MEASUREMENT OF SOLAR IRRADIANCE AT VARIOUS ALTITUTE ANGLES AND STUDY OF ITS CORRELATION IN OPTIMIZATION OF SOLAR POWER PLANT DESIGN

SAW THEAN EAK

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2016

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.

Signature : ______________________

Name : Saw Thean Eak

ID No. : 11UEB02819

Date : ______________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"MEASUREMENT OF SOLAR IRRADIANCE AT VARIOUS ALTITUTE ANGLES AND STUDY OF ITS CORRELATION IN OPTIMIZATION OF SOLAR POWER PLANT DESIGN "** was prepared by **SAW THEAN EAK** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ______________________________

Supervisor : Dr. Lim Boon Han

Date : ______________________________

Specially dedicated to
my beloved grandmother, mother and father
to whom I owe my state of
calm & peace

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Dr. Lim Boon Han for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to my loving parent and friends who had helped and given me encouragement.

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ABSTRACT

Shading is always an enemy of a solar array. Shading at one corner of a solar module can reduce half of the electricity production, so any shading created needs to be eliminated. Large shading occurred during low sun altitude angles, which are during sunrise and sunset. The distance required to separate rows of solar array during low sun altitude angle is large and hence the land is wasted. However, the solar irradiance during low sun altitude angles are low, a study is essential to be conducted to quantify solar irradiance at low sun altitude angle for array distance optimization for solar power plant design. Measurement of solar irradiance referenced to solar altitude angles was carried out. From the collected data, we have calculated the optimal distance to separate rows of solar array that would yield the lowest levelized cost of electricity for a simulated solar power plant with a constrained land area.

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LIST OF SYMBOLS / ABBREVIATIONS

PV	Photovoltaic
BP	By pass diode

CHAPTER 1

INTRODUCTION

1.1 Background

Renewable energy in Malaysia keeps growing to meet the green energy demand. Solar and bio-energy are the more popular renewable energy for Malaysia who has good sunshine all over the years as well as abundant supply of oil palm waste. Even though solar is popular but there are few disadvantages of solar energy. One of the major issues is related to the land occupied. The land needed for solar farm is usually large. As the rule of thumb, solar array row spacing is around 2.5 times of the row height (GREEN, 2011) to allow reasonable shading. This rule is generally applied for both ground mounted and flat roof top system. However, we hypothesis that the solar irradiance is low in the early morning, therefore, substantial amount of shadow can be allowed with relatively low power loss. Until now there have been no study carried out to optimise the distance between the arrays based on the percentage of energy that can be generated at various solar altitude angle for a constrained area. Since Malaysia has a tropic sun trajectory and also has a different temporal solar irradiance distribution profile, it is expected to have different optimal spacing distance between rows of solar arrays. In order to reduce land occupation for land constrained area such as rooftop, the optimal distance between solar arrays need to be studied. A measurement of the solar irradiance in Malaysia at different altitude angle is needed to justify the statement above.

1.2 Aims and Objectives

The main aim of this project is to optimise the distance between rows of solar arrays to obtain a minimum levelised cost of electricity of a solar power plant using the solar irradiance data quantified based on solar altitude angles.

- To quantify the solar irradiance in Malaysia at different altitude angle by measurement.
- To simulate the performance of solar array with different distance between array based on the solar irradiance measured.
- To optimise solar array spacing with respect to shadow effect based on irradiance at different altitude angle for land constrained power plant.

1.3 Project Scope

Measurement of solar irradiance at the rooftop of B Block, University Tunku Abdul Rahman Sungai Long Campus at different altitude angles was carried out randomly on sunny days from January to March 2016. In practice, the measurement should have been carried out throughout whole year due to different sun trajectory. However, the aim of this project is to provide a method of collecting data and method of optimise the best spacing distance between rows of solar arrays. The solar panel used in this project is a multicrystalline type, which contains 3 by pass diodes. The solar panel was elevated around 5 ° and facing true south. The system consists of 2 rows of arrays, each consisting of a single multicrystalline module. After the irradiation and power output were collected, the optimal spacing between the arrays were calculated based on the solar irradiance at different altitude angles for land constrained power plant.

CHAPTER 2

LITERATURE REVIEW

In this project, we need to understand a few theories such as sun trajectory, electrical characteristic of solar panel, shading effect to a solar panel etc.

2.1 Sun Declination Angle

The angle between the horizontal line to the sun and the earth equatorial plane is called the declination angle (δ). The declination angle δ depends on earth rotation around the sun. Earth is tilted by 23.45° on its axis of rotation hence the declination angle δ is within $\pm 23.45°$. Figure 2.1 shown how the earth declination changed while rotate around the sun. On March 22 and September 23, the declination angle is 0° and the phenomena is called equinox. On June 21 and December 22 the declination angle is $\pm 23.45°$ and the phenomena is called solstice.

The declination angle is calculated using the equation below (Stine & Geyer, 2001):

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

where n is the day number in a year.

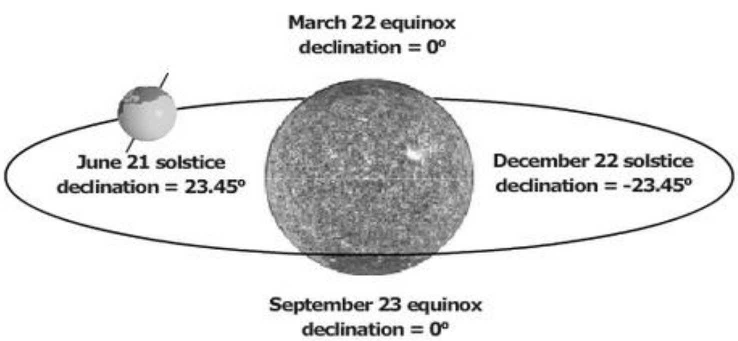


Figure 2.1: Sun declination angle δ varies around the orbit rotation.

2.1.1 Sun Elevation Angle

The sun elevation angle or attitude angle is the height of sun measured from the horizontal. During sunrise and sunset, the elevation angle is 0°, whereas during solar noon the elevation angle is 90°.

The sun elevation angle is calculated using the equation below (Stine & Geyer, 2001):

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

Φ is latitude of location and δ is declination angle.

ω is solar time in hours

2.1.2 Azimuth Angle

Azimuth angle is defined as the angle measured on the horizontal plane. The azimuth angle is like a compass direction with North = 0 ° and South = 180 °.

The sun azimuth angle is calculated using the equation below (Stine & Geyer, 2001):

- If $\cos A = (\sin\delta \cos\Phi - \cos\delta \cos\omega \sin\Phi)/\cos\alpha > 0$ (2.1)

$A = \sin^{-1} [-\cos\delta \sin\omega / \cos\alpha]$

- If $\cos A = (\sin\delta \cos\Phi - \cos\delta \cos\omega \sin\Phi)/\cos\alpha < 0$

$A = 180° - \sin^{-1}[-\cos\delta \sin\omega / \cos\alpha]$

Φ is latitude angle.

2.1.3 Type of radiation.

Solar irradiance can be categorised into three types, which are direct, diffuse and reflected solar radiation as shown in figure 2.2. Direct irradiation is also know as beam radiation. It is used to describe the sun irradiation that travels straight line to the surface earth. Diffuse radiation is described as the sunlight, which has been scattered by particles and molecules in the atmosphere before reaching surface earth. In comparison direct irradiation have definite direction whereas diffuse radiation is in any direction. Reflected radiation is described as the sunlight which has been reflected by non-atmospheric material like ground. For examples, Asphalt, which is used to build road will reflect about 4% of the sunlight while a lawn reflects about 25%. However reflected light is hardly been accounted for solar module due to the way we orientate the panel and it is insignificant in amount. (AM & David, 2011)

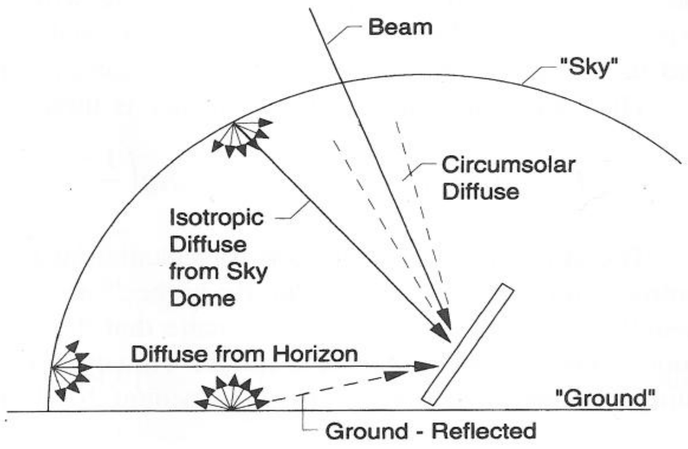


Figure 2.2 : Type of Solar Irradiation

2.1.4 Solar insolation

Solar insolation is defined as sum up of direct, diffuse and reflected light. It is also reflecting the amount of solar radiation energy received on a given surface area during a given time (unit in MJ/m^2) .

2.1. Sun Path Diagram

The sun path diagram provides information of solar altitude and solar azimuth form any date of the year and any hour of the day. Figure 2.3 shown that the sun path during May 2016 located at Kuala Lumpur Malaysia. The diagram was taken from (GAISMA, n.d.). From the diagram, it provided the information during May the azimuth angle will shifted from the range of 70° to 290° and maximum altitude angle will reach 78°.

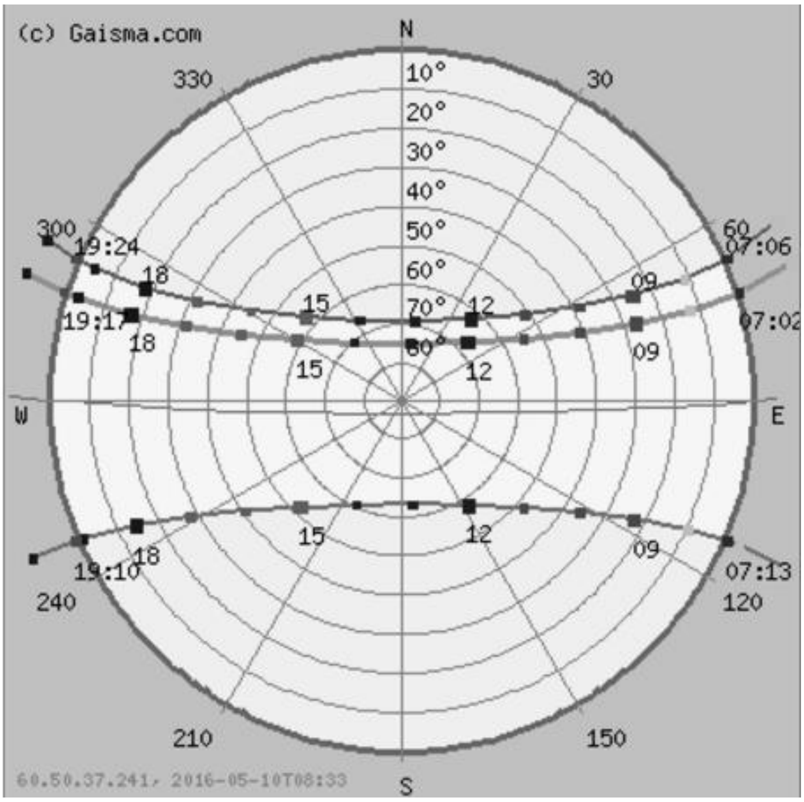


Figure 2.3: Sun Path Diagram

2.2 Multicrystalline Silicon (Poly-Si)

Multicrystalline solar panels are made of multicrystalline ingots, which is just molten silicon poured into a cast and allowed to solidify. The rectangular blocks of silicon ingot will then be cut into 156mm square wafers and will be soldered into three parallel-series of 20 cells each for a total of 60 cells to form a module. Multicrystalline solar cells have lower space efficiency as compared to monocrystalline. A typical Monocrystalline module can generate 190W as compared to a polycrystalline module, which only produces 180W in terms of one square meter. Polycrystalline also have a lower temperature coefficient as compared to monocrystalline solar cell.

2.2.1 Short Circuit Current

Short circuit current (Isc) is referred as the solar module's current during short circuit condition and the voltage is equal to null. Short circuit current is due to collection and generate by light generated carries. For an ideal case, short circuit current is equal as light generated current. Therefore it is the maximum current which generated by the solar module. Figure 2.4 shown that the IV curve of the solar cell and short circuit current occur when the voltage across the device is zero.

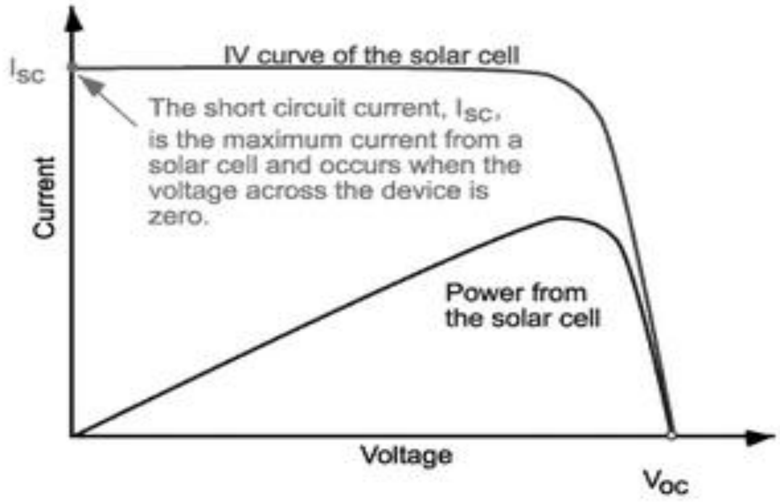


Figure 2.4: IV Curve of short circuit current on solar cell.

2.2.2 Open Circuit Voltage

Open Circuit voltage (Voc) is defined as the voltage of the solar module when there is no current being drawn. It represent the amount of forward bias current in the solar module. Figure 2.5 shown that the IV curve of the solar cell and open circuit voltage occur when the net current across the device is zero.

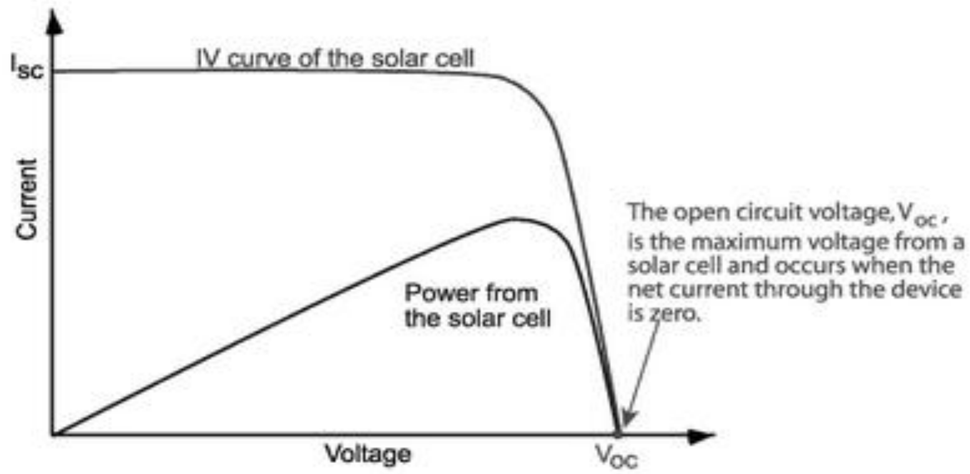


Figure 2.5: IV Curve of open circuit voltage on solar cell.

2.2.3 Irradiance on IV curve

Manufacturers often provide IV curve to show how the irradiance the power output as show as figure 2.6. As the insolation drops, short circuit current drops in direct proportions. As the solar insolation decreases the open circuit voltage also reduces and it follows a logarithmic relationship that result in relatively modest change.

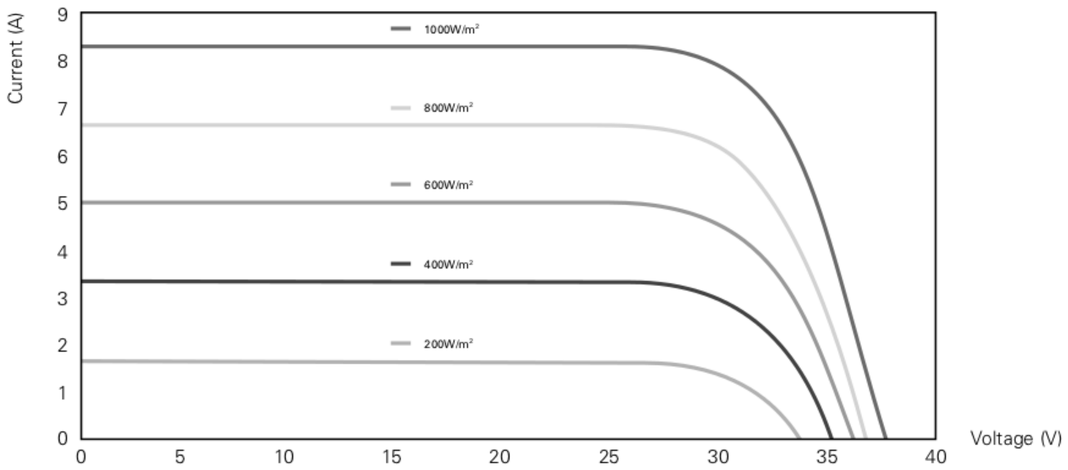


Figure 2.6 : Solar insolation effect on IV curve.

2.2.4 Fill Factor

The fill factor is the measurement of quality of power output. It compare the maximum power can be generate over theoretical power. Figure 2.7 shown that the the fill factor is measure of “squareness” of the solar cell and the largest of rectangular can fit into the iv curve.

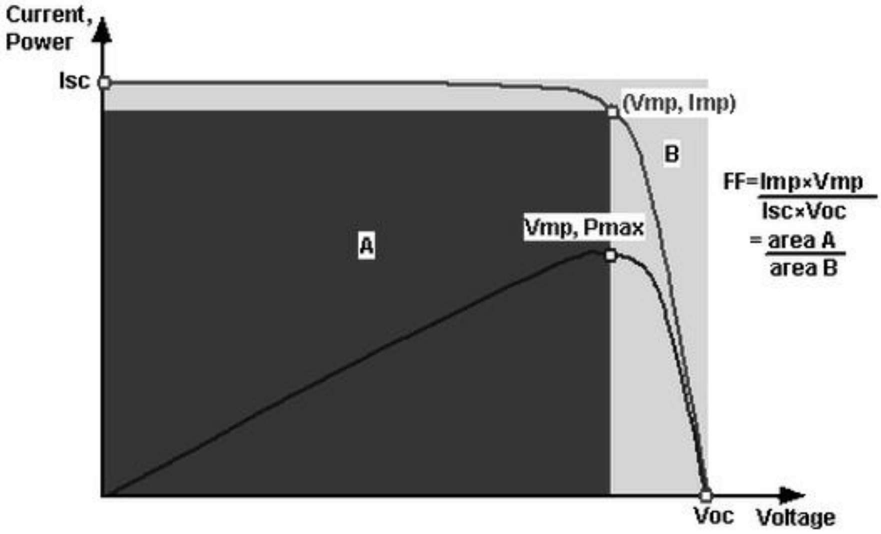


Figure 2.7: Graph of fill factor

2.3 Type of Shading

Shading can be categorised into two types, which is Objective shading and Subjective shading. Objective shading is unavoidable as it is caused by bad weather such as air pollution, haze or even cloudy days. For subjective shading, it can be further categorized into static shading and dynamic shading. Static shading is cause by something that adhered to the glass such as bird shit, leaves and dirt. Dynamic shading is cause by an object's shadow which is relative to the sun's angle such as building, array self shading and trees.

2.3.1 Shading Impact

Shading can be caused due to clouds, environmental obstructions such as trees and building and self-shading. In our case, we will focus of self-shading which is caused by the parallel rows of solar panels.

The output of the solar panels would be reduced critically even if there were only a small portion of shading. For example, a shading of only 8% on each PV module can reduce the power output by 94% (Thakkar, Cormode, Lonij, Pulver, & Cronin, 2010). Another impact of shading is localized heating, in a 60 cell module panel; each 20 cells are connected in series and then joined parallel together. When one of the 20 series cell is shaded, the power generate by the remanding 19 cell will dissipated on the one shaded cell and this will cause localized heating to occur with irreversible damage to the module.

2.3.2 Spacing distance of solar array

The minimum distance of solar array spacing shown in figure 2.8 can calculated by equation below (han, 2015):

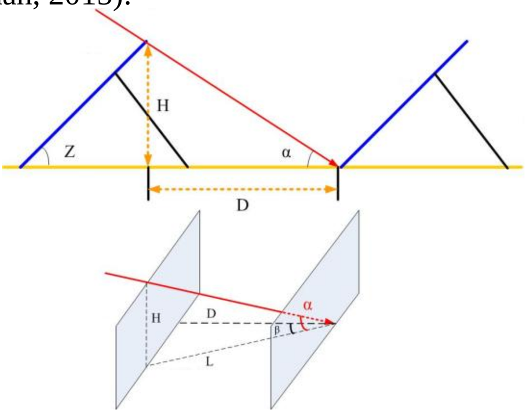


Figure 2.8: Equation of spacing distance of solar array

$$\sin\alpha = \sin\phi\ \sin\delta + \cos\phi\ \cos\delta\ \cos\omega \tag{2.3}$$

$$\sin\beta = \cos\delta\ \sin\omega / \cos\alpha$$

$D = \cos\beta \times L$, $L = H/\tan\alpha$

where

D = spacing between solar array

α = sun altitude angle

δ = declication angle

β = tilted angle from ground

Φ = latitude angle

2.3.3 Linear Shading along length of panel calculation

The height of shading by parallel row of solar array shown in figure 2.9 can be calculated by equation below (han, 2015):

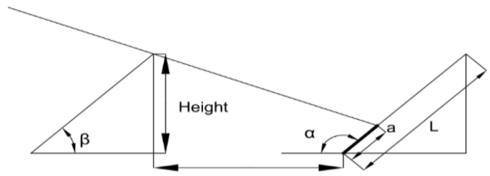


Figure 2.9: Equation of shading along length of solar panel

$$S = \frac{\cos(180\text{-}A)\sin\beta + \tan\alpha\cos\beta - \dfrac{D\tan\alpha}{l_{panel}}}{\tan\alpha\cos\beta + \sin\beta\cos(180 - A)} \tag{2.4}$$

where

S = a/L, % shaded of linear type shading along the length of panel

l_{panel} = length of panel or length of array looking from side

β = tilted angle from ground

α = sun altitude angle

A = sun azimuth angle

D = distance between two rows (sheds)

2.3.4 By pass diode

The purpose of a by pass diode is to shunt the current over the shaded module cell. During a sunny day, there is a voltage rise in cell and the diode will operate at a reverse bias, when under a shade the voltage will become negative and activate the by pass diode and shunt the current.

2.3.5 Substring of 3BP multicrystalline

Multicrystalline solar panel is the most commercially used solar panel these days. These solar panels come with 3BP (Bulanyi & Zhang, 2014) which mean a single module contains three by pass diode. The purpose of the by pass diode is to shunt module current when the module substring is shaded. A solar panel with three by pass diode can be divide into 3 substring. The effect of power yield is related to how the substring is shaded. The shading can be occur on several sub string or a particular sub string depending on the module orientation.

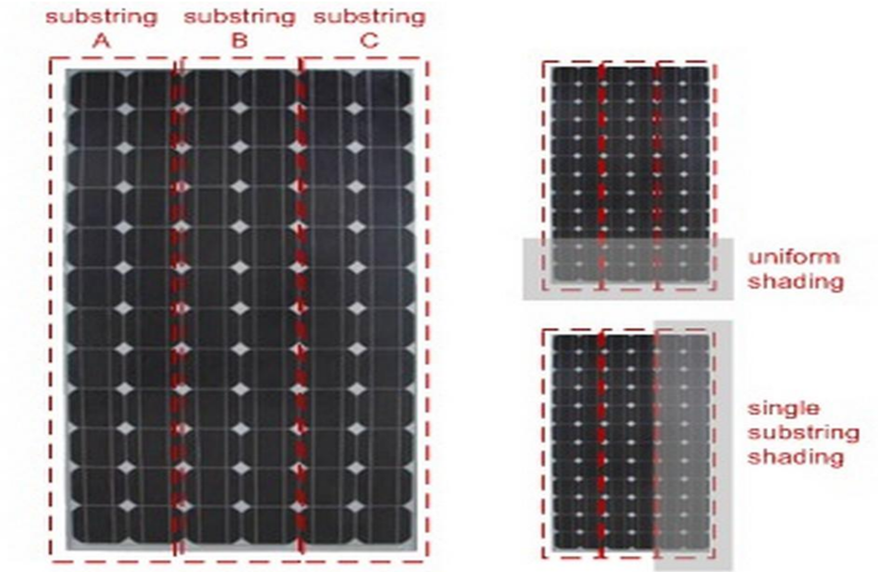
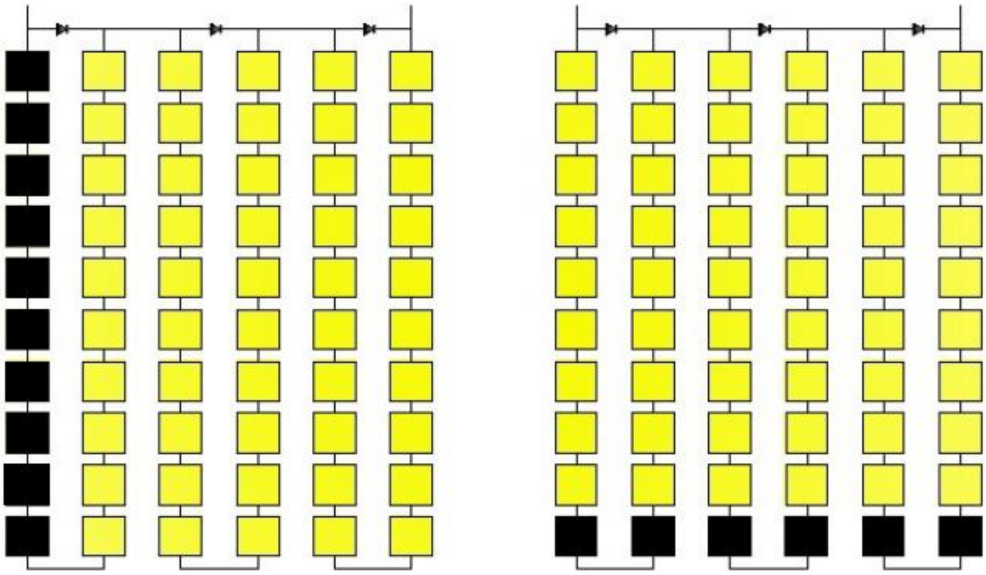


Figure 2.10: Type of shading effect on solar panel substring (yoscovish, 2010).

2.3.6 Shading Impact on vertical and horizontal 60 solar cell

For a 60 cell solar module in landscape arrangement, when there is self shading from parallel row of solar module the shadow will shade a series of 20 solar cell and this will cause the by pass diode to activate to shunt the current. When the 60 cell solar module is in portrait arrangement, the shading will totally cover 3 parallel row of 20 series solar cell and all 3 by pass diode will be activate and entire module is effectively disabled (Bulanyi & Zhang, 2014).



Landscape Arrangement Portrait Arrangement

Figure 2.11: Shading effect on 60 solar cell in landscape and portrait arrangement

2.3.7 Shading analysis on IV n power graph

The effect of the by pass diode in solar panel when during shading is shown as in the figure 2.12. When one of the substring is shaded the IV curve shows that there is an edge drop of power which implies that the by pass diode is activated and leaves other the other two substring to generate power (Conzaleq, 2012).

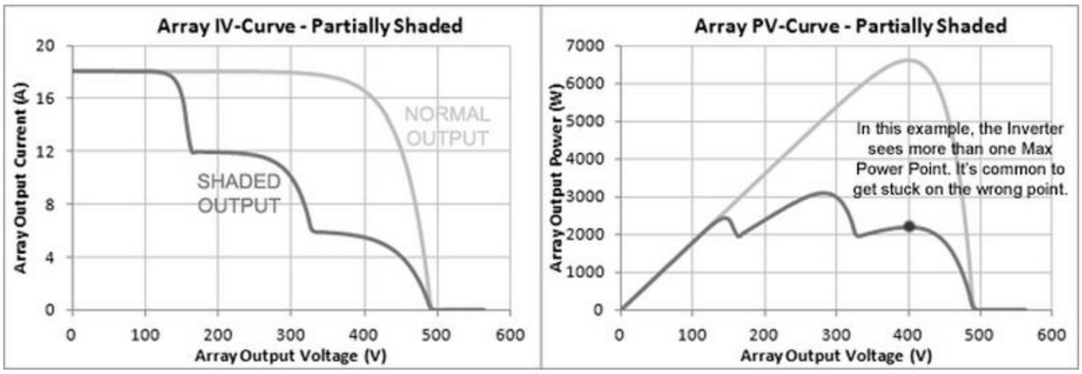


Figure 2.12 : IV curve and power curve of solar array under shading impact. (Anon., 2014)

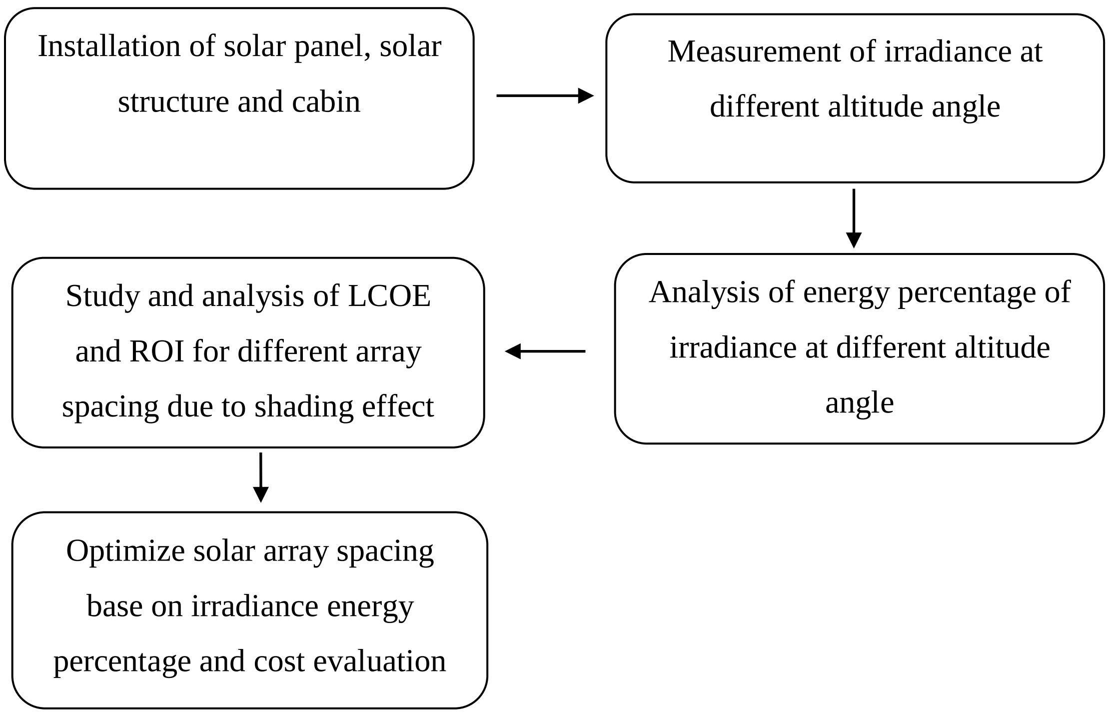
CHAPTER 3

METHODOLOGY

3.1 Overview

The project is breakdown into three steps. The first step is data collection of Malaysia irradiance referred to different altitude angle on a few particular sunny days in January, February and March 2016. The second step is analysis of percentage of energy of solar irradiance at various solar altitude angle. Last step is optimisation of solar array spacing with respect to shadow effect based on irradiance at different altitude angles and levelised cost of electricity (LCOE) of the electricity generated for a land constraint power plant.

3.2 Overall Flow Map



3.3 List of Material

Data collection Material

Item Description	Quantity
Seaward Pv150 power meter	1
Seaward S220R irradiance meter	1
Solar analyser PVPM 1040	1
Pyranometer	1
Solarimeter	1
Computer	1

Solar Panel and structure

Item Description	Quantity
Solar frame	2
Solar panel	2
Cabin	1

3.3.1 MSR 260W Solar Module

The solar module is manufactured by Malaysian Solar Resources Sdn. Bhd. It is a 60-cell 260W solar panel. The model is MYS-60M/B3/CF-260. Table 3.1 in the below shows the dimension and specifications of the solar module. (Product catalogue of 60 cell multicrystalline , n.d.)

Figure 3.2 : Solar Module Dimension from catalogue

Table 3.1: Specification of MSR 260W Solar Module.

Rated Maximum Power a STC	260W
Maximum Power Voltage	30.67Vmp/V
Maximum Power Current	8.48 Imp/A
Open circuit voltage	37.96 Voc/V
Short Circuit current	9.01 Isc/A
Temperature Coefficient of P_{max}	-0.4112% / ºC
Temperature Coefficient V_{oc}	-0.3137% / ºC
Temperature Coefficient I_{sc}	+0.0427% / ºC

3.3.2 Eppley Pyranometer SPP Model

Pyranometer was used to collect the irradiation data. The SPP have faster response time than the PSP model. Other than that, it also hass better temperature dependence and better cosine response (Catalogue of SPP Pyranometer, n.d.).

Figure 3.3: Eppley Pyranometer

Table 3.2: Specification of Eppley Pyranometer

Spectral Range	295-2800 nm
Output	0-10 mV analog
Sensitivity	approx. 8 µV / Wm-2
Impedance	approx. 700 Ω

3.3.3 Seaward PV150 Solar Meter and S200R Solarimeter

The solar power meter PV150 was used to take the Voc, Isc and power output of the solar module. The Seaward S200R solarimeter was used to measure the solar irradiance. Both PV150 and S200R have built in data logger, which provide convenience (Sepcification of Seaward pv150, n.d.). The datasheet for Seaward meter is attached as APPENDIX B.

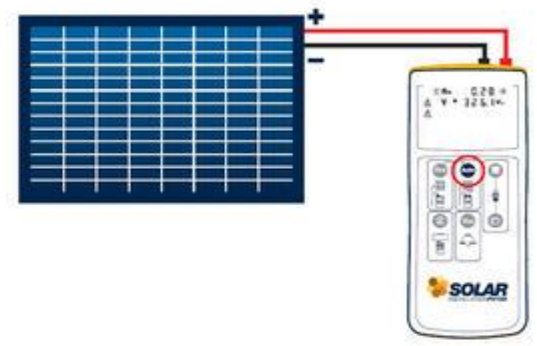


Figure 3.4: Seaward PV150 Solar Tester.

Figure 3.5 : Seaward S200R Solarimeter

Table 3.3 Specification of Seaward meter

Voc	5V-1000V DC
Isc	0.5A-15A DC
Data logging	Irradiance, Voc, Isc, W
Connectivity	USB to PC

3.3.4 Solar analyser PVPM 1040X

The solar analyser comes with irradiation collection and maximum power point tracking (MPPT) function. The meter was used to measure and logging solar irradiance and peak power of solar panel. The datasheet for solar analyser PVPM 1040X is attached as APPENDIX A.

Figure 3.5: Solar analyser PVPM 1040X

Table 3.4 : Specification of Solar analyser PVPM 1040X

Voltage DC	1000V
Current DC	20A
Accuracy I-V characteristic	1%, Peak performance 5%
Sampling rate	100khz, 12Bit
Flash storage	512MB

3.4 Experiment Setup

3.4.1 Solar Panel and Frame

The setup is installed at the rooftop of UTAR KB building which is located at 10th floor height as show as figure 3.6. The reason of installing the system at rooftop is due to no shading would be casted by the nearby buildings. The solar frame structure was constructed with using of angle metal bars to enable hold two solar module. Two solar structure was constructed and 4 solar panel was installed. The solar panel was set at 5^{o} tilted angle and faced south.

Figure 3.6 : Solar Panel and Structure.

3.4.2 Method of measurment

The measurement carried by using Seaward meter and Solar Analyser PVPM 1040. The reason of using 2 different set of measurement equipment is due to availability of equipment can be borrow. Both equipment does the jobs well but Solar Analyser PVPM 1040 provide additional future, which is MPPT power measurement.

Seward Power meter PV150 was plugged into MC4 connection of solar panel and power measurement was taken in every 5m interval as shown in figure 3.7. The Seaward solarimeter was set in the interval of 5minute to collect the irradiance.

Solar analyser PVPM 1040 was connected to solar panel through MC4 connection and solarimeter meter was clamped at the side of solar panel with same tilted angle. The solarimeter built in with temperature sensor to provide temperature measurement as show in figure 3.9. The solar analyser was connected to computer as well to act as data logger system as shown in figure 3.8. Cabin also have been built to store the solar analyser and computer for prevent rain and secure equipment during data collection as shown in figure 3.10.

Figure 3.7 : Power and irradiance measurement taken by Seaward meter

Figure 3.8 : Power and irradiance measurement took by Solar Analyser PVPM 1040

Figure 3.9 : Solar analyser Solarimeter

Figure 3.10 : Cabin to store Solar Analyser and Computer during data collection

3.5 Data analyse method

3.5.1 Energy percentage of irradiance

The irradiance was collected from sunrise to sunset. The irradiance is categorized according to solar altitude angle. For every 5 degree interval of altitude angle, the irradiance is averaged out. The average irradiance is multiplied with time interval within this 5 degree changes of altitude angle to get the energy per meter square, wh/m^2 at that interval. All energy of 5-degree intervals are summed up to get the total energy per meter square collected within the window of measurement. The energy of each 5-degree interval is then divided by the total energy per meter square to obtain the percentage of energy that represents the specific 5-degree interval.

$$Irrad\ ave = \frac{\sum irrad\ for\ 5\ altitude}{5} \tag{3.1}$$

$$Joule = Irrad\ ave\ x\ (\ Change\ of\ solar\ time\ of\ 5\ altitude\ angle) \tag{3.2}$$

$$\%E = \frac{Joule}{Total\ joule} \tag{3.3}$$

Where

Irrad = Irradiance (w/m^2)

Irrad ave = Average Irradiance

3.5.2 Average day of percentage energy receive with array spacing

Each day of different array spacing energy receive is summing up and divide by sum of each day energy available to show percentage of energy can be receive for multiple day.

3.5.3 Energy Receive with array spacing

For every 5 degree of energy received is then multiple with percentage of not shaded to show that energy that can be receive during shading. The energy that can be receive during shading is summed up to show the energy can be received for whole day. Different spacing of array gives different value of percentage of shading. The sum of energy can be receive during whole day is computed with different array spacing.

$$\text{Energy no shading} = \text{Joule x (1- shading \%)} \tag{3.4}$$

Shading%

$$S = \frac{\cos(180\text{-}A)\sin\beta + \tan\alpha\cos\beta - \dfrac{D\tan\alpha}{l_{panel}}}{\tan\alpha\cos\beta + \sin\beta\cos(180 - A)} \tag{3.5}$$

where

S = a/L, % shaded of linear type shading along the length of panel

l_{panel} = length of panel or length of array looking from side

β = tilted angle from ground

α = sun altitude angle

A = sun azimuth angle

D = distance between two rows (sheds)

3.5.4 Levelized Cost of Energy / Electricity (LCOE)

The LCOE is calculated by adding capital cost and land cost divided by total energy generated in a year with different array spacing. The capital cost is the cost of solar module base on RM6 per watt. The total energy in a year is calculated by total solar module capacity multiple with performance ratio of 0.75, 1500 peak sun hour of solar irradiance and percentage of energy receive with different array spacing (Lim, 2015).

Joule per year (wh/y) = Energy no shading x G_a x N x P_{mp} x P.R (3.6)

where

Ga = Peak sun hour (1500h)

N = No. panel

P.R = performance ratio (0.75)

P_{mp} = Panel watt (260)

$$LCOE\ 25\ year = \frac{\sum Land\ cost\ in\ 25\ year + Capital\ cost}{\sum kwh\ for\ 25\ year} \quad (3.7)$$

Operation and Maintenance cost is not considered in this study.

CHAPTER 4

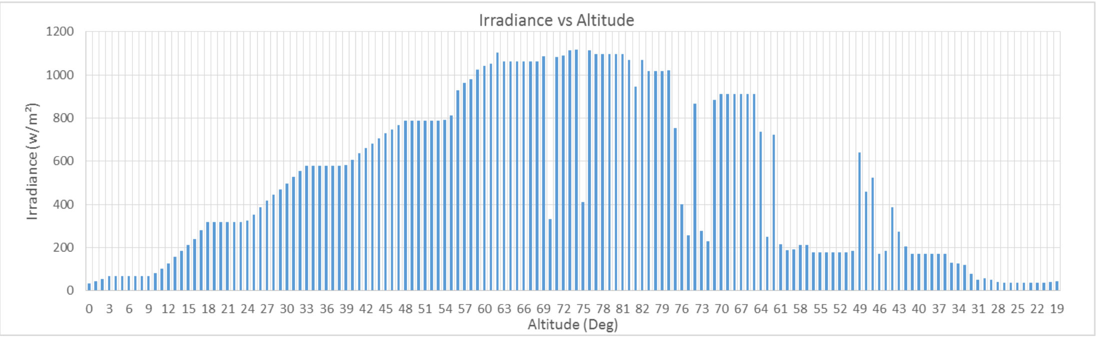
RESULT AND DISCUSSION

4.0 Introduction

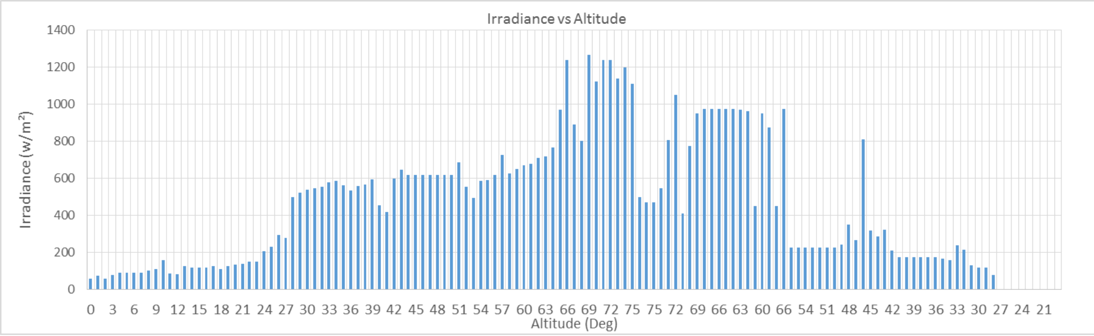
The irradiance data was collected on random day, started from January to March 2016. The data was collected for whole day period, which is from sunrise to sunset and further analysed according to energy available, energy loss for shading, ROI and LCOE to determine the optimum array spacing.

4.1 Solar Irradiance vs Solar Altitude Angle

Figure 4.1 shown that four day of data been collected and categorised according to altitude angle. The data been used is more on sunny day compare to cloudy day. The reason of doing so is due to Malaysia is more on sunshine day for long term period. However the data is only base on few particular day of data analysis, which is not sufficient enough due to time constraint. A year end long data collection should be carry out to have better accuracy and here we provide a method and example to show how the data should be collected and how the analysis should be done.



a) 12 March 2016



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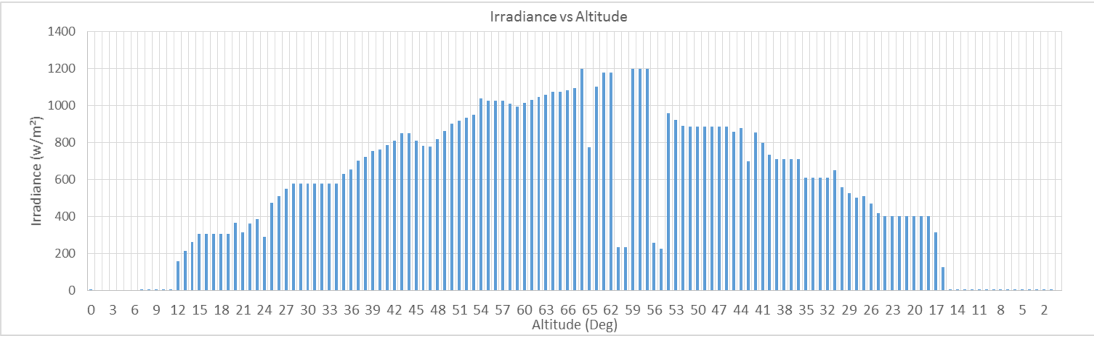

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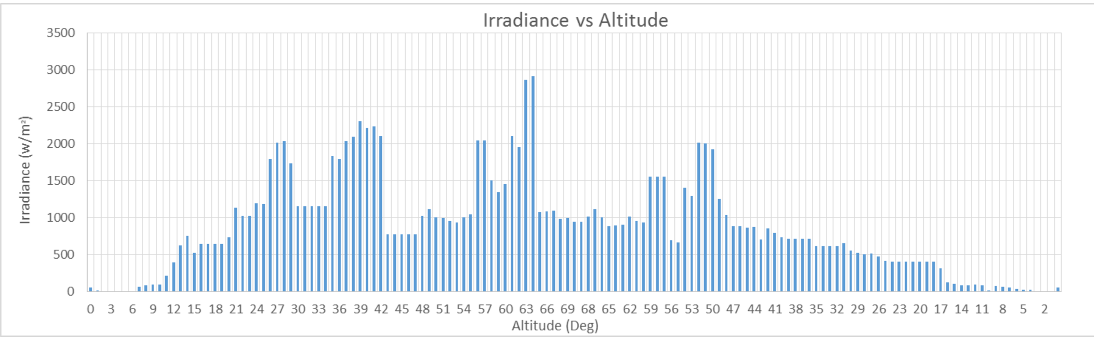
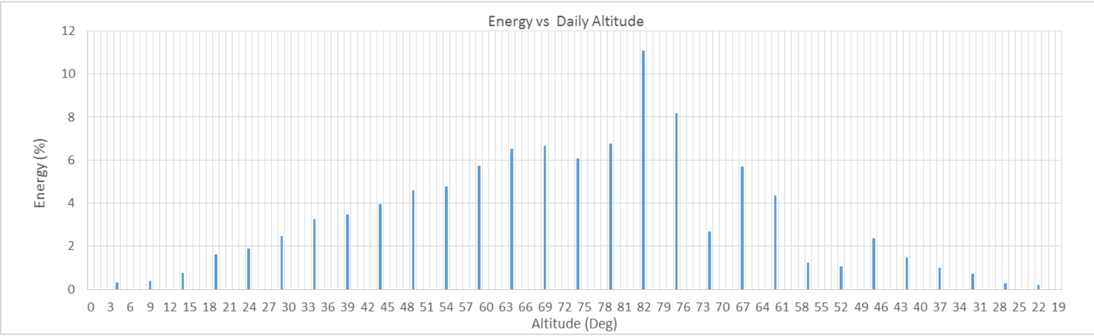


d) 23 January 2016

Figure 4.1 : Solar Irradiance vs Solar Altitude Angle

4.1.1 Percentage of Energy vs Daily Solar Altitude Angle

From the figure 4.2 irradiance data collection, every 5^{o} altitude of irradiance is average out. The average irradiance is multiple with time to show energy in joule. From the graph it shown that energy available was higher during morning compare to evening. During evening time the irradiance was not uniform and reduced at some altitude angle. This might due to sky clearness during evening time was effected by cloud or rain. The method of calculation used was from formula 3.1 to 3.3.



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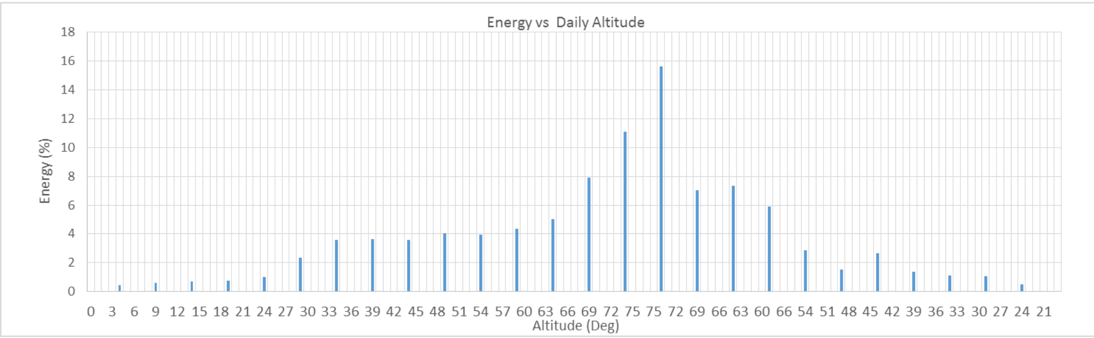

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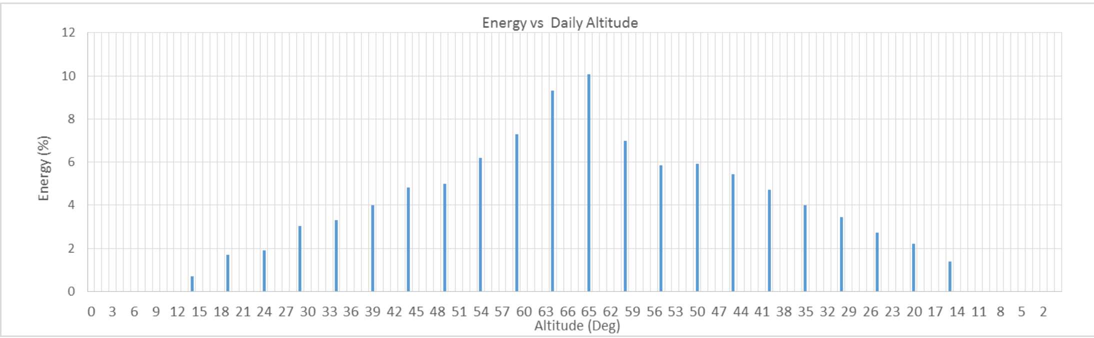

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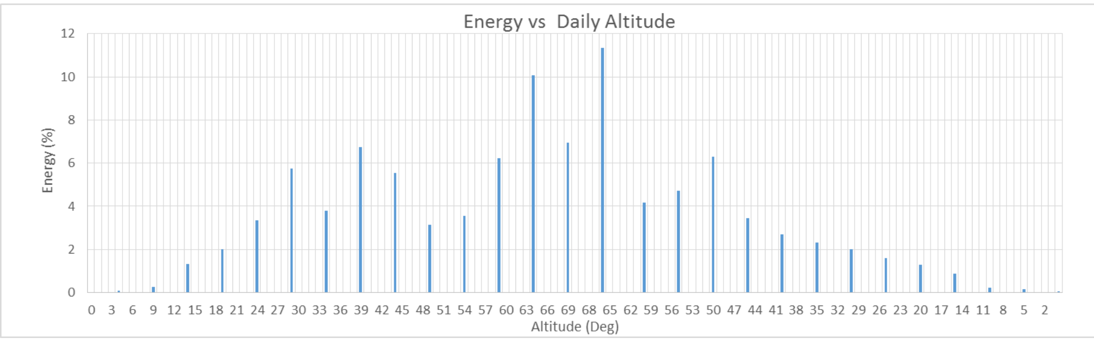
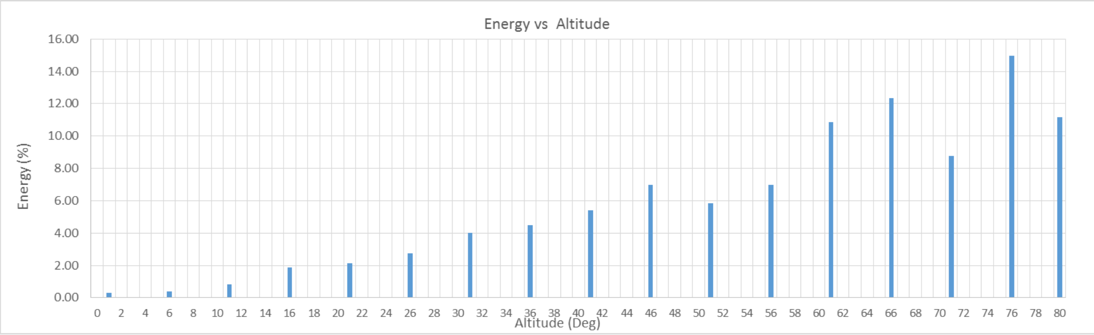


d) 23 January 2016

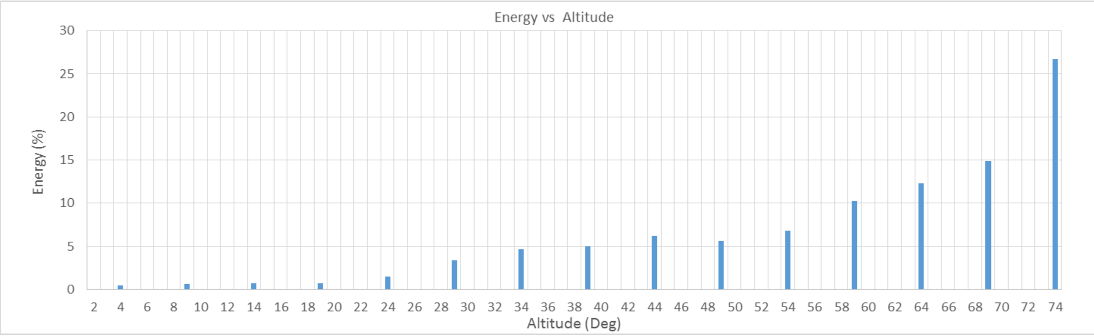
Figure 4.2 : Percentage of Energy vs Daily Solar Altitude Angle

4.1.2 Percentage of Energy vs Solar Altitude Angle

Figure 4.3 shown that the irradiance of same altitude angle for early morning and evening was combined to shown that for the same altitude angle the amount of energy that can be received for no shading. The reason of combined the same altitude angle for morning and evening is due to shading will not only will occur on morning but also at evening. This provide clearer view of percentage energy with respect to altitude angle.



a) 12 March 2016



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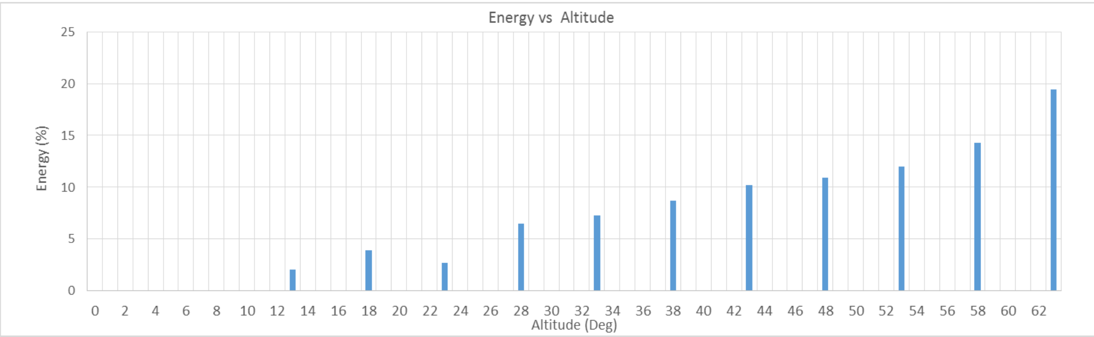

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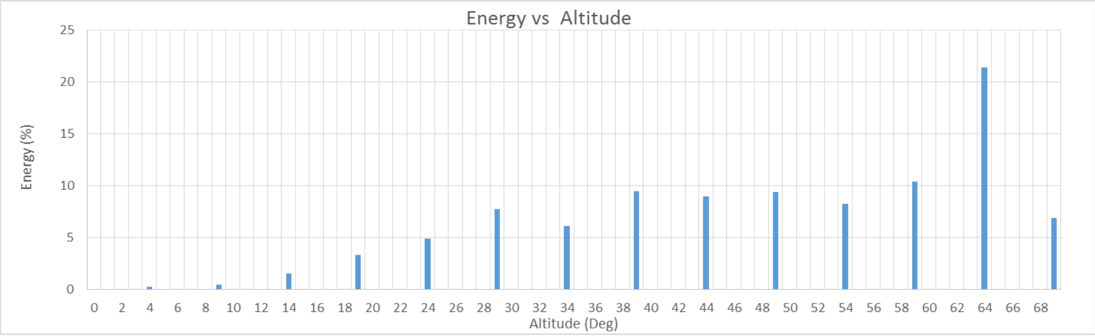
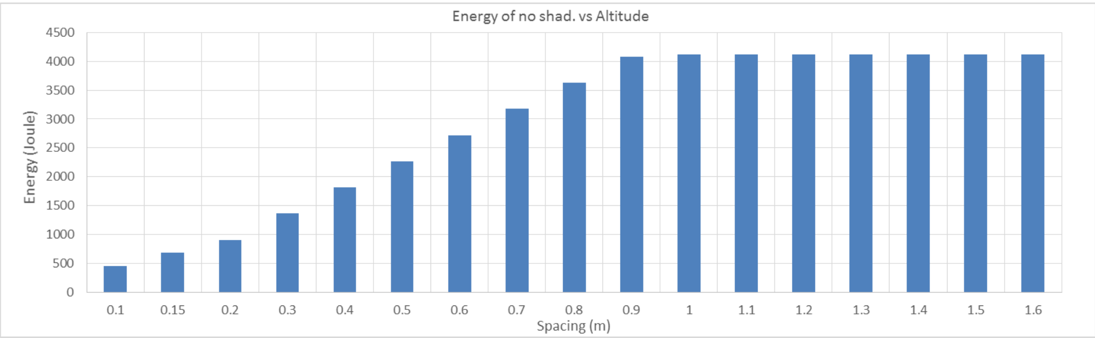


d) 23 January 2016

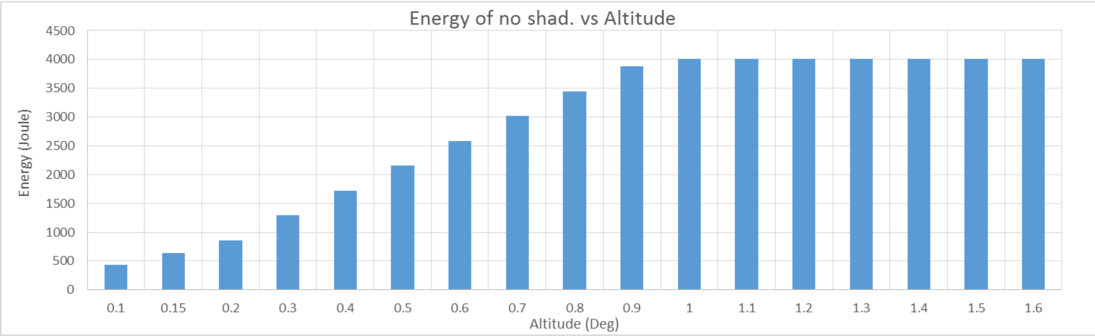
Figure 4.3 : Percentage of Energy vs Solar Altitude Angle

4.1.3 Energy of No Shading vs Array Spacing

Figure 4.4 shown that the percentage of energy that can be received for different array spacing. According to figure 4.4 24 February 2016, 0.8m of array spacing received 3445 joules which amounts to 85% of the energy available and a spacing of 0.9m results in 3876.51 joules of energy which amounts to 96% of the available energy. By increasing the gap from 0.8m to 0.9m the percentage of energy gained increased 11% however an increase from 0.9m to 1.0m results in an increment of only 3%. A further increase from 1.0m to 1.1m yields an energy increment of a mere 1%. The same result is also happened on other 3days, which shown that spacing of 0.9m will receive almost all the energy available and a further increase will not have any significant energy received. Thus it is concluded that 0.9m be the optimum distance between the solar arrays. The method of calculation used was form formula 3.4 and 3.5.



a) 12 March 2016



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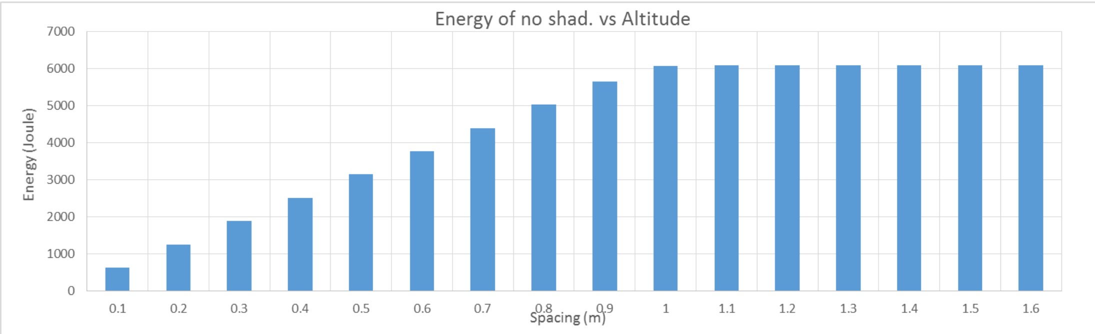
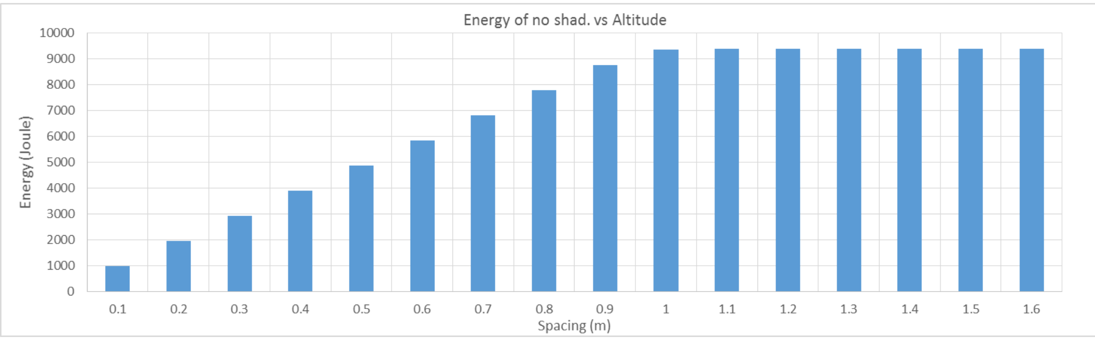


c) 24 January 2016



d) 23 January 2016

Figure 4.4 : Energy of no shading vs Solar Altitude Angle

4.2 Analaysis of Average day of percentage energy of irrdiance data

Table 4.1 shown that different days of solar irradiance energy of no shading due to different spacing was summed up and divide by total days of energy available. The table below shows the 7 days of irradiance data collected being averaged out to get percentage of energy.

Table 4.1 : Average day of percentage energy of irradiance data

Spacing (m)	24-Jan(J)	23-Jan(J)	3-Feb(J)	4-Feb(J)	24-Feb(J)	1-Mar(J)	12-Mar(J)	% E
0.1	628.3	973.7	258.3	313.6	615.4	368.8	453.4	0.111
0.2	1256.6	1947.3	516.6	627.3	1230.9	737.6	906.8	0.223
0.3	1884.8	2921.0	774.8	940.9	1846.3	1106.3	1360.2	0.334
0.4	2513.1	3894.6	1033.1	1254.6	2461.7	1475.1	1813.6	0.446
0.5	3141.4	4868.3	1291.4	1568.2	3077.1	1843.9	2267.0	0.558
0.6	3769.7	5842.0	1549.7	1881.8	3692.6	2212.7	2720.4	0.669
0.7	4397.9	6815.6	1807.9	2195.5	4308.0	2581.5	3173.8	0.781
0.8	5026.2	7789.3	2066.2	2509.1	4923.4	2950.3	3627.2	0.893
0.9	5654.5	8762.9	2324.5	2822.8	5538.9	3319.0	4080.6	1.004
1	6068.6	9348.9	2484.3	3010.6	5718.5	3410.4	4122.5	1.055
1.1	6093.0	9376.0	2491.1	3023.1	5722.0	3411.1	4123.1	1.058
1.2	6093.4	9378.1	2491.2	3024.5	5723.5	3411.6	4123.1	1.058
1.3	6093.5	9378.7	2491.2	3025.0	5724.7	3411.6	4123.1	1.058
1.4	6093.5	9379.2	2491.2	3025.5	5724.7	3411.6	4123.1	1.058
1.5	6093.5	9379.7	2491.2	3026.0	5724.7	3411.6	4123.1	1.058
1.6	6093.6	9380.0	2491.2	3026.1	5724.7	3411.6	4123.1	1.058

4.2.1 Average day of percentage energy receive with array spacing

Figure 4.5 below shows that when an array spacing is of 0.9m the energy received was almost 100%. Increasing the spacing between the array from 0.1m to 0.9m shows that the energy received was increases linearly with the increase in spacing. Any spacing above 1m was increase merely 1% to 2% and saturated.

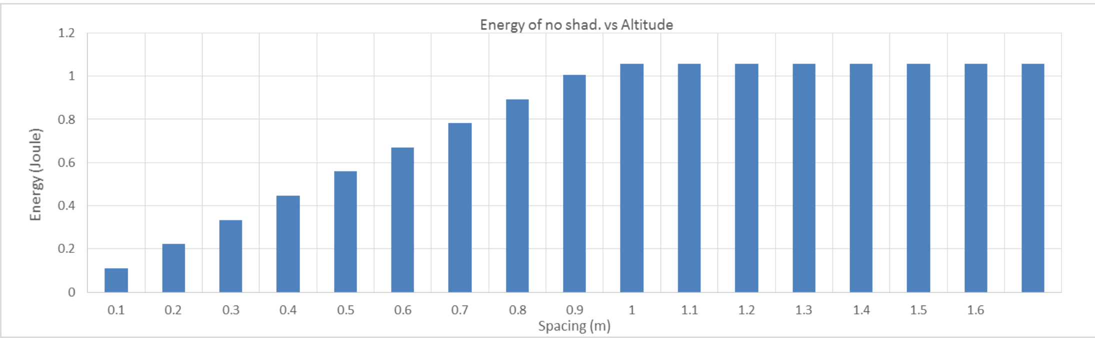


Figure 4.5 : Percentage Energy No Shading vs Different Array Spacing

4.2.2 Overall View of Irradiance Data Analaysis

From the result analysis shown that, 0.9m is the optimum spacing for solar array to have almost maximum energy generation. By increasing the distance from 0.9m above will increased 1% to 2% of energy output however if the distance was decreased from 0.9m to 0.8m the energy output will drop significantly around 11%. However, this result only based on 7day of average result. A year-end long irradiance data should be collect to have better accuracy.

4.3 Simulation analysis for a solar farm

The result of percentage energy that can be received due to the shading effect was simulated on a larger solar farm to have better view and comparison. The parameters which was altered for different analysis was the land size and land cost. The land size used ranged from $300m^2$ to $1000m^2$ and its cost ranged from $RM50/m^2$ to $RM600/m^2$. Figure 4.6 and 4.7 shown that the layout of solar farm simulation design.

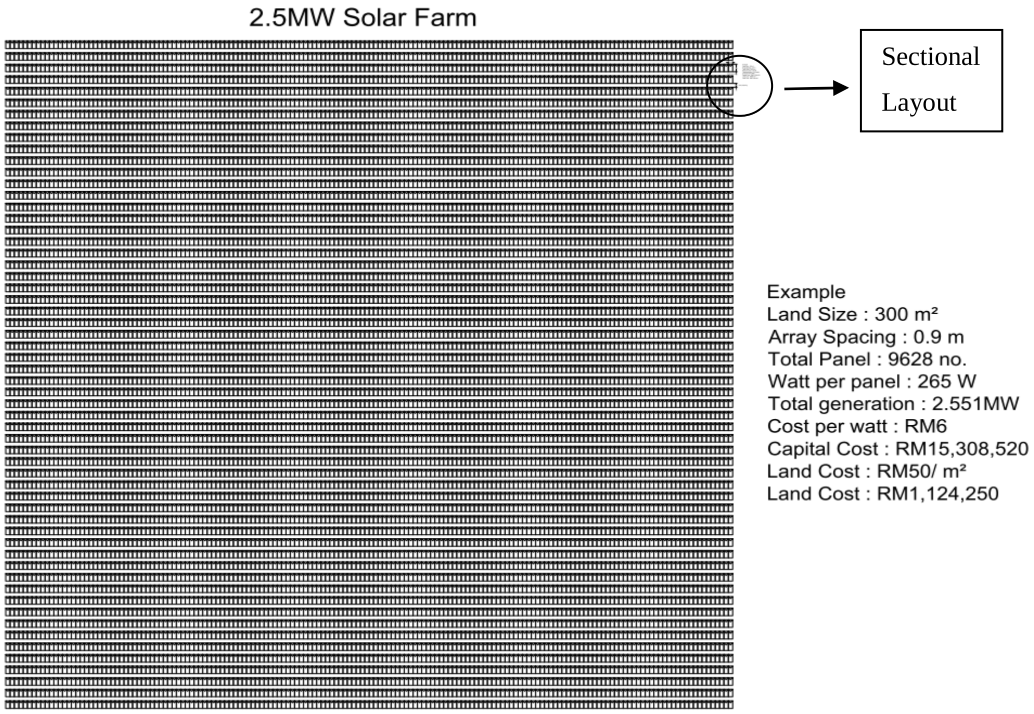


Figure 4.6 : Overall Layout of Solar farm simulation design

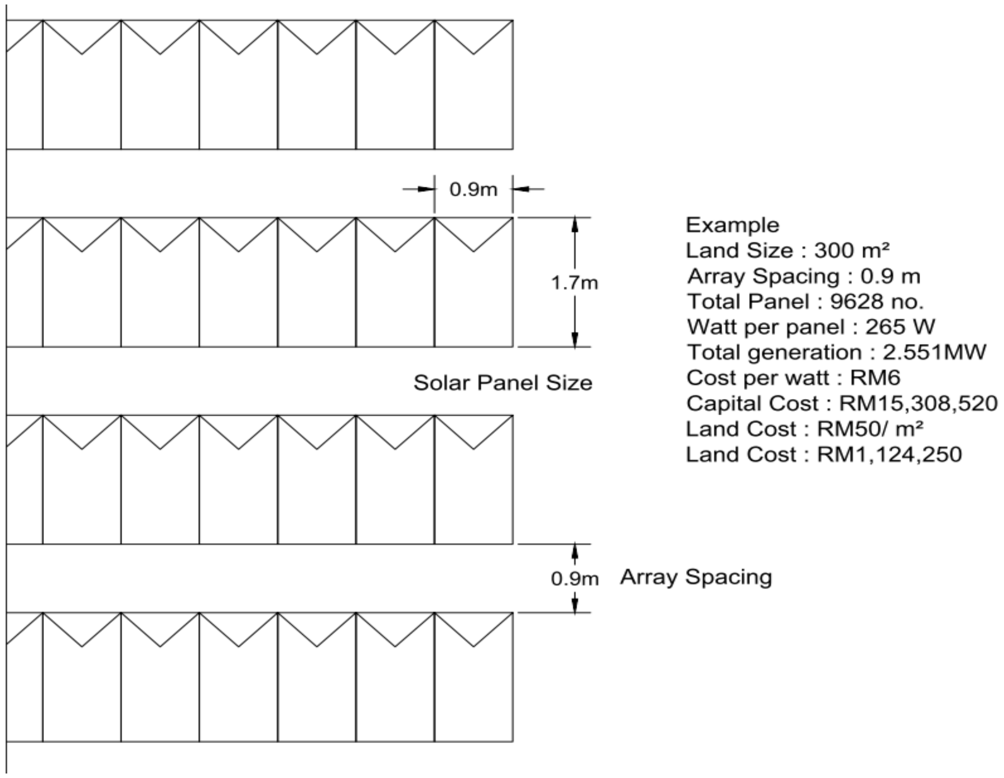


Figure 4.7 : Sectional Layout of Solar farm simulation design

4.3.1 Number of solar panel installed for the solar farm

The number of panels can be install in a land was calculated by assuming the solar panel was arranged in a row with portrait orientation. Each array consisted of only a row of portrait solar panel and spaced as required. The solar module size is 1.7m in length and 0.9m wide and the array spacing is ranged from 0.1m to 1.6m. The leftover land will be minus out to reduce land size required and as well reducing the land cost. Table 4.2 shows an example the amount of solar panels installed for a land size of 300m^2.

Land size : 300m^2.

Solar panel size : 1.7m x 0.9m = 1.53 m^2

Table 4.2 : Number of panels with different array spacing

Array Spacing (m)	Power installed (W)	No. of panel
0.1	3651170	13778
0.15	3563190	13446

0.2	3475210	13114
0.3	3299250	12450
0.4	3123290	11786
0.5	2991320	11288
0.6	2859350	10790
0.7	2727380	10292
0.8	2639400	9960
0.9	2551420	9628
1	2419450	9130
1.1	2331470	8798
1.2	2287480	8632
1.3	2199500	8300
1.4	2111520	7968
1.5	2067530	7802
1.6	1979550	7470

4.3.2 Energy generation per year for a solar farm

The energy production (Joule per year) was calculated based on the energy been installed multiply with the percentage of no shading. The value was further multiplied with the peak sun hour per year which is 1500 hour and performance ratio of 0.75. Table 4.3 below shows that the Joule per year produced base on the different solar array spacing.

Land size : 300m^2.

Table 4.3 : Energy generation per year with different array spacing

Array Spacing(m)	Power installed (W)	Joule per year (GJ)
0.1	3651170	0.425
0.15	3563190	0.830
0.2	3475210	1.214
0.3	3299250	1.537
0.4	3123290	1.819
0.5	2991320	2.090

0.6	2859350	2.331
0.7	2727380	2.541
0.8	2639400	2.767
0.9	2551420	2.859
1	2419450	2.720
1.1	2331470	2.621
1.2	2287480	2.572
1.3	2199500	2.473
1.4	2111520	2.374
1.5	2067530	2.325
1.6	1979550	2.226

Joule per year (wh/y) = Energy no shading x G_a x N x P_{mp} x P.R (4.1)

where

Ga = Peak sun hour (1500h)

N = No. panel

P.R = performance ratio (0.75)

P_{mp} = Panel watt (260)

(Lim,2015)

4.3.3 Capital Cost for solar farm

The capital cost was calculated based on the price per watt. It represents the cost in ringgit needed for producing one watt of electricity. The cost is inclusive of the cost of the solar module, inverter and other accessories which is needed to produce electricity. RM6 per watt was used for analysis (Lim,2015). The capital cost was calculated by multiplying total watt of solar generation with the price per watt. Table 4.4 shown the capital cost with different array spacing calculated.

Capital cost = N x P_{mp} x C (4.2)

Where

N = No. of Panel

P_{mp} = panel per watt

C = Cost per watt (RM6)

Land size : $300m^2$.

Table 4.4 : Capital cost with different array spacing

Array Spacing (m)	Power installed (W)	Capital Cost (RM)
0.1	425300338	21907020
0.15	830104275	21379140
0.2	1214411810	20851260
0.3	1537230139	19795500
0.4	1819055665	18739740
0.5	2090632989	17947920
0.6	2331465711	17156100
0.7	2541553830	16364280
0.8	2767014250	15836400
0.9	2859029605	15308520
1	2720333949	14516700
1.1	2621906048	13988820
1.2	2572573957	13724880
1.3	2473760574	13197000
1.4	2374928903	12669120
1.5	2325500306	12405180
1.6	2226543619	11877300

4.4 Anlaysis of LCOE and ROI

The solar farm was further analysed financially. LCOE and Return of Investment (ROI) was used as a measurement of financial viability. Operation and Maintenance cost is not considered in this study.

4.4.1 LCOE

The LCOE was calculated by adding up land cost in 25 years with inflation of 0.5% per year with capital cost and divide by energy generation joules in 25 years. Table 4.5 below shows the LCOE for land size of $300m^2$ and an array spacing of 0.9m.

$$LCOE\ 25\ year = \frac{\sum Land\ cost\ in\ 25\ year + Capital\ cost}{\sum kwh\ for\ 25\ year} \quad (4.3)$$

Table 4.5 : Example calculation of LCOE for 25years

Year	Land Cost (RM)	Gwh/y
1	1124250	2.859
2	1135520.606	2.836
3	1152638.721	2.813
4	1175864.969	2.790
5	1205557.033	2.768
6	1242178.853	2.746
7	1286312.718	2.724
8	1338674.707	2.702
9	1400134.038	2.681
10	1471737.077	2.659
11	1554736.915	2.638
12	1650629.686	2.617
13	1761199.098	2.596
14	1888571.01	2.575
15	2035280.376	2.554
16	2204353.46	2.534
17	2399408.998	2.514
18	2624782.941	2.494
19	2885682.65	2.474
20	3188377.997	2.454
21	3540438.871	2.434
22	3951031.197	2.415
23	4431287.005	2.395
24	4994768.469	2.376
25	5658051.62	2.357
Total	57301469	65017006812
	LOCE	0.0011168

4.4.2 Payback period vs Years for Different Spacing

Return of investment (ROI) was used to calculate the years of return investment. The investment was assumed with feed in tariff. The feed in tariff was provided by SEDA (Sustainable Energy Development Authority Malaysia) to help investors have better insight for their investment in solar renewable energy. The tariff of energy today is selling at RM0.4651 per kWh for the range of 1MW to 2MW. The solar energy is selling at RM0.4651 per kW for 25 years and each year the land cost is inflated by 0.5% and energy production drops at 0.8%. The price sold for generated energy is minus with inflated land cost and capital cost to be return in investment (ROI). The land size to installed was assumed at 300m^2 and the land cost per m^2 is at RM50. Figure 4.8 shown graph of ROI versus year.

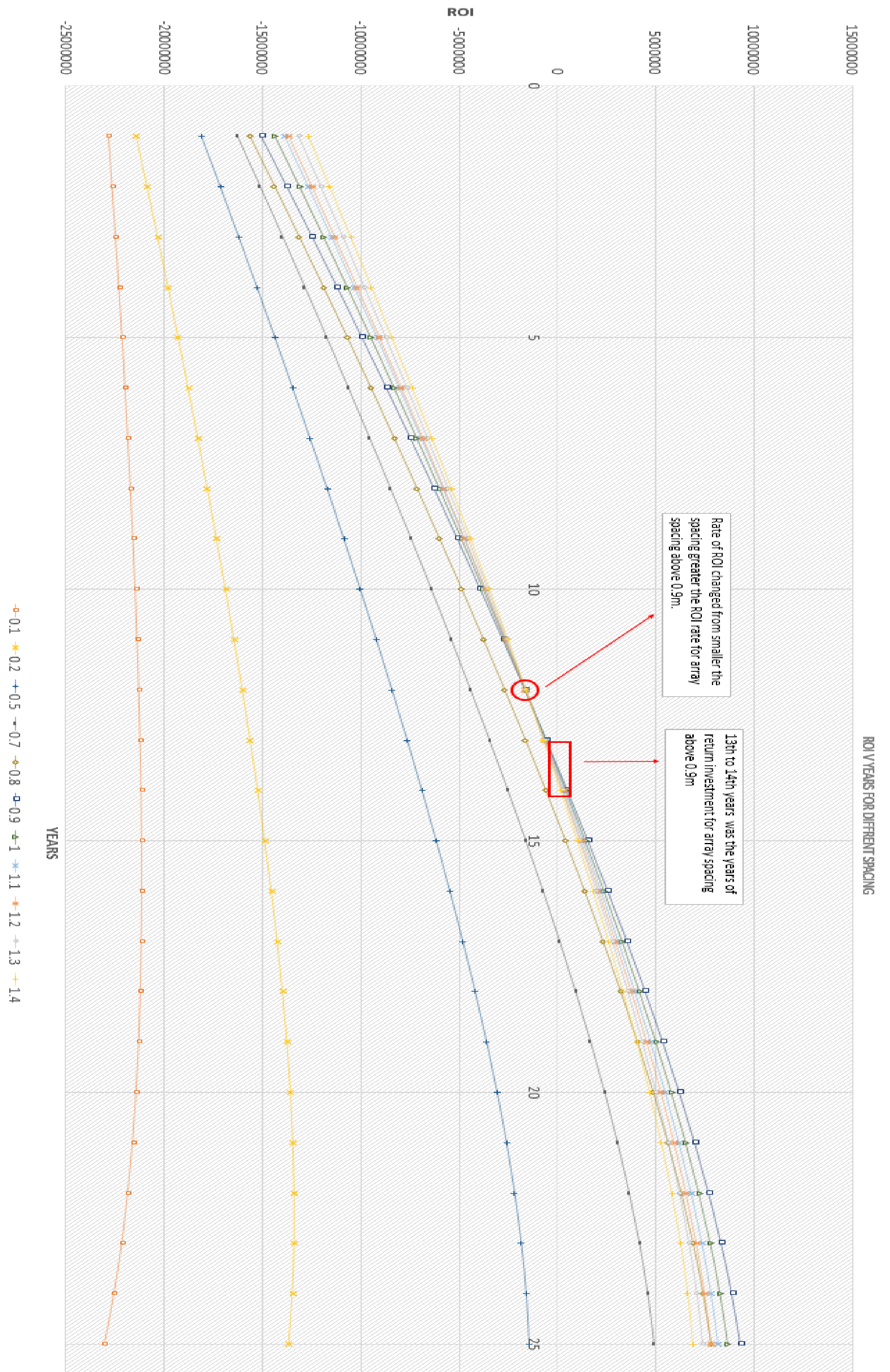


Figure 4.8 : ROI with different array spacing

Spacing from 0.1m to 0.8m shows that the rate of ROI increase linearly, the larger the spacing the fastest the ROI. Spacing beyond 0.9m does not have a linear increasing rate due to the panels having roughly the same energy received beyond that distance. Before 12^{th} year the rate of ROI is higher when the spacing is larger and it is due to the amount can be install for large spacing is less hence the capital cost is less and faster the ROI.

Rate of ROI before 12th year

1.4>1.3>1.2>1.1>1.0>0.9 (meter)

After the 12^{th} year the rate of ROI changing to the lesser the spacing the fastest the return and it is due to the profit from the power sales already covering up the capital cost and what really make the ROI different is the energy can be generate to sell.

Rate of ROI from 12^{th} year to 19^{th} year

0.9>1.0>1.1>1.2>1.3>1.4 (meter)

Between the 13^{th} to the 14^{th} year is the period where array spacing of 0.9m and above will have return of investment which means the profit of energy sold already cover up the capital cost and land cost.

At the year of 19^{th} the rate of profit of 0.8m spacing is faster than that of the 1.3m and 1.4m spacing and it is due to the amount of panels that could be installed. 0.8m spacing would result in 9960 panels installed compared to 1.3m's 8300 panel resulting in a difference of 1660 panel. For a land size of $300m^2$ a spacing of 0.1m to 0.7m would result in 10000 panels installed while a spacing of 0.8m to 1.0m would only see an installation of 9000 panels. For a spacing of 1.1m to 1.3m, the panels installed would further reduce to only 8000 panels while a spacing of 1.4m to 1.8m would see the amount drop to 7000.

Rate of ROI form 19^{th} year

0.9>1.0>1.1>1.2>0.8>1.3>1.4 (meter)

ROI = Profit of energy sells – land cost – capital cost (4.4)

Land cost = land area m^2 x land cost per m^2 (4.5)

Profit of energy sells = kwh x FIT (4.6)

where

FIT= Feed in Tariff (RM0.4651 per kwh)

(SEDA, 2016)

4.4.3 LCOE V Land price for land size of 300m2

By maintaining the same land size of 300m^2, the land cost per meter square was increased from RM50 to RM600 as shown in figure 4.9. We found that the lower the land cost, the lower the LCOE. The lowest value of LCOE for every land cost is 0.9m due to this distance giving the highest energy output for no shading. For lower land cost, spacing from 0.8m to 1.0m give almost the same LCOE due to the land's price not affecting much on the LCOE price.

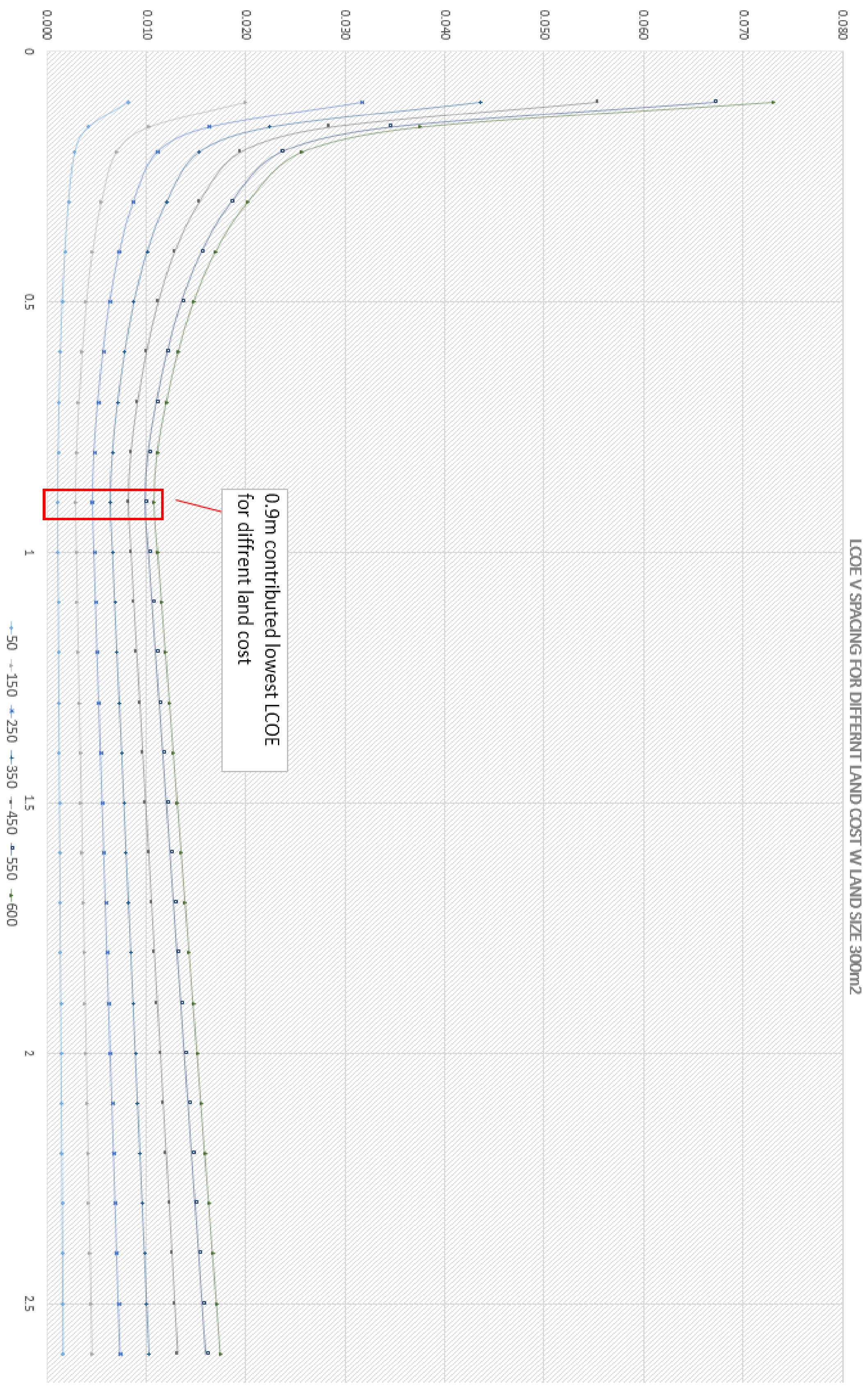


Figure 4.9 : LCOE with different Land Cost

Land cost = land area x land cost per m^2 (4.7)

Land cost inflation = land cost x 1.005^n (4.8)

where

n = year

1.005 = land rate per year

4.4.4 LCOE V Land size for land cost of 300/m2

By maintaining the same land cost of 300 per m^2, the land size was increased from 300m^2 to 1000m^2 as shown in figure 4.10. We found that the LCOE is almost the same for the different land size. This is due to the increase of land size also results in an increase in the number of panels installed. The total cost of increasing capital with land price divide with increasing of kwh/year results in almost the same LCOE for the different sized land.

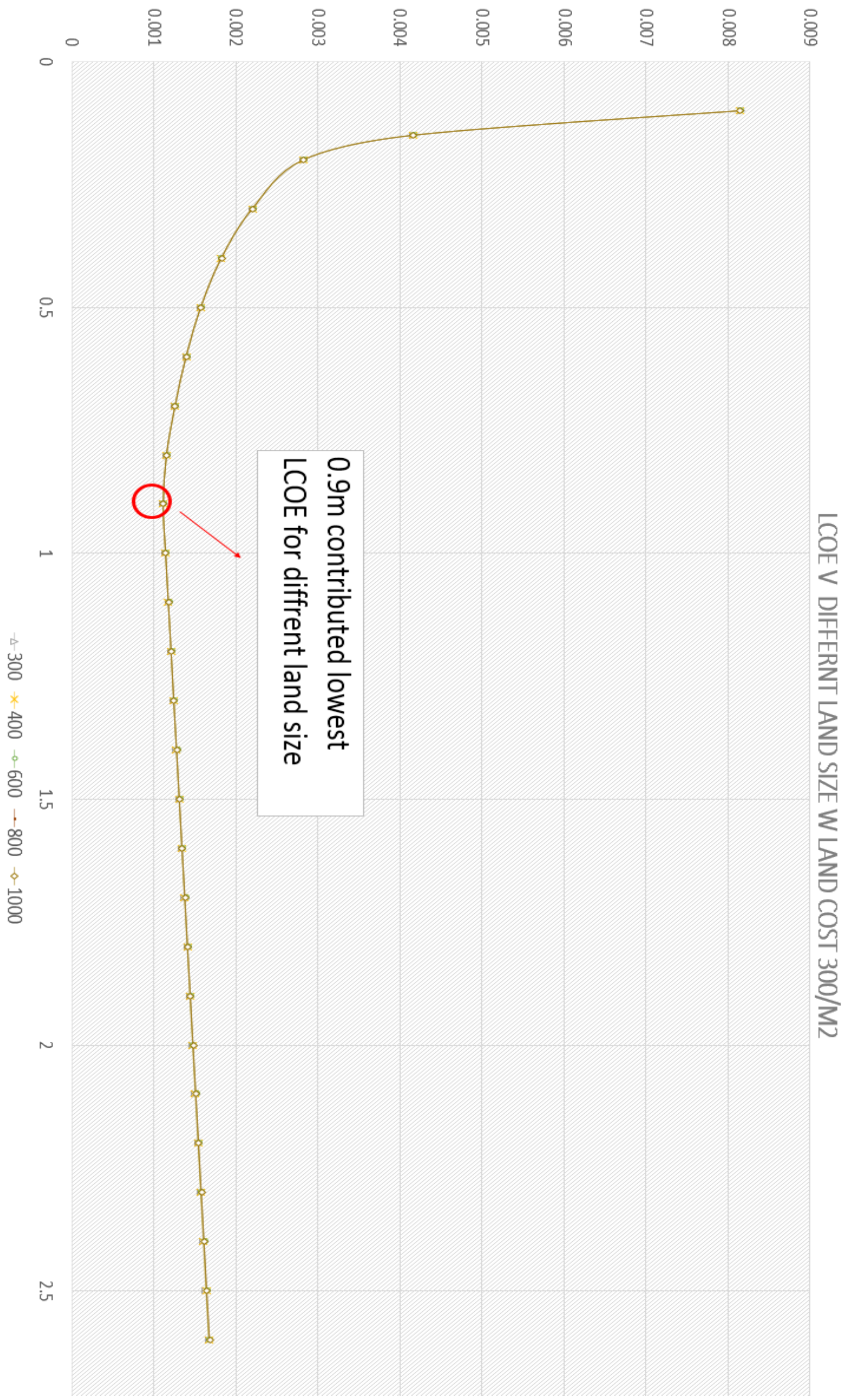


Figure 4.10 : LCOE with different Land Size

CHAPTER 5

CONCLUSION AND RECOMMEDNDATIONS

5.1 Conclusion

The main disadvantage for solar energy was the land required to be installed. One of the way to reduce the land required is reduce the spacing between solar arrays. The solar array spacing was for the purpose of shading effect but until today there is no proper study to determine the idea spacing for solar array in Malaysia.

In the simulation for solar farm, the solar panel use was 0.9m width and tilted with 5^{0} angle. The result shown from the average day of percentage energy, 0.9m is the optimum spacing for solar array to have almost maximum energy generation. By increasing the distance from 0.9m above will increase 1% to 2% of energy output however if the distance was decreased from 0.9m to 0.8m the energy output will drop significantly at 11%. In term of ROI 0.9m contribute more profit but slower return rate due to the capital cost was higher compare to larger array spacing. However after 12^{th} years 0.9m array spacing ROI rate start to surpass the larger spacing due to more solar energy been install and sold. The spacing lesser than 0.9m have low return rate due to solar panel have been shad and less energy generated . In term of LCOE 0.9m contribute the lowest value for land price and land size changed.

From the data analysis 0.9m is the optimum solar array spacing for highest energy generation and fastest ROI rate. If base on 12 march 2016 irradiance data collected, the solar array with 0.9m spacing does not have any further shading occur when the sun altitude angle was above 15^{o} and energy will be received in maximum. When sun altitude angle was on 1^{o} to 15^{o} there will be shading occur on solar module and the energy can be received is reduced however during that period the energy available was very less which does not contribute significant energy changed. If the spacing been reduced to 0.8m the sun altitude angle for no shading occur is above 27^{o} and there will be shading occur between 15^{o} to 27^{o} which was during significant energy moment. There was 17^{0} of sun altitude angle which amount to 40minute of significant energy loss compare to 0.9m. With length of solar panel 0.9m and tilt angle of 5^{o}, 0.9m is the minimum solar array spacing can be reduced. However the data is only base on few particular day of data analysis, which is not sufficient enough due to time constraint. A year end long data collection should be carry out to have better accuracy and here we provide a method and example to show how the data should be collected and how the analysis should be done .

5.2 Recommendations

Malaysia lack of sufficient ground measurement global horizontal solar irradiance database for solar energy research. The data which been used by today is based on satellite generated irradiance which is not accurate enough and there is lacking of direct and diffuse solar irradiance. If the data been collected for a long period such as a year we can plot the total irradiance data base on altitude angle and azimuth angle. The data will be presented in 3D form. The data will be useful for determine the best direction for solar panel to be install due to different irradiance distributed morning and evening. The data also can be useful to use as create a better model for solar simulation and research.

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APPENDICES

APPENDIX A : Datasheet of solar analyser PVPM 1040X

PVPM 2540C / 6020C / 1000C / 1000C40

Technical Data (subject to change)

Construction with sturdy metal housing, adjustable carrying handle, durable plastic foil front plate

Measurement and Evaluation Unit

Industrial class PC, Flash data storage 512MB (sufficient for several 1000 measurements)
No mechanically moved parts such as fixed disks, exhaust or similar
Sampling rate max. 100kHz, resolution 12Bit
Measuring accuracy for the I-V-characteristic better 1%, for the peak performance ±5%
Four-wire-measurement leads avoids systematic errors in voltage measurement
Measuring period single measurement below 2 seconds (100 pairs of measured values)
Irradiation reference sensor (Phox) with integrated Pt100/Pt1000 temperature sensor
Optional additional measurement of the back surface temperature of the module under test
Other commercially available irradiance reference sensors can be used

Measuring Range	*Voltage dc*	*Current dc*	*Temperature*	*Irradiance*
PVPM2540C	25 / 50 / 100 / 250 V	2 / 5 / 10 / 40 A	-40°C - +120°C with Pt1000	0 - 1300 W/m2 (Standard-Sensor)
PVPM6020C	25 / 100 / 300 / 600 V	2 / 5 / 10 / 20 A		
PVPM1000C	25 / 100 / 500 / 1000 V	2 / 5 / 10 / 20 A		
PVPM1000C40	25 / 100 / 500 / 1000 V	2 / 5 / 10 / 40 A		

The measuring ranges can be combined among each other.
The measuring instrument automatically selects an optimal measuring range.

Display

Large daylight-capable LCD with LED backlight, resolution 256 x 128 pixels, monochrome
Representation black text on white background, thus high contrast

Operation

Menu controlled by plastic foil keyboard directly at the device
Operation and analysis alternatively with MS-Windows® application, communication via RS232

Voltage Supply

Lead Acid accumulator 12V/3.4Ah (continuous operation 3h), optionally 12V/7.2Ah
External power supply with wide range input 90-264Vac, 47-63Hz, UL-approved, power 40W
Internal automatic battery charge controller with overloading protection
Display of the charge state over control LED at the front side of the housing

Dimensions

Width: 48cm, height: 16cm, depth: 35cm, weight: about 9.9kg (PVPM2540C), 10.9kg (PVPM1000C40)

Operating Conditions

	Temperature	*Dampness*
Operation	0°C to 40°C	10% to 90% (non-condensing)
Storage	-10°C to 85°C	5% to 95%

Scope of Supply

- Measuring instrument in sturdy metal housing with adjustable carrying handle
- Battery supply, external power supply for battery charging and line operation
- 4-wire-lead (10 meters, more on request)
- Standardised radiation sensor Phox and integrated temperature sensor Pt1000 with lead
- USB cable for linking an evaluation PC
- Control software for MS Windows® 2000, XP, Vista, 7
- Users Manual
- External Santon Security Switch 1000V / 32A
- Plastic case for leads and sensor

Optionally available

- Software for MS Windows for the automatic generation of test reports
- Test lead with 15 or 25 m (other lengths on request)
- Housing optionally as 19" rack mounting cover.

Warranty

We grant a warranty of 24 months starting from date of purchase on production and material defects as well as 12 months free updates of the firmware (download from Internet: www.pv-e.de)

Rev. 03/2011

PV-Engineering GmbH * Augustastraße 24 * DE-58644 Iserlohn * Germany * Tel: +49 (0)2371 1595347 * Fax: +49 (0)2371 1595348
e-mail: info@pv-engineering .de * www.pv-engineering .de

APPENDIX B: Data Sheet of Seaward meter

SEAWARD

SOLAR

www.seawardsolar.com

TECHNICAL SPECIFICATION:

GROUND CONTINUITY	
Display Range	0.00Ω to 199Ω
Measuring Range	0.01Ω to 199Ω
Resolution	0.01Ω maximum
Open Circuit Test Voltage	4VDC, nominal
Short Circuit Test Current	>200mA (as per IEC 61557-4)
Test Lead Compensation	Zero out up to 10Ω
User Protection	Warning and test inhibited if ≥ 30V AC/DC detected at inputs
INSULATION RESISTANCE	
Display Range	0.05MΩ to 199MΩ
Measuring Range	0.05MΩ to 199MΩ
Resolution	0.01MΩ maximum
Open Circuit Test Voltage	250V, 500V, 1000VDC (as per IEC 61557-2)
Short Circuit Test Current	>1mA, <2mA s/c as per IEC 61557-2
Visible Warning	≥ 30V AC or DC at inputs
OPEN CIRCUIT VOLTAGE	
Display Range	0.0VDC to 1000VDC
Measuring Range	5.0VDC to 1000VDC
Resolution	0.1V maximum
Enunciators	DC voltage polarity correct or reversed
SHORT CIRCUIT CURRENT	
Display Range	0.0ADC – 15.00ADC
Measurement Range	0.5ADC – 15.00ADC
Resolution	0.01A
OPERATING CURRENT (USING AC/DC CURRENT CLAMP)	
Display Range	0.0A – 40A
Measurement Range	0.5A – 40A
Resolution	0.1A max
DC OPERATING POWER	
Display range	0.0kW – 40.0kW
Measurement ranges	0.1kW – 40.0kW
Resolution	0.1kW
DATALOGGING AND CONNECTIVITY	
Datalogging	Up to 200 complete test datasets Download utility software included Compatible with SolarCert Elements software (version 1.1)
Connectivity	USB download to PC Wireless 'Solarlink™' to Survey 200R (range c. 100m / 330ft)
GENERAL SPECIFICATIONS	
Display	Custom LCD with backlight
Power Supply	6 x 1.5V Alkaline LR06
Battery Life	>1000 test sequences
Auto Power Down	User programmable
ADDITIONAL INFORMATION	
Warranty Period	2 years (Terms and conditions apply. Go to www.seawardsolar.com/register-product for details)
Calibration Interval	1 year **UKAS Calibration Certificate supplied as standard**

Part No: 388A913 Rev 1.1

ACCESSORIES: (optional)

- MC3 test lead adaptors
- Tyco (TE) Sunlok test lead adaptors
- Fused test leads - 1 pair of fused red and black test probes with alligator clips
- SolarTags
- PV Inspection & Test Report and PV System Verification Certificate Pads

Seaward, Bracken Hill, South West Industrial Estate, Peterlee, County Durham SR8 2SW United Kingdom

Tel: +44 (0) 191 586 3511
Fax: +44 (0) 191 586 0227
Email: sales@seaward.co.uk

SEAWARD

SOLAR

www.seawardsolar.com

TECHNICAL SPECIFICATION:

GROUND CONTINUITY

Display Range	0.00Ω to 199Ω
Measuring Range	0.01Ω to 199Ω
Resolution	0.01Ω maximum
Open Circuit Test Voltage	4VDC, nominal
Short Circuit Test Current	>200mA (as per IEC 61557-4)
Test Lead Compensation	Zero out up to 10Ω
User Protection	Warning and test inhibited if ≥ 30V AC/DC detected at inputs

INSULATION RESISTANCE

Display Range	0.05MΩ to 199MΩ
Measuring Range	0.05MΩ to 199MΩ
Resolution	0.01MΩ maximum
Open Circuit Test Voltage	250V, 500V, 1000VDC (as per IEC 61557-2)
Short Circuit Test Current	>1mA, <2mA s/c as per IEC 61557-2
Visible Warning	≥ 30V AC or DC at inputs

OPEN CIRCUIT VOLTAGE

Display Range	0.0VDC to 1000VDC
Measuring Range	5.0VDC to 1000VDC
Resolution	0.1V maximum
Enunciators	DC voltage polarity correct or reversed

SHORT CIRCUIT CURRENT

Display Range	0.0ADC – 15.00ADC
Measurement Range	0.5ADC – 15.00ADC
Resolution	0.01A

OPERATING CURRENT (USING AC/DC CURRENT CLAMP)

Display Range	0.0A – 40A
Measurement Range	0.5A – 40A
Resolution	0.1A max

DC OPERATING POWER

Display range	0.0kW – 40.0kW
Measurement ranges	0.1kW – 40.0kW
Resolution	0.1kW

DATALOGGING AND CONNECTIVITY

Datalogging	Up to 200 complete test datasets Download utility software included Compatible with SolarCert Elements software (version 1.1)
Connectivity	USB download to PC Wireless 'Solarlink™' to Survey 200R (range c. 100m / 330ft)

GENERAL SPECIFICATIONS

Display	Custom LCD with backlight
Power Supply	6 x 1.5V Alkaline LR06
Battery Life	>1000 test sequences
Auto Power Down	User programmable

ADDITIONAL INFORMATION

Warranty Period	2 years (Terms and conditions apply. Go to www.seawardsolar.com/register-product for details)
Calibration Interval	1 year UKAS Calibration Certificate supplied as standard

Part No: 388A913 Rev 1.1

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