



Faculty of Engineering

**SIMULATION AND PROTOTYPE DESIGN OF HYBRID
RENEWABLE ENERGY HARVESTING SYSTEM**

Muhammad Syukri Bin Nurulhak

Bachelor of Engineering

Electrical and Electronics with Honours

2022

SIMULATION AND PROTOTYPE DESIGN OF HYBRID
RENEWABLE ENERGY HARVESTING SYSTEM

MUHAMMAD SYUKRI BIN NURULHAK

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering
Electrical and Electronics with Honours

Faculty of Engineering
Universiti Malaysia Sarawak

2022

UNIVERSITI MALAYSIA SARAWAK

Grade: _____

Please tick (✓)

Final Year Project Report

✓

Masters

PhD

DECLARATION OF ORIGINAL WORK

This declaration is made on the26.....day of.....July.....2022.

Student's Declaration:

I MUHAMMAD SYUKRI BIN NURULHAK (64974), from FACULTY OF ENGINEERING hereby declare that the work entitled SIMULATION AND PROTOTYPE DESIGN OF HYBRID RENEWABLE ENERGY HARVESTING SYSTEM is my original work. I have not copied from any other students' work or from any other sources except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person.

26 July 2022
Date submitted

Muhammad Syukri bin Nurulhak (64974)
Name of the student (Matric No.)

Supervisor's Declaration:

I Yanuar Zulardiansyah Arief (SUPERVISOR'S NAME) hereby certifies that the work entitled Simulation and Prototype Design of Hybrid Renewable Energy Harvesting System (TITLE) was prepared by the above named student, and was submitted to the "FACULTY" as a * ~~partia~~ /full fulfillment for the conferment of (PLEASE INDICATE THE DEGREE), and the aforementioned work, to the best of my knowledge, is the said student's work.

Received for examination by: Yanuar Zulardiansyah Arief
(Name of the supervisor)

Date: 26 July 2022

I declare that Project/Thesis is classified as (Please tick (✓)):

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*
 RESTRICTED (Contains restricted information as specified by the organisation where research was done)*
 OPEN ACCESS

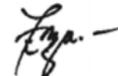
Validation of Project/Thesis

I therefore duly affirm with free consent and willingly declare that this said Project/Thesis shall be placed officially in the Centre for Academic Information Services with the abiding interest and rights as follows:

- This Project/Thesis is the sole legal property of Universiti Malaysia Sarawak (UNIMAS).
- The Centre for Academic Information Services has the lawful right to make copies for the purpose of academic and research only and not for other purpose.
- The Centre for Academic Information Services has the lawful right to digitalise the content for the Local Content Database.
- The Centre for Academic Information Services has the lawful right to make copies of the Project/Thesis for academic exchange between Higher Learning Institute.
- No dispute or any claim shall arise from the student itself neither third party on this Project/Thesis once it becomes the sole property of UNIMAS.
- This Project/Thesis or any material, data and information related to it shall not be distributed, published or disclosed to any party by the student except with UNIMAS permission.



Student signature _____ 26.07.2022 _____
(Date)



Supervisor signature: _____ 26 July 2022 _____
(Date)

Current Address: No. 2E, Lorong 2B, Sibujaya, 96000, Sibujaya, Sarawak

Notes: * If the Project/Thesis is **CONFIDENTIAL** or **RESTRICTED**, please attach together as annexure a letter from the organisation with the period and reasons of confidentiality and restriction.

[The instrument is duly prepared by The Centre for Academic Information Services]

ACKNOWLEDGEMENT

First, I would like to express my gratitude to my supervisor, Ts Dr Yanuar Zulardiansyah Arief from the Department of Electrical and Electronics Engineering for his continuous guidance and patience throughout my completion of research under his supervision.

After that, I also would like to express my thank to my family especially my parents for their moral and emotional support, encouragement, and motivation throughout my completion of Final Year Project research even though they are far away.

Finally, I also would like to give a special thanks to my fellow friends, especially my course mates and housemates who are always helping and cheering me to not give up throughout the semester. I really appreciate their kindness and motivation and I would never be able to go this far without all the support.

ABSTRACT

In this era of globalization, the energy harvesting technology for renewable energy has improved to combat the concern in energy conservation, global warming, and excessive waste materials. Additionally, the problem of getting continuous and reliable energy and power supply will become a real issue in the future. The energy harvesting technology can be an alternative to the current power generation and can lead to a potential of getting more reliable power supply for everyone. By combining multiple renewable energy harvesting system, more power can be continuously generated, and the efficiency of energy output will increase. This paper focus on the development of hybrid renewable energy harvester system consists of photovoltaic, piezoelectric and wind energy. The performance and the capabilities of the system are recorded are analyse under different conditions and parameters.

ABSTRAK

Pada era globalisasi ini, teknologi penuaian tenaga untuk tenaga yang boleh diperbaharui telah menjalani penambahbaikan untuk mengatasi permasalahan berkaitan penjimatan tenaga, pemanasan global, dan bahan buangan yang berlebihan. Selain itu, masalah untuk mendapatkan tenaga dan bekalan kuasa yang berterusan akan menjadi isu pada masa hadapan. Teknologi penuaian tenaga boleh menjadi alternatif kepada penjanaan kuasa yang sedia ada dan boleh membawa kepada potensi untuk mendapatkan bekalan kuasa yang boleh dipercayai untuk semua orang. Dengan menggabungkan pelbagai jenis sistem penuaian tenaga yang boleh diperbaharui, lebih banyak tenaga boleh dihasilkan, dan kecekapan tenaga akan bertambah. Kertas kerja ini menumpukan pada pembangunan sistem penuaian tenaga untuk tenaga yang boleh diperbaharui jenis hibrid yang terdiri daripada fotovoltai, piezoelektrik dan tenaga angin. Prestasi dan kebolehan sistem tersebut direkodkan dan dianalisis di bawah keadaan dan parameter yang berlainan.

TABLE OF CONTENTS

ACKNOWLEDGEMENT	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xii
LIST OF ABBREVIATIONS	xvi
Chapter 1 INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Objectives	3
1.4 Research Significance	3
1.5 Scope	3
1.6 Thesis Outline	4
Chapter 2 LITERATURE REVIEW	5
2.1 Overview	5
2.2 Energy Sources	5
2.3 Solar Energy Harvesting System	6
2.3.1 Photovoltaic Panel Types	7
2.3.2 Photovoltaic Panel Current-Voltage and Power-Voltage Characteristics	8
2.3.3 Light Intensity Effect	10
2.4 Piezoelectric Energy Harvesting System	11
2.4.1 Footstep Energy	12
2.4.2 Rainfall Energy	12
2.5 Wind Energy Harvesting System	14

2.6	Thermoelectric Energy Harvesting System	15
2.6.1	Thermoelectric Effect	15
2.6.2	Thermoelectric Generator	15
2.7	Radio Frequency Energy Harvesting System	16
2.8	Energy Storages	17
2.9	DC-DC Converter	18
2.9.1	Buck Converter	18
2.9.2	Boost Converter	19
2.9.3	Buck-Boost Converter	19
2.10	Power Inverter	20
2.11	Research gap	20
2.12	Summary	22
Chapter 3	METHODOLOGY	23
3.1	Overview	23
3.2	Flow Chart of Project Plan	23
3.3	Simulation of Hybrid Renewable Energy Harvesting System	27
3.3.1	Flowchart Process of MATLAB Simulation	27
3.3.2	Simulation Software (MATLAB)	28
3.3.3	Circuit Design Properties	28
3.3.4	Simulation Procedure	31
3.4	Prototype of Hybrid Renewable Energy Harvesting System	36
3.4.1	Flowchart Process of the Prototype	36
3.4.2	Block Diagram of the Prototype	37
3.4.3	Hardware List and Review	38
3.4.4	Hardware Quantity and Cost	44
3.4.5	Software List and Review	46

3.4.6	Hardware Prototype Procedure	47
3.5	Coding and Equations	50
3.6	Summary	50
Chapter 4	RESULTS AND DISCUSSION	51
4.1	Overview	51
4.2	Simulation Result of Photovoltaic Energy Harvester	53
4.3	Simulation Result of Wind Energy Harvester	56
4.4	Prototype Result of Photovoltaic Energy Harvester	57
4.5	Prototype Result of Piezoelectric Energy Harvester	64
4.6	Prototype Result of Wind Energy Harvester	68
4.7	Comparison for Result of Photovoltaic Energy Harvester	73
4.8	Comparison for Result of Piezoelectric Energy Harvester	75
4.9	Comparison for Result of Wind Energy Harvester	77
4.10	Continuity of Overall Renewable Energy Harvester	79
4.11	TP4056 Battery Module Indicator	84
4.12	LCD with I2C Module Display	85
4.13	Summary	86
Chapter 5	CONCLUSION	87
5.1	Summary	87
5.2	Recommendations for Future Work	88
	REFERENCES	89
	APPENDIX	96

LIST OF TABLES

Table	Page
Table 2. 1 Power densities for variety of energy sources [10].	6
Table 2. 2 Effect of colour on the intensity, voltage and current [20].....	11
Table 2. 3 Rain intensity classification [26].	13
Table 2. 4 Piezoelectric configuration and arrangement output values.....	14
Table 2. 5 Energy storage types with its specification [42].....	18
Table 2. 6 Research gap.....	20
Table 3. 1 Gantt chart for FYP 1.	25
Table 3. 2 Gantt chart for FYP 2.	26
Table 3. 3 Parameters for Wind Energy Harvester Simulation.	31
Table 3. 4 Hardware Quantity and Costs.....	45
Table 4. 1 Result of Photovoltaic Energy Harvester Simulation with Fixed Temperature.	54
Table 4. 2 Result of Photovoltaic Energy Harvester Simulation with Fixed Irradiance.	55
Table 4. 3 Result of Wind Energy Harvester Simulation with Increasing PWM Reference Voltage.	56
Table 4. 4 Result of Photovoltaic Energy Harvester Prototype on 16/05/2022.	58
Table 4. 5 Result of Photovoltaic Energy Harvester Prototype on 17/05/2022.	60
Table 4. 6 Result of Photovoltaic Energy Harvester Prototype on 18/05/2022.	62
Table 4. 7 Result of Piezoelectric Energy Harvester Prototype with 50kg Pressure.....	65
Table 4. 8 Result of Piezoelectric Energy Harvester Prototype with 55kg Pressure.....	66
Table 4. 9 Result of Piezoelectric Energy Harvester Prototype with 60kg Pressure.....	67
Table 4. 10 Result of Wind Energy Harvester Prototype on 16/05/2022.....	69
Table 4. 11 Result of Wind Energy Harvester Prototype on 17/05/2022.....	70
Table 4. 12 Result of Wind Energy Harvester Prototype on 18/05/2022.....	72
Table 4. 13 Comparison Result for 3-Days on Photovoltaic Energy Harvester.....	75
Table 4. 14 Comparison Result for Different Mass on Piezoelectric Energy Harvester.	76

Table 4. 15 Comparison Result for 3-Days on Wind Energy Harvester. 79

LIST OF FIGURES

Figure	Page
Figure 2. 1 PV module types [14].	8
Figure 2. 2 Photovoltaic Cell I-V and P-V Curve [16]......	9
Figure 2. 3 Photovoltaic Panel I-V and P-V Curve [16].	9
Figure 2. 4 Light intensity effects on I-V curve [8]......	10
Figure 2. 5 Piezo plate for piezoelectric [23].	11
Figure 2. 6 Block diagram for kinetic footstep prototype [24]......	12
Figure 2. 7 Wind turbine [32]......	14
Figure 2. 8 Thermoelectric generator mechanism [37].	16
Figure 2. 9 Circuit diagram for buck converter circuit [45].	18
Figure 2. 10 Circuit diagram for boost converter circuit [45].	19
Figure 2. 11 Circuit diagram for buck-boost converter [44].	19
Figure 3. 1 The flowchart of project plan.	24
Figure 3. 2 The flowchart for MATLAB Simulation.	27
Figure 3. 3 MATLAB Logo	28
Figure 3. 4 Simulink Library Browser Placement.	29
Figure 3. 5 Simulink Library Browser Window.	29
Figure 3. 6 Adding Block into Simulink General Interface.	30
Figure 3. 7 Open-circuit voltage setting for output voltage.	30
Figure 3. 8 Resistance block value to control output current.	30
Figure 3. 9 DC Motor Block Parameter.	31
Figure 3. 10 General interface of MATLAB.	32
Figure 3. 11 Simulink Start Page.	32
Figure 3. 12 Simulink General Interface	33
Figure 3. 13 Constant Block for Solar Cell.	33
Figure 3. 14 Temperature Dependence of Solar Cell.	34
Figure 3. 15 Results Display for Photovoltaic Simulation	34
Figure 3. 16 PWM Reference Voltage Window.....	35
Figure 3. 17 Results Display for Wind Energy Simulation.....	35

Figure 3. 18 The flowchart for Hardware Prototype Circuit.	36
Figure 3. 19 Block diagram of prototype of hybrid renewable energy harvesting system.	37
Figure 3. 20 Conceptual design of the project prototype.	38
Figure 3. 21 Mini Monocrystalline Solar Panel	38
Figure 3. 22 Piezoelectric Sensor.	39
Figure 3. 23 DC Motor.	39
Figure 3. 24 Rechargeable Battery (Li-ion).....	40
Figure 3. 25 Jumper Wires.	40
Figure 3. 26 Breadboard.	41
Figure 3. 27 DC-DC Boost Converter Module.	41
Figure 3. 28 Rectifier Module.	42
Figure 3. 29 INA219 DC Current Sensor.	42
Figure 3. 30 Light Bulb.	43
Figure 3. 31 Arduino Uno.	43
Figure 3. 32 I2C LCD.....	43
Figure 3. 33 TP4056 Lithium Battery Charger and Protection.	44
Figure 3. 34 Perspex Sheet.	44
Figure 3. 35 Arduino IDE.....	46
Figure 3. 36 Solcast Solar Irradiance Interface.	47
Figure 3. 37 Piezoelectric Plate Circuit.	48
Figure 3. 38 DC Motor with IR Sensor Module.....	49
Figure 3. 39 Coding and Equations of Parameters.	50
Figure 4. 1 Circuit for Simulation of Photovoltaic Energy Harvester.....	52
Figure 4. 2 Circuit for Simulation of Wind Energy Harvester.	52
Figure 4. 3 Completed Circuit for Prototype of Hybrid Renewable Energy Harvester.	53
Figure 4. 4 Graph of Power Output vs Irradiance for Photovoltaic Energy Harvester Simulation.	54
Figure 4. 5 Graph of Power Output vs Temperature for Photovoltaic Energy Harvester Simulation.	55
Figure 4. 6 Graph of Power Output vs PWM Reference Voltage for Wind Energy Harvester Simulation.....	57

Figure 4. 7 Graph of Power Output from Photovoltaic Energy Harvester Prototype on 16/05/2022.....	59
Figure 4. 8 Graph of Power Output from Photovoltaic Energy Harvester Prototype on 17/05/2022.....	62
Figure 4. 9 Graph of Power Output from Photovoltaic Energy Harvester Prototype on 18/05/2022.....	64
Figure 4. 10 Graph of Power Output from Piezoelectric Energy Harvester Prototype with 50kg Pressure.	65
Figure 4. 11 Graph of Power Output from Piezoelectric Energy Harvester Prototype with 55kg Pressure.	67
Figure 4. 12 Graph of Power Output from Piezoelectric Energy Harvester Prototype with 55kg Pressure.	68
Figure 4. 13 Graph of Power Output from Wind Energy Harvester Prototype on 16/05/2022.....	70
Figure 4. 14 Graph of Power Output from Wind Energy Harvester Prototype on 17/05/2022.....	71
Figure 4. 15 Graph of Power Output from Wind Energy Harvester Prototype on 18/05/2022.....	73
Figure 4. 16 Comparison between Simulation and Hardware Result for Photovoltaic Energy Harvester.	74
Figure 4. 17 Photovoltaic Energy Harvester Output Power Comparison for 3-Days. ...	74
Figure 4. 18 Piezoelectric Energy Harvester Output Power Comparison for Different Mass.....	76
Figure 4. 19 Comparison between Simulation and Hardware Result for Wind Energy Harvester.	77
Figure 4. 20 Wind Energy Harvester Output Power Comparison for 3-Days.....	78
Figure 4. 21 Graph of Continuity of Overall Power Output on 16/05/2022.	80
Figure 4. 22 Percentage of Overall Power Output on 16/05/2022.	81
Figure 4. 23 Graph of Continuity of Overall Power Output on 17/05/2022.	82
Figure 4. 24 Percentage of Overall Power Output on 17/05/2022.	82
Figure 4. 25 Graph of Continuity of Overall Power Output on 18/05/2022.	83
Figure 4. 26 Percentage of Overall Power Output on 18/05/2022.	83
Figure 4. 27 TP4056 Red LED during charging.	84
Figure 4. 28 TP4056 Blue LED after done charging.....	85

Figure 4. 29 The parameters and data shown on the LCD Display..... 85

LIST OF ABBREVIATIONS

EH	-	Energy Harvesting
IoT	-	Internet of Things
PV	-	Photovoltaic
HAWT	-	Horizontal Axis Wind Turbine
VAWT	-	Vertical Axis Wind Turbine
TEG	-	Thermoelectric Generator
RF	-	Radio Frequency
DC-DC	-	Direct Current to Direct Current
DC-AC	-	Direct Current to Alternating Current
AC-DC	-	Alternating Current to Direct Current

CHAPTER 1

INTRODUCTION

1.1 Background

Energy harvesting refers to the harnessing of readily available energy from the surrounding into electrical energy [1]. Some of the energy harvesting technology covers the conversion of light, kinetic, thermal and radio frequency via various mechanism such as photovoltaic, piezoelectric, and thermoelectric [2]. The electrical energy gathered can be use directly or stored for later use. The energy harvesting technology can be an alternative for places with no power grid or places that is not suitable for solar panels and wind turbines installation. Energy harvesting also has become one of the most-rapid growing technologies in the current year. It is estimated that the market size of energy harvesting can reach up to USD 817.2 Million by 2026 [3]. The motivation of adopting the energy harvesting technology for renewable energy comes from the concern in energy conservation, global warming, and excessive waste materials.

However, the energy harvested is in small amounts and adequate for low-power application such as remote sensing, body implants and most wireless applications [4]. For start, some of the IoT devices can integrate the energy harvester system for its own sustainability since it can be operated in low power. The Internet of Things or IoT can be describes as billions of physical devices that are linked to the internet to connect and exchange data [5, 6]. The IoT devices can be everything if it connected to the internet and can be interacted or controlled. It can be as small as switching on the lamps using smartphone application or exchanging massive data back and forth using thousands of sensors for monitoring system.

The self-sustainable operation of IoT devices is one of the main importance that have been discussed by many researchers. For long term accessibility, the usage of disposable battery can be ignored, and it can be charged by itself. The energy harvesters are divided into four groups that is based on their power output, which are high power (more than

10W), medium power (between 1W to 10W), low power (between 1mW to 1W) and ultra-low power (below 1mW) [7]. From the low-power devices, the energy harvesting system can move on to powering up the medium to high power devices. This can lead to the integration of energy harvesting technology into various industries such as transportation, automotive, power generation and more. There are already some existing energies harvesting devices and application such as photovoltaic solar energy at rooftop that convert light into electric energy or using wind energy to convert mechanical energy to electrical energy.

This is where the energy harvesting structure become hybrid with the combination of more energy harvesting system to produce more energy. Combining multiple sources of energy can maximised the peak energy as well as providing energy when some of the sources are unavailable [4]. There have been many research and experiment regarding hybrid energy harvesting such as solar-wind harvester, electromagnetic/piezo-electric harvester and solar-wind energy harvester [7]. Theoretically, the combination of more than one energy harvester can produce more energy and more efficient.

This paper presents the study of four types of energy harvester which are photovoltaic, piezoelectric, thermoelectric and radio frequency. The energy harvester will be combined and merged to create the hybrid energy harvester. The energy harvester will be tested using simulation and some of them will be implemented into hardware design depending on the availability and convenience.

1.2 Problem Statement

Theoretically, the hybrid energy harvester would be better than the single energy harvester. The power generation capacity can increase by merging multiple energy harvester to power the supply. However, most of the usage for renewable energy harvester are only using single energy harvester, for example photovoltaic energy. The method would be by harnessing energy from multiple sources such as photovoltaic, piezoelectric and wind energy.

Single energy harvester will lose its abilities to harvest energy at a certain time and condition when not functioning properly. For example, photovoltaic energy harvester only works wonder under the sun and will lose its abilities to harvest energy when it is raining or at night

The continuity of harvesting energy even when the other energy harvesters are not functioning properly is where hybrid energy harvester come in to yield maximum power output. There is also a lacks reports in hybrid renewable energy harvesting system particularly by comparing the simulation and prototype development works. So, this project will investigate the potential and feasibility of hybrid renewable energy to always generate energy continuously using simulation and hardware prototype.

1.3 Objectives

There are three objectives that served as a guideline for accomplishing this project, which are,

1. To simulate and build the prototype of the hybrid renewable energy harvesting system consists of photovoltaic, piezoelectric and wind energy.
2. To analyse the capabilities of hybrid renewable energy harvester to continue harvesting energy when one or more are not functioning well.
3. To compare the performance of hybrid renewable energy harvester on different conditions and parameters.

1.4 Research Significance

From this project, it is hoping that this project could give useful finding regarding hybrid renewable energy harvesting system (photovoltaic, piezoelectric and wind energy), such as generating continuous power for numerous applications. From there, the better energy harvesting system could be developed in the future for the application of renewable energy in everyday life. More devices and hardware would benefit from energy harvesting system for the self-sustainability, saving energy and reduce waste.

1.5 Scope

To fulfil the objectives, the scopes of project study are:

- i. Simulation for renewable hybrid energy harvester consists of photovoltaic and wind energy using MATLAB 2021a.
- ii. Prototype for renewable hybrid energy harvester using photovoltaic, piezoelectric and wind energy that have low specifications.

- iii. Data collections are done on different day that provides different parameters and weather conditions that gives variety of data pattern.
- iv. Applying display system for data and parameters monitoring and recording.

1.6 Thesis Outline

This paper presents the information about energy harvesting system including the simulation and prototype of the hybrid energy harvesting system.

Chapter 1 presents an introduction about this paper including the general information about energy harvesting technology and its application in real world.

Chapter 2 presents the extensive literature review for the relevant topic. Firstly, introducing about four types of energy harvesting system which are photovoltaic, piezoelectric, thermoelectric and radio frequency. Each of the energy harvesting system are explained including the types of material used and its efficiency. Other works and finding from researchers will be included as a reference and research gap.

Chapter 3 presents about the methodology of creating the simulation and prototype of energy harvesting system. For the first part, the simulation is done using MATLAB and other available software to simulate the energy harvesting system. The second part is making a design and prototype of hybrid energy harvesting system for photovoltaic, piezoelectric and wind energy. The output voltage and power will be calculated and then compare with the simulation. The prototype will also be tested under different condition to find out the performance of the system.

Chapter 4 presents the results and discussion for the simulation and prototype. The output voltage and power will be calculated and then compare with the simulation. From here, the analysis will be done to find out if it is efficient enough to generate enough power and if it can generate continuous power for long-term usage.

For Chapter 5, the conclusion is introduced and include some of the improvement that can be done in the future.

Chapter 2

LITERATURE REVIEW

2.1 Overview

Energy harvesting (EH) is a process or technique where the ambient energy is converted into an electricity. The ambient energy come from the surrounding such as light, thermal, motion, and radio frequency. This chapter discusses different types of EH systems and how it works. The photovoltaic energy will be discussing in detail such as the panel types, current-voltage curve, efficiency, and light intensity effects. In thermoelectric energy, the Seebeck effect and thermoelectric generator will be discovered [9]. For mechanical energy, the wind and piezoelectric energy will be discussed. In radio frequency energy, it seems to be popular but have lower power output. Then, the energy storages will be discussed that is essential for energy harvesting. Other than that, DC-DC converter and power inverter will be discussed. Finally, the summarisation is presented at the end of this chapter.

2.2 Energy Sources

The background of the energy sources will be discussed here. As mentioned in the overview, there are many types of energy sources that can be harvested from the environment. The environment energy can come from natural source or man-made activities. Some of the sources including solar radiation, mechanical vibration, radio frequency, thermal and turbine [9]. Solar energy comes from the sunlight. The photovoltaic converts the light into electricity using some semiconductor materials. For thermal energy, the differences across dissimilar materials will create electricity based on Seebeck effects [7]. Piezoelectric creates electric charges based on the mechanical stress applied on the material. The vibration also can create some energy on piezo plate. For wind energy, it uses turbine that transform kinetic energy from the wind into mechanical energy. The radio frequency energy can be harvested in a very small amount and collected

through the antenna. It approximately harvested around 100 picowatts per square centimetre [8]. From all this energy sources, the energy transducer is needed to convert it to electrical energy. It is important to find out which energy sources can output the most power density for power generation. Table 2.1 shows the comparison of energy sources and their power density [10].

Table 2. 1 Power densities for variety of energy sources [10].

Sources	Power Density ($\mu\text{W}/\text{cm}^2$)
Light Source (Outdoor)	10000 (Under the direct sun) 150 (Overcast or cloudy day)
Light Source (Indoor)	100
Thermal Energy	10-800
Radio Frequency	0.1 – 1

From the Table 2.1, it is shown that solar energy has the highest power density than the other energy sources, while radio frequency have the lowest power density.

2.3 Solar Energy Harvesting System

Solar energy harvesting system take and convert the solar energy into electricity by using Photovoltaic (PV) cells. The solar panel is used to convert the light into an electricity by using the photo-electric effect [8]. When sun cast light upon a solar cell, the light that is absorbed into semiconductor generating electron–hole pairs, which divide and transport charges towards the electrodes [11]. Solar energy is abundance at outside especially during daytime. Solar energy also can be harvested indoor enclosed environment likes school and offices by using artificial light for various application relating to low power consumption devices [9]. For outside situation, there is an inconsistency of solar illumination that is affecting the PV efficiency.

So, the Maximum Power Point Tracking (MPPT) Algorithm is used to improve the efficiency of a photovoltaic energy harvesting system [8]. It is basically the DC-DC

converter that improves the connection between the PV panels and the energy storage. MPPT views the output of panels and compare it to the energy storages, then it analyses what is the best power that can be put out to charge the energy storages. After that, it is converted to best voltage to get the maximum ampere into the energy storage [12].

Another factor that needs to be taken for the efficiency is the types of solar PV modules that will be discussed in detail after this section.

2.3.1 Photovoltaic Panel Types

Solar panel or PV module is a combination of many photovoltaic cells installed in a framework. The combination of solar panel is called PV panel, while the collection of PV panel is called an array. Solar panels are made from crystalline silicon since they are abundance on earth, high durability and used widely in microelectronics industry [13]. The most common solar panel types are monocrystalline, polycrystalline, and thin film [14]. The types of solar panel made are based on the types of silicon used. Different silicon types also have different method of creating photovoltaic cells. Adding to that, each silicon modules have different efficiency and cost based on the silicon purity and production method. The explanation of each silicon modules are as follows [13], [14],

1. Monocrystalline Silicon Modules

The silicon is made using the crystal pulling method. Higher cost than the other types of solar panel but have the best efficiency even in low-light condition [8]. Average energy performance of 546.82Wh with daily average photovoltaic panel efficiency of 6.65%. Another research shown about 15-20% efficiency and have decent heat tolerance.

2. Polycrystalline Silicon Modules

Have the easiest production method which is using the casting method. However, it has lower cost than monocrystalline with lower efficiency. Average energy performance of 517.52Wh with daily average photovoltaic panel efficiency of 5.38%. Another research shown about 13-16% efficiency.

3. Thin Film

Thin Film are made by putting a thin layer of photovoltaic materials onto a solid surface like glass [15]. It forms a lightweight sheet that is flexible. Thin film has the lowest cost among the three types of solar panel and the lowest efficiency. It has the general efficiency of around 10-13%.