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Comparative Analysis of Temperature Coefficients and Thermal Performance Degradation of 50 WP Monocrystalline and Polycrystalline Solar Panels using Artificial Radiation Simulation

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ABSTRACT

Solar panel performance is strongly influenced by thermal conditions during the energy conversion process, especially in high-temperature environments such as tropical regions. An increase in photovoltaic module surface temperature can reduce output voltage and directly affect power output and system efficiency. This study aims to compare the temperature coefficient and thermal degradation characteristics of 50 WP monocrystalline and polycrystalline solar panels through an experimental approach using artificial radiation simulation. The research method used two photovoltaic modules, namely monocrystalline and polycrystalline types, connected to a Maximum Power Point Tracking (MPPT) charge controller system. A 1000 W halogen lamp was used as an artificial radiation source to simulate solar exposure and increase the panel surface temperature. Electrical parameters, including voltage and current, were collected in real time using Modbus RS485 communication and monitored through computer software. Panel surface temperature was measured using an RS485-based temperature sensor integrated into the data acquisition system. The analysis included calculation of output power, power variation with temperature, and determination of the temperature coefficient based on experimental data. The results showed that both panel types experienced performance reduction as temperature increased, but with different degradation characteristics. In contrast, the polycrystalline panel showed more stable thermal behavior. These findings indicate that temperature has an important role in photovoltaic system performance and should be considered when selecting solar panels for high-temperature environments. This study also demonstrates that artificial radiation simulation can be used as an alternative method for thermal characterization, although it has limitations compared to standard solar radiation conditions.

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INTRODUCTION

The increasing global demand for energy, driven by population growth and industrial activities, has encouraged a shift toward more sustainable energy sources. Dependence on fossil fuels not only leads to the depletion of energy reserves but also has significant environmental impacts through greenhouse gas emissions. Therefore, renewable energy has become a strategic solution to support the sustainability of future energy systems. One renewable energy source with great potential is solar energy, which is abundantly available, especially in tropical regions such as Indonesia.

Solar Power Plants (PLTS) are technologies that utilize the photovoltaic effect to directly convert solar radiation into electrical energy. This system offers advantages such as being clean, modular, and relatively easy to implement on both small and large scales. In addition, advancements in solar panel technology and control systems such as Maximum Power Point Tracking (MPPT) have significantly improved energy conversion efficiency. With these characteristics, PLTS has become one of the primary alternatives in the transition toward more environmentally friendly energy systems.

However, the performance of solar panels is not only influenced by solar radiation intensity but is also highly sensitive to temperature changes. An increase in the surface temperature of photovoltaic modules can cause a decrease in output voltage due to the characteristics of semiconductor materials, which ultimately reduces the overall power and efficiency of the system. This phenomenon becomes a major challenge in the operation of PLTS, especially in regions with high ambient temperatures. Therefore, analyzing the effect of temperature on solar panel performance is an important aspect of optimizing solar energy systems.

In addition to temperature, the type of solar panel material also affects performance characteristics. Monocrystalline solar panels are known to have higher efficiency compared to polycrystalline panels due to their more uniform crystal structure. However, monocrystalline panels tend to be more sensitive to temperature changes. On the other hand, polycrystalline panels generally have lower initial efficiency but demonstrate more stable performance under temperature variations. These differences form an important basis for conducting comparative analyses to determine the most suitable type of panel for specific operating conditions.

Based on the above discussion, an experimental study is needed to quantitatively analyze the effect of temperature on solar panel performance, particularly in comparing the thermal characteristics of monocrystalline and polycrystalline panels. An artificial radiation simulation approach can be used as an alternative testing method in a controlled environment, allowing for more focused observation of temperature variables and real-time system responses.

LITERATURE REVIEW

Basic Principles of Photovoltaics

Photovoltaic (PV) technology is an energy conversion method that utilizes the photoelectric effect in semiconductor materials to directly generate electrical energy from light radiation. When photons with sufficient energy strike the surface of a solar cell, electrons are excited from the valence band to the conduction band, thereby generating an electric current. This process is influenced by radiation intensity, material properties, and environmental conditions such as temperature.

1. **Electrical Characteristics of Solar Panels**

The performance of solar panels is generally analyzed using current–voltage (I–V) and power–voltage (P–V) curves. The I–V curve shows the relationship between output current and voltage, while the P–V curve illustrates the distribution of power with respect to voltage. The optimal operating point is known as the Maximum Power Point (MPP), which is the condition at which the output power reaches its maximum value. Changes in radiation intensity and temperature shift the position of these curves, thereby affecting overall system performance.

2. **Effect of Temperature on Solar Panel Performance**

Temperature is one of the main factors influencing the performance of photovoltaic modules. An increase in temperature causes a decrease in output voltage due to the reduction of the bandgap energy in semiconductor materials. Although the current tends to increase slightly, the dominant effect is still a reduction in output power. The relationship between power and temperature can be expressed mathematically as follows:

$$P(T) = P_{ref} [1 + \gamma (T - T_{ref})]$$

where γ is the power temperature coefficient, which is generally negative. This indicates that an increase in temperature will result in a decrease in the output power of the photovoltaic module.

3. **Temperature Coefficient in Solar Panels**

The temperature coefficient is an important parameter used to describe the sensitivity of solar panels to temperature changes. It is expressed in percent per degree Celsius (%/°C) and indicates the rate of power reduction relative to temperature increase. In general, monocrystalline panels have a larger (more negative) temperature coefficient than polycrystalline panels, meaning they are more sensitive to temperature increases.

4. **Comparison of Monocrystalline and Polycrystalline Panels**

Monocrystalline and polycrystalline solar panels differ fundamentally in their crystal structures. Monocrystalline panels have a single, more homogeneous crystal structure, resulting in higher energy conversion efficiency. In contrast, polycrystalline panels consist of multiple crystals that create grain boundaries, leading to relatively lower efficiency. However, polycrystalline panels tend to exhibit better stability under temperature variations compared to monocrystalline panels.

5. **Thermal Performance Degradation**

Thermal performance degradation refers to the decline in solar panel performance due to increased operating temperature. This phenomenon is caused by increased internal resistance and changes in the electrical characteristics of semiconductor materials. This degradation can be analyzed through the reduction in power relative to reference conditions, usually expressed as a percentage of power loss. Studying thermal degradation is important for understanding system performance under real operating conditions, especially in high-temperature regions.

6. **Maximum Power Point Tracking (MPPT)**

Maximum Power Point Tracking (MPPT) is a technique used to optimize the output power of solar panels by ensuring the system always operates at its maximum power point. MPPT works by adjusting the operating point based on changes in environmental conditions such as radiation and temperature. The use of MPPT has been proven to improve system efficiency compared to conventional methods such as Pulse Width Modulation (PWM).

7. **Modbus RS485-Based Data Acquisition System**

Communication systems based on Modbus RS485 are widely used in industrial applications due to their high reliability against interference and their ability to transmit data over relatively long distances. In photovoltaic systems, this protocol is used to acquire data from devices such as solar charge controllers (MPPT) and temperature sensors in real time. The collected data can then be analyzed using computer software for system monitoring and performance evaluation.

8. **Artificial Radiation Simulation**

Artificial radiation simulation is used as an alternative method for testing solar panels in controlled laboratory conditions. Halogen lamps are commonly used because they can produce relatively high radiation intensity along with a heating effect. However, the light spectrum produced does not fully match the standard solar spectrum (AM1.5), so the test results have limitations in representing actual field conditions.

METHODOLOGY

Research Design

This study uses a quantitative experimental approach with a comparative method to evaluate the effect of temperature on the performance characteristics of monocrystalline and polycrystalline solar panels. Tests were conducted under laboratory conditions using artificial radiation simulations to obtain a more controlled measurement environment. This approach allows direct observation of changes in electrical parameters due to increasing surface temperature of photovoltaic modules.

The research subjects consisted of two 50W solar panel modules with different technologies: monocrystalline and polycrystalline. Both panels were tested in parallel under identical lighting and environmental conditions to ensure comparable results. obtained in a way objective.

Scenario Testing and Mechanism Data Acquisition

Testing done use method warmup controlled through source radiation artificial in the form of 1000 W halogen lamp, which is placed tense straight above solar panel surface with distance 60 cm. Halogen lamps are used For produce combination radiation light and energy thermal capable increase temperature solar panel surface in a way gradually. The two solar panels, namely monocrystalline and polycrystalline with a capacity of 50 WP, placed in position parallel with the same distance to source radiation For ensure condition uniform exposure.

When halogen lamp is turned on, increase temperature start occurs on the surface module photovoltaic. Temperature sensor based RS485 communication installed on each panel will detect change temperature in a way continuous. In a simultaneously, the electrical parameters include voltage, current, and power output read by each MPPT *Solar Charge Controller unit*.

Output data from MPPT and temperature sensor Then transmitted through network RS485 communication using Modbus RTU protocol. All parameters are recorded in real-time using device Modbus Poll software running on the monitoring computer. The recording process done in a way periodic with certain intervals, so change characteristics panel performance against increase temperature can observed in a way sustainable. System flow can shown in Figure 1.

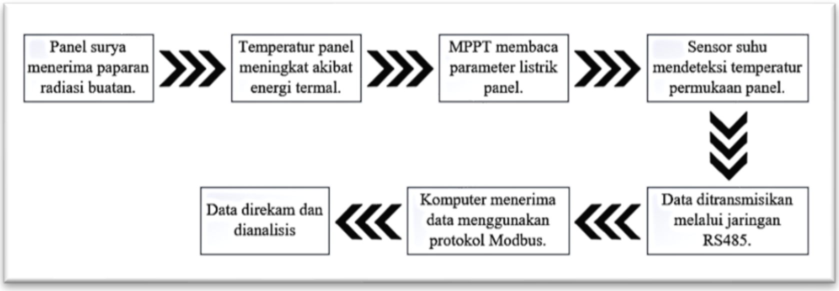

Figure 1. System Flow Study

Data collection was carried out since condition the start of the panel is at temperature approach temperature environment until happen improvement temperature that produces change performance significant between monocrystalline and polycrystalline panels. Testing stopped when trend decline Power both panels show stable patterns and differences performance thermal has seen in a way clear based on recorded electrical parameters.

Approach This aim For get characteristics response thermal panels in comparative, so that connection between temperature surface and degradation performance can analyzed in a way quantitative.

Design System Study

Design system study The system is built on the concept of real- time data acquisition based on industrial communications. Each solar panel is connected to an MPPT-based charge controller system to obtain electrical parameters during the test process. All output data is sent to a computer via RS485 serial communication using Modbus protocol .

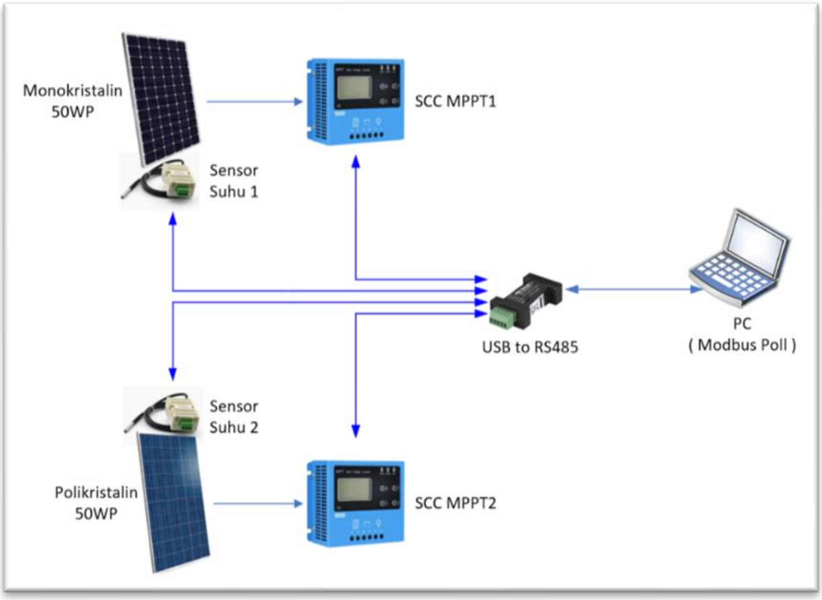

Figure 2. Design System Study

Observed data includes voltage, current, output power, and panel surface temperature simultaneous, system measurement designed For to obtain continuous panel performance data during the heating process. Both panels are placed in parallel and receive exposure radiation artificial from source the same light and heat in the form of 1000 W halogen lamp. Here is description from equipment study.

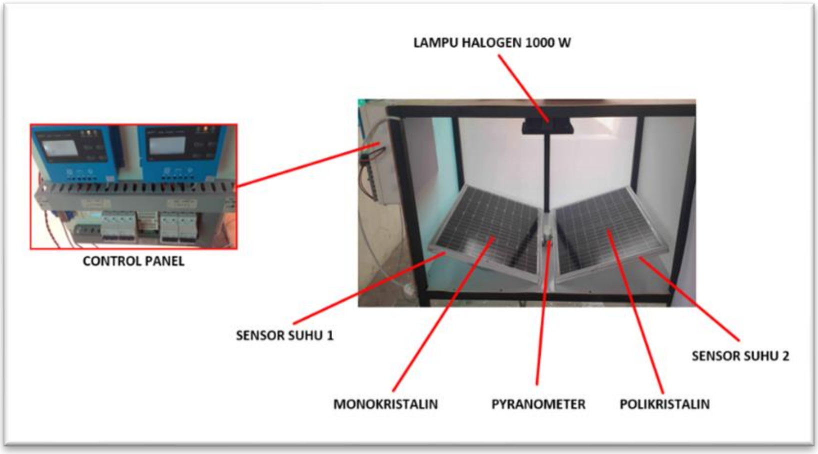

Figure 3. Testing Tools

Equipment Study

Table 1. The equipment used in this research includes

No	Equipment	Quantity	Function
1	Monocrystalline Solar Panel 50WP	1	Test and comparison object
2	Polycrystalline Solar Panel 50WP	1	Test and comparison object
3	MPPT Solar Charge Controller	2	Monitoring solar panel electrical output

4	1000 W Halogen Lamp	1	Artificial radiation simulation
5	RS485 Temperature Sensor	2	Temperature measurement
6	USB to RS485 Converter	1	Communication interface
7	Monitoring PC	1	Data acquisition and logging
8	Modbus Poll Software	1	Reading registered devices

Data Acquisition and Recording

Data acquisition is performed using a digital communication system based on the Modbus RTU protocol over an RS485 line. Data from the MPPT and temperature sensors is read using monitoring software on a computer.

Parameters recorded include:

- temperature (°C)
- Panel voltage (V)
- current (A)
- Power output (W)

Data collection was carried out simultaneously the heating process takes place which is produced by a 1000 W halogen lamp until output electricity show significant data differences from both solar panels the .

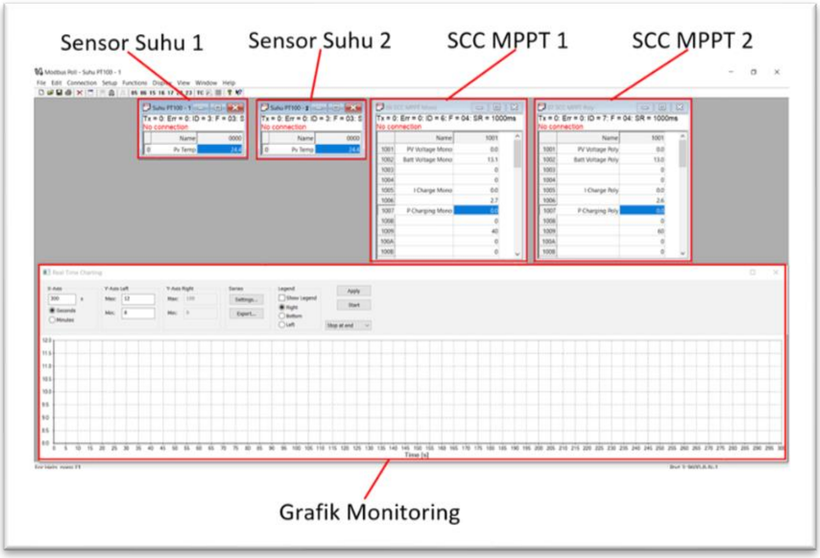

Figure 4. Modbus Poll Menu

Data Analysis

The test data were analyzed to determine the relationship between temperature and solar panel performance.

Calculation Power Output

The panel's electrical power is calculated based on the results of voltage and current measurements.

$$P = V \times I$$

Where:

- P = power output (W)
- V = voltage (V)
- I = current (A)

Analysis Coefficient Temperature

The temperature coefficient is used to determine the panel's sensitivity to temperature increases.

$$\gamma = \frac{P - P_{ref}}{P_{ref}\ x\ (T_2 - T_{ref})}$$

Or if in % equation his become

$$\gamma(\%) = \frac{P - P_{ref}}{P_{ref}\ x\ \left(T_2 - T_{ref}\right)} x\ 100\%$$

with:

- γ = coefficient temperature (%/ ° C or 1/ ° C)
- *P* = Power (W)
- P_{ref} = power reference (Watt) 50 W
- *T* = temperature (° C)
- T_{ref} = temperature reference (° C) 25 ° C

Analysis Degradation Thermal

Thermal performance degradation is calculated using the power loss percentage.

$$Loss(\%) = \frac{P_{ref} - P}{P_{ref}} x\ 100\%$$

Analysis Regression

The relationship between temperature and power was analyzed using linear regression.

$$P = aT + b$$

Equality regression used to determine the level of sensitivity of each panel to temperature changes.

Validation and Limitations Study

Use Using halogen lamps as a radiation source allows testing to be carried out under more stable laboratory conditions. However, the resulting light spectrum does not fully mimic the AM1.5 standard solar radiation used in *the International Electrotechnical Institute* 's photovoltaic testing standards. *Commission.* Therefore, the research results are focused on a relative comparative analysis between panels, not an absolute representation of field conditions.

RESULTS AND DISCCUSION

Characteristics Improvement Panel Temperature

The initial discussion focused on the thermal response of the two panels during irradiation using halogen lamps. The panel surface temperature gradually increases due to the absorption of radiant energy and heat accumulation in the semiconductor material.

The temperature increase was observed from the start of irradiation until it reached a condition approaching thermal stability. Temperature data was obtained from an RS485-based sensor placed on the panel surface , after which the data was collected. movement the temperature received by both The panel types can be seen in Figure 5.

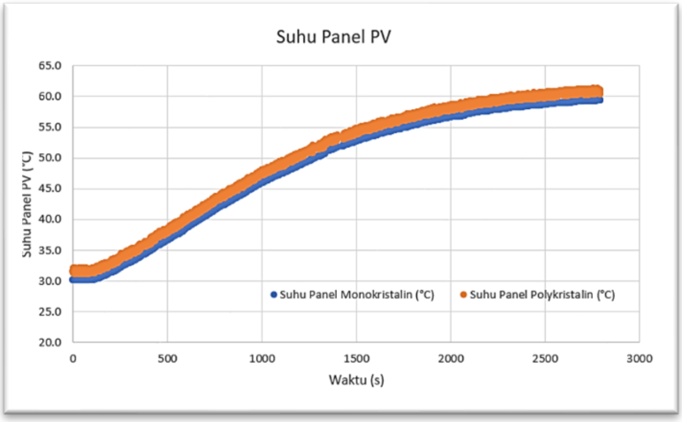

Figure 5. Graph increase Solar Panel Temperature

Result data measurement monocrystalline solar panel temperature shows that temperature module increase in a way gradually from condition beginning until reach mark maximum around 59°C. This pattern show existence phase warmup fast at the start exposure radiation, then followed by a decline rate increase temperature until reach condition approach stable. When the data is used as base approach for polycrystalline panels, obtained that profile increase temperature own the same tendency, with difference mark relative temperature small , namely about 1–2°C more tall.

Phenomenon This show that speed heating and stability thermal second relative panel type similar, because both of them using basic materials silicone. Difference small that appears can associated with structure crystals on polycrystalline which are more No regular, so that part energy radiation more Lots dissipated as hot. However thus, in a way general difference temperature No significant, so that factor the main thing that differentiates performance both panels are not at the same temperature absolute, but rather on the material response to change temperature.

This result consistent with study previously stated that temperature operation module photovoltaics are greatly influenced by conditions environment like radiation sun and temperature ambient , as well as mechanism displacement heat (convection and radiation), not solely by the type of cell material. Studies modeling temperature PV modules show that temperature is an important parameter second after irradiance in determine performance system, and is influenced by balance energy between radiation absorbed and heat released to environment. Besides that, other research confirms that part big energy radiation the sun that does not converted become electricity will changed become hot, so that increase temperature module during operation.

Analysis Voltage to Ascension Temperature

The voltage parameter is the main indicator that is most sensitive to temperature increases.

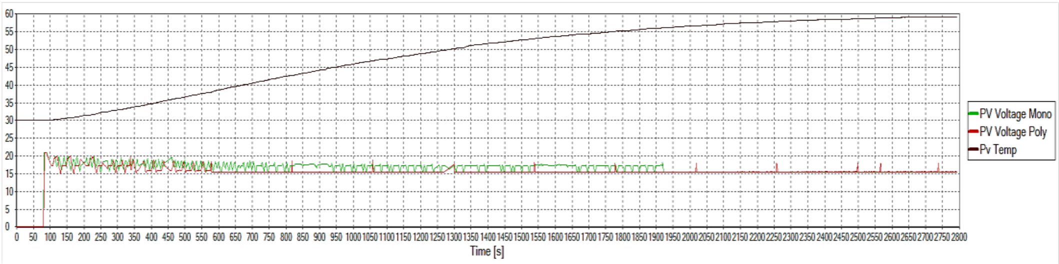

Figure 6. Solar Panel Temperature and Voltage

Based on chart results measurement, system start operating at approximately 80th second, which is marked with start emergence voltage output on solar panels Good monocrystalline and polycrystalline . In the phase beginning this, voltage both panels are in the range of 16–20 V with quite a fluctuation significant, which shows condition transient moment system start accept radiation and reach condition work. Along increase time, voltage both panels tend to experience decline and then stable in the range around 15–17 V. At the same time, the panel temperature increases in a way gradually from around 30°C to approaching 60°C at the end period observation. This pattern indicates existence connection backwards between increase temperature and voltage panel output.

Besides that, it looks that monocrystalline panels own trend higher voltage stable compared to polycrystalline, which is still show fluctuations small during observation. This is show that although both panels experienced improvement temperature that is almost same, material response to warmup different.

Structure crystal single on monocrystalline allows better performance consistent, whereas polycrystalline which has limit grains crystal tend experience variation response more electricity tall to change temperature.

Phenomenon decline voltage consequence increase temperature this has Lots reported in study previously. Study experimental show that improvement temperature PV cells cause decline higher voltage dominant compared to improvement current, so that Power output in a way overall decreased. This is caused by an increase energy thermal in semiconductor materials that affect bandgap and mobility characteristics carrier load. Other studies show that temperature own influence significant to performance PV modules, where the efficiency will decrease when temperature exceed condition optimal. In addition That, other studies also confirm that increase temperature cause decline voltage and power panel output, although current experience a little improvement**.**

Analysis Current to Temperature

Photovoltaic modules as an important parameter in system performance analysis. The discussion focuses on identifying the current change pattern in response to temperature variations during the operating process, in order to understand the thermal response characteristics that occur in solar modules. as shown in Figure 7, in the section on is chart temperature and parts lower is chart solar panel current monocrystalline (green) and polycrystalline (red)

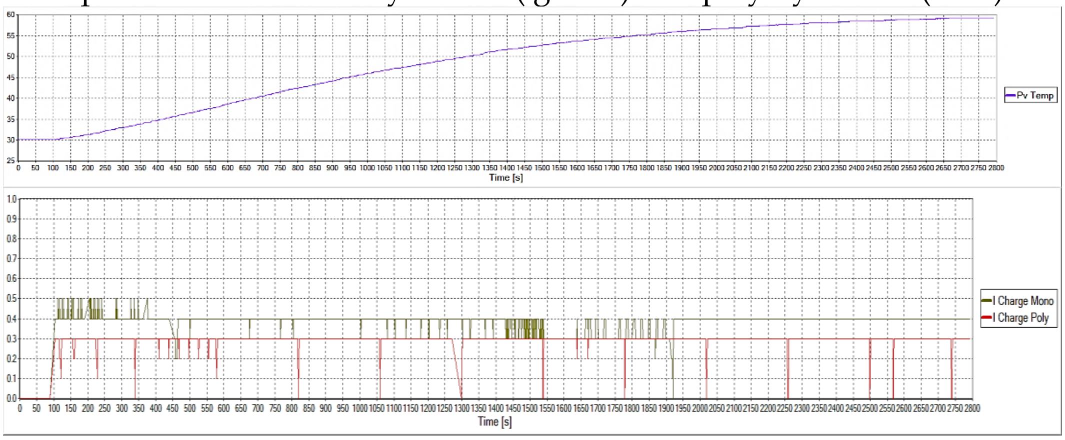

Figure 7. Temperature and Solar Panel Current

Based on the results data measurements displayed on the graph, the system start operating at approximately 80th second, which is marked with start readable current output on solar panels monocrystalline and polycrystalline. In phase beginning this, current both panels show relative value small with fluctuations light as response to condition transient moment system start accept radiation. Along increase time, current experience improvement in a way gradually and then tend stable, while panel temperature increases from around 30°C to approaching 60°C. This pattern show that increase temperature No followed by changes significant current, but rather only improvement in scale small.

Comparison between monocrystalline and polycrystalline panels show that both of them own pattern change almost current identical, although monocrystalline panels tend more stable compared to polycrystalline which is still show fluctuations small. This is indicates that influence temperature to current relatively weak, and variations current more influenced by intensity radiation compared by temperature module That Alone.

Phenomenon This in accordance with results study previously stated that current connection short-circuit current only experience improvement small to increase temperature, whereas influence temperature more dominant to voltage and power output. In physical, improvement temperature cause semiconductor bandgap narrowing so that increase amount carrier load and a little raise current. Besides that, research on the module polycrystalline also shows that current increase marginally with increase temperature, however no Enough significant for increase efficiency in a way overall.

Analysis Power Panel Output

This subchapter discusses the analysis of solar panel output power as a key parameter in evaluating the performance of a photovoltaic system. The discussion focuses on the characteristics of the power changes produced by the panels over operational conditions, such as variations in time and temperature, in order to understand the performance patterns and energy conversion efficiency that occur. during the testing process, in Figure 8 the section on is chart temperature and parts lower is chart solar panel current monocrystalline (blue) and polycrystalline (magenta).

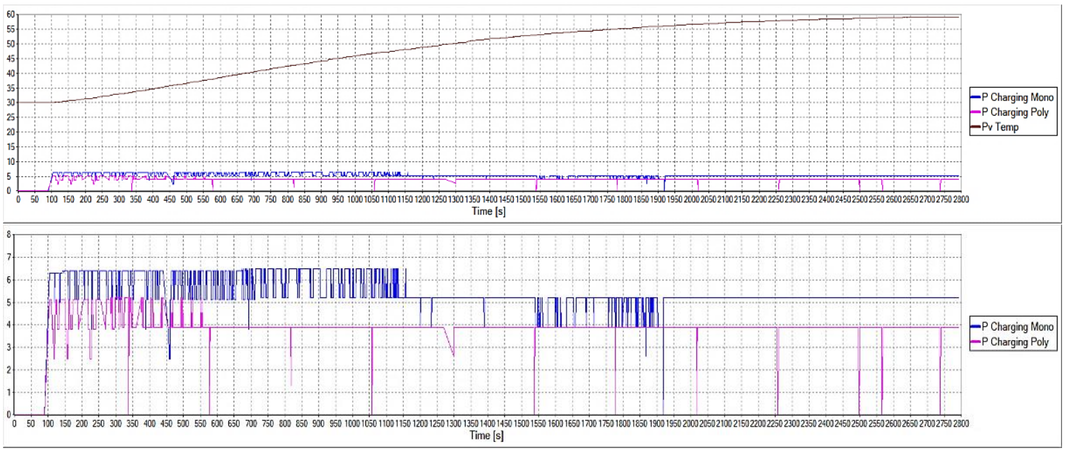

Figure 8. Solar Panel Temperature and Power

Chart results testing show that system start active in the range time around 80th second, marked with start read it mark Power solar panel output on the channel measurement. After the system turned on, curve solar panel power type monocrystalline and polycrystalline start show response output relative electricity stable in the range Power low – medium, with fluctuations small consequence change condition thermal and characteristics MPPT response during the measurement process. At the same time, the temperature the panel surface (brown line) is experiencing increase gradually from around 30°C to approaching 58–59°C during duration testing around 2800 seconds. This pattern show existence accumulation hot consequence radiation sustainable, so that temperature module increase in a way progressive along time. In terms of In general, the data shows that output Power second relative panel type stable in phase beginning, then experience trend decline small and fluctuating when the panel temperature increases, which indicates existence influence temperature to performance photovoltaic.

Phenomenon the consistent with various study previously stated that increase temperature surface module solar influential to decline efficiency and power photovoltaic panel output. In monocrystalline and polycrystalline panels, the increase temperature cause decline voltage Work consequence increasing activity thermal in semiconductor materials silicon, so that Power output effective become more low although intensity radiation still available. Temperature the panel surface has connection negative to capacity generated power, where the monocrystalline panel tend maintain performance more Good compared to polycrystalline in conditions temperature tall. Besides that, other research also confirms that solar panel efficiency in climate tropical influenced by accumulation hot surface modules , especially in testing term Long time.

Analysis Coefficient Temperature and Thermal Performance Degradation

Coefficient temperature obtained from connection between change Power to increase temperature relatively to condition reference, based on results calculation temperature coefficient (γ), it was found that the γ value on monocrystalline and polycrystalline panels showed different sensitivity characteristics to temperature changes.

Table 2. Coefficient Temperature

No	Data Record Waktu (s)	Suhu Monokristalin T_{mono} (°C)	Suhu Polikristalin T_{Poli} (°C)	Daya Monokristalin P_{mono} (Watt)	Daya Polikristalin P_{poli} (Watt)	P_{ref} (Watt)	Koef (%) Mono	Koef (%) Poli	Degradasi Thermal Mono *Loss(%)*	Degradasi Thermal Poli *Loss(%)*
1	103.6	30.2	32.1	6.3	5.1	6.3	-0.60%	-0.81%	17.46%	23.53%
2	2700.9	59.2	61.2	5.2	3.9	5.2				

Coefficient temperature obtained from connection between change Power to increase temperature relatively to condition reference. Coefficient value higher temperature negative show greater sensitivity tall to change temperature, such as seen in the results data the experiment shown in table 2, the experimental data taken and recorded at intervals from start seconds 1 to 2800 taken sample here that is casa enough to represent is at 100 seconds and ends at 2700 seconds, from result experimental % coefficient (%γ) for panel type monocrystalline show value -0.60% while for panel type polycrystalline show figure -0.81% coefficient value (γ) is higher small (more approach zero) on monocrystalline panels show that decline Power consequence increase temperature relatively more low compared to polycrystalline panels. On the other hand, the value coefficient (γ) on polycrystalline panels which is more big (more negative) indicates that the panel more sensitive to improvement temperature, so that experience decline more power significant in conditions temperature tall.

In study this, power reference ($P_{ref)}$does not use the nominal power value (STC), but instead uses the initial measurement power as a reference, considering that the test conditions are carried out with an artificial radiation source that does not represent standard conditions. so that equality his as following :

$$\gamma = \frac{\Delta P}{P_{ref}\ x\ \Delta T} \qquad \gamma = \frac{P_2 - P_1}{P_{ref}\ x\ (T_2 - T_1)}$$

Or if in % equation his become

$$\gamma(\%) = \frac{P_2 - P_1}{P_{ref}(T_2 - T_1)} x\ 100\%$$

with:

- γ = Coefficient temperature (%/ ° C or 1/ ° C)
- P_1, P_2 = Power beginning and power end measurement (W)
- P_{ref} = Power beginning measurement
- T_1, T_2 = Temperature Initial and Temperature end measurement (° C)
- ΔP = Change Power
- ΔT = Change temperature

For calculation degradation thermal performance or *Loss (%)* his become

$$Loss(\%) = \frac{P_1 - P_2}{P_1} x\ 100\%$$

Degradation thermal show the level of power loss in each panel during the heating process. Panels with lower power loss show better thermal performance stability, resulting in test visible type panel polycrystalline experience lost more power big with value of 23.53% compared to monocrystalline panels with value 17.46%.

Comparison results show that monocrystalline panels produce higher initial power than polycrystalline panels. However, their greater temperature sensitivity results in a more rapid performance decline during heating. The data shows that second type of panel experienced improvement temperature in a way gradually along duration exposure hot, but response Power output show different characteristics. Monocrystalline panels produce Power a better start tall compared to polycrystalline panels, but decline performance consequence increase temperature seen more quickly on the panel.

Heredity more power fast on monocrystalline panels can explained through characteristics of semiconductor materials-based crystal single that has level purity silicone higher. Structure crystal single allows mobility electron ongoing more Good so that efficiency conversion energy more high on condition temperature low or standard. However, materials with purity tall tend more sensitive to improvement temperature Because change band gap energy occurs more significant. When the temperature increased, voltage monocrystalline panel output experience decline more fast compared to polycrystalline, so that total power generated decrease in a way more real. This is reflected in the value coefficient temperature indicating sensitivity thermal more big to change temperature.

In contrast, polycrystalline panels own structured structure on Lots grains crystal silicone with orientation different. The existence of limit between crystal cause movement electron No as efficient as monocrystalline panels, so that Power initial results relatively more low. However Thus, the structure multicrystal the tend produce distribution more heat evenly on the surface module. As a result, the response to increase temperature become more stable and fast decline Power No as fast as monocrystalline panels. In other words, even though efficiency beginning polycrystalline more low, this material show tolerance more thermal good condition warmup sustainable.

CONCLUSIONS AND RECOMMENDATIONS

This study confirms that temperature has a significant impact on the performance of photovoltaic panels. Both monocrystalline and polycrystalline panels experienced a gradual increase in surface temperature during testing, which resulted in a decline in power output. The findings show that monocrystalline panels produced higher initial power but were more sensitive to temperature increases, while polycrystalline panels demonstrated greater thermal tolerance but lower initial efficiency. Overall, thermal degradation was higher in polycrystalline panels (23.53%) compared to monocrystalline panels (17.46%), highlighting the importance of thermal management in photovoltaic system performance.

Future research is recommended to conduct testing under real outdoor conditions using a standard solar simulator to better represent actual solar radiation. In addition, integrating cooling techniques or thermal management systems could be explored to reduce temperature-related efficiency losses. Further studies involving longer testing periods, varying environmental factors, and larger panel capacities are also suggested to strengthen the reliability and applicability of the results in real-world photovoltaic installations.

FURTHER RESEARCH

This study has limitations in the heat simulation method used, namely halogen lamps as the source of thermal radiation. The halogen radiation spectrum does not fully resemble the solar spectrum due to its higher infrared radiation dominance, so the test more closely represents the effect of temperature on monocrystalline and polycrystalline panels than actual solar irradiation conditions . Therefore, the results obtained emphasize the characteristics of the thermal response of both types of panels to increasing temperatures.

In addition, the study did not use a standard solar simulator which is generally applied in Standard Test- based photovoltaic testing. Conditions (STC). This was done because the research focused on a comparative analysis of the thermal behavior of monocrystalline and polycrystalline panels when exposed to controlled heat. Testing was also conducted in a laboratory environment, eliminating external variables such as wind, humidity, and changes in solar radiation intensity. Therefore, the research results are more relevant as a controlled comparative study than as a direct representation of field operational conditions.

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