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Determination of Optimal Elevation of Silicon Bifacial Solar Panel

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Abstract

In this paper, bifacial PV module was characterized to investigate the optimum height and tilt angle of bifacial solar cells in Baghdad location. The module elevation is a key factor in bifacial PVs because of the effect of self-shading on the amount of diffuse and albedo that can hit the rear side of the panel. This elevation is a function of latitude, daylight time, and season, which is never been determined before in Baghdad location up to our knowledge. Various heights above the ground were used (100, 120, 140, and 160cm), and for each height several tilt angles were taken (0°, 12°, 30°, 49°, and 70°). Data were collected in several days of November, 2020. PV parameters were characterized at each condition. Rated power of the panel showed an increase when elevation increases from 100cm to 120cm then tends to level off at 140cm and 160cm heights. This result suggests that the optimal elevation of a bifacial PV panel in Baghdad city location is 120cm. The results also showed that 49° gives the best photovoltaic performance. This can be elucidated by the seasonal effect. Since the measurements were done in winter, the optimal tilt angle should be 49° according to Baghdad latitude.

1. Introduction

Ever since the efficiency of solar panel reached the higher value ever, the researches aim to find and additive power harvest from solar photovoltaic cells. The researchers studied for an extra harvest energy converted from irradiance of direct solar intensity rays and from diffused irradiance at once. Silicon bifacial cell has been industrialized since early at 1980 [1]. Cuevas *et. al*. (1982) have been worked at bifacial module and got 50% more output power than monofacial module [2]. Castillo *et. al.* (2015) studied the effect of minimum height module ratio, tilt angle and ground albedo on the ground on annual energy output in six different experiments sites in USA [3]. Kreinin *et. al.* (2010) have developed a model simulating the back irradiance of the panel [4]. Although, they do not explain how their model is built, the numerical simulation fits – with a maximum divergence of 8% - to the experimental data.

Most solar cells are actually intrinsically bifacial, but the back side contacts prevent the light from reaching the cell from rear side. Figure (1) shows a schematic structure of monofacial and bifacial cells [5].

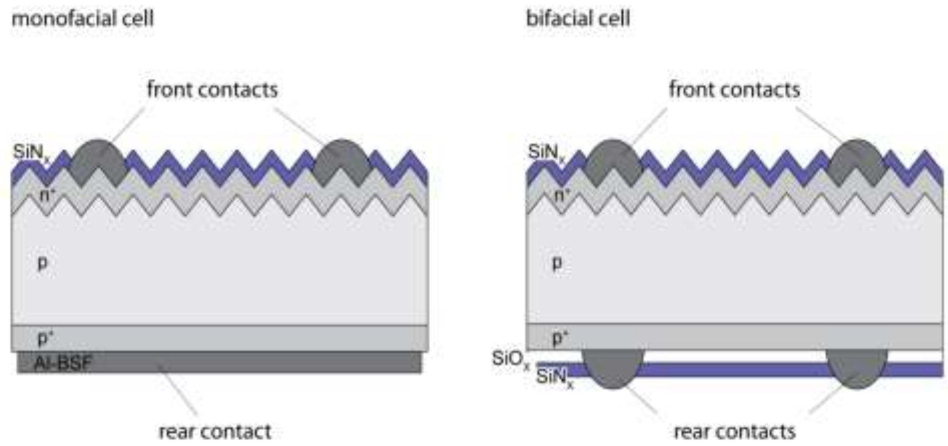

Figure (1). Schematic structure of monofacial and bifacial cell [5].

Bifacial Parameters Effectiveness

There are three design parameters that can be studied to increase the effectiveness of bifacial module and generate additional power and to increase the efficiency as well, these parameters are: elevation, azimuth angle, and tilt angle whereas the type of ground affects on diffuse radiation when reflects to the rear side of the bifacial panel. The bifacial PV module elevation might be an important parameter for maximum power module output. Hence, the ultimate power will increase for prioritize increasing of this type of module within same dimensions (via higher energy density and conversion efficiency) [6]. Therefore, elevation is an important design parameter to optimize the performance of bifacial module. However, the elevation continues to increase, and the loss due to self-shading decreases gradually until its effect is negligible [7]. Elevation of the module is a key factor along with the tilt angle, in determining the power production of the module [8]. The inhomogeneous irradiance distribution at the rear of the module influences the choice of the best tilt angle for bifacial modules. On the other hand, the azimuth angle effectiveness can produce more power energy according to the mounting module direction, for instance, two peaks will appear one in the morning, and the other in the evening when the azimuth direction is set to the west or to the east as shown in Figure (2) [6].

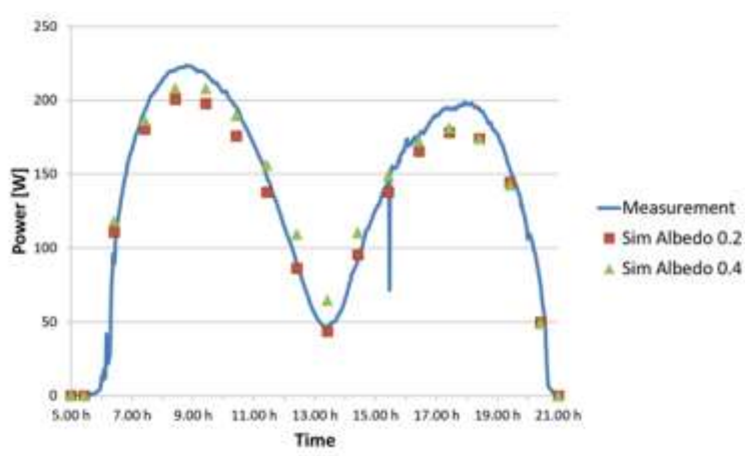

Figure (2). The azimuth angle behavior on the vertical bifacial installation.

Likewise, the tilt angle orientation of the module is very common option for bifacial type, the tilt angle is chosen to maximize the annual energy yield of the system, and varying tilts represent the optimal orientation of the individual bifacial module for the entire study [9].

In Middle East where the experiments were conducted. It was also noted that energy yield increases in summer compared to winter as the shadow of the modules on the roof surface depends on the seasonal position of the sun.

In summer, more direct sunlight is hitting the ground, and therefore reflected on the back of the modules. When diffuse sunlight dominates (in winter), the influence of the shading on the ground is less important [4]. The optimum tilt angle that maximizes the annual energy yield of the module is dependent on the latitude, the albedo and the elevation of the module [8]. The value of the optimum tilt angle decreases with the module elevation until a certain limit. Orientation is also depending on the elevation of the module [10]. The effect of self-shading is less severe with high elevation, and a smaller tilt angle allows taking a better advantage of the reflective irradiance [6].

The main thrust of this study is to maximize the incident solar radiation on a bifacial PV panel by optimizing the height and tilt angle of bifacial PV module, and to determine the optimum height required to install a bifacial PV panel in Baghdad location.

2. Experimental Procedure

High efficiency bifacial monocrystalline PV panel donated to us from Baghdad Renewable Energy and Sustainability Center was used in this study. The used panel is 1.9m × 0.9m bifacial panel with 72 bifacial cells each is 0.156m × 0.156m in dimensions. The two sides of the cell are connected in parallel, while the 72 cells are connected in series. The module is designed with 3 protection diodes and 3 busbars. A photograph of the front and rear sides of the panel is shown in Figure (3).

Front Side **Rear Side**

Figure (3). A photograph for the front and rear sides of the panel.

The photovoltaic parameters namely: maximum output power (Pm), maximum current (Im), maximum voltage (Vm), open circuit voltage (V_{OC}), and short circuit current (I_{SC}) according to the STC conditions are listed in Table (1). These specifications are demonstrated on the panel's nameplate.

The bifacial module fixed on a steal structure frame with adjustable height and angle in order to control the module optimum height and angle as shown in Figure (4). The installed bifacial panel is oriented to the south. Different heights above the ground where used (100, 120, 140, and 160cm), and for each height several tilt angles were taken (0°, 12°, 30°, 49°, and 70°). Data were collected in several days of November 2020.

Table (1). Photovoltaic parameters of the used bifacial PV panel.

Pm (W)	380
Vm (V)	43.7
Im (A)	8.71
Voc (V)	53.67
Isc (A)	9.32
PCE (%)	19.4

Figure (4). The bifacial solar panel oriented with two different tilt angles.

The photovoltaic parameters of the bifacial panel under real operation conditions were determined by using a portable photovoltaic system tester (SPI–ARRAY TESTER TM 5000) device shown in Figure (5-a). Solar radiation, tilt angle, and panel surface temperature for each reading were recorded instantaneously using a sensor type Solar-4000 equipped from Amprobe Instrument Corporation as shown in Figure (5-b).

(a) **(b)**

Figure (5). Instruments used to measure the photovoltaic parameters: (a) solar array tester, and (b) radiation, temperature, and tilt angle sensor.

3. Results and Discussion

Tilt angle of a PV panel varies with location and season because sun altitude is a function of location and time throughout the year. In Baghdad city, the optimum tilt angle at each month is shown in Table (2). For a fixed PV frame, average tilt angle of 33° is used, whereas an adjustable PV frame is set at different tilt angles for each month (e.g. 17° in July and 49° in November). This is because the altitude angle of the sun is high in summer and low in winter as described in Table (2) [11].

Table (2). Optimum tilt angle of a PV panel for each month in Baghdad [11].

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Optimal Angle	49°	41°	33°	25°	17°	10°	17°	25°	33°	41°	49°	56°	33°

Figure (6) presents the effect of tilt angle on the output power of the bifacial PV panel measured in November 4th, 2020 at two different heights. The figure shows a maximum output power at 49° tilt angle, which coincides precisely with data in Table (2). Power at smaller tilt angles (i.e. 0° and 12°) is significantly low.

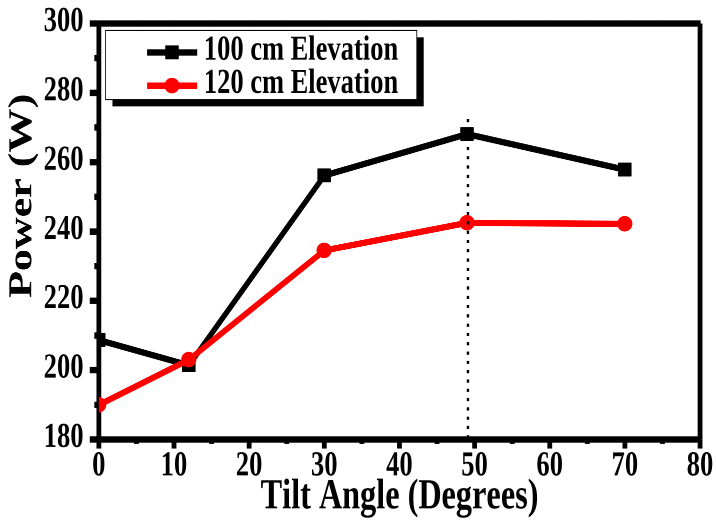

Figure (6). Output power of bifacial PV panel as a function of panel's elevation measured in Nov. 4th, 2020.

Elevation of bifacial PV panel from the ground is a crucial parameter on PV performance, because the shadow pattern changes with height [12]. Low elevations (< 100 cm) can cause a self-shading, while high elevations add additional costs to the installation [6]. The rear side of bifacial PV panel receives the diffuse and albedo radiation [13]. At low elevations, the amount of both diffuse and albedo lights reaching the rear side of the panel is small. As we lift the bifacial panel higher, more diffuse and albedo will reach the rear side and the self-shading diminishes, which leads to more generated power. At a certain elevation, shadow pattern reaches to a constant illumination density from albedo and diffuse, so the generated power will reach its rated value where any increase in height will no longer affect the photo generation. This height is greatly affected by the location of the installed PV panel. In Baghdad (33.3152° N, 44.3661° E Coordinates), no study has been performed to determine such height. Figure (7) illustrates the Isc and Voc variation with elevation of bifacial PV panel at 49° tilt angle. The choice of tilt angle is based on the data in Table (2), where data are collected in November. The lowest height used in the experiment was 100cm because of the limit due to panel's length (2m). The Isc shows a higher value at 100cm elevation, then drops steeply for higher elevations then tends to increase. This fluctuation in results could be attributed to the fluctuation in illumination density in the partially cloudy weather. The Voc values show insignificant change because Voc is not a function of illumination density [14].

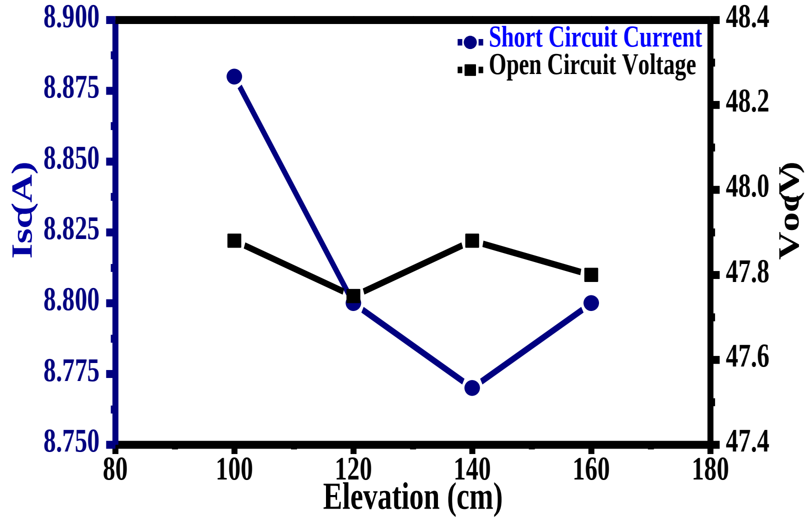

Figure (7). The Isc and Voc of bifacial PV panel collected at various elevations (at 49° tilting angle).

The variation of output power and power conversion efficiency (PCE) of the bifacial PV panel with elevation are presented in Figure (8). It is obvious from this figure that both power and PCE decrease to their minimum value at 140cm elevation. Since the current drops to the minimum value at 140cm as shown in Figure (7), whereas the voltage exhibits unnoticeable change, the power will drop to its minimum, since power is the multiplication of each current and voltage, and PCE takes the same behavior since PCE is directly proportional to power.

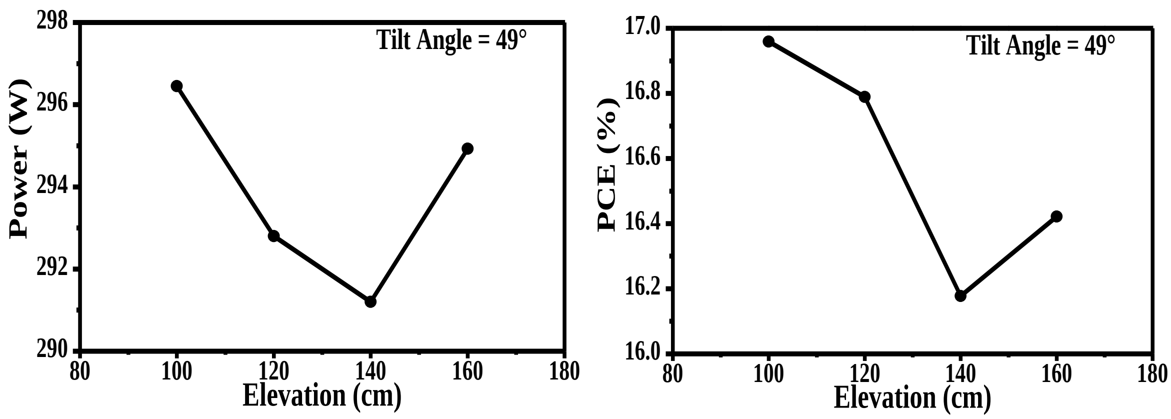

Figure (8). Output power and PCE of bifacial PV panel calculated at various elevations (at 49° tilting angle).

Figure (9) depicts the rated power of the bifacial PV panel in the inverted configuration (i.e. the rear side facing sun). The regular configuration is stacked along with the inverted configuration for comparison reasons. The inverted configuration gives lower power than the regular configuration and this is ascribed to the lower illumination during measurements. Moreover, the power shows an increase when elevation increases from 100cm to 120cm then tends to level off. This result suggests that the optimal elevation of a bifacial PV panel in Baghdad city location is 120cm.

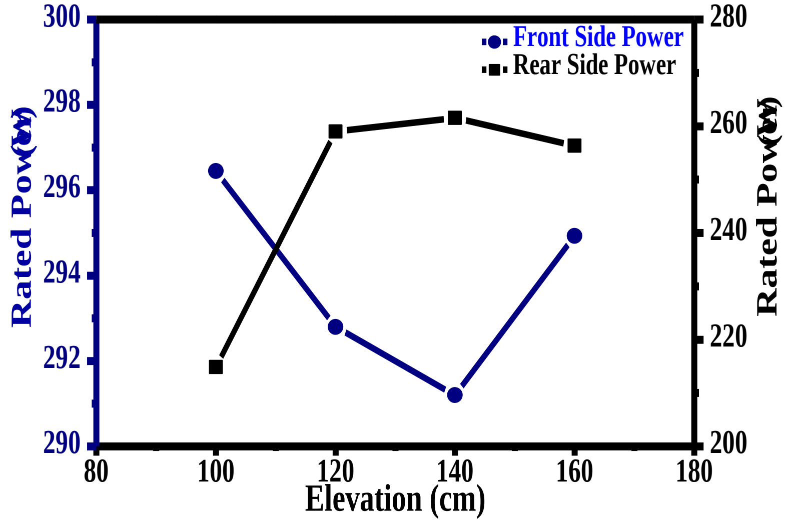

Figure (9). Rated power of rear (black) and front (blue) sides collected at various elevations (49° tilting angle).

4. Conclusions

Bifacial PV panels can be used to introduce more electrical power by harvesting the diffuse and albedo radiation that hit the rear side of the panel. The value of output power of the bifacial PV panel is affected by the tilt angle and panel's elevation. Optimum tilt angle is correlated with the location and time of the year. The elevation of the bifacial panel in Baghdad city is set to be 120cm (the distance between the lower edge of the panel and the ground. Further elevation will not cause any gain in power, but it will add additional cost on the frame and brings stability issues, especially in the windy weather.

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