Optimization The Utilization of Solar Power Plants with A Capacity of 50 WP in Supporting the Welfare of Rural Communities

Joshua Gilbert Daniel Marpaung
joshuamarpaung@gmail.com
Rahmaniar
rahmaniar@dosen.pancabudi.ac.id
Ahmad Faisal
ahmadfaisal@dosen.pancabudi.ac.id

University of Pembangunan Panca Budi

ABSTRACT
Solar Power Plants (PLTS) are a potential solution in providing energy access for rural communities in Indonesia, especially in areas that have not been reached by conventional electricity networks. This study analyzes the efficiency and performance levels of 50 Wp PLTS and evaluates the potential of polycrystalline solar panels in meeting the energy needs of rural communities. The research method involves measuring power output, energy conversion efficiency, and environmental factors that affect solar panel performance. The results of the study show that PLTS efficiency is influenced by solar radiation intensity, ambient temperature, and the presence of dust and dirt on the panel surface. Under optimal conditions, 50 Wp polycrystalline solar panels are able to provide energy for basic needs such as lighting and charging small electronic devices. However, increasing ambient temperature can reduce system efficiency, so mitigation strategies such as passive cooling and optimizing the panel tilt angle are needed. The implications of this study indicate that the use of 50 Wp PLTS based on polycrystalline panels has positive prospects as a solution for rural electrification in Indonesia. However, to improve system reliability and efficiency, additional technology development is needed such as reflectors, energy storage systems, and broader support policies to encourage the adoption of renewable energy. With proper system optimization and infrastructure support, a 50 Wp capacity solar power plant can be a sustainable alternative to increasing electricity access for rural communities.

Keywords: Solar Power Generation, Energy Efficiency, Polycrystalline Panels, Rural Electrification, Renewable Energy.

Introduction

Energy is a vital element that determines the welfare and progress of a country. However, the availability and distribution of energy throughout the world still face various obstacles, such as limited resources, environmental pollution, climate change, and uneven distribution of energy. Indonesia has great potential in developing solar energy because of its position in the equatorial and tropical zones. The equator is an imaginary line that divides the earth into two parts, namely north and south. In this region, sunlight is available throughout the year throughout Indonesia, except during the rainy season or when the sky is covered by clouds. Based on the solar radiation map, Indonesia has a solar energy potential of around 4.5 kWh/m²/day (Gonz'alez-Arjona et al., 2013)

Solar energy is one of the priorities for energy development in Indonesia because of its great potential. According to solar radiation data from 18 locations in Indonesia, solar radiation in the western region of Indonesia is around 4.5 kWh/m²/day with a monthly variation of around 10%, while in the eastern region of Indonesia it is around 5.1 kWh/m²/day with a monthly variation of around 9%. Overall, the potential for solar radiation in Indonesia averages 4.8 kWh/m²/day with a monthly fluctuation of around 9% . (Hamdani et al., 2022)

The sun is the main source of energy that sends large amounts of energy to the earth. In Indonesia, solar cells can be used as an alternative energy source because of the enormous potential of solar energy (Winata et al., 2021) . Given that Indonesia has a tropical climate and is located on the equator, the availability of sufficient solar energy is very important. The abundant solar energy in Indonesia can be utilized through the use of solar panels.

Solar Power Plant (PLTS) is a power plant that can convert sunlight into electricity. Sunlight is a form of natural energy that has been utilized to operate communication satellites using solar cells. These solar cells can generate unlimited electricity directly from the sun without moving components or fuel. Therefore, solar panel systems are often considered environmentally friendly and green (Rusmaryadi et al., 2022) .

Polycrystalline is a type of solar panel consisting of randomly printed crystals. This type requires a larger surface area compared to single crystals to produce the same amount of electricity. This type of solar panel has lower efficiency than monocrystalline, but is more affordable. This panel has the appearance of cracked glass and can generate electricity even in cloudy weather (Ezwarsyah & Bintoro, 2022) .

Modern solar cells generally use silicon and other semiconductor materials as their base materials. There are two main types of solar cells that are widely used in the market, namely monocrystalline and polycrystalline. Monocrystalline solar panels have the highest efficiency in generating electricity, but their performance can decrease significantly during cloudy weather. On the other hand, polycrystalline solar panels have lower efficiency, but can generate electricity even in cloudy or overcast weather (Nasution, 2022) .

This study aims to analyze the use of 50 WP polycrystalline solar panels as an alternative energy source to improve the welfare of rural communities in Indonesia. 50 WP polycrystalline solar panels are one type of solar panels that are widely used in Indonesia because of their affordable price, good efficiency, and long durability. This study is expected to contribute to the advancement of science, technology, and innovation in the field of renewable energy, especially solar panels. In addition, this study is also expected to be useful for the community, government, and industry in designing and implementing policies and programs that support the use of solar panels as an alternative energy to improve the welfare of rural communities in Indonesia.

Formulation of the problem:

1) What is the level of efficiency and performance of a 50 Wp capacity Solar Power Plant (PLTS) in rural environmental conditions in Indonesia?
2) What is the potential of 50 WP polycrystalline solar panels to meet energy needs in rural communities in Indonesia?

LITERATURE REVIEW

1). How Solar Cells Work

The working principle of silicon solar cells is based on the concept of pn junction semiconductors. Solar cells consist of n-doped and p-doped semiconductor layers that form a pn junction, an antireflection layer, and a metal substrate as a place for current to flow. N-type semiconductors are obtained by doping silicon with elements from group V, which causes an excess of valence electrons compared to the surrounding atoms. On the other hand, P-type semiconductors are obtained by doping silicon using elements from group III, which causes a deficit of valence electrons.

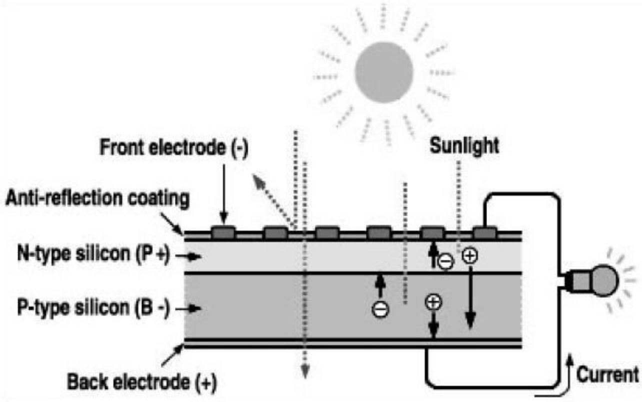

Figure 1. How silicon solar cells work

When these two types of materials come into contact, excess electrons from the N-type diffuse into the P-type. As a result, the n-doped area will be positively charged and the p-doped area will be negatively charged. The electric field formed at this boundary pushes electrons back into the N region and holes into the P region, forming a pn junction. By adding metal contacts on both sides, a diode is formed.

When the junction is illuminated, photons with energy equal to or greater than the energy band width of the material will excite electrons from the valence band to the conduction band, leaving holes in the valence band. These electrons and holes move in the material, creating electron-hole pairs. If resistance is placed across the terminals of the solar cell, electrons from the N area will return to the P area, creating a potential difference and an electric current flowing.

2). Solar Energy Potential in Indonesia

Indonesia has great solar energy potential because it is located in the equatorial region. Based on research from the Ministry of Energy and Mineral Resources (ESDM), the average intensity of solar radiation in Indonesia ranges from 4.5-6 kWh/m²/day, which is ideal for the use of PLTS. In rural areas with minimal PLN electricity networks, PLTS technology can be an alternative provider of reliable and sustainable energy. (Irtawaty et al., 2022) shows that the use of small-scale PLTS can make a significant contribution to village electrification programs, especially in remote areas such as East Nusa Tenggara, Papua, and Kalimantan. With increasingly affordable installation costs and government policy support, this potential can be optimized for the welfare of rural communities (Gholami, 2024) .

3). Advantages of 50 WP Capacity PLTS

The 50 WP capacity PLTS is designed to meet basic electricity needs with the following characteristics: Energy Efficiency: A capacity of 50 WP can be used for lighting (using LED lights) for up to 4-5 hours per day, charging mobile phones, or operating a small fan. Affordable Cost: This system has relatively low installation and maintenance costs compared to other energy systems. High Mobility: Small capacity PLTS are portable so they can be easily installed in various locations, even in areas with limited access. Environmentally Friendly: PLTS do not produce carbon emissions, making them a sustainable choice. Research by (Marzouk, 2022) shows that small capacity PLTS systems are very suitable for areas with low electricity needs but difficult energy access.

Research Method
System workflow planning on Solar Boats that use *solar* :

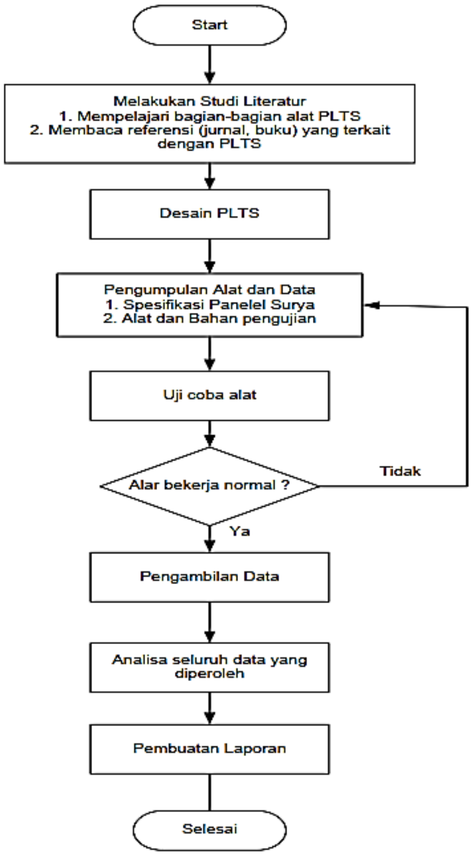

Figure 2. Flowchat Diagram

1. Literature Study
   - Learning the Parts of a Solar Power Plant: This includes understanding the main components of a solar power plant, such as solar panels, batteries, controllers, and loads (lighting). Make sure to learn how each component in the system works and its function.
   - Reading References (Journals, Books) Related to PLTS: Studying literature related to PLTS from journals, books, or other scientific sources to gain a deeper understanding of the technology, applications, and latest developments in solar power generation systems.
2. Design of PLTS
   - Designing a Solar Power Plant System: Based on the results of the literature study, design a solar power plant system that suits your energy needs. This includes planning the capacity of solar panels, battery types, and other components.
   - Determine Power Requirements: Determine how much power is needed for the loads to be used, such as lighting. Be sure to calculate the required solar panel capacity based on the total power required by the load.
3. Collection of Tools and Data
   - Solar Panel Specifications: Determine the specifications of the solar panels to be used (for example, a solar panel with a capacity of 50 Wp). Make sure the panel can produce enough power to meet the needs of the system.

- Testing Tools and Materials: Prepare all the tools and materials needed for testing, such as measuring instruments (ammeter, voltmeter), cables, and other devices needed to assemble and test the system.

4. Tool Testing
   - Perform testing on the assembled tools and systems to ensure that all components function properly and according to the design that has been made.
   - Normal Operation Check: During the test run, make sure all components are working normally. If there are any problems, check the connections, damaged components, or system settings that need to be fixed.
5. Data Collection
   - During testing, record the data obtained periodically, such as current (A) and voltage (V) at each hour of observation. This will provide an overview of the system's performance under real conditions.
6. Analysis of All Data Obtained
   - Once the data is collected, analyze the test results to evaluate the performance of the PV system. Note the variation in current and voltage throughout the day, and whether the system is able to produce enough power to meet the load needs.
7. Report Making
   - Based on the analysis results, create a report that includes:
     - Explanation of the design of the PLTS system used.
     - Test results and data analysis.
     - Evaluation of system performance.
     - Suggestions or recommendations for improvement or further development.
8. Done
   - Once the report is completed, this stage indicates that the PLTS project or research has been completed.

Results and Discussion

1. Solar Cell Performance

The electrical power produced by solar cells when receiving light comes from the ability of the solar cell device to produce voltage when given a load, while simultaneously flowing current through the load. This ability is represented in the form of a current-voltage (IV) curve, as shown in Figure 3.

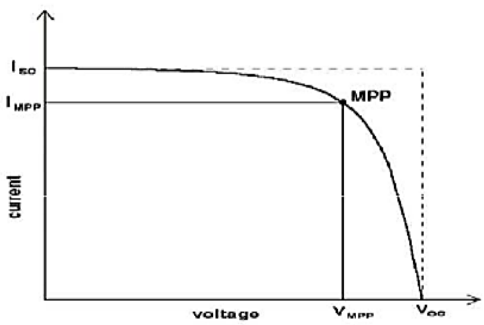

Figure 3. IV Curve Characteristics of Solar Cells

In *short circuit conditions* , the maximum current produced is called *short-circuit current* (Isc). Conversely, in *open circuit conditions* , no current flows, so the voltage reaches a maximum value, known as *the open-circuit voltage* (Voc). The point on the IV curve that produces the maximum combination of current and voltage is called *the Maximum Power Point* (MPP) or maximum power point (Yu et al., 2022) .

2. Tool Testing

Basically, every tool that is designed and assembled must first go through a testing process to find out how much performance and optimization of the output power of the tool is in actual use on the load. Testing is carried out after the circuit is properly installed. The function of the tool is tested by making a transmission cable jumper from the solar panel to *the change control* . (Shepherd & Shepherd, 2022) .

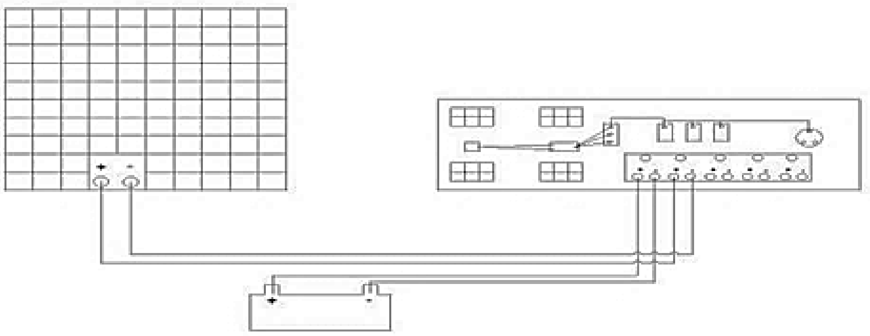

Figure 4. Solar panel test installation

Caption

1. Positive terminal of solar panel
2. Solar panel negative terminal
3. Diode
4. Installation cable
5. Mainboard/voltage regulator
6. Light switch
7. Rotary switch for 6, 9 and 12 volts
8. Terminal unit control change
9. Battery

3. Calculating Solar Radiation Heat Received by Solar Panels

It is known:

- Solar radiation value: 376 W/m^2 (according to data from the Meteorology and Geophysics Agency / BMG)
- Panel length: 63.3 cm = 0.633 m
- Panel width: 57 cm = 0.57 m

The surface area of the panel can be calculated as follows:

- Surface area=Length×Width=0.633 m×0.57 m=0.36 m2 Surface area = Length \times Width = 0.633 \, m \times 0.57 \, m = 0.36 \, ² Surface area=Length×Width=0.633m×0.57m=0.36m2
- So, the surface area of the panel = 0.36 m^2.

Next, the output power generated by the solar panel can be calculated using the formula:

- P=Surface area×Solar radiation
- P = Area \, surface \times Radiation \, sun P=SurfaceArea×SolarRadiation

- P=0.36 m2×376 W/m2P = 0.36 \, m² \times 376 \, W/m²P=0.36m2×376W/m2 P=135.74 WP = 135.74 \, WP=135.74W

So, the output power produced by the solar panel is 135.74 W.

The measuring instruments used in testing are:

- Ammeter (0–20 A) to measure current
- Voltmeter (0–30 V) to measure voltage

4. Large Current and Voltage from Solar Panels

The current and voltage magnitudes from the solar panel can be read directly on the ammeter and voltmeter, then the measurement results are recorded and tabulated.

Table 1. First Day of Testing: November 29, 2024

No	Observation Hours	Current (A)	Voltage (V)	Weather
1	8:00	0.14	12	Overcast
2	9:00	1.40	13	Overcast
3	10:00	1.14	15	Bright
4	11:00	1.10	15	Bright
5	12:00	1.24	14	Bright
6	13:00	1.26	15	Bright
7	14:00	1.30	14	Bright
8	15:00	1.40	15	Bright
9	16:00	0.53	12	Bright
10	17:00	0.31	11	Bright

Table 2. Day Two: November 30, 2024

No	Observation Hours	Current (A)	Voltage (V)	Weather
1	8:00	0.15	12.5	Bright
2	9:00	1.42	13	Bright
3	10:00	1.16	15	Bright
4	11:00	1.30	15	Bright
5	12:00	1.40	15	Bright
6	13:00	1.20	15	Bright
7	14:00	1.30	15	Bright
8	15:00	1.39	15	Bright
9	16:00	0.45	12	Bright
10	17:00	0.15	12	Overcast

The data recorded above shows current and voltage measurements at various times and under different weather conditions.

Table 3. Third Day of Solar Panel Testing

No	Observation Hours	Current (A)	Voltage (V)	Weather
1	8:00	0.16	12	Bright
2	9:00	1.44	16	Bright
3	10:00	1.15	15	Bright
4	11:00	1.37	15	Bright
5	12:00	1.39	15	Bright
6	13:00	1.39	15.5	Bright
7	14:00	1.40	16	Bright

8	15:00	1.39	15	Bright
9	16:00	0.61	12.5	Bright
10	17:00	0.30	12	Bright

This table shows the results of current (A) and voltage (V) measurements recorded at each hour of observation, under clear weather conditions.

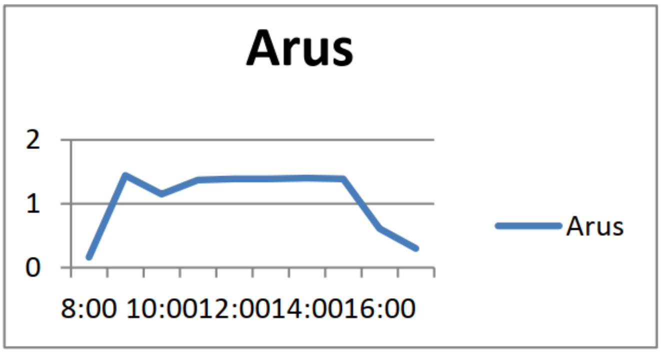

Figure 5. Current versus time graph in testing

In this study, measurements were conducted for three days by recording data every hour. Based on the tests conducted, the third test table is considered the most thorough and accurate. In this analysis, two main graphs were constructed to illustrate the relationship between current, voltage, and time. The first graph shows the relationship between current (A) and time, while the second graph illustrates the relationship between voltage (V) and time. Based on the measurement results and graphs obtained, it can be seen that the variation of current and voltage is influenced by time and weather conditions, which affect the performance of the solar panels. Sunny weather tends to increase the results of current and voltage measurements, while cloudy conditions reduce system performance. Through this observation, it can be concluded that the solar power generation system is functioning well, even though it is influenced by external factors such as weather.

1. **Efficiency and Performance Level of 50 Wp Solar Power Plant (PLTS) in Rural Environmental Conditions in Indonesia**

The efficiency and performance of the 50 Wp Te naga Solar Power Plant (PLTS) in rural areas are greatly influenced by various factors, such as the intensity of solar radiation, ambient temperature, panel tilt angle, and the presence of external factors such as dust and air humidity. Based on previous studies, the efficiency of solar panels tends to decrease with increasing ambient temperature (Ezwarsyah & Bintoro, 2022). Research by Nasution (2022) shows that in sunny weather conditions, a 50 Wp PLTS is able to generate sufficient electrical power for basic needs such as LED lighting and charging small electronic devices.

However, in rural environments, the main challenges faced in implementing PV systems are weather variations and maintenance of solar panels. According to research by Rusmaryadi et al. (2021), the use of reflectors can increase the output power of solar panels by reflecting sunlight to the surface of the panel, but high temperatures can also reduce energy conversion efficiency. Therefore, a panel cooling strategy such as that proposed by Sahar et al. (2019), which uses a concave reflector system and air conditioning, can help maintain optimal performance of PV systems under extreme environmental conditions.

Compared to the research of González-Arjona et al. (2021) which tested the efficiency of electrochemical cells in solar power systems, the results of this study confirm that the main challenge of PV in rural Indonesia is the conversion efficiency that depends on environmental factors. Therefore, an environmental adaptation-based approach such as panel tilt adjustment and cooling system is a solution that needs to be further developed.

2. Potential of 50 Wp Polycrystalline Solar Panels in Meeting Energy Needs in Rural Communities in Indonesia

Polycrystalline solar panels have great potential in providing electricity to rural communities, especially in areas that are not yet covered by the PLN electricity network. According to research by Jamil et al. (2023), polycrystalline panels offer a balance between efficiency and production costs, making them a viable option for remote areas. Research by Mustafa et al. (2023) also emphasizes the importance of monitoring the PLTS system based on the Human Machine Interface (HMI) to ensure optimal performance of solar panels in rural environments.

In the context of meeting the energy needs of the community, 50 Wp solar panels have limitations in supplying large electrical loads, but are sufficient for lighting, charging communication devices, and operating small electrical equipment such as mini water pumps and radios. Research by Irtawaty et al. (2022) on the implementation of 50 Wp PLTS for street lighting shows that this system can operate well as long as weather conditions are supportive and there is an efficient power storage system.

Compared to the large-scale solar power generation model studied by Khamlich et al. (2021), the 50 Wp system is more suitable for small-scale household needs in rural areas. However, research by Li et al. (2022) highlights that with better energy management and distribution, solar energy utilization can develop into a sustainable solution for rural electricity needs.

Implications of Research Results

1. Development of More Adaptive Solar Power Plant Technology
   The results of this study indicate that the use of 50 Wp capacity PLTS can contribute to meeting the basic energy needs of rural communities, but its efficiency is influenced by environmental factors. Therefore, the development of technologies that can adapt to local conditions, such as passive cooling systems or reflectors, is important to improve PLTS performance.
2. A More Inclusive Renewable Energy Policy
   With evidence that polycrystalline solar panels have the potential to provide electricity to rural areas, government policies need to focus more on developing renewable energy infrastructure in remote areas. This is in line with Gevorkian's (2010) research which emphasizes the importance of investing in renewable energy technologies that are affordable and accessible to the wider community.
3. Optimizing Energy Management and Storage
   Although the power capacity of 50 Wp is still limited, optimizing energy management, such as utilizing storage batteries and IoT-based control systems, can help increase the utilization of electricity from this PLTS. Research by Pasaribu & Reza (2021) shows that the development of a solar cell-based charging station system can increase the efficiency of power use in rural communities. Thus, this research contributes to supporting the renewable energy transition in Indonesia, especially for rural communities that have not been reached by conventional electricity networks.

Conclusion

The results of the study, the efficiency and performance of the 50 Wp Solar Power Plant (PLTS) in rural areas in Indonesia are greatly influenced by environmental factors such as solar radiation intensity, temperature, air humidity, and the presence of dust and dirt on the panels. Under optimal conditions, the 50 Wp PLTS is able to provide electrical energy for basic needs such as LED lighting and charging small electronic devices. However, increasing ambient temperature can cause a decrease in efficiency, so strategies such as passive cooling and adjusting the angle of the panel are needed to improve system performance.

In addition, polycrystalline solar panels have great potential in meeting the energy needs of rural communities, especially in areas that are not yet covered by the PLN electricity network. With more affordable production costs compared to monocrystalline panels, this type of panel can be a viable electrification solution for households with low electricity consumption. However, to improve system reliability, integration with storage batteries and more optimal energy management strategies is needed.

The implications of these findings suggest that the development of PV technology based on environmental adaptation, such as the use of reflectors and cooling systems, can improve energy conversion efficiency. In addition, more inclusive renewable energy policies are needed to expand access to solar-based electricity in remote areas. Optimization of power storage and electricity distribution systems is also a key factor in increasing the effectiveness of the use of 50 Wp PV in rural communities. Overall, this study indicates that 50 Wp PV based on polycrystalline panels is a potential solution for rural electrification in Indonesia, although further innovation and optimization are still needed to improve its efficiency.

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