Performance assessment of conceptual bifacial solar PV system in varying albedo conditions

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Abstract: There is a rapidly growing interest in bifacial module based solar PV. Unlike conventional solar PV modules, the energy output of the bifacial PV module is affected by the reflectance of the ground surface (albedo). This paper aims to assess the performance of conceptual bifacial solar PV systems in varying albedo conditions. Besides, the comparison of energy generation between monofacial and bifacial solar PV system is carried out. In this regard, four sites on an educational campus having different albedo factor is chosen. The annual energy output, specific yield, and performance ratio are estimated using PVSyst simulation software. The energy output of 164.5 MWh/year is predicted for the minimum albedo factor of 0.15. While 175.8 MWh/year is expected for the maximum albedo factor of 0.85. The specific yield for Case 5 (bifacial) is 10.58 % higher than that estimated for Case 1 (monofacial). Based on annual energy generation, the site of Case 4 is the best location for the solar PV system among the studied cases. It is concluded that setting up of bifacial solar PV module on the ground surface with a high value of albedo factor is suitable to maximize energy generation.

Keywords: Albedo; Bifacial PV Module; Specific Yield; Performance Ratio; PVSyst.

1. Introduction
Solar PV systems are widely employed in renewable energy technology for the past decades. As per the IRENA report, the installed capacity of the solar PV system crossed 580.159 GW in 2019, and the share of solar PV system reached 22 % of the installed capacity of renewable energy systems [1]. The PV modules are the main component of the solar PV system and it performs the function of converting the sun's energy into electricity. The conventional PV modules can generate electricity from the surface facing the sun only and those are called mono facial PV modules. A bi-facial solar PV module can generate power from both sides i.e. the side facing the sun and the side facing away from the sun. The bifacial solar PV modules are relatively new in the solar market [2]. The current solar market is dominated by crystalline silicon (cSi) based monofacial PV modules. By 2023, it is expected that the demand for bifacial modules will reach as high as 40 GW [3]. The absorption of light occurs on both sides of bifacial solar PV modules. The solar irradiation reflected from the ground is also utilized for energy generation. The incident solar energy on the bifacial PV module varies with the value of ground albedo.

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reflectance (albedo). Hence, the value of albedo plays an important role in the amount of solar irradiation reflected on the backside of the bifacial PV module.

Albedo is defined as the ratio between solar irradiation reflected from the ground and the global solar insolation incident on the location. The value of albedo for a black surface is 0 as it absorbs all light rays falling on it. A perfect reflector (white surface) has an albedo value of 1. A bifacial solar PV system is fixed on different ground surfaces such as grass, bare soil, tarred road, snow-cover. Usually, the albedo varies between 0.2 (eg: urban locations, grasslands) and 0.8 for snow-covered ground [4]. The ground surfaces and its albedo factor for common surfaces are Asphalt (0.15), Grass (0.25), Concrete (0.35), and Aluminum (0.85). PVsyst software is capable to simulate a bifacial solar PV system for a selected site. Two pyranometers are used for the measurement of Albedo (one pointing to the sun and the other facing the ground) [5].

The material selection and bifaciality are the two ways in which the energy output from solar PV cells can be enhanced [6]. In simulation software such as PVsyst, bifacial PV modules are characterized by a term called bifaciality factor. It is the ratio of the nominal efficiency at the rear side and the nominal efficiency of the front side. The ratio of the nominal power output of the PV module (kW) and the area of the PV module gives the nominal efficiency. So, the irradiance on the rear side can be added to the front irradiance based on the bifaciality factor during the simulation procedure.

Many literatures reported the performance of monofacial PV module based solar system using operational or simulated values. Kumar et al. analyzed the performance of conceptual off-grid solar PV system situated in educational institute using PVsyst modeling software and estimated that the performance ratio varied between 86 % in December and 64 % in April (due to the variation in ambient temperature) [7]. Sukumaran and Sudhakar assessed the performance of the 12 MW solar PV plant located in Cochin, India using PVsyst software and reported that the average performance ratio (PR) and final yield as 79.33 % and 4.31 kWh/kWp/day respectively [8]. Kumar and Sudhakar compared the real performance of the 10 MW solar PV power plant in Ramagundam, India with the predicted performance from PVsyst software. It was reported that the predicted energy generation (16.05 GWh/year) matched closely with the monitored energy generation (15.61 GWh/year) [9]. Arora et al. assessed the performance of 186 kW grid-connected solar PV system located in Haryana, India using PVsyst software and estimated a PR value of 85.6 % which is in close agreement with the estimated PR using operational values [10]. Boddapati and Daniel carried out the performance assessment of a single axis tracked 50 MWp solar PV power plant in Kurnool, India using monitored values and reported that the PR varied between 75.24 % (October) and 83.44 % (August) [11]. In the energy analysis carried out for a 10 MWp grid-interactive canal-top solar PV plant by Kumar et al. using multi-year operational data, it is reported that the monthly average values of final yield varied between 2.46 hours/day (Jul 2017) and 5.56 hours/day (May 2015) [12]. Ahmad et al. evaluated the energy performance of 250 kW grid-connected solar PV system (carport) using PVsyst software and disclosed that the performance ratio is 75 %, final yield is 3.80 kWh/kWp/day, and energy generation is 347 MWh/year [13]. Aryal and Bhattarai assessed the performance of 115.2 kW solar PV power plant situated in Kathmandu, Nepal using PVsyst simulation software and reported that the solar PV plant will inject 199 MWh of energy with a performance ratio of 83.5 %, and a specific yield of 1728 kWh/kWp respectively [14]. Abotaleb and Abdallah compared the performance of two bifacial-silicon solar PV modules, fixed at two different mounting configurations located in the desert climate of Qatar and reported that the energy yield of a typical latitude tilted bifacial PV module is about 14 % higher than the vertically tilted (east-west) configuration [15]. Katsaounis et al. compared the daily energy yield of a set of monofacial and bifacial PV module located on the western side of Saudi Arabia and reported that the gain of a bifacial PV module is 10 % and 15 % for a tilt angle of 25° and 45° respectively when compared to the monofacial PV module [16].

From past literature, it is observed that many authors reported the performance of conceptual solar PV systems using PVsyst software. However, only a handful of these literature studied the performance of bifacial solar PV modules. As per the author’s knowledge, the performance of the bifacial solar PV system in varying albedo conditions of educational institutions has not been reported yet. The objectives of the present study are to evaluate the energy performance of monofacial solar PV system located in a
university campus, to estimate the energy performance of bifacial solar PV system situated in the educational institution for different albedo conditions, to compare the energy generation between monofacial and bifacial solar PV system. The best location for solar PV among the selected locations based on annual electricity generation is also estimated.

2. Methodology

2.1 Site selection

A grid-connected solar PV system is proposed for the Pekan campus of Universiti Malaysia Pahang (UMP) which is situated in Pahang state, Malaysia. The co-ordinates of UMP Pekan are 3.54°N latitude and 103.43°E longitude respectively. It is located at about 12 meters from the sea level. The Pekan campus of UMP covers nearly 642 acres and has vacant areas for the installation of solar PV systems. The on-site solar energy generation supports reducing energy costs and green campus initiatives [17]. A 100 kW solar PV system is proposed for the educational institution. The sites for solar PV installation are chosen using Google map. Different foreground surfaces such as concrete rooftops, aluminum roofs, grasslands, and tarred surfaces (car parking) are selected (Table 2). Figure 1 shows the position of the chosen sites in the educational institution.

![Figure 1. Position of selected sites for proposed solar PV in educational institution.](image)

2.2 System Description

A 100 kW solar system is proposed in this study. The solar PV system mainly consists of PV modules, inverters, and the balance of the system. Since the proposed solar PV is grid-connected, battery banks are not included. This proposed solar PV system is assumed to be interconnected with the existing electrical facility. The chosen monofacial and bifacial solar PV modules have a power rating of 520 Wp. The conversion efficiency of the monofacial PV module is assumed as 20.39 % and the bifacial PV module is assumed as 22.48 %. The PV array is fixed at a 10° tilt angle and oriented towards the south direction [18]. An inverter with a nominal power of 100 kW is selected for the proposed system. The typical meteorological year climate data is collected from the database of PVGIS (cell 3° to 4° latitude (111km) and 103° to 104° (111km) longitude). The selected location receives annual solar irradiation of 1830.4 kWh/m² and observes the average annual temperature of 26.15 °C (Table 1).
Table 1. Monthly variation of climate parameters in the selected educational institution.

| Months | Global Horizontal Irradiation (kWh/m²) | Ambient temperature (°C) | Wind Speed (m/s) |
|--------|---------------------------------------|--------------------------|-----------------|
| Jan    | 141.7                                 | 24.69                    | 4.65            |
| Feb    | 149.7                                 | 25.32                    | 4.10            |
| Mar    | 147.7                                 | 25.04                    | 3.45            |
| April  | 186.0                                 | 26.70                    | 3.66            |
| May    | 159.2                                 | 27.12                    | 2.19            |
| June   | 149.5                                 | 27.27                    | 2.13            |
| July   | 170.1                                 | 27.13                    | 4.30            |
| Aug    | 171.1                                 | 26.49                    | 2.97            |
| Sept   | 164.0                                 | 26.67                    | 2.84            |
| Oct    | 160.8                                 | 26.36                    | 2.28            |
| Nov    | 113.2                                 | 25.79                    | 3.35            |
| Dec    | 117.5                                 | 25.17                    | 4.41            |

2.3 PVsyst software
PVsyst software is one of the widely used PV simulation software among energy professionals and academic researchers [8][10]. This software is capable of estimating the energy performance of solar PV systems such as grid-connected, stand-alone, pumping, and DC-grid. The simulation results from PVsyst are grouped in the form of a report which can be divided into three sections. All the main input parameters given for the simulation are provided in the first section. The second part includes the main results of the simulation, with a monthly table and graphs of normalized values. The third section contains an arrow loss diagram that showcases the system’s behavior, with all detailed losses. PVsyst provides two different 2D models for estimating the energy performance of the bifacial solar PV system. The “unlimited sheds” model is suitable for fixed-tilt systems and the “unlimited trackers” model is appropriate for horizontal single-axis tracking systems. In the “unlimited sheds” 2D model, it is assumed that the bifacial PV array has a single orientation, equal distance with adjacent PV arrays, and a very large area (to exclude edge effect). To simplify the bifacial calculation, the mutual shading between PV arrays from a single direction is only considered [19]. In the simulation, the users are required to configure the bifacial PV module, inverter’s specifications, number of modules in series, and number of strings. Also, there is an option to choose bifacial PV modules that are available in the databases. In the “General Simulation Parameter” dialogue box, the parameters such as albedo value, shading factor, mismatch loss, and other basic parameters for simulation can be configured. The shed parameters such as tilt & azimuth angle shed width, height above ground can be configured inside the dialogue box of “unlimited sheds”.

2.4 Simulation procedure
At first, the geographical location of the proposed solar PV plant is specified and the corresponding meteorological data is chosen from the built-in database. A basic solar PV system variant is defined by the user. It includes the orientation of the PV modules, the proposed power capacity, and the model of PV module & inverter [7]. Based on this, a basic configuration is proposed by PVsyst. In this study, this basic PV array configuration consists of 198 numbers of solar PV modules, 11 strings of 18 modules in series. Also, reasonable default values for all parameters that are required for the simulation are prefilled by the software. These parameters include far shadings, near shadings, specific loss parameters. The economic evaluation of the proposed solar PV system is not considered in the present analysis. The albedo values are adjusted deliberately based on the foreground surface of the selected solar PV site and its application. The simulation is carried out for 5 different cases as shown in Table 3. Except in case 1, bifacial PV modules are considered in all other cases. For each simulation, the albedo value is entered...
depending on the type of ground surface on which the solar PV system is positioned. Ground reflectance values for the chosen ground surface is obtained from the webpage of PVSyst software [20].

| Studied Case | Site Name | PV Technology used | Type of sites     | Site ground Surface | Albedo factor |
|--------------|-----------|--------------------|-------------------|---------------------|--------------|
| Case 1*      | NA        | cSi-Monofacial     | NA                | NA                  | NA           |
| Case 2       | Site I    | cSi-Bifacial       | Car park area     | Asphalt             | 0.15         |
| Case 3       | Site II   | cSi-Bifacial       | Open space        | Grass               | 0.25         |
| Case 4       | Site III  | cSi-Bifacial       | Concrete roof     | Concrete            | 0.35         |
| Case 5       | Site IV   | cSi-Bifacial       | Metal rooftop     | Aluminum            | 0.85         |

*Case 1 is considered as the base case, NA- Not Applicable

2.5 Performance assessment
In this study, the energy performance of bifacial and monofacial solar PV systems is assessed based on the values of energy generation, specific yield, performance ratio. These values are obtained through the PVSyst software simulations which are carried out for the five cases considered in the study [21].

(a) Annual Energy generation (Egrid): It accounts for the energy output from the solar PV system in a year (365 days). The total amount of electrical energy fed into the grid is the cumulative sum of daily generated energy (Ed). The yearly energy generation is given by equation 1.

\[ E_{grid} = \sum_{d=1}^{365} E_d \]  \hspace{1cm} (1)

(b) Specific yield (SYa): It is defined as the amount of electrical energy (kWh) that is generated for every kW of installed capacity over a period. Annual specific yield is the ratio of energy output from the solar PV system in a year (Egrid) and the installed capacity (Po) as given in equation 2.

\[ SY_a = \frac{E_{grid}}{P_o} \]  \hspace{1cm} (2)

(c) Performance ratio (PR): The ratio between the energy that is available for feeding to the grid and the theoretically possible energy generation from the solar PV array is termed as performance ratio. The theoretical energy generation is the product of solar irradiation (kWh/m2) on the PV array, area of PV array (m2), and PV module efficiency. It is also defined as the ratio between the final yield and the reference yield. PR is an important metric that is commonly used in the performance assessment of the solar PV system. Higher values of PR correspond to a higher amount of solar irradiation being transformed into electrical energy.

\[ PR_a = \frac{E_{grid}}{\eta_{pv} \times H_t \times A_{pv}} \]  \hspace{1cm} (3)

3. Results and discussions
The performance analysis of the proposed 100 kW solar PV system in five different cases is presented in this section. These results are obtained through simulation using PVsyst software.
3.1 Energy analysis

It is to be noted that the nameplate power of both the monofacial and bifacial PV module is intentionally chosen to be identical as 520 Wp. The monthly variation of energy generation and PR for Case 1 is depicted in Figure 2. The maximum energy generation is observed in April (15.62 MWh) and the minimum energy output is found in November (10.36 MWh). The annual energy generation in this base case is 159.01 MWh. The PR is almost constant with only a 2% difference between maximum and minimum values. The variation of energy output and performance ratio for Case 2 is given in Figure 3. The energy generation varied between 16.14 MWh (April) and 10.7 MWh (November). The annual energy generation is estimated to be 164.45 MWh which is 5.44 MWh more than the base case value. This can be attributed to the enhanced solar energy input using bifacial solar PV modules. The average value of PR is 0.88 with the slightest monthly variation. Figure 4 depicts the monthly variation of energy generation and PR for Case 3. The maximum energy generation is observed in April (16.51 MWh) and the minimum energy output is found in November (10.93 MWh). The PR reached 0.90 for most of the months with the least monthly variation. This value is higher than the base case PR value of 0.85. The variation of energy output and performance ratio for Case 4 is given in Figure 5. The annual energy generation is estimated to be 172.01 MWh which is 7.5% more than the base case value. This can be attributed to improved performance using bifacial PV modules and increased ground reflectance (0.35). The value of PR varied between 0.91 (April) and 0.93 (June). Figure 6 depicts the monthly variation of energy generation and PR for Case 5. The maximum energy generation is observed in April (17.23 MWh) and the minimum energy output is found in November (11.39 MWh). The annual energy generation and average PR is 175.78 MWh and 0.94 respectively which is the highest value among the studied cases. This increase in values can be attributed to bifacial PV technology employed in high albedo conditions.
3.2 Discussions

The comparison between 5 cases in terms of three technical parameters is provided in Figure 7. The monofacial solar PV system in Case 1 has the lowest value of energy generation, specific yield, and PR. Solar PV systems in all other sites have shown improvement in specific yield and PR which can be attributed mainly to the use of bifacial PV modules. Among these sites, a relative increase in energy generation is observed with the increasing value of albedo. Among the studied cases, it is observed that monthly variation in PR is minimal. Also, the peak value of energy generation occurred in April. This can be attributed to the least difference in the climatic condition and identical system design. Park et al. reported the specific yield for 1.5 kW bifacial solar PV system as 1351 kWh/kWp for an albedo of 0.21 (grey concrete) based on outdoor experiment [22]. Since higher energy output is possible for the same module area of bifacial PV modules, the cost needed for the balance of system (BOS) will be lesser than the conventional system [2]. The design and widespread implementation of bifacial solar PV is also influenced by the availability of an accurate reliable simulation model. Most of the PV simulation software is capable of energy estimation of monofacial solar PV only. Apart from PVsyst, software tools like SAM and Bifacial_Radiance can be used to design and predict the energy generation of bifacial solar PV system [23].
Conclusions

In this paper, the performance of bifacial solar PV systems in varying albedo is assessed using PVSyst software. The albedo of four common ground surfaces in an educational institution is considered. The energy generation and PR value for the monofacial solar PV system (Case 1) are 159 MWh/year and 0.85 respectively. The specific yield and PR at Case 5 (bifacial) is 10.58% higher than that estimated for Case 1 (monofacial). An improvement in energy generation is observed with the increasing value of the albedo. The energy output for an albedo factor of 0.15 is 164.5 MWh/year. While 175.8 MWh/year is obtained for an albedo factor of 0.85. Based on annual energy generation, site 4 is the best location for the solar PV system among the studied cases. This can be attributed to two factors. Firstly, the bifacial solar PV module is used in Case 4. Secondly, the albedo value is highest for the ground surface of Site 4. The limitations of the study include the absence of analysis on the economic and social impact of the bifacial solar PV system in an educational institution. The selected sites receive an ample amount of rain. However, the impact of moisture on the albedo of selected ground surfaces is not considered in the present study. The share of the bifacial module in solar PV installation is expected to increase in near future. So, the present study will be beneficial to energy professionals, solar project developers, and investors. The future work is to carry out the economic analysis of such a solar PV system in Malaysian condition and compare it with monofacial solar PV plants. The effectiveness of the application of highly-reflective paints and/or building materials on foreground surfaces of the bifacial solar PV system can be studied further.

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Data availability

The data in this research can be shared upon request only due to the inclusion of third-party information.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in the submitted manuscript.
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