# Panel Type and Tracking Configuration Based Performance Evaluation of Solar Photovoltaic System

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**Abstract-** The usage of various forms of renewable energy has increased over the past few decades to help fulfill the fast rising worldwide demand for energy. Solar has been deemed the most promising of these renewable energy sources according to recent studies. The solar photovoltaic (SPV) system is the most promising technology to capture solar energy. For effective implementation of the SPV system, the performance of the system has been evaluated for specific site. This paper evaluates the performance of various panel types (mainly monofacial and bifacial panel) as well as different tracking configurations (especially fixed axis, single axis, and double axis tracking) in the SPV system. Regarding this, the geographical site (Kajra, India) having latitude (25.1271° N) and longitude (86.2069° E), has been taken to examine the performance of grid connected SPV system (5 kWp) using system advisor model (SAM). The results show that the SPV system having bifacial panels injects more energy (8224 kWh/year) than monofacial panels (7732 kWh/year) considering fixed axis tracking. In terms of different tracking configuration, the double axis tracking injects more energy (10114 kWh/year) than both fixed axis (8224 kWh/year) and single axis (9183 kWh/year). The results also show that bifacial panels and double axis tracking incorporated SPV system has highest value of energy yield, capacity factor and performance ratio.

**Keywords-** Solar tracking configurations, Bifacial panels, Array energy, Grid energy, Energy yield, Capacity factor, Performance ratio

## 1. Introduction

The world now understands the value of renewable energy in achieving their everyday goals. The most potential renewable energy source is solar energy. Solar energy are able to play a significant part in meeting our needs for daily life while reducing the pollution caused by fossil fuels that are currently used to generate energy. This energy may be used to electrify homes and buildings, heat water, and even run automobiles. Even during installation, it produces no pollution. The use of solar energy is rapidly expanding all over the world. Many developing and developed countries [1-3] are working on ways to minimize the use of fossil fuels and the pollution caused by them. Grid-connected solar systems are critical to improving the overall area of this solar system [27]. Many countries have been working on grid-connected solar systems. In last few decades, India has executed an effective national energy plan to reduce greenhouse gas emissions and the cost of energy services supplied by fossil fuels, such as oil, while also promoting the development of renewable energy (especially solar energy). India has a significant amount of renewable energy resources, including solar energy with radiation of 4 – 7 $kWh/m^2$/day and potential of 5000 trillion kWh annually [4, 5].

The performance of various types of solar photovoltaic (SPV) technologies is highly dependent on the weather, location, solar radiation, and plane configuration [6, 7]. This system also accounts for the solar panel's maximum output, the surrounding temperature, the energy yield, and system loss. Numerous researches have been conducted for performance analysis of the SPV system for various locations considering different panel types as well as distinct solar tracking configurations. Satish et al. discovered overall energy production of 352.6 MWh/year and specific energy production of 1757 KWh/KWp/year in a 200 Kwp power plant in Dubai. The system's annual performance ratio has discovered to be 81.67% [8]. There is an accepted assertion between monocrystalline and polycrystalline solar cells that the efficiency and performance rate of monocrystalline are

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better than the polycrystalline in Ref. [9]. At 1000 W/m$^2$ solar radiation [9], monocrystalline and polycrystalline efficiency were 15.27 and 13.53%, respectively. To evaluate the effectiveness of the solar cell, 1000 rooftop photovoltaic systems have been set up in Germany. The annual performance ratio is determined to be between 47.5-81% (mean 66.5%) using the annual in-plane irradiation by Decker and Jahn [10]. A greater monthly total average final yield than polycrystalline modules have been found in Ref. [11] by Allouhi et al. With the use of PVSYST software, a remarkable annual performance ratio of the solar module of nearly 74%, including capacity factor of 9.27%, and system efficiency of 8.3% was discovered in article [12] by Sharma and chandel. Two types of PV modules have been created by Edalati et al. [13] that have had remarkably comparable properties. This investigation's PR ratio is 82.92%, with a final yield of 5.38 KWh/KWp/day. Kymakis et al have found that the grid-connected PV system in the Island park can produce 229 MWh in 2007 and PR of 67.37% annually [14]. Ferrada et al. determined that the PR ratio always declines for a summer location due to the dust collection, which ranges from 0.04% to 0.13% for positive ambient temperature [15]. The article [16] provides up-to-date measurement data that can be used to compare the effective energy production of PV plants positioned in various parts of the world. It presents one year measurement and performance analysis of two real-life grid connected PV power plants in Sardinia. The organization of a PV system demonstration in India, and an analysis of a 3 MWp plant to produce electricity have been conducted by Padmavathi and Daniel [17]. Kumar et al. in [18] proposed simple technique for evaluating the SPV availability factor using monitored data of 1 MWp system, located in south India. Kandasamy et al. have used PVsyst software to evaluate the sustainability of 1 MWp SPV system in Tamilnadu, India by formulating various power losses and performance ratio [19]. Kumar and Sudhakar compares the viability of PVsyst and PV-GIS software for simulation of 10 MWp SPV system at Ramagundam, India by estimating energy generation, energy yield and performance ratio [20].

Due to energy scarcity in some remote part of India, solar energy should be exploited to satisfy consumer demand as a renewable energy source [3]. According to a recent study, there are two out of three households of the country are facing energy shortage [21]. This shortage is increased in summer season [22] and might be minimized by adopting SPV system for energy production. The solar energy conversion into electricity can be enhanced by using bifacial panels [23]. Moreover, the energy production of the SPV system can also be boostup by orienting the panels in proper direction using solar tracker [2]. Therefore, solar panels namely monofacial and bifacial have been utilized in this investigation to demonstrate which panels are more effective in terms of energy production. The recent study found that the bifacial panels enhance production upto 21.4 % [24]. The purpose of this study is also to identify the most effective tracking configuration for bifacial panels (as it produces more energy than monofacial) based SPV system in terms of the energy injected into the grid. These kinds of performance evaluation based on both panel types and tracking configuration haven't been taken into account for generating energy in earlier investigations.

## 2. Description of the SPV system

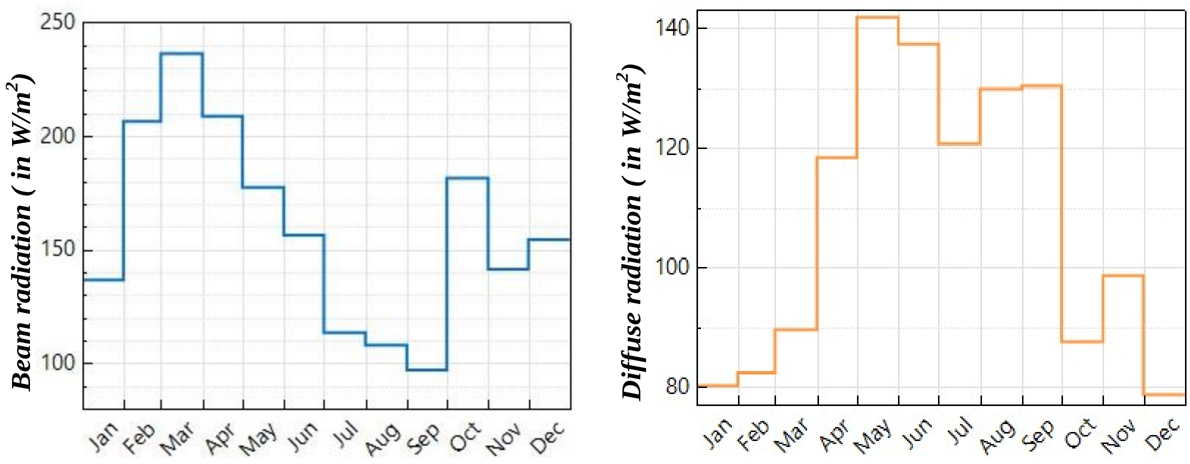


Fig. 1. Monthly beam and diffuse radiation of the study site (captured from SAM)

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Table 1. Specifications of the SPV system

| Parameters | Description/value |
|---|---|
| Nameplate capacity | 5 $kW_{dc}$ |
| Total number of modules | 50 |
| Maximum power per module | 100 $W_{dc}$ |
| Temperature coefficient | -0.5 %//˚C |
| Open circuit voltage | 36 $V_{dc}$ |
| Module efficiency | 13.5 % |
| Total numbers of strings | 5 |
| Total module area | 37 $m^2$ |
| Inverter efficiency | 96.049 % |
| Soiling losses | 5 % |
| DC losses | 4.44 % |
| AC losses | 1 % |

## 2.1 Study site

The study site for the SPV system at Kajra, which is located in Bihar, India. The geographical coordinates of the site are 25.1271° N (latitude) and 86.2069° E (longitude). This location was chosen for analysis because it has the sufficient potential to install a SPV System.The beam and diffuse radiation (monthly) of the study site over a year is presented in Fig. 1.

## 2.2 SPV system specification

Two types of solar panels are chosen for the SPV system. The first is a monofacial solar panel, and the second is a bifacial solar panel. The system is connected to grid that composed of 50 modules (100 Wp capacity) in which 10 modules are connected in series and 5 such strings are connected. It has a 4.2 kW AC inverter to inject energy to grid. Table 1 shows the specifications of the SPV system.

## 3. Methodology

The grid connected solar system of 5 kWp rating has been considered for performance evaluation in study site having geographical coordinates (25.1271° N, 86.2069° E). This system is used to demonstrate the various performance parameters over a year. The system advisor model (SAM) is used to simulate the SPV system using simple efficiency model [25] and generate the simulation report. Further, the following performance parameters of the SPV system have been evaluated for every month of the year.

- Energy generated by array ($E_{array}$)
- Energy injected to grid ($E_{grid}$)
- Energy yield ($E_{yield}$)
- Capacity factor (CF)
- Performance ratio (PR)

Let, the hourly energy generated by the array of the SPV system is $E_{array,hourly}$ and daily energy generated by the arrays of the SPV system is $E_{array,daily}$ then,

$$E_{array,daily} = \sum_{n=1}^{24} E_{array,hourly} \quad (1)$$

$$E_{array,monthly} = \sum_{n=1}^{d} E_{array,daily} \quad (2)$$

Where $E_{array,monthly}$ is the monthly energy generated by the arrays of the SPV system and d is the number of days in a certain month.

If η is the efficiency of the inverter of the SPV system, then the energy injected to the grid $E_{grid}$ (in a day/month/year) is calculated by multiplying energy generated by the arrays $E_{array}$ (in a day/month/year) and efficiency of the inverter as follows,


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$$E_{grid} = \eta \, E_{array} \quad (3)$$

The energy yield ($E_{yield}$) shows the time (in hr) elapse by the SPV array to produce $E_{grid}$ at its nominal power and is formulated for a day/month/year using $E_{grid}$ divided by rated power ($P_{rated}$) as below,

$$E_{yield} = \frac{E_{grid}}{P_{rated}} \quad (4)$$

The system's capacity factor (CF) is the amount of energy it would inject into grid if it were run continuously at full capacity [26]. It is computed as follows for a day,

$$CF = \frac{E_{grid}}{P_{rated} \times 24} \quad (5)$$

The Performance Ratio (PR) of the SPV system reveals its quality rather than its efficiency. It specifies how much the overall loss affects the SPV system. It is also regarded as a measure of one's proximity to an ideal loss-free SPV system [2]. It is defined as the ratio of the final yield and reference yield ($R_{yield}$) as below,

$$PR = \frac{E_{yield}}{R_{yield}} \times 100\ \% \quad (6)$$

## 4. Results and Discussions

The energy produced by the SPV array depends mainly on the effective plane of array (POA) radiation. The effective POA radiation varies with two important parameters, one is which type of array is used and other is how the array of the system is configured. Two types of array namely monofacial and bifacial array have been considered and three tracking configurations namely fixed axis tracking (FAT), one axis tracking (OAT) and double axis tracking (DAT) have been taken to figure out the sustainability of the panel types and tracking configurations in the SPV system to capture maximum energy from solar radiation. Therefore, the performance of the SPV system has been evaluated based on panel types and tracking configuration in this study.

## 4.1 Performance evaluation based on panel types

Between monofacial and bifacial panels, the superiority of the panels in the SPV system for the study site has been discussed in this section. Regarding this, the arrays of the system have been kept in FAT configuration. For simplicity, the angle of tilt in the FAT configuration has been considered equal to the latitude of the study site. The yearly value of $E_{array}$, $E_{grid}$, $E_{yield}$, $CF$ and $PR$ have been obtained from SAM report for different panel types and shown in Table 2.

The annual energy generated by the bifacial panels has superior value (8657 kWh), nearly 6.34 % more than the energy generated by monofacial panels (8141 kWh). However, the annual energy injected into grid shows higher value when bifacial panels (8224 kWh) are used in the SPV system instead of monofacial panels (7732 kWh). Moreover, the annual energy yield of the system is found as 1546 and 1741 hours for monofacial and bifacial panels respectively. Additionally, the annual capacity factor and performance ratio of the system are obtained as 17.70 % and 77 % respectively for monofacial panels while 19.90 % and 78 % consequently for bifacial panels. It is observed that between these two panel types, the bifacial panels have higher CF and PR and hence, performance of bifacial panels is better than monofacial panels in the SPV system.

For every month of the year, the energy injected to grid, energy yield, capacity factor and performance ratio has been shown in Fig. 2, Fig. 3, Fig. 4 and Fig. 5 respectively for different panel types (exact value has been displayed in Table 4 and 5 of Appendix section). March achieves maximum value and July records minimum value of energy injected to grid, energy yield, and capacity factor while January attains maximum value and May produces minimum value of performance ratio for both the panel types. The highest value of monthly energy injected into grid is found as 828.37 kWh for bifacial panels and lowest value is observed as 553.06 kWh for monofacial panels.


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Table 2. Yearly $E_{array}$, $E_{grid}$, $E_{yield}$, *CF* and *PR* value of the SPV system having FAT for different panel types

| Panel Type | $E_{array}$ (in kWh) | $E_{grid}$ (in kWh) | $E_{yield}$ (in h/y) | *CF* (in %) | *PR* (in %) |
|---|---|---|---|---|---|
| Monofacial | 8141 | 7732 | 1546 | 17.70 | 77 |
| Bifacial | 8657 | 8224 | 1741 | 19.90 | 78 |

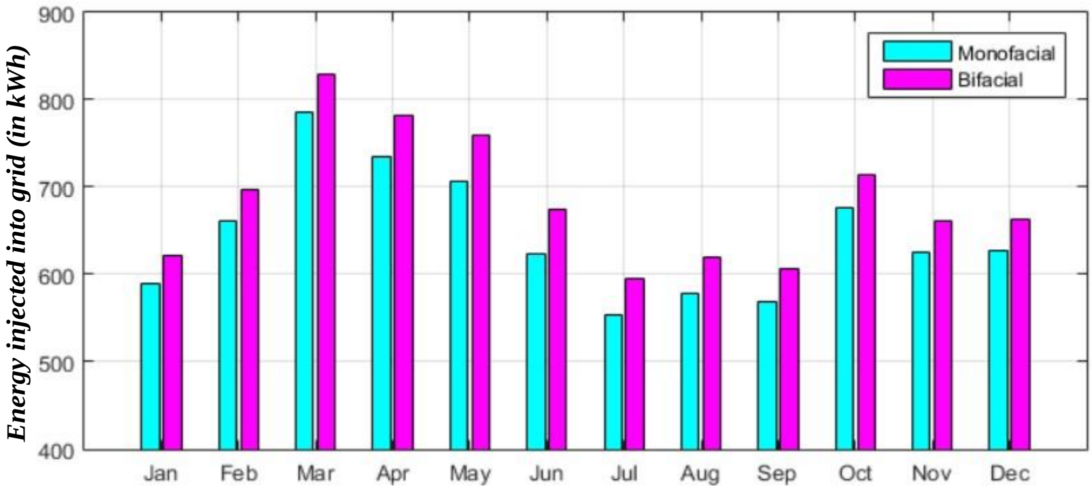

Fig. 2. Energy injected into grid by the SPV system having FAT for different panel types

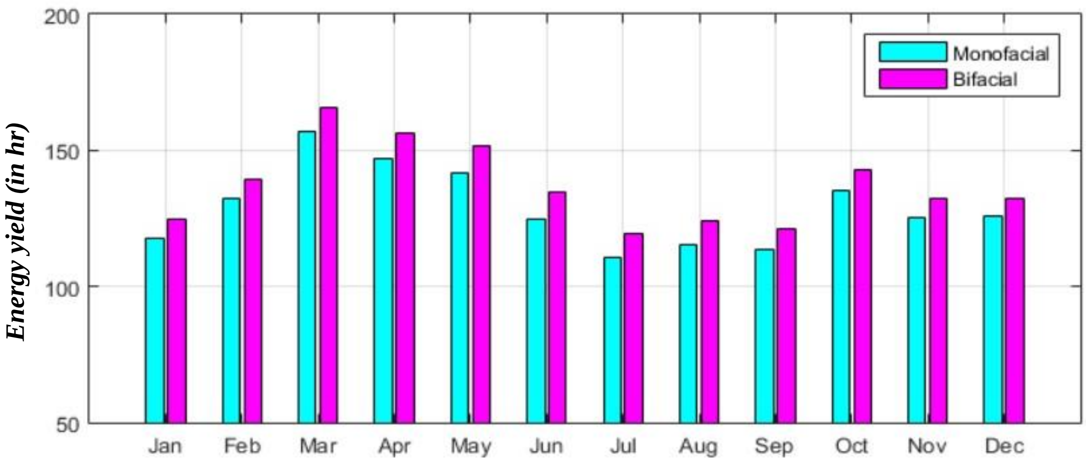

Fig. 3. Energy yield of the SPV system having FAT for different panel types

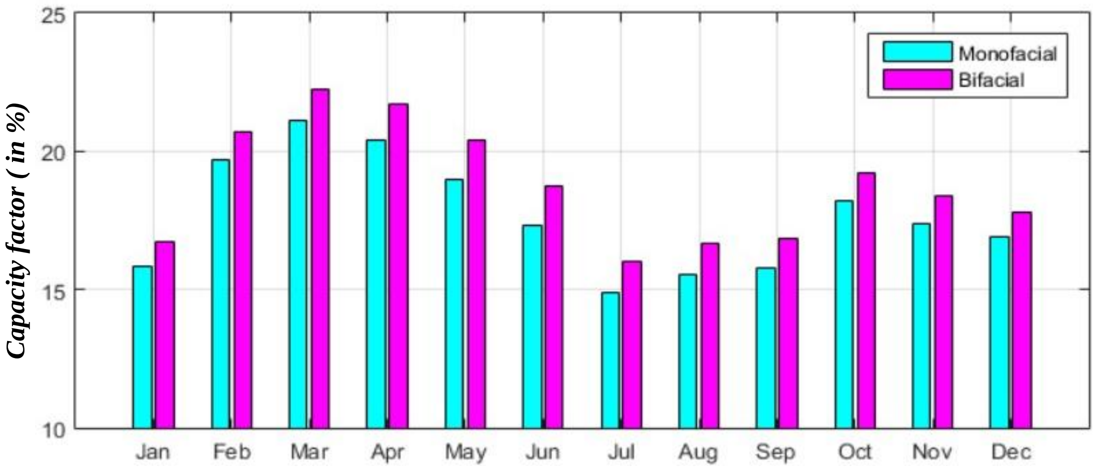

Fig. 4. Capacity factor of the SPV system having FAT for different panel types

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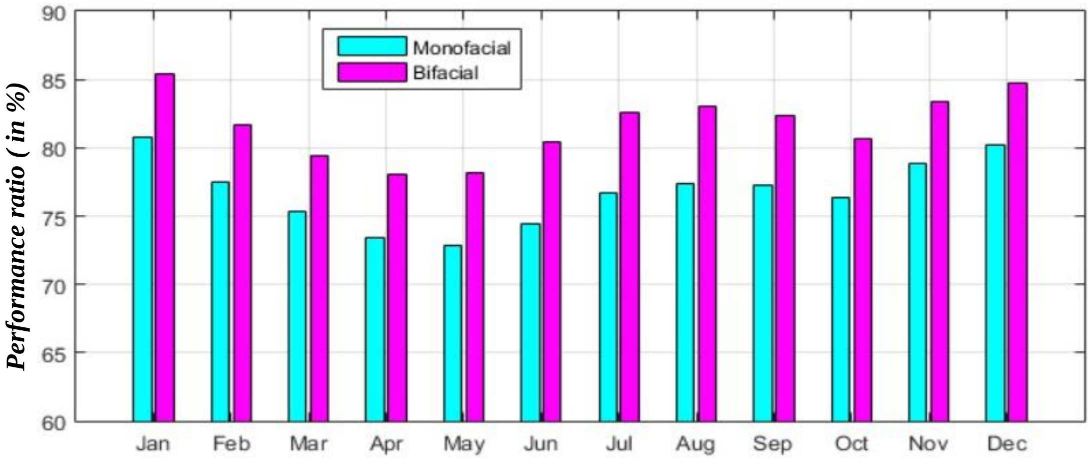


Fig. 5. Performance ratio of the SPV system having FAT for different panel types

Table 3. Yearly $E_{array}$, $E_{grid}$, $E_{yield}$, *CF* and *PR* value of the SPV system having bifacial panel for different configurations

| Configuratios | $E_{array}$ (in kWh) | $E_{grid}$ (in kWh) | $E_{yield}$ (in hr) | *CF* (in %) | *PR* (in %) |
|---|---|---|---|---|---|
| SAT | 9654 | 9183 | 1837 | 21.00 | 80 |
| DAT | 10634 | 10114 | 2023 | 23.10 | 80 |

## 4.2 Performance evaluation based on tracking configurations

The simulation results of SPV incorporated with FAT configuration for monofacial and bifacial panels have been discussed in previous section and figured out the most efficient panel types. Since the highest value of performance parameters for bifacial panels have been noticed and hence bifacial panels appear as most sustainable panel to use in grid-connected SPV system. Further, the energy production by the SPV system is also enhanced by tracking configuration. Hence, the performance of the SPV having bifacial panels has been evaluated for different tracking configurations (SAT and DAT) and compared with FAT in this section. The yearly value of $E_{array}$, $E_{grid}$, $E_{yield}$, *CF* and *PR* have been obtained from SAM report for different configurations and presented in Table 3.

The annual energy generated by the bifacial panels for DAT has superior value (10634 kWh), nearly 10.15 % more than the energy generated for SAT (9654 kWh) and possibly 22.84 % more than energy generated for FAT (8657 kWh). Moreover, the bifacial panels with DAT produce probably 30.62 % more energy as compared to monofacial panels with FAT (8141 kWh). However, the annual energy injected into grid shows higher value for DAT incorporated bifacial panels (10114 kWh) compared to any panel types and tracking configurations. Besides, the annual energy yield of the system is found as 1837 and 2023 hours for SAT and DAT configurations respectively. Additionally, the annual capacity factor and performance ratio of the system are obtained as 21.00 % and 80 % respectively for SAT while 23.10 % and 80 % consequently for DAT incorporated bifacial panels. It is observed that between considered tracking configurations, the DAT has higher CF and PR and hence, performance of DAT is better than FAT and SAT panels in the SPV system.

For every month of the year, the energy injected to grid, energy yield, capacity factor and performance ratio has been shown in Fig. 6, Fig. 7, Fig. 8 and Fig. 9 respectively for different tracking configurations having bifacial panels (exact value can be accessed through data shown in Table 4, 5, 6 and 7 of Appendix section). July records minimum value and March achieves maximum value of energy injected to grid, energy yield, and capacity factor while May produces minimum value and January gains maximum value of performance ratio for all considered tracking configurations. The highest value of monthly energy injected into grid is calculated as 1027.70 kWh for DAT incorporated bifacial panels and lowest value is observed as 553.06 kWh for FAT incorporated monofacial panels.

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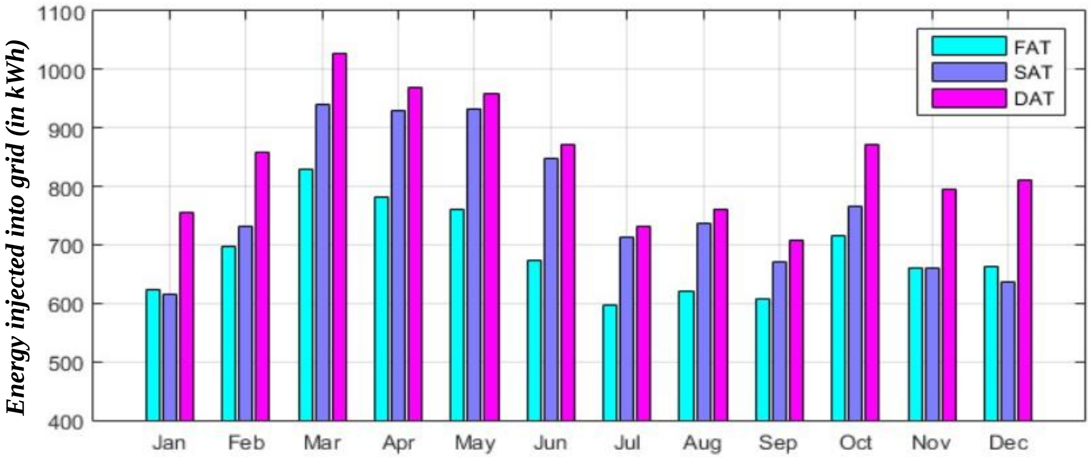

Fig. 6. Energy injected into grid by the SPV system having bifacial panels for different configurations

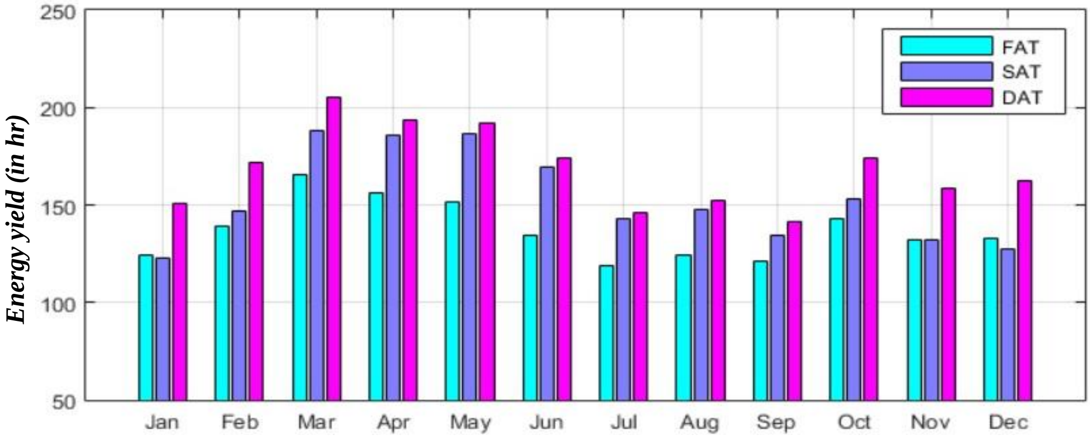

Fig. 7. Energy yield of the SPV system having bifacial panels for different configurations

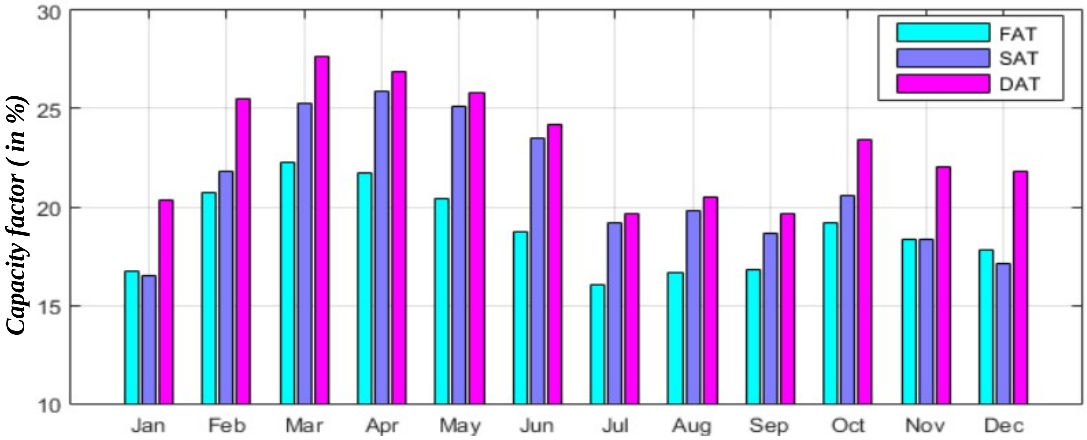

Fig. 8. Capacity factor of the SPV system having bifacial panels for different configurations

## 5. Conclusion

In the present study, the performances of 5 kWp SPV system have been evaluated based on panel types and solar tracking configurations. Two different types of panels (monofacial and bifacial) have been considered for installation in the SPV system and their effect on the performance of the system has been examined. The bifacial panels, with the annual energy yield of 1741 hours, capacity factor of 19.90 % and performance ratio of 78 %, has been established as the most effective panels. Furthermore, three tracking configurations (FAT, SAT, and DAT) have been taken into consideration for incorporating in the SPV system and their effect on the

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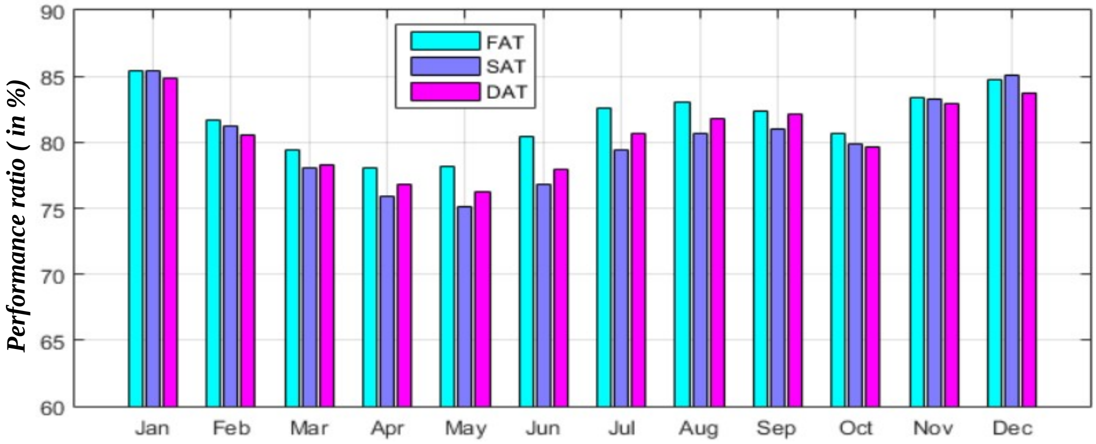

Fig. 9. Performance ratio of the SPV system having bifacial panels for different configurations

performance of the SPV system has been evaluated. The DAT has been identified as most feasible tracking configuration, capable of injecting energy to grid at a rate of 10114 kWh/year. The following outcomes are pointed from this study.

- The bifacial panels enhance energy production of the SPV system upto probably 6.34 % compared to monofacial panels.
- The DAT configuration increase energy production of the SPV system upto probably 22.84 % compared to FAT configuration.
- Both bifacial panels and DAT in the SPV system boost energy production nearly by 30.62 % compared to monofacial panels and FAT configurations.
- Bifacial panels and DAT incorporated SPV has highest value of energy production, energy yield, capacity factor and performance ratio.

Therefore, bifacial panels and DAT incorporated SPV system is the most sustainable option to extract maximum energy of solar radiation for the study site.

## Statements and Declarations

The Author declare that there is no conflict of interest. No funding was received for conducting this study.

## Acknowledgement

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## Appendix

Table 4. Simulation results of the SPV system having FAT for different panel types

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Monofacial* | | | | | | | | | | | | |
| $E_{array}$ (kWh) | 620.21 | 695.14 | 826.18 | 773.68 | 744.57 | 657.50 | 584.10 | 609.73 | 599.67 | 713.02 | 656.99 | 660.02 |
| $E_{grid}$ (kWh) | 588.79 | 660.98 | 785.65 | 735.29 | 707.21 | 624.00 | 553.06 | 578.02 | 568.81 | 677.17 | 625.32 | 627.93 |
| *Bifacial* | | | | | | | | | | | | |
| $E_{array}$ (kWh) | 655.47 | 732.41 | 871.37 | 822.71 | 799.43 | 709.74 | 629.03 | 653.60 | 639.02 | 752.33 | 694.73 | 696.76 |
| $E_{grid}$ (kWh) | 622.40 | 696.42 | 828.37 | 781.98 | 759.58 | 673.94 | 596.01 | 619.99 | 606.37 | 714.62 | 661.31 | 662.96 |

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Table 5. Calulated results of the SPV system having FAT for different panel types

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Monofacial* | | | | | | | | | | | | |
| $E_{yield}$ (hr) | 117.76 | 132.20 | 157.13 | 147.06 | 141.44 | 124.80 | 110.61 | 115.60 | 113.76 | 135.43 | 125.06 | 125.59 |
| *CF* (%) | 15.83 | 19.67 | 21.12 | 20.42 | 19.01 | 17.33 | 14.87 | 15.54 | 15.80 | 18.20 | 17.37 | 16.88 |
| *PR* (%) | 80.83 | 77.51 | 75.32 | 73.39 | 72.80 | 74.44 | 76.67 | 77.41 | 77.29 | 76.40 | 78.81 | 80.22 |
| *Bifacial* | | | | | | | | | | | | |
| $E_{yield}$ (hr) | 124.48 | 139.28 | 165.67 | 156.40 | 151.92 | 134.79 | 119.20 | 124.00 | 121.27 | 142.92 | 132.26 | 132.59 |
| *CF* (%) | 16.73 | 20.73 | 22.27 | 21.72 | 20.42 | 18.72 | 16.02 | 16.67 | 16.84 | 19.21 | 18.37 | 17.82 |
| *PR* (%) | 85.44 | 81.66 | 79.42 | 78.05 | 78.19 | 80.40 | 82.63 | 83.03 | 82.39 | 80.63 | 83.35 | 84.70 |

Table 6. Simulation results of the SPV system having bifacial panel for different configurations

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SAT* | | | | | | | | | | | | |
| $E_{array}$ (kWh) | 646.52 | 769.71 | 988.44 | 977.79 | 981.13 | 890.25 | 751.95 | 776.12 | 707.26 | 804.92 | 692.49 | 667.11 |
| $E_{grid}$ (kWh) | 614.47 | 732.82 | 940.99 | 930.49 | 933.52 | 846.80 | 713.67 | 737.58 | 671.98 | 765.53 | 659.78 | 635.31 |
| *DAT* | | | | | | | | | | | | |
| $E_{array}$ (kWh) | 795.05 | 901.99 | 1080.89 | 1017.69 | 1007.55 | 915.39 | 769.40 | 801.46 | 745.07 | 915.28 | 833.30 | 850.96 |
| $E_{grid}$ (kWh) | 755.75 | 857.57 | 1027.70 | 968.46 | 958.75 | 870.86 | 730.37 | 761.82 | 707.98 | 870.42 | 793.86 | 810.34 |

Table 7. Calculated results of the SPV system having bifacial panel for different configurations

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *SAT* | | | | | | | | | | | | |
| $E_{yield}$ (hr) | 122.89 | 146.56 | 188.20 | 186.10 | 186.70 | 169.36 | 142.73 | 147.52 | 134.40 | 153.11 | 131.96 | 127.06 |
| *CF* (%) | 16.52 | 21.81 | 25.30 | 25.85 | 25.09 | 23.52 | 19.18 | 19.83 | 18.67 | 20.58 | 18.33 | 17.08 |
| *PR* (%) | 85.46 | 81.25 | 78.11 | 75.86 | 75.11 | 76.83 | 79.45 | 80.62 | 81.04 | 79.87 | 83.26 | 85.03 |
| *DAT* | | | | | | | | | | | | |
| $E_{yield}$ (hr) | 151.15 | 171.51 | 205.54 | 193.69 | 191.75 | 174.17 | 146.07 | 152.36 | 141.60 | 174.08 | 158.77 | 162.07 |
| *CF* (%) | 20.32 | 25.52 | 27.63 | 26.90 | 25.77 | 24.19 | 19.63 | 20.48 | 19.67 | 23.40 | 22.05 | 21.78 |
| *PR* (%) | 84.84 | 80.53 | 78.27 | 76.82 | 76.22 | 77.95 | 80.61 | 81.78 | 82.11 | 79.59 | 82.94 | 83.74 |

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