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Photovoltaic Performance based on Radiation Intensity Examination using Experimental Study and Thermal Simulation

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ABSTRACT

Solar energy is a renewable energy source that can be converted into electrical energy through photovoltaic (PV) solar cells. However, the efficiency is low, with only 15-20% depending on solar irradiation converted into electricity. The angle of the sun and the structural position of the solar cell system also affect the amount of solar radiation received. Research has been carried out to determine the effect of radiation intensity on the performance of PV solar cells using experimental methods and thermal simulation. The temperature distribution of PV cells has been studied using experimental studies and thermal simulations. The highest temperature was produced at a solar radiation intensity of 1100 W/m2 of 68.4 ◦C for the experimental study and 69.4 ◦C for the thermal simulation study. The highest efficiency is produced at a radiation intensity of 1000 W/m2, with the highest efficiency being 11.5%. This study analyzes the impact of radiation intensity on the electrical efficiency of solar PV cells using two-way ANOVA. The radiation intensity has a P-value of 1.85E-05, which indicates an influence on the electricity produced. There is an MS value of research variation smaller than the MS error of 7.22E-07, indicating an interaction between the two variables.

Keywords: *Solar Energy, Radiation Intensity, Electrical Efficiency*.

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1. INTRODUCTIONS

Renewable energy is utilized to decrease environmental pollution caused by the prolonged use of traditional fossil fuels. Solar energy, as an infinite and sustainable renewable energy source, can be utilized to produce electrical energy through photovoltaic (PV) systems [1]. Then, The most significant issue is the conversion efficiency of solar energy into electricity remains relatively low, resulting in a significant amount of untapped solar energy. The PV modules can absorb these excess solar energy and produce a high efficiency [2]. Although PV technology has increased efficiency, it has been hindered by several drawbacks, such as inefficient heat dissipation and application issues at night[3]. Therefore, the study of PV technology remains of interest to address these drawbacks.

The PV technology is utilized the energy from the solar (or the sun). The solar is emits energy in the form of electromagnetic radiation. This radiant energy is created due to several hydrogen and helium fusion reactions [4], [5], [6]. The amount of radiant energy emitted perpendicular to one square meter of area by the sun outside the Earth's atmosphere (extraterrestrial) is called the solar constant (Gsc). According to the World Radiation Center (WRC), the solar constant equals 1367 W/m^2 with an uncertainty of 1% [7], [8]. These information is possible to utilized the solar energy become Pv technology through the appropriate circuit. Figure 1 provides the PV cell equivalent circuit reported by [8].

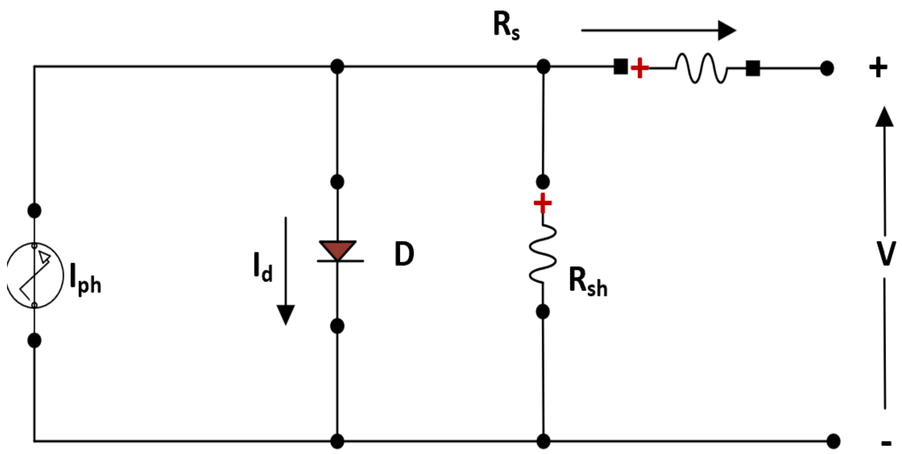


Figure 1. The practical model of single solar [8].

Solar cells are gadgets that use the photovoltaic method to transform solar energy into electrical energy [9]. In the photovoltaic process, electrons in semiconductor materials are excited by photons from sunshine at specific wavelengths, causing an electron flow [10], [11]. The photovoltaic (PV) solar cells will use this electron flux to create electrical energy [12], [13].

Due to the solar cells capacity to operate in diffuse sunlight, photovoltaic solar cells are employed more often worldwide. It is crucial to understand how PV solar cells behave in various climates. Th efficiency of the ensuing conversion depends on how well solar cells function [14], [15]. The angle at which the sun is positioned is another element that affects the volume of solar energy that solar cells will absorb. Each location on Earth will have a distinct angle at which the sun will be. This results from the elliptical nature of the Earth's orbit. To generate the most solar radiation revenue, the structural location of the solar cell system must be designed [16], [17].

The solar cells' efficiency could be better since some of the heat energy they capture is not utilized. Only 15 to 20% of solar radiation can be turned into electricity; the remainder is lost as heat energy [18], [19]. With each degree that the temperature of each module rises, the efficiency of PV solar cells will decline by around 0.40-0.65%. Therefore, research was done to ascertain how the performance of PV solar cells was affected by the radiation intensity they were exposed to [20], [21]. Thermal experimentation were used in this investigation. Then, Filipovic [22] suggests that modeling or simulation can be used to validate and produce the best results from experimental studies. Therefore, modeling or simulation are conducted for this purpose.

2. METHOD

2.1 Experiment Setup

The fundamental component of every photovoltaic system is the photovoltaic cell. In actuality, the photovoltaic cells are large-area semiconductors. Electrical signals can be generated from photon energy in a photovoltaic cell. Because this method of power generation does not affect the environment, PV power generation systems are gaining popularity for both large-scale and small-scale production. Power electronics designers can benefit from the experimental method and simulation of various physical and environmental parameters. These techniques enable the trouble-free simulation of photovoltaic cells. This project utilises experimental investigations and thermal simulation of photovoltaic (PV) solar cells as its research methodologies. For this project, the research workflow is illustrated in Figure 2.

The research experimental study was conducted at Sebelas Maret University. Experimental research uses photovoltaic (PV) solar cells as Polycrystalline 50 Wp YINGLI Solar JS50 with specifications in Table 1 [23]. The entire research setup is designed as Figure 3, which consists of variable resistors, multimeters, thermocouples, solar power meters, and a supporting frame system. The supporting frame is assembled from 40 mm angle steel. The surface angle of the PV solar cells is set according to calculations based on theory. Based on the test location, the latitude angle (ϕ) is -7.56º and the longitude angle is 110.85º. Therefore, the magnitude of the tilt/slope (β) is 21◦, which points north with an azimuth (γ) of 180◦.

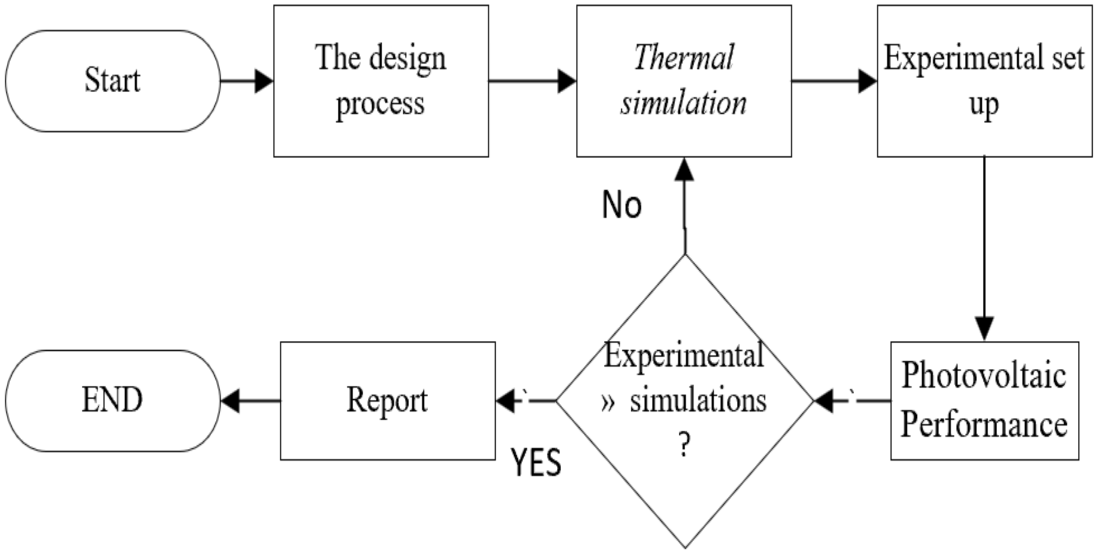


Figure 2. Photovoltaic (PV) solar cell research workflow.

Table 1. The Specification of 3 Phase Motor

Specification	Mark
Solar solar cells	Polycrystalline52 x 156 mm
Open-circuit voltage(VOC)	22.9 V
Short-circuit current(ISC)	2.87 A
Maximum power(PMPP)	50 Wp
Efficiency	14%
Operating module temperature	-40°C to 85°C
Dimensions	660 x 540 x 25mm
Temperature coefficient of power	-0.45% per °C

The variable resistor used has a selector whose function is to change the amount of electrical resistance by 17 points. Arrangement of resistors in series or parallel to produce an electrical resistance of 0; 2.5; 3.5; 4.7; 5.4; 5.8; 6; 6.4; 6.6; 6.9; 7.4; 8.5; 13.8; 19.6; 42.5; 111 and 330 Ω [24]. The resistance value of the resistor has been adjusted to produce the IV curve of the Len 50 Wp PV solar cell. Meanwhile, the PV temperature is obtained from thermocouple conversion in the reader.

A current-voltage curve (IV curve) may be used to quantify the electrical efficiency of solar cells to measure their performance. Several characteristics, including open-circuit photovoltage (Voc), short-circuit photocurrent (Isc), fill factor (FF), and efficiency (η), are produced by characterizing solar cells by measuring the IV curve. The most significant voltage that may be achieved in a circuit while no current is flowing through it is known as open circuit voltage (VOC). The most significant electric current that exists when there is no resistance in the circuit is known as open circuit current (ISC). Maximum power point (PMPP) is a point on the IV curve where the circuit's current and voltage combine to their greatest extent. Meanwhile, FF contrasts PMPP with the outcome of VOC and ISC [25].

The electrical efficiency (η) is the ratio of the solar cell's maximum power (PMPP) to the power it receives from solar radiation (Plight). As shown in equation 1, the solar radiation power (Plight) is calculated by multiplying the solar radiation intensity (Irad) by the active area of the solar cell (A) [26].

$$\eta = \frac{P_{MPP}}{I_{light}} = \frac{P_{MPP}}{I_{rad} \times A} = \frac{I_{SC} \times V_{OC} \times FF}{I_{rad} \times A} \quad (1)$$

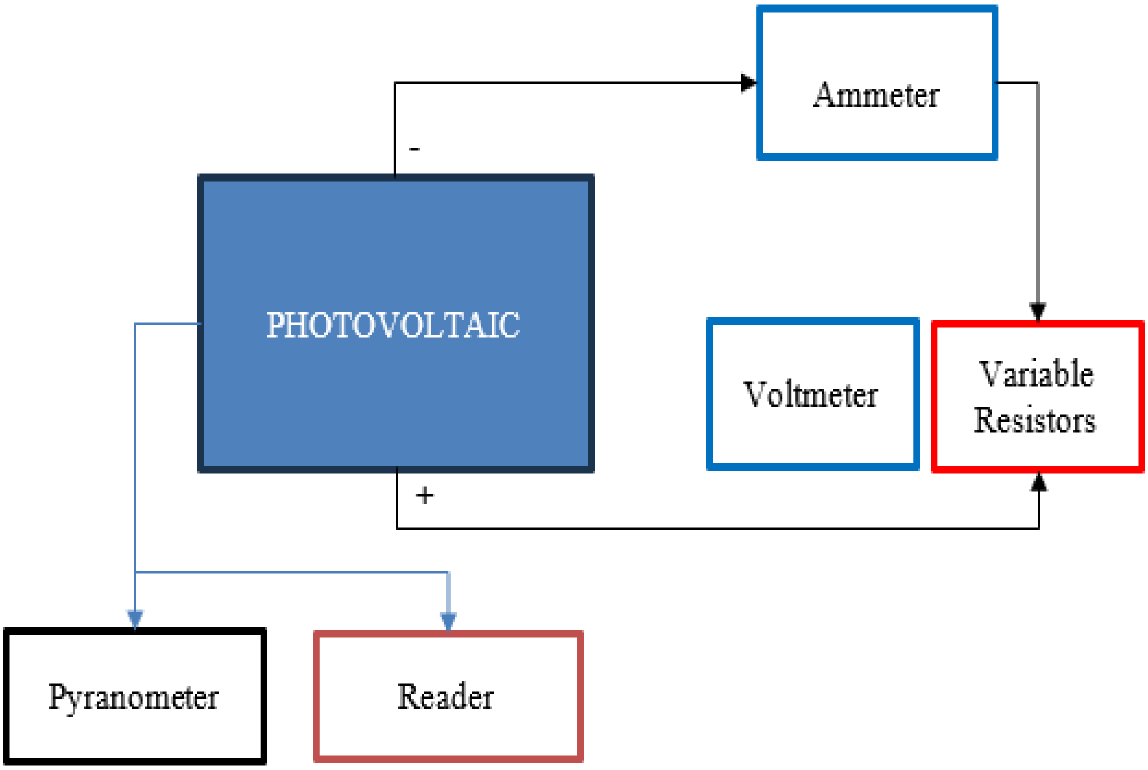


Figure 3. Experimental Scheme.

2.2 Thermal Simulation Setup

A thermal simulation study was carried out using the Solidworks 2021 application to design and determine the temperature results of photovoltaic (PV) solar cells. The PV solar cells were designed according to the PV specifications in the experimental study with dimensions of 540 x 660 x 4.33 mm [27], [28]. The characteristics of PV solar cells in the simulation study are shown in Table 2.

Table 2. Characteristics of PV Solar Cells [29]

Layers	Density (kg/m3)	Specific heat capacity (J/kgK)	Thermal conductivity (W/mK)	Thickness (mm)
Glass	2450	790	0.7	3.2
EVAs	960	2090	0.311	0.5
PV cells	2330	677	130	0.21
EVAs	960	2090	0.311	0.5
PVF	1200	1250	0.015	0.3

A three-dimensional computational model was created using Solidworks Thermal Simulation Tool for numerical solution. The PV temperature distribution is determined by computational calculations. For critical boundary conditions, the top surface of the PV is the only one in contact with the radiation intensity. As a result, only the outer layer of the PV will be taken into account to calculate its wind resistance and heat flow. The system ambient temperature, set to 25°, remained constant during the calculations. We run all simulations in a steady state. With radiation intensity varying from 600, 700, 800, 900, 1000, and 1100 W/m2, the boundary condition used is only natural convection of 12 W/m2K. Design nodes and components 65609 and 32296 were subjected to simulation.

The performance of photovoltaic (PV) cells in electrical efficiency is inversely proportional to the significant increase in cell operating temperature during absorption of solar radiation. The electrical efficiency (ηel) is expressed as equation 2. Where ηref represents the PV solar cell reference efficiency, βref represents the PV solar cell temperature coefficient, and Tref represents the initial PV reference temperature. When Tref is 25 ◦C, then ηref and βref are 14% and 0.0045 /◦C for silicon-based PV solar cells [29].

$$\eta_{el} = \eta_{ref}[1 - \beta_{ref}(T_c - T_{ref})] \quad (2)$$

Determine the influence of the values of two categorical variables on the average of quantitative variables based on statistical values obtained by conducting a two-way analysis of variance (ANOVA) without replication. Using this technique, you can see how two unrelated variables interact to influence the dependent variable. The significance level for this study was set at 0.05 [30].

3. RESULT AND DISCUSIONS

The temperature distribution of photovoltaic (PV) solar cells has been successfully researched using experimental studies and thermal simulations. The PV solar cell temperature distribution is generated for each intensity of radiation received. As in Figure 4. PV solar cell temperature distribution for each radiation intensity.the greater intensity received by PV solar cells results in higher temperatures. This is the case for experimental studies and thermal simulations. The highest temperature was produced at a solar radiation intensity of 1100 W/m^2 of 68.4 ◦C for the experimental study and 69.4 ◦C for the thermal simulation study. The exact temperature results were produced at a radiation intensity of 1000 W/m^2 of 65.3 ◦C for each study. Increasing the working temperature of PV solar cells can affect the performance of PV solar cells.

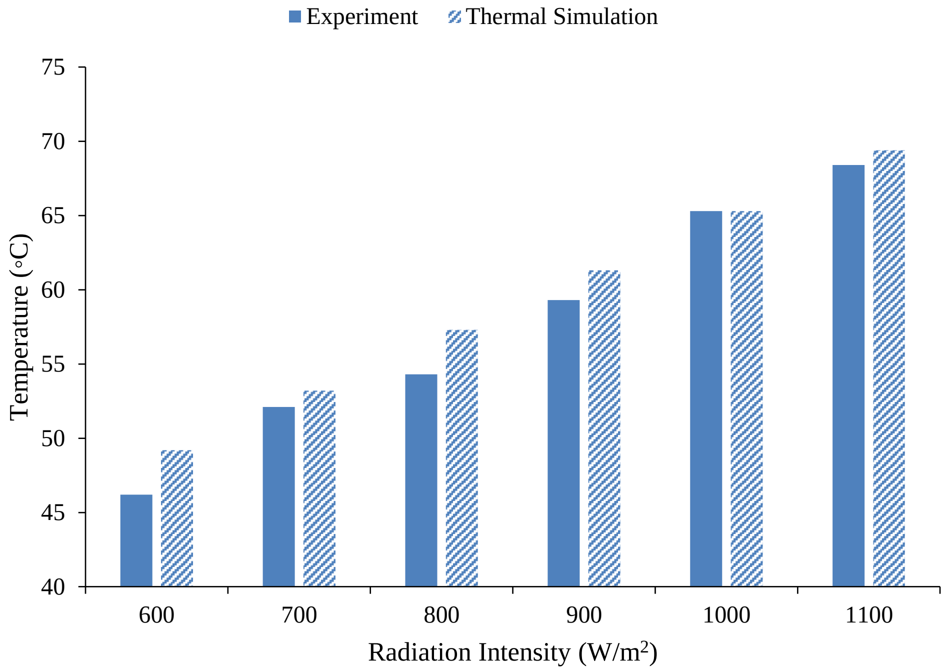
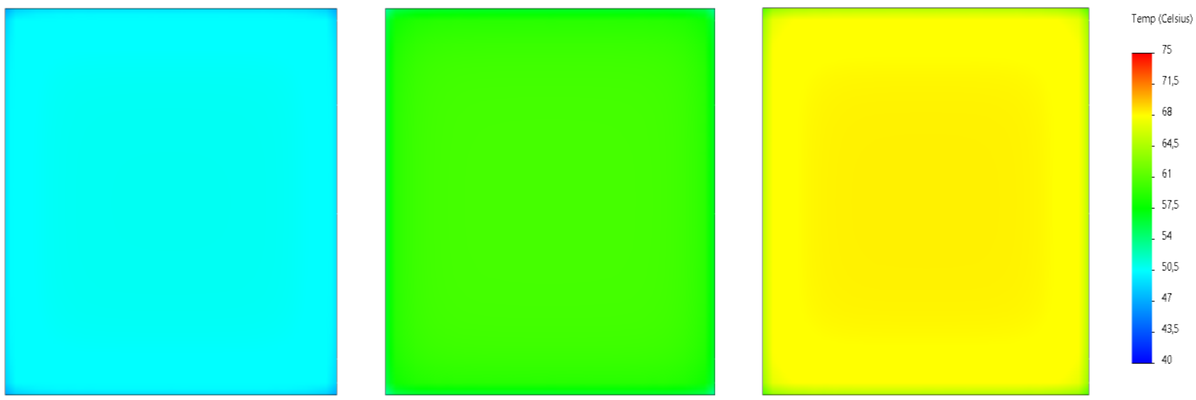


Figure 4. PV solar cell temperature distribution for each radiation intensity.

Thermal simulation produces temperature distribution contours. Figure 5. Temperature distribution contour of PV solar cells at radiation intensity (a) 600 (b) 800 (c) 1000 W/m2presents the temperature distribution contours of PV solar cells for several radiation intensities. The image presents the temperature distribution from 42 ◦C to 75 ◦C. The image presentation is used to visualize the temperature contour at the lowest and highest intensity for each radiation intensity. It is known that a radiation intensity of 1000 W/m^2 has a dominant yellow contour compared to green, indicating a high temperature. Meanwhile, the lowest radiation intensity produces a blue contour, indicating low temperature.



(a) (b) (c)

Figure 5. Temperature distribution contour of PV solar cells at radiation intensity (a) 600 (b) 800 (c) 1000 W/m2

The performance of PV solar cells is reviewed using a comparison between the maximum power (PMPP) and the radiation power received by the panel (Plight) for experimental studies. Meanwhile, the thermal simulation study is reviewed based on the temperature distribution of PV solar cells.

Figure 6. Electrical efficiency for each radiation intensityshows a graph of the relationship

between solar radiation intensity and PV solar cell efficiency. The graph shows that the efficiency of PV panels will increase and decrease with increasing radiation intensity. The highest efficiency was produced at a radiation intensity of 1000 W/m2 for each study. The highest efficiency was 11.5%. Several research results that have been reported show that increasing solar cell temperature will reduce solar cell output power and solar cell efficiency.

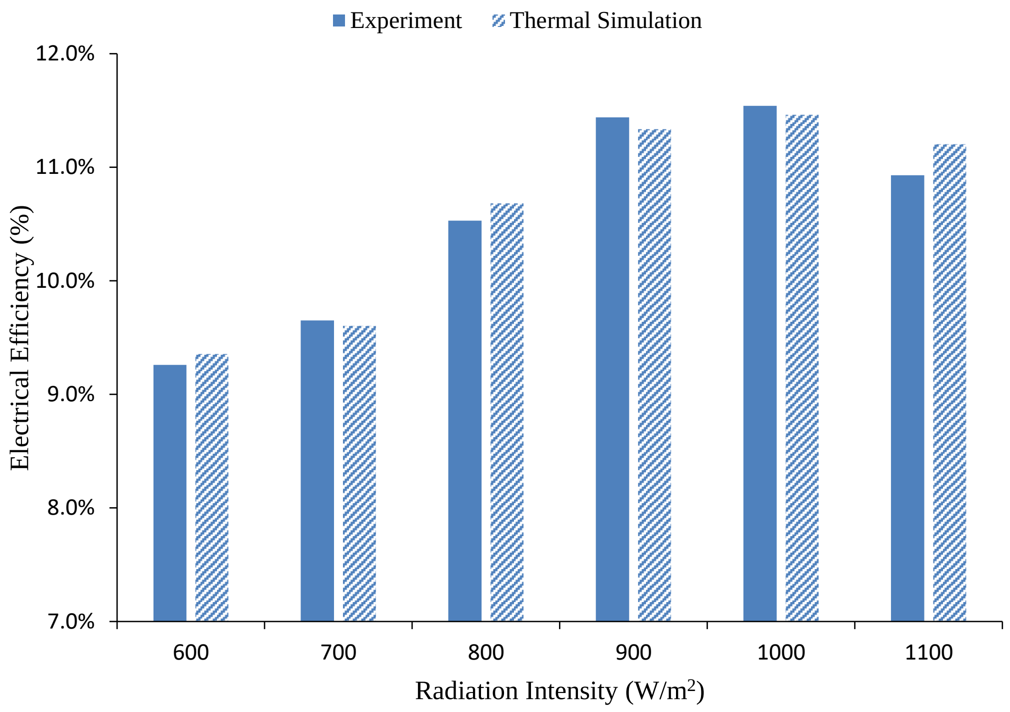


Figure 6. Electrical efficiency for each radiation intensity

Table 3. Percentage of research study errors

Radiation Intensity (W/m2)	Error	
	Temperature (◦C)	Electrical Efficiency (%)
600	6.1%	1.0%
700	2.1%	0.5%
800	5.2%	1.4%
900	3.3%	0.9%
1000	0.0%	0.7%
1100	1.4%	2.4%

The difference in PV temperature error percentage between research experimental and thermal simulation results produces error data varying between 0% and 6.1%, as in Table 3. This data is taken for PV solar cells' temperature distribution and performance. The highest error difference was 6.1% in the temperature distribution results with a radiation intensity of 600 W/m2. Therefore, the method in this research study has valid value and is assumed to apply to the cases in this research.

The validity of the thermal simulation results is determined through mesh independence testing. Mesh testing was carried out during PV treatment at a radiation intensity of 1000 W/m2. Specified mesh elements range in size from 13, 16, 19, 22, 25, and 28 mm. It is known that using mesh elements with sizes between 19 and 22 mm produces more consistent results and only requires a short simulation time, as illustrated in Figure 5.

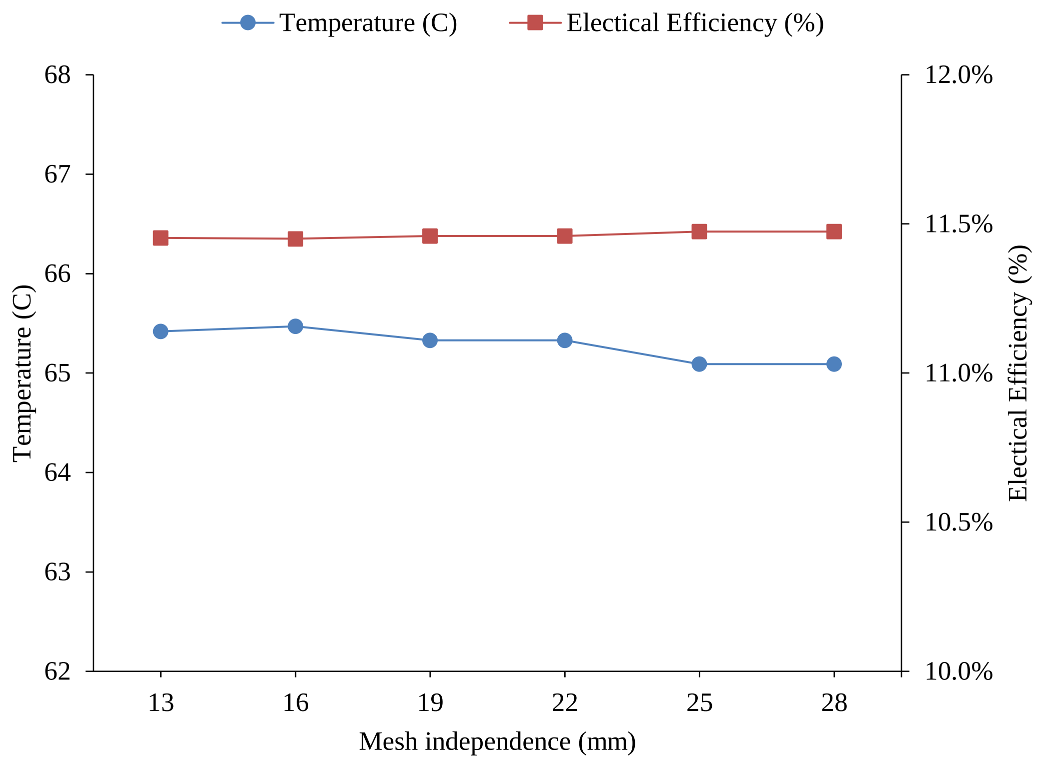


Figure 5. Mesh independence in thermal simulation studies

Table 4. Data on PV solar cell electrical efficiency for each research study and radiation intensity

SUMMARY	Count	Sum	Average	Variance
Experiment	6	0.6335	0.105583	8.78E-05
Thermal Simulation	6	0.636443	0.106074	8.38E-05
600 W/m2	2	0.186166	0.093083	4.66E-07
700 W/m2	2	0.192541	0.096271	1.05E-07
800 W/m2	2	0.212131	0.106066	1.17E-06
900 W/m2	2	0.227766	0.113883	5.35E-07
1000 W/m2	2	0.230011	0.115006	3.11E-07
1100 W/m2	2	0.221328	0.110664	3.72E-06

Based on the electrical efficiency data generated for each system variation with different research studies and radiation intensity, it has been grouped as in Table 4. The data is grouped to assess how different systems affect the performance of solar PV cells. To conduct this study, a two-way analysis of variance (ANOVA) without replication was used, with a significance level of 0.05. Because the radiation intensity has a P-value of 1.85E-05, it has been determined that this impacts electrical efficiency. Meanwhile, the P-value from the research study used is 0.45. Therefore, it has no impact on electrical efficiency. The MS of this research study is smaller than the MS error of 7.22E-07, as shown in Table 5.

Table 5. Results of Two-Way ANOVA analysis without Replication of PV solar cell electrical efficiency for each research study and radiation intensity

Sources of Variation	SS	df	MS	F	P-value	F crit
Research Study	7.22E-07	1	7.22E-07	0.645645	0.458155	6.607891
Radiation Intensity	0.000853	5	0.000171	152.5678	1.85E-05	5.050329
Error	5.59E-06	5	1.12E-06			
Total	0.000859	11				

4. CONCLUTIONS

The temperature distribution of photovoltaic (PV) solar cells has been studied using experimental studies and thermal simulations. The highest temperature was produced at a solar radiation intensity of 1100 W/m2 of 68.4 ◦C for the experimental study and 69.4 ◦C for the thermal simulation study. The highest efficiency was produced at a radiation intensity of 1000 W/m2 for each study used, with the highest efficiency being 11.5%. Increasing the temperature of PV solar cells will reduce the solar cell output power and efficiency. The thermal simulation results were validated through mesh independence testing, with the highest error difference of 6.1% at a radiation intensity of 600 W/m2. This research analyzes the impact of radiation intensity on the electrical efficiency of solar PV cells. Two-way ANOVA was carried out for the electricity efficiency produced in each variation. The radiation intensity shows a P value of 1.85E-05, which indicates an impact on the efficiency of the electricity produced. Meanwhile, the P value of the research study variation is 0.45, indicating no impact. There is an MS variation value smaller than the MS error of 7.22E-07, indicating an interaction between the two variables.

AUTHOR'S DECLARATION

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest..

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REFERENCES

[1] H. Xu, C. Zhang, N. Wang, Z. Qu, and S. Zhang, "Experimental study on the performance of a solar photovoltaic/thermal system combined with phase change material," *Solar Energy*, vol. 198, pp. 202–211, Mar. 2020, doi: 10.1016/j.solener.2020.01.064.

[2] P. Ocłoń *et al.*, "Modeling and experimental validation and thermal performance assessment of a sun-tracked and cooled PVT system under low solar irradiation," *Energy Convers Manag*, vol. 222, Oct. 2020, doi: 10.1016/j.enconman.2020.113289.

[3] M. M. Islam, M. Hasanuzzaman, N. A. Rahim, A. K. Pandey, M. Rawa, and L. Kumar, "Real time experimental performance investigation of a NePCM based photovoltaic thermal system: An energetic and exergetic approach," *Renew Energy*, vol. 172, pp. 71–87, Jul. 2021, doi: 10.1016/j.renene.2021.02.169.

[4] M. H. Ahmed and H. H. Ahmed, "The Role of Renewable Energy in the Protection of the Iraqi Environment," *International Journal of Scientific Trends*, vol. 2, no. 9, pp. 16–29, 2023.

[5] M. W. AlShaar, Z. Al-Omari, W. Emar, M. Alnsour, and G. Abu-Rumman, "Application of PV-Thermal Array for Pumping Irrigation Water as an Alternative to PV in Ghor Al-Safi, Jordan: A case study," *Evergreen*, vol. 9, no. 4, pp. 1140–1150, 2022, doi: 10.5109/6625725.

[6] A. L. Abdullah, S. Misha, N. Tamaldin, M. A. M. Rosli, and F. A. Sachit, "A review: Parameters affecting the PVT collector performance on the thermal, electrical, and overall efficiency of PVT system," *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 60, no. 2, pp. 191–232, 2019.

[7] I. Sansa, Z. Boussaada, M. Mazigh, and N. M. Bellaaj, "Solar radiation prediction for a winter day using ARMA model," in *2020 6th IEEE International Energy Conference (ENERGYCon)*, IEEE, 2020, pp. 326–330.

[8] A. Hysa, "Modeling and simulation of the photovoltaic cells for different values of physical and environmental parameters," *Emerging Science Journal*, vol. 3, no. 6, pp. 395–406, 2019, doi: 10.28991/esj-2019-01202.

[9] Z. Arifin, Suyitno, S. Hadi, S. D. Prasetyo, and M. Hasbi, "Promoting Effect of TiCl4 Pre-Coating Time on TiO2 Semiconductors on Double Layer Dye-Sensitized Solar Cell," *Journal of Sustainability for Energy*, vol. 1, no. 1, pp. 18–26, 2022, doi: 10.56578/jse010103.

[10] A. A. Ansari, M. K. Nazeeruddin, and M. M. Tavakoli, "Organic-inorganic upconversion nanoparticles hybrid in dye-sensitized solar cells," *Coordination Chemistry Reviews*, vol. 436, p. 213805, 2021.

[11] S. D. Prasetyo, A. R. Prabowo, and Z. Arifin, "The effect of collector design in increasing PVT performance: Current state and milestone," in *Materials Today: Proceedings*, 2022, pp. S1–S9. doi: 10.1016/j.matpr.2021.12.356.

[12] X. Zhang, Y. S. Ang, J.-Y. Du, J. Chen, and L. K. Ang, "Graphene-based thermionic-thermoradiative solar cells: Concept, efficiency limit, and optimum design," *Journal of Cleaner Production*, vol. 242, p. 118444, 2020.

[13] S. D. Prasetyo *et al.*, "Optimization of Photovoltaic Thermal Collectors Using Fins: A Review of Strategies for Enhanced Solar Energy Harvesting," *Mathematical Modelling of Engineering Problems*, vol. 10, no. 4, pp. 1235–1248, 2023, doi: 10.18280/mmep.100416.

[14] S. Gorjian *et al.*, "Progress and challenges of crop production and electricity generation in agrivoltaic systems using semi-transparent photovoltaic technology," *Renewable and*

Sustainable Energy Reviews, vol. 158, p. 112126, 2022.

[15] Y. Liu and K.-Y. Lin, "Enhancing Energy Efficiency in Sow Houses: An Annual Temperature Regulation System Employing Heat Recovery and Photovoltaic-Thermal Technology," *Journal of Sustainability for Energy*, vol. 2, no. 2, pp. 76–90, 2023, doi: 10.56578/jse020204.

[16] R. N. Myyas, M. Al-Dabbasa, M. Tostado-Véliz, and F. Jurado, "A novel solar panel cleaning mechanism to improve performance and harvesting rainwater," *Solar Energy*, vol. 237, pp. 19–28, 2022.

[17] M. Gonzalez-Sanchez and Y. Camaraza-Medina, "Application of the Thermal Solar Energy in the Primary Circuit of Hot Water of the Four Palms Hotel," *Journal of Sustainability for Energy*, vol. 1, no. 1, pp. 1–7, 2022, doi: 10.56578/jse010101.

[18] Q. Fan *et al.*, "Over 14% efficiency all-polymer solar cells enabled by a low bandgap polymer acceptor with low energy loss and efficient charge separation," *Energy & Environmental Science*, vol. 13, no. 12, pp. 5017–5027, 2020.

[19] M. Hasanuzzaman, A. B. M. A. Malek, M. M. Islam, A. K. Pandey, and N. A. Rahim, "Global advancement of cooling technologies for PV systems: A review," *Solar Energy*, vol. 137, pp. 25–45, 2016, doi: 10.1016/j.solener.2016.07.010.

[20] A. E. Kabeel, M. Abdelgaied, R. Sathyamurthy, and A. Kabeel, "A comprehensive review of technologies used to improve the performance of PV systems in a view of cooling mediums, reflectors design, spectrum splitting, and economic analysis," *Environmental Science and Pollution Research*, vol. 28, pp. 7955–7980, 2021.

[21] W. Lin and Z. Ma, "Using Taguchi-Fibonacci search method to optimize phase change materials enhanced buildings with integrated solar photovoltaic thermal collectors," *Energy*, vol. 106, pp. 23–37, 2016, doi: 10.1016/j.energy.2016.03.013.

[22] P. Filipović, D. Dović, I. Horvat, and B. Ranilović, "Evaluation of a novel polymer solar collector using numerical and experimental methods," *Energy*, vol. 284, Dec. 2023, doi: 10.1016/j.energy.2023.128558.

[23] Z. Arifin, S. D. Prasetyo, D. D. D. P. Tjahjana, R. A. Rachmanto, A. R. Prabowo, and N. F. Alfaiz, "The application of TiO<inf>2</inf> nanofluids in photovoltaic thermal collector systems," *Energy Reports*, vol. 8, pp. 1371–1380, 2022, doi: 10.1016/j.egyr.2022.08.070.

[24] C. Wang *et al.*, "Cross-point resistive memory: Nonideal properties and solutions," *ACM Transactions on Design Automation of Electronic Systems (TODAES)*, vol. 24, no. 4, pp. 1–37, 2019.

[25] H. Wirth, *Photovoltaic Module Technology*. Walter de Gruyter GmbH & Co KG, 2020.

[26] Z. Arifin, S. D. D. Prasetyo, B. A. A. Tribhuwana, D. D. D. P. Tjahjana, R. A. A. Rachmanto, and B. Kristiawan, "Photovoltaic Performance Improvement with Phase Change Material Cooling Treatment," *International Journal of Heat and Technology*, vol. 40, no. 4, pp. 953–960, 2022, doi: 10.18280/ijht.400412.

[27] S. D. Prasetyo, A. R. Prabowo, and Z. Arifin, "Investigation of Thermal Collector Nanofluids to Increase the Efficiency of Photovoltaic Solar Cells," *International Journal of Heat and Technology*, vol. 40, no. 2, pp. 415–422, 2022, doi: 10.18280/ijht.400208.

[28] Z. Arifin, S. D. Prasetyo, A. R. Prabowo, D. D. D. P. Tjahjana, and R. A. Rachmanto, "Effect of thermal collector configuration on the photovoltaic heat transfer performance with 3D CFD modeling," *Open Engineering*, vol. 11, no. 1, pp. 1076–1085, 2021, doi: 10.1515/eng-2021-0107.

[29] S. D. S. D. Prasetyo, A. R. A. R. Prabowo, and Z. Arifin, "The use of a hybrid photovoltaic/thermal (PV/T) collector system as a sustainable energy-harvest instrument in urban technology," *Heliyon*, vol. 9, no. 2, 2023, doi: 10.1016/j.heliyon.2023.e13390.

[30] G. R. Mugagga, I. B. Omosa, and T. Thoruwa, "Optimization and Analysis of a Low-Pressure

Water Scrubbing Biogas Upgrading System via the Taguchi and Response Surface Methodology Approaches," *International Journal of Renewable Energy Development*, vol. 12, no. 1, pp. 99–110, 2023, doi: 10.14710/ijred.2023.48269.