PERFORMANCE ANALYSES OF VARIOUS PHOTOVOLTAIC POWER PLANT BASED ON LOCAL SPECTRAL IRRADIANCES IN MALAYSIA USING GENETIC ALGORITHM

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LIM SONG WEI

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Science (Honours) Software Engineering

Lee Kong Chian Faculty of Engineering and Science
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April 2023

DECLARATION

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

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"PERFORMANCE ANALYSES OF VARIOUS PHOTOVOLTAIC POWER PLANT BASED ON LOCAL SPECTRAL IRRADIANCES IN MALAYSIA USING GENETIC ALGORITHM"** was prepared by **LIM SONG WEI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Honours) Software Engineering at Universiti Tunku Abdul Rahman.

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ACKNOWLEDGEMENT

First, I would like to express my sincere gratitude to all those who have contributed to the successful completion of this project. I would like to thank my project supervisor Prof. Dr Chong Kok Keong, who provided me invaluable guidance and support throughout the project. His insightful feedback, encouragement and suggestions have been instrumental in shaping the direction and quality of this work.

I would also like to extend my thank to University Tunku Abdul Rahman (UTAR) for providing the online library as well as other necessary facilities and resources for free which helped me to carry out this project easily and smoothly.

Finally, I am grateful and would like to express my gratitude to my parents for their unwavering support and encouragement throughout this project. They have provided not only financial support but also mental support which have been a constant source of inspiration for me.

ABSTRACT

Solar Photovoltaic (PV) technology is a method that converts solar energy or sunlight into electricity using semiconductor materials. Solar PV technology is renewable and sustainable, and it is environmentally friendly. However, The quantity of solar energy gathered by the fixed tilt solar photovoltaic (PV) system depends significantly on its orientation with respect to the sun, it is because the solar PV system can harvest the most solar radiation when the panel surface is perpendicular to the sunray. In order to harvest maximum amount of solar irradiance, a fixed tilt solar PV system must be set up with the optimal tilt angle and orientation angle so that it is efficient and able to generate maximum amount of energy.

This project aims to measure the performances of various photovoltaic power plants in Malaysia based on local spectral irradiances using genetic algorithm. A Python computational model that uses genetic algorithms will be developed to estimate the optimal tilt angle and orientation angle as well as the solar power received for the solar sites. The solar sites will be evaluated based on their annual average solar irradiation and the optimal tilt angle and orientation angle for solar panel at the solar sites can be estimated using the computational model.

Based on the analysis result, by comparing the simulation result of tilt angle and orientation angle with the actual on-site experiment result of tilt angle and orientation angle, the model in this project is able to achieve 75% accuracy. Besides, the genetic algorithm has showed that it is an effective and efficient way to perform estimation of optimal tilt angle and orientation angle for solar sites with genetic algorithm as it is able to produce correct and accurate result in a short amount of time.

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LIST OF SYMBOLS / ABBREVIATIONS

PV	Photovoltaic
DNI	Direct Normal Irradiance
GHI	Global Horizontal Irradiance
3D	Three Dimensional
EOT	Equation of Time
Wh/m^2	Watt Hour per Meter Square

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Renewable energy is a kind of energy that can be obtained from organic resources that constantly replenishing at a high rate (Lora, 2022). Solar energy, wind energy, geothermal energy, ocean energy, and bioenergy are the examples of renewable energy. The non-renewable energy, also known as dirty energy, for example gas, coal, and petroleum are available in limited amounts and will not be replenished. Solar energy is a type of renewable energy directly from the sun in solar radiation form. The most plentiful source of energy on Earth is solar energy and it can be harnessed to generate electricity with the help of technologies such as solar photovoltaic (PV). Nowadays, solar energy is commonly used as a replacement for fossil fuel as solar energy is more environmentally friendly compared to fossil fuel in terms of generation of electricity as it does not produce greenhouse gasses or air pollution.

Photovoltaic (PV) is the process of using solar cells on a solar panel to convert solar radiation into direct current (DC) power when the solar radiation strikes on the cells. Numerous solar cells comprised of semi-conducting materials like silicon make up a solar panel. When the photons from sunlight hit on the solar cells, the electrons will be knocked out from their atom and flow through the electric field in the solar cells and generate electricity (Michael, 2022). The whole process is known as the photovoltaic effect. Figure 1.1 shows the description of the photovoltaic effect.

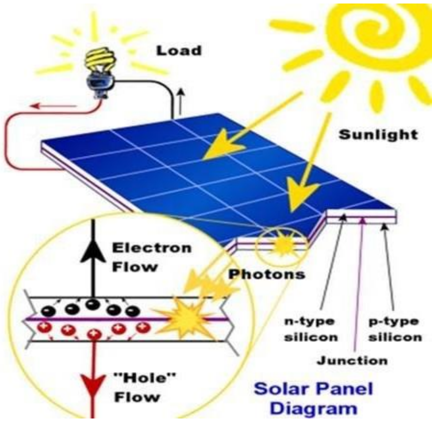


Figure 1.1: Description of photovoltaic effect on a solar cell (Nikolaos, 2018).

The amount of solar radiation received, the impacts of shade, the environment, and the orientation of the solar PV modules are some of the variables that have an effect on the overall performance of the PV panel. The solar PV module's orientation relative to the sun must not be ignored to guarantee the optimal performance of the modules. The tilt angle and azimuth angle are the angles that govern the orientation of solar PV modules; the tilt angle is the angle between the solar panel and the horizontal plane, while the azimuth angle provides the compass direction of the module face. According to Salih (2014), the difference in the tilt angle and azimuth angle of the solar PV module can significantly affect the power produced by the module. To increase the effectiveness of solar PV, the optimum tilt angle and azimuth angle must be established.

1.2 Problem Statement

The quantity of solar energy gathered by the fixed tilt solar photovoltaic (PV) system depends significantly on its orientation with respect to the sun, it is because the solar PV system can harvest the most solar radiation when the panel surface is perpendicular to the sunray. (Cara, 2018). A fixed tilt solar PV system is expected to be set up with the ideal tilt angle and azimuth angle so that it is efficient and able to generate maximum energy.

However, it is hard for individuals or companies to measure and estimate the optimum tilt angle and orientation for the installation of solar PV. It will require a lot of time to be spent on planning and designing before installing solar PV. The effectiveness of the fixed tilt solar PV system would be reduced if the tilt and azimuth angles were not put at their ideal positions as it is not able to generate the maximum amount of energy as expected which will cause financially lost or the project may fail.

In this project, a computational model will be constructed to help estimate the optimal tilt angle and orientation for the solar PV system. The model can estimate the optimal angles of the PV panels according to the historical meteorological data of the solar site.

1.3 Aims and Objectives

This project aims to measure the performances of various photovoltaic power plants in Malaysia based on local spectral irradiances using genetic algorithm.

1. To use Python Programming to construct a computational model for a year of meteorological data from Solcast © for the 28 solar sites.
2. To estimate the annual average solar irradiation and annual average peak sun hours received on the 28 solar sites.
3. To rank the 28 solar sites based on the solar irradiation received for a year.
4. To model the optimal tilt angle and azimuth angle of the solar panel based on the maximum total solar irradiation of the year.

1.4 Proposed Approach

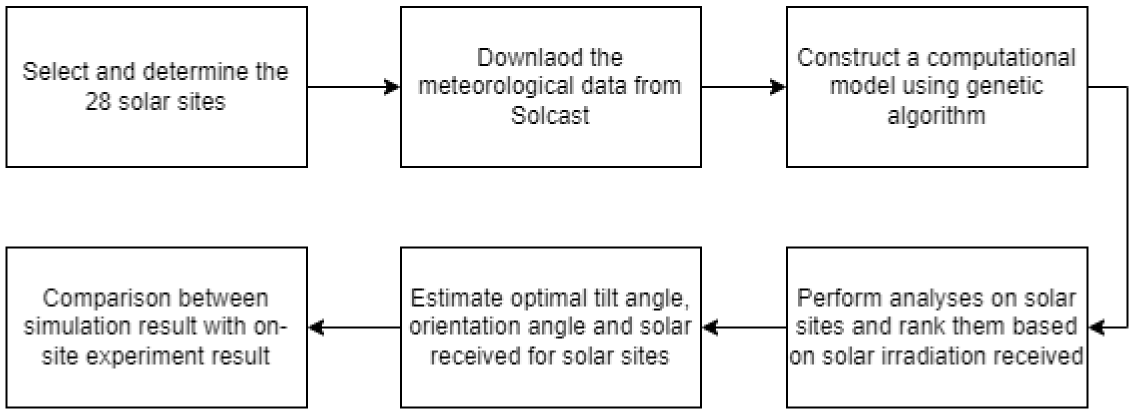


Figure 1.2: Overview Approach of Project

Figure 1.2 shows the overview process for this project where the project starts with select and determine the 28 solar sites to be used in this project. After determining the solar sites, the meteorological data for every solar sites will be downloaded from Solcast. After that, a computational model that used genetic algorithm will be constructed using Python programming language. Then, an analysis on solar sites will be performed and the solar sites will be ranked based on their solar irradiation received. After performing analyses on the solar sites, the optimal tilt angle, orientation angle and solar received for solar sites will be estimated using the computational model constructed in this project. Lastly, a comparison between simulation result with on-site experiment result will be carried out to test the reliability and accuracy of the model.

1.5 Gantt Chart

A Gantt chart is a chart that is commonly used in project management to manage the schedule and progress of the project. Figure 1.3 illustrates the Gantt chart for the proposed project.

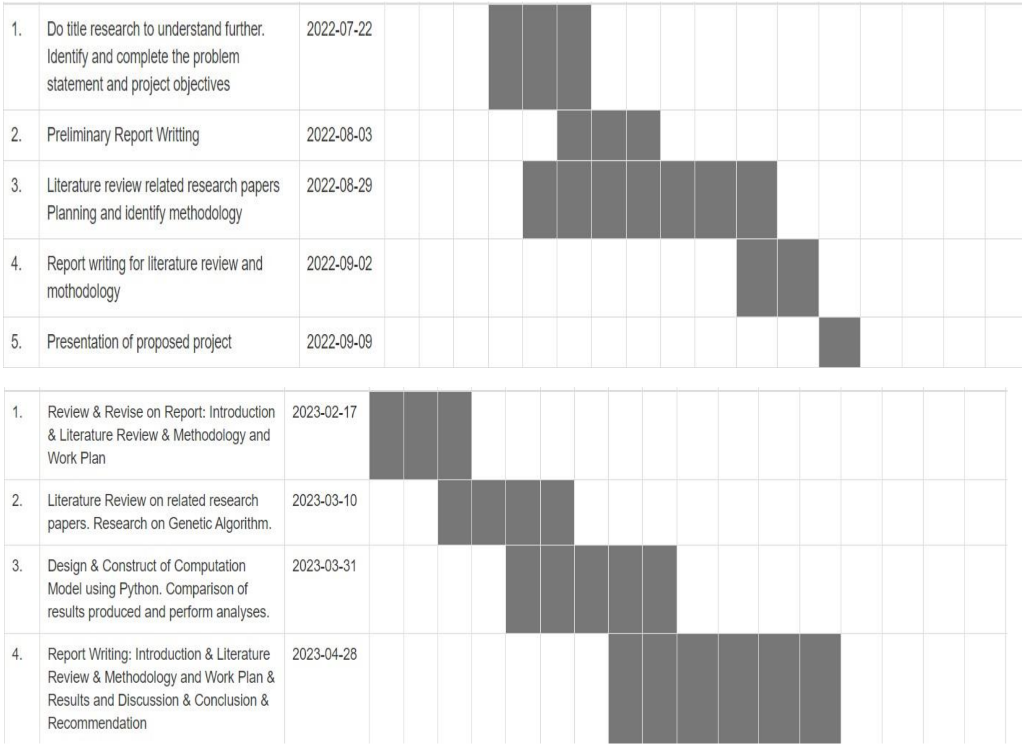


Figure 1.3: Gantt Chart for Proposed Project

1.6 Scope and Limitation of the Study

The scope of this project will be focused on performing a case study on 28 solar sites in Malaysia. This project develops a computational model using Python Programming to evaluate and analyse the performance of solar sites. The project will estimate the simulation results that consist of the optimum tilt angle and azimuth angle of the solar panel, the investment cost, annual income, and the payback period of the solar sites. The estimations are done using the historical meteorological data from Solcast © and various theoretical formulas using the model. The model allows the user to estimate the optimum tilt angle, and azimuth angle of solar panels as well as total solar irradiation received on the solar sites.

The limitation of the study is that all the results simulated by the Python computational model is based on the historical meteorological data provided by Solcast and theoretical formula. Therefore, it is necessary to carry out a comparison of simulation result with the actual on-site experiment result in order to make sure the simulated result is correct and reliable.

1.7 Report Outline

This report is separated into 5 different chapters as:

Chapter 1 Introduction

This chapter briefly explain about the proposed project as well as the planning such as the objectives, limitation and Gantt chart.

Chapter 2 Literature Review

This chapter outlines the studies on various thesis proposed by other researchers that is relevant to this project.

Chapter 3 Methodology

This chapter explains the procedure and implementation to carry out this project.

Chapter 4 Result and Discussion

This chapter explains and discusses the result produced as well as performing analysis.

Chapter 5 Conclusion

This chapter includes the conclusion and recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In chapter 2, the types of photovoltaic systems used in the market have been discussed in terms of their performance as well as the overall cost. The cosine effect on a photovoltaic panel that caused the loss of solar energy received by the PV panel due to the reduction of receiving area of the panel surface also been discussed. Another important element such as tilt angle and orientation of PV panel, sun position is also discussed in this chapter as both of the topics are important in analysing the performance of the PV panel. Besides, it was studied that environmental factors such as collection of dust, water droplets, shading, and birds' dropping can affect the performance of PV panels. Lastly, the on-site experiments in determining the optimal tilt angle are also reviewed so that the results can be used to compare with the simulation results produce in this proposed project to test the reliability of the model constructed. Journals and articles have been reviewed and studied to improve understanding and ensure the proposed project can be completed smoothly.

2.2 Fixed tilt and Axis Tracker Photovoltaic Panel

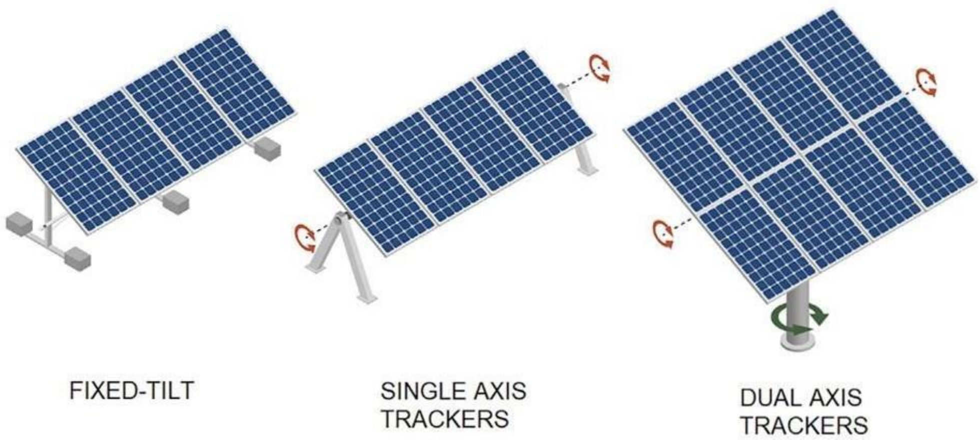


Figure 2.1: Three types of photovoltaic panels in use. (Scott Snowden, 2020)

As shown in Figure 2.1 above, there are currently a total of 3 types of PV panels that are in use in the market which are fixed tilt, single-axis trackers, and dual-axis tracker. A fixed tilt PV panel does not track the sun and it is mount remains fixed in place. Fixed tilt PV panels usually will be tilted with optimal angle and orientation to receive maximum solar irradiance and produce the maximum power output. A single-axis tracker allows the PV panel to be rotated around one axis, either on a horizontal axis or on a vertical axis. PV panels with single-axis trackers can track and follow the sun's movement. The last one which is the dual axis tracker allows 2 degrees of freedom and a 360° rotation on both the East-West and North-South axis.

According to a study conducted by Jacobson & Jadhav, (2018), the optimal tilt angle for PV panel was calculated and is used to determine the yearly ratio of sun rays normal to the 3 different types of PV panel relative to horizontal panels. It was found that the annual ratio of incident radiation normal to fixed tilt panel, single-axis tracker panel, and dual-axis tracker panel relative to the horizontal panel was ~1.19, ~1.35, and ~1.39 respectively. It showed that both fixed tilted and tracking PV panels are able to receive more solar power compared to PV panel that is placed horizontally on land. However, tracking PV panels can receive higher solar power if compared to a fixed tilt PV panel.

Another study carries out by Rao et al., (2015), in comparing the performance of PV panels on dual-axis tracker and fixed tilt. 2 sets of PV modules had been set up with one of the sets is mounted on a fixed stand with an optimal tilt angle of 15° South facing while another set is mounted on a dual axis tracking device. The experiment was carried out from August 2012 until March 2013 and the results showed that the tracking panel was able to produce 21.2% of power output compared to the fixed tilt panel. The authors also performed an overall cost analysis for both the tracking panel and fixed tilt panel. It was found that the cost for the tracking panel is higher and the additional cost for tracking panel required a total of 450 days to be paid back.

2.3 Cosine Effect of Photovoltaic Panel

One of the factors that contributes to the loss of solar energy received on the surface of PV panels is the cosine effect. According to Zhang et al., (2017), the cosine angle, α is the angle between the sun ray and normal of the PV panel which as shown in Figure 2.2, can cause the reduction in receiving area of the surface of PV panel which then cause loss of solar energy.

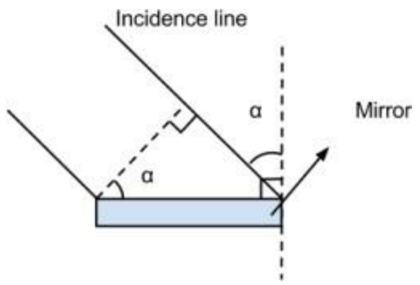


Figure 2.2: Definition of Cosine Effect (Zhang et al., 2017)

When the incident sunray is not perpendicular to the normal of a PV panel, the cosine effect arises.. The solar irradiance receive by the PV panel can be calculated using equation (2.1):

$$I_{o,h} = I_o \cos \alpha_i \quad (2.1)$$

Where $I_{o,h}$ is the actual solar energy received by surface the PV panel, I_o is the direct beam solar irradiance incident on PV panel and α_i is the incidence angle/cosine angle.

2.4 Tilt Angle and Azimuth Angle of Photovoltaic Panel

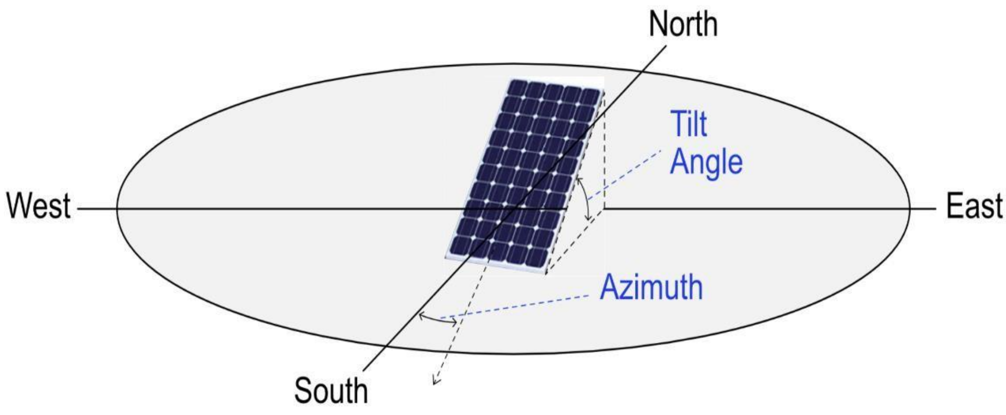


Figure 2.3: Tilt Angle and Azimuth Angle of PV Panel. (SolarDesignGuide, n.d.)

As shown in Figure 2.3, the tilt angle is the inclination of the solar panel with respect to the horizontal plane while the azimuth angle refers to the direction the PV panel faces. The tilt angle and azimuth angle of the PV panel play an important role in order for the PV panel to achieve high efficiency and receive maximum amount of solar radiation. In addition to climatic considerations, other parameters that affect the performance of PV panels include the tilt angle and azimuth angle of the panels.

According to Poobalan et al., (2020), to analyse the relationship between both angles with the performance of the PV panel. This study performed an analysis in 2 locations which are Chennai, India and Beijing, China. It found that an optimal tilt angle and azimuth angle applied to PV panel allow the PV panel to produce maximum power output and achieve higher efficiency. It also proved that both tilt angle and azimuth angle play a significant role for the PV panel to achieve maximum power efficiency. Therefore, in order to optimise the power output from the panel, it is crucial for the user to ascertain the ideal tilt and azimuth angles before they install.

2.5 Solar Altitude Angle and Azimuth Angle

According to Ray, (n.d.), position of the sun can be expressed in terms of sun altitude angle and azimuth angle. The altitude angle is the angle between the horizontal plane and sunray while the sun azimuth angle indicates the sun position in compass, as shown in Figure 2.4.

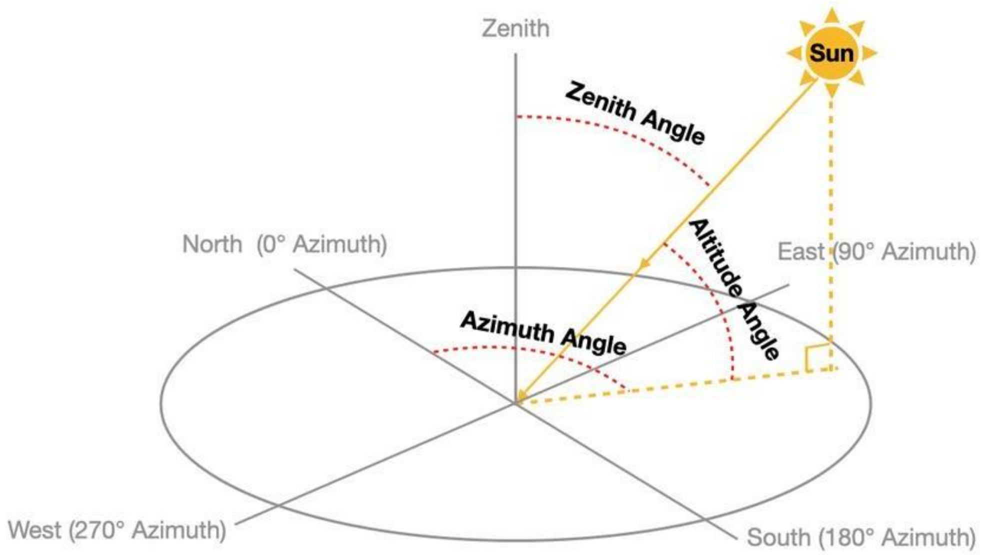


Figure 2.4: Solar Altitude Angle, Azimuth Angle and Zenith Angle. (Y. Zhang et al., 2021)

In the northern hemisphere, the azimuth angle of the sun during solar noon will be 180°S and for the southern hemisphere, the azimuth angle of the sun during solar noon will be 0°N. This is due to the fact that the sun comes up from the East and sets on the West. In order to get the most solar energy, several studies indicated that the orientation of the PV panel should be towards South for sites in the northern hemisphere and North for areas in the southern hemisphere.

2.6 Environmental Impact on Performance of PV Panel

Mustafa et al., (2020), performed a study to evaluate the effects of four environmental factors on the efficiency of solar panels. The deposition of dust, water droplets, shade, and bird droppings are the four environmental elements. In the study, 2 PV panels have been set up with a tilt angle of 31° facing South. In order to monitor the panels' current and voltage, a digital multi-meter was utilised to connect the panels. As shown in Figure 2.5, one of the PV panels with a pristine and spotless surface was chosen as the reference example while another PV panel was used to set up with 4 different conditions which are panel affected by dust, water duplet, partial shading and birds dropping.

Figure 2.5: PV Panels in Different Conditions. (Mustafa et al., 2020)

In summary, the dust on the surface of the PV panel will cause reduce in the power output produced by the panel by 8.8% and cause the efficiency of the panel to reduce by 11.86%. For the shading factor, it is clear that as the shading area increase, the higher reduction of power output is produced by the PV panel. However, the impact of the water droplet on PV panel did not reduce the power output of the panel but achieved a 5.6% improvement in power output of the PV panel. Because the water droplets may lower the temperature of the PV panel, which increase the efficiency of the panel. Last but not least, the amount of bird droppings on the PV panel causes it to produce less electricity, and the amount of this power output reduction is dependent on the amount of bird droppings.

2.7 On-Site Experiments

Based on the case study carried out by Krishna et al., (2021) in Nitte, India, a photovoltaic (PV) panel of 50W was installed in the Solar Energy Park, NMAM Institute of Technology to study the optimal tilt angle for PV panel. The latitude of the location is 13.1830° and the longitude is 74.9340° The solar panel was installed facing south without any shading effect and the tilt angle of the PV panel varied from 0 degrees to 36 degrees. The experiment lasted for five months, from December 2019 to April 2020, and the PV panel's power output was recorded hourly from 10 am to 4 pm every day to establish the ideal tilt angle from December to April. The case study discovered that a solar PV panel in Nitte, India has an ideal tilt angle around 0-36 degrees to produce the maximum power output. However, it is not recommended to place to PV panel with a tilt angle of 0 degree or horizontally on land as the environmental factors such as dust and dew accumulation on the surface of PV panels can happen which will affect the performance of PV panel.

Location	Latitude	Longitude	Optimal tilt	Orientation
Nitte, India	13.1830°N	74.9340° E	0° - 36°	Due South

Shaker Al-Sayyab et al., (2019), completed a case study in determining the optimal tilt angle of PV panel in Basra City, Iraq. Basra City has a latitude of 30.5258° N and a photovoltaic cell of 24 W is used in this case study. While doing the experiment, the tilt angle of the PV panel varies over a range from 0 degree to 90 degree with an increment of 5 degree. The case study was carried out for a year and the average value of power output over a year is calculated to determine the best tilt angle. The yearly tilt angle for solar panels in Basra City, Iraq, was discovered to be 28 degrees. In this study, the authors didn’t state the azimuth angle used for the PV panel.

Location	Latitude	Longitude	Optimal tilt	Orientation
Basra City, Iraq	30.5258° N	-	28°	-

According to a case study conducted by Khin et al., (2018) at Khon Kaen University, Thailand with a latitude equal to 16.472 °N and longitude equal to 102.826°E, a 5 W monocrystalline solar PV panel facing south was set up for 5 different tilt angle which are 0°, 16°, 30°, 45°, 60°. The experiment was carried out for 3 months in 2017 from March to May and the voltage and current of the PV panel were measured every hour from 11 am to 1 pm. In summary, the case study found that the optimal tilt angle for Khon Kean University, Thailand was varying around 0°-16° to optimise the power generated by the PV panel. However, the authors didn’t justify the 5 different tilt angles used for the PV panel in the experiment and the experiment was carried out for a few days only, for example, 8, 10, and 9 days in March, April and May respectively.

Location	Latitude	Longitude	Optimal tilt	Orientation
Khon Kean University, Thailand	16.472 °N	102.826°E	0° - 16°	Due South

Mohammed, (2019) conducted a case study to calculate the ideal solar panel tilt angle and orientation in Baghdad, Iraq. A total of 4 PV panels had been set up in the case study and all of the PV panels were mounted on the building's roof with no shadowing impact. All the panels were installed due south with the tilt of 0°, 15°, 35°, and 45° and the measurement data was collected for all months of 2018. The brand of PV panels used is JS Solar with an area of about $0.1m^2$. The yearly ideal tilt angle for PV panels in Baghdad, Iraq, according to the case study, is 35° to achieve maximum power output. Moreover, the latitude and longitude for Baghdad, Iraq is 33.3152° N, 44.3661° E and the optimum tilt angle has slightly different from the latitude.

Location	Latitude	Longitude	Optimal tilt	Orientation
Baghdad, Iraq	33.3152° N	44.3661° E	35°	Due South

Based on a case study conducted by Adibah Ayuni Abd Malek et al., (2018), 6 PV panels are set up at Padang Besar, Perlis, Malaysia with a latitude equal to 6.6626° N, longitude equal to 100.3217° E. The six PV panels were installed on the rooftop of UniCITI ALAM with 3 different orientations and 11 tilt angles for each panel. The 3 orientations of PV panels are North 70° East, South 20° East and true South 180°. The 11 tilt angles of PV panels are adjusted to range from -25° to +25° with an interval of 5°. The case study was carried out for 10 days in July 2017, from 9am to 5pm and the data was collected every 1-hour interval. It was discovered that the best title angle and orientation for solar panels in Padang Besar, Perlis is -10° and South 20° East facing.

Location	Latitude	Longitude	Optimal tilt	Orientation
Padang Besar, Perlis, Malaysia	6.6626° N	100.3217° E	-10°	South 20° East

In Chandigarh, India, a case study was conducted to establish the optimal tilt angle for PV panels was carried out by Sharma et al., (2020). 5 PV panels were installed on the rooftop of the University Institute of Engineering and Technology (UIET), Panjab University, Chandigarh, India at a latitude equal to 30.7580°N and longitude equal to 76.7685°E. The model of the PV panels is Zytech Model ZT 320P with 1 kW each and the panels were installed with different tilt angles which are 10°, 20°, 25°, 30°, 40°. This case study was carried out for 1 year in 2018 and the real-time data from PV panels were collected from January 2018 until December 2018. In conclusion, the optimum tilt angle for PV panels in Chandigarh, India varies around 26°-28° to harness maximum power output from solar panels. The orientation of the PV panels is not stated by the author.

Location	Latitude	Longitude	Optimal tilt	Orientation
Chandigarh, India	30.7580°N	76.7685°E	26° - 28°	-

Another case study performed by Ullah et al., (2019), was conducted in Lahore, Pakistan which located at 31.5°N, 74.3°E. Two tests were carried out on the rooftop of the School of Science and Engineering building at Lahore University of Management and Sciences by installing five PV panels at varied tilt angles. The first experiment started by setting up the PV panels facing North at angles of 25°, 30°, 35°, 40°, 45° on 27 September 2017 and the second experiment started by setting up the PV panels facing North at angles of 50°, 55°, 60°, 65°, 70° on 16 January 2018. Every 15 minutes, the current and voltage of the PV panels were monitored and recorded. The ideal tilt angle for PV panels in Lahore, Pakistan was discovered to be 31.5°, which is identical to the city's latitude. The authors of the study also covered how soiling on PV panels will affect how well the panels operate. Power loss of approximately 10% to 40% may result from PV panels that are dirty based on the soiled condition and PV panels with lower tilt angles will have higher power loss due to soiling.

Location	Latitude	Longitude	Optimal tilt	Orientation
Lahore, Pakistan	31.5°N	74.3°E	31.5°	-

In Lagos, Nigeria, with a latitude of 6.6080°N and longitude of 3.6218°E, Obiwulu et al., (2022), did a case study to determine the ideal tilt angle for PV panels. 6 PV modules were installed with 2 modules tilted 5.5° and 10.1° faced North, 3 modules with tilt angles 6.7°, 16.8°, 26.8° facing South and 1 module placed horizontally (0°). The output voltage from the PV panels was recorded every 5 minutes in a day from 6 am to 6 pm which equals to a total of 144 readings in a day. The experiment was conducted from October 2017 to September 2018 to identify the tilt angle and orientation that received the greatest amount of incoming solar energy. In conclusion, the outcome indicates that the tilt angle and orientation of the module with a tilt angle of 16.8° due South is ideal for PV panels in Lagos, Nigeria.

Location	Latitude	Longitude	Optimal tilt	Orientation
Lagos, Nigeria	6.6080°N	3.6218°E	26.8°	Due South

Table 2.1 shows the research results done by various researcher in finding out the optimum tilt angle and orientation for PV panels for a specific location.

Table 2.1: Results of Different On-Site Experiments

No.	Author	Location	Latitude/ Longitude	Optimal Tilt	Orientation	Date	Duration
1	Krishna et al., (2021)	Nitte, India	13°10'58.8"N 74°56'02.4"E	0° - 36°	Due South	December 2019 to April 2020	5 months
2	Shaker Al-Sayyab et al., (2019)	Basra City, Iraq	30°31'32.9"N 47°46'25.7"E	28°	-	-	-
3	Khin et al., (2018)	Khon Kean University, Thailand	16°28'48.7"N 102°49'53.0"E	0° - 16°	Due South	March to May 2017	3 months
4	Mohammed, (2019)	Baghdad, Iraq	33°18'54.7"N 44°21'58.0"E	35°	Due South	2018	1 year

5	Adibah Ayuni Abd Malek et al., (2018)	Padang Besar, Perlis, Malaysia	6°39'45.4"N 100°19'18.1"E	-10°	South 20° East	July 2017	10 days
6	Sharma et al., (2020)	Chandigarh, India	30°45'28.8"N 76°46'06.6"E	26°- 28°	-	January to December 2018	1 Year
7	Ullah et al., (2019)	Lahore, Pakistan	31°30'00.0"N 74°18'00.0"E	31.5°	-	27 September 2017 & 16 January 2018	2 days
8	Obiwulu et al., (2022)	Lagos, Nigeria	6°36'28.8"N 3°37'18.5"E	26.8°	Due South	October 2017 to September 2018	1 year

2.8 Research Gap

By studying the related literature, it can be seen that many researchers tend to use the latitude angle of a location as the optimum tilt angle for the PV panel. However, it is not suitable to be used for PV panels for every location as studies have found that the tilt angle that enable the PV panel to produce maximum power output has a slight difference with latitude for many places. Therefore, to determine a more accurate result for optimal tilt angle, this proposed project will perform the determination of optimum tilt angle and orientation for solar panels for a location using a Python computational model based on the actual solar power collected by the surface of solar panel. Every combination of tilt angle (from 0° to 90°) and orientation (from 0° to 360°) will be used to calculate how much solar energy was received and the cosine effect will also be considered which allow this project to produce more accurate results for optimum tilt angle and orientation of PV panel.

The majority of the studies reviewed favour a fixed tilt PV system over an axis tracking solar system. because it is more economically friendly, and the overall cost for setting up a fixed tilt PV system is lower. Moreover, there are significantly less research about solar sites or PV systems in Malaysia has been done so far. The goal of this proposed project is to identify the ideal tilt angle and orientation for fixed tilt PV systems as well as analyse the performance of solar sites in Malaysia and the environmental impacts will not be evaluated in this proposed project.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The objectives of this proposed project is to perform analyses of various photovoltaic power plant in Malaysia based on their local spectral irradiances, model the optimal tilt angle and azimuth angle of the solar panel in 3D and lastly estimates the investment cost, annual income and payback period of the solar sites.

In this chapter, the process and the mathematical formulas used in this proposed project is discussed in detail. It all started with select and determine the solar sites in Malaysia to be used in the case study, the meteorological data of the chosen solar sites will be downloaded from Solcast©. The period of the meteorological data will be from 31 July 2021 to 1 August 2022. After that, the meteorological data downloaded will be imported into the computational model constructed using Python programming with various mathematical formulas to analyse the performance of solar sites based on their local spectral irradiances. Moreover, the sun position for each hour in a day for a year will also be determined in order to estimate the optimal tilt angle and orientation for PV panel. The optimum tilt angle and orientation of PV panel is determined according to the maximum amount of solar energy received in a year and every combination of tilt angle (from 0° to 90°) and orientation (from 0° to 360°) will be used in calculation of the optimal result. The computational model will also be tested by comparing the simulated optimal tilt angle with real on-site experiment results done by other researchers to test the reliability of the model. Lastly, the performance of solar sites is analysed by estimating their investment cost, annual income and payback period.

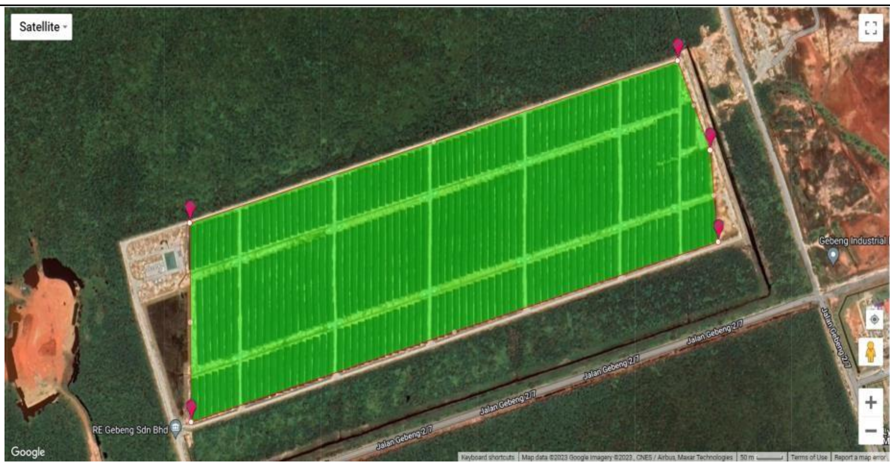
3.2 Solar Sites

There are a total of 28 solar sites have been chosen to be used to perform performance analyses in this proposed project. Table 3.1 below shows the name, latitude, longitude, image, and state of the solar sites. The image of the solar sites is obtained from Google Maps.

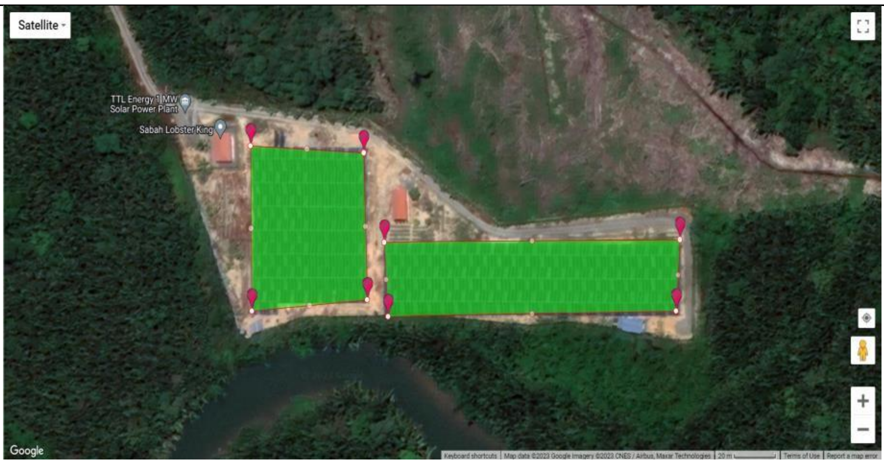
Table 3.1: 28 Solar Sites in Malaysia for Case Study.

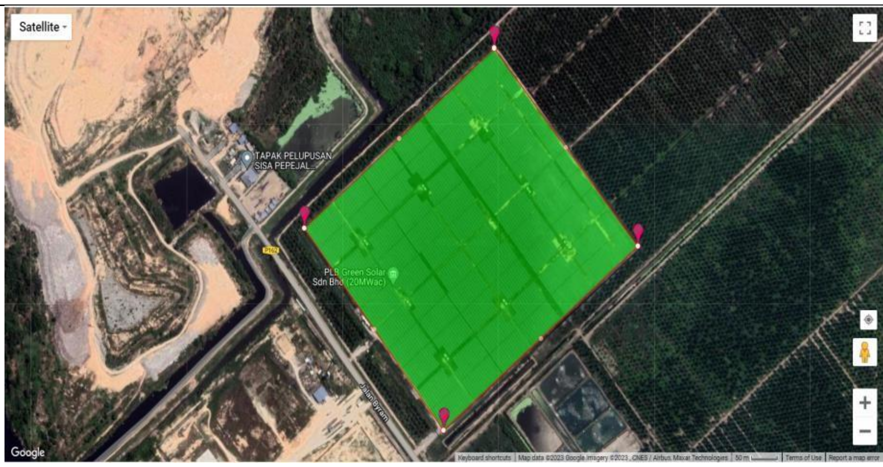
No	Name, State	Latitude / Longitude, Area	Image
1	Scatec Itramas solar 65MW Gurun Solar Power Plant Pendang, Kedah	5°51'45.2"N 100°32'15.5"E 676265.71 m² 167.11 acres 67.63 hectares	
2	Pasir Mas Solar Farm Pasir Mas, Kelantan	5°59'32.0"N 102°06'40.2"E 47960.48 m² 11.85 acres 4.80 hectares	

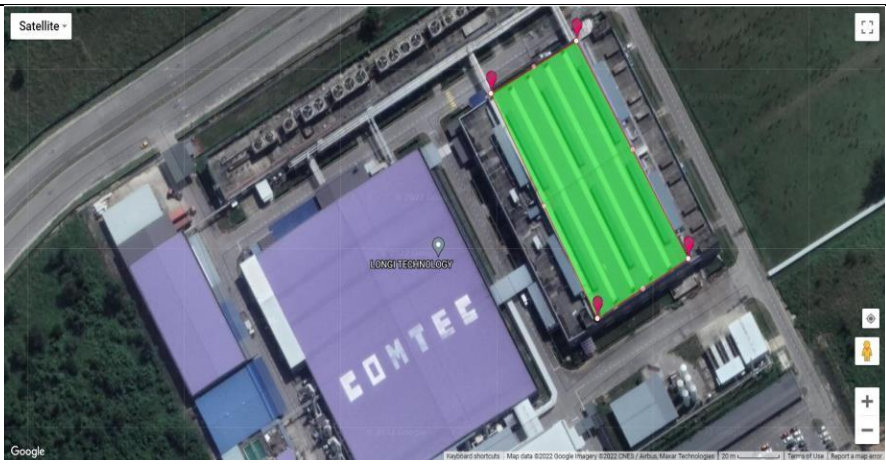
3	Sepang Solar Panel (SunEdison) Sepang, Selangor	2°46'46.3"N 101°42'50.0"E 97132.06 m² 24.00 acres 9.71 hectares	
4	WD Floating Solar Selangor	2°48'59.6"N 101°40'07.1"E 108820.74 m² 26.89 acres 10.88 hectares	
5	TNB Large Scale Solar Farm Banting, Selangor	2°47'04.2"N 101°36'52.5"E 713514.68 m² 176.31 acres 71.35 hectares	

6	TNB BUKIT SELAMBAU SOLAR Sungai Petani, Kedah	5°40'17.7"N 100°37'32.6"E 383861.87 m² 94.85 acres 38.39 hectares	
7	Synergy Generated Sdn. Bhd. Sungai Tong, Terengganu	5°23'05.0"N 102°51'36.7"E 54437.74 m² 13.45 acres 5.44 hectares	
8	RE Gebeng Sdn Bhd Balok, Pahang	4°00'18.3"N 103°21'40.7"E 334111.37 m² 82.56 acres 33.41 hectares	

9	Fairview Project Solar Farm Kluang, Johor	2°00'47.1"N 103°15'48.2"E 108469.38 m² 26.80 acres 10.85 hectares	
10	Fairview Project (Mersing) Solar Farm Mersing, Johor	2°22'34.1"N 103°51'03.4"E 2076.29 m² 0.51 acres 0.21 hectares	
11	Gading Kencana 30 MW Bidor Solar Power Plant Bidor, Perak	4°04'56.7"N 101°14'45.3"E 323150.82 m² 79.85 acres 32.32 hectares	

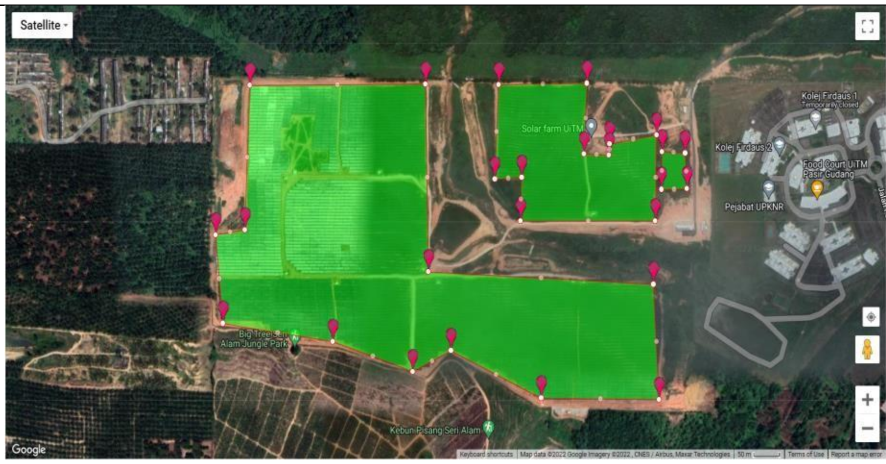
12	Mudajaya 10 MW Gebeng Solar Power Plant Balok, Pahang	3°58'44.2"N 103°23'25.9"E 123783.51 m² 30.59 acres 12.38 hectares	
13	TTL Energy 1 MW Solar Power Plant Papar, Sabah	5°45'06.0"N 115°55'03.4"E 8079.72 m² 2.00 acres 0.81 hectares	
14	Tadau Energy 48 MW Solar Power Plant Kudat, Sabah	6°56'43.5"N 116°49'45.4"E 209362.60 m² 51.73 acres 20.94 hectares	

15	PLB Green Solar Sdn Bhd (20MWac) Mukim 11, Penang	5°11'51.1"N 100°25'49.4"E 212459.64 m² 52.50 acres 21.25 hectares	
16	Amcorp 10.25MW Gemas Solar Power Plant Gemas, Negeri Sembilan	2°35'43.7"N 102°37'15.7"E 95581.66 m² 23.62 acres 9.56 hectares	
17	SBU Power Sdn Bhd (5.2MWp) Padang Siding, Perlis	6°28'30.2"N 100°21'10.2"E 43724.17 m² 10.80 acres 4.37 hectares	

18	Tanjung Batu Hybrid Solar Power Plant Sandakan, Sabah	5°48'01.8"N 118°09'29.2"E 1984.78 m² 0.49 acres 0.20 hectares	
19	Comtec Solar International (m) Sdn Bhd Kuching, Sarawak	1°31'10.6"N 110°23'50.0"E 5336.63 m² 1.32 acres 0.53 hectares	
20	Solar Power Plant Telok Melano, Sarawak Energy Berhad Lundu, Sarawak	2°00'16.6"N 109°38'42.5"E 535.22 m² 0.13 acres 0.05 hectares	

21	Bukit Kayu Hitam Solarvest 12MWp Bukit Kayu Hitam, Kedah	6°28'40.8"N 100°25'42.0"E 140175.06 m² 34.64 acres 14.02 hectares	
22	Pokok Sena Solar PV plant Jitra, Kedah	6°10'51.3"N 100°28'21.0"E 228730.43 m² 56.52 acres 22.87 hectares	
23	LSS PV 30MWac Kuala Muda Kedah Sungai Petani, Kedah	5°39'25.3"N 100°34'21.2"E 298746.31 m² 73.82 acres 29.87 hectares	

24	Scatec Itramas Solar 66MW Jasin Solar Power Plant Bemban, Melaka	2°17'56.7"N 102°21'16.0"E 311427.61 m² 76.96 acres 31.14 hectares	
25	Scatec Itramas Solar 66 MW Merchang Solar Power Plant Marang, Terengganu	4°56'04.4"N 103°20'13.4"E 648928.38 m² 160.35 acres 64.89 hectares	
26	Pekan Pahang Solar Farm Pekan, Pahang	3°19'24.9"N 103°25'20.9"E 464450.20 m² 114.77 acres 46.45 hectares	

27	UITM Solar Park II (LSS2 Pasir Gudang) Masai, Johor	1°31'36.7"N 103°51'50.4"E 305555.17 m² 75.50 acres 30.56 hectares	
28	Kenyir Gunkul Solar Sdn Bhd Kuala Dungun, Terengganu	4°38'55.8"N 103°23'13.5"E 298835.51 m² 73.84 acres 29.88 hectares	

3.3 Solcast©

Solcast© is a cloud based online platform that provides historical, live and forecast data for solar irradiance and power data. Solcast© uses the latest technologies such as satellite, machine learning as well as computer vision and big databases to provide their solar data services (Solcast, n.d.). There are various services provided by Solcast©, however, we will only focus on the historical meteorological data provided by Solcast©. Solcast© allows user to download meteorological data for various location starting from year 2007 to 7 days ago. Solcast© provide accurate meteorological data which enable various researcher to use the data and carry out their study easily.

3.4 Steps to Download Meteorological Data from Solcast©

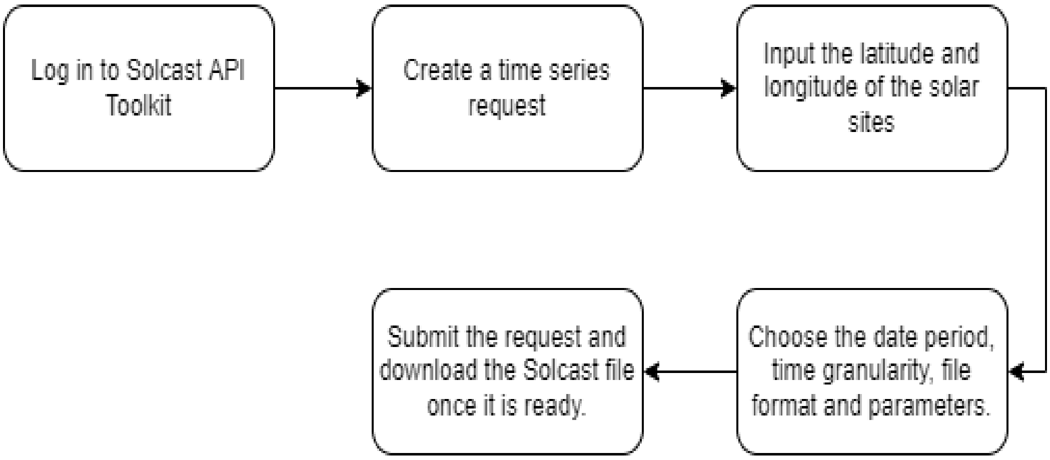


Figure 3.1: Steps to Download Meteorological Data from Solcast©

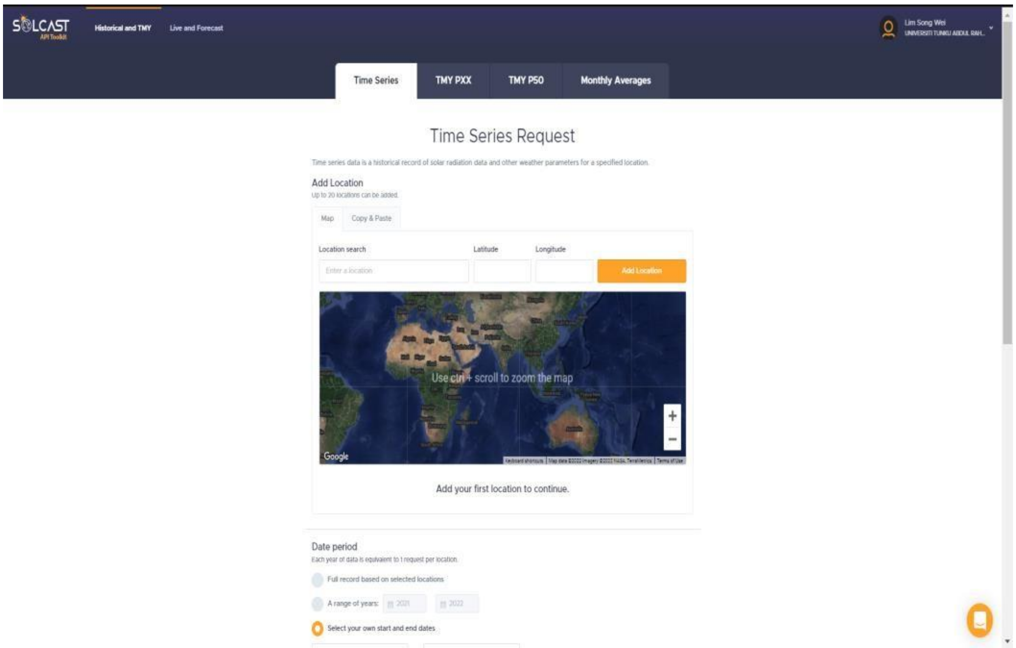


Figure 3.2: Steps to Download Meteorological Data from Solcast©

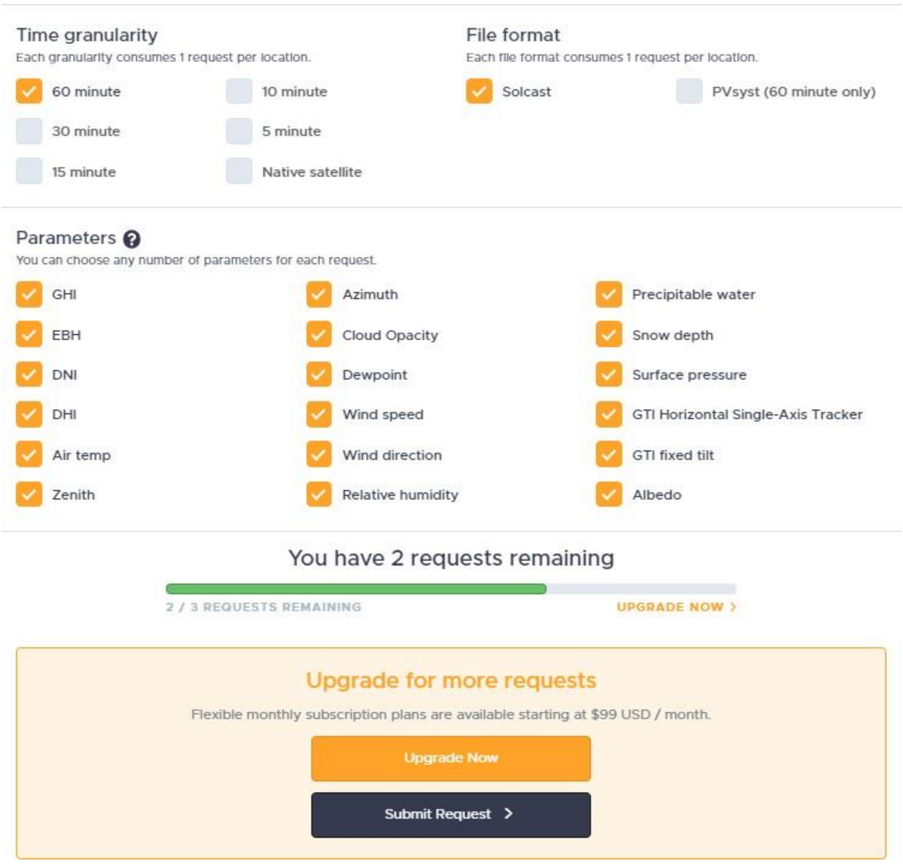


Figure 3.3: Steps to Download Meteorological Data from Solcast©

Figures 3.1, 3.2 and 3.3 show the steps to download meteorological data from Solcast©. In this project, the meteorological downloaded are within the range of data period from 31st July 2021 to 1st August 2022. All the parameters are chosen to be included in the data and the important parameters will be GHI, EBH, DNI and DHI. 60 minutes is chosen for time granularity so that each row of data produce will be 60 minutes which mean there will be 24 rows of data for a day and a total of 8766 rows of data for a date period from 31st July 2021 to 1st August 2022. The meteorological data downloaded from Solcast© will be in csv file format.

3.5 Software Used

The software used in this project are Microsoft Excel and Jupyter Notebook. Microsoft Excel is used when download the meteorological data from Solcast©.

It is because the data downloaded from Solcast© will be stored using Microsoft Excel in comma-separated values (csv) format. Besides, the results produce by Jupyter Notebook will also be stored using Microsoft Excel. For Jupyter Notebook, it is used to run Python programming code which is the computational model constructed in this project. Jupyter Notebook is a web application that can be used to produce and share computational documents and it supports more than 40 programming languages including Python (Jupyter, n.d.). Microsoft Excel is used to store data in this project as it offers a tidy and clean interface even handling large amount of data which then makes it a suitable software to be used. Jupyter Notebook is easy to use and provide user friendly interface and it supports Python which is why it is used in this project.

3.6 List of Formulas

The list of formulas used in the computational model constructed using Python programming is explained in this section.

3.6.1 Equation of Time (EOT)

$$EOT = 0.258 \cos x - 7.416 \sin x - 3.648 \cos 2x - 9.228 \sin 2x$$

Where EOT will be in minute, the x can be found using the formula

$$x = \frac{360(N-1)}{365.242}$$

Where x will be in degree format and N is the day number.

3.6.2 Solar Time

$$LCT = t_s - \frac{EOT}{60} - LC + D$$

Where LCT is Local Clock Time, t_s is the solar time, LC is longitude correction and D is daylight saving. LC can be found using the formula

$$LC = \frac{local\ longitude - longitude\ of\ standard\ time\ zone\ meridian}{15}$$

Where LC will be in degree format. As daylight saving is not applicable for Malaysia, therefore the equation of solar time can be derived as below

$$t_s = LCT + \frac{EOT}{60} - LC$$

Where t_s will be in hour format.

3.6.3 Declination Angle

$$sin\ \delta = 0.39795\ cos[0.98563(N - 173)]$$

$$\delta = \sin^{-1}[\ 0.39795\ \cos[0.98563\ (N - 173)]]$$

Where N is the day number, expressed as N = 1 when it is 1st January and N = 365 when 31st December (Chong et al., 2009).

3.6.4 Hour Angle

$$\omega = 15\ (t_s - 12)$$

Where t_s is the solar time in hour.

3.6.5 Altitude Angle

The altitude angle is the angle between the horizontal plane and sunray.

$$\alpha = \sin^{-1}(\sin\delta\sin\varphi + \cos\delta\cos\omega\cos\varphi)$$

Where δ is altitude angle, φ is location's latitude, ω is hour angle.

3.6.6 Zenith Angle

Zenith angle is the angle of sunray calculate from the North axis or vertical plane. Zenith angle can be calculated by minus the altitude angle with 90°.

$$\theta_z = 90 - \alpha$$

Where α is altitude angle.

3.6.7 Azimuth Angle

Azimuth angle indicates the sun position in compass. In the northern hemisphere, the azimuth angle for sun during solar noon will be 180°S and for the southern hemisphere, the azimuth angle of sun during solar noon will be 0°N. It is because the sun rises from East side and set at the West side. Azimuth angle can vary depending on the place and the time in any of the four trigonometric quadrants; therefore, azimuth angle can be determined in 2 scenarios:

$$A = \sin^{-1}(-\frac{\cos\delta \sin\omega}{\cos\alpha})$$

When $cos\ A = (sin\ \delta\ cos\ \varphi - cos\ \delta\ cos\ \omega\ sin\varphi)/\ cos\ \alpha > 0$

$$A = 180° - \sin^{-1}(-\frac{\cos\delta \sin\omega}{\cos\alpha})$$

When $cos\ A = (sin\ \delta\ cos\ \varphi - cos\ \delta\ cos\ \omega\ sin\varphi)/\ cos\ \alpha < 0$

3.6.8 Cosine Effect

One of the elements that contributes to a PV panel's surface losing solar energy is the cosine effect, when the normal of PV panel is not perpendicular to the incident sunray. In order to calculate the actual solar power received on the surface PV panel, the formula below can be used

$$I_{o,h} = I_o\ cos\ \theta_z$$

Where $I_{o,h}$ is the solar irradiance received by the PV panel, I_o is the direct beam solar irradiance incident on PV panel and θ_z is the incidence angle/cosine angle.

3.7 Introduction of the Computational Model

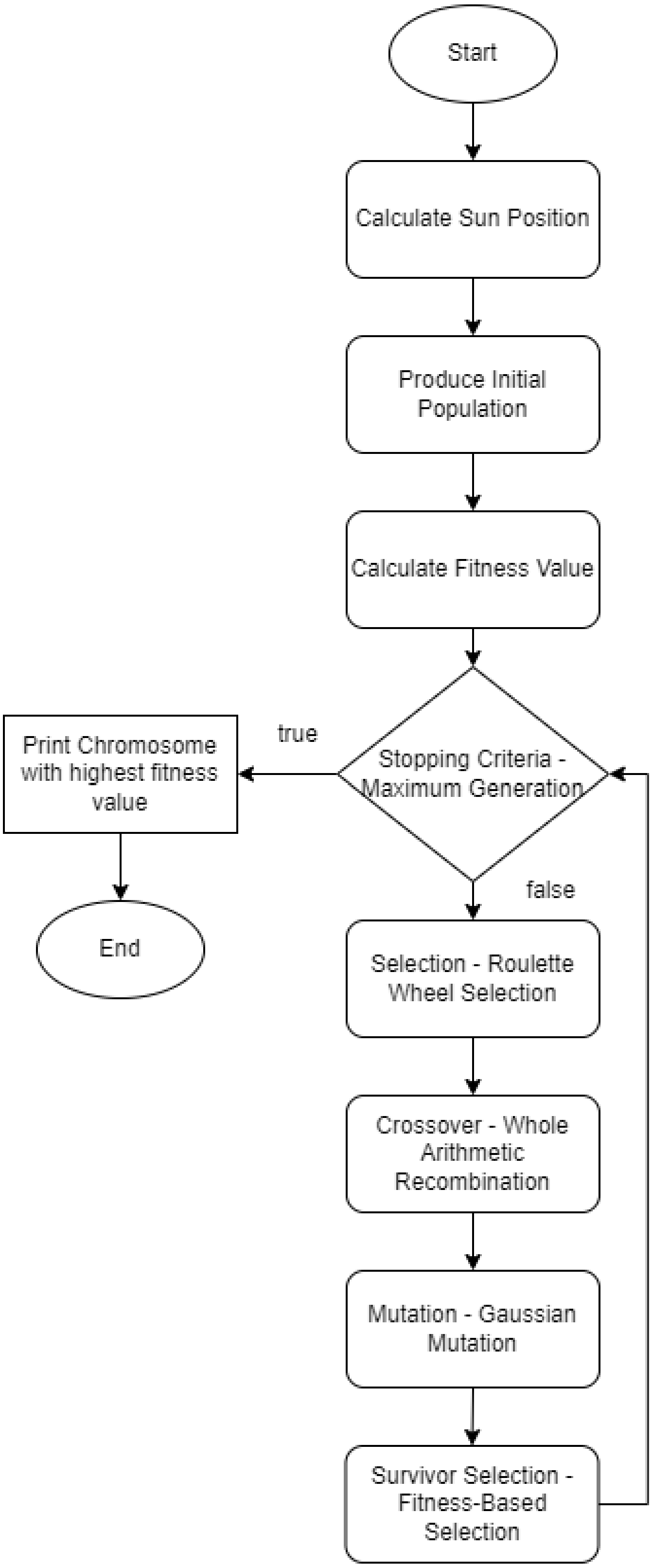


Figure 3.4: Flowchart of the Computational Model

The computational model consists of 2 parts which are the determination of the sun position and genetic algorithm. The first part of the model is to calculate the sun position for the location using the meteorological data downloaded from Solcast. After the sun position is determined, the second part of the model which is the genetic algorithm that consists of a series of processes will be executed to find the optimal combination of tilt angle and orientation angle for the solar panel for the location. The genetic algorithm part will start from producing an initial population until the end of the computational model.

3.7.1 Calculation of Sun Position

To calculate the sun position for each datetime for a particular location, it can be separated into 2 parts where the first part will determine the number of days, angle x, equation of time (EOT) and solar datetime while the second part will determine the sun position by calculating the decline angle, hour angle, altitude angle, zenith angle and azimuth angle.

3.7.1.1 Determination of Number of Days, Angle X, Equation of Time (EOT) and Solar Datetime

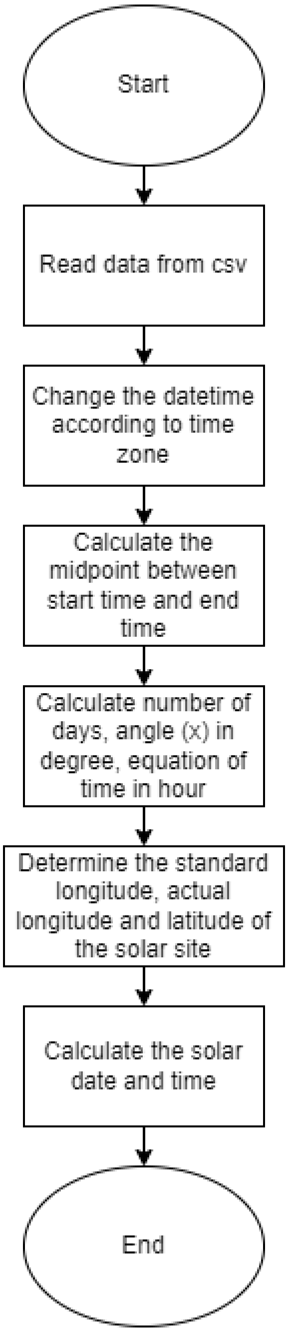


Figure 3.5: Flowchart on Determination of Number of Days, Angle X, Equation of Time (EOT) and Solar Datetime

After downloaded the meteorological data from Solcast for the location, the meteorological data can be used in the computational model to calculate values to determine the sun position. The Python model starts with reading the meteorological from the CSV file and store the data in the CSV file into a dataframe.

As the datetime provided by Solcast data is in UTC time (Greenwich Time), the datetime of the data will need to be changed to the timezone of the location. For example, the datetime in the data will need to add 8 hours to localize with Malaysia Time if the solar site is located in Malaysia as Malaysia time is 8 hours ahead of Greenwich Time. After changing the datetime of the data, the midpoint time will be calculated using the start time and end time and the midpoint time will be use in the calculation in later stage.

Next, the number of days will be determined and store in a dataframe with the label ‘n’ and the angle x will be calculated using the formula and then store in the same dataframe with label ‘x’

Programming Code	Remarks
df5['n'] = df4.dt.dayofyear	To determine the number of days based on the datetime processed in the previous step
df5['x'] = ((360*(df5['n']-1))/365.242)*(m.pi/180)	To determine the angle x using the formula with number of days

After determined the number of days and angle x, both of the values can be substituted into the formula to calculate the equation of time (EOT) and the result produced will be in minute format. Then the EOT will be converted to hour format to ease the calculation in the later stage.

Programming Code	Remarks
df5['eot'] = (0.258*np.cos(df5['x']) - 7.416*np.sin(df5['x']) - 3.648*np.cos(2*df5['x']) - 9.228*np.sin(2*df5['x']))/60	To determine the equation of time (EOT) in minute format using the formula
df5['eot'] = pd.to_timedelta(df5['eot'], unit='h')	To convert the equation of time (EOT) into hour format

After determining the number of days, angle x and equation of time, the standard longitude, actual longitude and latitude of the solar site will also be determined. The standard longitude will be determined using the formula while the actual longitude and latitude can be extracted from the filename of the CSV file from Solcast.

Programming Code	Remarks

stdLong = Timezone*15
 	
stdLongEW = 'E'
 	
if stdLongEW == 'E':
    stdLong = stdLong*(1)
 	
elif stdLongEW == 'W':
    stdLong = stdLong*(-1)
	To determine the standard longitude of the solar site. It can be calculated by multiplying the timezone determined in the previous stage with 15 degrees as each zone covering 15 degrees of longitude.
	
	If the longitude is on East, the value is +
	If the longitude is on West, the value is -

actLong = float(filename.split('_')[1])
 	
actLongEW = 'E'
 	
if actLongEW == 'E':
    actLong = actLong*(1)
 	
elif actLongEW == 'W':
    actLong = actLong*(-1)
	To determine the actual longitude of the solar site. The actual longitude is extracted from the filename of the CSV file.
	
	If the longitude is on East, the value is +
	If the longitude is on West, the value is -

Lat = float(filename.split('_')[0]) LatNS = 'N' if LatNS == 'N': Lat = Lat*(1)	To determine the latitude of the solar site. The latitude is extracted from the filename of the CSV file. If the latitude is on North, the value is + If the latitude is on South, the value is -

elif LatNS == 'S': Lat = Lat*(-1)	

Once the standard longitude, actual longitude and latitude of the solar site is determined, the solar time for each datetime can be calculated using the formula.

Programming Code	Remarks
df5['solar_datetime'] = df4 + df5['eot'] - timedelta(hours = (actLong - stdLong)/15)	To determine the solar time for each datetime. df4 = dataframe that store midpoint time df5[‘eot’] = dataframe column that store equation of time actLong = actual longitude stdLong = standard longitude

3.7.1.2 Determination of Sun Position

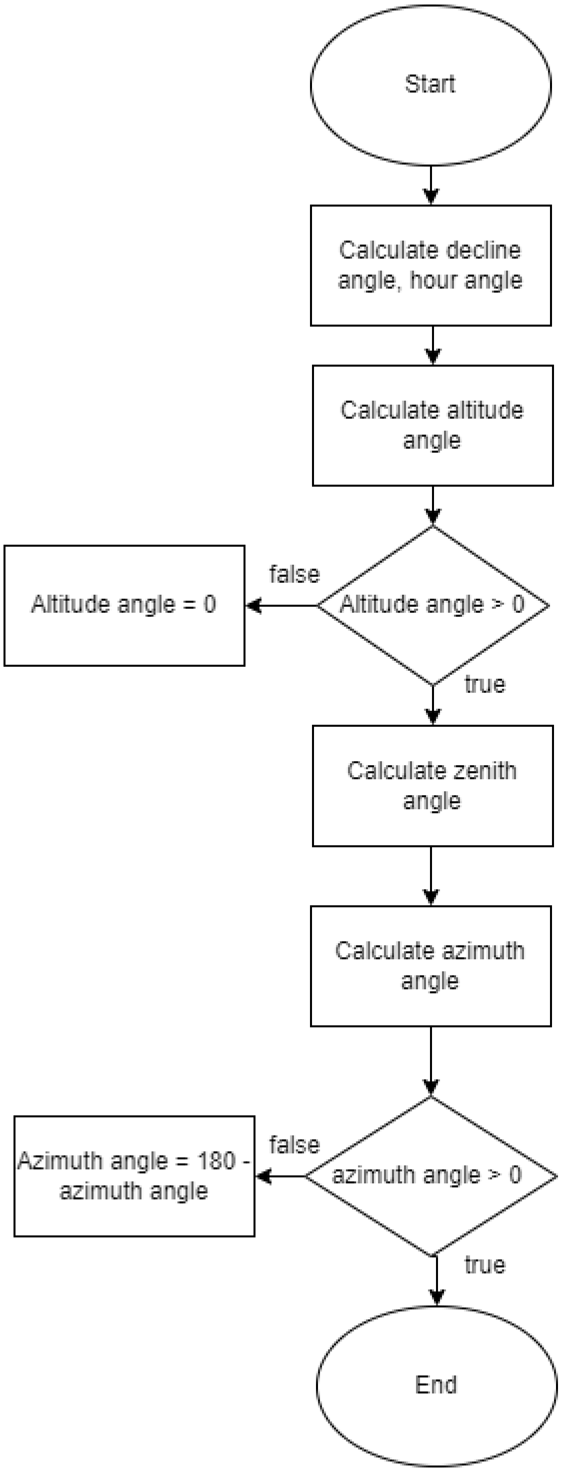


Figure 3.6: Flowchart on Determine Sun Position

In the second part of determining the sun position, the decline angle, hour angle, altitude angle, zenith angle and azimuth angle will be calculate using formulas. The sun position for each datetime in the meteorological data will be calculated in this section.

Programming Code	Remarks
df5['decline_angle'] = np.arcsin (0.39795*np.cos(0.98563*(df5['n'] - 173)*(m.pi/180)))*(180/m.pi)	To determine the decline angle of the sun for each datetime df5[‘n’] = number of days
df5['hour_angle'] = 15*((df5.solar_datetime.dt.hour + df5.solar_datetime.dt.minute/60 + df5.solar_datetime.dt.second/3600)-12)	To determine the hour angle of the sun for each datetime df5.solar_datetime = solar datetime
df5['altitude_angle'] = np.arcsin(np.sin(df5['decline_angle'] *(m.pi/180)) *np.sin(Lat*(m.pi/180)) + np.cos(df5['decline_angle']*(m.pi/180)) *np.cos(df5['hour_angle']*(m.pi/180)) *np.cos(Lat*(m.pi/180)))*(180/m.pi)	To determine the altitude angle of the sun for each datetime Lat = latitude
df5['altitude_angle'] .values[df5['altitude_angle'] .values < 0] = 0.0	During the night time (sun is not presence), the altitude angle is less than 0 degree and the value of altitude angle will be assign to 0
df5['zenith_angle'] = 90 - df5['altitude_angle']	To determine the zenith angle of the sun for each datetime
df5['cosA'] = (np.sin(df5['decline_angle']* (m.pi/180))*np.cos(Lat*(m.pi/180)) - np.cos(df5['decline_angle']* (m.pi/180))*np.cos(df5['hour_angle']* (m.pi/180))*np.sin(Lat*(m.pi/180)))/ (np.cos(df5['altitude_angle']* (m.pi/180)))	To determine the value of cosA, which is the cosine of Azimuth angle.

df5.loc[df5['cosA'] > 0, 'Azimuth'] = np.arcsin((-np.cos(df5['decline_angle']*(m.pi/180)) *np.sin(df5['hour_angle']*(m.pi/180)))/(np.cos(df5['altitude_angle']*(m.pi/180))))*(180/m.pi)	If cosA > 0, the azimuth angle of the sun will be calculated using this formula
df5.loc[df5['cosA'] < 0, 'Azimuth'] = 180 - np.arcsin((-np.cos(df5['decline_angle']*(m.pi/180)) *np.sin(df5['hour_angle']*(m.pi/180)))/(np.cos(df5['altitude_angle']*(m.pi/180))))*(180/m.pi)	If cosA < 0, the azimuth angle of the sun will be calculated using this formula

3.7.2 Genetic Algorithm

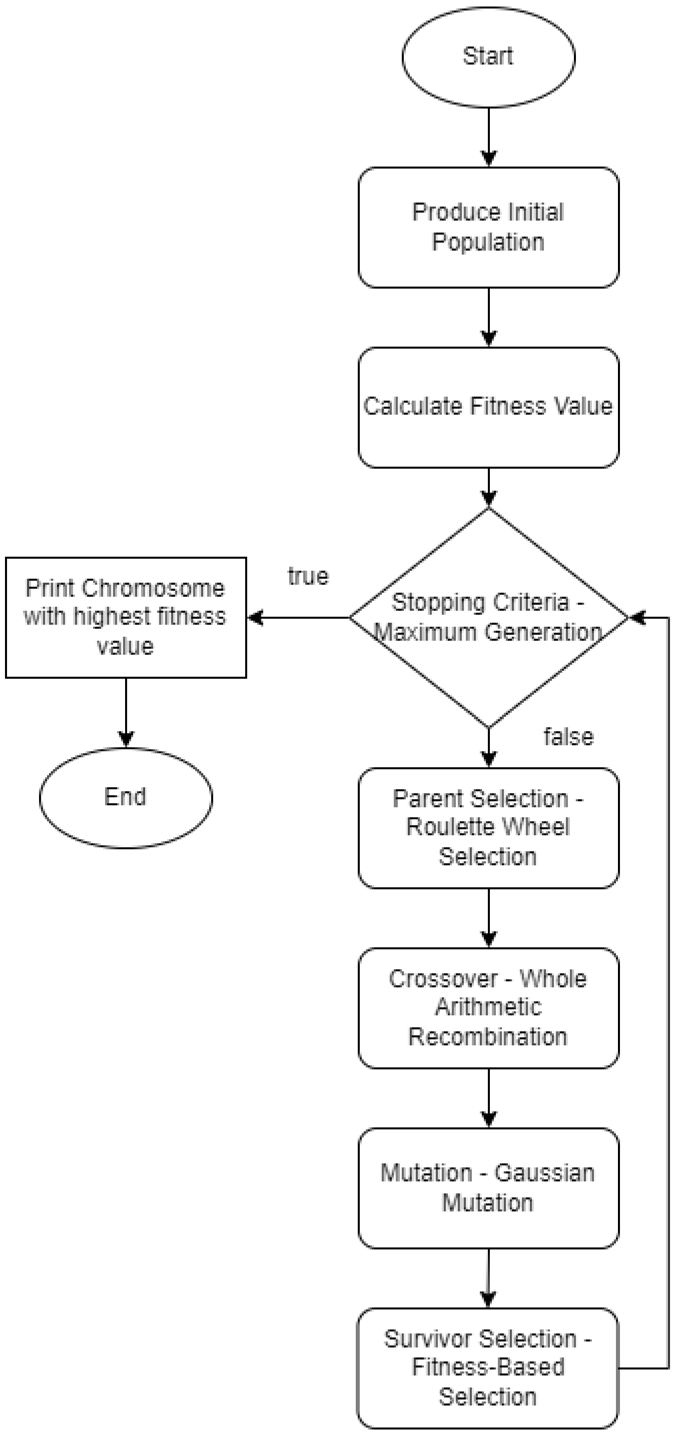


Figure 3.7: Flowchart for Genetic Algorithm

A genetic algorithm is a type of search optimization algorithm which is used to explore a search space and find the optimal solution to a given problem. The process of generating new solutions and selecting the best one is repeated for a number of generations and the population will converge to an optimal solution in the end of the execution of genetic algorithm.

The genetic algorithm started by randomly generating an initial population that consists of many possible solutions known as chromosomes. In this study, the possible solutions (chromosomes) are made up of combination of tilt angle and orientation of the solar panel, for example, (8.6, 107.7). All the chromosomes will then be evaluated using the fitness function to obtain the fitness value for each chromosome. The fitness function is the function to calculate the total solar received on the surface of solar panel (fitness value). After that, the genetic algorithm will loop and the chromosomes will undergo different operations such as parent selection, crossover, mutation and survivor selection to produce new chromosome until it meets the stopping criteria which is the maximum number of generations (loop). The newly produced chromosome will also be evaluated with the fitness function and the chromosome in the population with lower fitness value than the newly produced chromosome will be replaced.

3.7.2.1 Generate Initial Population

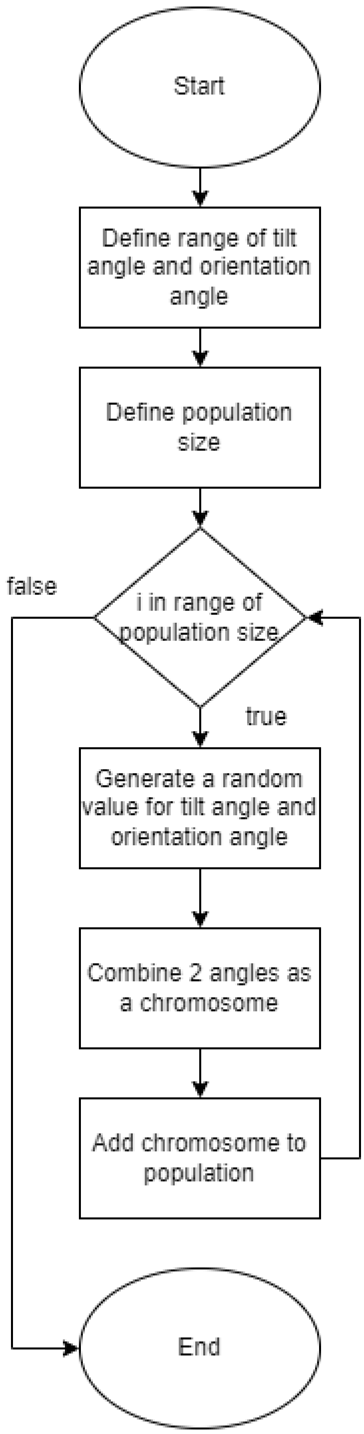


Figure 3.8: Flowchart for Generating Initial Population

To generate the initial population, the range of tilt angle, orientation angle and population size will need to be defined. The range of tilt angle will be from 0.0 degree to 90.0 degree while the range of orientation angle will be from 0.0

degree to 360.0 degree. Both tilt angle and orientation angle will have 1 decimal only. The population will have a size of 50.

Programming Code	Remarks
tilt_angle_range = [0, 90] orientation_angle_range = [0, 360] precision = 1	To determine the range of tilt angle and orientation angle with precision equals to 1
pop_size = 50	To determine the population size

After defining the range for tilt angle and orientation angle as well as the population size, the model will loop and randomly generate 2 values each for tilt angle and orientation angle and combine the 2 values to form a chromosome. The chromosome will be made up of 2 real value, for example, the format of the chromosome will be (13.4, 277.9). The number of loops will depend on the population size, for example, the model will loop 50 times to create 50 chromosomes if the population size is 50. All the chromosomes produced will be stored and form the initial population.

Programming Code	Remarks
x = round(random.uniform(0, 1) * (tilt_angle_range[1] - tilt_angle_range[0]) + tilt_angle_range[0], precision) y = round(random.uniform(0, 1) * (orientation_angle_range[1] - orientation_angle_range[0]) + orientation_angle_range[0], precision)	To randomly generate 2 values (x & y) which represent tilt angle and orientation angle
chromosome = [x, y]	To combine the 2 values generated to form a chromosome

population.append(chromosome)	To add the chromosome into the population

3.7.2.2 Calculate Fitness Value

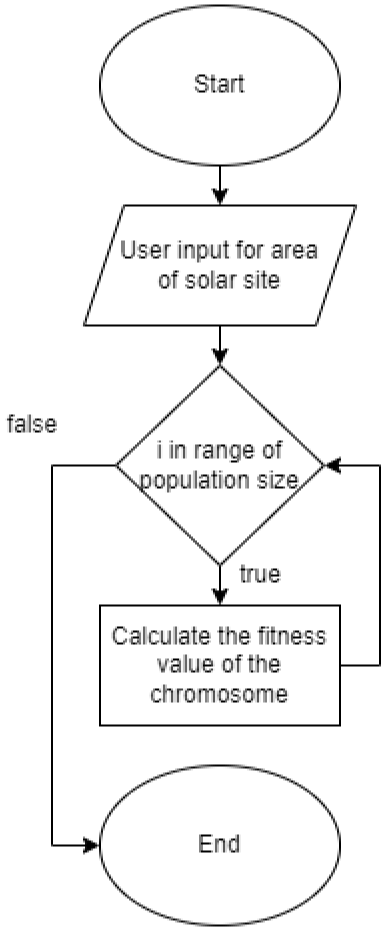


Figure 3.9: Flowchart for Calculate Fitness Value

After generating the initial population, all the chromosomes in the population will be evaluated using the fitness function to obtain the fitness value for each chromosome. The fitness function referring to the function to calculate the total solar received on the surface of the solar panel while fitness value referring to the amount of solar received on the surface of the solar panel. Before calculating the fitness value for chromosomes, user will need to input the area of the solar sites as it will be used to calculate the fitness function. After that, a loop will be executed to loop each and every chromosome in the population and calculate the fitness value for all chromosomes.

Programming Code	Remarks
cosine = np.cos((za)*(rd)) *np.cos((df20['tilt_angle'][i])*(rd)) + np.sin((za)*(rd))* np.sin((df20['tilt_angle'][i])*(rd))*np.cos(((az)-(df20['orientation_angle'][i]))*(rd))	To determine the incident angle between the solar panel and the sun with given tilt angle and orientation angle za = zenith angle az = azimuth angle rd = radians
direct_solar = dni*cosine	To determine the direct solar received by the solar panel dni = direct normal irradiance
intensity_received = direct_solar + dhi	To determine the intensity received by the solar panel dhi = diffused horizontal irradiance
solar_power_received = intensity_received * site_area	To determine the solar received on the surface of solar panel (fitness value)

3.7.2.3 Parent Selection (Roulette Wheel Selection)

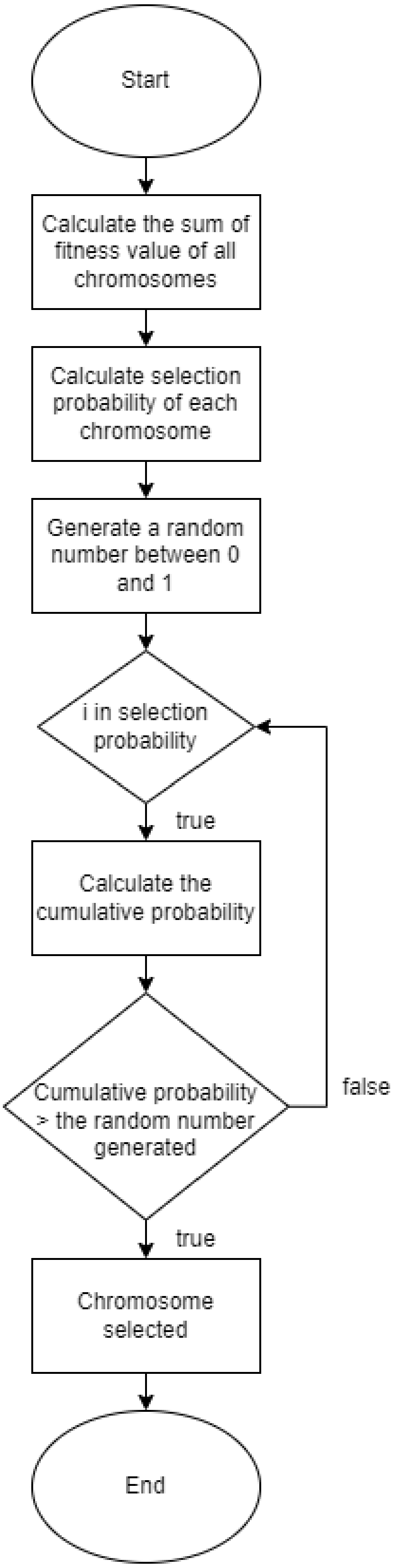


Figure 3.10: Flowchart for Parent Selection (Roulette Wheel Selection)

Parent selection in genetic algorithm is a process that select 2 chromosomes from the population as the parents to undergo crossover and mutation to produce 2 new chromosomes. In roulette wheel selection, it will first calculate the sum of fitness value of all chromosomes in the population and compute the selection probability of each chromosome by dividing the fitness value of each chromosome with the sum of fitness value.

Programming Code	Remarks
fitness_sum = sum(fitness_values)	To calculate the sum of fitness value of all chromosomes
selection_probs = [fitness/fitness_sum for fitness in fitness_values]	To calculate the selection probability for each chromosome

A random number between 0 and 1 will then be generated. After that, a loop will loop through the chromosomes and the selection probability of chromosome will be recorded. The chromosome whose cumulative probability exceeds the random number generated previously will be selected as the parents. The while process will be executed twice to select 2 parents.

Programming Code	Remarks

cum_prob = 0
for i, prob in enumerate(selection_probs):
cum_prob += prob
if cum_prob > r:
return population[i]
	To select the chromosome whose cumulative probability exceeds the random number as parent

3.7.2.4 Crossover (Whole Arithmetic Recombination)

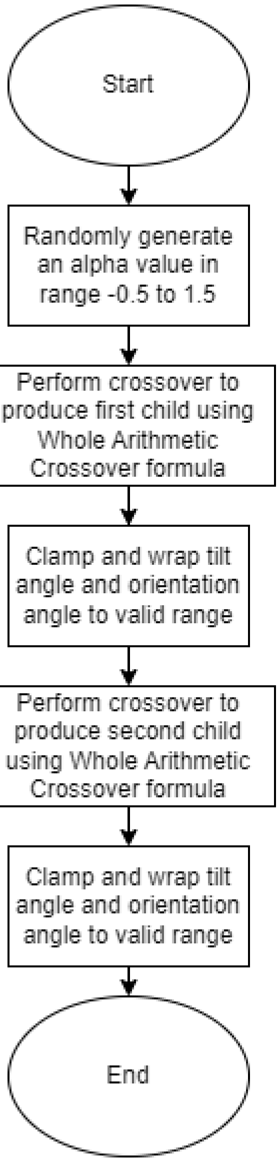


Figure 3.11: Flowchart for Crossover Operator (Whole Arithmetic Recombination)

After 2 parents have been selected from the population in the previous stage, the 2 parents selected will undergo crossover operation to produce 2 children. Firstly, alpha value will be randomly generated in range between -0.5 to 1.5. The alpha value determines the degree of crossover between the parent individuals in genetic algorithm. It determines the weight given to each parent individual in the creation of the child individual. The 2 children will be produced using the formula below:

$$Child1 = \alpha * x + (1-\alpha) * y$$

$$Child2 = \alpha * y + (1-\alpha) * x$$

Where x is first parent, y is second parent.

Programming Code	Remarks
child1 = [(1-alpha)*p1 + alpha*p2 for p1, p2 in zip(parent1, parent2)] child2 = [(1-alpha)*p2 + alpha*p1 for p1, p2 in zip(parent1, parent2)]	To produce 2 children using Whole Arithmetic Recombination formula

The 2 newly produced children will undergo clamp and wrap to make sure their value is within the valid range which is from 0.0 degree to 90.0 degree for tilt angle and 0.0 degree to 360.0 degree for orientation angle.

3.7.2.5 Mutation (Gaussian Mutation)

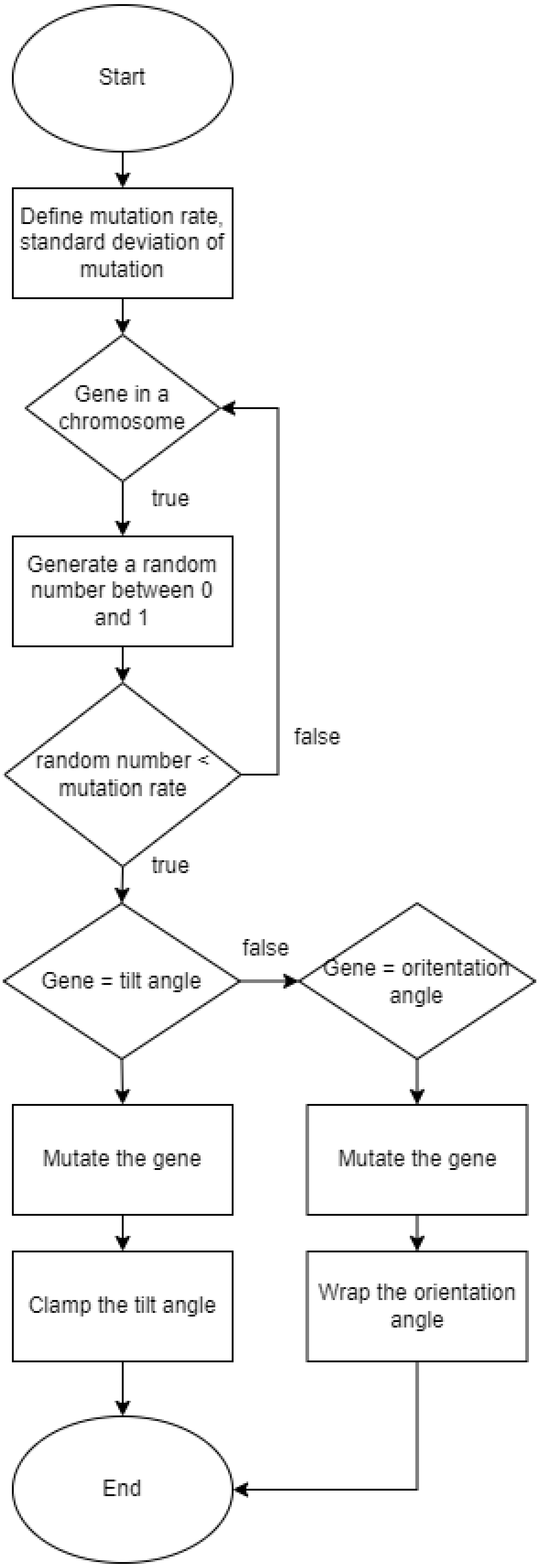


Figure 3.12: Flowchart for Mutation (Gaussian Mutation)

Gaussian mutation is a type of mutation that modifies the gene values of a chromosome by adding a small random value drawn from Gaussian (normal) distribution. The gene referring to the value in the chromosome, for example, if the chromosome is (24.7, 205.6), the genes of the chromosome will have 2 which are 24.7 and 205.6.

The mutation operation started by defining the mutation rate and standard deviation for mutation. The mutation rate referring to the probability that a gene will be mutated while the standard deviation referring to the magnitude of the mutation. For each gene in a parent chromosome, it will be assigned with a randomly generated number range from 0 to 1. The gene will undergo mutation only if the random number is smaller than the mutation rate defined before.

If a gene is selected for mutation, a random value is drawn from a Gaussian distribution with the mean 0 and standard deviation defined before to produce a new value of gene that is likely to be within a few standard deviations of the old value. If a gene is not selected for mutation, the value for the gene will remain the same. The whole process will be executed for both gene of each chromosome for both parent chromosome. After that, the value of chromosomes will be clamped and wrapped in order to make sure their values are in valid range. The whole process takes 2 parents as input and produce 2 children.

Programming Code	Remarks
mutated_gene = gene + random.gauss(0.0, mutation_std_dev1)	To mutate the gene using Gaussian Mutation

3.7.2.6 Survivor Selection (Fitness-Based Selection)

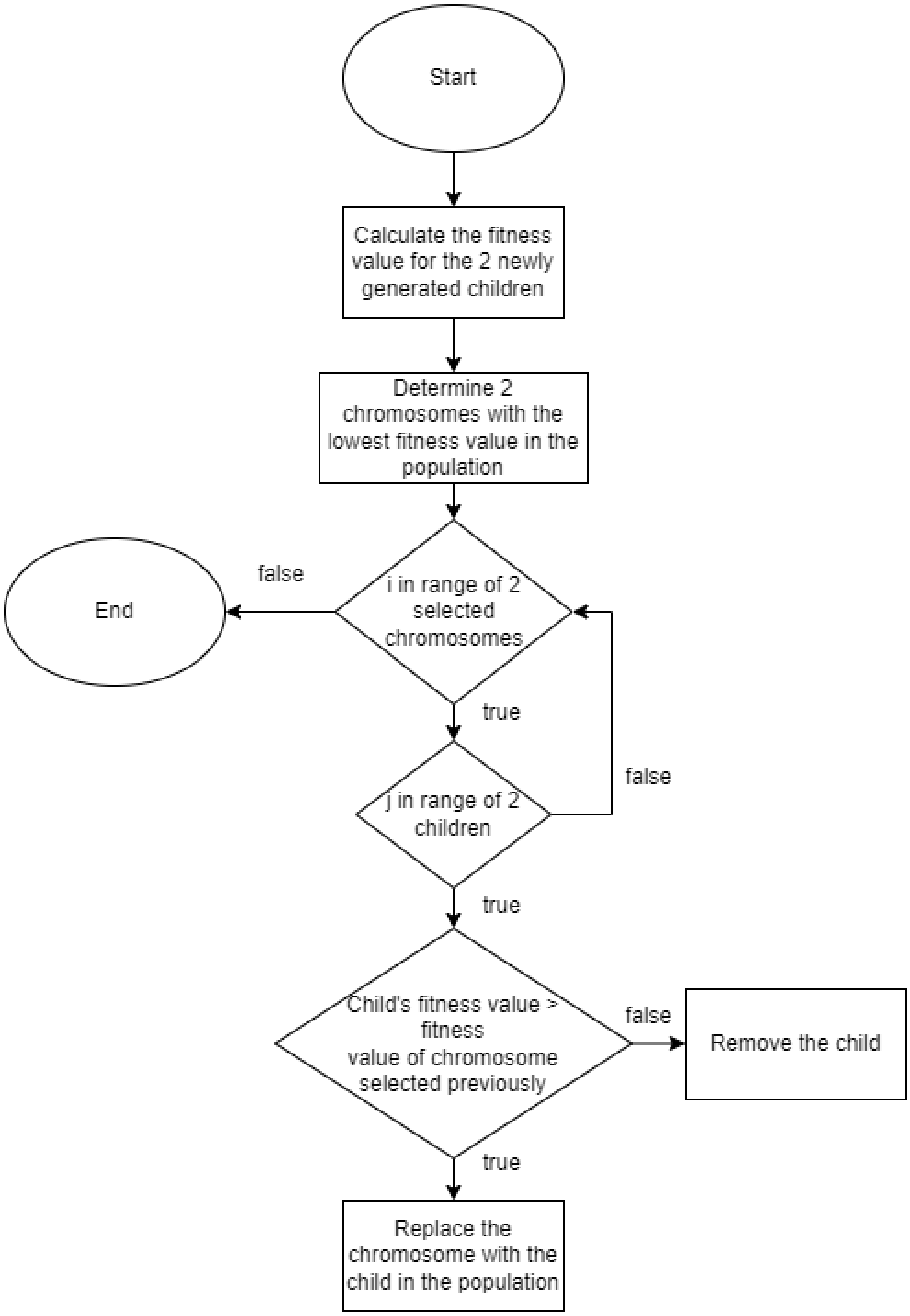


Figure 3.13: Flowchart for Survivor Selection

After mutation operation, the fitness value of the 2 newly generated children will be calculate using the fitness function. Beside, the 2 chromosomes with the lowest fitness value in the population will also be determined. A comparison between the fitness value of the newly generated children with the chromosome with the lowest fitness value in the population will be carried out. If the fitness value of the child is larger than the selected chromosome from population, the chromosome in the population will be replaced with the child. In this stage, we replace the chromosome with lower fitness value in the population with newly generated chromosome with higher fitness value. The survivor selection ensures the best solutions are preserved in the population and used to generate better solutions in the next generation.

3.8 Summary

In this project, many calculations will be done by the Python computational model using the formulas in this chapter. The model will determine the sun position for a particular time and using the genetic algorithm to find the optimal tilt angle and orientation angle for solar panel based on the actual solar power received by the panel after the cosine effect. With genetic algorithm, which is an optimization search algorithm used to explore a search space and find the optimal solution to a given problem, it significantly speeds up the process of finding the optimal tilt angle and orientation angle compared to the brute force search which include every combination of tilt angle and orientation angle of the solar panel. The ideal tilt angle and orientation for PV panels at that specific site will then be determined by the combination of tilt angle and orientation that received the most solar energy over the course of a year.

CHAPTER 4

RESULTS AND DISCUSSIONS

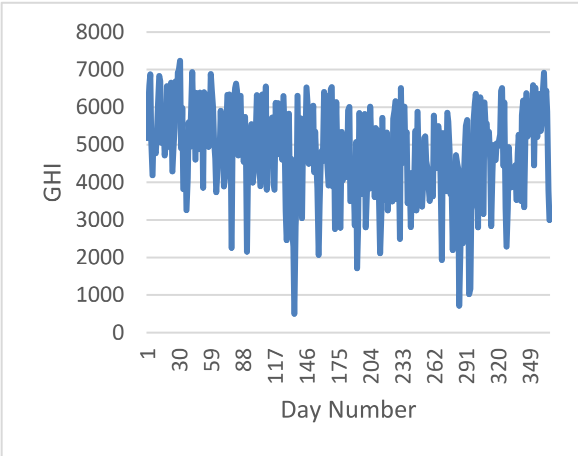
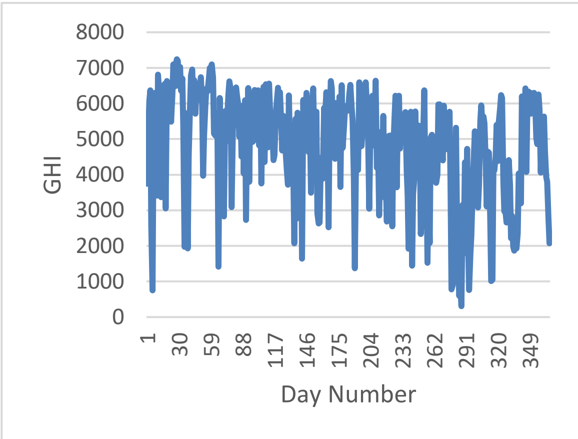
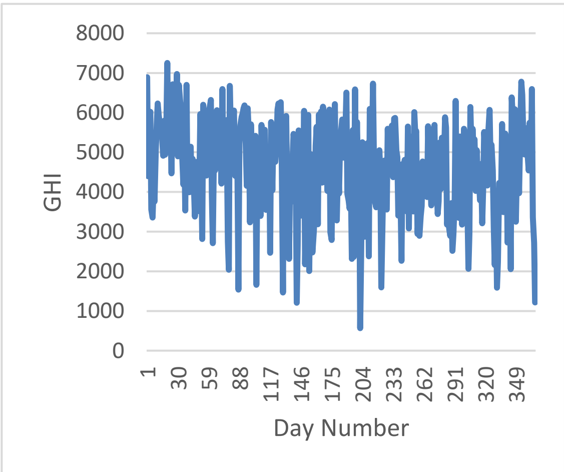
4.1 Introduction

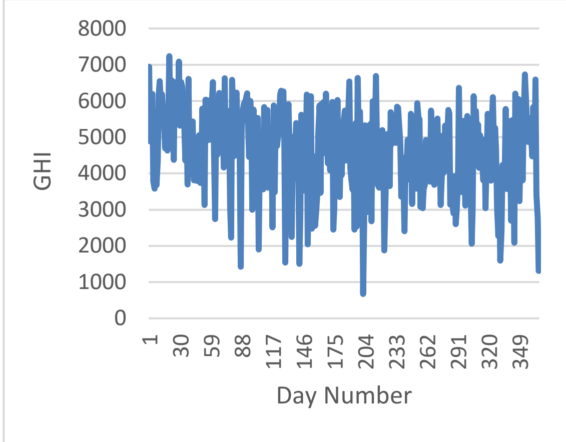
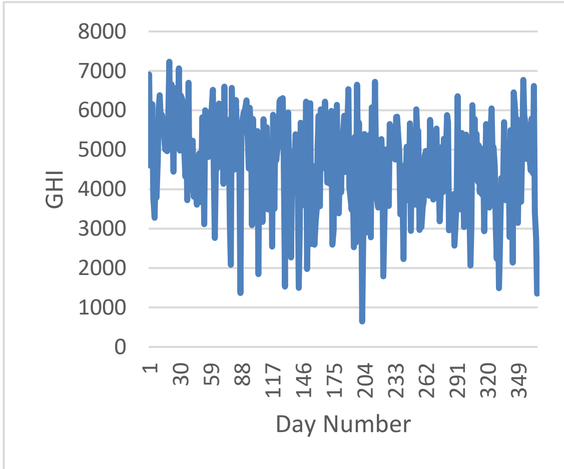
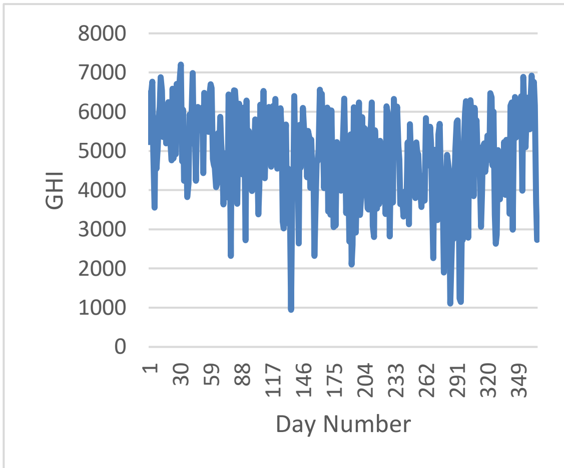
In this section, the annual average solar irradiation (GHI) and annual average peak sun hours for a total of 28 solar sites will be estimated and tabulated. The data for GHI of the solar site can be retrieved from the meteorological data downloaded from Solcast. The data will be processed and used to plot a graph to display the total solar irradiance of each month for a year. The 28 solar sites will then be ranked according to their GHI. The optimal tilt angle and orientation angle as well as the solar received on the surface of solar panel for each solar site will also be estimated. The estimation will be done using the Python computational model which include the genetic algorithm to determine and tabulate the optimal tilt angle, orientation angle and solar received for every solar sites.

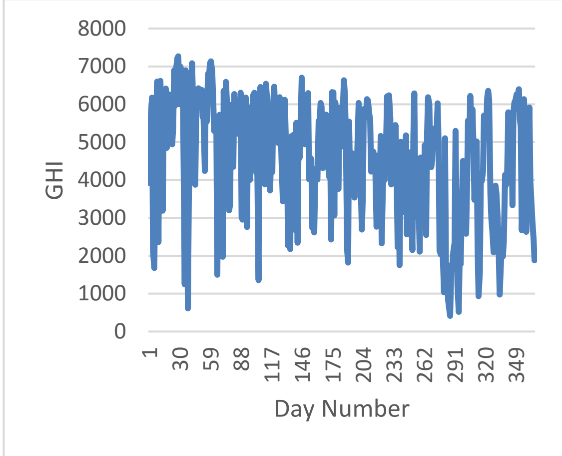
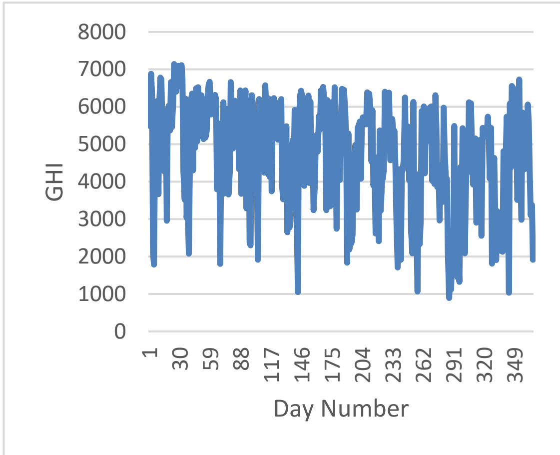
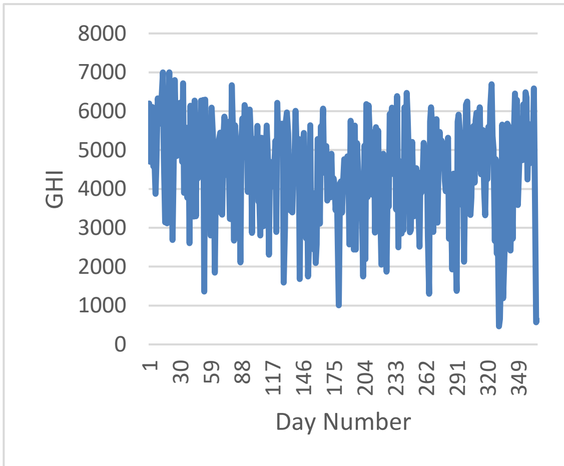
4.2 GHI for 28 Solar Sites

There are a total of 28 solar sites have been selected which all located in Malaysia including both East and West Malaysia. The annual average solar irradiation in this section referring to the average solar received on the solar site daily while the annual average peak sun hours referring to the average hours of sunlight received by the solar site throughout the day. Table 4.1 below shows the annual average solar irradiation and annual average peak sun hours for all 28 solar sites.

Table 4.1: GHI for 28 Solar Sites

	Solar Site	Annual Average Solar Irradiation (kWh/m^2) (∑GHI)	Annual Average Peak (PSH) (h)	GHI
1	Scatec Itramas solar 65MW Gurun Solar Power Plant 5°51'45.2"N 100°32'15.5"E 5.862556, 100.537639	4.824297003	4.824297003	
2	Pasir Mas Solar Farm 5°59'32.0"N 102°06'40.2"E 5.992222, 102.111167	4.814043597	4.814043597	
3	Sepang Solar Panel (SunEdison) 2°46'46.3"N 101°42'50.0"E 2.779528, 101.713889	4.625542234	4.625542234	
4	WD Floating Solar	4.669332425	4.669332425	

	2°48'59.6"N 101°40'07.1"E 2.816556, 101.668639			
5	TNB Large Scale Solar Farm 2°47'04.2"N 101°36'52.5"E 2.784500, 101.614583	4.663057221	4.663057221	
6	TNB BUKIT SELAMBAU SOLAR 5°40'17.7"N 100°37'32.6"E 5.671583, 100.625722	4.875343324	4.875343324	
7	Synergy Generated Sdn. Bhd. 5°23'05.0"N 102°51'36.7"E 5.384722,	4.586711172	4.586711172	

	102.860194			
8	RE Gebeng Sdn Bhd 4°00'18.3"N 103°21'40.7"E 4.005083, 103.361306	4.777019074	4.777019074	
9	Fairview Project Solar Farm 2°00'47.1"N 103°15'48.2"E 2.013083, 103.263389	4.470836512	4.470836512	
10	Fairview Project (Mersing) Solar Farm 2°22'34.1"N 103°51'03.4"E 2.376139,	4.688880109	4.688880109	

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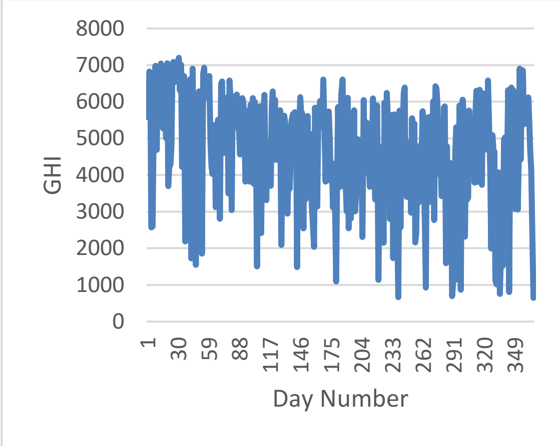
<tr><td></td><td>103.850944</td><td></td><td></td><td>
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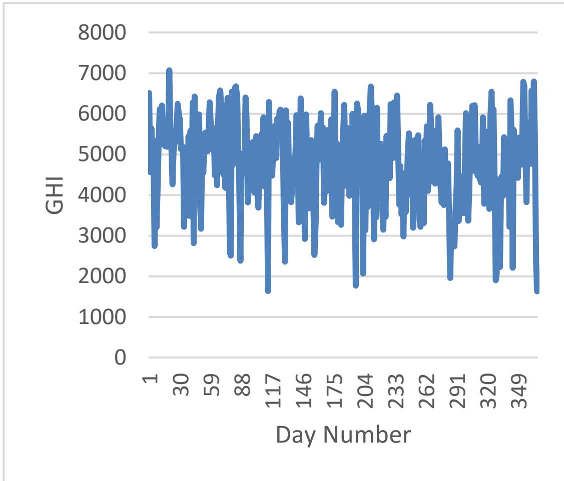
<tr><td>11</td><td>Gading Kencana 30 MW Bidor Solar Power Plant

4°04'56.7"N 101°14'45.3"E

4.082417, 101.245917</td><td>4.821340599</td><td>4.821340599</td><td>
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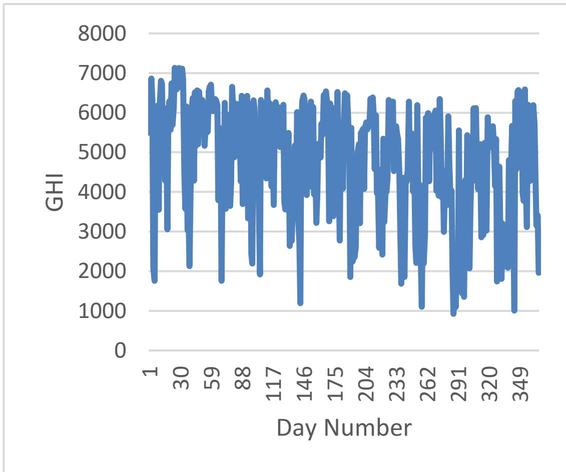
<tr><td>12</td><td>Mudajaya 10 MW Gebeng Solar Power Plant

3°58'44.2"N 103°23'25.9"E

3.978944, 103.390528</td><td>4.813408719</td><td>4.813408719</td><td>
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<tr><td>13</td><td>TTL Energy 1 MW Solar Power Plant

5°45'06.0"N 115°55'03.4"E

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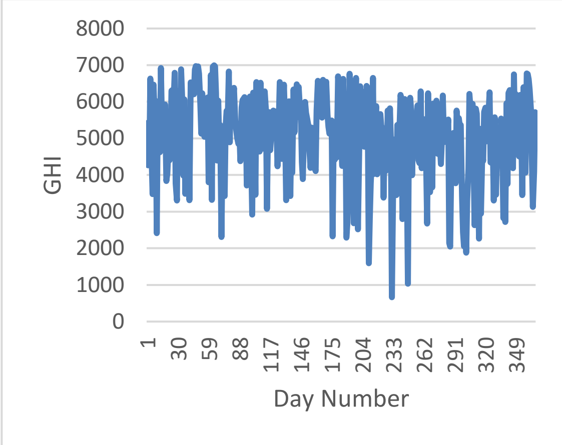
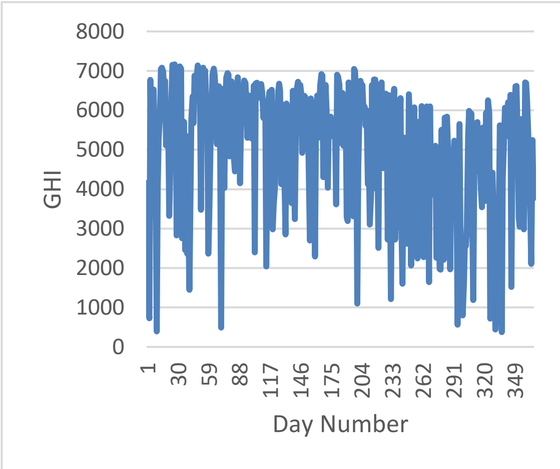
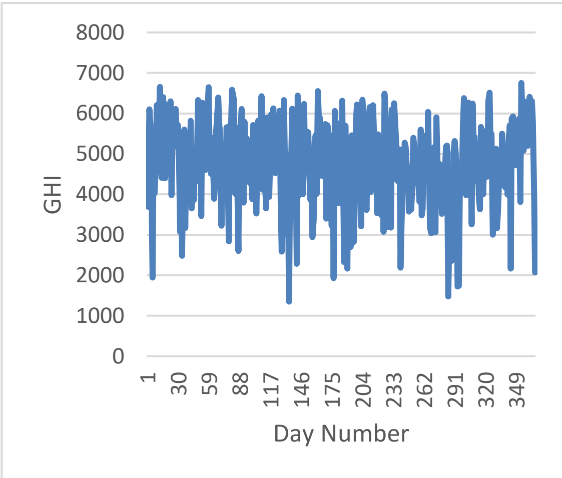
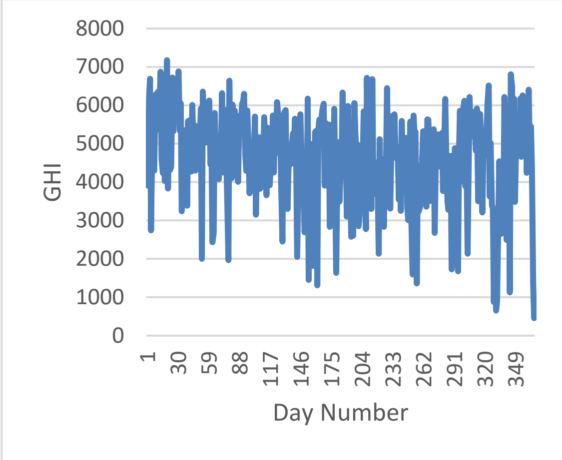
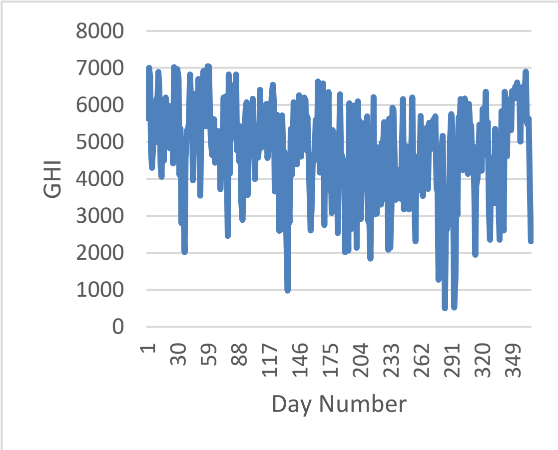
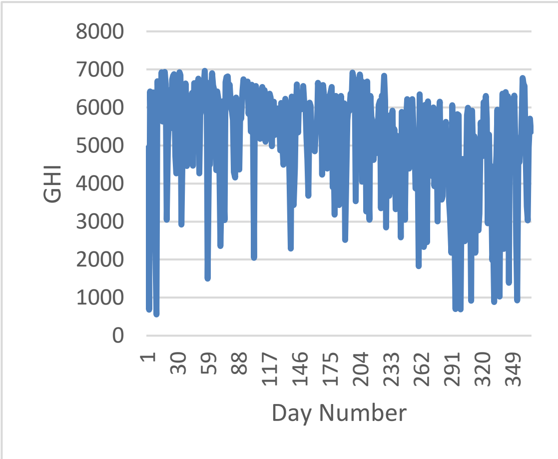
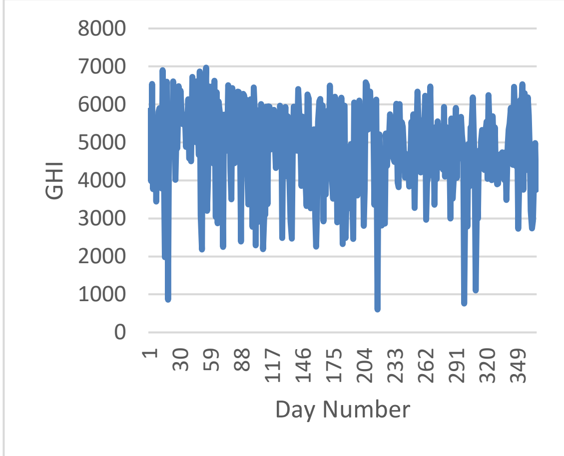
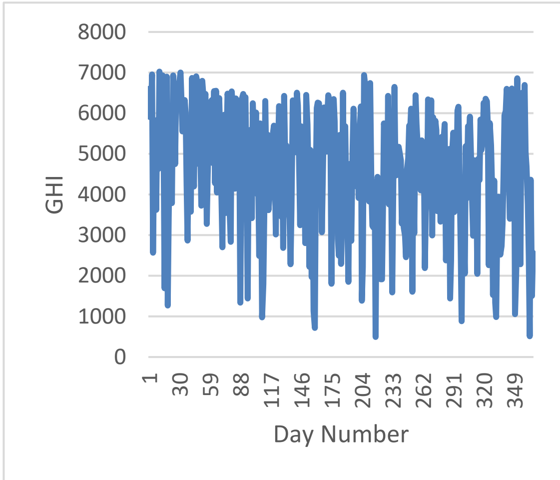
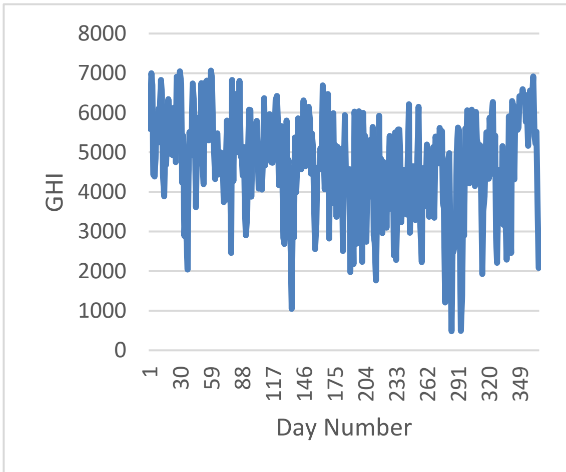
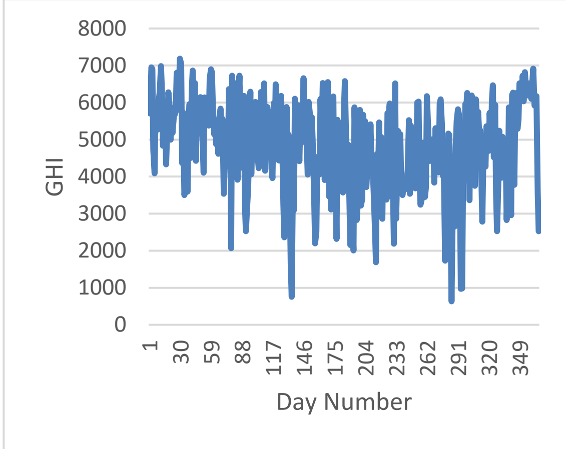
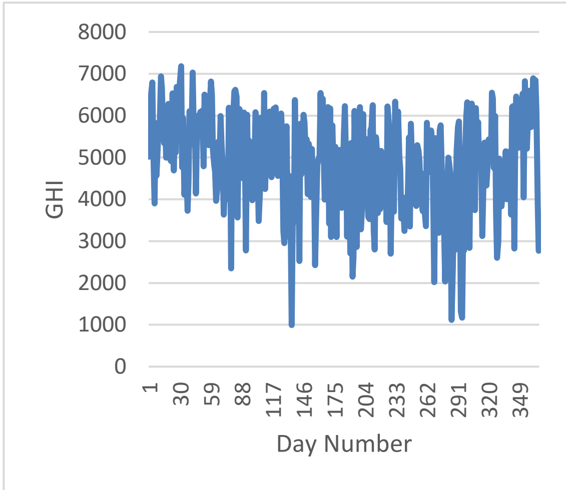
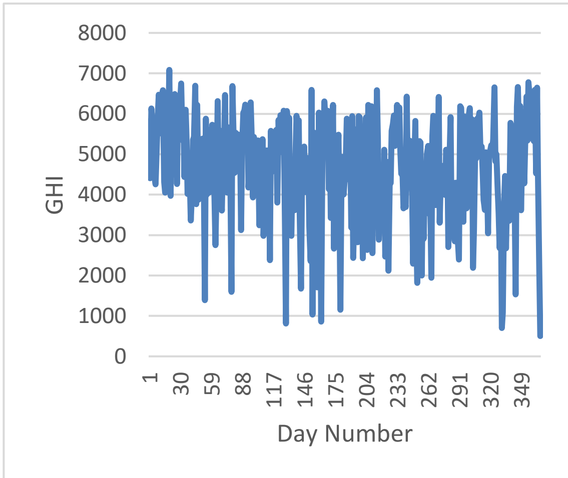
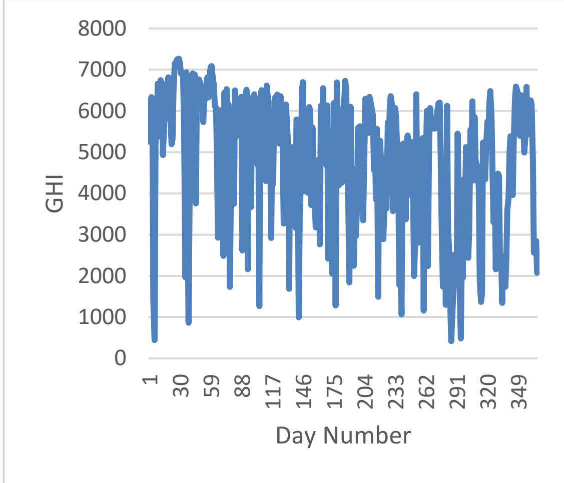
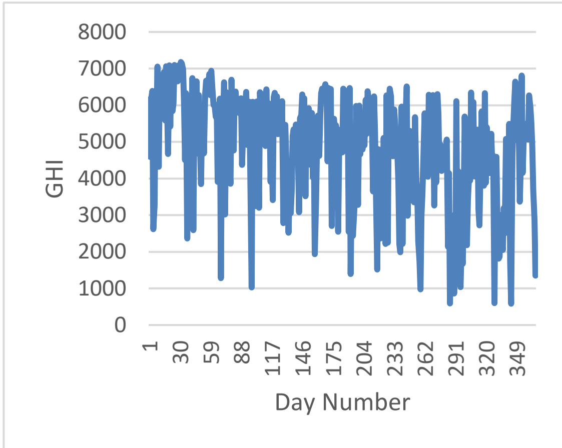
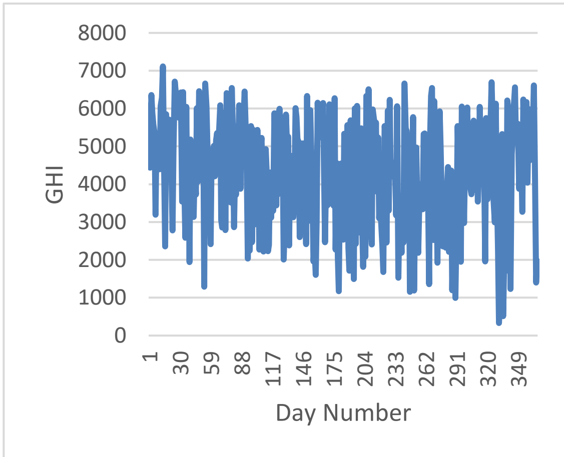
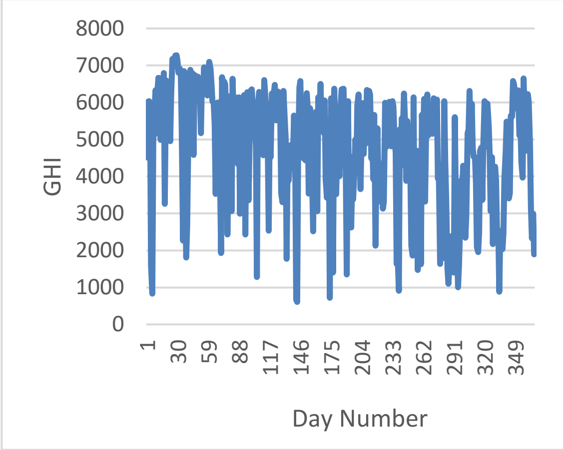
	115.917611			
14	Tadau Energy 48 MW Solar Power Plant 6°56'43.5"N 116°49'45.4"E 6.945417, 116.829278	4.98859673	4.98859673	
15	PLB Green Solar Sdn Bhd (20MWac) 5°11'51.1"N 100°25'49.4"E 5.197528, 100.430389	4.772117166	4.772117166	
16	Amcorp 10.25MW Gemas Solar Power Plant 2°35'43.7"N 102°37'15.7"E	4.604141689	4.604141689	

	2.595472, 102.621028			
17	SBU Power Sdn Bhd (5.2MWp) 6°28'30.2"N 100°21'10.2"E 6.475056, 100.352833	4.796035422	4.796035422	
18	Tanjung Batu Hybrid Solar Power Plant 5°48'01.8"N 118°09'29.2"E 5.800500, 118.158111	5.168367847	5.168367847	
19	Comtec Solar International (m) Sdn Bhd 1°31'10.6"N 110°23'50.0"E 1.519611,	4.835185286	4.835185286	

	110.397222			
20	Solar Power Plant Telok Melano, Sarawak Energy Berhad 2°00'16.6"N 109°38'42.5"E 2.004611, 109.645139	4.684716621	4.684716621	
21	Bukit Kayu Hitam Solarvest 12MWp 6°28'40.8"N 100°25'42.0"E 6.478000, 100.428333	4.735558583	4.735558583	
22	Pokok Sena Solar PV plant 6°10'51.3"N 100°28'21.0"E 6.180917,	4.887940054	4.887940054	

	100.472500			
23	LSS PV 30MWac Kuala Muda Kedah 5°39'25.3"N 100°34'21.2"E 5.657028, 100.572556	4.889673025	4.889673025	
24	Scatec Itramas Solar 66MW Jasin Solar Power Plant 2°17'56.7"N 102°21'16.0"E 2.299083, 102.354444	4.66993733	4.66993733	
25	Scatec Itramas Solar 66 MW Merchang Solar Power Plant 4°56'04.4"N 103°20'13.4"E	4.834585831	4.834585831	

	4.934556, 103.337056			
26	Pekan Pahang Solar Farm 3°19'24.9"N 103°25'20.9"E 3.323583, 103.422472	4.861621253	4.861621253	
27	UITM Solar Park II (LSS2 Pasir Gudang) 1°31'36.7"N 103°51'50.4"E 1.526861, 103.864000	4.33060218	4.33060218	

28	Kenyir Gunkul Solar Sdn Bhd 4°38'55.8"N 103°23'13.5"E 4.648833, 103.387083	4.794950954	4.794950954	

4.3 Ranking of Solar Sites

After processing the meteorological data from Solcast for every solar sites, the annual average solar irradiation (GHI) and annual average peak sun hours were compiled and tabulated in the previous section. The 28 solar sites will be ranked based on their annual average GHI in order from solar sites with highest annual average GHI to the lowest.

Table 4.2: Ranking of Solar Sites

Rank	Solar Site	Coordinate	Annual Average GHI (Wh/m^2)
1	Tanjung Batu Hybrid Solar Power Plant	5°48'01.8"N 118°09'29.2"E	5168.367847
2	TTL Energy 1 MW Solar Power Plant	5°45'06.0"N 115°55'03.4"E	5082.980926
3	Tadau Energy 48 MW Solar Power Plant	6°56'43.5"N 116°49'45.4"E	4988.059673
4	LSS PV 30MWac Kuala Muda Kedah	5°39'25.3"N 100°34'21.2"E	4889.673025
5	Pokok Sena Solar PV plant	6°10'51.3"N 100°28'21.0"E	4887.940054
6	TNB BUKIT SELAMBAU SOLAR	5°40'17.7"N 100°37'32.6"E	4875.343324

7	Pekan Pahang Solar Farm	3°19'24.9"N 103°25'20.9"E	4861.621253
8	Comtec Solar International (m) Sdn Bhd	1°31'10.6"N 110°23'50.0"E	4835.185286
9	Scatec Itramas Solar 66 MW Merchang Solar Power Plant	4°56'04.4"N 103°20'13.4"E	4834.585831
10	Scatec Itramas solar 65MW Gurun Solar Power Plant	5°51'45.2"N 100°32'15.5"E	4824.297003
11	Gading Kencana 30 MW Bidor Solar Power Plant	4°04'56.7"N 101°14'45.3"E	4821.340599
12	Pasir Mas Solar Farm	5°59'32.0"N 102°06'40.2"E	4814.043597
13	Mudajaya 10 MW Gebeng Solar Power Plant	3°58'44.2"N 103°23'25.9"E	4813.408719
14	SBU Power Sdn Bhd (5.2MWp)	6°28'30.2"N 100°21'10.2"E	4796.035422
15	Kenyir Gunkul Solar Sdn Bhd	4°38'55.8"N 103°23'13.5"E	4794.950954
16	RE Gebeng Sdn Bhd	4°00'18.3"N 103°21'40.7"E	4777.019074
17	PLB Green Solar Sdn Bhd (20MWac)	5°11'51.1"N 100°25'49.4"E	4772.117166
18	Bukit Kayu Hitam Solarvest 12MWp	6°28'40.8"N 100°25'42.0"E	4735.558583
19	Fairview Project (Mersing) Solar Farm	2°22'34.1"N 103°51'03.4"E	4688.880109
20	Solar Power Plant Telok Melano, Sarawak Energy Berhad	2°00'16.6"N 109°38'42.5"E	4684.716621
21	Scatec Itramas Solar 66MW Jasin Solar Power Plant	2°17'56.7"N 102°21'16.0"E	4669.93733
22	WD Floating Solar	2°48'59.6"N 101°40'07.1"E	4669.332425

23	TNB Large Scale Solar Farm	2°47'04.2"N 101°36'52.5"E	4663.057221
24	Sepang Solar Panel (SunEdison)	2°46'46.3"N 101°42'50.0"E	4625.542234
25	Amcorp 10.25MW Gemas Solar Power Plant	2°35'43.7"N 102°37'15.7"E	4604.141689
26	Synergy Generated Sdn. Bhd.	5°23'05.0"N 102°51'36.7"E	4586.711172
27	Fairview Project Solar Farm	2°00'47.1"N 103°15'48.2"E	4470.836512
28	UITM Solar Park II (LSS2 Pasir Gudang)	1°31'36.7"N 103°51'50.4"E	4330.60218

Based on table 4.2, the solar site that has the highest annual average GHI is Tanjung Batu Hybrid Solar Power Plant with 5168.367847 Wh/m^2 annual average GHI. The second and third rank are TTL Energy 1 MW Solar Power Plant and Tadau Energy 48 MW Solar Power Plant with annual average GHI of 5082.980926 Wh/m^2 and 4988.059673 Wh/m^2 respectively. Moreover, for the 3 solar sites with the lowest annual average GHI among the 28 solar sites are Synergy Generated Sdn. Bhd., Fairview Project Solar Farm and UITM Solar Park II (LSS2 Pasir Gudang) with annual average GHI of 4586.711172 Wh/m^2, 4470.836512 Wh/m^2 and 4330.60218 Wh/m^2 respectively.

4.4 Optimal Tilt Angle, Orientation Angle and Solar Power Received on Solar Panel

In this section, the optimal tilt angle, orientation angle and solar power received on the solar panel will be estimated using the Python computational model with genetic algorithm including the meteorological data downloaded from Solcast for every 28 solar sites selected. The estimation result will then be recorded and display in Table 4.3 below.

Table 4.3: Optimal Tilt Angle, Orientation Angle and Solar Power Received on Solar Panel

	Solar Site	Tilt Angle (degree)	Orientation Angle (degree)	Solar Power Received (Wh)
1	Scatec Itramas solar 65MW Gurun Solar Power Plant 5°51'45.2"N 100°32'15.5"E 5.862556, 100.537639	27.3	257.9	1218267737533.237061
2	Pasir Mas Solar Farm 5°59'32.0"N 102°06'40.2"E 5.992222, 102.111167	27.9	266.7	85458418824.757507
3	Sepang Solar Panel (SunEdison) 2°46'46.3"N 101°42'50.0"E	24.2	268.9	166986012249.882843

	2.779528, 101.713889			
4	WD Floating Solar 2°48'59.6"N 101°40'07.1"E 2.816556, 101.668639	24.1	268.7	188953012522.852997
5	TNB Large Scale Solar Farm 2°47'04.2"N 101°36'52.5"E 2.784500, 101.614583	24.7	269.1	1235782952901.330322
6	TNB BUKIT SELAMBAU SOLAR 5°40'17.7"N 100°37'32.6"E 5.671583, 100.625722	25.2	257.4	700955960955.400391

7	Synergy Generated Sdn. Bhd. 5°23'05.0"N 102°51'36.7"E 5.384722, 102.860194	23.9	268.7	92581923816.237411
8	RE Gebeng Sdn Bhd 4°00'18.3"N 103°21'40.7"E 4.005083, 103.361306	29.3	270.7	588266365552.513428
9	Fairview Project Solar Farm 2°00'47.1"N 103°15'48.2"E 2.013083, 103.263389	18.2	266.3	181208747246.69809
10	Fairview Project (Mersing) Solar Farm	22.5	272.2	3606171075.730489

	2°22'34.1"N 103°51'03.4"E 2.376139, 103.850944			
11	Gading Kencana 30 MW Bidor Solar Power Plant 4°04'56.7"N 101°14'45.3"E 4.082417, 101.245917	23.6	263.6	581748483565.053711
12	Mudajaya 10 MW Gebeng Solar Power Plant 3°58'44.2"N 103°23'25.9"E 3.978944, 103.390528	29.4	270.6	219590757200.684296
13	TTL Energy 1 MW Solar Power Plant	6.7	132.3	15316432212.353628

	5°45'06.0"N 115°55'03.4"E 5.751667, 115.917611			
14	Tadau Energy 48 MW Solar Power Plant 6°56'43.5"N 116°49'45.4"E 6.945417, 116.829278	3.7	206.6	383537422869.508789
15	PLB Green Solar Sdn Bhd (20MWac) 5°11'51.1"N 100°25'49.4"E 5.197528, 100.430389	26.7	259.6	378370147701.211975
16	Amcorp 10.25MW Gemas Solar Power Plant 2°35'43.7"N 102°37'15.7"E	22.4	268.2	163439477248.10318

	2.595472, 102.621028			
17	SBU Power Sdn Bhd (5.2MWp) 6°28'30.2"N 100°21'10.2"E 6.475056, 100.352833	27.1	258	78421820563.622787
18	Tanjung Batu Hybrid Solar Power Plant 5°48'01.8"N 118°09'29.2"E 5.800500, 118.158111	2.5	182.8	3762478161.43879
19	Comtec Solar International (m) Sdn Bhd 1°31'10.6"N 110°23'50.0"E 1.519611, 110.397222	9.6	273.1	9533338634.590971

20	Solar Power Plant Telok Melano, Sarawak Energy Berhad 2°00'16.6"N 109°38'42.5"E 2.004611, 109.645139	17	272	921235303.152606
21	Bukit Kayu Hitam Solarvest 12MWp 6°28'40.8"N 100°25'42.0"E 6.478000, 100.428333	26.6	257.5	248441183992.491852
22	Pokok Sena Solar PV plant 6°10'51.3"N 100°28'21.0"E 6.180917, 100.472500	27.9	257.6	417812418715.93811

23	LSS PV 30MWac Kuala Muda Kedah 5°39'25.3"N 100°34'21.2"E 5.657028, 100.572556	25.3	256.6	547264733483.437988
24	Scatec Itramas Solar 66MW Jasin Solar Power Plant 2°17'56.7"N 102°21'16.0"E 2.299083, 102.354444	23.7	266.6	539941623432.924011
25	Scatec Itramas Solar 66 MW Merchang Solar Power Plant 4°56'04.4"N 103°20'13.4"E 4.934556, 103.337056	28.5	268.6	1156786350288.033203

26	Pekan Pahang Solar Farm 3°19'24.9"N 103°25'20.9"E 3.323583, 103.422472	29.6	272.9	832213213124.590698
27	UITM Solar Park II (LSS2 Pasir Gudang) 1°31'36.7"N 103°51'50.4"E 1.526861, 103.864000	17.6	268.3	493714693387.454712
28	Kenyir Gunkul Solar Sdn Bhd 4°38'55.8"N 103°23'13.5"E 4.648833, 103.387083	28.6	270.1	528319784307.589722

4.5 Comparison of Simulation Result with On-Site Result

In this section, the simulated result by the genetic algorithm which are the tilt angle and orientation will be used to compare with the on-site result produced by other researchers in literature review. The on-site results are the collected from the thesis paper published by other researcher who actually carried out physical on-site experiment to estimate the optimal tilt angle and orientation angle for a specific location. The simulated result referring to the optimal tilt angle and orientation angle simulated by the Python computational model and genetic algorithm using the meteorological data downloaded from Solcast for the same location as on-site result. The duration and period of the meteorological data that is used to simulate the result will be the same as the duration and period that the research carried out the on-site experiment provided in their thesis. It is necessary to carry out the comparison to make sure that the Python computational model is reliable and able to produce accurate and correct result. Table 4.4 below shows the simulation result for the 8 solar sites and Table 4.5 below shows the comparison between the simulation results with the on-site results produce by other reserachers.

Table 4.4: Simulation Results for Solar Sites

No.	Solar Site	Tilt Angle (degree)	Orientation Angle (degree)
1	Nitte, India 13°10'58.8"N 74°56'02.4"E	31.8	214.3
2	Basra City, Iraq 30°31'32.9"N 47°46'25.7"E	29.1	159.6
3	Khon Kean University, Thailand 16°28'48.7"N 102°49'53.0"E	8.5	155.5
4	Baghdad, Iraq 33°18'54.7"N 44°21'58.0"E	27.6	177.2
5	Padang Besar, Perlis, Malaysia 6°39'45.4"N 100°19'18.1"E	37.5	307.9

6	Chandigarh, India 30°45'28.8"N 76°46'06.6"E	37.1	205.6
7	Lahore, Pakistan 31°30'00.0"N 74°18'00.0"E	34.8	188.2
8	Lagos, Nigeria 6°36'28.8"N 3°37'18.5"E	29.5	257.6

Table 4.5: Comparison Between the Simulation Results with the On-Site Results

No.	Solar Site	Simulation Result	On-site Result	Remarks
1	Nitte, India 13°10'58.8"N 74°56'02.4"E	Tilt Angle: 31.8° Orientation Angle: 214.3°	Tilt Angle: 0°-36° Orientation Angle: Due South	From the result, the simulation result of tilt angle is 31.8° which is fall in the range of the on-site result which is 0°-36°. For the simulated orientation angle, it is facing the south area also. Therefore, the result is accepted.
2	Basra City, Iraq 30°31'32.9"N 47°46'25.7"E	Tilt Angle: 29.1° Orientation Angle: 159.6°	Tilt Angle: 28° Orientation Angle: -	From the result, the simulation of tilt angle is 29.1° which is only 1.1° difference with the on-site result for tilt angle. The simulated orientation angle is facing the south site. Therefore, the result is accepted.

3	Khon Kean University, Thailand 16°28'48.7"N 102°49'53.0"E	Tilt Angle: 8.5° Orientation Angle: 155.5°	Tilt Angle: 0°-16° Orientation Angle: Due South	From the result, the simulation result of tilt angle is 8.5° which fall in the range of on-site result which is 0°-16°. For the simulated orientation angle, it is 155.5° which is facing south. Therefore, the result is accepted.
4	Baghdad, Iraq 33°18'54.7"N 44°21'58.0"E	Tilt Angle: 27.6° Orientation Angle: 177.2°	Tilt Angle: 35° Orientation Angle: Due South	From the result, the simulated tilt angle is 27.6° which has a big difference of 7.4° from the on-site result which is 35°. The simulated orientation angle shows that it is facing the south side. Therefore, the result is rejected.
5	Padang Besar, Perlis, Malaysia 6°39'45.4"N 100°19'18.1"E	Tilt Angle: 37.5° Orientation Angle: 307.9°	Tilt Angle: -10° Orientation Angle: South 20° East	From the result, the simulation result of tilt angle is 37.5° which has a significant difference of 47.5° from the on-site result which is -10°. The simulated orientation angle shows that it is facing the west area. Therefore, the result is rejected.
6	Chandigarh, India 30°45'28.8"N 76°46'06.6"E	Tilt Angle: 37.1° Orientation Angle: 205.6°	Tilt Angle: 30°-40° Orientation Angle: -	From the result, the simulation result of tilt angle is 37.1° which fall in the range of on-sire result which is 30°-40°. The simulated orientation angle is facing the south area.

				Therefore, the result is accepted.
7	Lahore, Pakistan 31°30'00.0"N 74°18'00.0"E	Tilt Angle: 34.8° Orientation Angle: 188.2°	Tilt Angle: 31.5° Orientation Angle: -	From the result, the simulated tilt angle is 34.8° which is 3.3° difference from the on-site result, 31.5°. The simulated orientation angle shows that it is facing the south side. Therefore, the result is accepted.
8	Lagos, Nigeria 6°36'28.8"N 3°37'18.5"E	Tilt Angle: 29.5° Orientation Angle: 257.6°	Tilt Angle: 26.8° Orientation Angle: Due South	From the result, the simulated tilt angle is 29.5° which is 2.7° difference from the on-site result, 26.8°. The simulated orientation angle shows that it is facing the south area. Therefore, the result is accepted.

For the case study in Nitte, India, as mentioned by the author, the experiment was carried out in 5 months duration from December 2019 to April 2020. The historical meteorological data from December 2019 to April 2020 is downloaded from Solcast and used in the Python computational model to simulate the result. By comparing the simulation result and the on-site result, the simulated tilt angle is 31.8° and the on-site tilt angle suggested by the authors is in the range of 0°-36°, which means the simulated tilt angle fall in the range of the on-site tilt angle. For the simulated orientation angle, it is 214.3°, facing south area which is near to the on-site orientation angle of due south. Therefore, the simulation result for Nitte, India is accepted.

For the case study in Basra City, Iraq. As the author didn't mention the date and duration for the experiment, so the meteorological data from January

2018 to December 2018, 1 year period is downloaded from the Solcast to be used to produce the result. By comparing the simulation result with the on-site result, the simulated tilt angle is 29.1° while the on-sire tilt angle is 28°. Both of them has a minor difference only which is 1.1°. For the simulated orientation angle, it is 159.6° facing the south area while the author didn't mention about the orientation angle for on-site result. Therefore, the simulation result for Basra City, Iraq can be accepted.

For the case study in Khon Kean University, Thailand, as mentioned by the author, the experiment was carried out in 3 months duration from March 2017 to May 2017. Therefore, the historical meteorological data with period of 3 months from March 2017 to May 2017 is downloaded from Solcast to be used in simulating the result. By comparing the simulation result with the on-site result, the simulated tilt angle is 8.5° which fall in the range of tilt angle proposed by the author which is 0°-16°. For the orientation angle, the simulated orientation angle is 155.5° which is almost same with the on-site result of due south. Therefore, the simulation result for Khan Kean University, Thailand can be accepted.

For the case study in Baghdad, Iraq, as mentioned by the author, the experiment was carried out throughout the whole year of 2018. Therefore, the historical meteorological data for 2018 is downloaded to be used in producing the result. By comparing the simulation result with the on-site result, the simulated tilt angle is 27.6° which is 7.4° difference from the on-site result. For the simulated orientation angle, it is 177.2° and quite similar to the orientation angle for on-site result. However, the difference between both tilt angle is huge, therefore, the simulation result for Baghdad, Iraq cannot be accepted.

For the case study in Padang Besar, Perlis, Malaysia, as mentioned by the author, the experiment was carried out with period of 10 days in July 2017. Therefore, the historical meteorological data for July 2017 with a period of 10 days is downloaded to be used in simulating the result. By comparing both the tilt angle, the simulated tilt angle is 37.5° which has a significant difference of 47.5° as compared to the on-site tilt angle which is -10°. Therefore, the simulation result for Padang Besar, Perlis, Malaysia is rejected.

For the case study in Chandigarh, India as mentioned by the author, the experiment was carried out throughout the whole year of 2018. Therefore, the historical meteorological data for 2018 is downloaded to be used in producing the result. By comparing both of the tilt angle, the simulated tilt angle is 37.1° which falls in the range of on-site tilt angle which is 30°-40°. As the author didn’t mention the on-site orientation angle, the simulated orientation angle suggested that it should be 205.6° facing south area. Overall, the simulation result for Chandigarh, India can be accepted.

For the case study in Lahore, Pakistan, as mentioned by the author, the experiment was carried out on 2 different days which are 27 September 2017 and 16 January 2018. Therefore, the historical meteorological data for these 2 days is downloaded from Solcast to be used. By comparing both the tilt angle, there is only a minor difference of 3.3° where the simulated tilt angle is 34.8° while the on-site tilt angle is 31.5°. As the author didn’t mention the on-site orientation angle, the simulated orientation angle suggested that it should be 188.2° facing south area. Overall, the simulation result for Lahore, Pakistan can be accepted.

For the case study in Lagos, Nigeria as mentioned by the author, the experiment was carried out from October 2017 to September 2018 which took 1 year. Therefore, the historical meteorological data from October 2017 to September 2018 is downloaded to be used in producing the result. By comparing both of the tilt angle, the simulated tilt angle is 29.5° which only has slightly difference of 2.7° from the on-site tilt angle which is 26.8°. The simulated orientation angle is 257.6° facing the southwest area. Overall, the simulation result for Chandigarh, India can be accepted.

4.6 Accuracy of Simulation

In this section, the accuracy of the simulation will be calculated and table 4.6 below shows the comparison between the simulated result with the on-site result and whether the simulation is accepted or rejected. The accuracy of the simulation can also be calculated by using the formula below:

$$Accuracy = \frac{Number\ of\ accepted}{Total\ case\ study} \times 100\%$$

$$= \frac{6}{8} \times 100\% = 75\%$$

Table 4.6: Accept/Reject of Simulation Result

No.	Solar Site	Simulation Result	On-site Result	Accept/Reject
1	Nitte, India 13°10'58.8"N 74°56'02.4"E	Tilt Angle: 31.8° Orientation Angle: 214.3°	Tilt Angle: 0°-36° Orientation Angle: Due South	Accepted.
2	Basra City, Iraq 30°31'32.9"N 47°46'25.7"E	Tilt Angle: 29.1° Orientation Angle: 159.6°	Tilt Angle: 28° Orientation Angle: -	Accepted.
3	Khon Kean University, Thailand 16°28'48.7"N 102°49'53.0"E	Tilt Angle: 8.5° Orientation Angle: 155.5°	Tilt Angle: 0°-16° Orientation Angle: Due South	Accepted.
4	Baghdad, Iraq	Tilt Angle: 27.6°	Tilt Angle: 35°	Rejected.

	33°18'54.7"N 44°21'58.0"E	Orientation Angle: 177.2°	Orientation Angle: Due South	
5	Padang Besar, Perlis, Malaysia 6°39'45.4"N 100°19'18.1"E	Tilt Angle: 37.5° Orientation Angle: 307.9°	Tilt Angle: -10° Orientation Angle: South 20° East	Rejected.
6	Chandigarh, India 30°45'28.8"N 76°46'06.6"E	Tilt Angle: 37.1° Orientation Angle: 205.6°	Tilt Angle: 30°-40° Orientation Angle: -	Accepted.
7	Lahore, Pakistan 31°30'00.0"N 74°18'00.0"E	Tilt Angle: 34.8° Orientation Angle: 188.2°	Tilt Angle: 31.5° Orientation Angle: -	Accepted.
8	Lagos, Nigeria 6°36'28.8"N 3°37'18.5"E	Tilt Angle: 29.5° Orientation Angle: 257.6°	Tilt Angle: 26.8° Orientation Angle: Due South	Accepted.

The Python computational model has achieved an accuracy of 75% where 6 out of 8 simulation result is accepted which proven that the model is reliable and can be used to simulate optimal tilt angle and orientation angle.

4.7 Analysis on Population Size and Maximum Amount of Generation in Genetic Algorithm

In this section, an analysis will be carried out to evaluate and determine the population size and maximum amount of generation in genetic algorithm. In genetic algorithm, the population size and maximum amount of generation are 2 important parameters that can significantly affect the performance and convergence of the algorithm.

The population size in genetic algorithm referring to the number of possible solutions that are maintained and evolved in each generation of the algorithm. A large population size allows the genetic algorithm to explore the solution space more thoroughly. However, as the population size increase, it will also increase the computational time as the memory required will also increase.

The maximum amount of generation referring to the number of iterations the genetic algorithm will run before it terminates. The maximum amount of generation is a parameter that can affect the convergence and efficiency of the algorithm. If the maximum amount of generation is too large, it will cause overfitting or heavy burden for computational. However, if the maximum amount of generation is too small, it will cause the algorithm to not converge to an optimal solution before it terminates.

In order to develop a genetic algorithm that is able to converge to an optimal solution in a short amount of time, an experiment was carried out to test both the parameter for a range of possible values. Table 4.7 below shows the result of sensitivity analysis to determine the value for population size and maximum amount of generation.

Table 4.7: Sensitivity Analysis on Population Size and Maximum Amount of Generation

Population / Generation	50	275	500	2750	5000
250	2.29 (0.43%)	2.15 (6.52%)	2.41 (-4.78%)	2.27 (1.3%)	2.24 (2.6%)

	177.64 (0.03%) 1956534.799553 (0.0004%) 0.031126	175.07 (1.48%) 1956448.7875565 (0.0048%) 0.041597	179.01 (-0.74%) 1956489.4148086 (0.0027%) 0.056431	180.34 (-1.49%) 1956516.377207 (0.0014%) 0.250414	177.56 (0.079%) 1956526.683377 (0.00084%) 0.380781
1375	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 0.116577	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 0.195203	2.32 (-0.87%) 177.44 (0.15%) 1956542.7834775 (0.000015%) 0.25413136084874466	2.29 (0.43%) 176.67 (0.58%) 1956532.4723174 (0.00054%) 0.757776	2.27 (1.3%) 178.34 (-0.36) 1956533.6774534 (0.00048%) 1.033752
2500	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 0.216025	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 0.279503	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 0.449361	2.3 (0%) 177.95 (-0.14%) 1956541.1822949 (0.000097%) 1.187427	2.35 (-2.17%) 177.99 (-0.16%) 1956538.102925 (0.00025%) 1.774834
13750	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 1.090535	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 1.307692	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 2.236232	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 6.084474	2.3 (0%) 177.75 (-0.028) 1956543.0654627 (0.00000026%) 8.086688

25000	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 2.266244	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 3.130347	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 3.811192	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 10.402153	2.3 (0%) 177.7 (0%) 1956543.070455 (0%) 13.960615

Red Colour = Tilt Angle

Green Colour = Orientation Angle

Blue Colour = Energy Received

Purple Colour = Time Required (in minute)

Value inside () = Deviation with Correct Result

Based on table 4.7, the genetic algorithm is tested with population size of 50, 275, 500, 2750 and 5000 and maximum amount of generation of 250, 1375, 2500, 13750 and 25000. Each combination of both parameters values are tested for 10 times to ensure they produce the same result and the average result are recorded are as shown in the table 4.7. The red colour value refers to the tilt angle, green colour refers to the orientation angle, blue colour refers to the energy received on solar panel, purple colour refers to the time required (in minutes) for the genetic algorithm to execute and the value inside the bracket are the deviation with the correct result.

The correct result are the results that generated by a Python computational model developed by Edbert Huam Jun Ping in 2022. The model developed by Edbert used brute force search to find the optimal tilt angle, orientation angle and solar energy received on solar panel. Brute force search is a method that perform exhaustively checking for all possible solutions and it involves systematically enumerating all possible solutions to a problem.

Based on the result in table 4.7, it is clearly that the combination of 50 for population size and 1375 for maximum amount of generation in genetic algorithm is able to produce the correct result with 0% deviation in the shortest amount of time compared to others combination of parameters. With population size of 50 and maximum amount of generation of 1375, the genetic algorithm is able to quickly converge to a set of optimal solutions and produce the correct answer even it was being tested for many times. Therefore, the population size and maximum amount of generation in genetic algorithm that are used in this study are 50 and 1375 respectively.

4.8 Comparison the Performance of Genetic Algorithm with Brute Force Search

In this section, the performance of the genetic algorithm will be evaluated according to the time it used to produce the result. The genetic algorithm will then be compared to another Python computational model that used brute force search method developed by Edbert Huam Jun Ping in 2022 as shown in table 4.8 below.

Table 4.8: Comparison of Genetic Algorithm with Brute Force Search

No	Solar Site	Genetic Algorithm	Brute Force Search
1	Scatec Itramas solar 65MW Gurun Solar Power Plant 5°51'45.2"N 100°32'15.5"E 5.862556, 100.537639	Tilt Angle: 27.3° Orientation Angle: 257.9° Solar Received: 1218267737533 Wh Time Required: 0.2485 minutes	Tilt Angle: 27.3° Orientation Angle: 257.9° Solar Received: 1218267737533 Wh Time Required: 86.23 minutes
2	Pasir Mas Solar Farm 5°59'32.0"N 102°06'40.2"E	Tilt Angle: 27.9° Orientation Angle: 266.7° Solar Received: 85458418824 Wh Time Required: 0.2308 minutes	Tilt Angle: 27.9° Orientation Angle: 266.7° Solar Received: 85458418824 Wh Time Required: 83.4 minutes

	5.992222, 102.111167		
3	Sepang Solar Panel (SunEdison) 2°46'46.3"N 101°42'50.0"E 2.779528, 101.713889	Tilt Angle: 24.2° Orientation Angle: 268.9° Solar Received: 166986012249 Wh Time Required: 0.2402 minutes	Tilt Angle: 24.2° Orientation Angle: 268.9° Solar Received: 166986012249 Wh Time Required: 86.02 minutes
4	WD Floating Solar 2°48'59.6"N 101°40'07.1"E 2.816556, 101.668639	Tilt Angle: 24.1° Orientation Angle: 268.7° Solar Received: 188953012522 Wh Time Required: 0.2451 minutes	Tilt Angle: 24.1° Orientation Angle: 268.7° Solar Received: 188953012522 Wh Time Required: 85.37 minutes

The comparison above is done by producing the results using the one laptop with specification of Intel(R) Core(TM) i5-8300H CPU @ 2.30GHz 2.30 GHz processor, 12.0 GB ram, 64-bit operating system, x64-based processor and with NVIDIA GeForce GTX 1060. The time required for model to produce the result are recorded using the function of time library in Python. According to table 4.8 above, it is clearly that genetic algorithm as a search optimization algorithm able to produce to correct and same result as model using brute force search in significantly short amount of time which is below a minute.

4.9 Summary

In summary, Chapter 4 introduce the results produced and analysis performed in this study using the formula in Chapter 2 and the methodology in Chapter 3. In this chapter, all the 28 solar sites in Malaysia are ranked according to their annual average GHI. Besides, the optimal tilt angle and orientation angle for the 28 solar sites are also estimated using the python computational model with genetic algorithm developed in this study. The model is also used to produce simulation results for 8 different solar sites around the world with real on-site experiment result. The simulated result such as the optimal tilt angle and orientation angle is then used to compared with the on-site results to estimate the accuracy of the model. The model is able to achieve a 75% accuracy through the comparison which means the model is reliable and is suitable to be used to estimate optimal tilt angle and orientation angle for a location. Then, an analysis was performed to determine the value of the parameters in genetic algorithm such as the population size and maximum amount of generation. The value that is suitable to be used for population size and maximum amount of generation are 50 and 1375 respectively as the combination of these parameter values is converge to an optimal solution in a short amount of time. Lastly, a comparison between the genetic algorithm and model with brute force search method is carried out to evaluate the performance of genetic algorithm.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This project is strived to simulate and estimate the optimal tilt angle and orientation angle for solar panel for a particular location by using genetic algorithm in Python programming language. In this project, a Python computational model that uses genetic algorithm is developed with the objective to estimate the optimal tilt angle and orientation angle for solar panel of a location. The main activities carried out in this project are the development of Python computational model with genetic algorithm, downloading of historical meteorological data for every solar site from Solcast, performing estimation of optimal tilt angle and orientation angle using the model developed, and performing analysis on the genetic algorithm. The comparison of the simulation results with the real on-site experiment is also carried out to make sure the model is reliable and suitable to be used to estimate optimal tilt angle and orientation angle. Based on the result, the model has achieved a 75% accuracy of estimation as 6 out of 8 simulation results is acceptable which certainly increase the confidence on the model developed. Besides, the genetic algorithm is used in this project to estimate the optimal tilt angle which allows the estimation of angles to be done in a significantly short amount of time, as compared to model that uses brute force search. Based on the analysis performed, genetic algorithm is able to produce a correct and accurate result in short amount of time which able to help to user to save a lot of time in estimating optimal tilt angle and orientation angle for solar site. In conclusion, the aim and objectives of this project as mentioned in Chapter 1 are all successfully achieved.

5.2 Recommendation for Future Work

The analysis on parameters of genetic algorithm involves 2 parameters only which are population size and maximum number of generations. Moreover, both parameters are tested with 5 different values only which is not sufficient. To get a more optimum parameter values and a better genetic algorithm, the parameters should be tested with more different values in order to determine and obtain a better value for parameters. Besides, others parameter besides population size and maximum number of generations should also be tested in order to produce a better genetic algorithm. A more comprehensive analysis should be carried out on genetic algorithm.

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APPENDICES

APPENDIX A: Python Programming Part 1: Import Library and Read Meteorological Data File

```
from datetime import datetime
from datetime import timedelta
from mpl_toolkits import mplot3d
import numpy as np
import matplotlib.pyplot as plt
from IPython import get_ipython
import math as m
import pytz
import csv
from datetime import datetime
import random
import time

# Read the csv file from Solcast
filepath = r'C:\Users\limso\Desktop\\'

filename = '5.862556_100.537639_Solcast_PT60M.csv'

df = pd.read_csv(filepath+filename)
```

APPENDIX B: Python Programming Part 2: Modify Time Zone According to Location of Solar Site

```
import pandas as pd

# Ask user input for Timezone of the solar site

Timezone = float(input("Please Enter the Timezone for your case study in hours,
(eg: Malaysia Timezone = +8 hours from Greenwich\n"))



# df2 = period start

df2 = (pd.to_datetime(df['PeriodStart']).dt.tz_localize(None)) + timedelta(hours
= Timezone)


# df3 = period end

df3 = (pd.to_datetime(df['PeriodEnd']).dt.tz_localize(None)) + timedelta(hours
= Timezone)


# df4 = midpoint date

df4 = df2 + (df3 - df2)/2


# df5 = dataframe to store values related to sun position

df5 = pd.DataFrame()


df5['Middle_datetime'] = df4
```

APPENDIX C: Python Programming Part 3: Determine Number of Days, Angle x and Equation of Time (EOT)

```
# Day number, n
df5['n'] = df4.dt.dayofyear

# Angle x of the day number n, in degree form
df5['x'] = ((360*(df5['n']-1))/365.242)*(m.pi/180)

# EOT, in minutes
df5['eot'] = (0.258*np.cos(df5['x']) - 7.416*np.sin(df5['x']) - 3.648*np.cos(2*df5['x']) - 9.228*np.sin(2*df5['x']))/60

# Convert EOT to hours
df5['eot'] = pd.to_timedelta(df5['eot'], unit='h')
```

APPENDIX D: Python Programming Part 4: Determine Standard Longitude, Actual Longitude, Solar Datetime and Latitude

```
# Standard longitude (E negative) (W positive)
stdLong = Timezone*15
stdLongEW = 'E'
if stdLongEW == 'E':
    stdLong = stdLong*(1)
elif stdLongEW == 'W':
    stdLong = stdLong*(-1)

# Actual longitude (E negative) (W positive)
actLong = float(filename.split('_')[1])
actLongEW = 'E'
if actLongEW == 'E':
    actLong = actLong*(1)
elif actLongEW == 'W':
    actLong = actLong*(-1)

# Solar datetime is the date and time of the solar time
df5['solar_datetime'] = df4 + df5['eot'] - timedelta(hours = (actLong - stdLong)/15)

# Latitude angle of a location (NS)
Lat = float(filename.split('_')[0])
LatNS = 'N'
if LatNS == 'N':
    Lat = Lat*(1)
elif LatNS == 'S':
    Lat = Lat*(-1)
```

APPENDIX E: Python Programming Part 5: Determine Sun Position

```
# Declination angle in degree
df5['decline_angle'] = np.arcsin(0.39795*np.cos(0.98563*(df5['n'] - 173)*(m.pi/180)))*(180/m.pi)

# Hour angle
df5['hour_angle'] = 15*((df5.solar_datetime.dt.hour + df5.solar_datetime.dt.minute/60 + df5.solar_datetime.dt.second/3600)-12)

# Altitude angle, in degree
df5['altitude_angle'] = np.arcsin(np.sin(df5['decline_angle']*(m.pi/180)) *np.sin(Lat*(m.pi/180)) + np.cos(df5['decline_angle']*(m.pi/180)) *np.cos(df5['hour_angle']*(m.pi/180)) *np.cos(Lat*(m.pi/180)))*(180/m.pi)

# Altitude angle < 0 = sun not presence
df5['altitude_angle'].values[df5['altitude_angle'].values < 0] = 0.0

# Zenith angle, in degree
df5['zenith_angle'] = 90 - df5['altitude_angle']

# Azimuth angle
df5['cosA'] = (np.sin(df5['decline_angle']*(m.pi/180))*np.cos(Lat*(m.pi/180)) - np.cos(df5['decline_angle']*(m.pi/180))*np.cos(df5['hour_angle']*(m.pi/180)) *np.sin(Lat*(m.pi/180)))/(np.cos(df5['altitude_angle']*(m.pi/180)))

# If cosA > 0
df5.loc[df5['cosA'] > 0, 'Azimuth'] = np.arcsin((-np.cos(df5['decline_angle']*(m.pi/180)) *np.sin(df5['hour_angle']*(m.pi/180))) /(np.cos(df5['altitude_angle']*(m.pi/180))))*(180/m.pi)
```

```
# If cosA < 0

df5.loc[df5['cosA'] < 0, 'Azimuth'] = 180 - np.arcsin((-np.cos(df5['decline_angle']*(m.pi/180))  *np.sin(df5['hour_angle']*(m.pi/180)))/(np.cos(df5['altitude_angle']*(m.pi/180)))))*(180/m.pi)


# Dni = direct normal irradiance

df5['Dni'] = df['Dni']


# Dhi = diffuse horizontal irradiance

df5['Dhi'] = df['Dhi']


print(df5)
```

APPENDIX F: Python Programming Part 6: Generate Initial Population

```
# Define the range of tilt angle, orientation angle and precision
tilt_angle_range = [0, 90]

orientation_angle_range = [0, 360]

precision = 1

# Define the size of the initial population
pop_size = 50

# Initialize an empty population
population = []

# Generate the initial population randomly
for i in range(pop_size):

    # Generate a random value for the tilt angle
    x = round(random.uniform(0, 1) * (tilt_angle_range[1] - tilt_angle_range[0])
+ tilt_angle_range[0], precision)

    # Generate a random value for the orientation angle
    y = round(random.uniform(0, 1) * (orientation_angle_range[1] -
orientation_angle_range[0]) + orientation_angle_range[0], precision)

    # Combine the two angles to form the chromosome
    chromosome = [x, y]

    # Add the chromosome to the population
```

```
    population.append(chromosome)

# df20, a dataframe to store tilt_angle, orientation_angle and fitness_value
df20 = pd.DataFrame(population, columns = ['tilt_angle', 'orientation_angle'])

df20['fitness_value'] = 0

print(df20)
```

APPENDIX G: Python Programming Part 7: Calculate Fitness Function

```
# Ask user input for solar site area
site_area = float(input("Please Enter the Area for the solar site in m2\n"))

# A function to calculate the fitness value (energy received by solar panel) for whole population
def fitness_function(za, az, dni, dhi, df20):

    rd = m.pi/180

    for i in df20.index:

        cosine = np.cos((za)*(rd))*np.cos((df20['tilt_angle'][i])*(rd)) + np.sin((za)*(rd))*np.sin((df20['tilt_angle'][i])*(rd))*np.cos(((az)-(df20['orientation_angle'][i]))*(rd))

        direct_solar = dni*cosine

        intensity_received = direct_solar + dhi

        solar_power_received = intensity_received * site_area

        #####***

        df20.loc[i, 'fitness_value'] = solar_power_received.sum()

    return df20

# Function call
```

```
df20 = fitness_function(df5['zenith_angle'], df5['Azimuth'], df5['Dni'], df5['Dhi'], df20)


print(df20)
```

APPENDIX H: Python Programming Part 8: Parent Selection, Crossover, Mutation and Survivor Selection

```
# Set the maximum number of generations / maximum number of loop
(Stopping Criteria)
max_generations = 1375

# Initialize the generation counter
generation = 0

while generation < max_generations:


    # Parent Selection
    # Selects a chromosome from the population using Roulette Wheel Selection.
    def roulette_wheel_selection(population, fitness_values):

        # Compute the sum of fitness values
        fitness_sum = sum(fitness_values)

        # Compute the selection probability of each chromosome
        selection_probs = [fitness/fitness_sum for fitness in fitness_values]

        # Generate a random number between 0 and 1
        r = random.uniform(0, 1)

        # Select the chromosome whose cumulative probability exceeds the
random number
        cum_prob = 0
        for i, prob in enumerate(selection_probs):
```

```
        cum_prob += prob
        if cum_prob > r:
            return population[i]

#Selects two parent chromosomes using Roulette Wheel Selection.
def select_parents(population, fitness_values):

    parent1 = roulette_wheel_selection(population, fitness_values)
    parent2 = roulette_wheel_selection(population, fitness_values)
    return parent1, parent2

parents = []
parents = select_parents(population, df20['fitness_value'])



# Crossover
# Applies Whole Arithmetic Recombination Crossover to two parent chromosomes.
def war_crossover(parent1, parent2):

    # Randomly generate an alpha value
    alpha = random.uniform(-0.5, 1.5)

    child1 = [(1-alpha)*p1 + alpha*p2 for p1, p2 in zip(parent1, parent2)]

    # clamp tilt angle to valid range
    child1[0] = max(0.0, min(90.0, child1[0]))

    # wrap orientation angle to valid range
    child1[1] = child1[1] % 360.0
```

```
    child2 = [(1-alpha)*p2 + alpha*p1 for p1, p2 in zip(parent1, parent2)]

    # clamp tilt angle to valid range
    child2[0] = max(0.0, min(90.0, child2[0]))

    # wrap orientation angle to valid range
    child2[1] = child2[1] % 360.0

    child1 = [round(child1[i], 1) for i in range(len(child1))]
    child2 = [round(child2[i], 1) for i in range(len(child2))]

    return child1, child2

childs = []
childs = war_crossover(parents[0], parents[1])



# Mutation
# Define mutation rate and standard deviation for Gaussian mutation

# Probability of mutating each gene
mutation_rate = 0.05

# Standard deviation of mutation, 1 for tilt angle, 2 for orientation angle
mutation_std_dev1 = 1.0
mutation_std_dev2 = 10.0

# Define a function to mutate a chromosome
```

```
def mutate(chromosome):
    mutated_chromosome = []

    for i, gene in enumerate(chromosome):

        # Apply Gaussian mutation to each gene with probability mutation_rate
        if random.random() < mutation_rate:

            # Gene represents tilt angle
            if i == 0:
                mutated_gene = gene + random.gauss(0.0, mutation_std_dev1)
                mutated_gene = max(min(mutated_gene, 90.0), 0.0) # Clamp to
valid range
                mutated_chromosome.append(round(mutated_gene, 1)) # Round
to 1 decimal place

            # Gene represents orientation angle
            elif i == 1:
                mutated_gene = gene + random.gauss(0.0, mutation_std_dev2)
                if mutated_gene < 0.0:
                    mutated_gene += 360.0 # Wrap around if angle is negative
                elif mutated_gene > 360.0:
                    mutated_gene -= 360.0 # Wrap around if angle is greater than
360
                mutated_chromosome.append(round(mutated_gene, 1)) # Round
to 1 decimal place
        else:
            mutated_chromosome.append(gene)
    return mutated_chromosome

# Function call
```

```
mutated_child = [mutate(childs[0]), mutate(childs[1])]



# Survivor Selection using fitness-based selection

# A function to calculate the fitness value (energy received by solar panel) for newly generated children

def fitness_function(za, az, dni, dhi, chromosome):

    rd = m.pi/180

    cosine = np.cos((za)*(rd))*np.cos((chromosome[0])*(rd)) + np.sin((za)*(rd))*np.sin((chromosome[0])*(rd))*np.cos(((az)-(chromosome[1]))*(rd))

    direct_solar = dni*cosine

    intensity_received = direct_solar + dhi

    solar_power_received = intensity_received * site_area

    #print(total_solar_received.sum())

    fitness_value = solar_power_received.sum()

    return fitness_value

# Function call to calculate fitness value of 2 newly generated children

child_fitness_values = [fitness_function(df5['zenith_angle'], df5['Azimuth'], df5['Dni'], df5['Dhi'], mutated_child[0]),

                        fitness_function(df5['zenith_angle'], df5['Azimuth'], df5['Dni'], df5['Dhi'], mutated_child[1])]
```

```
# df21 stores the 2 newly generated children
df21 = pd.DataFrame(mutated_child, columns = ['tilt_angle', 'orientation_angle'])
df21['fitness_value'] = child_fitness_values

print("Children Generated")
print(df21)
print("\n")


# Determine and locate the 2 chromosomes with the lowest fitness value in the population
lowest_fitness_indices = sorted(range(len(df20['fitness_value'])), key=lambda k: df20['fitness_value'][k])[:2]
lowest_fitness_values = [df20['fitness_value'][i] for i in lowest_fitness_indices]\

print("Before")
print(population[lowest_fitness_indices[0]])
print(population[lowest_fitness_indices[1]])
print(df20.iloc[lowest_fitness_indices])
print("\n")


# Replace the chromosome in population with newly generated children if the fitness value of the chromosome is lower than children
for i in range(2):
    chromosome_fitness = lowest_fitness_values[i]
    chromosome_index = lowest_fitness_indices[i]
```

```
        # Compare the chromosome fitness value with the children fitness value
        for index, row in df21.iterrows():
            if chromosome_fitness < row['fitness_value']:
                # replace the chromosome with the child
                population[lowest_fitness_indices[i]] = [row['tilt_angle'], row['orientation_angle']]

                df20.iloc[chromosome_index] = row
                # remove the chosen child from the dataframe
                df21 = df21.drop(index)
                break # exit the inner loop once a child has been chosen to avoid duplication



    print("After")
    print(population[lowest_fitness_indices[0]])
    print(population[lowest_fitness_indices[1]])
    print(df20.iloc[lowest_fitness_indices])
    print("..........................................................................................................................")
    print("\n")

    # Generation counter
    generation += 1
```

APPENDIX I: Python Programming Part 9: Determine Optimal Tilt Angle, Orientation Angle and Solar Received on Solar Panel

```
# Print the optimal combination of tilt angle and orientation angle as well as its fitness value

# find the index of the row with the highest fitness value
max_fitness_index = df20['fitness_value'].idxmax()

# retrieve the corresponding row of data
max_fitness_row = df20.loc[max_fitness_index]

def format_number(x):
    return "{:.6f}".format(x).rstrip('0').rstrip('.')

df_formatted = max_fitness_row.apply(format_number)



print(df_formatted.iloc[0])
print(df_formatted.iloc[1])
print(df_formatted.iloc[2])
```