges that might occur due to lightning strikes or adjustments to the electrical grid. To prevent the system's electrical components from damage, they work by diverting excess power out of the system towards the ground.

In general, electrical protection equipment is necessary to guarantee the security and durability of a solar PV system. These gadgets may assist in ensuring that the system runs securely and dependably for many years by preventing electrical overloads, short circuits, and voltage spikes.

2.2.3.5 Monitoring System

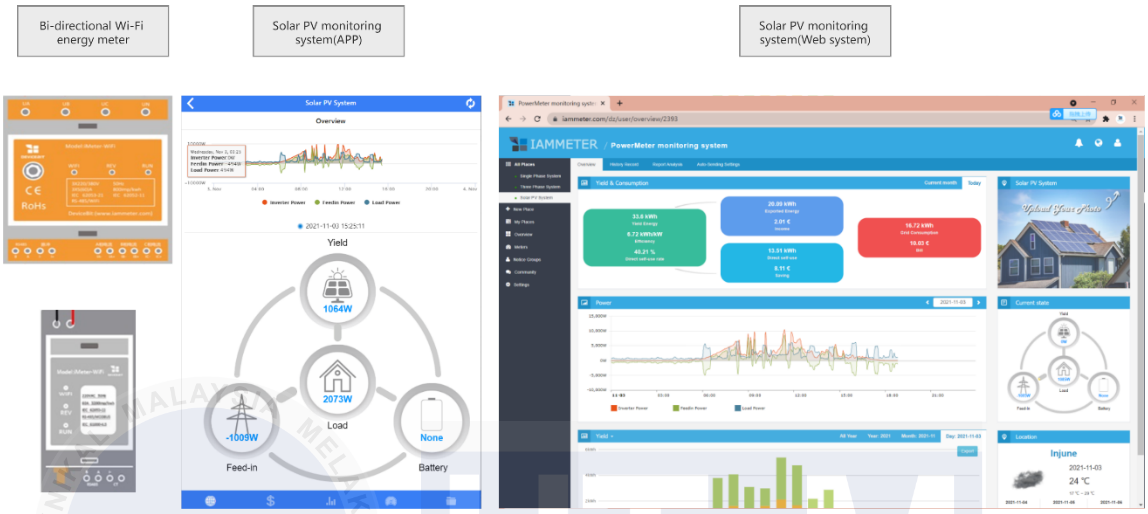


Figure 2.11 Several type of ways to monitoring the performance of solar system [23]

The performance and the output of solar panels are monitored by a solar monitoring system, which is a part of a solar PV system. It generally comprises of a hardware or software system that gathers information from the solar panels, inverter, and other system parts and gives real-time data on the system's operation. You may also monitor the output of your solar panels with this. Typically, a solar monitor is installed at the same time as your solar panels [24].

The monitoring system may monitor a variety of parameters, including the amount of energy produced by the solar panels and the amount of energy utilised by the system, the effectiveness of the solar panels, and any defects or problems that can arise in the system. Figure 2.11 above show that the system owner may track the operation of their solar PV system from any location by accessing this data through a web portal or mobile app [24].

Figure 2.12 Energy Monitoring and Analysis app (EMA) [25]

Figure 2.13 Emphase Enlighten application [26]

The owner of the solar PV system can spot any problems or hardware flaws by keeping an eye on the system's performance and then take appropriate steps to guarantee that the system is operating as efficiently as possible. Figure 2.12 and 2.13 above is two out of the top application that have been use for monitoring solar system. By pointing out areas for improvement which is an altering orientation or the tilt angle of the solar panels, the monitoring system may also assist the owner in maximizing the effectiveness of the system.

Therefore, anyone who has installed a solar PV system needs a solar monitoring system. It offers real-time data on the system's operation, enabling the owner to monitor its effectiveness and maximize the quantity of energy produced by sunshine.

2.2.4 Solar PV Performance Measurement System (SPVPMS)

Many important components that are simply constructed for a solar PV measuring system utilizing Arduino allow to perform efficiently photovoltaic performance analyze and monitoring. In this part will cover all those component that often used in the solar measurement system.

2.2.4.1 Voltage Sensor

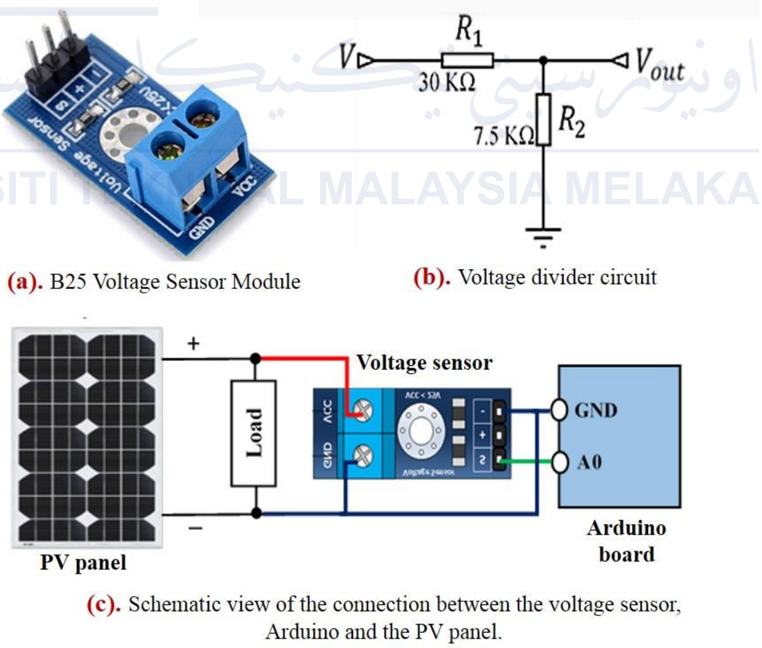


Figure 2.14 Voltage sensor module and connection with Arduino and the PV panel [27]

Figure above show the voltage sensor that is usually use in solar measurement system. A voltage sensor is know as a device to measures as well as records the voltage level of the measurement. They produce analogue voltage signals, current levels, and frequency when the presence of electricity is recognized [5]. Numerous applications, including electric cars, battery management systems, and solar measurement system, make extensive use of voltage sensors. They offer precise and dependable voltage readings that make it possible to monitor, manage, and safeguard electrical systems and circuits. Additionally, they are crucial for enhancing the effectiveness and performance of electrical systems by supplying feedback for control algorithms and voltage regulation. The analogue interface of voltage module can only detect input of voltage value up to 5V, thus any voltage value that are greater than that value cannot be recognised by it. A voltage divider was used to measure the solar PV voltage [28].

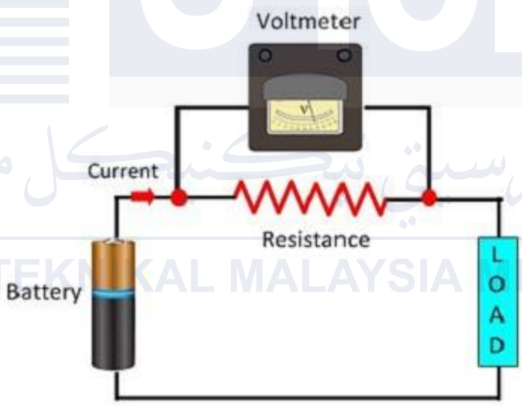


Figure 2.15 Voltmeter connection to measure voltage drop in the circuit [29]

Compare to voltage sensor, there are another method that we always use to measure instrument which is voltmeter. The voltage drop between a circuit element or group of circuit elements can be measured using a voltmeter [30]. The measurement and verification of voltage levels in electrical circuits and systems requires the use of voltmeters. They offer useful details on a circuit's electrical properties, such as voltage levels, fluctuations, and trends. They are used in a variety of fields, including electronics, electrical engineering, and electrician work, as well as industrial control systems, vehicle diagnostics, scientific research, and educational settings. Voltmeters are frequently used for simple electrical measurements and repairs in homes as well as by professionals and amateurs in a variety of sectors. The connection of voltmeter with circuit must be in parallel as show in figure 2.15. The way to use this voltmeter is put leads into the same jack to use the multimeter as a voltmeter. You should always have a lead in the common input jack while using a multimeter. Then, start the knob until "Vdc" or "Vac" is shown [30].

2.2.4.2 Current Sensor

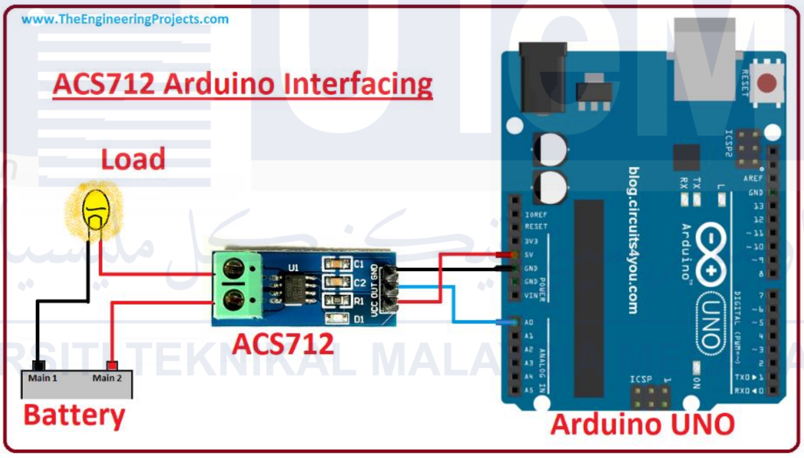


Figure 2.16 Connection current sensor with Arduino to measure current [31]

The ACS712 is a fully integrated linear current sensor based on the hall effect that has a built-in low resistance current conductor and 2.1k VRMS voltage isolation [32]. Current sensors, which provide real-time data regarding current levels, changes, and trends, have significance for monitoring, regulating, and safeguarding electrical systems. They are utilized in many different sectors and by a wide spectrum of experts and people, including electrical engineers, electricians, technicians, scientists, and researchers. For the aim of controlling and monitoring current, they are also included into systems, appliances, and electronic gadgets. Renewable energy systems, motor control, and other electrical and electronic systems all make use of current sensors. The sensor is connected in series to the current-carrying system that you want to measure. The connection can be refer in figure 2.16 to measure the current by using an Arduino. Slice the circuit wire in half, then attach one end to IP+ and the other to IP-. Recall back what you have learned in school where current can only be measured in series same as ammeter connection. Therefore, avoid connecting the sensor in parallel since doing so might result in harm [33].

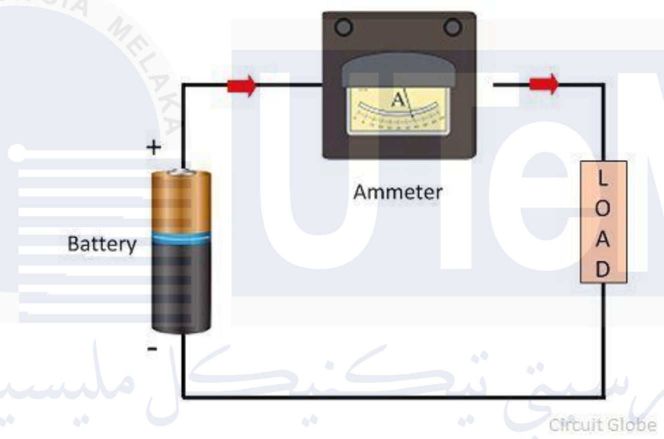


Figure 2.17 Connection of Ammeter to measure current across the circuit [34]

An ammeter is an instrument used for determining the electric current flowing through a circuit. It is linked in series since the current being measured must travel through it [35]. The resistance on an ammeter should be zero. However, the internal resistance of the ammeter is actually rather low. The amount of resistance affects the ammeter's measurement range. The measured current and internal resistance of the ammeter produce a power loss. Low resistance inside the ammeter circuit allows for a little voltage loss within the system. Ammeters are crucial instruments for measuring and keeping track of electric current in electrical systems and circuits. Electrical engineers, electricians, technicians, scientists, students, and enthusiasts are just a few of the people that utilize them. Ammeters are frequently used to measure currents in circuits and other electrical equipment in electronics, electrical engineering, and electrician work. For different current measuring jobs, they are also employed in educational settings, industrial control systems, scientific research, and car diagnostics.

2.2.4.3 Temperature Sensor

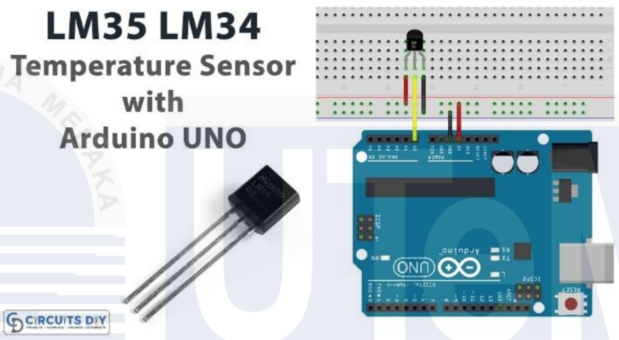


Figure 2.18 LM35 Temperature sensor connection with Arduino UNO [36]

The LM35 as in figure 2.18 is a well-liked analogue temperature sensor that is frequently employed to gauge temperature in electronic circuits. It is an integrated circuit sensor with extremely high accuracy that generates an analogue voltage at the output equivalent to the ambient temperature in Celsius [37]. Without any external calibration or trimming, the LM35 device can give an average precision of 14°C at room temperature and 34°C over an entire temperature range of 55°C to 150°C. Lower costs are guaranteed through trimming and calibrating at the semiconductor level. The LM35 device is incredibly simple to connect with reading or control circuitry because due to its low output impedance, linear output, and precise intrinsic calibration. LM35 temperature sensors are necessary for delivering precise and trustworthy temperature measurements in a straightforward and economical manner. They may be readily interfaced with microcontrollers and other electronic components since they are simple to use, have a wide temperature range, and produce a linear output voltage. They are widely accessible and employed in a variety of industries, including electronics, transportation, manufacturing, and environmental monitoring. Given that it draws just 60µA from the supply, the LM35 device has exceptionally low self-heating of less than 0.1°C in ambient air. The LM35 device is qualified to operate in a 40°C environment, while the LM35C device is rated to operate in an ambient temperature range of 55°C to 150°C [38].

Figure 2.19 Infrared Thermometer [39]

As we know, we always used thermometer to measure the temperature of solar panel. As shown in figure 2.19, an infrared thermometer in this example is a temperature sensor that consists of a lens to focus infrared (IR) light into a detector, which then converts that energy into an electrical signal that may be shown in temperature units after being corrected for ambient temperature changes. Infrared thermometers monitor an object's surface temperature. The optics of the device detect energy that is transmitted, reflected, and emitted; this energy is then gathered and concentrated onto a detector. The electronics of the device convert the data into a temperature measurement that is shown on the device. The laser is only utilized for targeting. Because they give non-contact temperature readings without the need for physical touch, infrared thermometers are crucial. They are the best tools for measuring hot, moving, or challenging-to-reach things since they are secure, sanitary, and capable of monitoring temperatures from a distance. Numerous professionals and everyday people utilize them, including industrial workers, HVAC technicians, maintenance workers, and technicians [40].

2.2.4.4 Irradiance/Reference Cells

An instrument known as a pyranometer measures the total solar irradiance, or the total quantity of solar radiation that a horizontal surface receives. In direct proportion to the irradiance, expressed in watts per square meter, the pyranometer outputs a voltage signal. The pyranometer is specially designed to accept light from all directions, to have a flat response to light ranging from the ultraviolet through the far infrared, and to have a steady output regardless of changing environmental and sky conditions [41]. Pyranometer measurements may be used as a reference regardless of the precise kind of PV cell, and they can also be used to evaluate the weather and compare different sites. Many different types of experts and researchers use pyranometers to monitor sun radiation for a variety of purposes. In addition to various scientific and industrial uses, they are often employed in meteorology, climatology, renewable energy systems, agricultural and environmental research, building energy performance studies, and other fields. To measure the total sun irradiance received on a horizontal surface, pyranometers are often mounted on the ground or on a stationary structure with a horizontal orientation [42].

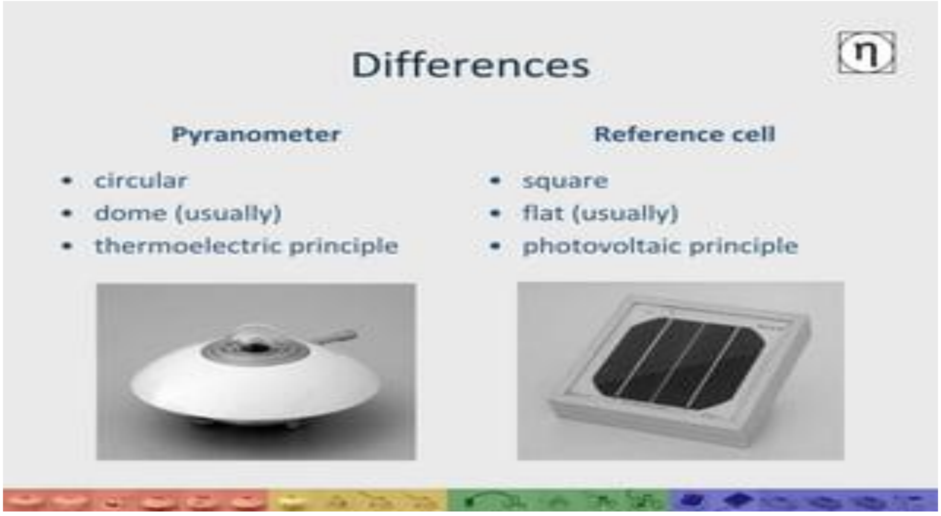


Figure 2.20 Difference between Pyranometer and reference cell [43]

In the scientific community, pyranometers are the most reliable tools for monitoring solar-power systems. Reference cells, on the other hand, are less costly and respond to irradiance similarly to PV modules [44]. An instrument used in electrical and electrochemical experiments to create a recognized reference point or baseline for comparison is a reference cell, sometimes referred to as a reference standard or reference electrode. Irradiance measurements can also be made using PV reference cells. They operate in a fundamentally different manner, though photons with energies above the band gap of the PV material are instantly transformed into positive and negative charges that may be gathered and employed in an external circuit [41]. The quantity and spectral distribution of the photons affect the current that the reference cell produces. The voltage across a tiny resistor that is part of the reference cell package is often used to determine the current of the reference cell. Scientists, engineers, researchers, and experts in a variety of areas utilize reference cells to measure electrical or electrochemical potentials. They are employed in situations such as labs, research facilities, workplaces, and other places where precise measurements are essential. They are often used in the fields of electrochemistry, pH analyses, corrosion studies, analytical chemistry, and other fields where it is important to determine an electrode's potential in respect to an established reference point.

2.3 Previous Work on Solar PV Performance Measurement System by Others

Other researchers have previously worked on creating reliable methods to evaluate and improve the efficiency of photovoltaic systems while analyzing solar PV performance monitoring systems. Researchers have investigated many sensor systems, including irradiance and temperature sensors, to monitor the environmental factors that impact solar panels. To increase the precision and real-time monitoring capabilities of these systems, advances in data gathering methods, data processing algorithms, and communication protocols have also been studied. IoT (Internet of Things) technology integration for remote monitoring and control has been the subject of certain research. All things considered, the combined efforts of earlier studies have refined techniques for measuring and increasing the performance of solar PV systems, developing the foundation for further developments in renewable energy technology.

2.3.1 Design and analysis of a low-cost PV analyzer using Arduino UNO

The new PV analyzer, which was developed using the open-source Arduino electrical platform, has been shown to have sufficient precision and offers detailed information about PV arrays. Research and use of solar energy in underdeveloped regions are of particular importance. Based on this article which is “Design and analysis of a low-cost PV analyzer using Arduino” that show a designed PV analyzer with low-cost device to monitor the performance of PV module. The PV analyzer is housed in a small box and is connected to the PV module using a cable. The PV analyzer measures the voltage, current, and solar irradiance and sends the data to a computer. The system was used to measure the

P-V and I-V characteristics of a PV module. MATLAB/Simulink software was used to plot the findings and analyse the module's behaviour. The acquired current and voltage were used to compute the fill factor and efficiency [45].

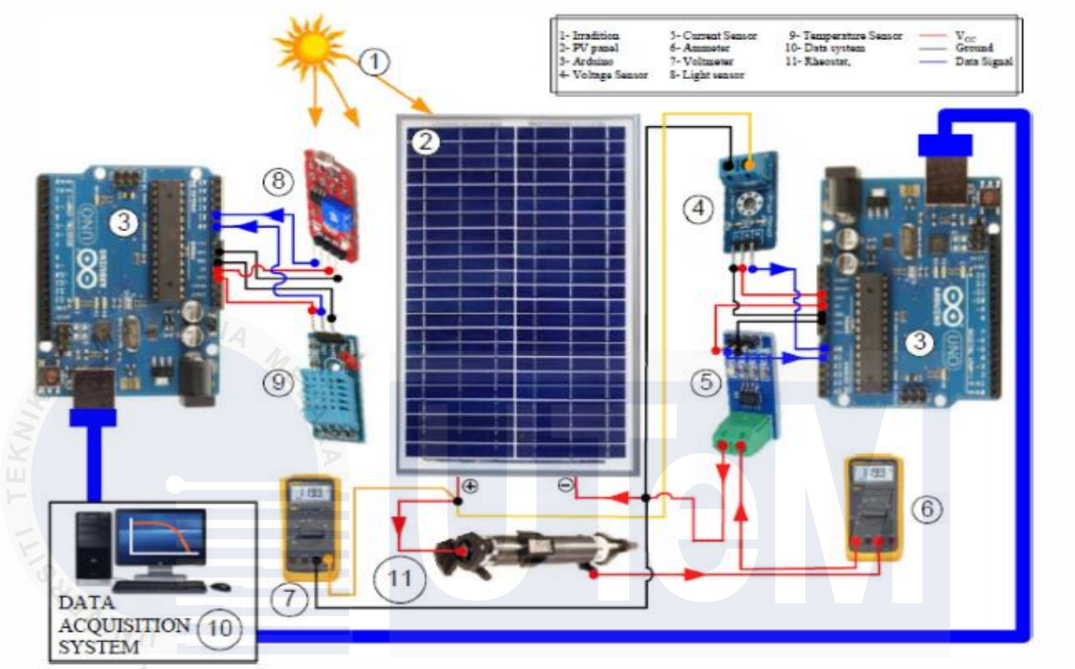


Figure 2.21 Layout of designed system [45]

2.3.2 Design and Construction of an Arduino – Based Solar Power Parameter-Measuring System with Data Logger

The goal of this study was to develop a microprocessor-based Arduino-based parameter-measuring tool for solar photovoltaic panels. Comparing measured characteristics to those of traditional standard measuring tools, which displayed good accord, allowed researchers to assess the system's precision. According to the observed factors, temperature and solar irradiance play a significant role in determining how much energy solar photovoltaic cells produce as output [28]. This research created an inexpensive Arduino-based device for monitoring solar photovoltaic metrics, including voltage, current, temperature, and incident light strength. Design and construction of a solar PV parameter measurement device were done using the Proteus ISIS optimized virtual parameter. Then, this method was used to gather information about the current, voltage, electricity, temperature, pressure, and light intensity coming from solar panels. The measurement results showed that sun irradiance, temperature, and air pressure had a direct impact on the solar PV energy output.

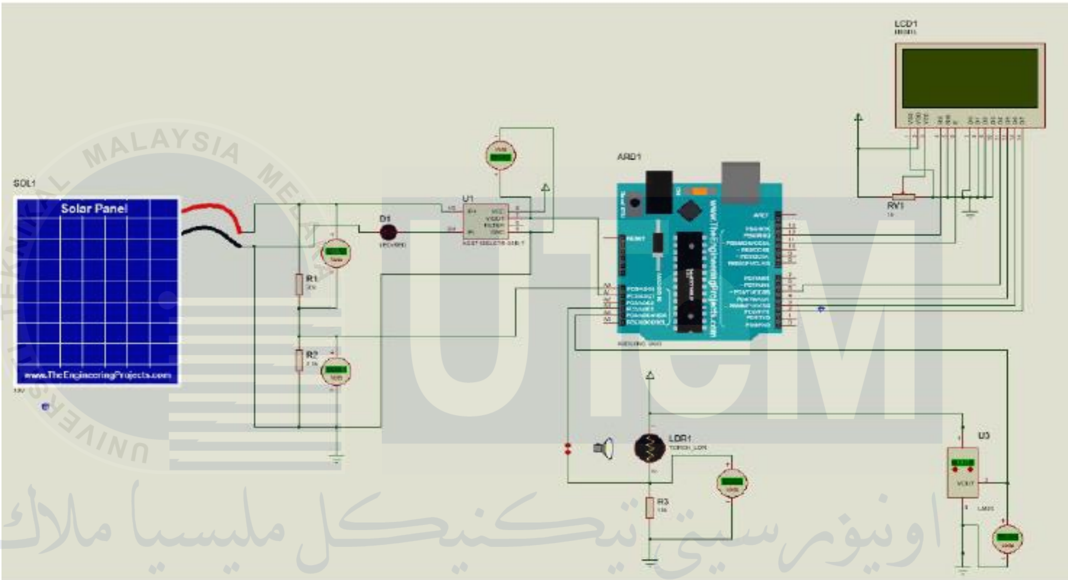


Figure 2.22 Simulated solar PV parameter measuring system [28]

2.3.3 Design and Cost Minimization of PV Analyzer based on Arduino UNO

This PV analyzer is a progressive assembly comprising an Arduino UNO, a variable rheostat, a voltage sensor, a current sensor, and a temperature sensor. It has been put to the test under a variety of likely factors, and it passed with outstanding results. This analyzer has a lower cost estimate than others. All of the significant parameters may be measured using the PV analyzer, and the data can be stored consecutively at any time. This is important because it allows researchers to better understand how a PV system works and how to improve it. The analyzer's performance data shows that it is accurate and efficient, and can be used for research and other purposes [46].

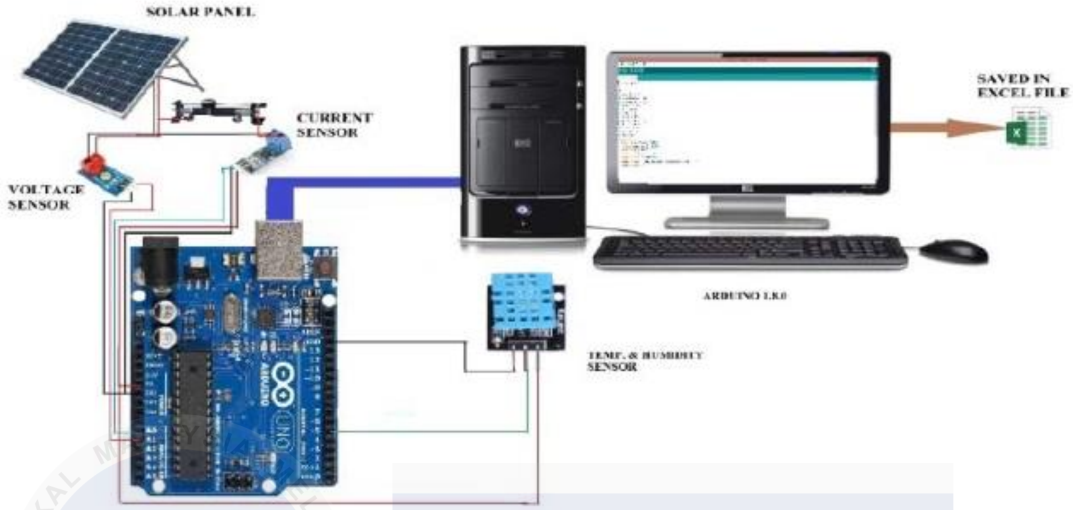


Figure 2.23 Schematic diagram of experiment setup [46]

2.3.4 Solar Efficiency Measurement Using Arduino

The aim of this project is to use an Arduino Board to create a solar PV measuring. This paper presents a potential solar system that uses two set of stepper motor to improve the power collection efficiency by 65%. The maximum current and voltage for this project's output IV curve are 1.56A and 20V, respectively, with a sun irradiation of 500W/m2 and a temperature of 34.5°C [47]. This paper is focused on measuring the solar power using Arduino. The project was able to measure solar panel parameters such as voltage, current, and light intensity. The best position and time for solar power to be effective was found to be the sunrise position with the highest voltage value.

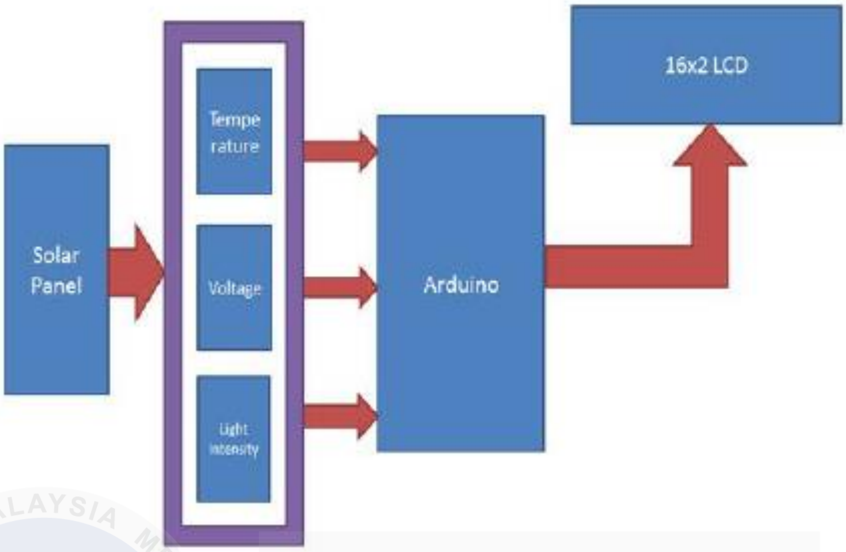


Figure 2.24The block diagram of the research [47]

2.3.5 Solar Energy Measurement System

The goal of the attempt is to use Arduino Board technology to create a solar energy gauge. The instruments attached to the Arduino are used to monitor voltage, current, and Maximum Power Point Tracking (MPPT). The information is delivered to Thing Speak for processing. The text above describes how a solar panel's characteristics, such as voltage, current, and Maximum Power Point Tracking (MPPT), are monitored using an Arduino microprocessor. The microprocessor will activate the load to relieve the pressure on the solar panel if the solar panel is producing more electricity than it can manage. The purpose of this project is to create a solar energy monitoring system using Arduino Board technology [5]. Measurements were made of the voltage, current, and highest power point monitoring.

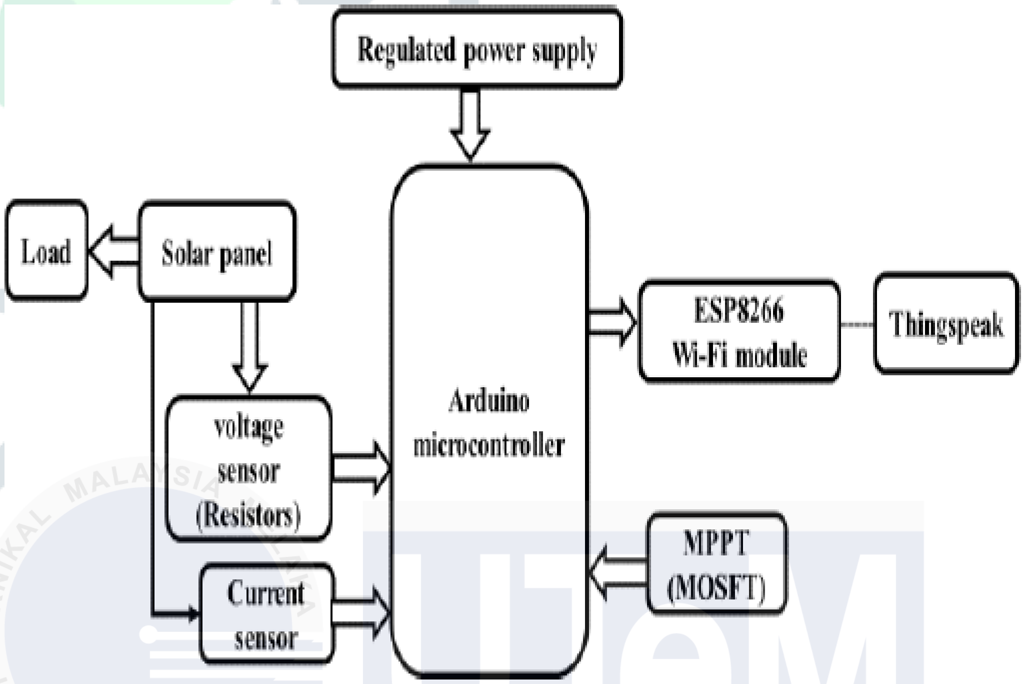


Figure 2.25 Block diagram of solar energy measuring system [5]

2.3.6 Solar Energy Measurement using Arduino Board

This project's goal is to use an Arduino board to gauge sun energy. Temperature, illumination output, voltage, and current will all be monitored as variables. While the LDR sensor measures light strength, the temperature sensor measures temperature. Voltage was measured using a voltage divider since the voltage generated by the solar panel is excess for the Arduino to deal with. The current sensor module, which can identify the current generated by the solar panel, will ultimately be utilised to measure current. These factors take an input number from the Arduino and show the result on the LCD. The output of the temperature, voltage, and current number are displayed on the LCD panel. The Arduino's purpose is converting a parameter's analogue input into a digital output and show it on an LCD screen [48]. Solar power, which converts sunlight into energy, is presently used throughout the globe to help meet the growing demand for electric power. Hundreds of megawatts are produced by solar power plants. The four parameters, temperature, light intensity, voltage, and current, will all be fulfilled by the undertaking. We'll assess these variables in relation to the appropriate sensors. When it is in the best location, solar power will efficiently energize the energy.

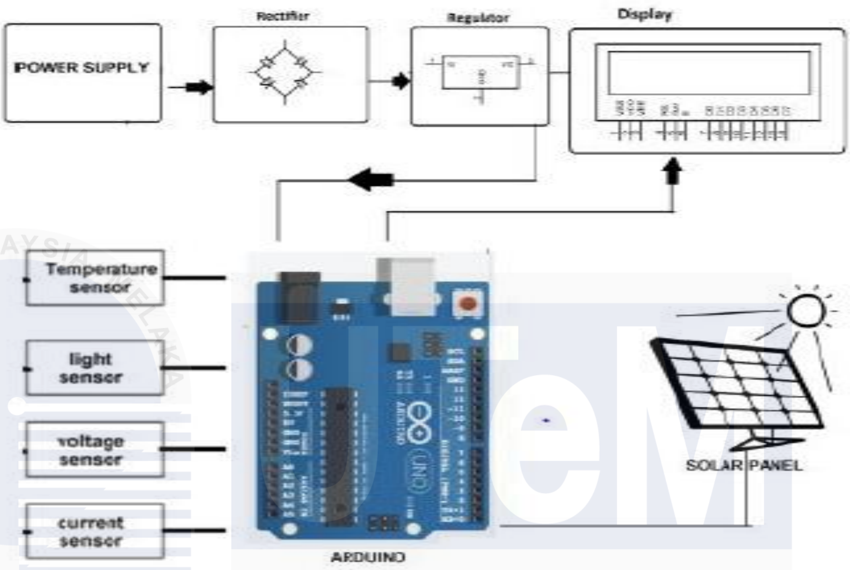


Figure 2.26 The connection of every component with arduino [48]

2.3.7 Solar Energy Measurement Using Arduino

The goal of this project is to use Arduino Board technology to create a solar energy gauge. On an LCD panel, measurements of the temperature, light strength, voltage, and current were shown. Solar energy, which is becoming more accessible and ecologically favorable, is created by turning sunlight into power. Maximum power point monitoring and sun tracking are two distinct techniques that are being used to increase the power gathering efficiency of solar panels. While the solar tracking method is more precise but takes longer to compute the total power, the highest power point tracking method is quicker and more accurate [49]. The initiative was able to gauge the power, current, and temperature of solar panels. It was discovered that at sunrise with a high voltage value, the optimum location and time for solar electricity to be successful were.

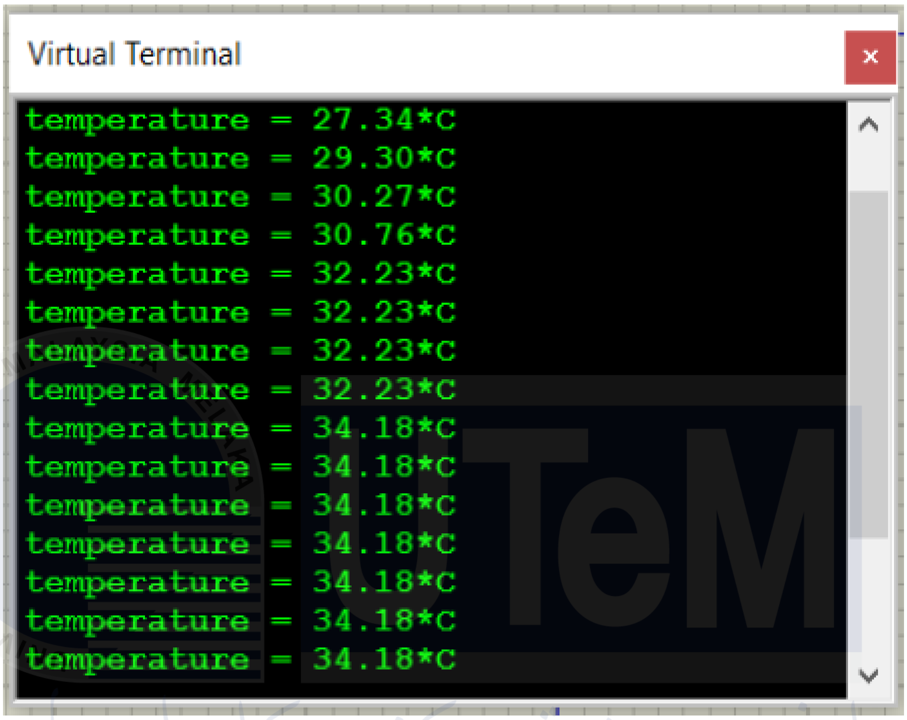


Figure 2.27 The output of temperature during experiments [49]

2.3.8 Solar Energy Monitoring System (SEMS)

As we look for methods to satisfy our expanding energy needs, solar energy is a sustainable and environmentally favorable power source that is taking on increasing importance. Solar power facilities can be monitored wirelessly to make sure everything is running smoothly and without any problems. Solar energy is a fantastic form of electricity that can supply all of our daily needs. To make sure they are operating correctly, solar cells must be observed, though. It is explained how IoT technology can be used to successfully implement a solar electricity monitoring device [50]. The device can monitor the solar power system's temperature, humidity, and solar power production, among other variables. The effectiveness of the system can then be increased using this knowledge.

Figure 2.28 The us of solar PV in daily life [50]

2.3.9 System to Measure Solar Power

The project is discussed in the book, which uses a variety of instruments to gauge solar energy. After that, the information is sent to an Arduino, which uses it to show the data on an LCD. By comparing it to experimental findings, the initiative aims to increase a solar panel's effectiveness. A sustainable energy source that is used to produce power is solar energy. Solar energy is passively collected by focused solar energy as opposed to directly absorbed by solar cells. Solar PV energy devices employ solar cells to transform sunlight photon energy into power. Using Proteus' optimized simulated parameters, the solar energy parameter monitoring device was created [51]. Then, data on solar current, voltage, temperature, and light strength were gathered using the gadget. This device is capable of measuring solar panel statistics. The recorded data revealed that temperature and sun irradiance have a direct impact on PV.

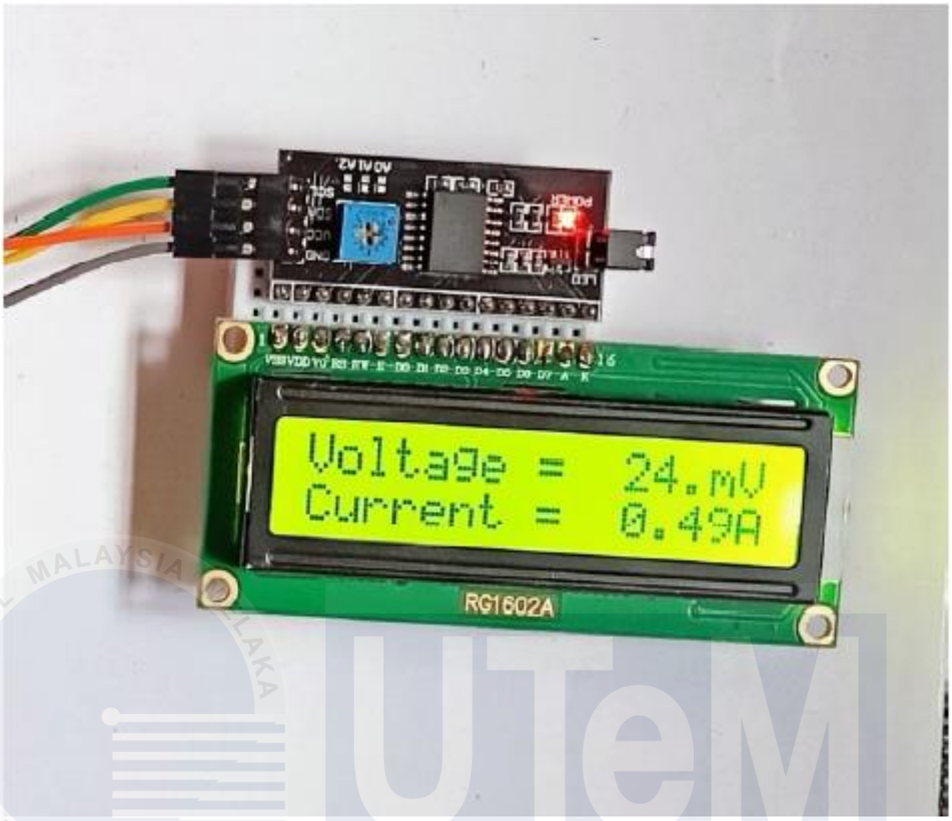


Figure 2.29 Result show the voltage and current of the eperiment [51]

2.3.10 Design of a Low Cost Irradiance Meter using a Photovoltaic Panel

This research shows budget irradiance meter to measures the quantity of exposure to sunshine by using a solar cell. It is possible to calculate the effective energy by monitoring the voltage at the open circuit and short circuit current of the solar cell. The quantity of solar panel radiation and the local climate are strongly connected. An inexpensive movable irradiance meter is used to calculate the amount of electricity the PV system will produce. The device that is being shown can measure the total irradiance across a PVM [52]. It is portable and ideal for use in a variety of uses because it is simple to assemble and only requires a few components.

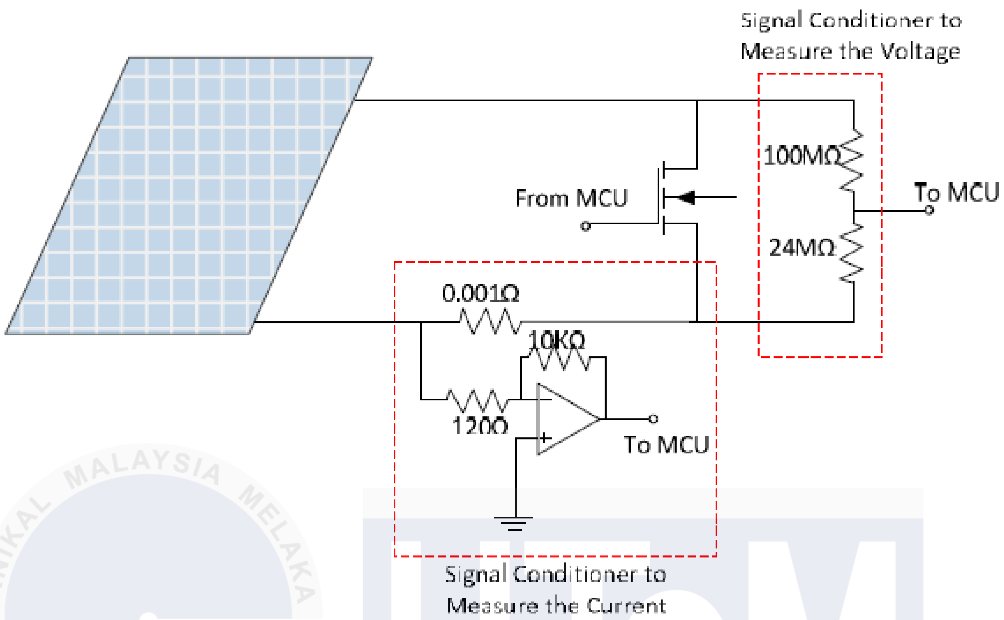


Figure 2.30 Measure circuit in design irradiance meter [52]

2.4 Comparison of Previous Work on Solar PV Performance Measurement System by Others

Table 2.1 This is a comparison of previous work on solar pv performance measurement system by other

No.	Author	Tittle	Application	Remark (special feature)
1	Rahul Anand, Rupendra Kumar Pachauri, Ankit Gupta and Yogesh K. Chauhan	Design and Analysis of a Low-Cost PV Analyzer using Arduino UNO	To monitor the performance of PV module.	1.To measure P-I and I-V characteristic. 2. Fill factor and efficiency can be calculated using obtained current and voltage.
2	Oladimeji I, Adediji Y. B, Akintola J. B, M. A. Afolayan, O. Ogunbiy, Ibrahim S. M, Olayinka S. Z	Design and Construction of an Arduino – Based Solar Power Parameter – Measuring System with Data Logger	To determine how much solar photovoltaic cell produce as output	1.To monitor solar photovoltaic metrics 2. To monitor voltage, current, temperature and incident light strength.

No.	Author	Tittle	Application	Remark (special feature)
3	Vinay Gupta, Prateek Raj and Ankit Yadav	Design and Cost Minimization of PV Analyzer based on Arduino UNO	To measure all of the parameter and store the data sequentially at any particular time.	1.To measure voltage, current and temperature. 2.Performance data is accurate and efficient.
4	Prof. Rasika Vishal Pujari	Solar Efficiency Measurement Using Arduino	To focus on measuring the solar power using Arduino.	1. Measure temperature, light intensity, voltage and current and displayed on LCD screen.
5	K.G.Shravan, N.Swapna, M.Bharath Kumar, and V.Padmaja	Solar Energy Measurement System	To create a solar energy monitoring system using Arduino board technology.	1. To monitor voltage, current and maximum power point tracking.
6	Dr. N. Pushpalatha M.Tech., Ph.D, P. Sravani , C . Rajasekhar , N. Sai kalyan and K. Soma pramodh	Solar Energy measurement using Arduino Board	To convert an analog input of parameter to the digital output and display it through LCD screen.	1. To monitor temperature, illumination output, voltage and current.
7	Siti Amely Jumaat, Mohamad Hilmi Othman	Solar Energy Measurement Using Arduino	To use Arduino board technology to create solar energy gauge.	1. Measure temperature, light strength, voltage and current.
8	Dippen Duta, Suvashus Das Arpan, tarak Hossain, Shamim Al Mamun, Daman Kumar Shah, and Sachin Mishra	Solar Energy Monitoring System (SEMS)	To monitor the energy output from the Solar Panel.	1. Monitor solar power system temperature, humidity and power production.
9	Dr. H. H. Kulkarni, Prathamesh Mali, Rahul Mali, Devesh Chaudhari, Ritesh Chauhan	System to Measure Solar Power	To increase solar panel effectiveness.	1.Measure data on solar current, voltage, temperature and light strength using device. 2. Temperature and sun irradiance have direct impact on PV.

No.	Author	Tittle	Application	Remark (special feature)
10	Eduardo I. Ortiz-Rivera	Design of a low-cost irradiance meter using a photovoltaic panel	That measures the quantity of exposure to sunshine using a solar cell.	1. To determine the effective energy by tracking the solar cell's open circuit voltage and short circuit current. 2. Movable irradiance meter is used to calculate the amount of electricity the PV system will produce. 3. The device that is being shown can measure the total irradiance across a PVM.

2.5 Summary

The studies and developments related to the measuring and monitoring of solar PV systems are the main topics of a review of the literature on solar PV measurement systems. Studies on a range of measuring factors, including solar irradiance, voltage, temperature, and current are included. The literature study provides a summary of the measuring methods, equipment, and procedures currently in use for solar PV measurement systems. It includes information on the difficulties and developments in solar PV measuring technology and accuracy of various measurement techniques. The study also identifies gaps in the existing literature that might be filled by future research and emphasizes the significance of precise measurements in solar PV systems for performance evaluation, monitoring, and maintenance reasons. Overall, the analysis of the literature offers a thorough overview of the state of the art for solar PV measuring systems and serves as a starting point for more study in this area.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, it will discuss the methods and techniques that are used in this project, as well as the hardware and tools required to complete it, with a focus on the measurement systems used to detect voltage, current, temperature, and irradiance. An Arduino Uno microcontroller will be used in this project, together with appropriate software and hardware, to assure its success.

3.2 Flowchart

Figure 3.1 below represents the process flow diagram for the project, which starts with identifying the objective, a background project, and a review of some earlier work that has been completed by others.

The next step is to construct the project's circuit by referring to the previous work done by other, which also includes running a simulation to determine the main outcome. Proteus 8 is the programmed that was used to perform the simulation for this project. The simulation's results were then used to determine whether the project had been successful or not. If not, a new testing of the circuit connection is required before the simulation may proceed.

Next is to build a hardware and software implementation, which is based on the structure and layout that was agreed on with the supervisor.

This project was then put to the test to gather data, and the results were used to make improvements until the project was performing as it should. Same goes with simulation, if the project was not run successfully then it required a testing to overcome the problem. Finally, this project's completion involved giving it a makeover in terms of appearance.

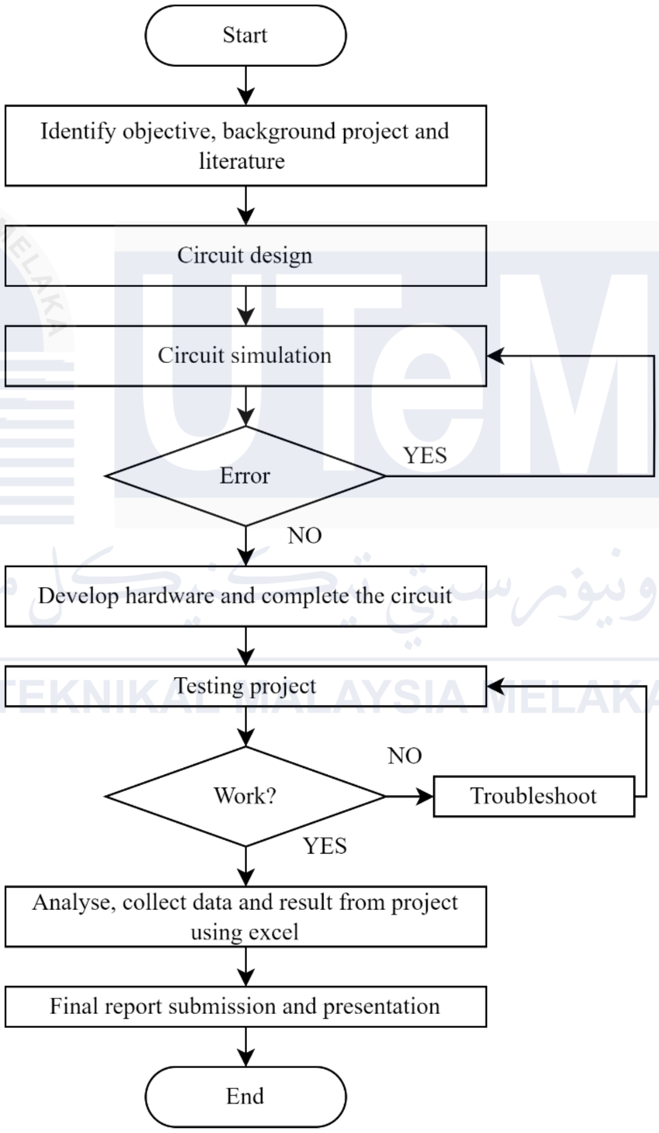


Figure 3.1 Flowchart of the project

3.3 Project Block Diagram

A specific project flow is decided upon for the implementation of the hardware project before the hardware configuration. Here, the project's methodology is chosen in accordance with the hardware setup's intended goals.

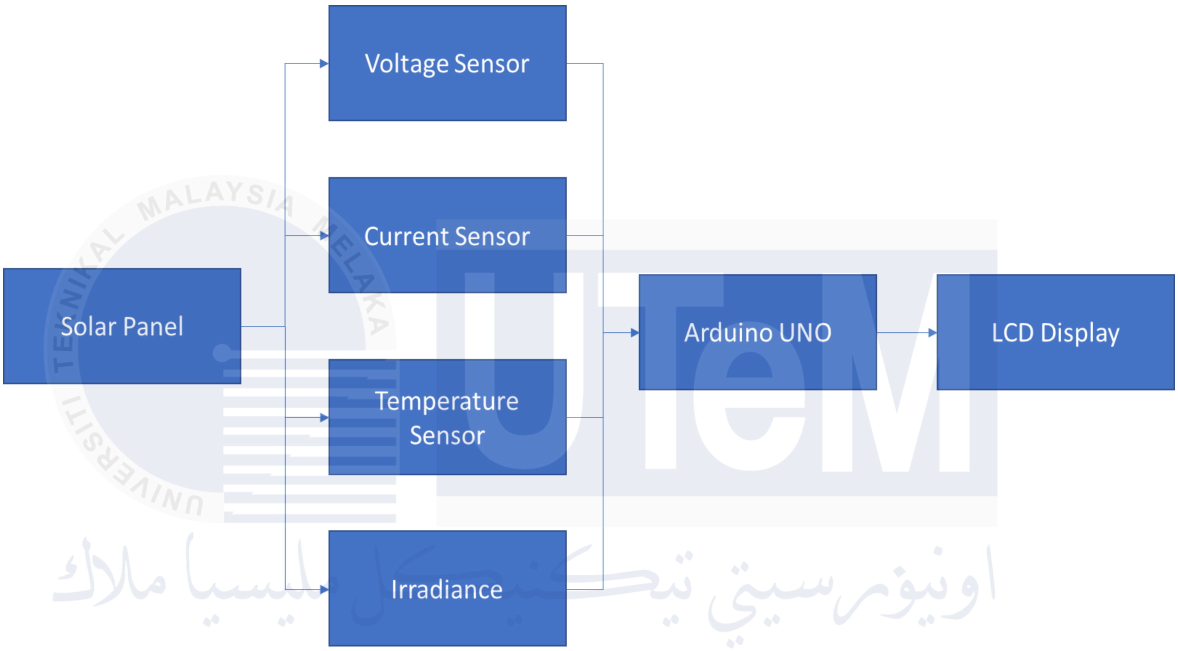


Figure 3.2 Project block diagram

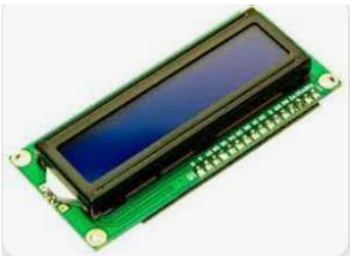
The flow is initiated by the values collected from the solar panel and is supplied to all sensors. This allows for the accurate calculation of parameters like as voltage, current, temperature, and irradiance. The parameters' data is then transmitted to Arduino, where it is analyzed and computed according to the appropriate formula for each parameter. Following that, the generated data on the LCD panel displays the estimated parameter values.

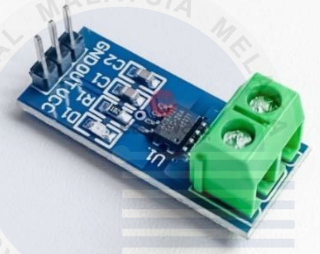
3.4 Component

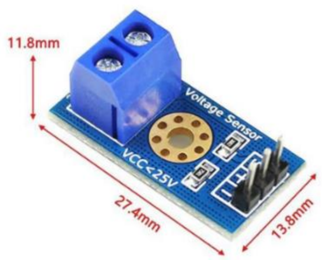
Table 3.1 Show the description of each component that use for this project

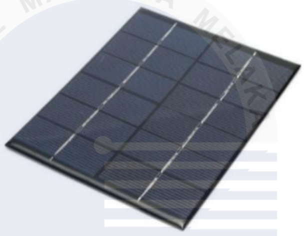
No.	Component	Application	Description
1	Monocrystalline Solar Panel 10W 18V 	i. Outdoor lighting ii. Battery charging because of its excellent durability and weather resistance.	i. A 10W monocrystalline solar panel is a photovoltaic device constructed from a single silicon crystal and is more effective than polycrystalline panels due to its homogeneity. ii. Under standard test conditions (STC), the device can produce 10 watts of electricity at a cell temperature of 25 °C and an irradiation of 1000 watts per square meter. iii. With dimensions of around 320 x 235 mm and a thickness of 17 mm, the panel is generally rectangular in shape.
2	Polycrystalline Solar Panel 10 W 18V 	i. Perfect for small-scale solar projects like supplying off-grid RVs or cottages with electricity ii. Lighting outdoor lights iii. Charging portable gadgets.	i. A 10W polycrystalline solar panel is a specific kind of photovoltaic module comprised of many silicon crystals. A single panel is created by melting all of these crystals together, giving it a characteristic blue hue. ii. The panel is made to use the photovoltaic effect to turn sunlight into electricity.

No.	Component	Application	Description
			iii. The 10W power output is the most electricity the panel is capable of producing under typical test settings. iv. The panel normally has a rectangular form, is around 320 x 235 mm, and has a thickness of 17 mm.
3	Arduino Uno 	i. Data logging ii. Home automation iii. Robotics. iv. Any project that using Arduino as microcontroller.	i. A well-known microcontroller board for novices and supporters in electronics and programming is called the Arduino Uno. ii. With 14 digital input/output pins, six analogue inputs, and a variety of communication interfaces like Universal Asynchronous Receiver/Transmitter (UART), and Serial Peripheral Interface (SPI) it is based on the ATmega328P microcontroller. The Arduino Integrated Development Environment (IDE), which makes it simple to create, upload, and debug code, may be used to programming the board. iii. With a large user and developer

No.	Component	Application	Description
			community that shares projects and code libraries online, it is also very configurable.
4	Resistor 	i. They are frequently employed to limit or regulate the flow of current and voltage in electronic circuits, including amplifiers, filters, and voltage regulators, to guarantee correct functioning and prevent component damage.	i. A resistor is an electrical component used to limit how much current may flow through a circuit. ii. It is a passive component, which means it doesn't need an outside power source to work. iii. The main job of a resistor is to lower the voltage or current flowing through a circuit, which in turn regulates how much power is sent to other components.
5	LCD Display 16x2 	i. Menu-driven interfaces for equipment like vending machines and small appliances, temperature and humidity sensors, and digital clocks.	i. Alphanumeric displays of the 16x2 LCD (Liquid Crystal Display) kind are frequently employed in electronics applications. ii. The 16x2 name refers to the rectangular screen, which is 16 characters wide and 2 rows deep. Characters and symbols may be shown on the module's array of small liquid crystals by selectively

No.	Component	Application	Description
			turning them on or off with the application of an electric field. iii. With just a few pins from a microcontroller, the LCD 16x2 module is simple to use.
6	ACS712 Current Sensor Module 	Since the ACS712 module is offered in a variety of versions with different measurement ranges, it can be used in a wide range of applications, including power management, energy monitoring, and motor control. Additionally, it is simple to use and can connect to a microcontroller with just a few pins.	i. Electric current travelling over a circuit may be measured and detected using the ACS712 Current Sensor Module, an electrical gadget. ii. It is a non-intrusive sensor that can be quickly and safely applied to an electrical wire without breaking the circuit. iii. The module detects the magnetic field produced by the current flow and transforms it into a proportional voltage output using a Hall Effect sensor. A microcontroller can read and analyses the output voltage to get the current value.

No.	Component	Application	Description
7	LM35 temperature sensor 	i. Weather Monitoring ii. Industrial Process Control iii. Laboratory Instruments iv. Temperature monitoring	i. Precision IC temperature sensors of the LM35 series have an output voltage that is directly proportional to the Centigrade temperature. ii. In comparison to linear temperature sensors calibrated in Kelvin, the LM35 has the benefit that the user does not need to deduct a significant constant voltage from the output to get suitable Centigrade scaling. iii. The LM35 can achieve average accuracies of 14°C at room temperature and 34°C during a complete cycle of operation without the need for external calibration or trimming.
8	DC 0V to 25V Voltage Volt Sensor 	i. The sensor is appropriate for a broad range of DC voltage measurement applications, including battery monitoring, power supply voltage monitoring, and voltage level detection in electronic circuits.	iii. An electrical gadget called the DC 0V to 25V Voltage Volt Sensor is made to measure and detect the voltage of a DC power source. iv. It is a non-intrusive sensor that can be quickly connected to a voltage source without having to break the circuit or unplug it. v. A voltage divider circuit is used by

No.	Component	Application	Description
		ii. To measure voltage levels from 0V to 25V.	the sensor to transform the input voltage into a proportionate DC voltage output that can be read and processed by an analogue circuit or microcontroller.
9	Reference cells monocrystalline 	i. Calibration of Solar Radiation Sensors ii. Performance Testing of Solar Panels iii. Characterization of Solar Materials iv. Solar Energy System Monitoring	i. A monocrystalline solar cell known as a reference cell serves as a benchmark for evaluating the effectiveness and performance of other solar cells. ii. It is constructed from a single crystal of highly pure silicon, and under particular illumination circumstances, it is precisely calibrated to create a specified quantity of electrical current. iii. By comparing additional solar cells' current output to the reference cell's known current output under identical illumination circumstances, the efficiency of those solar cells is commonly ascertained.

No.	Component	Application	Description
10	Reference cell Polycrystaline 	i. Calibration of Solar Radiation Sensors ii. Performance Testing of Solar Panels iii. Characterization of Solar Materials iv. Solar Energy System Monitoring	i. An exact measurement of the quantity of sunlight reaching a solar panel is made possible by reference cells, which are solar cells. Multiple silicon crystals are fused together to form a single block to create polycrystalline reference cells. ii. The cell's surface is textured to maximize sunlight absorption, and the electrical connections are expertly crafted to reduce any resistance-related losses.
11	Voltmeter 	i. To measure the voltage flow from the solar panel	i. The voltmeter is connected to the solar panel terminals when it is not connected to any load to measure open circuit voltage. ii. This measurement represents the maximum voltage the solar panel can produce under ideal conditions, providing insight into its overall health and efficiency. iii. The voltmeter is used to identify the voltage at which the solar panel

No.	Component	Application	Description
			produces maximum power. iv. This crucial measurement helps determine the optimal operating conditions for the solar panel, allowing for the proper configuration of the connected system to extract the maximum power output.
12	Clamp meter / Ammeter  	i. To measure the current flow from the solar panel.	i. The ammeter is connected in series with the solar panel, bypassing any external load (short circuit condition). ii. This measurement represents the maximum current the solar panel can deliver in the absence of resistance, providing insight into its current-producing capabilities. iii. The ammeter is utilized to identify the current at which the solar panel produces maximum power. iv. This measurement is crucial for optimizing the solar panel's performance, helping to configure the connected system

No.	Component	Application	Description
			for extracting the maximum power output under specific operating conditions.
13	Irradiance Meter 	i. To measure irradiance	i. The irradiance meter is used to measure the solar panel's output under normal operating conditions, capturing the average intensity of sunlight falling on the panel during regular daylight hours. This provides a baseline for assessing the panel's overall efficiency. ii. The meter is employed to measure irradiance during peak sunlight hours, ensuring that the solar panel is exposed to maximum sunlight intensity. This measurement helps evaluate the panel's capacity to generate power under optimal conditions. iii. In some instances, solar panels may be partially shaded due to nearby structures or objects. The irradiance meter is used to measure sunlight intensity when shadows partially cover the panel. This

No.	Component	Application	Description
			information is crucial for identifying potential efficiency losses and optimizing the panel's placement to minimize shading impact.
14	Temperature Meter 	i. To measure the ambient temperature	i. The temperature meter is employed to measure the baseline ambient temperature in a specific location. This reading represents the typical temperature of the environment and serves as a reference point for understanding daily or seasonal fluctuations. ii. In certain situations, it's essential to measure the highest and lowest ambient temperatures that an area experiences. The temperature meter is used to capture extreme temperature conditions, helping users understand the temperature range the environment may encounter. iii. The meter is applied to measure ambient temperature during critical operating conditions, such as when electronic

No.	Component	Application	Description
			equipment, sensitive materials, or certain processes are highly temperature-dependent. This helps ensure that the environment remains within specified temperature thresholds for optimal performance.

3.5 Quotation of The Project

Table 3.2 The quotation for this project

No.	Component name	Description	Quantity	Price
1	Solar Panel Monocrystalline 10 W 18 V	1xRM43.00	1	RM43.00
2	Solar Panel Polycrystalline 10 W 18 V	1XRM44.00	1	RM44.00
3	Monocrystalline Solar Cell 6V 3W 500mA	1xRM25.00	1	RM25.00
4	Polycrystalline Solar Panel 2W 5V 400mA	1xRM17.30	1	Rm17.30
5	Arduino Uno	1xRM39.90	1	RM39.90
7	Resistor	RM2.50	2	RM5.00
8	LCD Display	1xRm8.50	1	RM8.50
9	ACS712 Current Sensor Module	1xRM8.00	2	RM16.00
10	LM35 temperature sensor	1xRM4.50	1	RM4.50
11	DC 0V to 25V Voltage Volt Sensor	1xRM2.90	1	RM2.90
TOTAL				RM206.10

Table 3.2 show a quotation for a solar measuring system project is a piece of writing that details the estimated costs for different goods and services needed for the project, including sensors, installation and maintenance fees, and any other hardware or software that may be necessary. The table normally contains the overall cost for each good or service as well as the itemized prices and quantities. Project supervisors can use this information to evaluate the cost be using for this project. Additionally, it guarantees that every expense is taken into consideration and aids in preventing unforeseen costs or project cost overruns.

3.6 Project Design

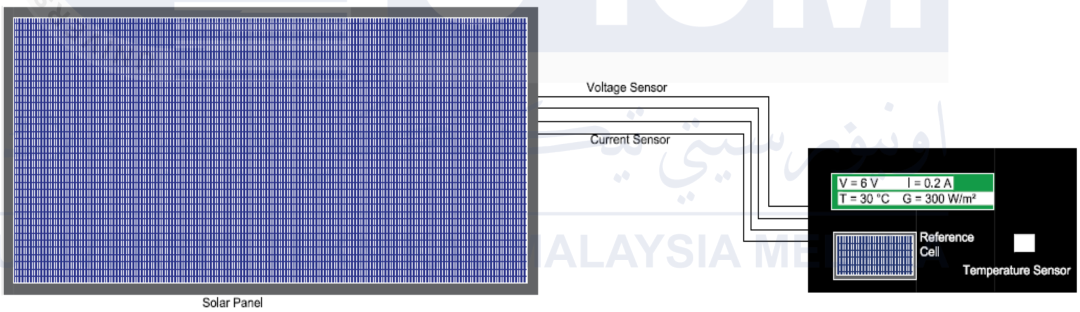


Figure 3.3 Design of project

Figure above show the design of the project which is consist of the component that used in this project. The temperature, voltage and current sensor are all put in together in a box meanwhile the LCD display the output of the result with reference cell also above the box. The line represent the wiring connected between the sensor and solar panel.

3.7 Simulation of Project Measurements

In order to simulate and assess the project measurement, a virtual environment for the solar PV system performance must be created. It is possible to do predictive assessments, optimize design parameters, and identify any problems before the implementation by utilizing Proteus 8 Professional software. Simulations are required in order to guarantee the effectiveness and dependability of the measuring system.

3.7.1 Measure Voltage

The simulation circuit for measuring voltage is shown in the figure 3.4. Voltage sensor is used in this project to detect the voltage coming from the solar panel, as discussed in chapter 2. A voltage divider has been utilized in the simulation to simulate the use of a voltage sensor to measure the value of voltage that present in the solar panel. The output can be seen in the LCD display.

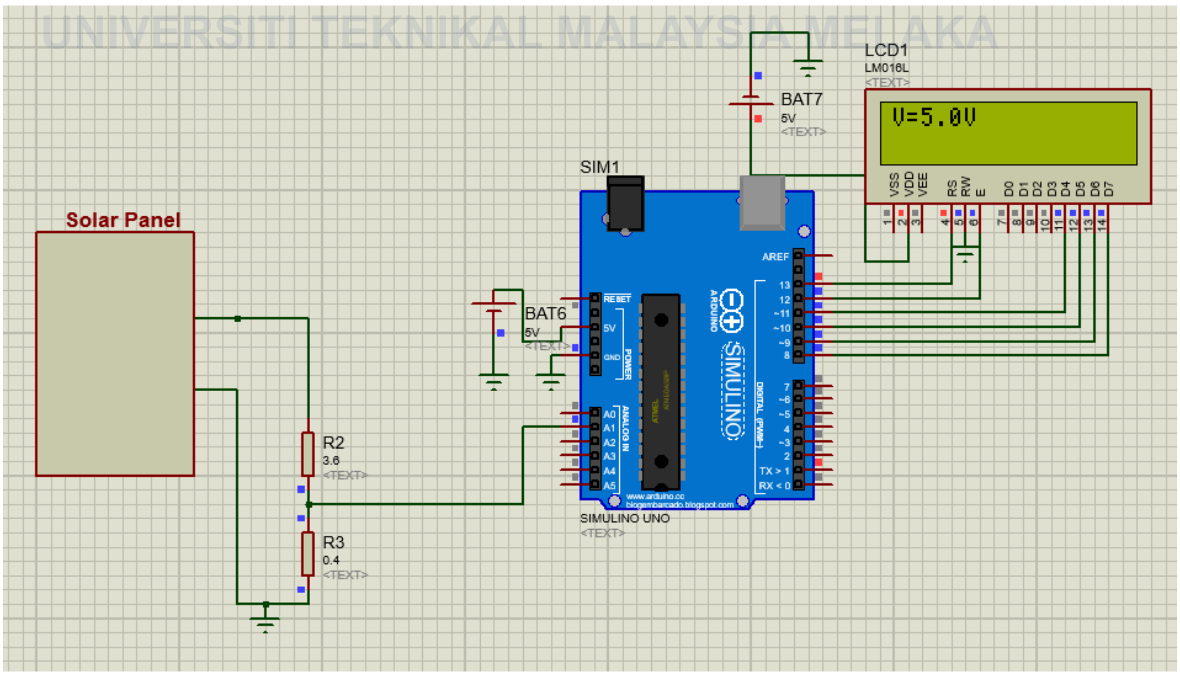


Figure 3.4 Simulation circuit to measure voltage

3.7.2 Measure Current

Figure 3.5 show solar measuring performance system uses an Acs712 current sensor to detect current. Similar to hardware, the simulation may also measure the current in the circuit using an acs712 current sensor. As seen in the above diagram, it is linked to a solar panel as a power source and a mosfet as a load. The output can be seen by using LCD display.

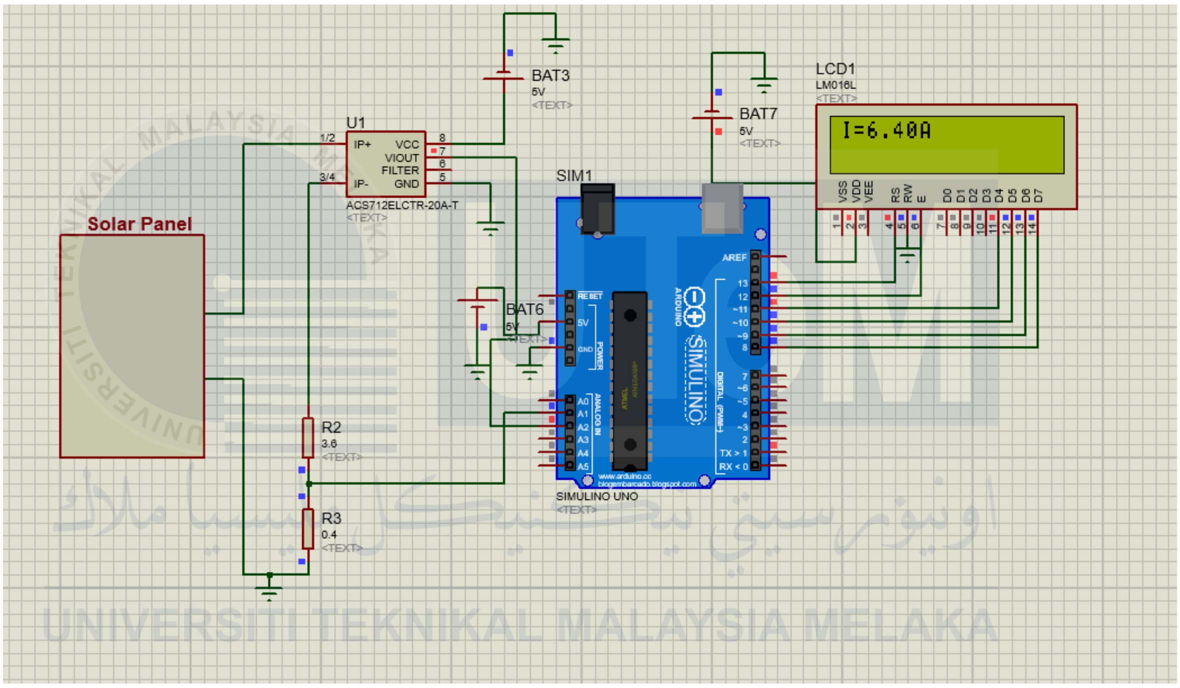


Figure 3.5 Simulation circuit to measure current

3.7.3 Measure Temperature

As is usual a thermometer is applied to measure the ambient temperature; however, as show in figure 3.6, an LM35 temperature sensor is used to determine the ambient temperature. Similar to hardware, the LM35 temperature sensor is used in simulation to detect temperature and display the results in the LCD.

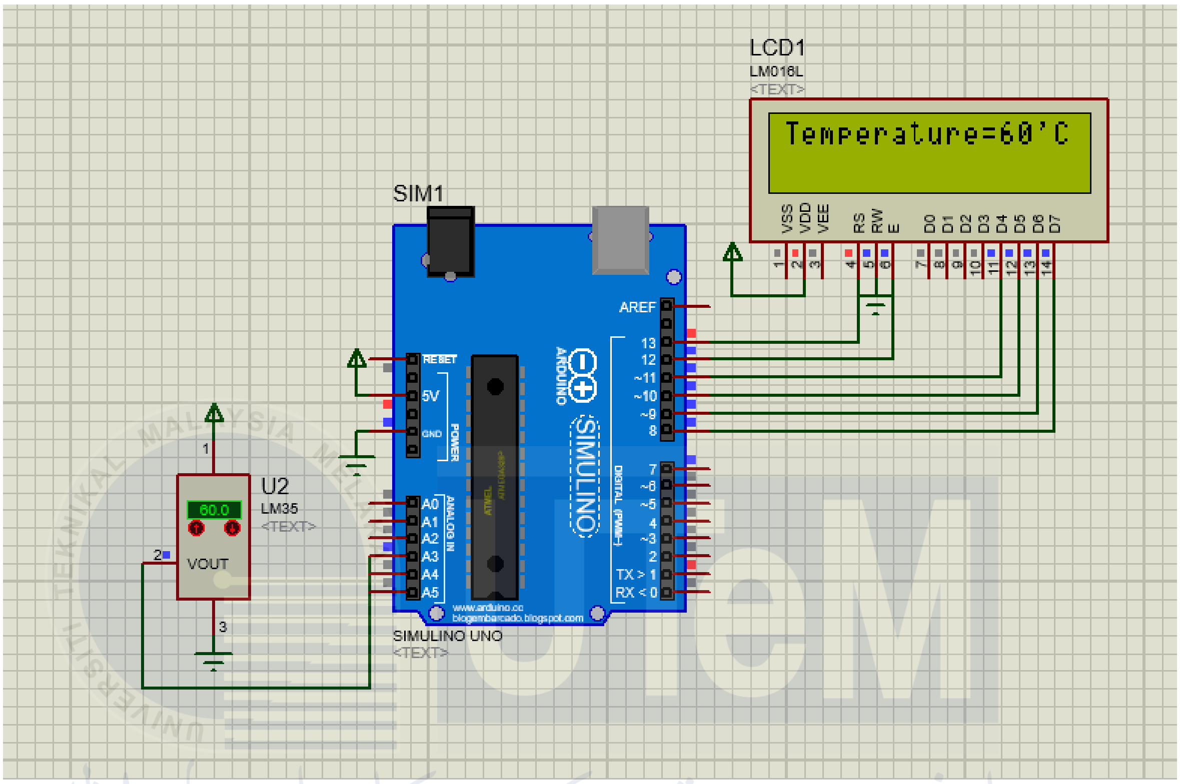


Figure 3.6 Simulation circuit to measure temperature

3.7.4 Measure Irradiance

One of the instruments used to measure irradiance is the pyranometer. Since reference cells are a less expensive alternative to pyranometers, they may be used to measure irradiance. Because the reference cell is created from a solar cell and coupled to a current sensor, the solar cell is used in this simulation as a substitute. The output is then shown on the LCD screen when it successfully established a connection with Arduino as shown in figure 3.7.

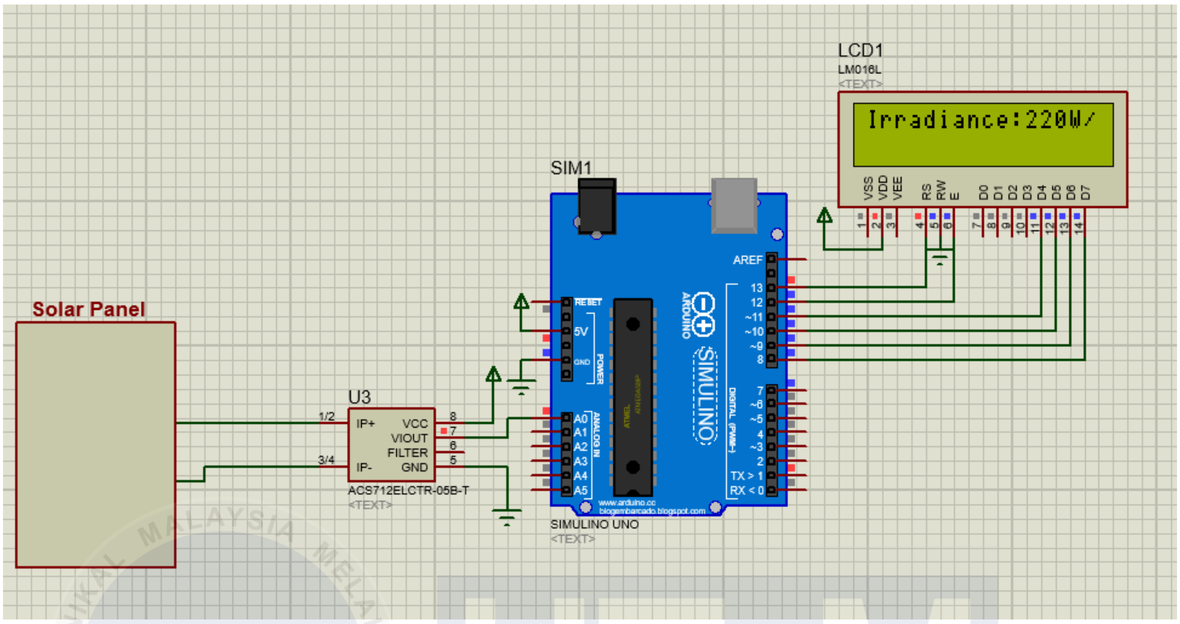


Figure 3.7 Simulation circuit to measure irradiance

3.8 Hardware of Project Measurements

This part will show a completed hardware of the project, procedure to collected data analysis which is to measure irradiance, current, temperature and voltage utilizing SPVPMS and compared to an actual meter such as irradiance meter, clamp meter, temperature meter and voltmeter. In order to gather data in real time from the solar panels, the system interfaces with a variety of sensors, including reference cells, temperature, voltage and current sensors, using Arduino microcontrollers. The hardware of project can be referred by figure 3.8 below while the different point of view for this project hardware can be refer in figure 3.9.

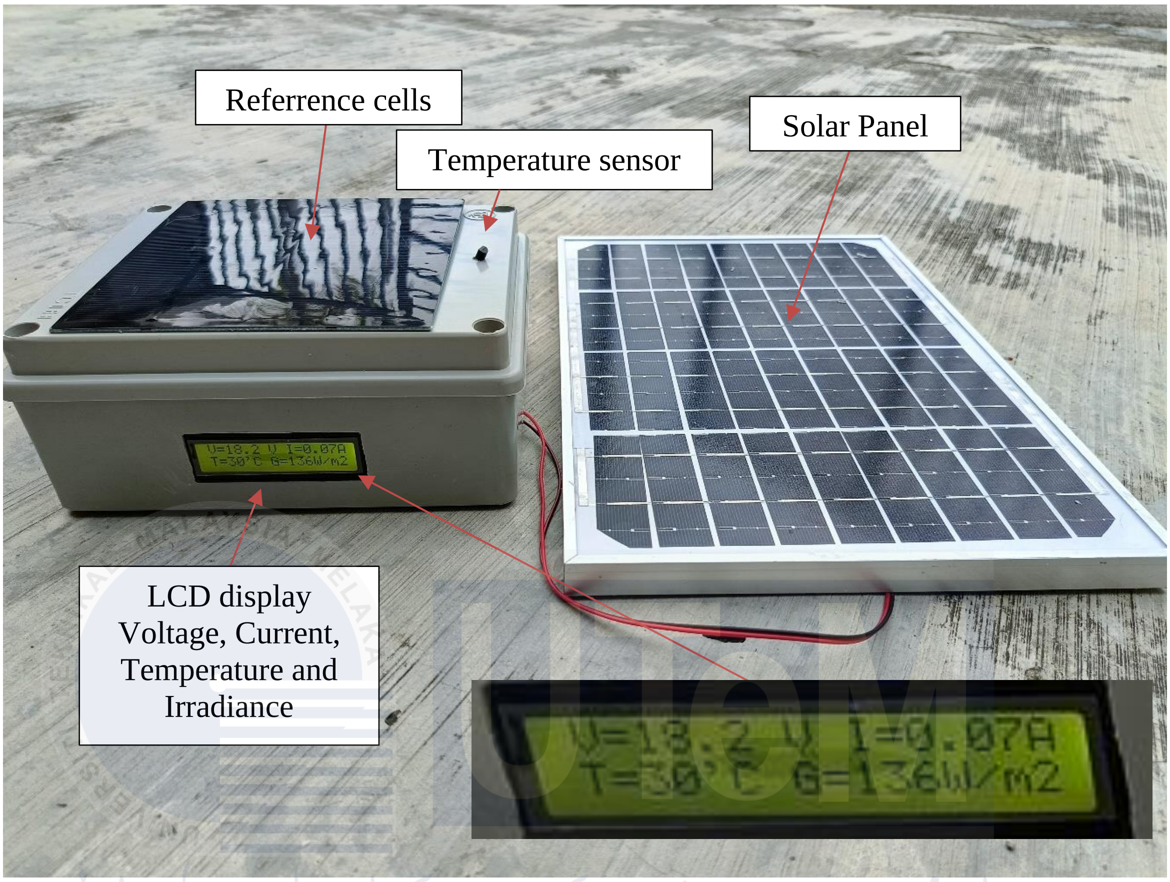
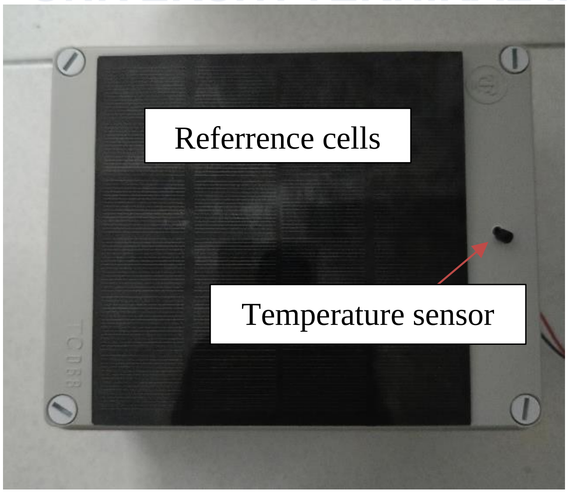
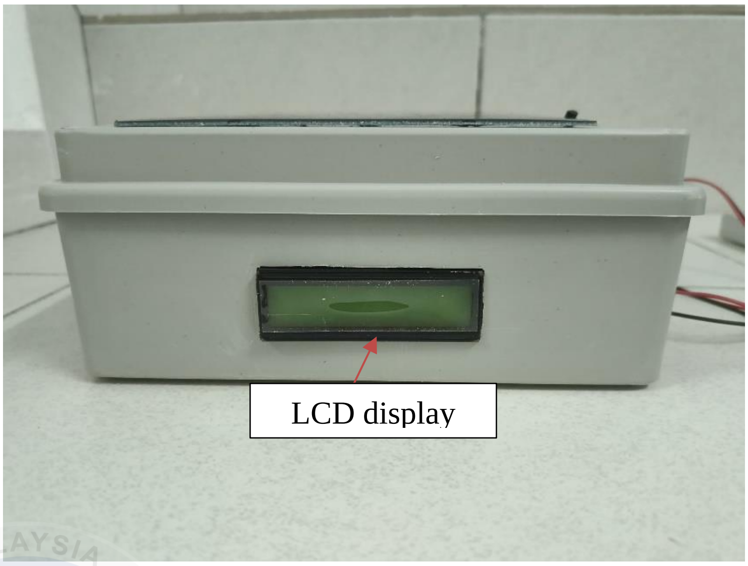


Figure 3.8Hardware of Solar PV Performance Measurement System



Top View

Side View



Front View

Figure 3.9Different view of hardware for Solar PV Performance Measurement System

3.8.1 Measure irradiance and current

Figure 3.10 show the arrangement of SPVPMS hardware to measure the value of irradiance and current from solar panel monocrystalline while comparing the value with actual meter which is clamp meter and irradiance meter. By using SPVPMS, irradiance value was measure by using the reference cell of monocrystalline while current is using current sensor and both of the measurement value is show by using LCD display. Different to actual meter which is directly show the value measured by using clamp meter and irradiance meter. To take the reading of this measurement parameter, two people is needed so that the data can be taken accurately within real time. The function of digital watch in the figure is to show that the data taken is within real time.

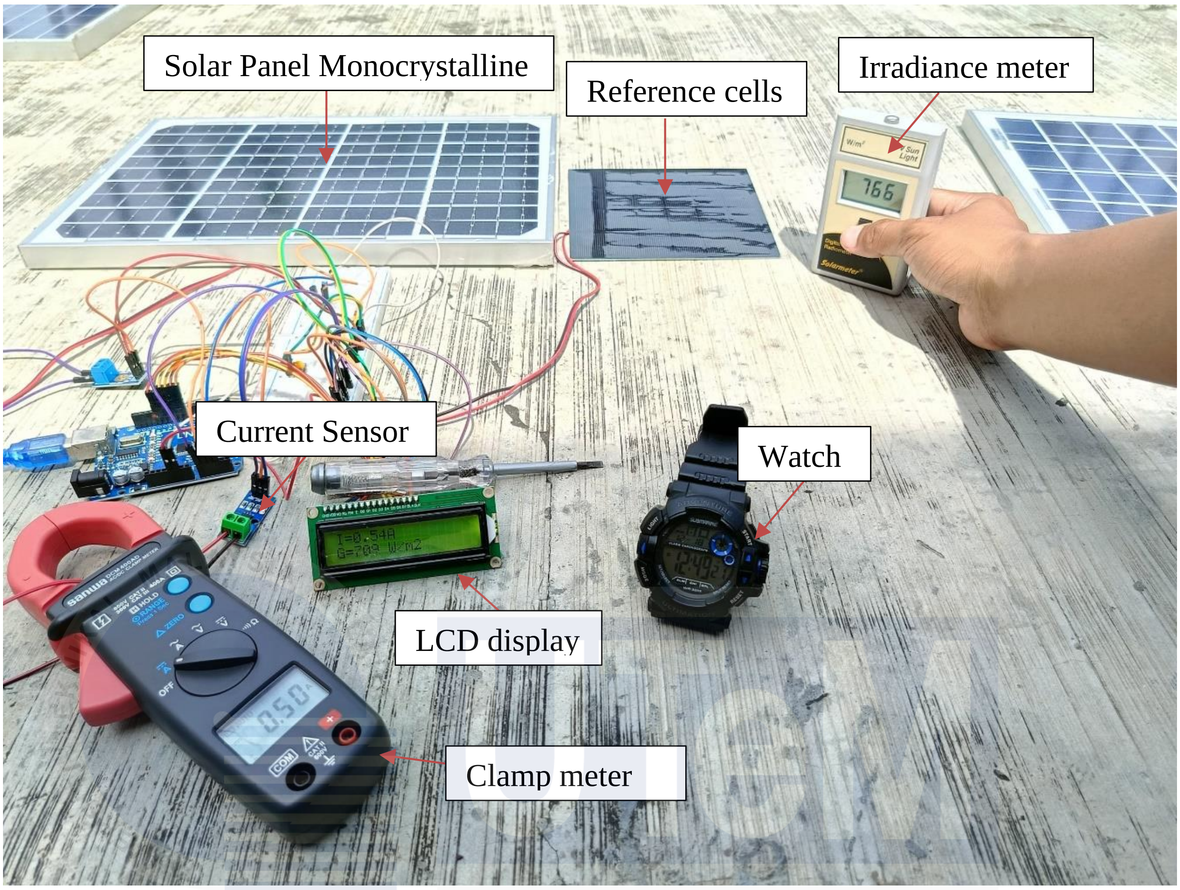


Figure 3.10 Hardware to measure irradiance and current for solar panel monocrystalline

Besides, figure 3.11 also show the same arrangement of SPVPMS hardware to measure irradiance and current. But, the different between these two figure is that the solar panel type, for figure 3.10 used solar panel type monocrystalline meanwhile in figure 3.11 used solar panel type polycrystalline. For SPVPMS, same thing as before that the irradiance value was measure by using the reference cell of polycrsytalline while current is using current sensor and both of the measurement value is show by using LCD display. Different to actual meter which is directly show the value measured by using clamp meter and irradiance meter. To take the reading of this measurement parameter, two people is needed so that the data can be taken accurately within real time. The function of digital watch in the figure is to show that the data taken is within real time.

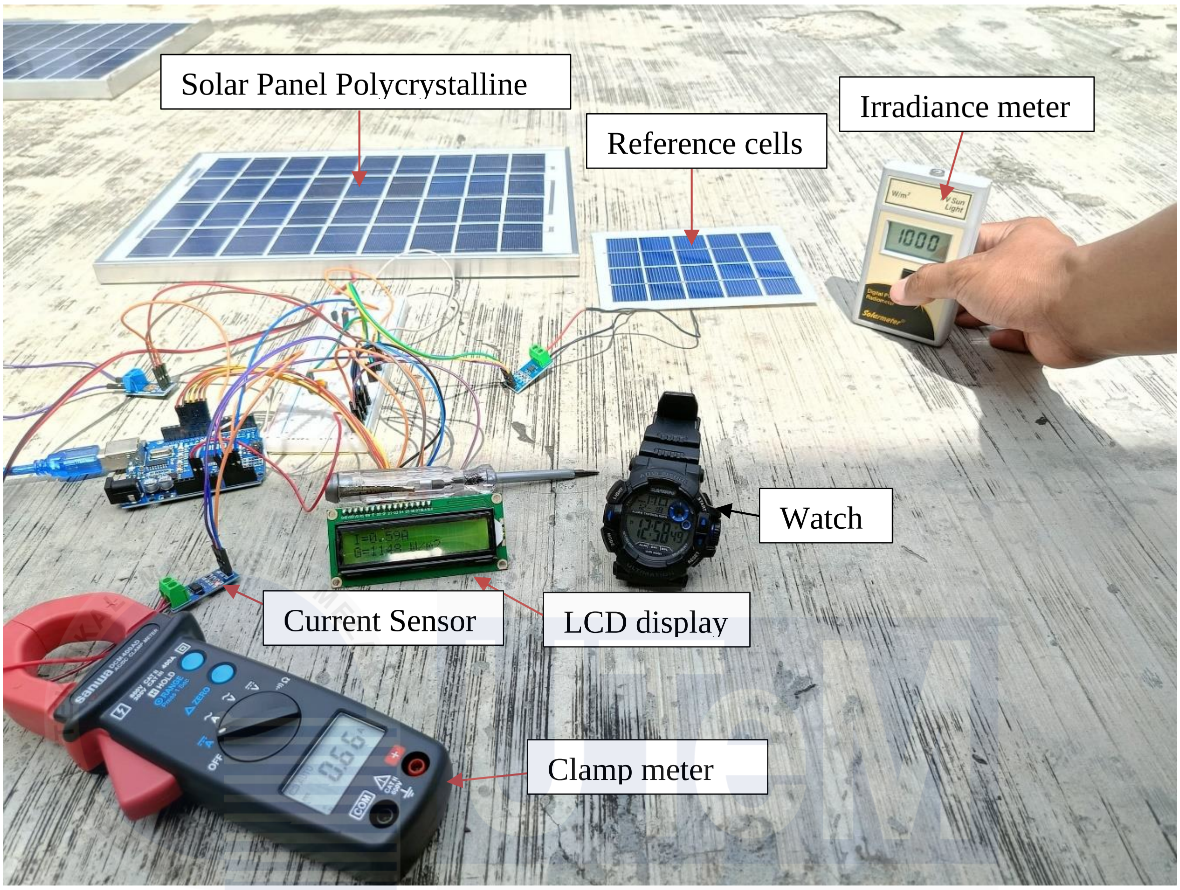


Figure 3.11 Hardware to measure irradiance and current for solar panel polycrystalline

3.8.2 Measure temperature and voltage

Figure 3.12 show the arrangement of SPVPMS hardware to measure temperature and voltage for solar panel type monocrystalline. Besides, figure 3.13 also show the arrangement of SPVPMS hardware to measure voltage and temperature but using the different type of solar panel which is polycrystalline. As show in both figure, for SPVPMS the value of voltage is measure by using voltage sensor while temperature is using temperature sensor LM35 and the value of measurement is display by using LCD display. Meanwhile, the value for actual meter for both voltmeter and temperature meter is show at the meter itself.

While in figure 3.14 show that the temperature meter sensor is put beside temperature sensor LM35 so that the sensor can measure at the same level of ambient temperature. Same procedure with irradiance and current, to measure this parameter two people is needed to taken the measurement value so that the data taken is accurately within the real time. The function of digital watch also same is to show the real time during the data taken.

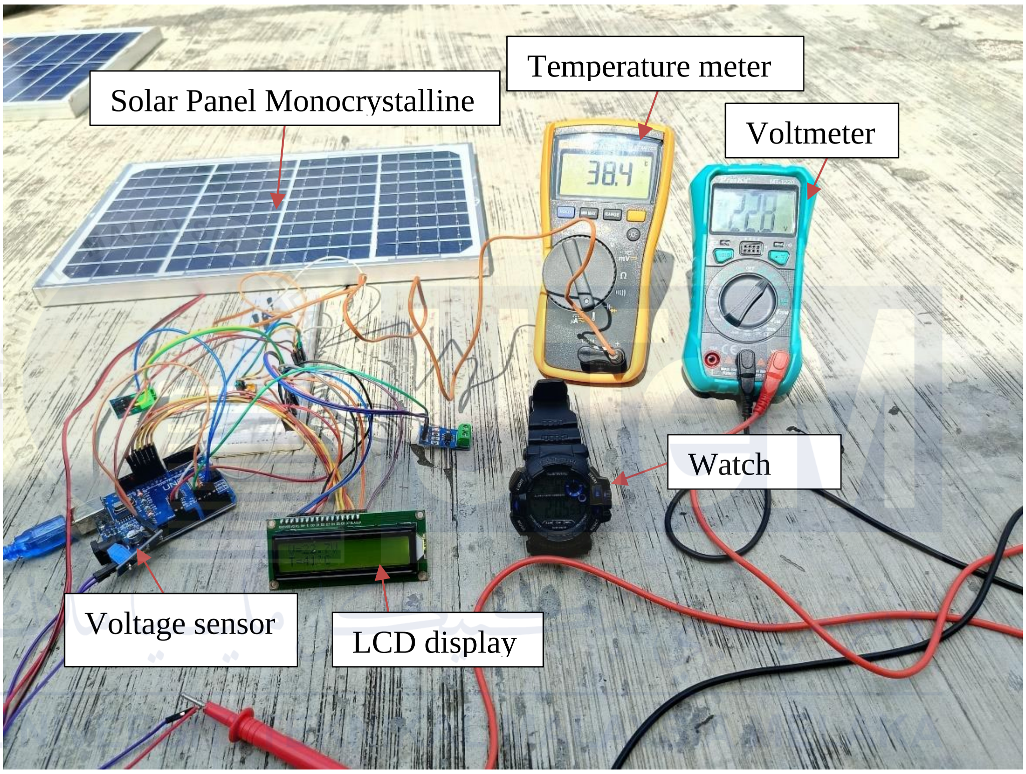


Figure 3.12 Hardware to measure temperature and voltage for solar panel monocrystalline

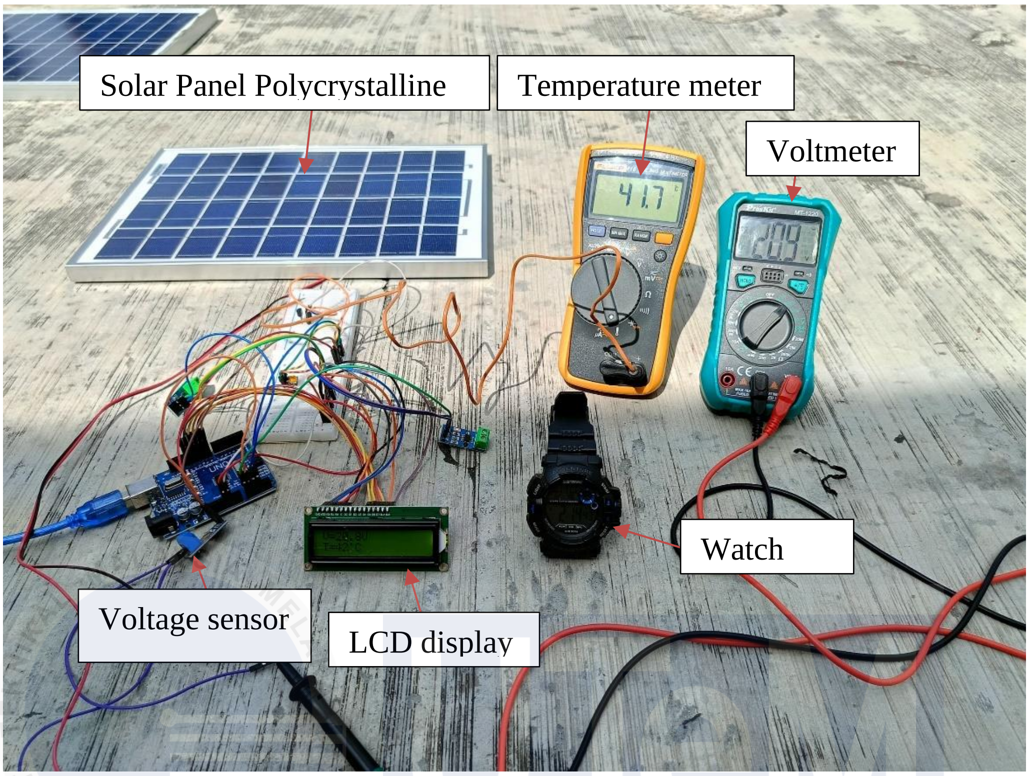


Figure 3.13 Hardware to measure temperature and voltage for solar panel polycrystalline

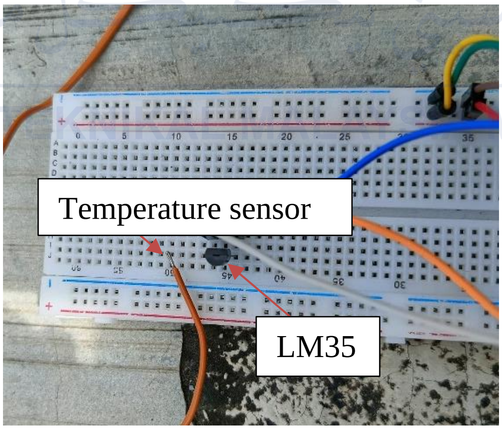


Figure 3.14 Temperature meter sensor is beside temperature sensor LM35

3.9 Gantt Chart

No.	Task	PSM1														PSM2													
	Weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Briefing for PSM 1 by JK, PSM, FTKEE	■																											
2	Project Title Conformation and Registration		■																										
3	Briefing with Supervisor			■																									
4	Study the Project Background			■																									
5	Drafting Chapter 1: Introduction								■																				
6	Task progress evaluation 1						■																						
7	Drafting Chapter 2: Literature Review			■	■																								
8	Table of Summary Literature Review			■	■																								
9	Drafting Chapter 3: Methodology					■	■	■																					
10	Work on the Software/Hardware								■	■	■																		
11	First Draft submission to Supervisor										■																		
12	Task progress evaluation 2											■	■	■															
13	Submission Report to the Panel													■															
14	Presentation of BDP1														■														
15	Drafting Chapter 4: Analyze Data and Result									■	■																		
16	Data Analyze and Result									■	■						■	■											
17	Record the Result									■	■								■	■									
18	Drafting Chapter 5: Conclusion and Recommendation															■					■	■	■						
19	Compiling Chapter 4 and Chapter 5																							■	■	■			
20	Submit Latest Report to Supervisor																										■		
21	Finalize the Report																											■	
22	Presentation of BDP2																												■

Table 3.3 Gantt chart of the project

A Gantt chart is a diagram that shows the tasks, deadlines, dependencies, and progress of a project. The Gantt chart would show the many phases of a solar PV measurement system project, including creating the project report, designing and trying out the system's components, conducting performance testing, and logging analytical data and results. The graphic would also display the estimated completion dates, job dependencies, and timetables for each step. This would make it easier for project managers to monitor development, spot any problems or delays, and make sure the project is finished on schedule and under budget.

3.10 Summary

A solar PV performance measuring system's technique normally includes the installation of sensors and data loggers to gather data on the energy production of the PV panels as well as environmental variables like voltage, current, temperature and irradiance. The system's effectiveness and performance are then evaluated, along with any potential performance-related problems, using this data. By measuring the values of voltage, current, temperature, and irradiance, the approach seeks to give precise and trustworthy performance data that can help in improving the effectiveness of the solar PV system.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The focus of the result and discussion part of our solar measurement system is on analysing its effectiveness and precision in monitoring current, voltage, temperature, and irradiance using Arduino. The technology was created to offer solar energy installations real-time data collection and monitoring. The ability of the system to detect changes in current, voltage, temperature, and irradiance, as well as the precision and accuracy of the readings. It also demonstrate the efficiency and dependability of our solar measuring system in precisely tracking important solar power characteristics through this thorough review.

4.2 Simulation Result and Analysis

For this part will show the result and analysis of simulation by using Proteus 8 Professional software. There will be three values recorded in this simulation which is minimum, average and maximum.

4.2.1 Simulation of minimum value

The circuit used to simulate this project is shown in the figure 4.1. This simulation shows that the operating voltage for this circuit is 5V, and that the temperature is 27°C and the current is 6.40A. Additionally, it indicates that the irradiance value at this temperature which is 506W/m² reflect the lowest value for this simulation in terms of voltage and current values.

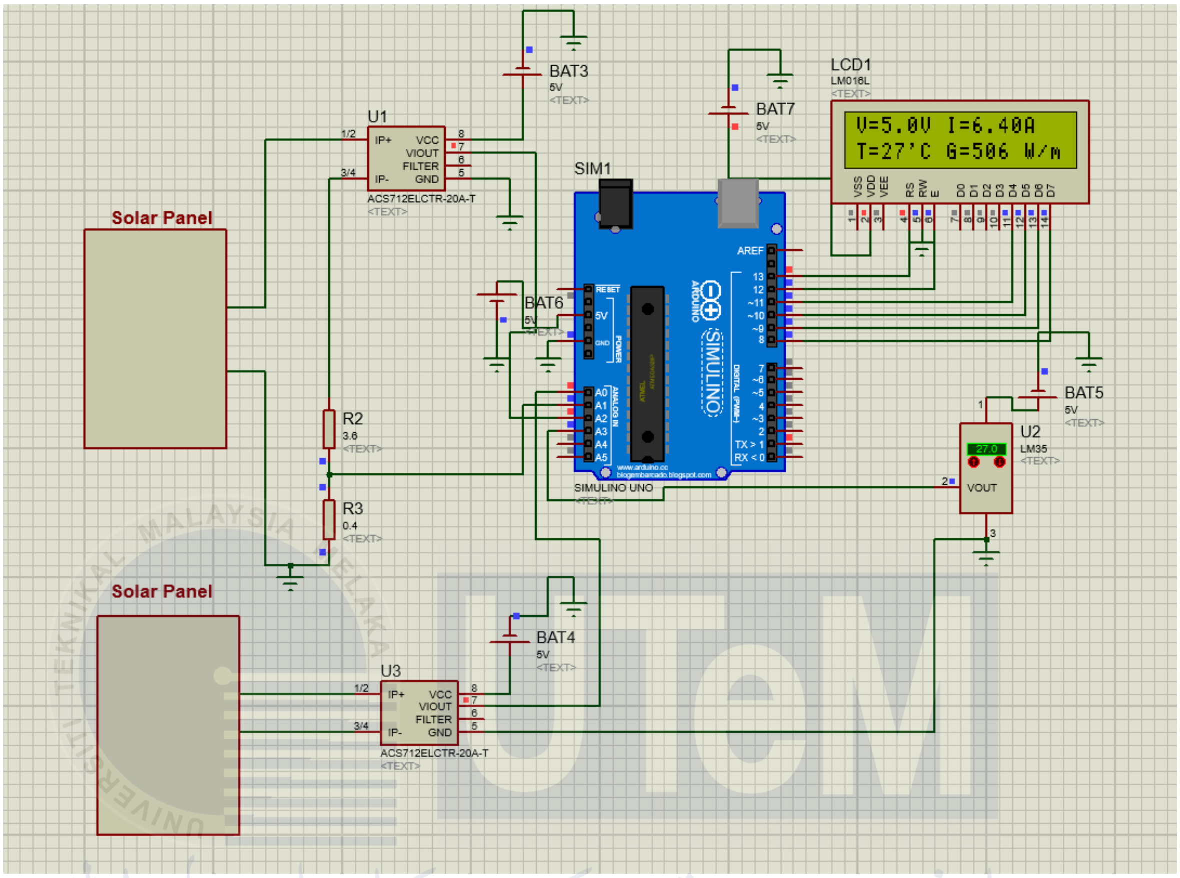


Figure 4.1 Simulation circuit with minimum voltage value

4.2.2 Simulation of average value

The average value of the simulation that was ran for this simulation appears in Figure 4.2 below. According to this simulation, the circuit's working voltage is 16.0V, the temperature is 30°C, and the current is 7.07A. Additionally, it shows that at this temperature, the irradiance value is 764W/m².

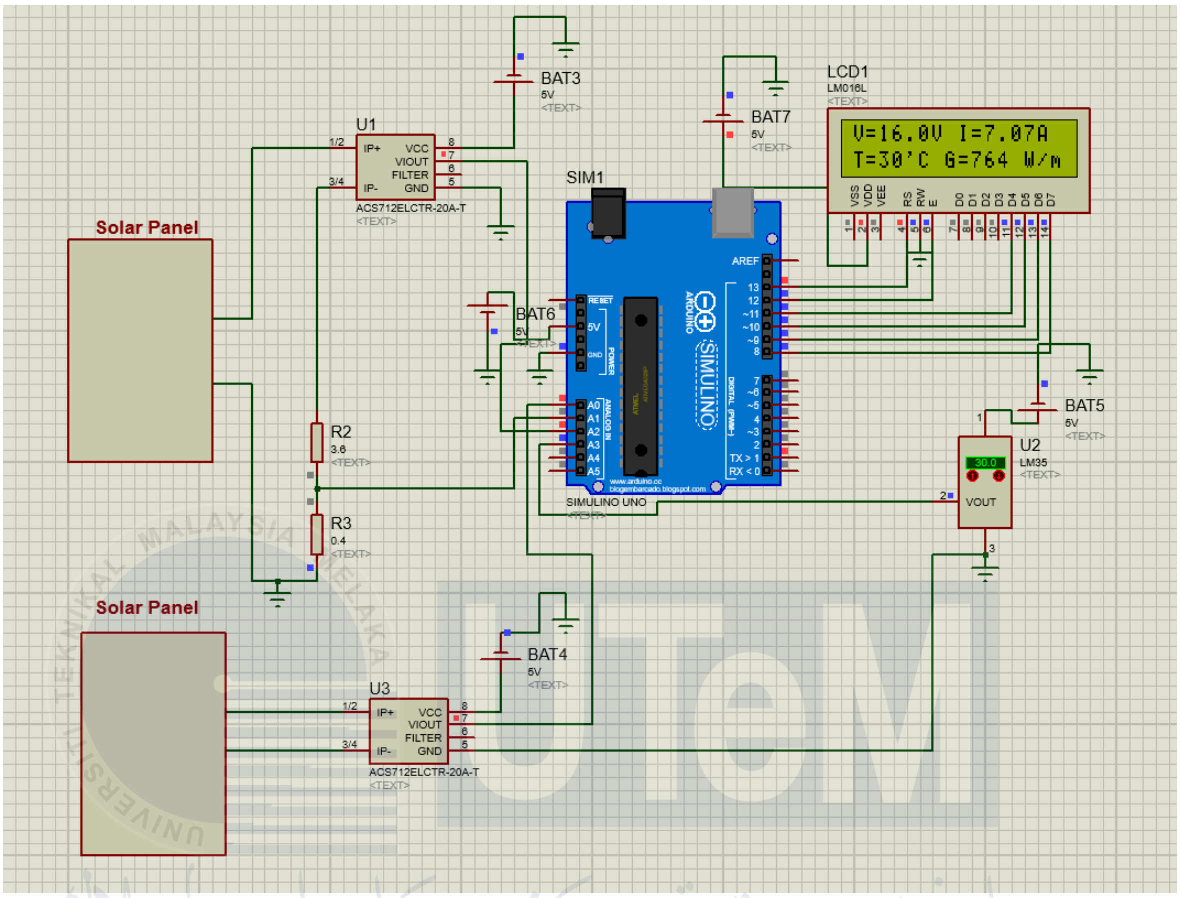


Figure 4.2 Simulation circuit with average voltage value

4.2.3 Simulation of maximum value

The maximum result of the simulation that was run for the simulation shown in figure 4.3 below. This simulation indicates that the operating voltage of the circuit is 32.2V, the temperature is 32°C, and the current is 8.05A. Additionally, it demonstrates that the irradiance value at this temperature is 1216W/m²

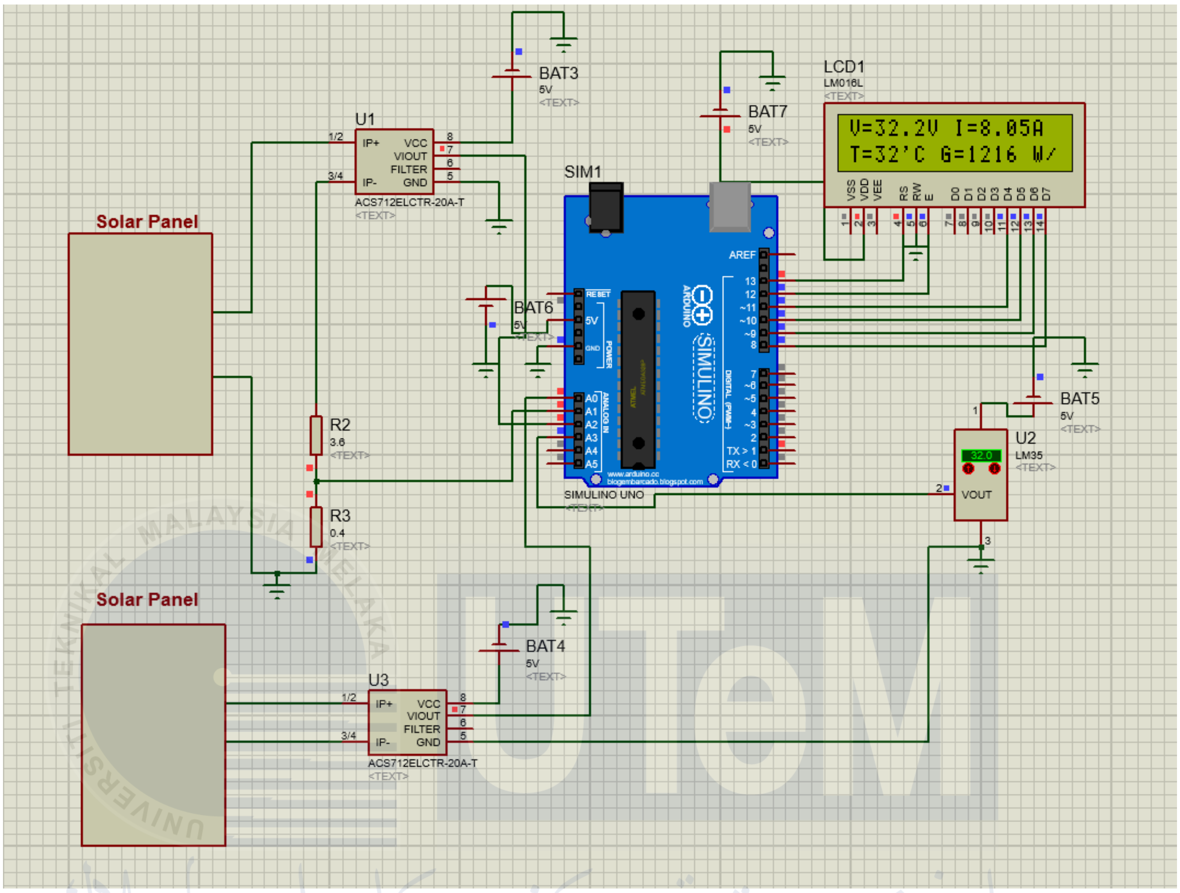


Figure 4.3 Simulation circuit with maximum voltage value

4.3 Hardware Result and Analysis

An experiment was carried out to test the effectiveness and functionality of SPVPMS (Solar PV Performance Measurement System). The SPVPMS was test on two different solar panel which is Monocrystalline and Polycrystalline to obtain the relevant result. The result obtain are irradiance, current, temperature and voltage. Two type of test was carried out to analyses the relationship between irradiance vs current and temperature vs voltage. The discussion part is an explanation of the results obtained during the measurement process. An actual meter such as irradiance meter, voltmeter, temperature meter and clamp meter also use in the experiment in order to give a comparison between SPVPMS reading and actual meter.

4.3.1 Result analysis of Monocrystalline panel

Table 4.1 shows the reading of irradiance and current using SPVPMS and actual meter as a benchmark. Both SPVPMS and actual meter will measure a parameter from Monocrystalline solar panel. For SPVPMS, current sensor was used to measured the current while reference cells is used to measured irradiance and both of the measured parameter is show by using LCD display. Meanwhile, clamp meter used to measured the current flow from the solar panel while irradiance meter was used to measured irradiance as a benchmark to compare the value with SPVPMS value. The reading of irradiance for SPVPMS giving a range from 181 W/m² up until 751 W/m² meanwhile the reading record by using irradiance meter is giving a range from 106 W/m² until 891 W/m². There are around 100 W/m² different for both reading. While, the reading of current for SPVPMS is in range of 0.04 A until 0.56 A meanwhile the reading value for clamp meter is giving a value in range of 0.04 A until 0.62 A. The different reading between both SPVPMS and benchmark is approximate 0.05 A.

Table 4.2 shows the reading of temperature and voltage using SPVPMS and actual meter as a benchmark during measuring parameter process. Both SPVPMS and actual meter will measure a parameter from Monocrystalline solar panel. For SPVPMS, voltage sensor was used to measured the voltage while temperature sensor lm35 is used to measured temperature and both of the measured parameter is show by using LCD display. Meanwhile, voltmeter used to measured the voltage from the solar panel while temperature meter was used to measured ambient temperature as a benchmark to compare the value with SPVPMS value. The reading of temperature for SPVPMS giving a range from 35°C up until 40°C meanwhile the reading record by using irradiance meter is giving a range from 30.8°C until 34.2°C.There are around 5°C different for both reading. While, the reading of current for SPVPMS is in range of 21.5 V until 22.5 V meanwhile the reading value for clamp meter is giving a value in range of 21.5 V until 22.6 V. The different reading between both SPVPMS and benchmark is approximate 0.1 V

Table 4.1 Irradiance vs Current for SPVPMS and benchmark

Monocrystalline																	
Time, hour	SPVPMS								Benchmark								
	Irradiance, W/m²			**Average W/m²**	Current, A			**Average, A**	Irradiance, W/m²			**Average, W/m²**	Current, A			**Average, A**
12:00	678	678	686	**681**	0.54	0.54	0.59	**0.56**	836	834	836	**835**	0.62	0.62	0.62	**0.62**
12:20	600	600	546	**582**	0.36	0.36	0.28	**0.33**	544	477	348	**456**	0.36	0.32	0.25	**0.31**
12:40	181	181	181	**181**	0.04	0.04	0.04	**0.04**	106	106	106	**106**	0.04	0.04	0.04	**0.04**
13:00	180	181	181	**181**	0.04	0.04	0.04	**0.04**	106	106	106	**106**	0.04	0.03	0.04	**0.04**
13:20	510	510	510	**510**	0.28	0.28	0.28	**0.28**	468	458	458	**457**	0.30	0.29	0.28	**0.29**
13:40	734	734	734	**734**	0.48	0.48	0.48	**0.48**	780	781	781	**780**	0.52	0.52	0.52	**0.52**
14:00	701	697	697	**698**	0.50	0.55	0.55	**0.53**	808	813	813	**812**	0.51	0.52	0.50	**0.51**
14:20	751	751	751	**751**	0.55	0.55	0.55	**0.55**	892	889	889	**891**	0.58	0.57	0.58	**0.58**
14:40	702	690	690	**694**	0.48	0.50	0.50	**0.49**	793	793	793	**793**	0.52	0.51	0.51	**0.51**
15:00	343	343	343	**343**	0.05	0.05	0.05	**0.05**	140	141	139	**140**	0.10	0.11	0.10	**0.10**

Table 4.2 Temperature vs voltage for SPVPMS and benchmark

Monocrystalline																
Time, hour	SPVPMS								Benchmark							
	Temperature, °C			**Average, °C**	Voltage, V			**Average, V**	Temperature, °C			**Average, °C**	Voltage, V			**Average, V**
12:00	35	35	36	**35**	22.0	22.0	22.1	**22.0**	30.7	30.0	31.0	**30.8**	22.2	22.3	22.3	**22.3**
12:30	35	35	36	**35**	22.4	22.5	22.5	**22.5**	32.1	32.3	32.4	**32.3**	22.6	22.6	22.6	**22.6**
13:00	39	39	39	**39**	21.9	21.9	21.9	**21.9**	33.1	32.4	32.0	**32.5**	22.2	22.1	22.2	**22.2**
13:30	36	36	37	**36**	21.7	21.8	21.8	**21.8**	32.9	32.7	32.9	**32.8**	22.0	22.0	22.0	**22.0**
14:00	40	40	39	**40**	21.5	21.5	21.4	**21.5**	34.2	34.0	33.1	**33.8**	21.8	21.7	21.6	**21.7**
14:30	37	37	36	**37**	21.6	21.6	21.6	**21.6**	33.6	33.4	33.5	**33.5**	21.9	21.9	21.9	**21.9**
15:00	40	40	40	**40**	21.8	21.8	21.9	**21.8**	34.3	34.3	34.0	**34.2**	21.9	21.9	22	**21.9**
15:30	40	40	40	**40**	21.2	21.2	21.2	**21.2**	33.6	33.5	33.4	**33.5**	21.5	21.5	21.5	**21.5**
16:00	39	39	39	**39**	22.0	22.0	22.0	**22.0**	34.2	34.2	34.1	**34.2**	22.2	22.0	22.0	**22.1**
16:30	39	40	39	**39**	21.6	21.6	21.7	**21.6**	33.6	33.7	33.6	**33.6**	21.8	21.8	21.9	**21.8**

4.3.1.1 Irradiance versus current

Figure 4.4 show the relationship between irradiance and current from Monocrystalline solar panel by using SPVPMS for data acquisition. The changing interaction between irradiance and current is demonstrated through the collection of numerous of data. The minimum irradiance recorded was 181 W/m² during periods of low sunlight, resulting in a minimum current output of 0.04 A. This happen is due to a several of factor such as shading happen. Conversely, the system demonstrated its peak performance under maximum irradiance of 751 W/m², yielding a maximum current output of 0.55 A. The average irradiance over the entire data collection period was approximately 500 W/m², corresponding to an average current of 0.3 A. By observing the graph, it is clearly show that irradiance is directly proportional to the current.

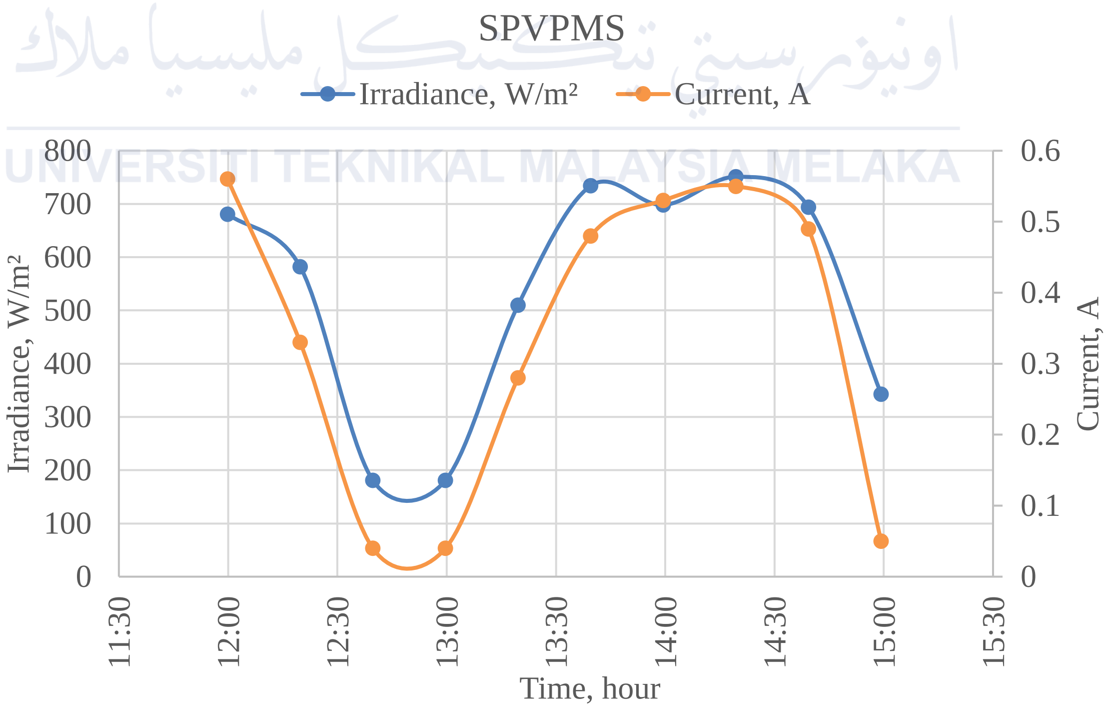


Figure 4.4 Irradiance vs current for SPVPMS

Figure 4.5 show the relationship between irradiance and current by using irradiance meter and clamp as a benchmark. The recorded minimum irradiance of 106 W/m² and its corresponding minimum current output of 0.04 A revealing the systems capacity to generate power even under low-light conditions. The maximum irradiance observed at 891 W/m², with a peak current output of 0.58 A, demonstrated the instruments accuracy in capturing the systems response to optimal sunlight exposure. The average irradiance recorded was approximately 500 W/m² and the corresponding average current output of 0.3 A underscore the reliability of the irradiance meter and ammeter in providing understanding of the changing relationships between irradiance levels and the resulting current.

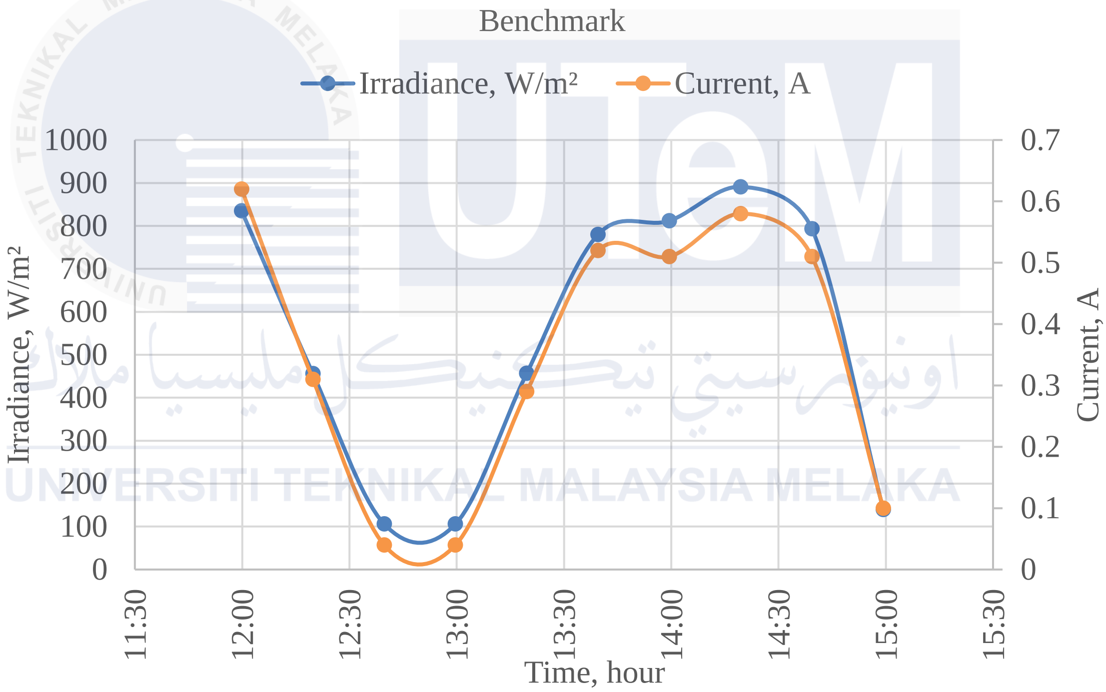


Figure 4.5 Irradiance vs current for benchmark

4.3.1.2 Temperature versus voltage

Figure 4.6 show the relationship between temperature and voltage measured by using SPVPMS. By analysis the data in the graph, it show that temperature is inversely proportional to the voltage. Hence, the value of temperature will always opposite to the voltage. The maximum value that record for temperature is approximately 40°C while the minimum value of voltage is approximately 21.5 V. Meanwhile, the minimum value of temperature recorded is approximately 35°C and maximum voltage is approximate 22.5 V. The average value for both temperature and voltage is likely approximate 37°C and 22.0 V.

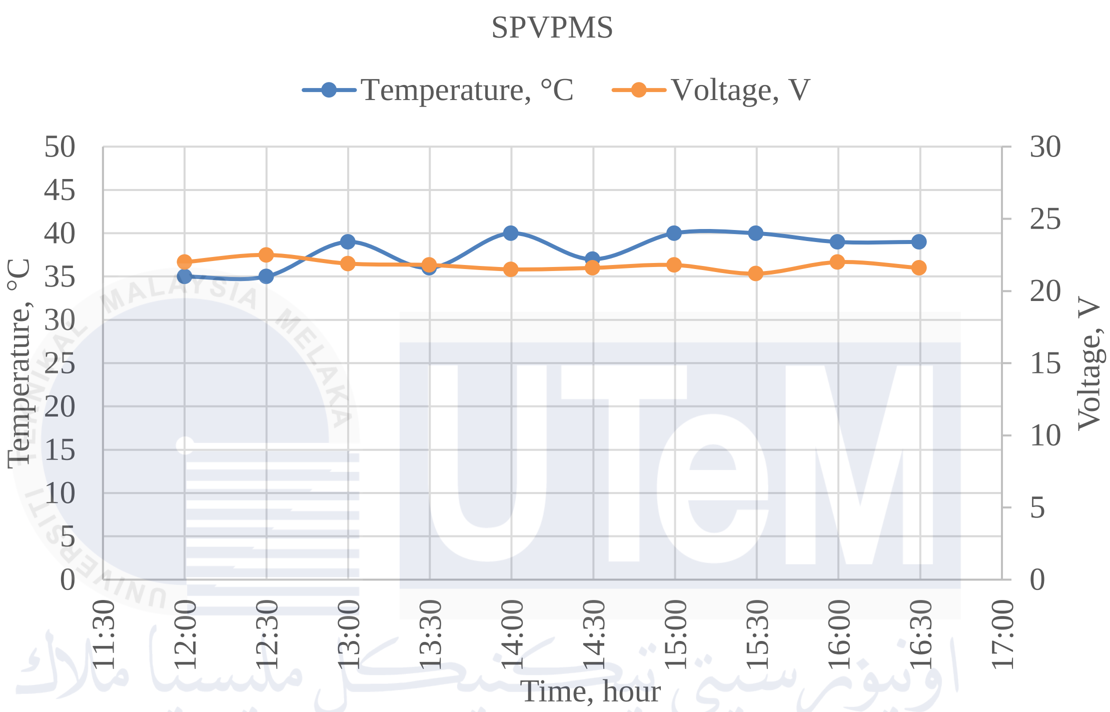


Figure 4.6 Temperature vs voltage for SPVPMS

Figure 4.7 show the relationship between temperature and voltage by utilizing temperature meter and voltmeter as a benchmark . By analysis the data in the graph, it also show that temperature is inversely proportional to the voltage. Hence, the value of temperature will always opposite to the voltage. The maximum value that record for temperature is approximately 35°C while the minimum value of voltage is approximately 21.7 V. Meanwhile, the minimum value of temperature recorded is approximately 30°C and maximum voltage is approximate 22.5 V. The average value for both temperature and voltage is likely approximate 33°C and 22.0 V.

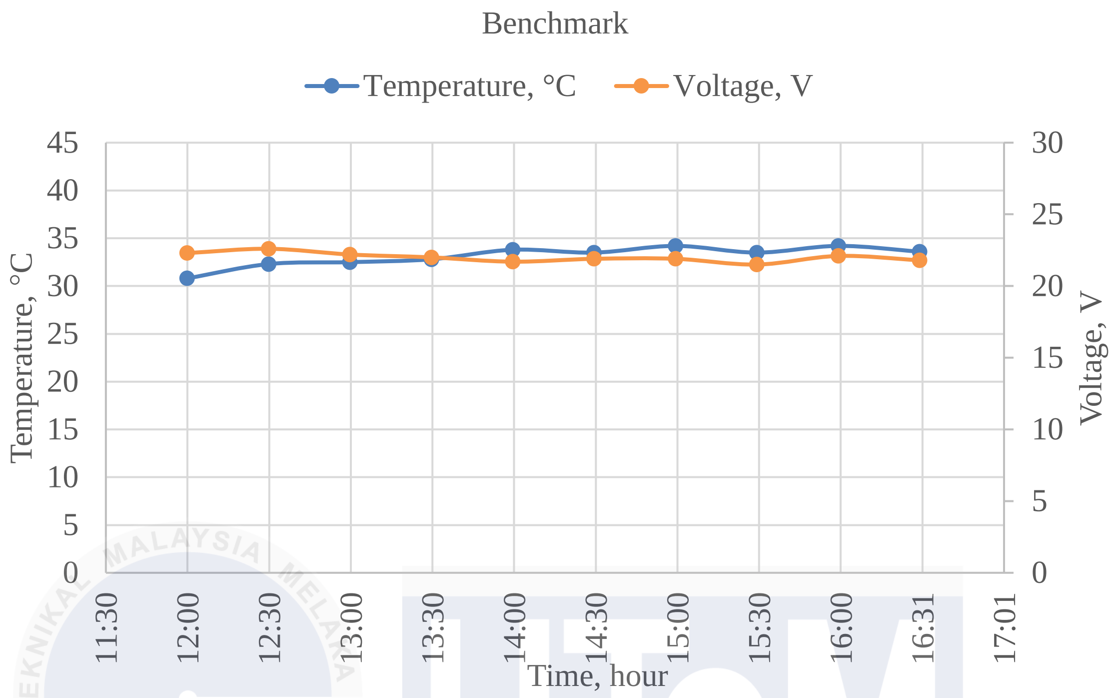


Figure 4.7 Temperature vs voltage for benchmark

4.3.1.3 SPVPMS irradiance benchmark test with actual irradiance sensor

Figure 4.8 show the comparison of measuring irradiance by utilizing SPVPMS and irradiance meter as a benchmark. By analyse the graph, the reading value taken using SPVPMS is not much different from the reading value taken using the irradiance meter. The lowest value that records by SPVPMS is approximate 200 W/m² while by using the irradiance meter, the value of irradiance is approximate 100 W/m². It stated that the measurement value of any irradiance that taken below 500 W/m² is consider as invalid by according to the SEDA guideline and procedure for solar PV system installation and commissioning. Meanwhile, the average value which also the validity value of irradiance for both reference cell and irradiance meter is approximate 600 W/m² and 500 W/m². The maximum value that taken from both measurement meter is approximate 800 w/m² for refence cell and 900 W/m² for irradiance meter. By comparing every value from minimum to maximum value, it shows that for the minimum reading it is only different around 100

W/m² for both SPVPMS and irradiance meter. This is happened due to SPVPMS is using a refence cell as a sensor to measure the irradiance. By utilizing refence cell, it also uses a current sensor to detect the current flow from the refence cell before using the Arduino uno to generate the input of irradiance that was detected by reference cell and current sensor to produce an output by displaying it using LCD display. Hence, during the current flow from reference cell to the Arduino, the length of wire from reference cells also effects the value of irradiance that show by LCD display because the more length of wire the more resistivity it has, so low current produces a low irradiance value. Besides, the components of the irradiance meter and reference cell may differ in quality. Measurements from higher-quality sensors such as irradiance meter are often more precise and consistent. This may be the cause of the difference in reading values recorded by SPVPMS and irradiance meter.

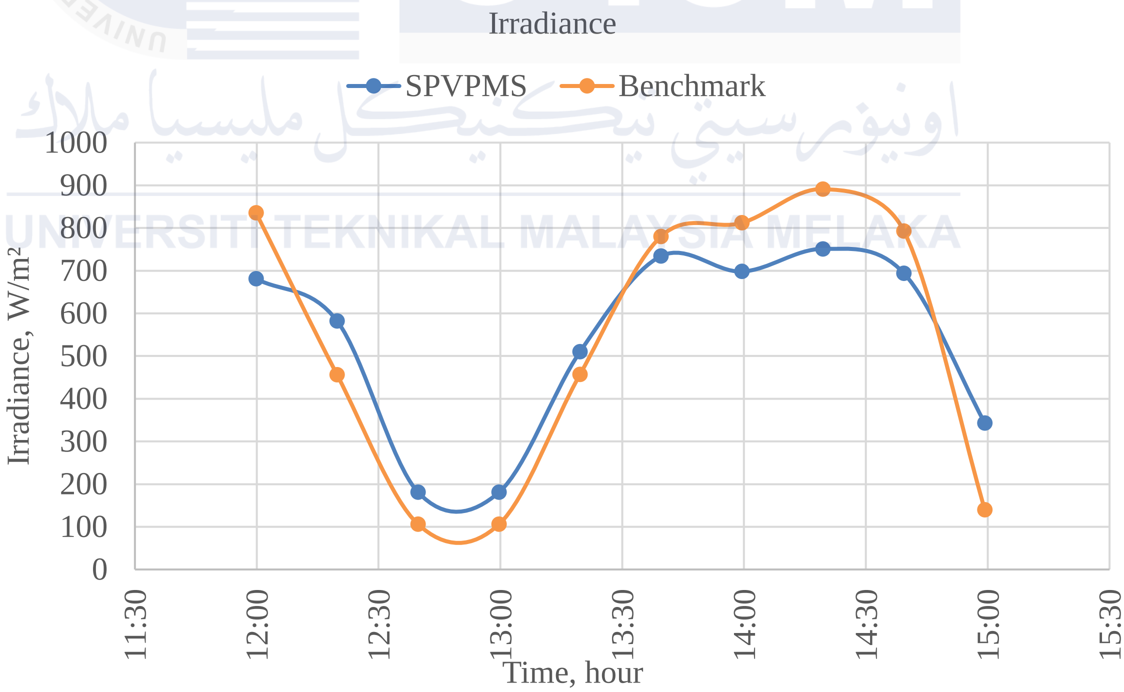


Figure 4.8 Comparison of irradiance between SPVPMS and benchmark

4.3.1.4 SPVPMS current benchmark test with actual current sensor

Besides, Figure 4.9 show the measurement value for current by utilizing both SPVPMS and ammeter as a benchmark. The graph is purposely to show the comparison of measuring the value of current by using SPVPMS and clamp meter. The lowest value that taken for both SPVPMS and clamp meter is approximate 0.00 A. This is due to shading happpened during the data taken make the solar panel achieve a few amount of sunlight cause the value of current also lowest. Meanwhile, the average value taken from both SPVPMS and ammeter is approximate 0.30 A. The maximum value taken for both measurement system show a slight different which is for SPVPMS is around 0.56 A while 0.6 A for clamp meter. By comparing the minimum to maximum value of current taken, it show that for current measurement value does not have a lot of different. It also show that the current sensor ACS712 use in SPVPMS can be used to measure the current from solar panel because it almost given the same value as if use an clamp meter. The slight different value between SPVPMS and clamp meter because of there may be differences in the analog-to-digital converter (ADC) of the Arduino and the resolution of the current sensor. It is possible for an ADC or low-resolution sensor to misread tiny current variations. Besides, it also due to a several factor such as lenght of wire from solar panel to the current sensor, the measure value taken during the transition from shading to clear sky that take a time for the current sensor to measure the value, and the sensitivity of clamp meter is more accurate compare to current sensor.

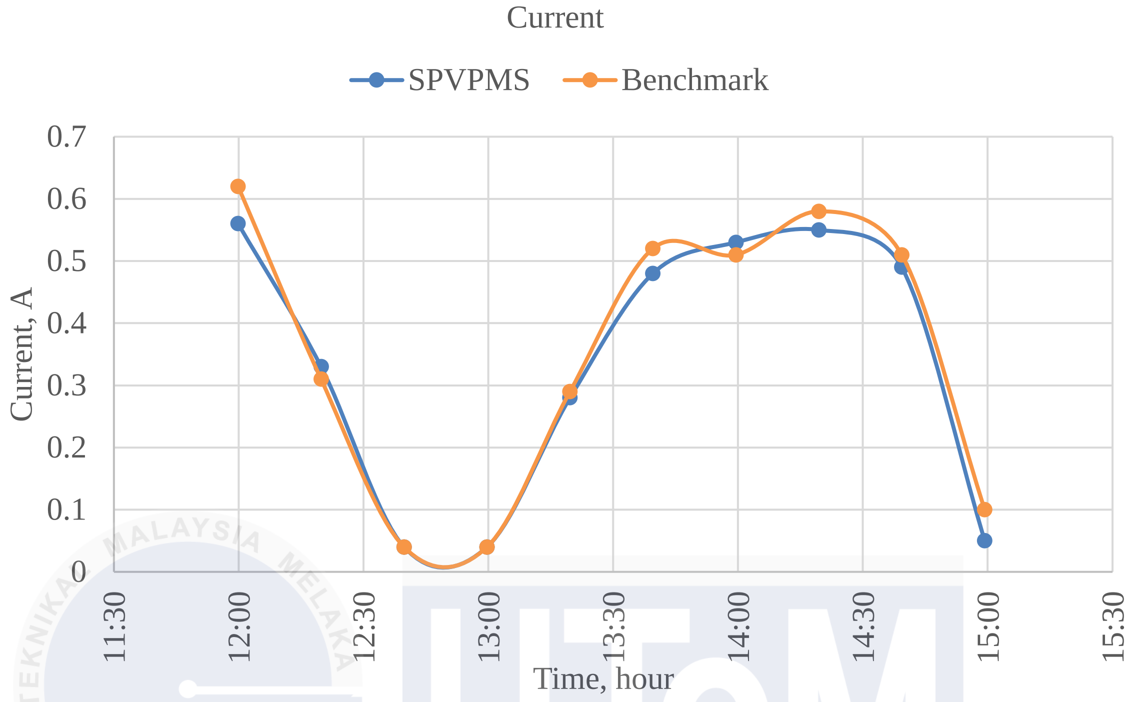


Figure 4.9 Comparison of current between SPVPMS and benchmark

4.3.1.5 SPVPMS temperature benchmark test with actual temperature sensor

Figure 4.10 show the measurement value for temperature by utilizing both SPVPMS and temperature meter as a benchmark. This graph is show that the different of measuring the value of ambient temperature by using SPVPMS and temperature meter. The minimum value that taken from SPVPMS is approximate 35°C while value taken from temperature meter is approximate 30°C. This is due to shading happpened during the data taken make the surrounding temperature become the minimum and cool area. Meanwhile, the average value taken for SPVPMS is around 37°C and for temperature meter is approximate 32.5°C. The maximum value taken for SPVPMS is approximate 40°C while 34.5°C for temperature meter. SPVPMS is using LM35 as a temperature sensor while benchmark is using temperature meter. By comparing the minimum to maximum value of temperature, it show that the temperature value for both meter have a quite different which is around 5°C. The different value between SPVPMS and temperature meter is due to the measure value taken during the transition from shading to clear sky that take a time for the current sensor to measure the value, the sensitivity of temperature meter is more accurate compare to temperature sensor, and the different places of the sensor and temperature meter sensor.

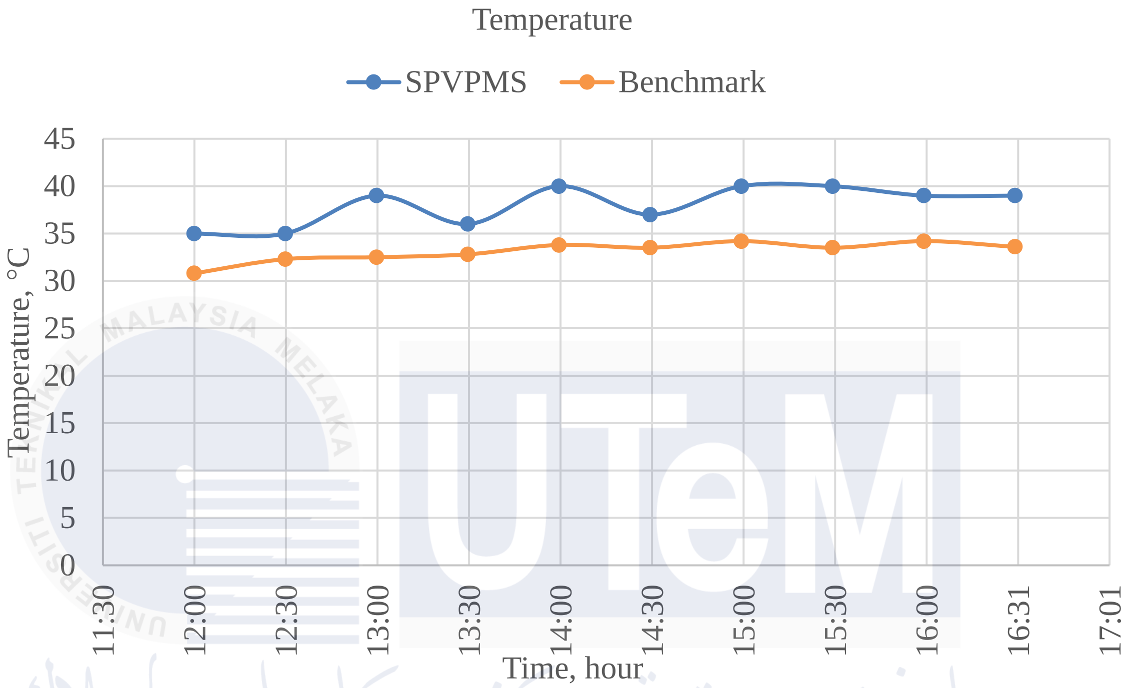


Figure 4.10 Comparison of temperature between SPVPMS and benchmark

4.3.1.6 SPVPMS voltage benchmark test with actual voltage sensor

Besides, Figure 4.11 show the measurement value for voltage by utilizing both SPVPMS and voltmeter as a benchmark. The graph is purposely to show the comparison of measuring the value of current by using SPVPMS and voltmeter. The minimum value that taken for both SPVPMS and voltmeter is approximate 21.5 V. Meanwhile, the average value taken from both SPVPMS and voltmeter is approximate 22.0 V. The maximum voltage taken is approximate 22.6 V for both SPVPMS and voltmeter measurement. By comparing the minimum to maximum value of voltage taken, it show that for voltage value does not have a lot of different. It also show that the voltage sensor that use in SPVPMS can be used to measure the voltage from the solar panel because it almost given the same value as if use an voltmeter. The slight different value between SPVPMS and voltmeter is due to several factor such as the precision of voltage readings may be restricted by the resolution of the Arduino's ADC, lenght of wire from solar panel to the voltage sensor, the measure value taken during the transition from shading to clear sky that take a time for the current sensor to measure the value, and the sensitivity of voltmeter is more accurate compare to current sensor.

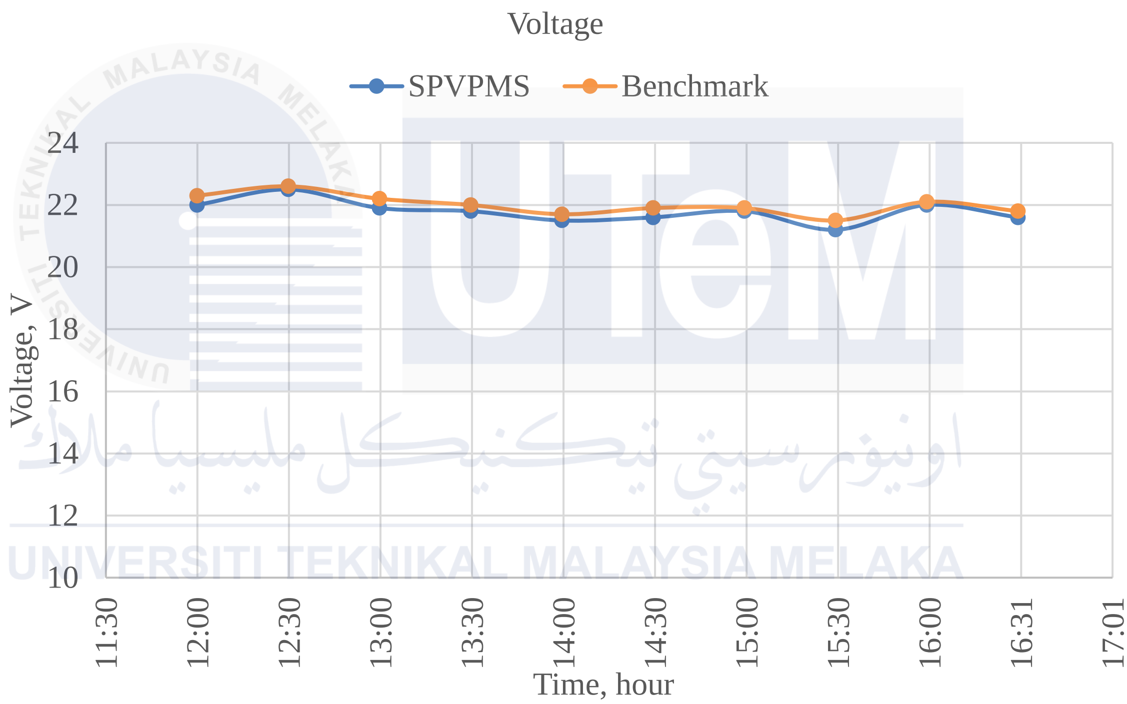


Figure 4.11 Comparison of voltage between SPVPMS and benchmark

4.3.2 Result analysis of Polycrystalline panel

Table 4.3 shows the reading of irradiance and current using SPVPMS and actual meter as a benchmark. Both SPVPMS and actual meter will measure a parameter from Polycrystalline solar panel. For SPVPMS, current sensor was used to measured the current while reference cells is used to measured irradiance and both of the measured parameter is show by using LCD display. Meanwhile, clamp meter used to measured the current flow from the solar panel while irradiance meter was used to measured irradiance as a benchmark to compare the value with SPVPMS value. The reading of irradiance for SPVPMS giving a range from 0 W/m² up until 877 W/m² meanwhile the reading record by using irradiance meter is giving a range from 110 W/m² until 892 W/m². There are around 100 W/m² different for both reading. While, the reading of current for SPVPMS is in range of 0.02 A until 0.59 A meanwhile the reading value for clamp meter is giving a value in range of 0.06 A until 0.52 A. The different reading between both SPVPMS and benchmark is approximate 0.05 A.

Table 4.4 shows the reading of temperature and voltage using SPVPMS and actual meter as a benchmark during measuring parameter process. Both SPVPMS and actual meter will measure a parameter from Polycrystalline solar panel. For SPVPMS, voltage sensor was used to measured the voltage while temperature sensor LM35 is used to measured temperature and both of the measured parameter is show by using LCD display. Meanwhile, voltmeter used to measured the voltage from the solar panel while temperature meter was used to measured ambient temperature as a benchmark to compare the value with SPVPMS value. The reading of temperature for SPVPMS giving a range from 32°C up until 47°C meanwhile the reading record by using irradiance meter is giving a range from 32.7°C until 39.7°C.There are around 5°C different for both reading. While, the reading of current for SPVPMS is in range of 14.4 V until 19.5 V A meanwhile the reading value for clamp meter is giving a value in range of 14.5 V until 19.7 V. The different reading between both SPVPMS and benchmark is approximate 0.1 V.

Table 4.3 Irradiance vs Current for SPVPMS and benchmark

Polycrystalline																
Time, hour	SPVPMS								Benchmark							
	Irradiance, W/m²			**Average, W/m²**	Current, A			**Average, A**	Irradiance, W/m²			**Average, W/m²**	Current, A			**Average, A**
12:00	884	865	865	**871**	0.59	0.52	0.52	**0.54**	913	874	871	**886**	0.52	0.52	0.51	**0.52**
12:20	877	877	877	**877**	0.59	0.59	0.59	**0.59**	894	890	892	**892**	0.52	0.52	0.52	**0.52**
12:40	511	501	501	**504**	0.38	0.36	0.36	**0.37**	592	595	595	**594**	0.34	0.34	0.35	**0.34**
13:00	551	551	551	**551**	0.38	0.38	0.38	**0.38**	666	668	673	**669**	0.38	0.38	0.38	**0.38**
13:20	685	685	685	**685**	0.41	0.41	0.41	**0.41**	767	766	766	**766**	0.44	0.43	0.43	**0.43**
13:40	484	484	484	**484**	0.33	0.33	0.33	**0.33**	540	539	528	**536**	0.30	0.29	0.29	**0.29**
14:00	331	331	349	**337**	0.25	0.25	0.25	**0.25**	481	443	412	**445**	0.27	0.25	0.23	**0.25**
14:20	0	0	0	**0**	0.04	0.01	0.01	**0.02**	113	109	107	**110**	0.07	0.06	0.05	**0.06**
14:40	279	191	191	**220**	0.25	0.23	0.23	**0.24**	325	329	336	**330**	0.21	0.21	0.21	**0.21**
15:00	68	68	68	**68**	0.15	0.15	0.15	**0.15**	217	217	217	**217**	0.14	0.15	0.15	**0.15**

Table 4.4 Temperature vs Voltage for SPVPMS and benchmark

Polycrystalline																
Time, hour	SPVPMS								Benchmark							
	Temperature, °C			**Average, °C**	Voltage, V			**Average, V**	Temperature, °C			**Average, °C**	Voltage, V			**Average, V**
12:00	34	34	34	**34**	18.3	18.3	18.3	**18.3**	31.2	31.1	31.2	**31.2**	18.6	18.6	18.6	**18.6**
12:30	44	43	44	**44**	19.5	19.5	19.4	**19.5**	38.5	38.6	38.7	**38.6**	19.8	19.7	19.6	**19.7**
13:00	36	36	36	**36**	19.1	19.1	19.1	**19.1**	34.1	34.0	34.1	**34.1**	19.2	19.2	19.2	**19.2**
13:30	39	39	39	**39**	18.3	18.3	18.4	**18.3**	34.1	34.3	34.2	**34.2**	18.6	18.6	18.6	**18.6**
14:00	47	47	47	**47**	19.1	19.1	19.1	**19.1**	39.8	39.7	39.5	**39.7**	19.3	19.4	19.4	**19.4**
14:30	40	40	40	**40**	18.7	18.7	18.7	**18.7**	36.2	36.2	36.3	**36.2**	19.0	18.9	18.9	**18.9**
15:00	38	37	38	**38**	18.5	18.5	18.6	**18.5**	35.0	35.1	35.3	**35.1**	18.8	18.8	18.8	**18.8**
15:30	37	38	38	**38**	18.7	18.7	18.7	**18.7**	34.3	34.5	34.6	**34.5**	18.9	18.9	18.9	**18.9**
16:00	33	33	33	**33**	15.2	15.2	15.2	**15.2**	32.9	32.9	32.9	**32.9**	15.4	15.3	15.3	**15.3**
16:30	32	32	32	**32**	14.5	14.4	14.3	**14.4**	32.8	32.7	32.7	**32.7**	14.6	14.5	14.4	**14.5**

4.3.2.1 Irradiance versus current

Figure 4.12 show the reading value between irradiance and current taken from Polycrystalline solar panel by using SPVPMS. The minimum irradiance recorded was 0 W/m² during periods of low sunlight, resulting in a minimum current output of 0.02 A. This happen is due to a several of factor such as shading happen. Conversely, the system demonstrated its peak performance under maximum irradiance of 877 W/m², yielding a maximum current output of 0.59 A. The average irradiance over the entire data collection period was approximately 500 W/m², corresponding to an average current of 0.3 A. By observing the graph, it is clearly show that irradiance is directly proportional to the current.

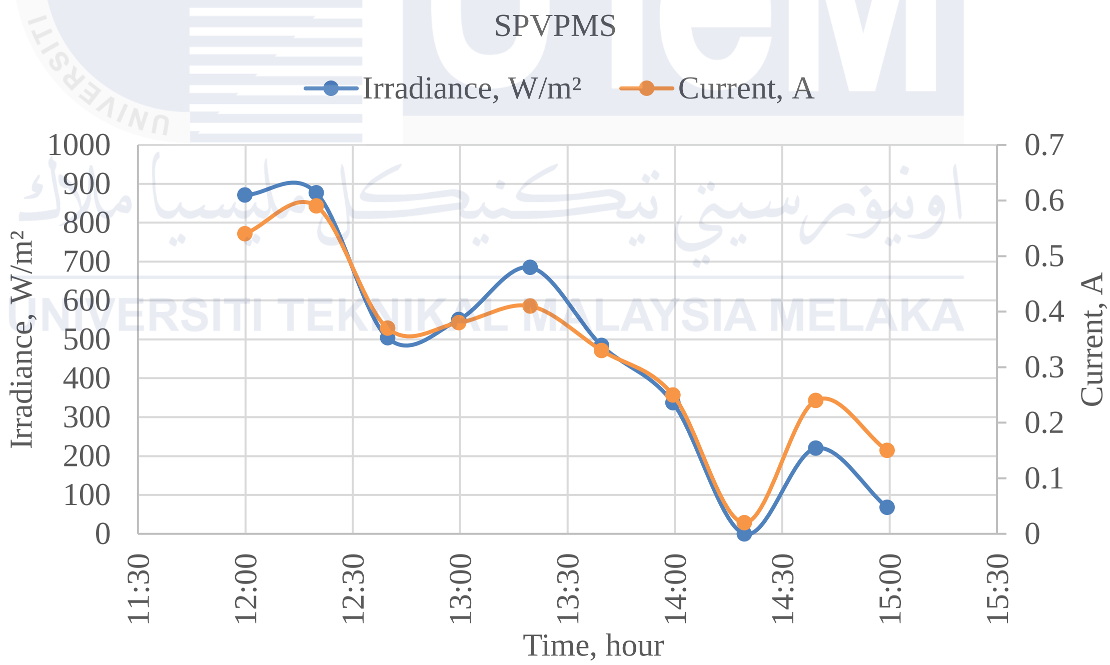


Figure 4.12 Irradiance and current for SPVPMS

Figure 4.13 show the graph between irradiance and current by using irradiance meter and clamp meter as a benchmark. The recorded minimum irradiance of 110W/m² and its corresponding minimum current output of 0.06 A revealing the systems capacity to generate power even under low-light conditions. The maximum irradiance observed at 892 W/m², with a peak current output of 0.52 A, demonstrated the instruments accuracy in capturing the systems response to optimal sunlight exposure. The average irradiance recorded was approximately 500 W/m² and the corresponding average current output of 0.3 A underscore the reliability of the irradiance meter and ammeter in providing understanding of the changing relationships between irradiance levels and the resulting current.

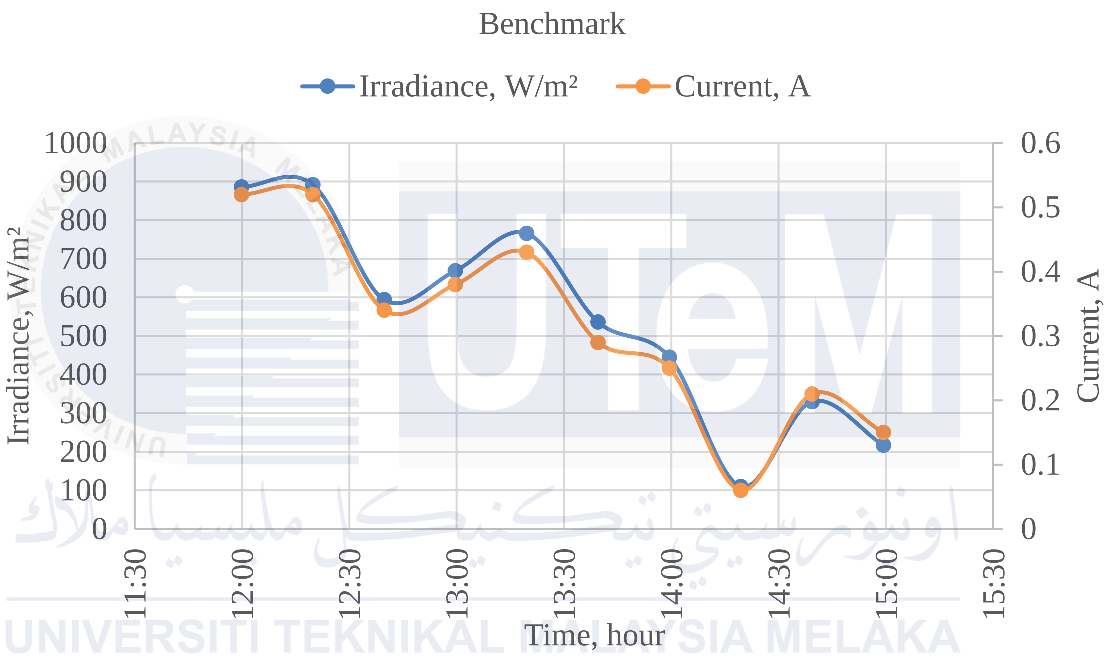


Figure 4.13 Irradiance and current for benchmark

4.3.2.2 Temperature versus voltage

Figure 4.14 show the relationship between temperature and voltage measured by using SPVPMS. By analysis the data in the graph, it show that temperature is inversely proportional to the voltage. Hence, the value of temperature will always opposite to the voltage. The maximum value that record for temperature is approximately 47 °C while the minimum value of voltage is approximately 14.4 V. Meanwhile, the minimum value of temperature recorded is approximately 32 °C and maximum voltage is approximate 19.7 V. The average value for both temperature and voltage is likely approximate 39 °C and 18.0 V.

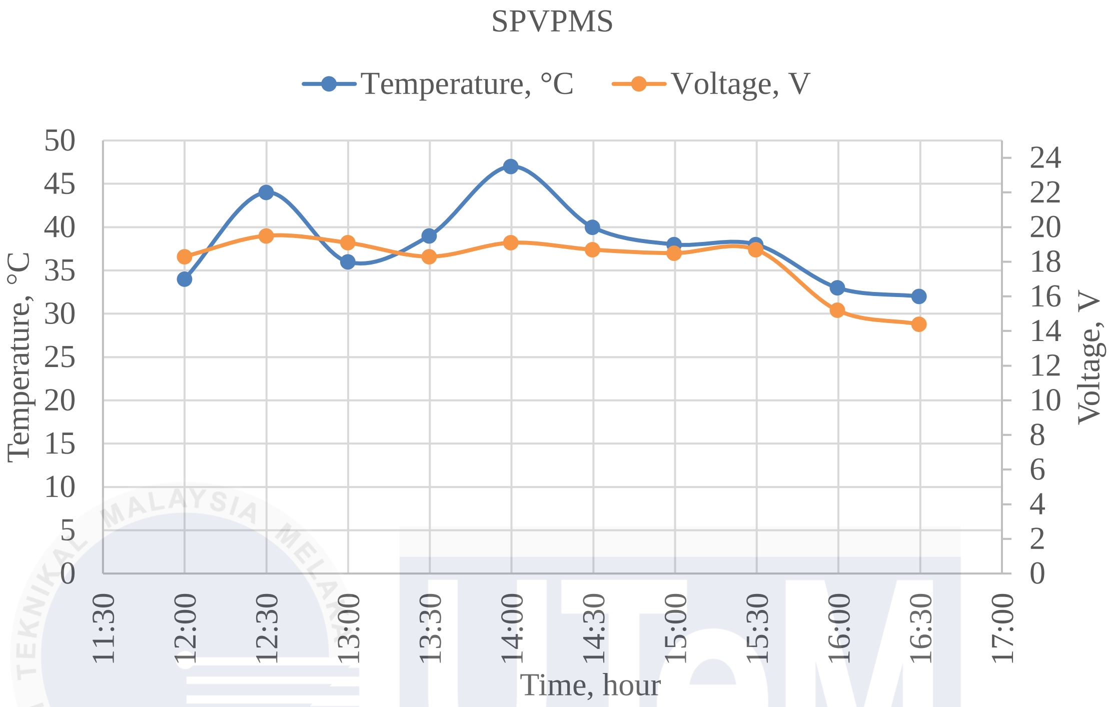


Figure 4.14 Temperature vs voltage for SPVPMS

Figure 4.15 show the relationship between temperature and voltage by utilizing temperature meter and voltmeter as a benchmark. The maximum value that record for temperature is approximately 39.7 °C while the minimum value of voltage is approximately 14.5 V. Meanwhile, the minimum value of temperature recorded is approximately 31.2 °C and maximum voltage is approximate 19.7 V. The average value for both temperature and voltage is likely approximate 35.0 °C and 17.0 V. By analysis the data in the graph and all the compared value, it show that temperature is inversely proportional to the voltage. Hence, the value of temperature will always opposite to the voltage.

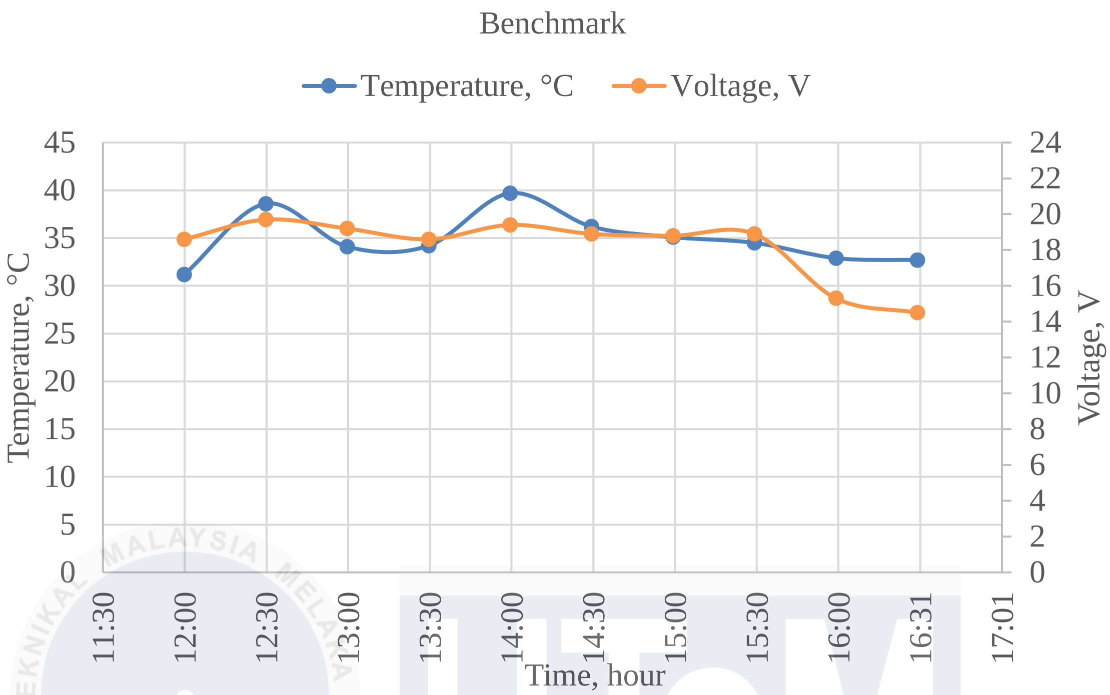


Figure 4.15 Temperature vs voltage for benchmark

4.3.2.3 SPVPMS irradiance benchmark test with actual irradiance sensor

Figure 4.16 show the comparison of measuring irradiance from polycrystalline solar panel by utilizing SPVPMS and irradiance meter as a benchmark. The lowest value that records by SPVPMS is 0 W/m² while by using the irradiance meter, the value of irradiance is approximate 100 W/m². As mentioned before, any measurement value of irradiance that taken below 500 W/m² is consider as invalid by according to the SEDA guideline and procedure for solar PV system installation and commissioning. Meanwhile, the average value which also the validity value of irradiance for both reference cell and irradiance meter is approximate 500 W/m² and 600 W/m². The maximum value that taken from both measurement meter is approximate 900 w/m². By comparing every value from minimum to maximum value, it shows that for the minimum reading it is only different around 100 W/m² for both SPVPMS and irradiance meter. This is happened due to SPVPMS is using a refence cell as a sensor to measure the irradiance. By utilizing refence cell, it also uses a current sensor to detect the current flow from the refence cell before using the Arduino uno to generate the input of irradiance that was detected by reference cell and current sensor to produce an output by displaying it using LCD display. Hence, during the current flow from reference cell to the Arduino, the length of wire from reference cells also effects the value of irradiance that show by LCD display because the more length of wire the more resistivity it has, so low current produces a low irradiance value. Besides, the components of the irradiance meter and reference cell may differ in quality. Measurements from higher-quality sensors such as irradiance meter are often more precise and consistent. This may be the cause of the difference in reading values recorded by SPVPMS and irradiance meter.

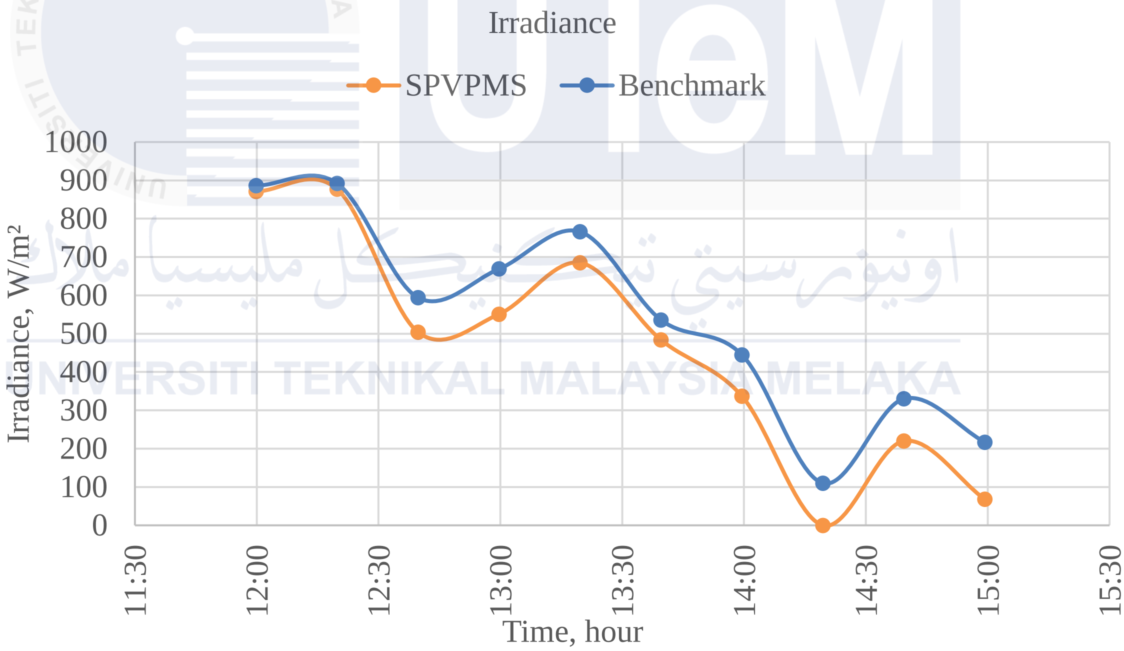


Figure 4.16 Comparison of irradiance between SPVPMS and benchmark

4.3.2.4 SPVPMS current benchmark test with actual current sensor

Besides, Figure 4.17 show the measurement value for current by utilizing both SPVPMS and clamp meter as a benchmark. The graph is purposely to show the comparison of measuring the value of current by using SPVPMS and clamp meter. The lowest value that taken for both SPVPMS and ammeter is 0.02 A and 0.06 A. This is due to shading happpened during the data taken make the solar panel achieve a few amount of sunlight cause the value of current also lowest. Meanwhile, the average value taken from both SPVPMS and ammeter is approximate 0.30 A. The maximum value taken for both measurement system show a slight different which is for SPVPMS is around 0.59 A while 0.52 for clamp meter. By comparing the minimum to maximum value of current taken, it show that for current measurement value does not have a lot of different. It also show that the current sensor ACS712 use in SPVPMS can be used to measure the current from solar panel because it almost given the same value as if use an ammeter. The slight different value between SPVPMS and clamp meter because of there may be differences in the analog-to-digital converter (ADC) of the Arduino and the resolution of the current sensor. It is possible for an ADC or low-resolution sensor to misread tiny current variations. Besides, it also due to a several factor such as lenght of wire from solar panel to the current sensor, the measure value taken during the transition from shading to clear sky that take a time for the current sensor to measure the value, and the sensitivity of ammeter is more accurate compare to current sensor.

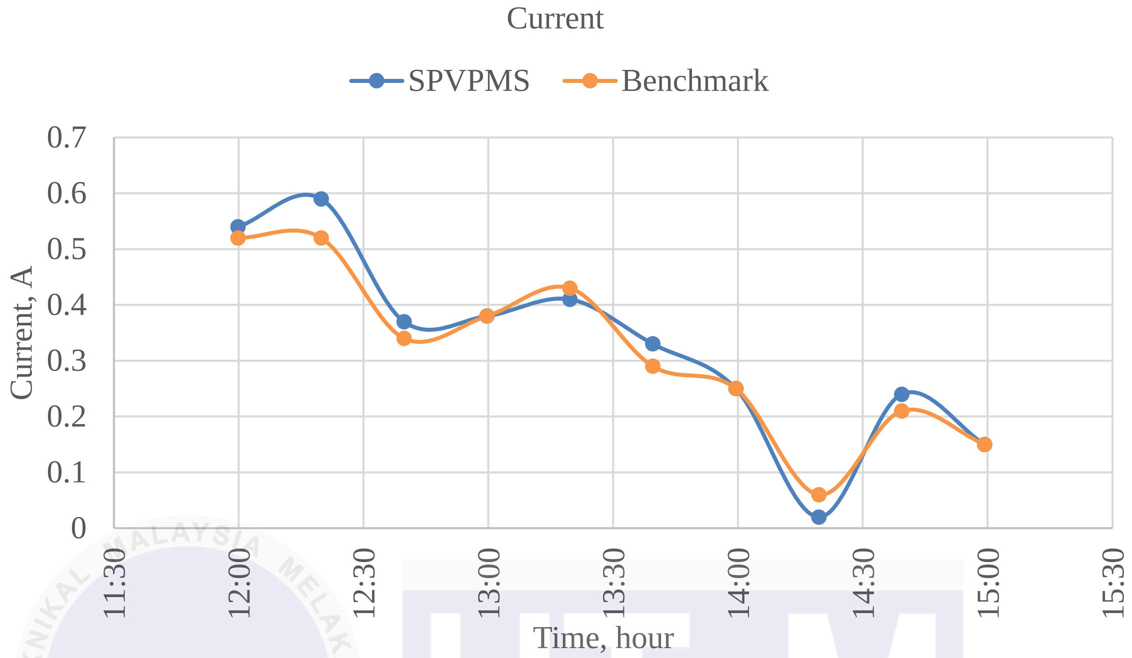


Figure 4.17 Comparison of current between SPVPMS and benchmark

4.3.2.5 SPVPMS temperature benchmark test with actual temperature sensor

Figure 4.18 show the measurement value for temperature by utilizing both SPVPMS and temperature meter as a benchmark. This graph is show that the different of measuring the value of ambient temperature by using SPVPMS and temperature meter. The minimum value that taken from SPVPMS is approximate 32 °C while value taken from temperature meter is approximate 31 °C. This is due to shading happpened during the data taken make the surrounding temperature become the minimum and cool area. Meanwhile, the average value taken for SPVPMS is around 39 °C and for temperature meter is approximate 35 °C. The maximum value taken for SPVPMS is approximate 47 °C while 40 °C for temperature meter. SPVPMS is using LM35 as a temperature sensor while benchmark is using temperature meter. By comparing the minimum to maximum value of temperature, it show that the temperature value for both meter have a quite different which is around 5 °C. The different value between SPVPMS and temperature meter is due to the measure value taken during the transition from shading to clear sky that take a time for the current sensor to measure the value, the sensitivity of temperature meter is more accurate compare to temperature sensor, and the different places of the sensor and temperature meter sensor.

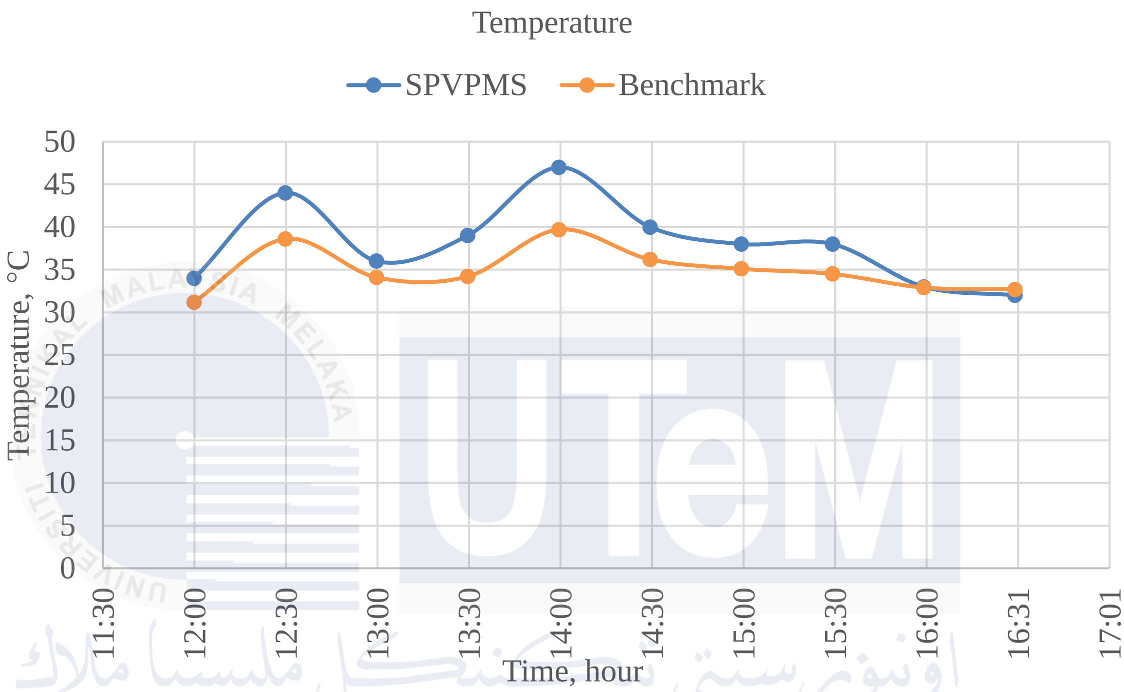


Figure 4.18 Comparison of temperature between SPVPMS and benchmark

4.3.2.6 SPVPMS voltage benchmark test with actual voltage sensor

Besides, Figure 4.19 show the measurement value for voltage by utilizing both SPVPMS and voltmeter as a benchmark. The graph is purposely to show the comparison of measuring the value of current by using SPVPMS and voltmeter. The minimum value that taken for both SPVPMS and voltmeter is approximate 14.4 V. Meanwhile, the average value taken from both SPVPMS and voltmeter is approximate 17.0 V. The maximum voltage taken is approximate 20.0 V for both SPVPMS and voltmeter measurement. By comparing the minimum to maximum value of voltage taken, it show that for voltage value does not have a lot of different. It also show that the voltage sensor that use in SPVPMS can be used to measure the voltage from the solar panel because it almost given the same value as if use an voltmeter. The slight different value between SPVPMS and voltmeter is due to several factor such as the precision of voltage readings may be restricted by the resolution of the Arduino's ADC, lenght of wire from solar panel to the voltage sensor, the measure value taken during the transition from shading to clear sky that take a time for the current sensor to measure the value, and the sensitivity of voltmeter is more accurate compare to current sensor.

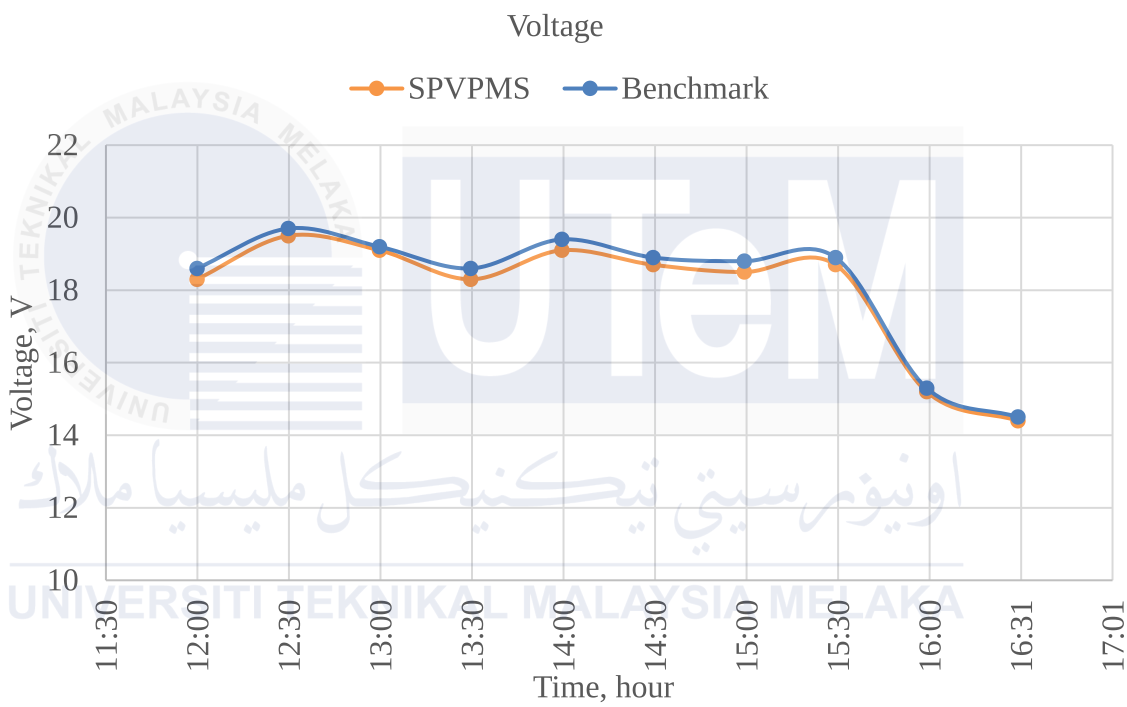


Figure 4.19 Comparison of voltage between SPVPMS and benchmark

4.4 Summary

Voltage, current, temperature, and irradiance were all successfully monitored and analysed by the solar measuring system developed using Arduino. By keeping an eye on the simulation which have been measured by using minimum, average and maximum value of voltage, the system could assure correct power distribution and spot any possible problems, such voltage drops. The measured current revealed details about the system's power usage and load characteristics. Temperature sensors made it possible to analyse thermal behaviour and identify surrounding temperature. The system's responsiveness to various lighting conditions was assessed using the irradiance measurement. Overall, this thorough examination of the Arduino-based solar measuring system's performance yielded useful insights for enhancing its effectiveness and guaranteeing its dependability in capturing solar energy.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

An affordable, user-friendly, and flexible technique for monitoring and analysing solar panels is to be design by using solar measuring system with Arduino. A real-time measurements of solar parameters including irradiance, temperature, and voltage with current are available by the combination of microcontrollers with sensors and components. Each parameter's output was measured using an individual sensor, such as a voltage sensor for measuring voltage. Yet, when comparing its measurements with those from real meters, significant differences were found.

For the first measurement parameter which is irradiance, it shows that it is only different around 100 W/m² for both SPVPMS and irradiance meter by comparing every value from minimum to maximum value. This is happened due to SPVPMS is using a refence cell as a sensor to measure the irradiance. Since reference cell is using current sensor to detect the current flow from the reference cell to the Arduino, the length of wire from reference cells also effects the value of irradiance that show by LCD display because the more length of wire the more resistivity it has, so low current produces a low irradiance value. Besides, the components of the irradiance meter and reference cell may differ in quality. Measurements from higher-quality sensors such as irradiance meter are often more precise and consistent.

Besides, the value measure by both current and voltage measure by using SPVPMS also give a slightly different when compare to actual meter. This is due to may be differences in the analog-to-digital converter (ADC) of the Arduino and the resolution of the current sensor. It is possible for an ADC or low-resolution sensor to misread tiny current variations. Besides, it also due to a several factor such as lenght of wire from solar panel to the current and voltage sensor. Environmental factors that change with time, such as shifts in temperature, shading and electromagnetic interference, also affect sensor accuracy and add to the causes of error. The different level of accuracy and sensitivity of SPVPMS and actual meter also affect the different value taken.

Next is the value of temperature for both SPVPMS and actual temperature meter also giving a slight different when the data taken. This is due to the measure value taken during the transition from shading to clear sky that take a time for the current sensor to measure the value, the LM35 sensor's potential weakness in terms of accuracy or resolution when compared to the real temperature meter, and the LM35 sensor being positioned incorrectly or having insufficient heat dissipation.

However, by implementing a thorough methodology is necessary can resolve differences between the data recorded by a solar PV performance measuring system and an actual meter. Make use of high-precision sensors and make sure that the surrounding conditions are the same for them. To handle shifts caused by temperature, use temperature adjustment methods. Maintain and inspect the measuring system on a regular basis, looking for loose connections or component deterioration. Finally, keep thorough records of all calibration methods, changes to the system, and outside effects on readings. The use of this integrated technique is expected to improve the solar PV performance measuring system's accuracy and dependability, resulting in a closer alignment of its values with those obtained from the real meter.

5.2 Recommendation of Future Work

For future improvements, accuracy of solar measurement performance system results could be enhanced as follows:

i) Implement data logging by creating an instrument to record and save information about solar energy generation over time for review and future analysis.

ii) Improve the accuracy of measurement system by study on ways to make solar measurements more accurate.

iii) If finacial is not a problem, perhaps we might use a different measuring system to obtain a more precise result. For example, we could measure irradiance using a pyranometer, even if we are aware of its high market cost.

5.3 Potential for Project Commercialization

With the growing on renewable energy worldwide, there is significant economic potential for an Arduino-based solar pv performance measurement system device. The system may meet the increasing need for dependable solar solutions by providing accurate measurements of temperature, solar irradiance, current and voltage. The device is applicable to both household and business sectors because to its user-friendly interface, fexiblility and affordability choices. Technical factors like power economy and waterproof design provide environmental adaptation. To improve sales even further, focus competitive pricing, subscription services, and collaborations with industry giants. To position the system as a reliable and in-demand solution in the renewable energy sector.

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