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The use of wavy vortex generators in the cooling system to reduce the photovoltaic temperature rise

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ABSTRACT

A solar panel will be exposed to sunlight when in use, which causes its temperature to increase. The performance of power production will be impacted if the solar panel's temperature conditions are too hot. High-temperature solar panels can reduce the amount of electrical energy generated. To prevent the temperature of the solar panels from rising too much, a cooling system is required. The proposed solution of this research is a cooling system for solar panels that makes use of heat transfer through water. The solar panels tested in this study have a tilt angle of 20 degrees. The cooling device has dimensions of 400 mm length, 278 mm width, and 20 mm height, with a wavy-type vortex generator positioned in the cooling device mounted on the underside of the solar panel. As a result of the heat flux applied to the top surface of the solar panel, it causes an increase in temperature. The resulting voltage and electric current are reduced. Computational simulations were carried out to determine the performance of the type of vortex generator used. At a cooling water flow rate of 200–600 ml/min, heat transfer with a vortex generator type B works optimally.

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1. INTRODUCTION

The need for electrical energy is a basic need at this time. Various electronic devices, industries, and public service sectors use electricity in their operations. The dependence on electricity from fossil energy is slowly reduced by switching to renewable energy to achieve a 29% emission reduction by 2030 [1]. Examples of renewable energy are energy that comes from the use of wind energy, water, and sunlight. Utilization of the sun as a source of electrical energy is increasingly in demand; on a global scale, it is predicted to increase by 30% by 2022 [2]. This can be seen from the support of the Indonesian government by setting policies on new and renewable energy for 2030 [3]. The public service sector such as airports has begun to adopt renewable energy source because it is considered more environmentally friendly [4]–[6].

Devices to convert energy sources from sunlight into electrical energy are referred to as solar panels. This device works by utilizing the photovoltaic (PV) effect to convert energy [7]. During operation, solar panels will be exposed to sunlight, which has an impact on increasing the temperature of the solar panels. Changes in temperature on the solar panel will affect the performance of the solar panel [8]–[13]. Solar panels work optimally at a certain temperature range. A cooling system is needed that keeps the photovoltaic operating at normal temperatures. If the temperature conditions on the solar panel are too hot, it will have an impact on decreasing the performance of electricity production. This is because an increase in temperature can reduce the amount of electrical energy produced and also have an impact on the efficiency of the device [14]–[16]. This condition will be a problem that must be resolved [17]–[20].

Solar panel cooling systems can be in the form of cooling using air, water, or phase change materials [21]–[23]. Each type of cooling has its own advantages and disadvantages. Especially in photovoltaic cooling devices that use a fluid flow system in the channel, there are types of cooling devices with large channel sizes and small channel sizes [24], [25]. There are devices that use the addition of a vortex generator and ones that do without the addition of a vortex generator. All the methods used have something in common, namely to prevent the photovoltaic from overheating when operating. In this paper proposes a solar panel cooling system by utilizing heat transfer through water. The purpose of the first research is to find out the effect of solar panel temperature on the voltage and current generated. The second is to find out the effect of volume flow rate and coolant temperature on solar panels.

2. METHOD

The solar panel being tested has an inclination angle of 20 degrees. The solar panel cooling system is shown in Figure 1 with no vertex generator. The water pump circulates water from the first tank to the PV cooler and then the second tank. In the PV cooling, the water increases in temperature because it absorbs heat from the PV cooling, whose temperature increases due to a light source from two 500 W halogen lamps. The coolant flows at a rate of 800 ml/min at a maximum speed of pump 12 VDC at a temperature of 19.4 °C. During the 10-minute observation, data was collected on the photovoltaic top surface temperature, voltage, and electric current generated. The schematic for measuring voltage and current is shown in Figure 2. A resistance of 1 kOhm is installed on the electrical system as an electrical load during the operation of PV.

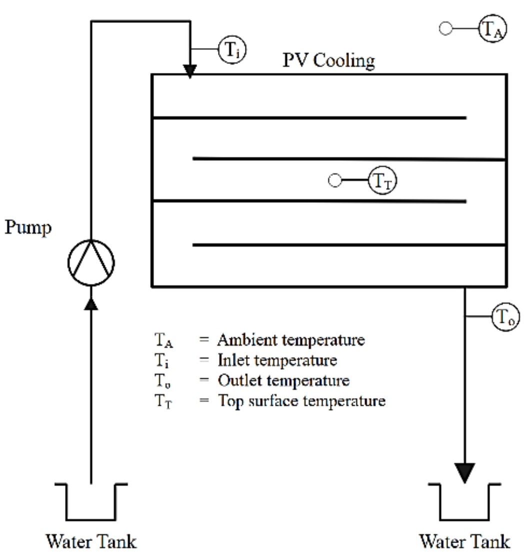


Figure 1. Schematic diagram and structure of cooling system

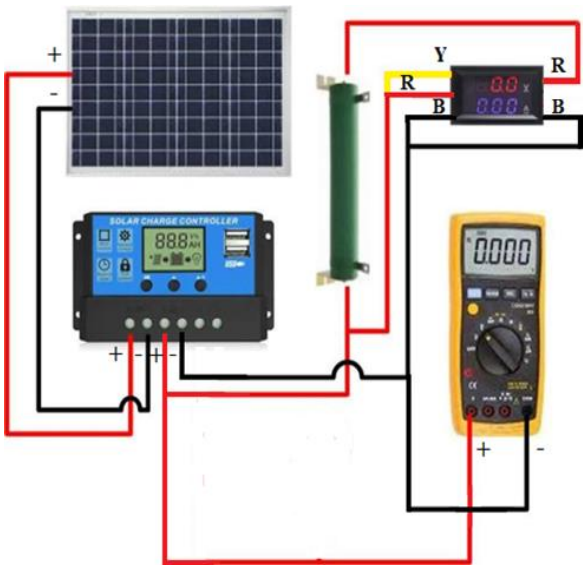


Figure 2. Schematic diagram of voltage and current measurement

The geometry of the cooling device is made with a length of 400 mm, a width of 278 mm, and a height of 20 mm with the vortex generator positioning in Figure 3(a). One of the models does not use a vortex generator, while the other two use a vortex generator, which is placed at the bottom (vortex generator type–A) and at the top (vortex generator type–B), as shown in Figure 3(b). The shape of the vortex generator in Figure 3(c) refers to research on wavy vortex generators [26].

The simulation model has a number of elements of 33826, with the flow model in the simulation using a laminar flow model. On the top surface of the PV materials used, refer to Table 1 [27]. The results of the mesh independence study are in Table 2. The flow rate of the cooling system was varied from 100-800 ml/min in increments of 100 ml/min. To increase the system temperature, heat flux was applied to the top surface of the PV by 1000 W/m^2. Observations were made by varying the inlet temperature by 20 °C, 25 °C, and 30 °C according to the available water temperature in the tropics, which can be used for cooling systems. The variables taken into account in the simulation are the temperature of the cooling fluid, the temperature of the top surface of the PV and the velocity distribution in the cooling channel.

Table 1. Thermophysical properties of layers of photovoltaic top surface

Name	Thickness (mm)	Thermal conductivity (W/m °C)	Heat capacity (J/kg °C)	Density (kg/m^3)
Aluminum	1.00	160	900	2700
Tedlar	0.35	0.23	1465	1162
PV	0.20	150	712	2330
Eva	0.45	0.31	2090	960
Glass	3.20	0.98	820	2515

Table 2. Mesh independence test

Mesh elements	Photovoltaic top surface temperature	Deviations (*hi*+1 - *h*)/*h*
6789	36.18	-
8087	36.22	0.12%
10234	35.30	2.55%
15376	32.53	7.83%
20564	32.47	0.18%
33832	32.38	0.28%
43364	31.28	3.40%
99260	30.60	2.16%

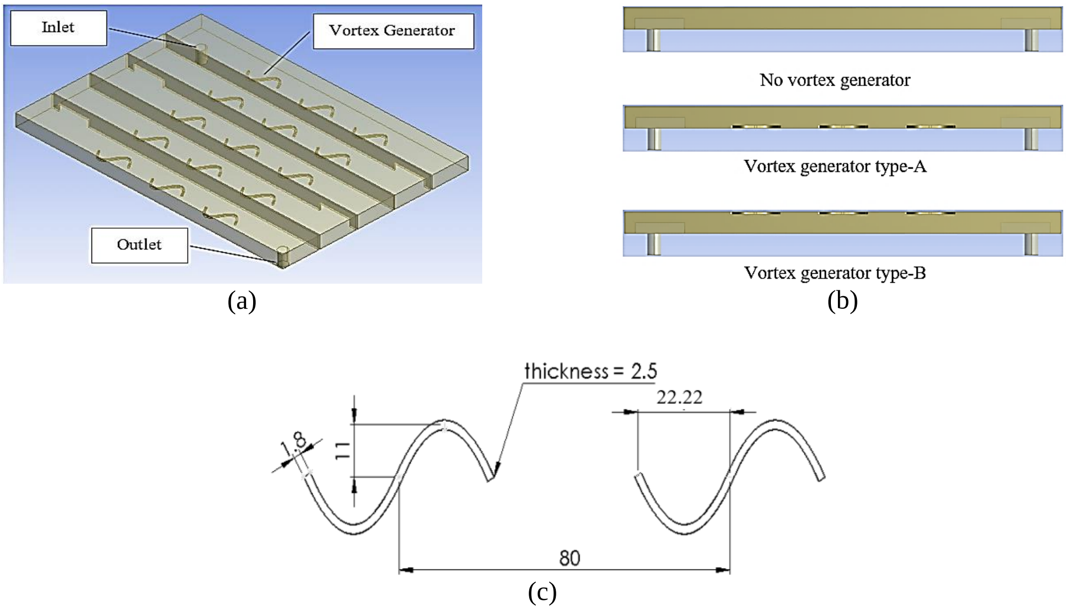
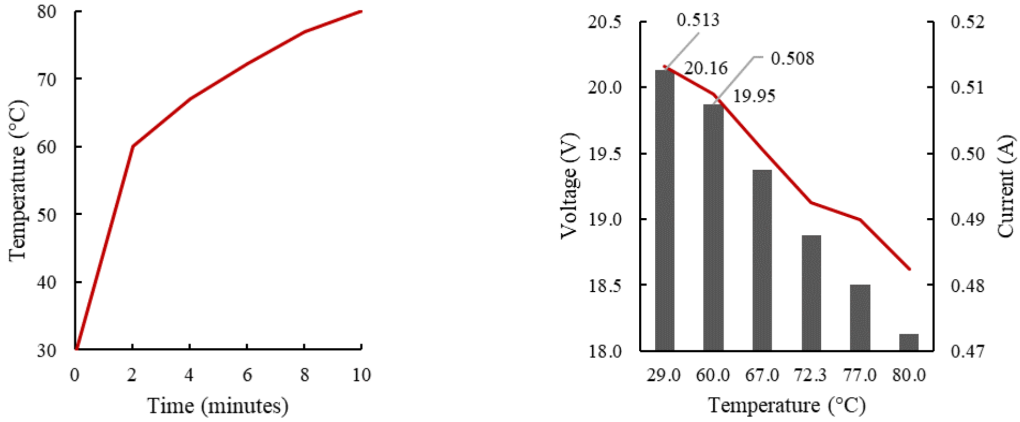


Figure 3. Vortex generator of cooling system with (a) domain of computational, (b) vortex generator type, and (c) dimensions of vortex generator

3. RESULTS AND DISCUSSION

The temperature of the solar panel increases when the solar panel is given a light source from two lamps, each having a power of 500 W. Figure 4 shows experimental results the (a) top surface temperature of photovoltaic and (b) voltage and current of photovoltaic. As shown in Figure 4(a), the temperature increase occurs non-linearly during the observation time of 0–10 minutes. During the first two minutes, there was a significant increase in temperature. After 2 minutes of increasing observation time, the temperature slowly rises. As shown in Figure 4(b), the increase in temperature further affects the voltage and electric current generated by the solar panel. Both voltage and current decrease in value if the temperature increases. At a temperature of 29 °C, the voltage generated is 20.16 V and the electric current is 0.513 A. At a temperature of 60 °C, the voltage generated is 19.95 V and the electric current is 0.508 A. This indicates a 1% decrease in the temperature increase of 31 °C. This shows that the temperature will affect the performance of the solar panel. A cooling system is needed to prevent an excessive temperature rise.

There is no significant difference in heat transfer in the solar panel cooling system as shown in Figure 5. At a volume flow rate of 200–600 ml/min, vortex generator type–A has good heat transfer performance compared to other models at a volume flow rate of 200–600 ml/min. Vortex generator type–B has good heat transfer performance at a volume flow rate of 300–600 ml/min, but is still lower than vortex generator type–A. Cooling performance without a vortex generator shows better results than other models at a volume flow rate of 600–800 ml/min. This shows that the tested vortex generator has good performance at medium flow rates based on the test variable flow rate of 100–800 ml/min. The height of the vortex generator needs to be tested further to determine its correlation with the volume flow rate of the cooling fluid.



(a) (b)

Figure 4. Experimental results the (a) top surface temperature of photovoltaic and (b) voltage and current of photovoltaic

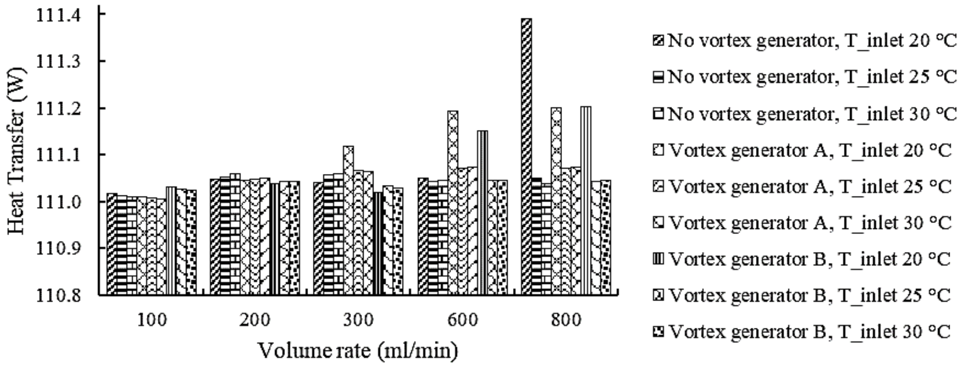


Figure 5. Heat transfer of cooling system

Figure 6 shows temperature of the (a) working fluid and (b) photovoltaic top surface. The working fluid temperature has a correlation with the volume flow rate shown in Figure 6(a), where the higher the fluid volume flow rate, the lower the working fluid temperature. This is because the temperature of the working fluid in the cooling device approaches the inlet temperature of the cooling device as the mass of the working fluid in the cooling system absorbs heat. The increase in volume flow rate also has an impact on the temperature of the top of the solar panel, which also decreases as shown in Figure 6(b). The vortex generator type–B shows better performance than other models at a flow rate of 300–800 ml/min with an inlet temperature of 20–30 °C. Although the vortex generator type–B has a lower heat transfer than the model without a vortex generator, it has a better temperature distribution as indicated by the lower surface temperature of the top panel. By referring to the correlation between temperature and electrical energy, a decrease in the temperature of the solar panel can increase the amount of electrical energy produced by the solar panel.

At a volume flow rate of 800 ml/min, the temperature distribution of the top of the solar panel is shown in Figure 7. Figure 7 shows the temperature distribution of top surface (a) no vortex generator, (b) vortex generator type–A and (c) vortex generator type–B. Without a vortex generator, the top surface of the solar panel has a high temperature on the bottom side. This is due to the accumulation of the increase in the temperature of the working fluid in the cooling device because it has absorbed heat while in the cooling device. By adding a vortex generator type–A, the upper surface area of the high-temperature solar panel can be reduced. The upper surface area of the solar panel increasingly shows a decrease with the use of vortex generator type–B.

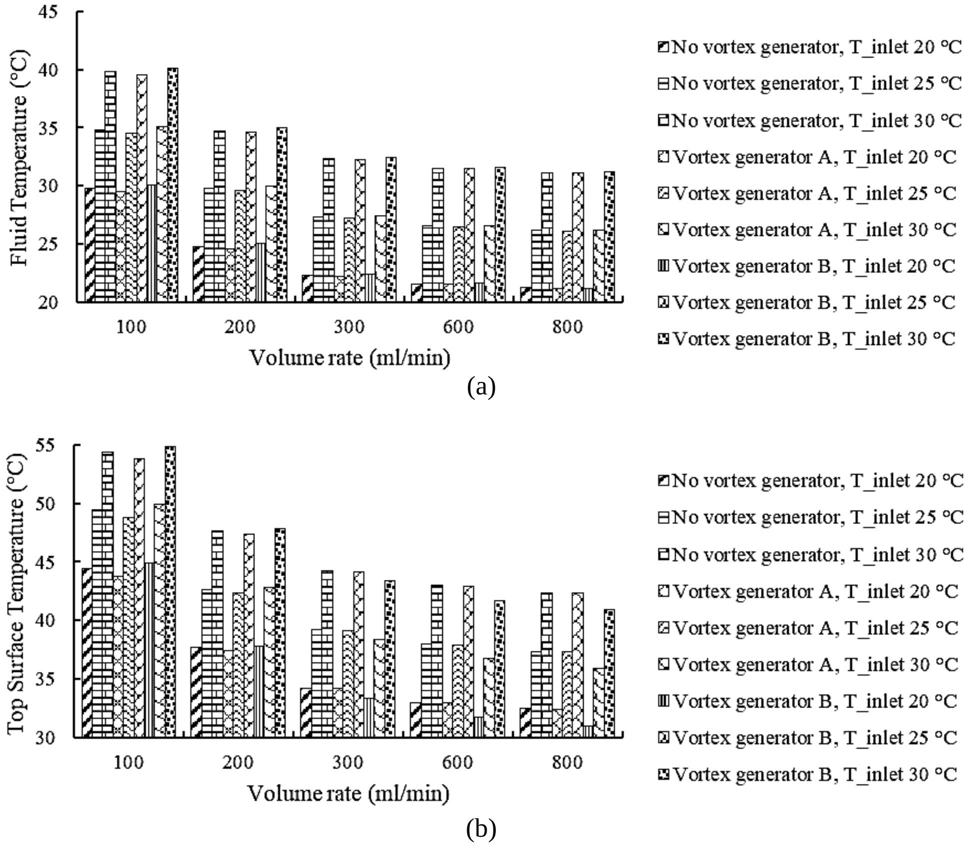


Figure 6. Temperature of the (a) working fluid and (b) photovoltaic top surface

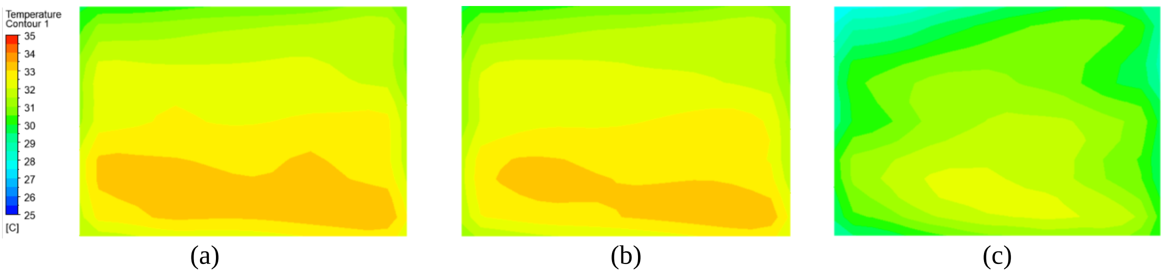
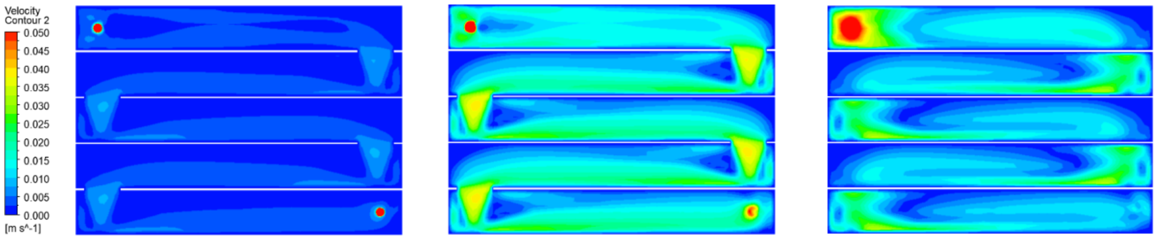


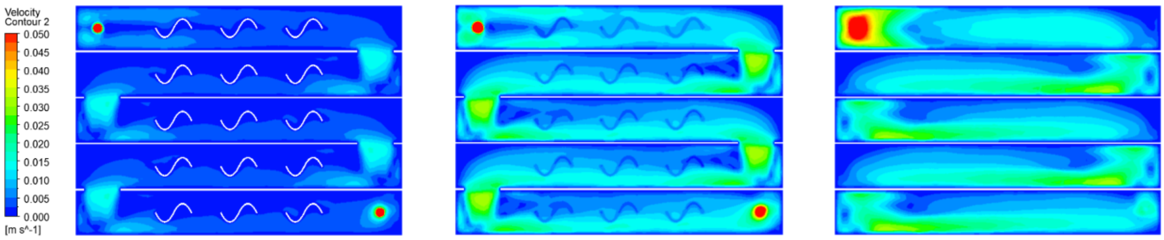
Figure 7. Temperature distribution of top surface (a) no vortex generator, (b) vortex generator type–A , and (c) vortex generator type–B

Figure 8 shows velocity distribution from the bottom of cooling device with no vortex generator installed (a) 1 mm, (b) 5 mm, and (c) 18 mm. Figure 9 shows velocity distribution from the bottom of cooling device with vortex generator type–A installed (a) 1 mm, (b) 5 mm, and (c) 18 mm. At a position of 1 mm from the bottom surface of the cooling device, there is an increase in the velocity of the vortex generator type–A, namely in the channel connecting the channels, as an effect of the position of the vortex generating device being attached to the bottom surface of the cooling device. Figure 10 shows velocity distribution from the bottom of cooling device with vortex generator type–B installed (a) 1 mm, (b) 5 mm, and (c) 18 mm. At a position of 5 mm from the bottom surface of the cooling device, the channel connecting the channel without a vortex generator and vortex generator B shows higher velocity results. Vortex generator type–B has a more even velocity distribution at this position. At a position 18 mm from the bottom surface of the cooling device, the vortex generator type–A actually has a more even velocity distribution at this position. From the observations, the even distribution of velocity at a position of 5 mm from the bottom surface of the cooling device contributes to a better decrease in the temperature of the top surface of the solar panel.



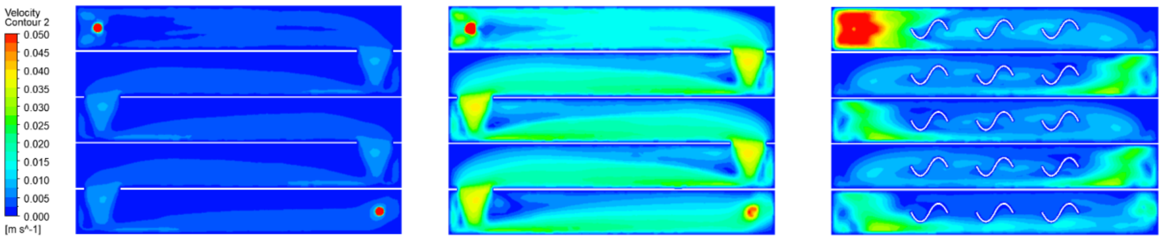
(a) (b) (c)

Figure 8. Velocity distribution from the bottom of cooling device with no vortex generator installed (a) 1 mm, (b) 5 mm, and (c) 18 mm



(a) (b) (c)

Figure 9. Velocity distribution from the bottom of cooling device with vortex generator type–A installed (a) 1 mm, (b) 5 mm, and (c) 18 mm



(a) (b) (c)

Figure 10. Velocity distribution from the bottom of cooling device with vortex generator type–B installed (a) 1 mm, (b) 5 mm, and (c) 18 mm

4. CONCLUSION

The increase in the temperature of the solar panels by 31 °C reduces the voltage and electric current generated by 1%. Experiments in this research show that there is an effect on the performance of solar panels when the temperature is above 29 °C. Heat transfer by installing a vortex device on the upper side of the cooling device has good performance at a coolant volume flow rate of 200-600 ml/min. The temperature distribution of the vortex generator type–B has a lower upper surface temperature of the solar panel than the vortex generator type–A and without a vortex generator because the velocity distribution at position 5 mm of the bottom surface of the device is more even. Overall, vortex generator type–B has overall better performance than other models in this study.

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REFERENCES

[1] Ministry of EMR, “Energy Minister Asserts Indonesia’s Committment to Carbon Neutral,” Jun. 21, 2022. [Online]. Available: https://www.esdm.go.id/en/media-center/news-archives/energy-minister-asserts-indonesias-committment-to-carbon-neutral

[2] PV Magazine, “Global Solar Capacity to Grow 30% This Year, Said Analyst,” Aug. 01, 2022. [Online]. Available: https://pv-magazine-usa.com/2022/08/01/global-solar-capacity-to-grow-30-this-year-said-analyst/

[3] A. Rahman, P. Dargusch, and D. Wadley, “The political economy of oil supply in Indonesia and the implications for renewable energy development,” *Renewable and Sustainable Energy Reviews*, vol. 144, p. 111027, Jul. 2021, doi: 10.1016/j.rser.2021.111027.

[4] S. Sreenath, K. Sudhakar, Y. A.F., E. Solomin, and I. M. Kirpichnikova, “Solar PV energy system in Malaysian airport: Glare analysis, general design and performance assessment,” *Energy Reports*, vol. 6, pp. 698–712, Nov. 2020, doi: 10.1016/j.egyr.2020.03.015.

[5] S. Sreenath, K. Sudhakar, A. F. Yusop, E. Cuce, and E. Solomin, “Analysis of solar PV glare in airport environment: Potential solutions,” *Results in Engineering*, vol. 5, p. 100079, Mar. 2020, doi: 10.1016/j.rineng.2019.100079.

[6] S. Sreenath, K. Sudhakar, and A. F. Yusop, “Solar PV in the airport environment: A review of glare assessment approaches & metrics,” *Solar Energy*, vol. 216, pp. 439–451, Mar. 2021, doi: 10.1016/j.solener.2021.01.023.

[7] N. F. Voudoukis, “Photovoltaic technology and innovative solar cells,” *European Journal of Electrical Engineering and Computer Science*, vol. 2, no. 1, pp. 1–7, Dec. 2018, doi: 10.24018/ejece.2018.2.1.13.

[8] I. Marinić-Kragić, S. Nižetić, F. Grubišić-Čabo, and A. M. Papadopoulos, “Analysis of flow separation effect in the case of the free-standing photovoltaic panel exposed to various operating conditions,” *Journal of Cleaner Production*, vol. 174, pp. 53–64, 2018, doi: 10.1016/j.jclepro.2017.10.310.

[9] A. Shukla, K. Kant, A. Sharma, and P. H. Biwole, “Cooling methodologies of photovoltaic module for enhancing electrical efficiency: A review,” *Solar Energy Materials and Solar Cells*, vol. 160, pp. 275–286, 2017, doi: 10.1016/j.solmat.2016.10.047.

[10] S. Verma, S. Mohapatra, S. Chowdhury, and G. Dwivedi, “Cooling techniques of the PV module: A review,” *Materials Today: Proceedings*, vol. 38, pp. 253–258, 2021, doi: 10.1016/j.matpr.2020.07.130.

[11] İ. Ceylan *et al.*, “Determination of the heat transfer coefficient of PV panels,” *Energy*, vol. 175, pp. 978–985, 2019, doi: 10.1016/j.energy.2019.03.152.

[12] B. Tuncel, T. Ozden, R. S. Balog, and B. G. Akinoglu, “Dynamic thermal modelling of PV performance and effect of heat capacity on the module temperature,” *Case Studies in Thermal Engineering*, vol. 22, p. 100754, 2020, doi: 10.1016/j.csite.2020.100754.

[13] K. Kant, A. Shukla, A. Sharma, and P. H. Biwole, “Thermal response of poly-crystalline silicon photovoltaic panels: Numerical simulation and experimental study,” *Solar Energy*, vol. 134, pp. 147–155, 2016, doi: 10.1016/j.solener.2016.05.002.

[14] A. K. Tripathi, S. Ray, and M. Aruna, “Analysis on photovoltaic panel temperature under the influence of solar radiation and ambient temperature,” *2021 International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT)*, Dec. 2021, pp. 1–5. doi: 10.1109/ICAECT49130.2021.9392619.

[15] M. Libra, T. Petrik, V. Poulek, I. I. Tyukhov, and P. Kourim, “Changes in the efficiency of photovoltaic energy conversion in temperature range with extreme limits,” *IEEE Journal of Photovoltaics*, vol. 11, no. 6, pp. 1479–1484, Dec. 2021, doi: 10.1109/JPHOTOV.2021.3108484.

[16] S. Dubey, J. N. Sarvaiya, and B. Seshadri, “Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world – a review,” *Energy Procedia*, vol. 33, pp. 311–321, 2013, doi: 10.1016/j.egypro.2013.05.072.

[17] A. D. Dhass, N. Beemkumar, S. Harikrishnan, and H. M. Ali, “A review on factors influencing the mismatch losses in solar photovoltaic system,” *International Journal of Photoenergy*, vol. 2022, p. 2986004, Feb. 2022, doi: 10.1155/2022/2986004.

[18] T. S. Wurster and M. B. Schubert, “Mismatch loss in photovoltaic systems,” *Solar Energy*, vol. 105, pp. 505–511, 2014, doi: 10.1016/j.solener.2014.04.014.

[19] R. K. Pachauri, I. Kansal, T. S. Babu, and H. H. Alhelou, “Power losses reduction of solar PV systems under partial shading conditions using re-allocation of PV module-fixed electrical connections,” *IEEE Access*, vol. 9, pp. 94789–94812, 2021, doi: 10.1109/ACCESS.2021.3093954.

[20] M. Hashim Siddig, S. Mohammed Hashim, and A. Eltayeb Osman, “Formulation of an efficiency correlation for mono-crystalline PV modules using dimensional analysis,” *Solar Energy*, vol. 205, pp. 456–460, Jul. 2020, doi: 10.1016/j.solener.2020.05.089.

[21] W. Salameh, C. Castelain, J. Faraj, R. Murr, H. E. Hage, and M. Khaled, “Improving the efficiency of photovoltaic panels using air exhausted from HVAC systems: thermal modelling and parametric analysis,” *Case Studies in Thermal Engineering*, vol. 25, p. 100940, Dec. 2021, doi: 10.1016/j.csite.2021.100940.

[22] S. M. Shalaby, M. K. Elfakharany, B. M. Moharram, and H. F. Abosheiasha, “Experimental study on the performance of PV with water cooling,” *Energy Reports*, vol. 8, pp. 957–961, Dec. 2022, doi: 10.1016/j.egyr.2021.11.155.

[23] M. Sharaf, A. S. Huzayyin, and M. S. Yousef, “Performance enhancement of photovoltaic cells using phase change material (PCM) in winter,” *Alexandria Engineering Journal*, vol. 61, no. 6, pp. 4229–4239, Dec. 2022, doi: 10.1016/j.aej.2021.09.044.

[24] H. E. Kharaz, K. Khallaki, M. S. Kadiri, and K. Choukairy, “Performance’s improvement methods of PV solar panel by different cooling systems: a review of experimental and numerical studies,” *AMT2020: The 6th International Congress on Thermal Science*, 2021, p. 20039. doi: 10.1063/5.0049573.

[25] N. Karami and M. Rahimi, “Heat transfer enhancement in a PV cell using boehmite nanofluid,” *Energy Conversion and Management*, vol. 86, pp. 275–285, Dec. 2014, doi: 10.1016/j.enconman.2014.05.037.

[26] E. Hosseinirad and F. Hormozi, “Performance intensification of miniature channel using wavy vortex generator and optimization by response surface methodology: MWCNT-H2O and Al2O3-H2O nanofluids as coolant fluids,” *Chemical Engineering and Processing - Process Intensification*, vol. 124, pp. 83–96, Dec. 2018, doi: 10.1016/j.cep.2017.12.003.

[27] A. J. Chamkha and F. Selimefendigil, “Numerical analysis for thermal performance of a photovoltaic thermal solar collector with SiO2-water Nanofluid,” *Applied Sciences*, vol. 8, no. 11, p. 2223, Dec. 2018, doi: 10.3390/app8112223.

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