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Bifacial Vertical Photovoltaic System Design for Farming Irrigation System

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ABSTRACT

The increase in population leads to an upsurge in food demands which also expend the agricultural activities. A wide range of electrically powered machines is essential for the success of modern agriculture setup. Farming required electrical power for numerous activities such as irrigation and electric tractors. A large number of farms are located in remote areas where access to electricity could be costly. Also, farms that are located within the electrical grid suffer from the cost of electricity bills. In line with the United Nations' recommendations to deploy renewable energy sources for electrical power generations, photovoltaic systems are installed for farming activities across countries. A photovoltaic system converts solar radiation into electrical power and with the use of advanced power electronics devices, PV technologies become very attractive to farmers. The work in this paper capture the PV system operation for farming purposes. The contents cover standard PV panels and their current deployment layout for farms. The paper introduces the bifacial panel's concept and its novel layout. Furthermore, the paper proposed a novel installation layout for bifacial panels to support the farm's electrical demands. The case study, which is based on three-phase irrigation pumps, explains and verifies the advanced role that the proposed layout of bifacial panels over the standard one. The advantages of the proposed installation layout are also included.

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1. INTRODUCTION

According to the United Nations, the World population is expected to reach 9.8 billion in 2050 [1]. This growth supports a solid growth in food and electricity demands. The food demand is expected to increase by 50% between 2012 and 2050 [2]. The projected growth in food demands lead to an increase in farming activities. These activities could be in the form of expanding the operation of an existing farm or the establishment of new farms to support the food increase demands. The increase in electricity demands leads to an increase in power generation which could have an impact on climate change if the power is sourced from fossil fuels. In this province, United Nations (UN) along with numerous governments set regulations and policies to address climate change issues from electrical generations [3-5]. These policies promote the deployment of renewable energy systems for electrical generation purposes. Photovoltaic (PV) systems are considered one of the main renewable energy systems for power generations without any gas emissions [6-8].

The farming industries can take advantage of the PV system to support their electrical needs, reduce electricity bills, and aid in controlling climate change due to electricity generation. For large farming industries, a bulky amount of electrical power is required to support the water pump for their irrigation systems. The cost of electricity or diesel puts a burden on farmers which impacts their yearly performance. The advancement in

PV panel technologies increased its suitability for a wide range of purposes including farming industries. The introduction of the Bifacial panels adds great benefits to PV system installations, especially for large farms.

The works in this paper include the operating concept of PV systems using standard panels and how it is currently deployed within farms. The paper also introduces the bifacial panels and their advantages over the standard PV panels. Furthermore, the author includes the proposed novel layout for the bifacial PV system for farming purposes, which reduces the required land for the PV system, reduces the maintenance requirements, increases system productivities, and offers a shield for products under heavy winds. The included case study is based on a large water pump for irrigation purposes.

2. THEORETICAL STUDY

Photovoltaic panels convert solar radiation into electrical power for domestic and commercial usage. The current research shows that the PV cell can be presented by a current source as shown in figure 1 [9-13]. The intensity of the current is related to the solar radiation and the operating voltage across the cell. Figure 2 shows the PV cell's output under different sun radiations and operating voltage levels. The sun's radiation is controlled by the seasons, time of the day, and sky conditions. Therefore, the designer can't control the incoming solar radiation to the surface of the earth. However, from figure 2, it is clearly shown that controlling the voltage can control the output power of the panels. Based on this concept, researchers introduce the maximum power point tracker (MPPT) to harvest the maximum power from the PV system [14-16].

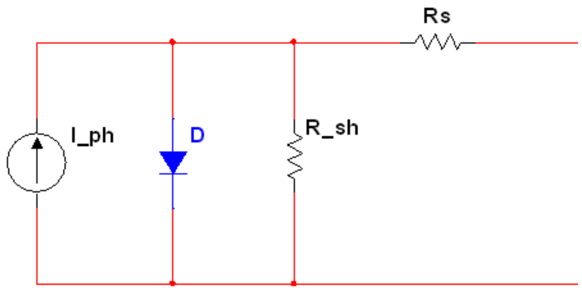

Figure 1. Circuit representation for solar cell

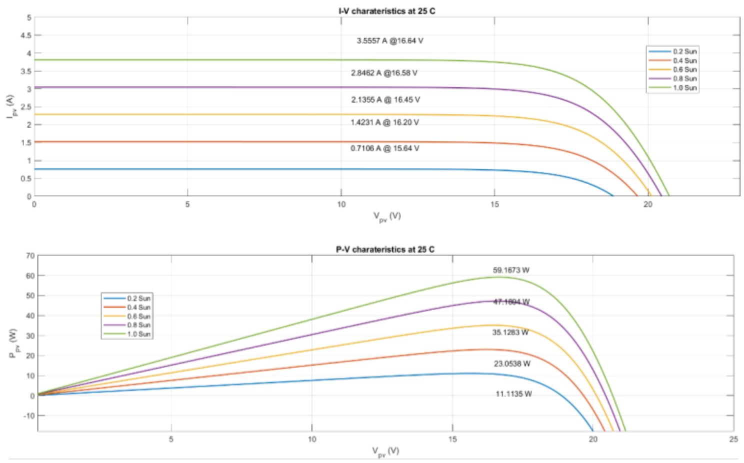

Figure 2. PV output concerning sun radiation

2.1. Standard PV System

The PV system generates electricity when the solar radiation reaches the silicon and forces the electrons to move. Figure 3 shows the elements of standard PV panels. The panels have one side of tempered glass and the backside is covered with a solid sheet. Therefore, the sun can reach the silicon only from one side of the panels. Based on the information from figure 3, for maximum output power, the panels should face the sun at 90 degrees if possible. Due to the change in sun orientations throughout the day and months, this can only be possible with the aid of a mechanical tracking system [17].

Figure 3. PV Panels layout

Mechanical tracking is not possible in many situations due to location, cost, power requirements, and maintenance. Therefore, for this paper mechanical tracking will not be considered during the analysis or case study sections.

For standard PV panels installation, figure 4 shows the panel tilts and angle in respect of the sun location for a given time and date. It is worth noting that Gi which is the radiation amount that forms 90 degrees with the panel is what gets converted into electrical power. From figure 4, when the panel tilt change, the angle between G and Gi changes which reduce or increase the magnitude of Gi and impacts the output power of the system. This highlights the importance of panels orientations and tilts for power outputs. Figure 5 shows the PV output of the 1kW system under different tilt angles with the same weather conditions and orientation. It is clearly shown that the change in tilt angle will either reduce or increase the power generation of the installed PV system. The change depends on the seasons and the location of the installed system. For irrigation purposes, electrical energy is required outside the rainy seasons, as an example, the period for the middle east location can be captured between April and October. Therefore, the designer aims for the optimum tilt for these months. The author previously published work can be used to determine the optimum tilt and orientation [18].

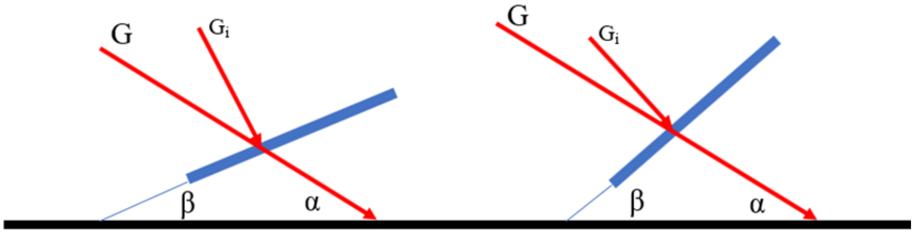

Figure 4. Direct radiation on the panels for different tilt angles and sun angle to the ground

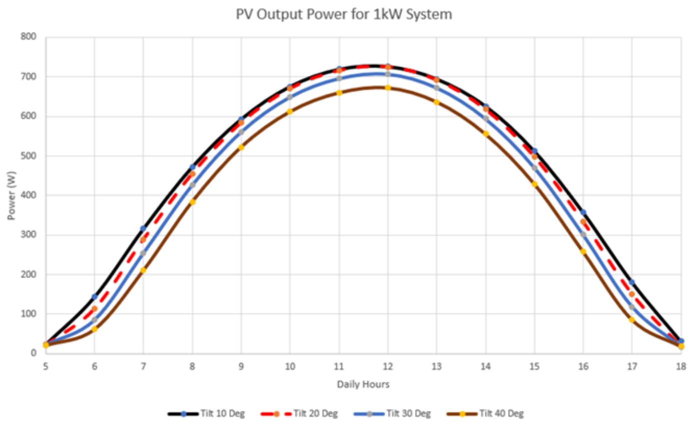

Figure 5. PV output power of 1kW system under different tilt angle

2.2. Bifacial PV System

Recently, the bifacial panels started to gain strong momentum worldwide. the layout of the bifacial panel is presented in figure 6. The tempered glass is located at both sides of the silicon which allows the system to harvest solar radiation from both sides of the system. Figure 7 shows the ability of the bifacial panels to harvest direct and reflected sun radiations on both sides. The current research shows that the bifacial panels can increase the power generation by up to 25% depending on the surrounding infrastructure [19]. The paper used the MATLAB engineer tool to determine the solar radiation that reaches the front and back panels. Figure 8 shows the simulation outputs. It is clearly showing the increase in the total radiation that reaches the solar cells which increases its outputs. The simulation is completed for a given panel orientation and tilts for different ground conditions.

Figure 6. Bifacial panel layout

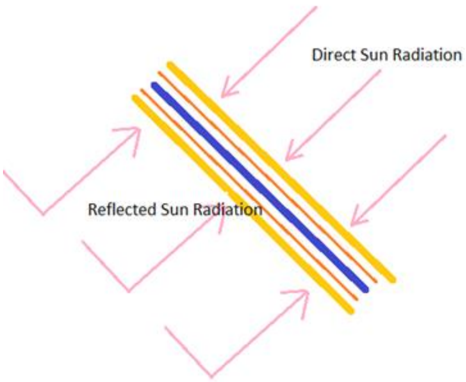

Figure 7. Bifacial sun interception

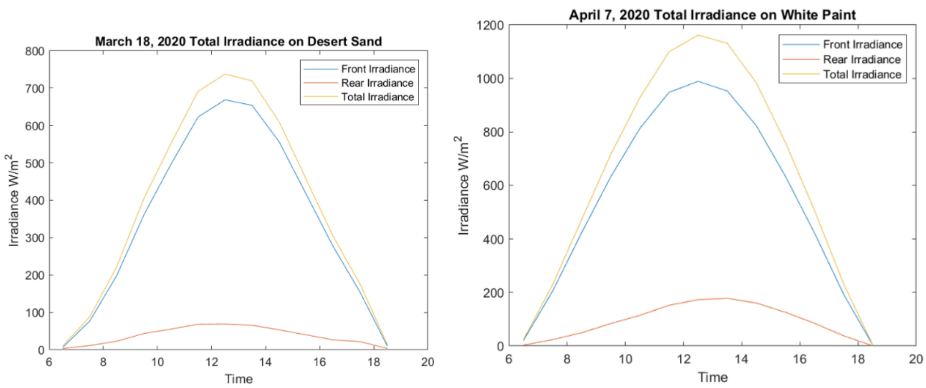

Figure 8. Solar radiation at a panel with nominal tilts

The PV system output increases when the solar radiation that reaches the solar cell increases. In this paper, MATLAB software is used to simulate the power output of the bifacial PV panels. The input radiation that was used is the total radiation obtained by adding the front and back radiation at each moment.

3. BIFACIAL PV SYSTEM FOR FARMS

Recently, the use of renewable energy sources in agricultural areas becomes very popular for maximizing land productivity with additional potential benefits including reduced irrigation budget, improved crop yield, agricultural land preservation, and, socio-economic welfare of farmers [20][21]. The use of photovoltaic energy systems in farms had rapidly attracted worldwide attention which is prompting the need to develop effective solutions for its landscape integration that can minimize ecological changes to the land and favor the local community [22][23]. In [24], an Agrivoltaics approach had been proposed. In this approach, arrays of PV panels are designed to partially cover the crops with optimal elevation and density to manipulate the desired balance for sharing sunlight intensity between energy and crop production. These arrays can also cover to protect crop yield against adverse weather conditions. In [25], an optimization model for bifacial photovoltaic in agrivoltaic systems has been proposed. The model combines three main sub-models: photovoltaics, solar radiation, and crop yield. The authors conclude that the row distance between bifacial photovoltaic module structures had a significant effect on the photosynthetic radiation distribution.

Farming industries required electrical power for numerous activities. Water irrigation pumps are one of the main requirements for electricity. For acceptable performance, this paper considers that the electricity should be available between seven and eight hours a day for the period starting April 15th and September 30th of each year. It is worth noting this period is based on middle east weather conditions. Equation 1 is used to govern this requirement

$$P_R \geq P_L \; for\ seven\ hours\ a\ day \qquad [1]$$

Where
- PR is the receiving power from the PV system
- PL is the required load for optimum operation
- PR must be maintained between seven and eight hours per day between the nominated dates

For standard PV panels (one tempered glass), the maximum output is achieved for a south orientation and nominal tilts [18]. It is worth noting that this orientation is suitable for the upper section of the earth, while in the down section (Australia as an example) the orientation should be toward the north. The PV output should reach PL between 8 am and 3 pm or 9 am and 4 pm. It is worth noting that the solar radiation at 8 or 9 am doesn't reach maximum daily radiation intensity. Figure 9 shows the global horizontal irradiance for the required mid-months. From the figure, it is clearly shown that the engineer should design the system to operate between 8 am and 3 pm. Outside these hours the sun radiation is reduced and to compensate for this drop, a larger PV system is required which incurs costs.

The sun radiation incident on the panel plays an important role in determining the output power of the system. Refer to figure 4 for more information. Figure 10 shows the output power for a 900W standard PV system for solar radiation as per figure 9. The figure shows that between 9 am and 2 pm, the system can maintain around 600W output. Between 8 and 9 am that system output can maintain around 400W similar to the output between 2 and 3 pm. For motoring applications, variable frequency drive (VFD) can be used to ensure the motor still operates between 8 and 9 am and also between 2 and 3 pm however at lower motoring power.

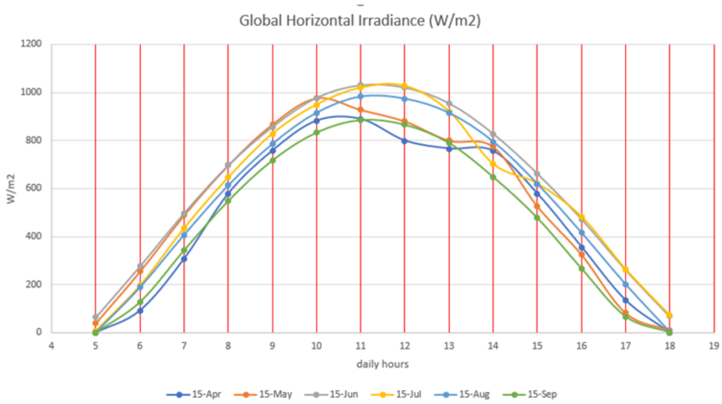

Figure 9. Global Horizontal Irradiance for the Middle East region

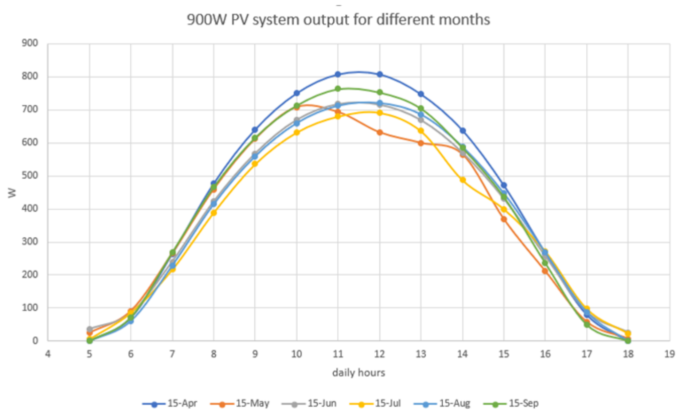

Figure 10. PV system output for different months

Based on the discussed information and from figures 9 and 10, it can be concluded that for the farming system with a VFD inverter, the PV sizing should meet equation 2.

$$P_{PV} \geq 1.5P_L \quad [2]$$

Where

PPV is the PV system required to operate the required load for 7 to 8 hours a day

Equation 3 is used to determine the number of panels required:

$$N_{PV} = \frac{P_{PV}}{P} \quad [3]$$

Where
- NPV is the number of PV panels
- P is the chosen PV panel rated power as per the manufacture datasheet

Equation 4 is used to determine the area required for the PV system. Please note, that this equation assumes that all panels are installed on the same plane and no elevation difference between different strings.

$$A_{PV} = N_{PV} \times A \times \cos{(\alpha)} \quad [4]$$

Where
- APV is the total area required for the proposed PV system
- A is the size of each panel
- α is the tilt angle of the PV system

For the bifacial panels, the paper proposes vertical installation facing east and west. The distance that separates two rows could be tens of meters which eliminate the shading factor of one vertical panel to another one. Figure 11 shows the proposed bifacial design for the farming system. The figure shows the vertical installation facing east and west. It is clearly showing that the land can still be utilized for farming purposes between the two rows. Depending on the land size, it is possible to install multiple rows which will divide the land into sections and the length of the section can be determined to suit.

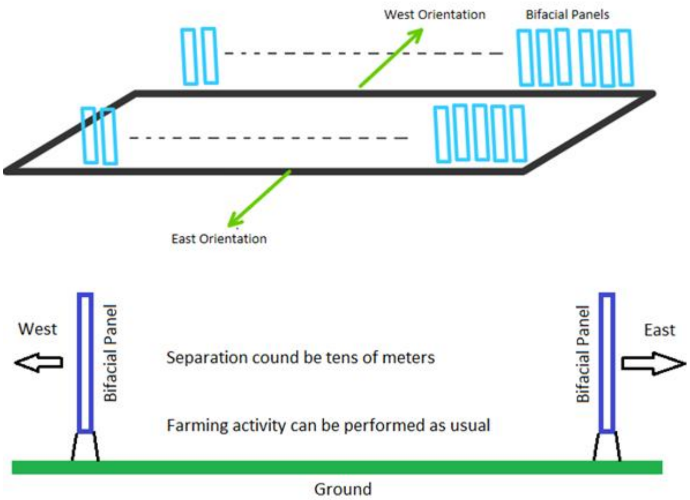

Figure 11. Bifacial panels installation for farming

The layout in figure 11 allows for the bifacial panels to capture the solar radiation from sunset to sunrise and expend the full operating hours of the system. Figure 12 shows the power output of the 900W bifacial system when it is placed vertically. The figure shows that the system operates between the following hours:

- 6 am and 9:40 am at full capacity
- 9:40am and 10:30am above 75% capacity
- 1 pm and 4 pm at full capacity
- 4 pm and 5 pm full capacity for June- July and above 75% for the rest of the months

The comparison between figures 10 and 12 shows the higher output that the bifacial offers for farmers and how it can support the required load for a longer period during the day. Also, it is important to mention that the standard arrangement for the panels (south orientation with tilt angle) attracts specks of dust and soil residue on the tempered glass which reduces the system output. Therefore, cleaning is required to ensure system output is always maintained at the designed rated power. while the vertical arrangement for the bifacial reduces the risk of soiling factor and also makes cleaning easier when required. It is worth noting the simulation is based on measured sun radiations for the year, which explain the minor fluctuation in the power output during certain hours.

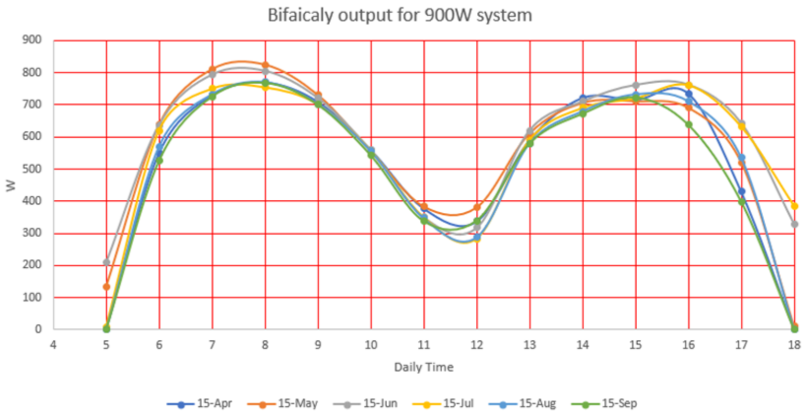

Figure 12. bifacial PV output for different months

4. DISCUSSIONS

Nowadays, farming industries are critical for human health and future sustainability. Electrical power forms an indispensable element for the success of the farming setup. One of the main power requirements is to support the pump irrigations for the proposed farm activities. Photovoltaic technology plays an important role to support the irrigation electrical power requirements without impacting the greenhouse gasses. The standard PV panels, which have one tempered glass, can harvest the sun's energy from one direction. The standard PV panels are installed facing south at a nominal tilt which is usually between 20 to 30 degrees for the middle east regions to meet the hot seasons [18]. This layout highlights two main elements:

- Area requirements to support the installation
- Cleaning requirements to ensure the system output is maintained as per the designed system

Both elements impact the farm by reducing its available land and the cost of cleaning the system. Without the cleaning, the output of the system drops which reduces the operating hours of the irrigation system. The work in this paper proposes the vertical installation of the bifacial panels which offers the following benefits:

Increase the number of operating hours; as shown in figures 10 and 12, the output of the bifacial system is higher than the normal system which extends the operation hours. Also, it is worth noting that the bifacial offers power to the irrigation system during the early morning and afternoon which is a healthier period for the plants to be watered. The heavy sun midday while the water is being supplied to the plant could impact its performance.

- Reduction in the required land area for the PV system. This area can also be eliminated if the panels are installed at the fencing line of the properties.
- Reduce the cleaning requirements which reduces the cost and time
- Act as a shield under heavy wind.

Based on the mentioned points, the paper proposed a novel setup for the farm that advances the photovoltaic installation and promotes higher sustainability.

5. CASE STUDY

A new farm for potatoes is planned on a large flat open area. The farm has a 60hp three-phase water pump to support potato growing. There is no available utility grid in the vicinity of the farm. The owner engaged a PV engineer to design the required system for a full operation of seven or more hours. The engineer determined the required electrical power by converting the 60hp into kW which is just under 45kW.

The required PV system as per this paper is 67.5kW. The engineer decides to include an additional 7kW of PV as a margin which increases the system to reach the 74kW of PV capacity. The engineer designed the system to suit the middle east weather conditions, the system includes 200 panels oriented toward the south and tilted by 20 degrees. The total required area of the system exceeds 400m2. The output of the simulation is captured in table 1.

After completing the design using standard PV, the engineer modeled 200 bifacial panels using the following setup:

- Vertical installation facing east
- Two rows of panels, each row has 100 bifacial panels
- The separation between the two rows is 100 meters.

The output modeling is captured in table 1. The table also includes the percentage of the operation for the pump, when the system output is equal to or exceed the pump rated power, the system will operate at 100% capacity and when the power drops, the pump work under lower capacity under the supervision of the variable frequency drive (VFD).

The table clearly shows the advanced benefits of the bifacial over standard panels when it comes to power generation and operating hours. The findings from Table 1 support the theoretical discussions and verify the advantages of using bifacial panels vertical assembly for food farming industries. The bifacial system allows for 7 hours of operation under full capacity and one hour of 98% and 2 hours between 90-95% capacity; while the standard system allows for 6 hours of operation under full capacity and two hours between 80-90% capacity.

Table 1. Modeling output for standard and bifacial system

30 April	Standard PV (W)	Pump Operating capacity	Bifacial PV (W)	Pump Operating capacity
6:00	7314		51183	100%
7:00	22781		61970	100%
8:00	37811	80-90%	62774	100%
9:00	49348	100%	56141	100%
10:00	56864	100%	43152	98%
11:00	60897	100%	26374	
12:00	60779	100%	25173	
13:00	56487	100%	41190	90-95%
14:00	49131	100%	53305	100%
15:00	36696	80-90%	58210	100%
16:00	21815		55319	100%
17:00	6875		41209	90-95%

6. CONCLUSIONS

The paper addresses the design of standard and bifacial PV systems to meet the farming irrigation electrical demands. The usage of PV systems advances the sustainability stand and reduces the electricity cost burden on farmers. The standard PV system requires land to support the installation also it only offers maximum power during the midday period. While the introduced novel bifacial panel vertical layout reduces or eliminates the land requirements and offers wider operating hours. Also, the bifacial vertical system offers peak generation during the early morning and late afternoon which are considered better watering periods. The outputs highlight the advantages of using a bifacial vertical system over standard PV panel installations. The advantages include higher output power, longer operating hours, lower maintenance requirements, and a reduction in land requirements. These benefits were supported and verified by the case study**.**

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