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Remote Monitoring and Optimization of Solar Panel Power Efficiency: A Community Engagement Approach

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ABSTRACT

Indonesia has significant potential in harnessing sunlight as an alternative energy source, converted into electricity using photovoltaic (PV) modules. The performance of PV modules is influenced by factors such as light intensity and temperature, where increased light intensity results in higher input power (P_in). To effectively monitor solar panel performance, Internet of Things (IoT) technology is employed, utilizing a RESTful web server. The system uses an Arduino Uno, ESP8266 Wi-Fi module, and a CodeIgniter-based web service platform to transmit real-time voltage data to a server. This study, conducted through direct observation, compares the performance of standard solar panels with those equipped with Fresnel lenses. The results show that solar panel efficiency is influenced by solar radiation, with peak efficiency occurring at midday. Fresnel lenses enhance power output by concentrating light; however, they also create penumbral shading, affecting panel performance during the morning and evening. Panels with Fresnel lenses demonstrated higher output power than standard panels. This research highlights the potential to improve solar energy generation and efficiency using innovative technologies, contributing to efforts to optimize renewable energy in rural areas of Indonesia. It promotes the use of solar energy in underserved communities, providing tools for real-time monitoring, fostering sustainable energy practices, and offering broader environmental benefits. This approach aligns with community empowerment goals, supporting the transition to cleaner, more efficient energy sources.

Key Word: *arduino, esp8266, iot, solar panel*

I.INTRODUCTION

Solar panels are devices capable of converting light intensity into electrical voltage[1]. The solar cells consist of semiconductor materials, specifically p-type and n-type, where the n-type has an excess of electrons and the p-type has an excess of holes[2][3]. When sunlight hits the solar cells, photons separate the electrons and holes, creating a flow of electricity as electrons move toward the negative region and holes move toward the positive region[4]. This natural process generates an electric current.

Previous research has explored various methods to improve solar panel efficiency, including the use of water treatment on the surface of solar cells and the application of Fresnel lenses[5]. These techniques aim to increase light concentration and thereby enhance the performance of solar panels[6][7]. The current research intends to further investigate these approaches with the hope of achieving greater efficiency in both voltage and current output, contributing to the optimization of solar energy systems.

The expansion of internet connectivity to remote rural areas has greatly expanded its utility, enabling the implementation of more than just informational access via online news channels or social media[8][9]. One of the key applications of this advancement is the design and development of solar panel monitoring systems. Solar panels, as alternative energy sources, are especially suitable for Indonesia, a country abundant in sunlight[10]. By integrating internet technologies, the monitoring and management of solar panel performance can be enhanced, even in the most remote locations[11][12].

The research leverages web service technologies, utilizing a RESTful web server for real-time data monitoring. On the hardware side, Arduino microcontrollers and ESP8266 Wi-Fi modules are employed to collect and transmit performance data from solar panels[13][14]. This system will enable users, particularly in rural areas, to track and optimize the energy efficiency of their solar installations, ensuring sustained power generation and improving energy access in underserved communities.

By implementing such systems, this research not only addresses the technical aspects of optimizing solar panel performance but also supports broader community engagement goals, empowering local populations with the tools necessary to harness renewable energy efficiently[15]. This approach fosters sustainable development by promoting the use of solar energy, contributing to both energy security and environmental conservation in rural areas.

II.METHODOLOGY

This previous research has served as a significant reference point for the authors in conducting this study. The findings of these prior studies have not only informed the methodology but also contributed to the broader understanding of solar panel power optimization. These studies, derived from both academic journals and internet articles, provide a foundation for this work and its focus on solar energy efficiency in community-based settings[16].

To address this issue, the authors of the current study propose a novel solution: a solar panel cooling system using a metal heatsink design made from materials such as aluminum or copper. The heatsink would absorb and dissipate the heat efficiently, enhancing thermal transfer from the solar panel to the environment. This approach prevents the cooling system from becoming ineffective due to the heat absorption by the cooling medium. Moreover, unlike other cooling systems, the heatsink does not place any additional load on the solar panels, ensuring that the power output remains optimal and efficient.

This research is directly aligned with the goals of community engagement and empowerment through the utilization of renewable energy. The findings from the studies referenced above, along with the innovative solutions proposed in this research, have significant implications for solar energy adoption in rural and underserved communities. By improving solar panel performance and efficiency, this study aims to contribute to sustainable development in areas with limited access to the power grid.

1. Methode

The research to be conducted will be a direct observation study, aimed at collecting data on voltage improvement with various experimental variations to obtain a reliable comparison of the characteristics of short-circuit current (Isc) and open-circuit voltage (Voc)[17]. Prior to conducting these experiments, the characteristics of the solar panels will be standardized to ensure that both panels exhibit similar properties. This standardization will be followed by the design and development of the system for the study. The design and system layout are typically presented in the form of a block diagram for clarity and easier understanding.

Referring to the block diagram shown in Figure X, the system consists of a modified standard solar panel. A Fresnel lens is placed on top of the standard solar panel, while a heat sink is positioned beneath the panel to serve as a cooling mechanism[18].

Additionally, the system incorporates remote monitoring using Internet of Things (IoT) technology. Two sensors are employed to monitor the solar panel system: the INA219 sensor to measure current and voltage, and the DHT-11 sensor to measure temperature on the solar panel.

An Arduino Uno board is used to process the data collected from the INA219 and DHT-11 sensors. The processed data is displayed on a 16x2 LCD screen and transmitted to the NodeMCU board. The NodeMCU board is responsible for sending the data over the internet to a Blynk server, which functions as a database and a display interface for smartphones[19].

This study supports community engagement by providing a simple, affordable method for remote monitoring and optimization of solar panel power efficiency in rural areas. It aligns with the reviewers' requests for incorporating user-friendly technologies and editorial recommendations to design practical systems that improve energy efficiency while ensuring ease of use for communities with limited technical resources[20]. This approach contributes to the empowerment of rural communities by providing them with tools to monitor and enhance the efficiency of their renewable energy sources.

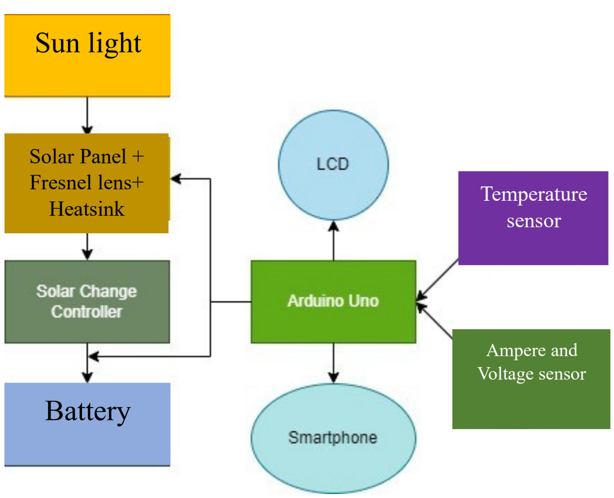

Figure 1. Block Diagram

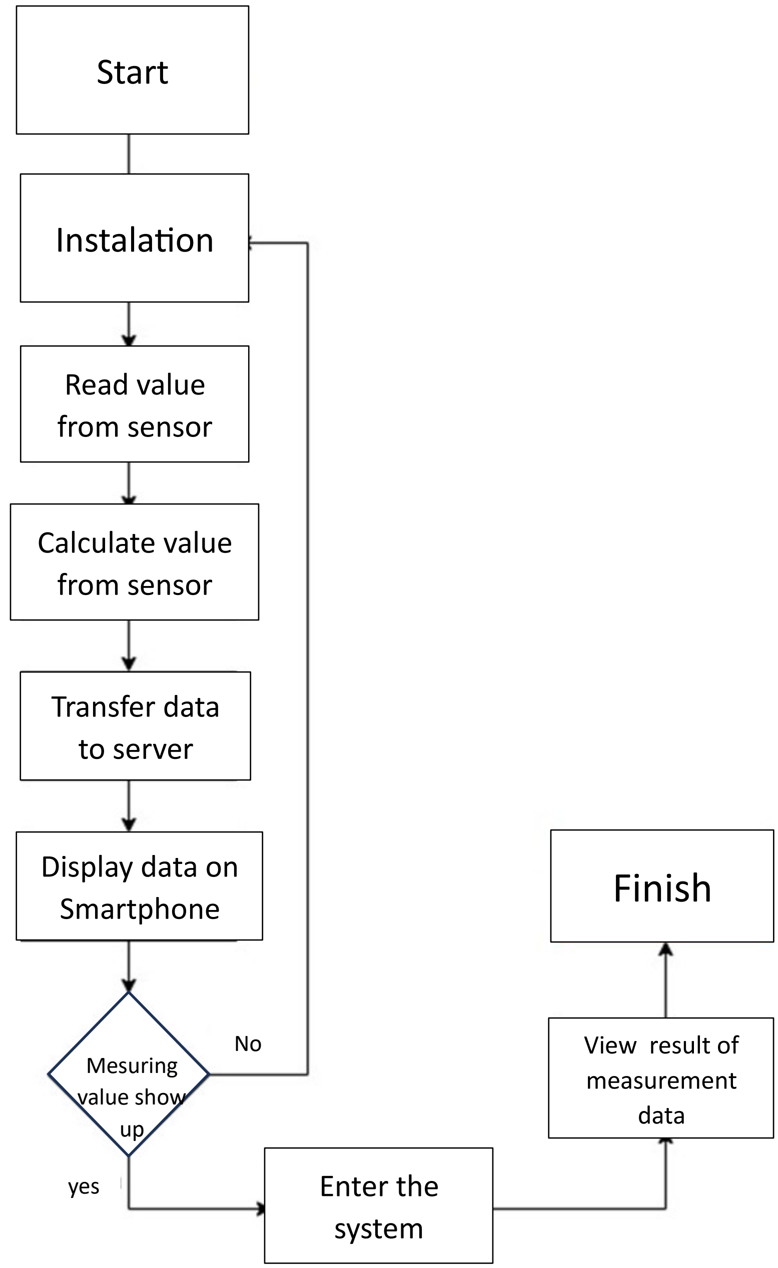

Figure 2. flowchart

III.RESULT & DISCUSION

1.Result

After the explanation of the methodology and approach used in this study, we will now present the test data obtained from the experiments conducted. This data will provide a clearer understanding of the performance of the tested system and offer insights into the impact of various factors, such as light intensity and temperature, on the performance of the solar panels.

Next, the test results collected during the experiment will be presented in detail. This data will illustrate how the developed system can monitor and measure power output in real-time, as well as compare the performance of standard solar panels with those equipped with Fresnel lenses. These results are expected to contribute to the development of renewable energy technology, particularly in Indonesia, and provide a foundation for decision-making in the utilization of solar energy resources.

Table 1. data from *Fresnel lens*

Time	Fresnel Lens		
	Voc (V)	Isc (A)	T (C)
7:30	9,7	0,2	28,6
8:00	9,94	0,32	30,57
8:30	10,3	0,47	30,57
9:00	10,68	0,37	35,77
9:30	10,48	0,4	39,56
10:00	10,51	0,45	40,51
10:30	10,64	0,43	38,64
11:00	10,67	0,44	38,64
11:30	10,72	0,46	37,99
12:00	10,77	0,48	35,5
12:30	10,68	0,45	37,46
13:00	10,55	0,43	38,56
13:30	10,27	0,35	37,69
14:00	10,43	0,38	36,41
14:30	9,72	0,25	34,56
15:00	9,68	0,15	32,06
15:30	9,69	0,07	31,49

This table shows data collected on three key parameters related to the performance of a solar panel using a Fresnel Lens: open-circuit voltage (Voc), short-circuit current (Isc), and temperature (T) at various times throughout the day. The measurements were taken at half-hour intervals, from 7:30 AM to 3:30 PM, with the goal of analyzing the panel's performance over the course of the day. Voc indicates the maximum electrical potential generated by the panel without a load, while Isc represents the maximum current produced when the panel's terminals are short-circuited. The temperature (T) reflects the surrounding conditions, which influence the panel's energy conversion efficiency.

In the early hours, at 7:30 AM, Voc was recorded at 9.7 V with Isc at 0.2 A and a temperature of 28.6°C. As time progressed, the Voc gradually increased, reaching its highest value of 10.77 V at 12:00 PM. This rise indicates that the solar panel was receiving increasingly stronger sunlight, which resulted in higher voltage output. Isc also showed an upward trend as sunlight intensity increased, with the highest recorded value of 0.48 A at 12:30 PM. This reflects a higher current generated by the panel during the peak sunlight period.

The temperature around the panel showed significant fluctuations throughout the day. In the morning, the panel temperature was relatively low, around 28.6°C at 7:30 AM, but it gradually increased as the sunlight became more intense. The highest temperature recorded was 39.56°C at 9:30 AM, before slightly decreasing in the afternoon. High temperatures can negatively affect the efficiency of solar panels, as they tend to perform less effectively at elevated temperatures. Thus, while both Voc and Isc increased, the higher temperature could reduce the overall energy conversion efficiency.

During midday, from around 11:00 AM to 12:30 PM, Voc and Isc remained relatively stable, while the temperature slightly dropped. Solar panels typically perform most efficiently around noon when the sun is at its highest point, providing the most direct and intense sunlight. After 12:30 PM, both Voc and Isc began to decrease, which can be attributed to the declining sunlight intensity as the sun moved westward.

In the late afternoon, from around 2:00 PM to 3:30 PM, there was a notable decrease in both Voc and Isc. At 2:30 PM, Voc dropped to 9.72 V and Isc to 0.25 A, while at 3:30 PM, Voc further declined to 9.69 V and Isc fell to just 0.07 A. This drop is due to the decreasing sunlight intensity in the later part of the day, which resulted in the panel producing less voltage and current. The temperature also decreased in the afternoon, reflecting the reduced energy being received by the panel

Table 2. data from Standart Condition

Time	Standart Condition		
	Voc (V)	Isc (A)	T (C)
7:30	9,63	0,09	29,36
8:00	9,69	0,22	35,71
8:30	10,03	0,36	42,58
9:00	10,42	0,39	43,87
9:30	10,4	0,42	49,31
10:00	10,41	0,46	45,82
10:30	10,53	0,43	51,27
11:00	10,48	0,42	49,32
11:30	10,32	0,39	54,02
12:00	9,92	0,38	55,34
12:30	10,12	0,44	49,81
13:00	10,35	0,41	45,97
13:30	10,01	0,34	40,61
14:00	10,02	0,29	40,3
14:30	9,9	0,27	38,15
15:00	9,57	0,13	33,59
15:30	9,42	0,07	32,48

This table presents data on the performance of a solar panel under standard conditions, tracking three key parameters: open-circuit voltage (Voc), short-circuit current (Isc), and temperature (T) at various times of the day. The measurements were taken in half-hour intervals from 7:30 AM to 3:30 PM. These parameters are crucial for understanding how efficiently the solar panel operates as sunlight and environmental conditions change throughout the day. Voc represents the maximum voltage the panel generates under no load, while Isc measures the maximum current under a short-circuit condition. Temperature (T) shows the environmental conditions that influence the panel's overall performance.

At 7:30 AM, the initial readings show Voc of 9.63 V, Isc of 0.09 A, and a temperature of 29.36°C. These values gradually increase as sunlight intensity rises. For instance, at 8:30 AM, Voc increased to 10.03 V, and Isc rose to 0.36 A. This indicates that as the sun rises and the panel receives more direct sunlight, both voltage and current begin to increase, allowing the solar panel to generate more power. The temperature also rises during this period, from 29.36°C to 42.58°C, highlighting the effect of sunlight on the panel's surrounding environment.

From 9:00 AM to 11:00 AM, both Voc and Isc show steady increases, reaching a peak Voc of 10.53 V and Isc of 0.46 A at 10:00 AM. During this time, the temperature rises as well, peaking at 54.02°C by 11:30 AM. The combination of higher temperature and increased sunlight intensity contributes to the improved electrical output of the panel. However, the increasing temperature may start to have a negative impact on the efficiency of the panel. While higher sunlight increases voltage and current, the rising temperature can cause a decrease in efficiency due to thermal losses.

Around midday, the panel starts to experience a slight decline in performance. At 12:00 PM, Voc drops to 9.92 V and Isc decreases to 0.38 A, while temperature reaches its highest recorded value of 55.34°C. The decrease in voltage and current, despite the high temperature, could indicate that the panel is reaching its thermal limit. High temperatures can cause the materials in the panel to become less efficient, reducing its ability to convert solar energy into electricity effectively.

In the afternoon, from 12:30 PM to 3:30 PM, the values for both Voc and Isc continue to decline. At 3:30 PM, Voc is recorded at 9.42 V and Isc at 0.07 A, indicating a significant reduction in the panel's performance. The temperature also decreases, from 55.34°C at 12:00 PM to 32.48°C by 3:30 PM. This decline in performance correlates with the reduced intensity of sunlight as the sun moves lower in the sky. As the solar panel receives less energy, its output decreases in response.

Overall, the data illustrates the typical behavior of a solar panel over the course of the day, with a peak in performance around late morning to early afternoon, when sunlight is most intense. While higher temperatures contribute to an increase in sunlight exposure, they can also reduce the panel's efficiency. The afternoon shows a clear drop in performance, reflecting the reduced sunlight and increasing temperature limitations. The results highlight the importance of managing both the environmental conditions and the temperature of solar panels to ensure optimal energy production throughout the day.

2. Comparation

The two tables provided show the performance of solar panels under two different conditions: one using a Fresnel lens (Table 1) and the other under standard conditions (Table 2). Both tables track three parameters: open-circuit voltage (Voc), short-circuit current (Isc), and temperature (T) at various times throughout the day. While both sets of data demonstrate how the panel's performance changes over time, the Fresnel lens configuration generally produces higher voltage and current compared to the standard condition, suggesting that the Fresnel lens may increase the efficiency of the solar panel.

In terms of open-circuit voltage (Voc), Table 1 (Fresnel Lens) shows consistently higher values compared to Table 2 (Standard Condition). For instance, at 7:30 AM, the Voc for the Fresnel lens setup is 9.7 V, whereas for the standard condition, it is slightly lower at 9.63 V. The difference in Voc becomes more pronounced around noon, with the Fresnel lens reaching 10.77 V at 12:00 PM, while the standard condition peaks at 10.12 V. This suggests that the Fresnel lens configuration helps concentrate sunlight more effectively, which likely results in a higher voltage output, improving the panel's performance.

Similarly, the short-circuit current (Isc) in Table 1 is consistently higher than in Table 2, reflecting the increased efficiency of the Fresnel lens system. For example, at 8:00 AM, Isc for the Fresnel lens is 0.32 A, compared to 0.22 A for the standard condition. By 12:30 PM, Isc reaches 0.48 A under the Fresnel lens, while the standard condition's Isc is lower at 0.44 A. The Fresnel lens thus seems to capture more sunlight and convert it into current more effectively, which enhances the overall energy production.

Temperature data in both tables shows a general increase as the day progresses, peaking during midday. However, the Fresnel lens setup leads to slightly higher temperatures compared to the standard condition. For instance, at 9:30 AM, the temperature for the Fresnel lens is 39.56°C, while for the standard condition, it is 49.31°C. By 12:00 PM, the standard condition temperature reaches 55.34°C, compared to 40.51°C for the Fresnel lens. The higher temperature in the standard condition may lead to a decrease in efficiency since high temperatures can reduce the conversion efficiency of solar panels. The Fresnel lens, however, appears to maintain more favorable temperatures that might help the panel operate more efficiently.

In conclusion, while both setups show a clear trend of increasing Voc, Isc, and temperature from morning to noon, the Fresnel lens configuration generally outperforms the standard condition in terms of both voltage and current. The higher voltage and current under the Fresnel lens suggest that it may offer enhanced performance by focusing more sunlight onto the panel. Moreover, the lower temperature associated with the Fresnel lens setup could contribute to better overall efficiency, as the panel is not subjected to the high temperatures seen in the standard condition. These comparisons indicate that using a Fresnel lens may significantly improve solar panel performance.

3. Discussion

The analysis of the data from the research conducted reveals that even under cloudy conditions, the values of open-circuit voltage (Voc) and short-circuit current (Isc) can still appear and show different output levels. This indicates that solar panels are capable of generating power even when the sunlight intensity is reduced. The results suggest that the performance of solar panels is not entirely dependent on clear skies, which is a significant finding for areas that frequently experience cloud cover.

One of the key factors in improving the efficiency of the solar panels was the application of cooling mechanisms. The data showed that introducing a cooling system to the solar panels resulted in an increase in voltage output. This finding aligns with previous research that suggests cooling reduces the thermal resistance of solar cells, which in turn enhances their performance. Therefore, incorporating cooling technologies such as heat sinks or water-based cooling systems could potentially optimize energy generation, particularly in regions with high ambient temperatures.

Additionally, the current measurements for the solar panels were higher on bright, sunny days. The data collected indicates that when sunlight intensity is high, the panels generate more current, especially when placed at optimal distances from the light source. This result demonstrates the direct relationship between solar irradiance and the electrical output of the panels. It suggests that adjustments in the installation setup, such as optimal panel positioning and distance from the light source, can significantly influence the energy efficiency of solar systems.

Overall, the research findings highlight the importance of environmental conditions and technological interventions such as cooling in optimizing the performance of solar panels. The data supports the potential for enhancing solar power efficiency through remote monitoring systems and practical solutions that can be adapted by communities. By integrating these findings with community-based engagement, such as using Internet of Things (IoT) technology for monitoring, rural areas can benefit from more sustainable and efficient renewable energy systems.

IV.CONCLUSION

Based on the research conducted on the performance enhancement of solar panels using Fresnel lenses with water cooling, the following conclusions can be drawn:

a. Voltage and Current Improvement: From the calculations, it can be concluded that the solar panel with the addition of a Fresnel lens and heatsink exhibited higher voltage and current outputs compared to the standard panel. This demonstrates that the use of these additional components can effectively enhance the energy generation capability of the panel by improving light concentration and heat dissipation.

b. Irradiance Comparison: The data indicate that the irradiance received by the panel with the Fresnel lens was 4.9%, while the standard panel only received 4.4%. This shows that the Fresnel lens allows the panel to capture a higher amount of irradiance, thus improving its overall performance. The increased irradiance contributes to better energy conversion efficiency, leading to higher electrical outputs.

c. Output Power Comparison: A comparison of the output power (P_out) between the standard panel and the panel with the Fresnel lens revealed that the modified panel consistently generated higher output power. This outcome underscores the potential of using Fresnel lenses as a practical solution for optimizing the efficiency of solar power systems, particularly in regions where solar energy is a critical renewable resource.

In the context of community service and sustainable energy solutions, this research provides valuable insights into optimizing solar panel efficiency, which can be crucial for improving energy access in rural and underserved areas.

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