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Preliminary Comparative Analysis of Polycrystalline Solar Cells and Solar Emulators in Near-Unobstructed Sunlight Conditions

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ABSTRACT: *Solar cell technology provides a promising solution to energy and environmental issues. Under near-unobstructed sunlight conditions, this study conducts a preliminary comparative analysis of polycrystalline solar cells and solar emulators, exemplified by the Bp solar SX-310J model. Because of their low cost, polycrystalline solar cells are critical for renewable energy applications. Recent advances in solar cells have focused on improving energy conversion efficiency and resilience. Solar intensity, solar cell characteristics, applied load, and solar radiation are all measured as part of the experimental methodology. The findings show a clear relationship between sunlight intensity and polycrystalline solar cell performance. Maximum voltage (Vmpp) and maximum current (Impp) are at their highest during the zenith of the sun. This study also evaluates the solar emulator's ability to accurately replicate actual sunlight conditions. Lux measurements demonstrate consistent alignment with natural solar intensity changes, validating the emulator's reliability. In conclusion, this study contributes to understanding polycrystalline solar cell behavior and affirms the reliability of solar emulators for testing. These insights are pivotal for advancing solar cell technology's efficiency and sustainability in various environments.*

NOMENCLATURE

Symbol	Description	Unit
n	The day of the year	*day*
I	Current	*A*
PV	Photovoltaic	
V	Voltage	*V*

Greek letter

α	Angle of the sun	°
δ	Declination of the sun	°
φ	The geographical latitude of the location	°
ω	The solar angle at a certain time	°

Subscripts

mpp	Maximum power point
sc	Short circuit
op	Open circuit

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I. INTRODUCTION

Renewable energy, particularly solar cell technology, has emerged as a critical solution to energy and environmental challenges. Solar cells use sunlight as an infinite source of energy, offering an environmentally friendly alternative and potentially reducing reliance on fossil fuels [1]. The main challenges it faces, however, are efficiency and production costs [2]. Renewable energy's future holds great promise for significant innovation. Solar cell design breakthroughs, the use of advanced materials, and advances in energy storage can all increase efficiency and lower costs [3]. The incorporation of solar cells into electric vehicles, smart buildings, and decentralized power grids will also help this industry grow [4]. Government support and public awareness of renewable energy are growing, which encourages greater adoption. With these changes, the future of solar cell technology looks brighter, as it will play an important role in reducing greenhouse gas emissions and providing a clean and sustainable energy source [5].

Polycrystalline PV (Photovoltaic) is a type of solar cell that is widely used in renewable energy applications. They are made up of several small crystals that combine to form a solar cell, and the main advantage is that they are less expensive to produce than monocrystalline solar cells [6]. Several studies have been conducted in order to improve the performance of these polycrystalline solar cells. For example, research has been conducted to improve energy conversion efficiency in polycrystalline solar cells by optimizing the structure and semiconductor materials used [7]. In addition, there has been progress in research into techniques for increasing resistance to extreme temperatures and harsh environmental conditions [8]. All of this is done to maximize the energy potential of polycrystalline solar cells and make them a more appealing option for solar energy application.

Recent advances in polycrystalline solar cell technology have revealed exciting advancements in improving the efficiency and performance of these solar cells. A study explored enhanced matching materials to minimize energy loss in polycrystalline solar cells, resulting in notable enhancements in energy conversion efficiency [9]. Additionally, research in enhancing polycrystalline solar cell designs to improve efficiency and withstand extreme temperatures has shown promising results [10]. In parallel, recent advancements in solar emulator technology have introduced compelling innovations. For instance, the application of machine learning algorithms to enhance the accuracy of solar emulators in replicating sunlight conditions has bolstered the reliability of solar cell testing [11]. Furthermore, efforts to develop more efficient hardware solutions for controlling solar emulators have led to more precise and efficient testing procedures [12].

Solar emulators, such as the Bp solar SX-310J model, are useful tools for developing and testing solar cell technology, including polycrystalline solar cells. Solar emulators can simulate sunlight conditions in a controlled environment, allowing researchers to test solar cell performance under a variety of customizable conditions. Researchers have been able to better understand the response and efficiency of solar cells under varying light intensities and temperatures thanks to the use of the SX-310J solar emulator and similar devices, resulting in valuable insights for the development of better and optimized solar cells. This study aims to provide more in-depth information about the performance of both in situations similar to actual sunlight conditions by comparing results from polycrystalline solar cells and tests performed using a solar emulator.

The motivation for this study stems from the need to develop more efficient solar cell technology. Even though polycrystalline solar cells are less expensive to produce, increasing their efficiency remains a challenge. Solar emulators, on the other hand, such as the SX-310J, have aided in understanding the response of solar cells to varying light intensities and temperatures. However, the performance comparison of polycrystalline solar cells and solar emulators requires further investigation. The intensity results of both in conditions close to unobstructed sunlight will be compared in order to provide important insights that can aid in the development of more efficient and sustainable solar cell technology.

These studies show a strong commitment to overcoming efficiency and accuracy challenges in polycrystalline solar cell technology, as well as the development of increasingly sophisticated solar emulator technology. The comparative studies conducted in this research will contribute significantly to a better understanding of the performance of these technologies in sunlight conditions similar to actual conditions, enriching the scientific literature in this area.

II. EXPERIMENTAL SETUP

The solar emulator used in this study is the Bp Solar SX-310J (Fig. 1) and polycrystalline type solar panel. Tabel 1 shows the specifications of solar emulator.

In the experiment, these solar panels were chosen to simulate sunlight conditions. The solar panels have been installed and are linked to the solar emulator control system. Maximum voltage (Vmpp) and maximum current (Impp) settings are adjusted to the desired standard sunlight conditions for this experiment.

Table 1. Specification of solar emulator

Specifications	**Data**
Panel dimensions	42.49 x 27.28 x 5 cm
Number of Cell per module	36 cells
Output power	10 Wp
Maximum power voltage	16.8 Volts
Maximum power current	0.59 Amps
Open circuit voltage	21 Volts
Short circuit current	0.65 Amps
Maximum system voltage	50 Volts

1. Measurement

A lux meter is used to measure the intensity of sunlight. To ensure accurate measurements, the Lux meter is placed at an appropriate distance from the solar panel. During the experiment, measurements were taken at predetermined time intervals to record variations in sunlight light intensity. Meanwhile, the to-be-tested Polycrystalline Solar Cell is placed in front of the Bp Solar SX-310J solar panel. Multimeters are used to measure the open circuit voltage (Voc), short circuit current (Isc), maximum power voltage (Vmpp), and maximum power current (Impp) of solar cells. Measurements are made at the same time as the intensity of sunlight is measured.

2. Testing

The experiment was conducted by connecting polycrystalline solar cells to a load (variable resistor) that could be changed to produce load variations (Fig. 2). During the experiment, the variable resistor value is changed to vary the load applied to the solar cell. Meanwhile, a pyranometer was used to measure solar radiation over time to obtain more complete data about solar radiation during the experiment. This solar radiation data, along with light intensity data, will be used to analyze the results.

Data on light intensity, solar cell characteristics, applied load, and solar radiation were recorded on a regular basis throughout the experiment. The collected data will be analyzed to better understand how polycrystalline solar cells respond to changes in light intensity and applied load.

The obtained data will be thoroughly analyzed in order to evaluate and compare the performance of polycrystalline solar cells in sunlight conditions similar to actual condition with the test results obtained using the SX-310J solar emulator. This experimental method will provide a better understanding of the response and performance of polycrystalline solar cells under actual condition, allowing for a more accurate assessment of solar cell technology's potential in renewable energy applications.

Fig. 1 Solar emulator

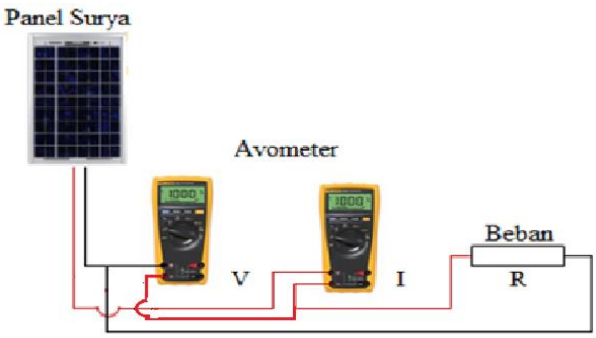

Fig. 2 Experimental setup scheme

III. RESULTS AND DISCUSSION

Fig. 3 shows the solar radiation intensity from 08:00-15:20. Due to the sun is still on the eastern horizon and has not yet reached its peak, the intensity of solar radiation appears low at 8 am. The intensity of radiation tends to increase over time as the sun rises higher in the sky. The radiation intensity can reach its peak at 12:45 pm, displaying the highest value in the graph. Natural variations in radiation intensity, such as passing clouds or shadows from specific objects, may occur during this period. There appears to be a decrease in radiation intensity at 09:45 am. This is due to clouds passing overhead and blocking sunlight from reaching the solar panels. The radiation intensity will then begin to decrease as the sun moves lower in the sky in the afternoon. The radiation intensity decreases further at 15:15 pm as the sun approaches the western horizon and dusk.

On March the declination of the sun can be calculated using the formula [13]:

$$\delta = -23.5°. cos(\frac{360°}{365}.(n + 284)) \quad (1)$$

Where n is the day of the year (Julian date). On March 17, n is 76 (because of a leap year). Thus, we can calculate the value of δ:

$$\delta = -23.5°.cos\left(\frac{360°}{365}.(76+284)\right) \approx -2.11° \quad (2)$$

With the calculated value of δ, the angle of the sun (α) at 8 am can be determined using the formula:

$$\alpha = \arcsin(sin(\varphi).sin(\delta) + cos(\varphi).cos(\delta).cos(\omega)) \quad (3)$$

Where φ is the geographical latitude of the location (approximately -8.6° for Mataram, Lombok), δ is the calculated solar declination, and ω is the solar angle at a certain time. For 8 am, ω can be calculated as follows:

$$\omega = (pukul - 12).15°$$

$$= (8-12).15° = -60°$$

The angle of the sun at 8 am can now be calculated:

$$\alpha = \arcsin(sin(-8.6°).sin(-2.11°) + cos(-8.6°).cos(-2.11°).cos(-60°)) \quad (4)$$

$$\alpha \approx 75.7°$$

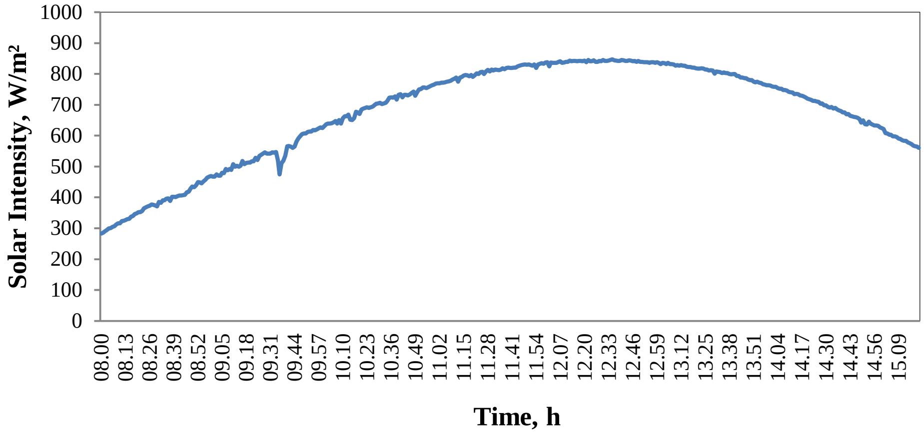

Fig.3 Solar radiation intensity from 08:00-15:20

Therefore, the angle of the sun at 8 am in Mataram, Lombok, Indonesia, on March 17, is about 75.7° from the zenith (the point above the head). This describes the elevation angle of the sun at that time. The sun's elevation angle, approximately 75.7° at 8 am, indicates a high position in the sky, signifying morning's brightness. This high sun angle holds significance for solar cell testing due to the intense morning sunlight, potentially enhancing solar cell performance and energy capture. As time progresses towards noon, the sun's angle will further increase, suggesting improving sunlight conditions and peak intensity around midday.

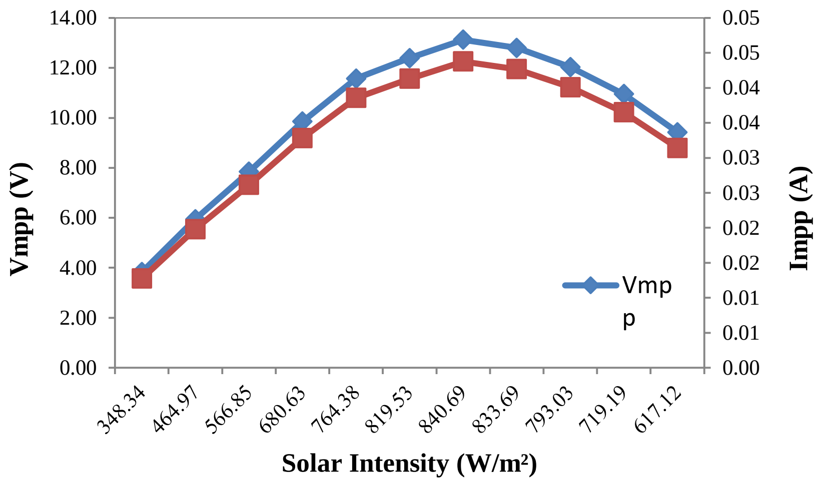

Fig. 4 Relationship between solar intensity and Vmpp and Impp

Fig. 4 shows the relationship between solar intensity and Vmpp and Impp. The experimental results show a clear relationship between solar intensity (from 8 am to 3 pm) and polycrystalline solar cell maximum voltage (Vmpp) and maximum current (Impp). Vmpp and Impp have low values in the morning, when the intensity of sunlight is still low. This is consistent with the basic principle of solar cells, which states that the less energy available to produce maximum voltage and current, the lower the intensity of sunlight [14].

The sun's intensity gradually increases over time, peaking around 12:40 pm. Vmpp and Impp reach their maximum values at this time, indicating that the solar cell produces the most voltage and current when the intensity of sunlight is at its peak. This peak represents the point at which the polycrystalline solar cell performs optimally, producing the greatest amount of output power. Both Vmpp and Impp begin to fall slowly after reaching the peak. This could be due to a variety of factors, including changes in the sun's angle, potential shadows from passing objects or clouds, or internal factors in the solar cell that affect its performance. This decrease indicates that when the intensity of sunlight decreases, the solar cell cannot maintain its maximum output power.

Comparing these results with prior studies reveals a parallel pattern. For instance, in the realm of polycrystalline solar cells, a study by [15] identified a congruent correlation between sunlight intensity, Vmpp, and Impp._These discoveries underscore the significance of comprehending the responsiveness of solar cell voltage and current to alterations in light intensity. Additionally, [16] underscores the importance of overseeing and regulating solar cell voltage and current amidst fluctuating lighting conditions to enhance efficiency. Their findings are useful in the development of efficient solar cell systems. Overall, the experimental findings contribute to a better understanding of how the intensity of sunlight affects the Vmpp and Impp of polycrystalline solar cells. This knowledge can help to develop more efficient and optimal solar cell systems for generating solar energy.

The device's ability to replicate actual sunlight conditions is an important aspect of solar cell performance testing. This work compared the light intensity (Lux) measurements produced by the solar emulator with the average solar intensity measured during the test period to ensure the validity of the results. The findings of this comparison have important implications for understanding how reliable solar emulators can be used for testing solar cells. The results show excellent consistency between the solar emulator's light intensity measurements and the average solar intensity measured during the experiment period. Lux measurements taken by the solar emulator increase over time as natural solar intensity increases, reflecting changes in the intensity of sunlight received by polycrystalline solar cells. This is a strong indication that the solar emulator, in this case the SX-310J model, is capable of effectively simulating sunlight conditions that are similar to actual condition.

This dependability and consistency are especially important in solar cell testing. Researchers must be confident that the conditions produced by the solar emulator accurately reflect actual sunlight conditions when using it. This enables researchers to accurately understand the performance of solar cells across a wide range of sunlight intensities and use test results to guide the development of more efficient solar cell technology [17].

The consistency in Lux measurements from the emulator validates the experimental results in the context of comparing polycrystalline solar cells and solar emulator tests. The solar emulator's data enables the comparison of polycrystalline solar cell performance under varying sunlight intensities, bolstering our experimental findings and ensuring an accurate reflection of their real-world performance.

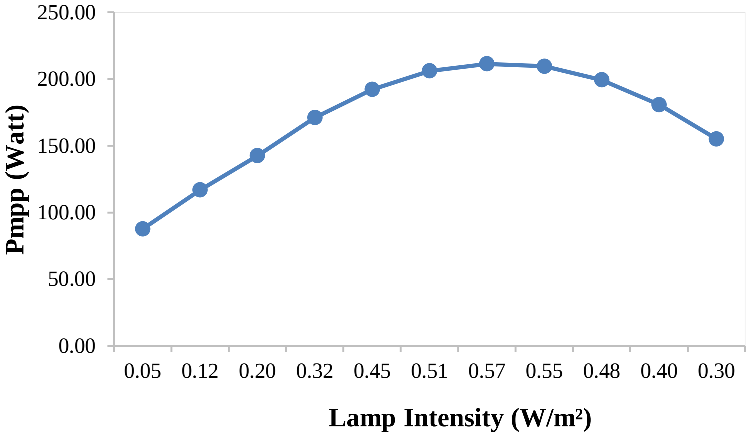

Fig.5 Relationship between lamp intensity and Pmpp

Fig. 5 shows the relationship between lamp intensity and Pmpp. The experimental results show a clear relationship between solar intensity (from 8 am to 3 pm) and polycrystalline solar cell peak output power (Pmpp). Pmpp has a low value in the morning, when the intensity of sunlight is still low. This is expected because the lower the solar intensity, the less energy the solar cells receive, resulting in lower power output. The sun's intensity gradually increases over time, peaking around 12.40. When the sunlight intensity is at its peak, Pmpp reaches its maximum value, indicating that the solar cell produces the most power. This peak represents the optimal point at which polycrystalline solar cells convert the majority of the sun's energy into electricity. Pmpp begins to fall slowly after reaching the top. This could be due to a variety of factors, such as changes in the sun's angle, possible shadows from passing objects or clouds, or even internal factors in the solar cell affecting its performance.

IV. CONCLUSION

This preliminary comparative analysis between polycrystalline solar cells and solar emulators, such as the Bp solar SX-310J model, under near-unobstructed sunlight conditions provides valuable insights for advancing solar cell technology. The findings demonstrate a strong correlation between solar intensity and the performance of polycrystalline solar cells. As sunlight intensity increases, maximum voltage (Vmpp) and maximum current (Impp) reach their zenith, reflecting optimal solar cell performance. However, a gradual decline follows, suggesting that reduced sunlight intensity diminishes the solar cell's output power. Moreover, the study validates the solar emulator's ability to accurately replicate actual sunlight conditions. Lux measurements by the emulator consistently align with natural solar intensity changes, affirming its reliability for testing solar cells. These results underscore the importance of understanding how solar intensity influences solar cell behavior. Such knowledge is instrumental in designing more efficient and sustainable solar cell systems. As the renewable energy sector continues to grow, these insights will aid in harnessing solar power's full potential and reducing a reliance on fossil fuels, ultimately contributing to a cleaner and more sustainable future.

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