

## Optimizing Energy Collection using Monocrystalline Solar Cells

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### Abstract

This study explores the best settings for maximizing energy production with monocrystalline solar cells, renowned for their effectiveness and long-lasting performance in solar power systems. The research seeks to discover the optimal environmental and operational conditions as including temperature, light intensity, and angle of incidence that can improve the performance of solar cells without changing the electrical load. To accomplish this, a mix of experimental tests and computer simulations was utilized. The testing configuration featured halogen lamps on a steel frame placed on adjustable steel beams for accurate positioning. The results provide important information on how to improve the efficiency of solar panels in different situations, enhancing the performance of solar energy systems and promoting the use of sustainable renewable energy technologies to meet worldwide needs. In the second, the solar panels were accurately positioned and exposed to different angles and levels of sunlight over a period of time, allowing for a thorough examination of how these factors affect energy capture and conversion efficiency. Findings show that adjusting the angle of light and keeping the panel temperature within a certain range can greatly enhance energy absorption, increasing efficiency by around 10-15%. Moreover, it is essential to keep the load conditions constant all day in order to ensure consistent performance.

**Keywords:** Monocrystalline Cell; Solar Radiation; Sustainable Energy; Tilt Angle

### 1. INTRODUCTION (12 pt)

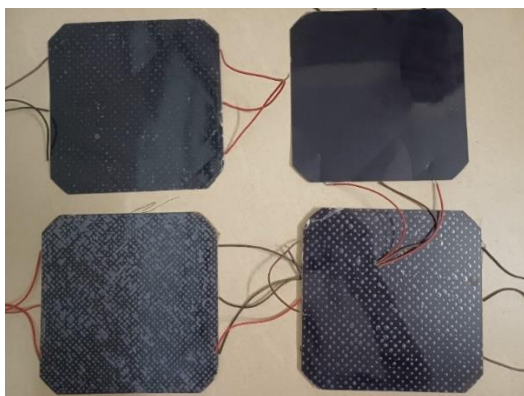
As the worldwide need for sustainable energy grows, the effectiveness and dependability of PV systems have become key areas of focus in solar energy studies. Monocrystalline solar cells, valued for their high efficiency and ability to last a long time, have become a top technology in the development of sustainable energy solutions [1]. Yet, achieving the highest energy production from these cells necessitates a detailed comprehension of the external and operational factors that impact their efficiency. Monocrystalline solar panels are a type of photovoltaic technology made from high-purity silicon crystals, known for their efficiency and aesthetic appeal. These panels are constructed using a single continuous crystal structure, which allows for superior performance compared to other types, such as polycrystalline panels. Monocrystalline panels typically consist of layers including tempered glass, adhesive films, and the monocrystalline silicon cells themselves, which are designed to maximize light absorption and conversion efficiency [2]. Monocrystalline cells are of many types, including, Passivated Emitter

and Rear Contact (PERC) panels, Bifacial panels, Roof tile panels and Interdigitated back contact panels. Factors such as light intensity, angle of incidence, temperature, and load conditions have a significant impact on the efficiency of monocrystalline solar cells [3]. Each parameter has the potential to either improve or impede the cells' capacity to absorb and transform sunlight into electricity [4]. Monocrystalline solar panels are modules made by stacking tempered glass, adhesive films, monocrystalline silicon cells, reflecting layers, and back plates, providing durability, UV resistance, and long service life [5]. Such as the angle of sunlight hitting the solar panel can change during the day and in different seasons, affecting how much light the cell absorbs. In the same way, changes in temperature can impact the cell's electrical characteristics and influence its overall performance [6]. Hence, pinpointing the best conditions for the functioning of these cells is essential for enhancing their ability to harvest energy. The objective of this research is to methodically investigate and pinpoint the best environmental and operational factors for

optimizing monocrystalline solar cell efficiency. The research aims to offer practical insights for real-world PV system deployments by changing important parameters and studying how they impact power output and efficiency [7]. The results of this research are foreseen to help increase the use of monocrystalline solar cells as a dependable and effective renewable energy option, fulfilling the rising demand for sustainable energy alternatives.



**FIGURE 1. Monocrystalline Solar Cell Panel**

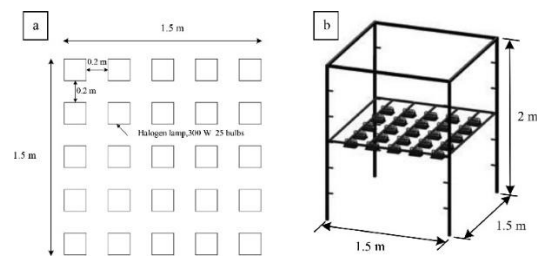


**FIGURE 2. Doped Monocrystalline cell**

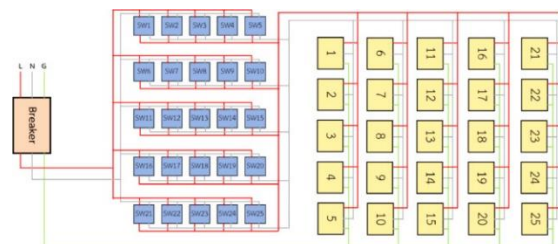
**2. METHOD**

We used doped monocrystalline solar cells (Figures. 1 &2) to conduct our experiments at different sunlight angles [8]. The panel used can handle voltages as high as 12V. The load provided was kept constant and the data was recorded. A steel frame measuring 1.5 meters by 1.5 meters by 2.0 meters was built for testing sunlight simulation. (Figure 3) It held twenty-five 300 W tungsten halogen lamps spaced 0.2 meters apart on adjustable steel beams for precise alignment and optimal light distribution. To ensure safety and regulation, every lamp was linked to its own

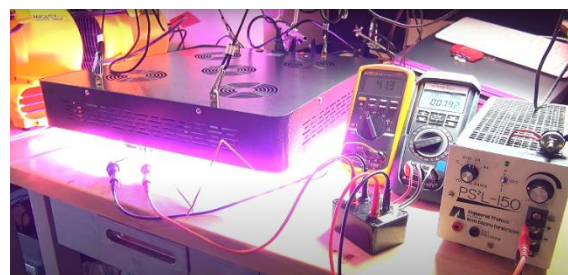
Residual Current Circuit Breaker with Over Current Protection (RCBO), while a main control breaker switch was employed to oversee the total lighting. (Figure 4) In order to improve consistency and avoid light scattering outside of the intended area, a 1 mm thick flat steel sheet was used to cover the sides of the steel frame. (Figure. 5) This reflective surface decreased light scattering and maintained a uniform light intensity throughout the entire light field, resulting in less variation in intensity from the center to the edges [9].



**FIGURE 3. Halogen Lamp Alignment**



**FIGURE 4. Circuit Control of Proton Bombarding**

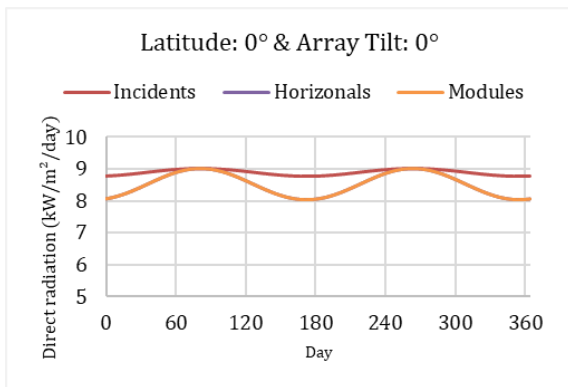


**FIGURE 5. Experimental Simulator for Solar Cell Testing**

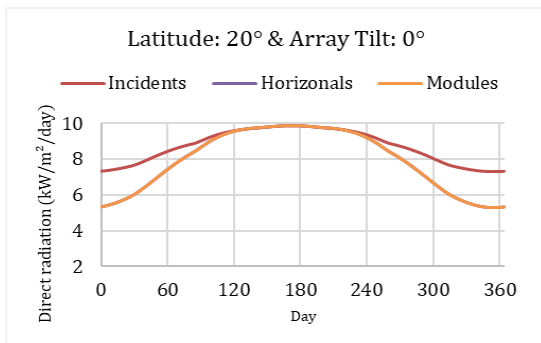
**3. RESULTS AND DISCUSSION**

The experiment was conducted at our university premises (location: 20.35°N, 85.82°E), using monocrystalline solar cells at different hours of the day and at different tilt angles. The graphical data indicates that for specific latitudes and array tilts, there is a distinct pattern in the incident and direct radiation, which correlates with the highest energy collection efficiencies. For instance, the graphs depicting the relationship between latitude, array

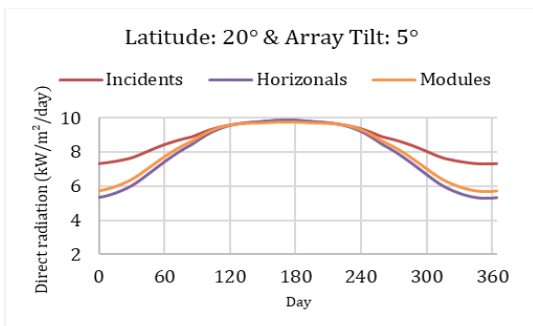
tilt, and direct radiation demonstrate that a tilt of 10° at a 20° latitude maximizes energy collection, particularly during peak sunlight hours [10]. These insights are crucial for optimizing the deployment of monocrystalline PV systems in various geographic and environmental settings, thereby enhancing their contribution to sustainable energy solutions. Below are the graphs showing the solar intensity throughout the days of the year from different angles. (Figure. 6) This does not take into account factors such as clouds, air pollution and atmospheric scattering [11].



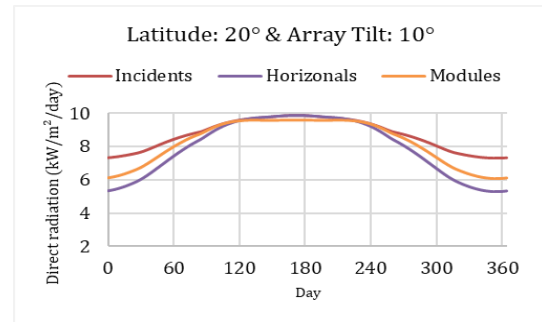
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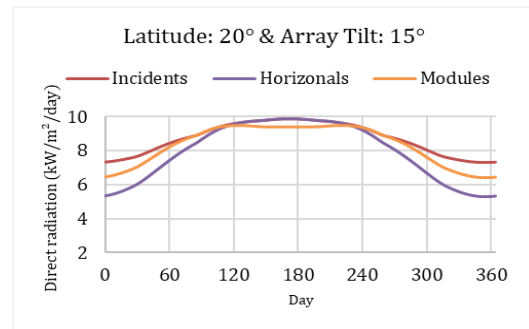
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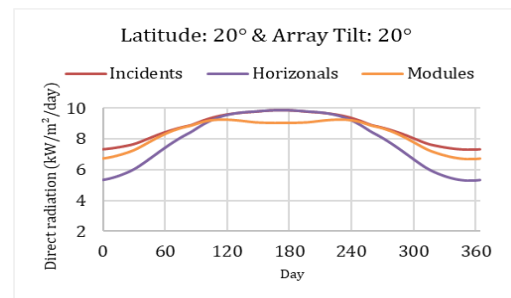
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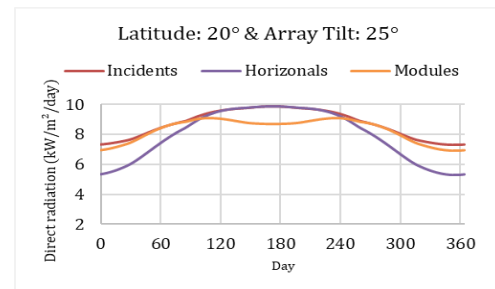
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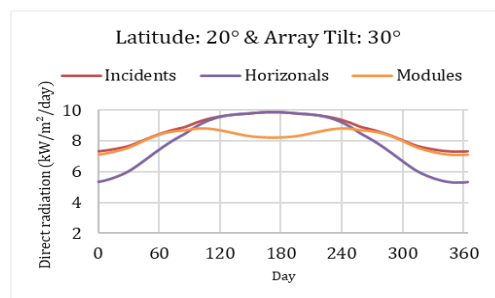
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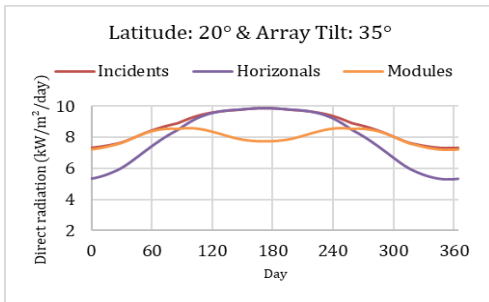


FIGURE 6. Solar Radiation at different angles (A-I) on different days for a year

The equations to generate the plots are given below. These equations are calculated in solar time, and not in local time.

The number of sun hours is simply the time between sunrise

$$\text{Sunrise} = 12 - \frac{1}{15^\circ} \cos^{-1} \left( \frac{-\sin \phi \sin \delta}{\cos \phi \cos \delta} \right)$$

and sunset

$$\text{Sunset} = 12 + \frac{1}{15^\circ} \cos^{-1} \left( \frac{-\sin \phi \sin \delta}{\cos \phi \cos \delta} \right)$$

The direct component of solar radiation is determined from the air mass

$$I_D = 1.353 \times 0.7 (AM^{0.678})$$

The Air Mass can be determined by

$$AM = \frac{1}{\cos \theta}$$

In latitudes above 67° the sun shines for 24 hours during part of the year. (Figure 7) Surprisingly, when averaged over the year, the sun shines an average of 12 hours per day everywhere in the world. In the northern latitudes, the average intensity is lower than at the southern latitudes [12].

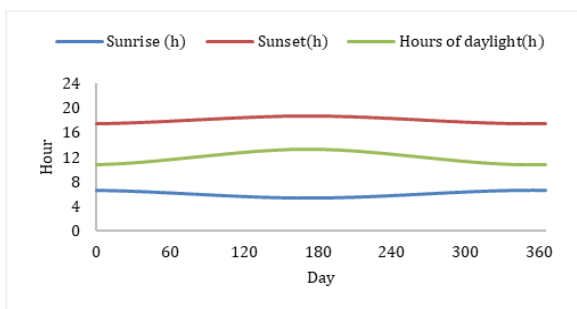


FIGURE 7. Daylight Hours recorded throughout the year

The visual examination in this research provides valuable insights into the daily and yearly variations of direct sunlight in Bhubaneswar, India. According to the data, the highest solar radiation

recorded during the summer solstice reaches around 10-11 kW/m<sup>2</sup>/day, while the yearly average is approximately 5-6 kW/m<sup>2</sup>/day. Sunlight levels fluctuate by 20-25% between seasonal highs and lows. The study highlights that solar radiation decreases with increasing latitude, and Bhubaneswar, located at around 20°N, experiences solar radiation levels within the expected range. Hourly fluctuations are also observed, with radiation peaking at noon and decreasing towards sunrise and sunset [13].

To optimize solar energy capture in Bhubaneswar, the research suggests tilting solar panels towards the south at an angle of 15-20 degrees for maximum year-round absorption [14]. Additionally, energy storage systems like batteries can mitigate the effects of seasonal and daily changes, while solar tracking systems, though more expensive, can enhance energy capture by adjusting the panel's orientation to follow the sun's movement [15 & 16].

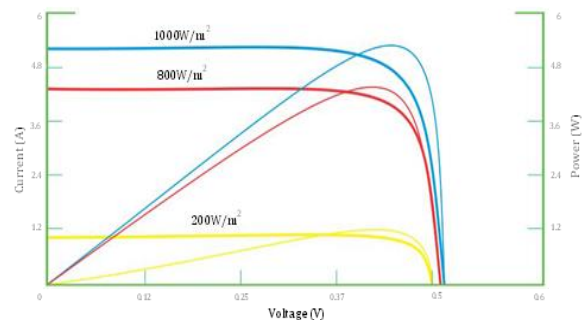


FIGURE 8. Resultant Graph of IV-PV

The I-V graph (Figure. 8) illustrates the current-voltage (I-V) and power-voltage (P-V) characteristics of a monocrystalline solar cell under varying irradiance levels: 1000 W/m<sup>2</sup>, 800 W/m<sup>2</sup>, and 200 W/m<sup>2</sup>.

At higher irradiance (1000 W/m<sup>2</sup>), the short-circuit current ( $I_{sc}$ ) is the highest, while the open-circuit voltage ( $V_{oc}$ ) remains relatively stable. As irradiance decreases to 800 W/m<sup>2</sup> and 200 W/m<sup>2</sup>, the current drops significantly due to fewer photons reaching the solar cell. The voltage is less affected by irradiance, though a small reduction occurs.

The power curves (P-V) show the maximum power point (MPP) where the solar cell delivers the highest power output. As irradiance decreases, the

MPP shifts downward, indicating reduced power generation. This graph demonstrates that the cell's efficiency and power output decline with lower light intensity, with the current being directly proportional to irradiance and voltage being less sensitive to it.

While Monocrystalline solar panels have high efficiency and durability, their higher cost compared to polycrystalline panels restricts their adoption in affordable regions. Enhancing the efficiency of solar cells via research and development has the potential to boost the total energy yield from solar systems.

Even though monocrystalline solar panels are often praised for their effectiveness and durability, their higher cost compared to polycrystalline options may restrict their application in budget-conscious regions. Enhancing the effectiveness of solar cells via research and development efforts has the potential to boost overall energy output from solar systems.

Comparing our data with the IV curves of 405WP Monocrystalline PV Modules using a tracer machine [17], the graph and the measured data show a similar trend in the relationship between irradiance and power output. According to the graph, the maximum power point (MPP) shifts downward as irradiance decreases, indicating reduced power generation. Similarly, the measured data shows that the power output ( $P_{max}$ ) is higher at higher irradiance levels. For example, at an irradiance of  $881 \text{ W/m}^2$ , the  $P_{max}$  is 302 W, while at an irradiance of  $869 \text{ W/m}^2$ , the  $P_{max}$  is 291 W.

The graph also shows that the open-circuit voltage ( $V_{oc}$ ) remains relatively stable as irradiance decreases. This is consistent with the measured data, which shows that the  $V_{oc}$  values remain relatively stable across different irradiance levels. For instance, the  $V_{oc}$  values for the three measurements at irradiance levels of  $869 \text{ W/m}^2$ ,  $865 \text{ W/m}^2$ , and  $866 \text{ W/m}^2$  are 43.8 V, 43.8 V, and 43.8 V, respectively.

In contrast, the short-circuit current ( $I_{sc}$ ) values in the measured data show a direct relationship with irradiance. As irradiance increases, the  $I_{sc}$  values also increase, at an irradiance of  $881 \text{ W/m}^2$ , the  $I_{sc}$  is 9.31 A, while at an irradiance of  $869 \text{ W/m}^2$ , the  $I_{sc}$  is 8.78 A. This is consistent with the graph,

which shows that the  $I_{sc}$  decreases significantly as irradiance decreases.

The measured data also shows a slight decrease in  $V_{oc}$  values as temperature increases. For example, the  $V_{oc}$  value at a temperature of  $53.8^\circ\text{C}$  is 43.8 V, while the  $V_{oc}$  value at a temperature of  $57.7^\circ\text{C}$  is 43.3 V. This decrease in  $V_{oc}$  values with increasing temperature is consistent with the expected behavior of solar cells, where higher temperatures can lead to a decrease in voltage output.

Overall, the measured data supports the trends observed in the graph, demonstrating a direct relationship between irradiance and power output, and a relatively stable relationship between irradiance and voltage.

## CONCLUSION

The graphical analysis and numerical insights presented in this study provide a comprehensive understanding about the significant impact of array tilt and latitude on the performance of monocrystalline solar cells. The data highlights that optimizing the tilt angle, particularly around  $10^\circ$  at a latitude of  $20^\circ$ , maximizes energy collection during peak sunlight hours, making this configuration ideal for solar installations in similar geographic regions. These findings emphasize the importance of considering local environmental conditions when deploying photovoltaic systems to achieve optimal efficiency. While the experiment successfully identifies key parameters for maximizing energy collection, further studies should include the effects of atmospheric factors such as clouds, air pollution, and scattering, which could influence real-world energy output. Overall, the insights gained are crucial for enhancing the deployment of solar energy systems and their role in sustainable energy solutions.

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