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Performance Analysis of Solar Power Generation System Using MATLAB Simulation Based on Radiation and Temperature Variations

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Abstract:
This research analyzes the performance of Solar Power Plant (PLTS) systems through MATLAB/Simulink simulations, focusing on the effects of varying solar radiation intensity and ambient temperature on the current-voltage (IV) and power-voltage (PV) characteristics of solar panels. The panel model was initially constructed based on datasheet parameters to closely replicate real-world conditions. Subsequent testing involved varying radiation (500–1000 W/m²) and temperature (20–50°C) to assess panel response under changing operational conditions. Simulation results reveal that rising temperatures significantly reduce maximum power (Pmax) due to decreasing output voltage, despite relatively stable current. Conversely, higher radiation intensity substantially increases output current, yielding greater Pmax. Radiation emerges as the dominant factor enhancing panel performance, while temperature acts as a key efficiency limiter. This simulation approach enables cost-effective analysis without field testing, serving as a reference for designing adaptive PLTS systems optimized for environmental conditions. It also provides a foundation for future studies on renewable energy modeling and control in Indonesia's tropical climate.

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Introduction

Solar energy represents a sustainable, environmentally friendly renewable resource with unlimited availability, serving as a strategic alternative to diminishing fossil fuels that contribute significantly to greenhouse gas emissions. Indonesia, strategically positioned in the tropical equator belt, receives average solar radiation of 4.8 kWh/m²/day, positioning it as Southeast Asia's highest potential market for Solar Power Plants (PLTS) both at utility scale and rooftop installations. Government initiatives through the National Energy General Plan (RUEN) target 23% renewable energy mix by 2025, with PLTS expected to play a pivotal role in achieving net-zero emissions by 2060 and reducing 29% coal dependency by 2030. [Niwanda et al., 2025]

Despite abundant solar resources, PLTS performance suffers substantial efficiency degradation from environmental factors prevalent in Indonesia's tropical climate. High ambient temperatures frequently exceeding 30°C elevate panel surface temperatures to 60-70°C, causing voltage output drops of 0.4-0.5% per °C above standard 25°C test conditions. Concurrently, radiation fluctuations from cloud cover reduce photocurrent generation, creating output power instability that undermines grid reliability and delays national energy transition targets. Field observations confirm these issues manifest as 15-25% annual energy yield losses in operational PLTS installations. [Safarudin et al., 2018][Makkulau & Fikri, 2021]

Prior studies provide foundational insights: Safarudin et al. (2018) documented temperature-induced efficiency losses through MPPT hardware testing; Makkulau & Fikri (2021) established linear regression models correlating radiation intensity with polycrystalline cell characteristics; Suryana & Ali (2020) quantified monocrystalline panel voltage-temperature relationships in Surabaya's industrial setting; while Mayasari et al. (2022) demonstrated educational PLTS outreach. Niwanda et al. (2025) mapped Medan City's solar potential. These works predominantly employed static field measurements under limited environmental ranges.

Existing literature reveals critical limitations: reliance on expensive, weather-dependent physical prototyping yields inconsistent datasets; absence of comprehensive MATLAB/Simulink models simultaneously analyzing radiation-temperature interactions across full operational spectra (200-1000 W/m², 25-45°C); and insufficient focus on predictive optimization for Indonesia-specific tropical conditions combining high humidity, dust accumulation, and rapid weather transitions. No studies integrate multi-variable controlled simulations enabling cost-effective PLTS design optimization without field deployment risks, representing the core innovation addressed herein.

Research Methods

This research uses a quantitative approach through simulation with the aim of studying the effect of varying radiation and temperature on the output voltage. The research process includes literature review, parameter determination, circuit model creation with MATLAB/Simulink, and testing through simulation. The devices used in this research include: Laptop as the main tool in designing and implementing simulations. MATLAB/Simulink software to build a Solar Power Plant model, regulate radiation

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variations from 200 to 1000 W/m2 and temperatures from 25 to 45oC, while producing voltage output data.

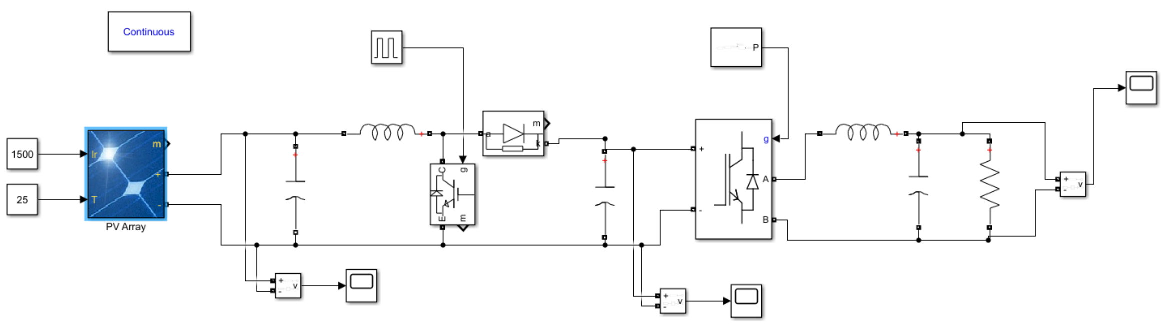
The selection of radiation variations ranging from 200 to 1000 W/m2 and temperatures ranging from 25 to 45oC is based on actual conditions in tropical regions such as Indonesia, where radiation intensity varies from cloudy to sunny conditions, while the average ambient temperature ranges from 25–45°C and can increase to more than 50°C on the panel surface due to direct exposure to sunlight. By using these variations, the simulation is expected to be able to represent the real operational conditions of the PV system in the field. In addition, changes in radiation and temperature values provide an overview of the dynamic characteristics of solar panels, where increasing radiation intensity will increase output power, while increasing temperature tends to decrease panel efficiency due to a decrease in the working voltage of the solar cells. Therefore, the analysis of these two parameters is important to understand the relationship between environmental conditions and the performance of electrical energy produced, as well as as a reference in the development of PV systems that are more optimal and adaptive to weather variations.(Suryana & Ali, 2020)

The simulation results were then analyzed by observing changes in output voltage at various temperatures and solar radiation intensities. The data obtained from these tests were presented in graphs and tables to provide a comprehensive overview of the performance and characteristics of the solar power plant system. This presentation also aimed to identify the optimal operating point that achieves the best efficiency and stability in the energy conversion process.

Results and Discussion

Simulation Results of Radiation and Temperature Analysis of Solar Power Plant Output

Testing is carried out by designing a PLTS circuit using MATLAB (Simulink) as in Figure 2, to find out how variations in radiation and temperature affect the PLTS voltage output. This simulation design determines the initial parameters, namely maximum power, voltage at pp, current at pp, no-load voltage (Voc), short circuit current (Isc), voltage drop



with temperature, current increase with temperature, inductor value, capacitor value.

Figure 1.Design of solar power plant circuit in MATLAB (Simulink)

ParameterThe data that will be used in the research are shown in Table 1.

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Table 1.PLTS parameters in MATLAB

Parameter	Mark
Pmax	213.5 W
Vmp	29 V
Imp	7.35 A
Voc	36.3 V
Isc	7.84 A
Kv	-0.36099 %/deg.C
Ki	0.102%/deg.C
L	20 mH
C	6 mF

These fixed parameters are determined based on literature studies and adaptation to the research objectives, namely analyzing the effect of radiation and temperature variations on the output voltage of PLTS.

Radiation and temperature variation testing

At this stage, testing is carried out by periodically adjusting the radiation and temperature values, by increasing or decreasing them, in the PLTS circuit, the radiation and temperature variation factors affect the resulting output. The following are the results of experiments conducted in MATLAB (Simulink). From experiments with (temperature = 25oC; radiation = 200 – 1000 W/m2) and (temperature = 25 – 45oC; radiation = 1000 W/m2).

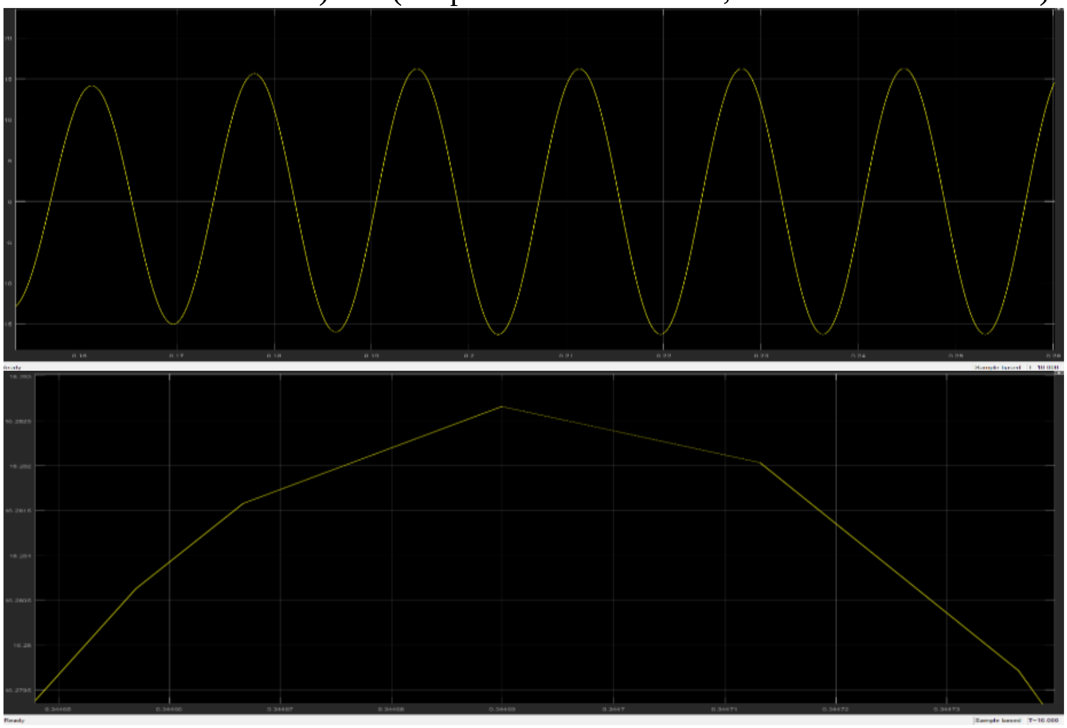

Figure 2.Graph form for (temperature = 25oC; radiation = 200 W/m2)

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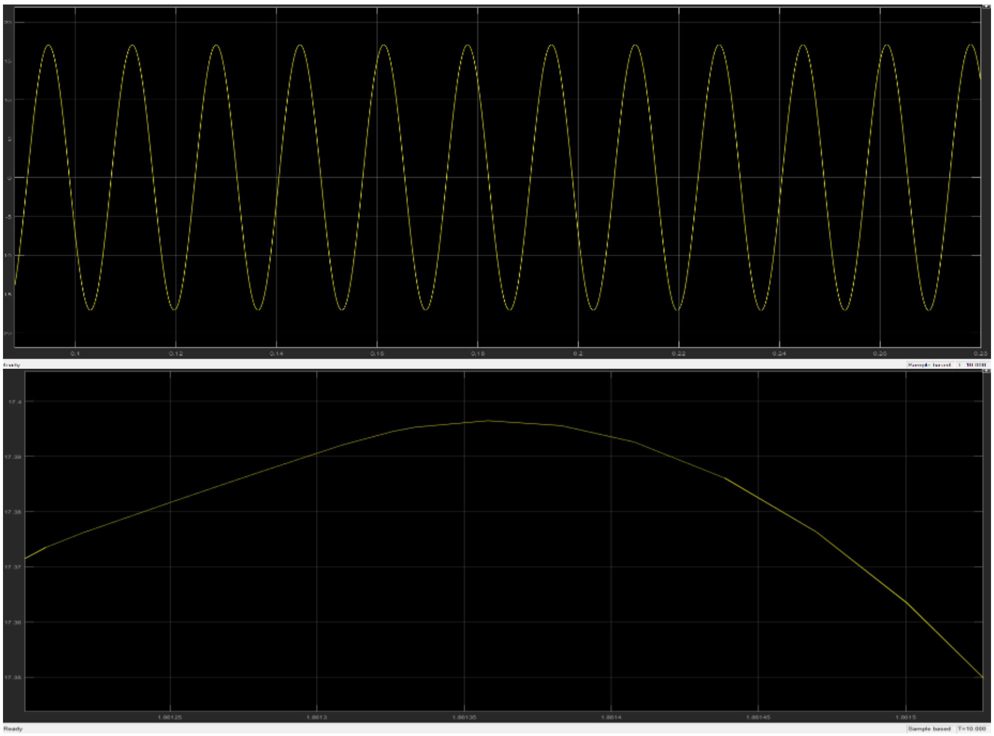

Figure 3.Graph form for (temperature = 25oC; radiation = 400 W/m2)

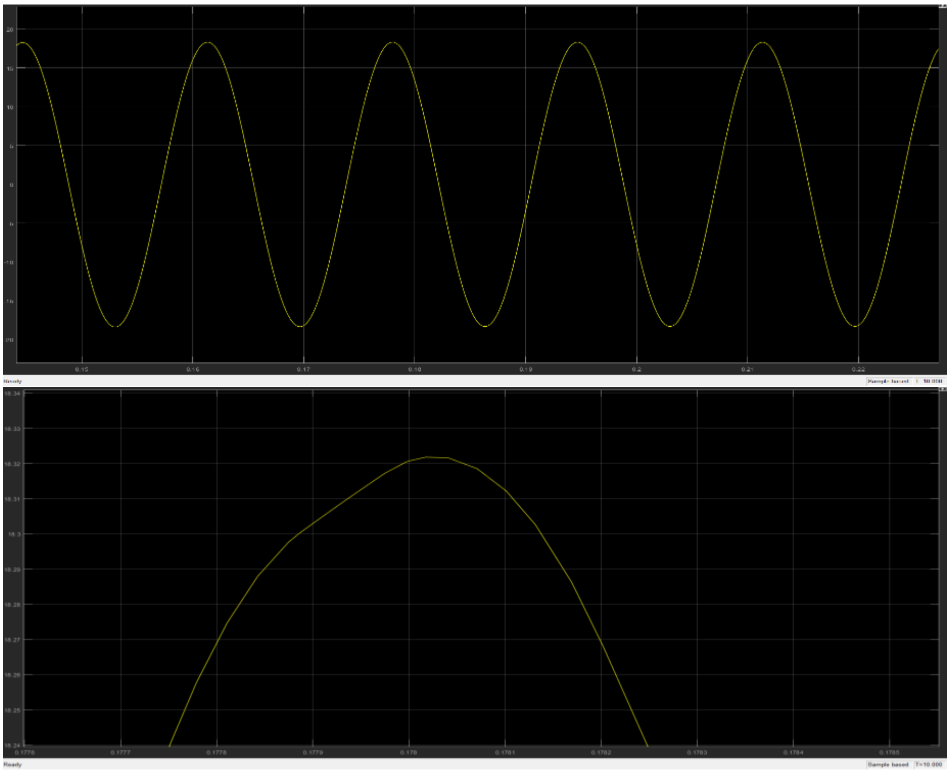

Figure 4.Graph form for (temperature = 25oC; radiation = 600 W/m2)

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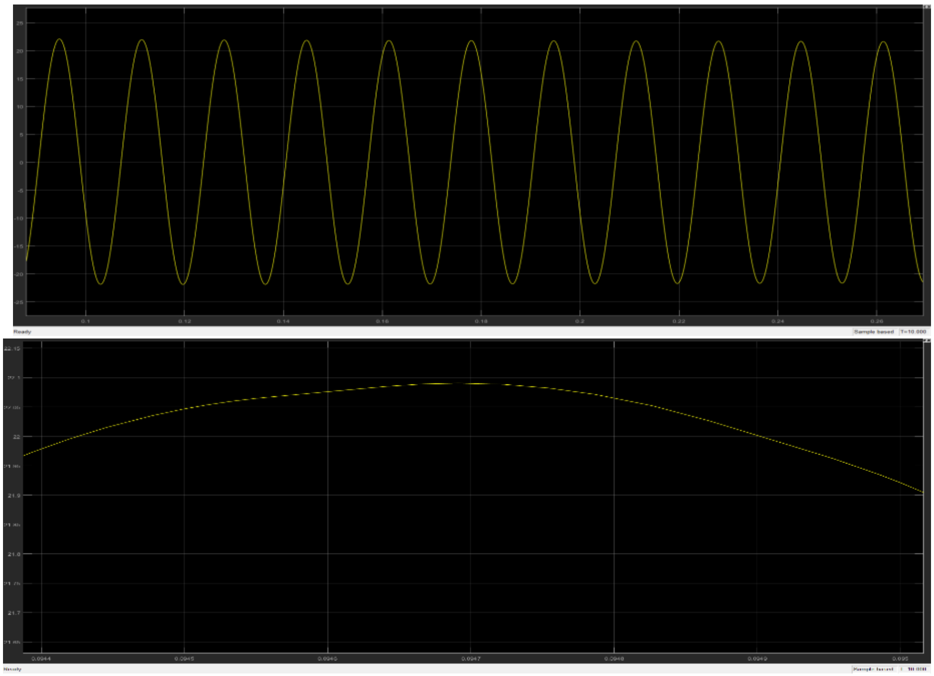
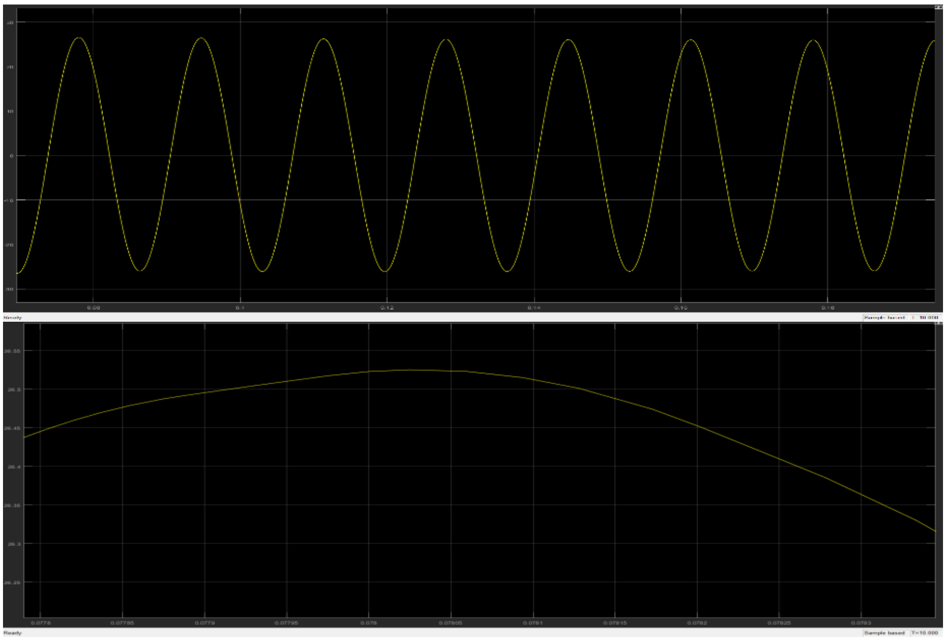


Figure 5.Graph form for (temperature = 25oC; radiation = 800W/m2)Figure



6.Graph form for (temperature = 25oC; radiation = 1000 W/m2)

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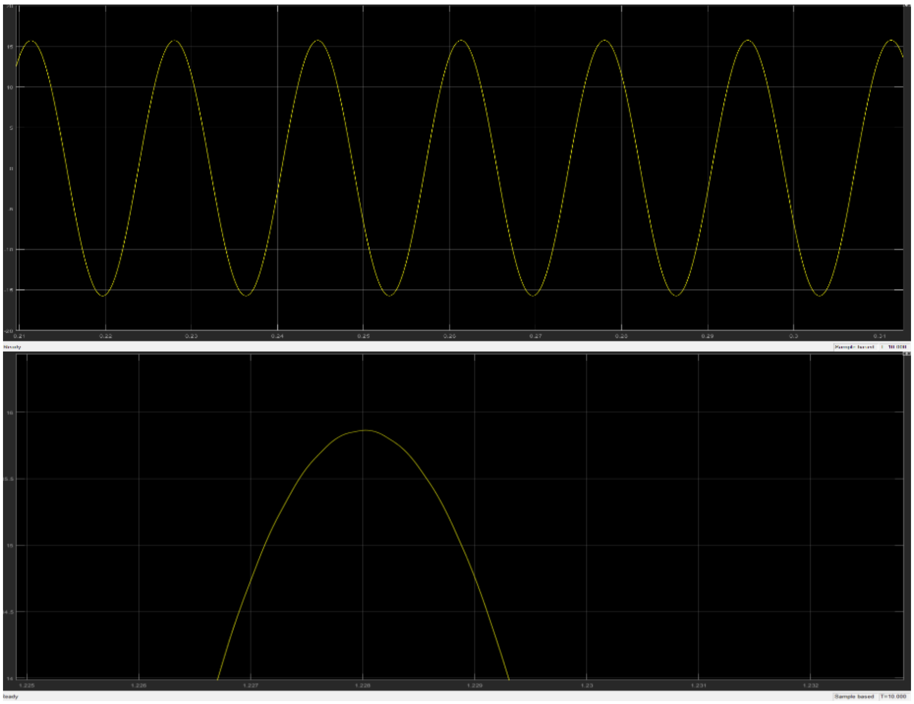

Figure 7.Graph form for (temperature = 35oC; radiation = 10000 W/m2)

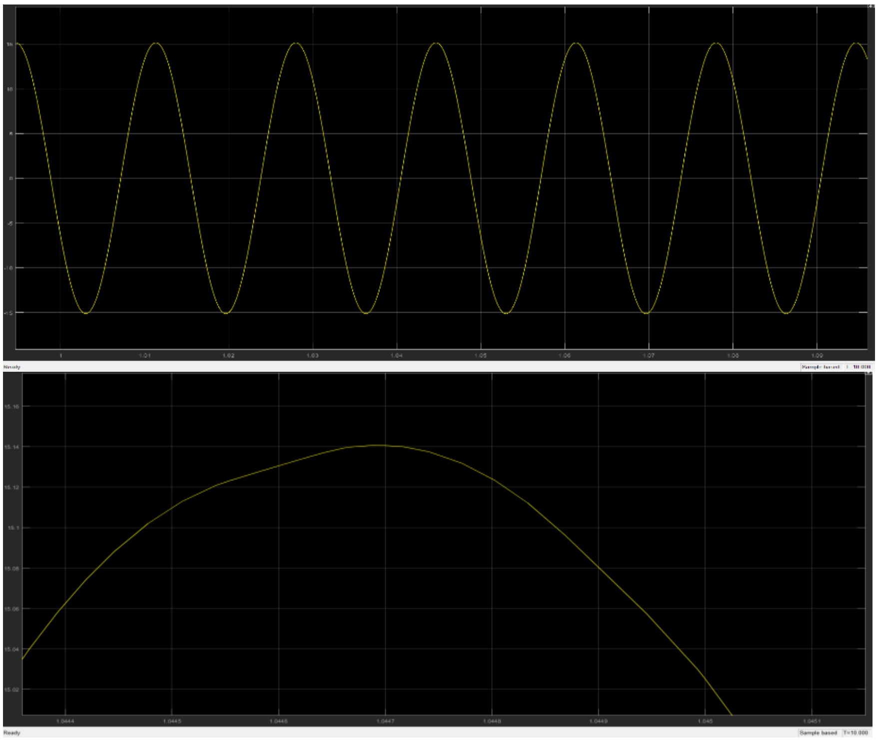

Figure 8.Graph form for (temperature = 45oC; radiation = 1000 W/m2)

The results of the simulation experiment of the effect of radiation and temperature variations on PLTS using MATLAB, obtained a graphic image of the output voltage produced as shown in Figure 3-9.

Temperature	Radiation	V Output	V max
25	200	16	16.28
25	400	18	18,325
25	600	17	17.35

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25	800	22	22.09
25	1000	26	26,524
35	1000	15	15.7
45	1000	15	15.14

In the simulation results, it can be seen that the greater the radiation, the greater the output voltage value (V Output), and in temperature variations, the opposite occurs, the output voltage (V Output) decreases, this pattern is in accordance with the theory of the influence of temperature and radiation variations on the output voltage of PLTS, which states that the output voltage of PLTS is directly proportional to the increase in solar radiation (Vout PLTS | | Radiation), and also like the theory in the mathematical model of single diode PLTS that the higher the temperature, the more current leaks so that the voltage drops

In addition to the increase in output voltage, in the results of this simulation also found a decrease in voltage as well as a drastic increase as well as a normal increase, the PLTS voltage experienced a decrease in temperature variations of 25oC; 600 W / m2 where the initial 18 volts became 17 volts, and at 35oC; 1000 W / m2 where the PLTS output voltage which was previously 26 volts became 15 volts, and among the experimental results the voltage that experienced a drastic increase was at 25oC; 800 W / m2 and 25oC; 1000 W/m2 where each experienced an increase of 5 volts and 4 volts respectively, with also in the experiment of changing the temperature variation the increase in the output voltage of the PLTS was not too drastic or significant where the voltage increase was only around 0.7 volts from 15.7 to 15.14, this case provides information that there are certain operating conditions in the PLTS, where the system runs better or more stable and produces a high increase in output voltage, and reduces the probability of a voltage drop, this case can be explained by the statement of Suwarti, Wahyono, & Budhi Prasetiyo, 2018) showing that a temperature increase of 1°C can reduce the efficiency of solar panels by around 0.4%. This is because the condition of the solar panels or PLTS components experiences excessive heating or overheating which results in the performance of the PLTS decreasing and being more efficient in producing output voltage.

Conclusion and Recommendation

Conclusion

Based on the results of simulations and analyses that have been operated, it can be seen that the output voltage (V out) on the PLTS is greatly influenced by the conditions of temperature variations and solar radiation. When radiation increases, the output voltage (V out) also increases, but in certain patterns the PLTS output voltage decreases by 11 volts at a temperature of 35oC - 45oC; with radiation of 1000 W / m2 this is because the condition of the components in the PLTS overheats which causes the output voltage to decrease. And as explained in the theory in the equation below.

$$I = I_{ph} - I_0(e^{\frac{q(V+IRs)}{nkT}} - 1) - \frac{V\ + IRs}{Rsh}$$

Where if the temperature conditions in the PLTS increase or get hotter, then the leakage current value is greater, which results in a voltage drop. There are also simulation results that show an increase in output voltage of 4 - 5 volts in PLTS with temperature

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conditions; radiation (25oC; 200,400,800,100 W / m2) From here it can be concluded that changes in radiation and temperature variations can affect the output voltage of the PLTS, but not all of these changes are good or beneficial, because in the analysis obtained when radiation increases the output voltage also increases, but when the temperature increases, the output voltage of the PLTS drops or experiences a significant decrease. So not all increases in temperature and radiation variations are directly proportional to the output voltage, but temperature and radiation variations still affect the output voltage

Suggestion

This research is limited to computer simulations usingMATLAB (Simulink). Therefore, direct real-time testing using a real solar power plant circuit is needed to ensure the accuracy of the research results. Physical experimental analysis can provide more realistic data because it can identify unknown factors in the simulation, such as the influence of unstable temperature variations or humidity factors in each research area.

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