SHADING ANALYSIS FOR THE SITING OF SOLAR PV POWER PLANT

Vinodh Annathurai, Chin Kim Gan, Kyairul Azmi Baharin, and Mohd Ruddin Ab. Ghani
Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Melaka, Malaysia
E-Mail: viha168@gmail.com

ABSTRACT

Solar Photovoltaic (PV) system is environmentally-friendly which could reduce the consumption of electricity from the non-renewable energy sources. However, the generation of the PV system is highly dependent on weather conditions. More specifically, the shading of PV modules is a common phenomenon which can affect the performance of the PV system. Hence, this paper aims to establish relationship between the distance of a PV plant from a building object and its associated height. To achieve this, the Solar Pro software is used to simulate the shading conditions and estimate the PV systems's output. For validity, the data of PV energy, total irradiation, Peak Sun Hour and performance ratio obtained from the simulation were compared with the Meteonorm software. The findings from this research suggest the relative distance of a PV plant should be located in relationship to its nearest building object. It is expected that such findings will provide a good rule-of-thumb for the solar PV system designer in selecting the viable project site.

Keywords: PV system, shading assessment, PV yield.

INTRODUCTION

At present, the electrical energy plays an important role in our daily life. Most of the electrical energy is produced by fossil fuels and nuclear energy. Since these kinds of energy sources are exhaustible, many countries have started to promote and utilise the renewable energy. Among all the renewable energy resources, solar Photovoltaic (PV) has the highest attention in Malaysia. Subsequently the Feed-in-Tariff (FiT) was introduced. This is to encourage the uptake of solar PV system in both residential and commercial sectors. However, few main factors are still influencing the performances of the PV system. The shading phenomenon is one of the main problems that decrease the PV performances. There are many types of shading phenomena in a PV system, and it can be divided into the following categories after long time surveys and observation on one large ground-based grid connected PV system [1]. The surrounding plant and guano (bird drop) shading phenomenon, the front row shading phenomenon, the nearby power distribution room and wire pole shading phenomena [2,3]. The shading in the photovoltaic can effect in disproportional high losses in performance. Shaded solar cells are frequently driven in the negative voltage range. The annual loss in a performance in some systems is more than 10% [4,5]. The influence of cell shading on electrical parameters is the short circuit current, open circuit voltage V_{oc}, fill factor, maximum power point P_{MPP} and efficiency [4,5,6]. A PV system comprises of many PV modules that are connected in series and parallel way. If the array layout is irrational or there are shades around the arrays, shading will occur in some modules [7]. In practical condition, a module with shading in a long series will not generate photovoltage, while other modules in the same series still produce voltage normally. So there is a current going through this shaded module [2,3,8].

In this regard, this research aims to study the shading effect on PV module by using Solar Pro simulation tool. This research is to identify the suitable distance between the surrounding building and solar power plant which minimizes the shading factor. In addition the distance of the surrounding building from the power plant and the height of surrounding building are considered as the shading phenomenon. The case study considers the solar panel to face towards the South and designed in Melaka with the coordinate of 2.2ᵒN, 102.25ᵒE. This paper consists of 3 main sections. The first section explains the research background and the objective of the research. The second section describes the methodology used in this paper for shading analysis. Section 3 interpreted and explained the result by representing it in tables, graphs, and diagrams. Last section provides the summary work and conclusion for this work.

METHODOLOGY

This section discusses the methods used and the assumption made in carrying out the study of this work. The house-shape building size is 20m by 20m which is kept constant with the varied height and placed in east and west direction of the solar plant. The PV power plant is only designed for the size of 400m², 1,600m², 3,600m², 6,400m² and 10,000m² with the maximum capacity of 16.2kW, 58.32kW, 126.36kW, 233.28kW and 356.40kW respectively. The details are provided in the subsequent sections.
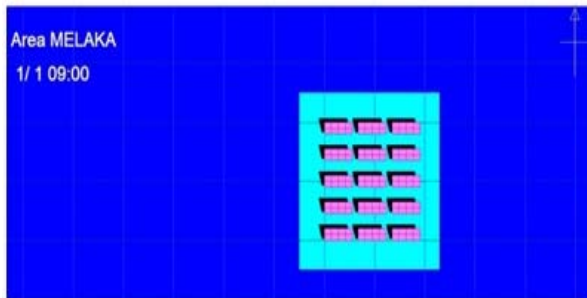
Layout of the solar power plant

Photovoltaic systems use solar panels for converting the sun irradiance power into electricity in the form of DC power. Each solar power application is uniquely designed, taking into consideration specific influences such as climate condition, system capacity, and installation location and shading analysis [8]. The main aim of considering these factors is to enhance the performance. Table-1 shows the technical parameters of the PV power plant. Figure-1 shows the layout of 20m by 20m solar power plant with the maximum capacity of

16.2kW was designed in the coordinate of 2.2ºN, 102.25ºE using the Solar Pro software. The Sharp brand solar module was used in this designing process where PV module faces towards the South direction. The surface area of the power plant is 400m^2 which is around 0.0988 acres (approximate 0.1 acres). The same method is used to design different sizes of solar power plant. This simulation was carried out during 5am-8pm.

Table-1. Technical parameters.

Parameters	
Brand	Sharp [9]
Module	NA-V135H5 [9]
Module Size,mm	1409x1009x46 [9]
Capacity,W	135 [9]
Tilt angle,degree	10 [10,11,12,13]
Direction	Facing South [10]
Coordinate	2.2ºN, 102.25ºE(Melaka)

Figure-1. The layout of 20m by 20m solar power plant

Table-2 shows the size of the solar power plant and total number of PV modules required with total capacity of the plant. The length and width increases constantly in unit metre. The maximum numbers of PV modules where Sharp brand with model number NA-V135H5 (135W) are arranged in the different area of the power plant[14,15].

Table-2. Size of power plant with the parameters.

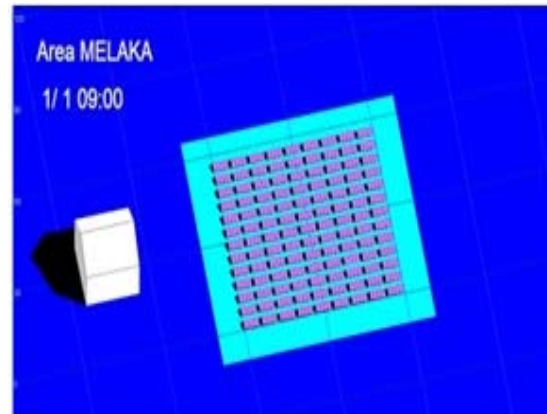| Length, m	Width, m	Area, m^2	Area, Acre	No. PV Modules	Total Capacity, kW
20	20	400	0.10	120	16.20
40	40	1600	0.40	432	58.32
60	60	3600	0.89	936	126.36
80	80	6400	1.58	1728	233.28
100	100	10000	2.47	2640	356.40

Designed building beside the power plant (Varied Distance)

Figure-2 and Figure-3 show the house shaped building is designed beside the varied size of the power plant. The size of the building which is 20 meter by 20

meter was kept constant throughout the analysis. The distance between the PV power plant and the building was increased constantly until obtained the zero shading factor.

Figure-2. 20m by 20m building beside the 20m by 20m PV power plant.

Figure-3. 20m by 20m building beside the 80m by 80m PV power plant.

RESULT

This research utilized Solar Pro software version 4.1 for the shading analysis. The data obtained from the simulation are compared with the standards, published journals, papers and previous experiments. All the data gathered from the simulation such as PV energy, peak sun hour, total irradiation and performance ratio were declared as valid and compatible for the coordinates of Melaka [15,16,17].

The 20m by 20m building built in left of the power plant and the height and distance of the building is varied to obtain the zero shading factor in the PV power plant. The building height starts with 10m (Table-3) and zero meter distance which is nearest to the PV power plant. Table-3 to Table-7 shows the various heights of the building and the PV energy obtained.

Table-3. Height of the building (10m).

Distance from PV Plant,m	PV Energy, kWh/kWp	PV Energy (no shading), kWh/kWp	Energy Reduction, %
0	995.09	1248.46	20.29%
10	1167.97	1248.46	6.45%
20	1217.55	1248.46	2.48%
30	1236.83	1248.46	0.93%
40	1242.76	1248.46	0.46%
50	1244.44	1248.46	0.32%
60	1245.79	1248.46	0.21%
70	1246.69	1248.46	0.14%
80	1247.41	1248.46	0.08%
90	1247.73	1248.46	0.06%
100	1247.9	1248.46	0.04%
110	1248.05	1248.46	0.03%
120	1248.23	1248.46	0.02%
130	1248.46	1248.46	0.00%

Table-4. Height of the building (20m).

Distance from PV Plant,m	PV Energy, kWh/kWp	PV Energy (no shading), kWh/kWp	Energy Reduction, %
0	946.13	1248.46	24.22%
10	1103.98	1248.46	11.57%
20	1177.49	1248.46	5.68%
30	1201.2	1248.46	3.79%
40	1231.54	1248.46	1.36%
50	1238.78	1248.46	0.78%
60	1235.33	1248.46	1.05%
70	1238.45	1248.46	0.80%
80	1244.11	1248.46	0.35%
90	1245.93	1248.46	0.20%
100	1246.11	1248.46	0.19%
110	1246.98	1248.46	0.12%
120	1247	1248.46	0.12%
130	1247.49	1248.46	0.08%
140	1247.63	1248.46	0.07%
150	1247.89	1248.46	0.05%
160	1247.93	1248.46	0.04%
170	1248.03	1248.46	0.03%
180	1248.15	1248.46	0.02%
190	1248.24	1248.46	0.02%
200	1248.36	1248.46	0.01%

Table-5. Height of the building (30m).

Distance from PV Plant,m	PV Energy, kWh/kWp	PV Energy (no shading), kWh/kWp	Energy Reduction, %
0	926.89	1248.46	25.76%
10	1062.65	1248.46	14.88%
20	1143.6	1248.46	8.40%
30	1191.39	1248.46	4.57%
40	1218.11	1248.46	2.43%
50	1230.08	1248.46	1.47%
60	1232.45	1248.46	1.28%
70	1235.79	1248.46	1.01%
80	1240.89	1248.46	0.61%
90	1244.52	1248.46	0.32%
100	1245.01	1248.46	0.28%
110	1246.21	1248.46	0.18%
120	1246.7	1248.46	0.14%
130	1247.06	1248.46	0.11%
140	1247.21	1248.46	0.10%
150	1247.5	1248.46	0.08%
160	1247.62	1248.46	0.07%
170	1247.67	1248.46	0.06%
180	1247.69	1248.46	0.06%
190	1247.71	1248.46	0.06%
200	1247.73	1248.46	0.06%
210	1248.08	1248.46	0.03%
220	1248.16	1248.46	0.02%
230	1248.28	1248.46	0.01%
240	1248.38	1248.46	0.01%
250	1248.39	1248.46	0.01%
260	1248.41	1248.46	0.00%
270	1248.46	1248.46	0.00%

Table-6. Height of the building (40m).

Distance from PV Plant,m	PV Energy, kWh/kWp	PV Energy (no shading), kWh/kWp	Energy Reduction, %
0	917.08	1248.46	26.54%
10	1045.97	1248.46	16.22%
20	1121.9	1248.46	10.14%
30	1143.42	1248.46	8.41%
40	1211.08	1248.46	2.99%
50	1221.09	1248.46	2.19%
60	1228.91	1248.46	1.57%
70	1231.02	1248.46	1.40%
80	1239.43	1248.46	0.72%
90	1241.12	1248.46	0.59%
100	1242.35	1248.46	0.49%

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110	1243.79	1248.46	0.37%
120	1246	1248.46	0.20%
130	1246.7	1248.46	0.14%
140	1246.9	1248.46	0.12%
150	1247.11	1248.46	0.11%
160	1247.25	1248.46	0.10%
170	1247.35	1248.46	0.09%
180	1247.51	1248.46	0.08%
190	1247.58	1248.46	0.07%
200	1247.62	1248.46	0.07%
210	1247.75	1248.46	0.06%
220	1247.86	1248.46	0.05%
230	1247.93	1248.46	0.04%
240	1248.11	1248.46	0.03%
250	1248.21	1248.46	0.02%
260	1248.29	1248.46	0.01%
270	1248.35	1248.46	0.01%
280	1248.41	1248.46	0.00%
290	1248.46	1248.46	0.00%

180	1247.12	1248.46	0.11%
190	1247.31	1248.46	0.09%
200	1247.38	1248.46	0.09%
210	1247.43	1248.46	0.08%
220	1247.52	1248.46	0.08%
230	1247.61	1248.46	0.07%
240	1247.73	1248.46	0.06%
250	1247.86	1248.46	0.05%
260	1247.98	1248.46	0.04%
270	1248.16	1248.46	0.02%
280	1248.35	1248.46	0.01%
290	1248.41	1248.46	0.00%
300	1248.46	1248.46	0.00%

Table-7. 10m Height of the building (50m).

Distance from PV Plant,m	PV Energy, kWh/kWp	PV Energy (no shading), kWh/kWp	Energy Reduction, %
0	913.08	1248.46	26.86%
10	1023.6	1248.46	18.01%
20	1115.13	1248.46	10.68%
30	1163.19	1248.46	6.83%
40	1197.93	1248.46	4.05%
50	1212	1248.46	2.92%
60	1223.72	1248.46	1.98%
70	1232.67	1248.46	1.26%
80	1237.1	1248.46	0.91%
90	1238.45	1248.46	0.80%
100	1239.39	1248.46	0.73%
110	1242.32	1248.46	0.49%
120	1244.53	1248.46	0.31%
130	1245.93	1248.46	0.20%
140	1246.1	1248.46	0.19%
150	1246.25	1248.46	0.18%
160	1246.87	1248.46	0.13%
170	1246.93	1248.46	0.12%

The height of the building is increased gradually and the PV energy is recorded. The final distance is recorded when the PV energy same as free shading PV energy[18,19].

20m by 20m PV power plant

The simulation begins with the 20m by 20m PV power plant and the specific PV energy and the energy reduction were recorded. Table A1 shows the 10m height of the building and the PV energy obtained. The specific PV energy for free shading is 1248.46kWh/kWp. The simulation was carried out for five different heights of buildings with the distance which results in zero shading factor or the amount of free shading PV energy.

Figure-4 and Figure-5 show the graph with PV energy and the percentage of the energy reduction, respectively in the 20m by 20m size of PV power plant with various the distance of the building from the power plant.
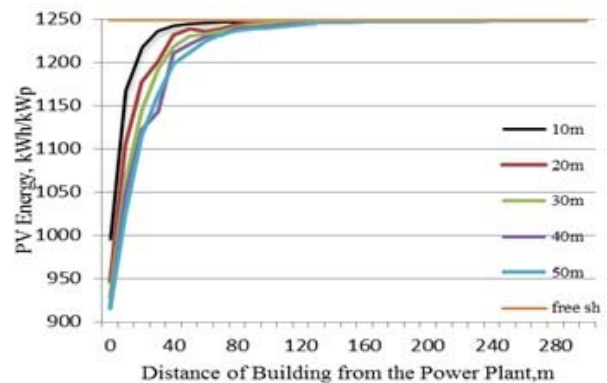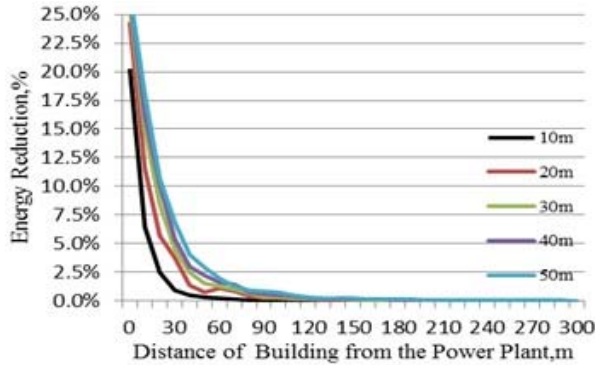

Figure-4. PV energy versus distance of building from the 20m by 20m power plant.

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Figure-5. PV energy reduction versus distance of building from the 20m by 20m power plant.

The yield of 20m by 20m building size with the height of 10m at 0m distance from the power plant is 995.09kWh/kWp and for the 50m height of the building the PV energy declines to 913.08 kWh/kWp. When the distance is constant and the height of the building increases the PV energy decreases. Besides, the energy reduction is higher for the height of 50m building compared to the height of the 10m building.

Table-8 shows the height of the building with a distance of 20m by 20m PV power plant with no shading. When the height of the building is 10m, the distance from the PV power plant is 60m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 100m, 130m,160m, and 200m respectively.

Table-8. Height of the building with a distance of 20m by 20m PV power plant with no shading.

Size PV plant: 20m X 20m					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	60	100	130	160	200

From the data obtained, for the size of 20m by 20m PV power plant with the capacity of 16.20kW, the distance from the power plant is four to six times of the height of 20m by 20m size of building.

Different sizes of PV power plant

Table-9 shows the height of the building with the distance of 40m by 40m from the PV power plant with no shading. When the height of the building is 10m, the distance from the PV power plant is 50m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 90m, 125m, 170m, and 190m respectively.

Table-9. Height of the building with a distance of 40m by 40m PV power plant with no shading.

Size PV plant: 40m X 40m					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	50	90	125	170	190

From the data obtained, for the size of 40m by 40m PV power plant with the capacity of 58.32kW, the distance from the power plant is 3.8 to 5 times of the height of the 20m by 20m building.

Table-10 shows the height of the building with the distance of 60m by 60m PV power plant. When the height of the building is 10m, the distance from the PV power plant is 45m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 80m, 120m, 150m, and 160m respectively.

Table-10. Height of the building with a distance of 60m by 60m PV power plant with no shading.

Size PV plant: 60m X 60m					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	45	80	120	150	160

From the data obtained, for the size of 60m by 60m PV power plant with the capacity of 126.36kW, the distance from the power plant is 3.2 to 4.5 times of the height of the 20m by 20m size of building.

Table-11 shows the height of the building with the distance from the 80m by 80m PV power plant with no shading. When the height of the building is 10m the distance from the PV power plant is 40m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 70m, 100m, 125m, and 130m respectively.

Table-11. Height of the building with a distance of 80m by 80m PV power plant with no shading.

Size PV plant: 80m X 80m					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	40	70	100	125	130

From the data obtained, for the size of 80m by 80m PV power plant with the capacity of 233.28kW, the

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distance from the power plant is 2.6 to 4.0 times of the height of the 20m by 20m size of building.

Table-12 shows the height of the building with the distance of 100m by 100m PV power plant with no shading. When the height of the building is 10m the distance from the PV power plant is 35m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 70m, 95m, 115m, and 120m respectively.

Table-12. Height of the building with a distance of 100m by 100m PV power plant with no shading.

Size PV plant: 100m X 100m					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	35	70	95	115	120

From the data obtained, for the size of 100m by 100m PV power plant with the capacity of 356.40kW, the distance from the power plant is 2.4 to 3.5 times of the height of the 20m by 20m size of building.

Table-13 shows the distance of the building from the PV power plant in terms of the multiplication of the height. When the size of the PV power plant increases, the distance of the building from the PV power plant in terms of the multiplication of the height decreases. The building with the length of 20m and the width of 20m only give a huge impact to the smaller size of the power plant. The bigger size of the power plant like 60m by 60m, 80m by 80m and 100m by 100m is not affected much in its yield with the present of the building.

Table-13. Distance of the building from the PV power plant in terms of the multiplication of the height.

Building size is 20m by 20m with varied height						
Size of the PV power plant, m	Distance of the building from the PV power plant, multiples of the height					
	Height of Building, m					
	10	20	30	40	50	Range
20 x 20	6.0	5.0	4.3	4.0	4.0	**4 to 6**
40 x 40	5.0	4.5	4.2	4.3	3.8	**3.8 to 5**
60 x 60	4.5	4.0	4.0	3.8	3.2	**3.2 to 4.5**
80 x 80	4.0	3.5	3.3	3.1	2.6	**2.6 to 4**
100 x 100	3.5	3.5	3.2	2.9	2.4	**2.4 to 3.5**

CONCLUSIONS

Shading of photovoltaic modules is a widespread phenomenon which affects the performances of the PV system. The distance and height of the building located next to the solar power plant may cause shading and affects the performance of the PV. This paper identifies the suitable distance of a solar PV plant that should be located from the surrounding buildings. This is to achieve a low or zero shading factor by both considering the distance and height of the buildings.

The analysis of shading factors is carried out with the aid of Solar Pro software which considers the year-round sun trajectory in estimating the PV plant output performance under shading condition.

Peak Sun Hour, PV energy, irradiation, sun path diagram and performance ratio were considered and validated against the real data. The results obtained suggest the distance of a solar plant that should be located away from the surrounding buildings. The presented studies show that for a 20m by 20m power plant, the distance of the building from the PV plant should be the multiple of 4 to 6 of the height of the building. In addition, the distance of the building for 40m by 40m, 60m by 60m , 80m by 80m and 100m by 100m PV power plants are 3.8 to 5, 3.2 to 4.5, 2.6 to 4 and 2.4 to 3.5, respectively, with the multiples of the building.

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