JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering

Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

Feasibility Analysis of the Implementation of a Photovoltaic Water Cooling System

Riyani Prima Dewi[1], Saepul Rahmat[2]
[1,2] Departement of Electrical Engineering, Politeknik Negeri Cilacap, Jl. Dr. Soetomo, No.1, Cilacap 53212, Indonesia

ARTICLE INFO

Article historys:

Received : 14/09/2023
Revised : 31/10/2023
Accepted : 01/04/2024

Keywords:

Efficiency; Net Output Power; Photovoltaic; Temperature; Water Cooling System

ABSTRACT

This research examines the impact of implementing a cooling system on PV panels, utilizing a water flow controller, to enhance efficiency and augment power generation. The cooling system was affixed to pre-existing 200W monocrystalline photovoltaic panels. The controller effectively regulates the temperature of the photovoltaic (PV) panel at a constant value of 30°C by employing a water-cooling system. This system utilizes PVC tubes that are strategically positioned on the surface of the panel. The cooling control system is programmed to operate according to a predetermined schedule. The experimentation involved the implementation of a cooling system during PV testing, with the inclusion of non-cooled PV panels for comparison. The analysis examines the impact of temperature on the output power of a photovoltaic system, taking into account losses from the cooling system. In conclusion, an assessment was conducted on the comprehensive utilization of a water-cooling system for PV panels. The experimental findings indicate that the PV output power exhibited a 7.8% increase when the cooling system was employed as compared to the PV system without cooling. Incorporating the computation of system losses results in a net increase of 5.9% in the output power of the photovoltaic system.

Copyright © 2024. Published by Bangka Belitung University
All rights reserved

Corresponding Author:

Riyani Prima Dewi
Departement of Electrical Engineering, Politeknik Negeri Cilacap, Jl. Dr. Soetomo, No.1, Cilacap 53212, Indonesia
Email: riyanipd@pnc.ac.id.

1. INTRODUCTION

Indonesia, as a nation, benefits from a consistently high level of sunlight throughout the year. Consequently, the Indonesian government has prioritised harnessing this abundant solar resource as a means to address the persistent issue of power supply shortages inside the country. The objective is to mitigate excessive reliance on fossil energy as a power source due to its insufficiency. The prevalence of solar energy as a form of electricity generation in Indonesia is more pronounced compared to other renewable energy, mostly due to the country's ample sunlight resources.

Solar photovoltaic (PV) is an emerging form of renewable energy that is employed for the purpose of generating electricity. Photovoltaic (PV) technology is capable of directly converting solar energy into electrical energy, which can then be utilized, stored, or transmitted over large distances[1]. The utilization of photovoltaic technology is expected to experience significant growth in the future due to its reliance on solar energy as a clean, dependable, scalable, and cost-effective source of electricity on a worldwide scale[2].

Solar or photovoltaic (PV) cells are composed of semiconductor materials. When the material absorbs photon energy, the electrons are liberated from the atomic bonds and become mobile, resulting in the generation of a direct current electric voltage over time. The majority of photovoltaic (PV) cells utilized in commercial applications are composed of silicon and can be classified into three main categories: monocrystalline, polycrystalline, and amorphous. Monocrystalline cells, also known as single crystals, are manufactured by utilizing silicon wafers that are derived from individual cylindrical silicon crystals. The aforementioned photovoltaic cell variant has the highest level of efficiency, approximately 15%, as measured by the proportion of solar energy successfully transformed into electrical energy[3]. However, it is worth noting that this particular type of cell is also characterized by a rather high production cost.

Temperature is an additional component that can exert an influence on the performance of photovoltaic (PV) panels, in addition to solar radiation. Photovoltaic (PV) panels commonly experience an increase in temperature as a result of solar radiation. This rise in temperature often surpasses the ideal threshold, leading to a significant decline in the performance and efficiency of both monocrystalline and polycrystalline solar cells. A rise in solar panel temperature by 1°C beyond the baseline of 25°C is associated with a decrease in the generated output power by around 0.4-0.5% [4, 5, 6, 7] . The output voltage of solar panels can be reduced by up to 0.22 V/°C due to a rise in cell temperature [8, 9, 10]. The relationship between temperature change characteristics and the electrical parameters of photovoltaic (PV) systems is illustrated in Figure 1. The rise in temperature leads to a notable decline in PV voltage, accompanied by a minor increase in PV current, resulting in a reduction in output power.

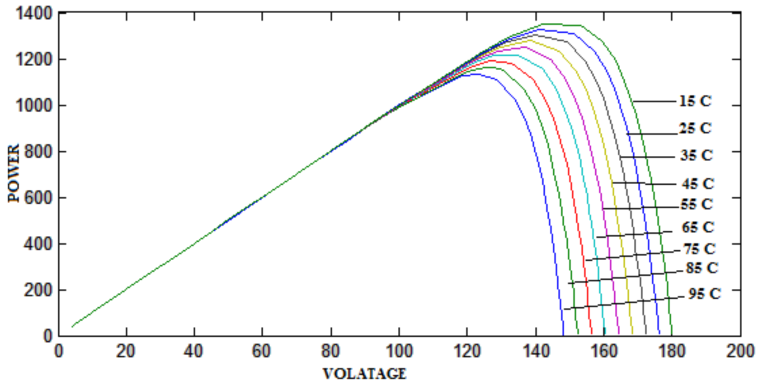

Figure 1. PV characteristics for different temperatures

Several cooling approaches have been previously suggested to enhance the effectiveness of photovoltaic (PV) systems in response to increasing temperatures. These techniques include the implementation of an active cooling system that utilizes water [11, 12, 13] and thermoelectric [14, 15]. In the context of active cooling systems, it is imperative to account for the additional electricity required in order to accurately assess the overall efficiency. Passive cooling relies on the principles of natural convection and conduction to facilitate the extraction of heat. The utilization of passive cooling with a heat sink has resulted in a notable improvement in electric efficiency[16]. Heat pipe cooling is a technique that combines phase change cooling with convection of a cooling medium[17, 18], together with the utilization of thermoelectric cooling systems that operate based on the Peltier effect[19]. Nanofluids are commonly regarded as heterogeneous blends including a cooling fluid and solid nanoparticles that are scattered throughout it. The majority of the particles employed in this context consist of metal oxides. The primary benefits associated with nanofluids are enhanced thermal conductivity, resulting in improved connection, as well as a modest increase in heat capacity[20, 21]. Through various studies and experiments, it has been demonstrated that the implementation of a cooling system can result in an increase in power output ranging from 1% to 15%.

Numerous cooling approaches have been proposed; however, only a limited number of studies have conducted comprehensive measurements and computations to determine the net power gained, as well as the relative and overall increase in efficiency. The objective of this study is to examine the impact of temperature on photovoltaic (PV) net power increases through the implementation of a suggested water cooling system. The determination of net power was conducted by incorporating cooling system losses,

Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

which were derived from the measurement of pump power during operation. Moreover, an examination and assessment of the various aspects that impact cooling system losses, which have the potential to decrease the net power output of a photovoltaic system, are conducted in order to ascertain their practicality.

2. RESEARCH METHOD

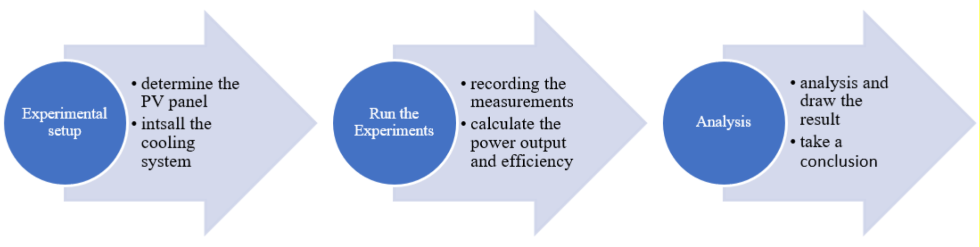

Figure 2. Research Methodology

Figure 2 shows the research methodology of this study. There are 3 main stages in this experiments, namely Experimental setup, Run the experiments, and Analysis. A detailed explanation of this research methodology will be provided in the subsequent section.

2.1. Photovoltaic (PV Panel)

The PV panel employed for experimentation in this study consisted of monocrystalline silicon solar panels with a power capacity of 100 Wp, as depicted in Figure 3. Table 1 presents the specifications of the photovoltaic (PV) panel by the standard testing conditions (STC), which include an irradiance level of 1,000W/m^2, a temperature of 25^{o}C, and an air mass of 1.5.

Figure 3. The 100 Wp monocrystalline PV Panel

The calculation of maximum power (Pm) involves the multiplication of maximum voltage (Vm) and maximum current (Im), as expressed by the following equation (1) [22]:

$$P_m = V_m I_m \tag{1}$$

Table 1. The Specification of PV

Parameter	Value
Dimension	1020*540*30 mm
Nominal Output (Pm)	100 W
Open circuit voltage (Voc)	21.8 Vdc
Short circuit current (Isc)	6.05 A
Maximum power voltage (Vm)	17.8 Vdc
Maximum power current (Im)	5.62 A
NOCT	47±2°C

Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

2.2. Water Cooling System

The study implements a photovoltaic (PV) cooling system that involves the application of water onto the PV panel's surface. The primary objective of this system is to regulate and sustain the temperature of the PV panel at 30ºC, hence mitigating the impact of increasing ambient and panel temperatures. The schematic representation of the cooling system controller, as depicted in Figure 4, is typically utilized.

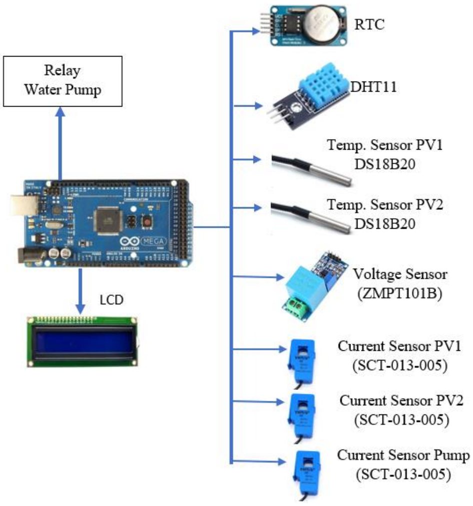

Figure 4. Schematic of cooling system controller

The primary controller utilizes an Arduino Mega 2560 microcontroller, which operates at a resolution of 10 bits. It receives input from a temperature sensor, specifically the DHT11, to measure the ambient temperature (Ta). Additionally, it utilizes an NTC (DS18B20) sensor to measure the temperature of the photovoltaic (PV) cell (Tc). Additional inputs are obtained from the voltage sensor and the current sensor. These sensors are utilized to measure the output power of the photovoltaic system (PPV). The output controller consists of relay switches that serve as regulators for the on-off operation of the pump. Additionally, it has an LCD display which presents the measured temperature values and the electricity generated by the photovoltaic system. A water pump was utilized, which was fitted a PVC tube perforated at a distance of 2 cm to circulate water on the surface of the solar panel. This PVC tube is installed at the top of the solar panel, as depicted in Figure 5. Table 2 presents the comprehensive specs of the water cooling system.

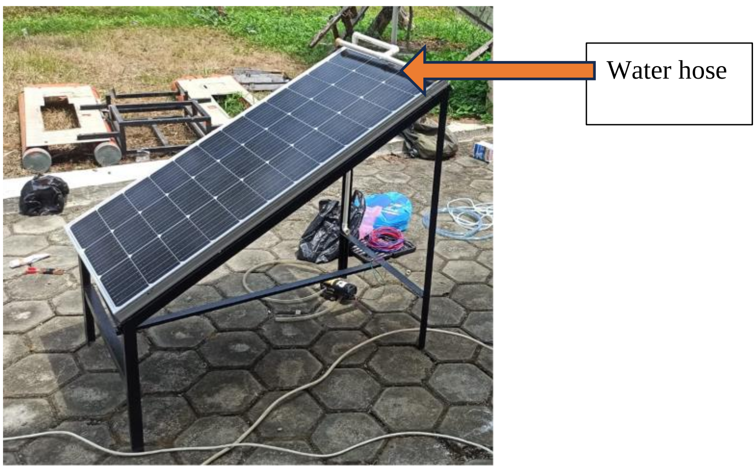

Figure 5. The position of PVC Tube on solar panel

Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

Table 2. The Specification of Watercooling System

Devices	Specification
Controller	Arduino Mega 2560, 10 Bit, with 1 DHTII, 2 DS18B20
Pump	DC water pump, 12V, 8 W, 4L/m
Water hose	PVC 5/8''

The initiation of the water cooling system program involves activating the liquid crystal display (LCD) and issuing a series of display commands. The software initiates the sensor to collect temperature data. The looping sensor operates based on predetermined settings. Specifically, if the RTC module detects the time at 09.00 am, the relay is activated. Consequently, the system triggers the pump to release water onto the surface of solar panel. In contrast, in the event that the temperature of the photovoltaic module is equal to or below 30°C, the pump will off, resulting in the cessation of water into the PV. Figure 6 displays the flowchart illustrating the designed method for controlling the cooling of photovoltaic panels.

2.3. Experimental Setup

A total of two solar panels were subjected to testing utilizing a cooling system. These panels were arranged in a linked system configuration, as depicted in Figure 7. The output of the photovoltaic (PV) system was connected to water pump, lamp, and battery. The controller records and measures the photovoltaic (PV) power, which is in the form of direct current (DC). This measurement is then examined in relation to variations in the temperature of the PV panel. The power capacity of the system is 200 watts peak (Wp). The evaluation of PV panel performance, namely PV1, involves the incorporation of non-cooled PV panels (PV2) of equivalent capacity for concurrent comparison in daylight conditions. In the photovoltaic (PV) system equipped with a cooling mechanism, there are PVC tube positioned on the top side of solar panel (see Figure 5).

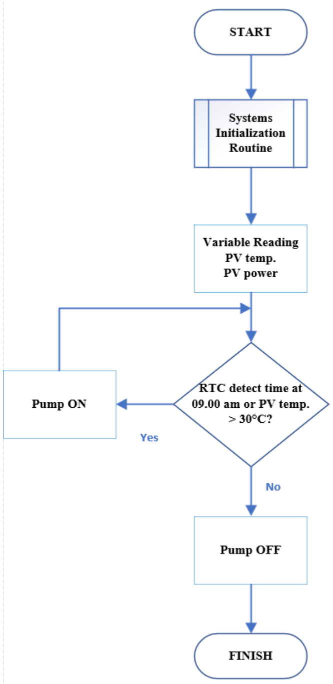

Figure 6. The flowchart of system

During the experimental procedure, the controller effectively captured and recorded all relevant parameters from the sensor in a simultaneous manner. These parameters encompassed the PV temperature and PV output power. The determination of the duration of pump operation throughout the test necessitates the acquisition of pump power values. The aggregate energy consumption of the pump

JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering
Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

is attributed to the electrical losses incurred by the cooling system. The purpose of this study was to assess the efficacy and importance of implementing a cooling system in the solar photovoltaic power system, specifically in relation to the overall net power output.

3. RESULTS AND DISCUSSION

In this section the experimental results are interpreted and presented. The measurements were recorded between 06:00am and 17:00 pm. All the readings have been recorded in a clear day on on Augustus 28th, 2023 in Cilacap. The present discourse encompasses an examination of the performance of the water cooling system, the impact of cooling PV panels on output power, and the evaluation of the system. In an early study by Bahaidarah et al. [23], the operating temperature of the water cooled CPV is reduced by 43.75% and 33.8% relative to the CPV system and the PV module, respectively, by the cooling system. And it is noted from the results that reducing the operating temperature has an obvious impact on the power output, as the power output of water cooled CPV system is almost twice as high as that of the CPV system. By comparing the present study with Bahaidarah et al., it is noted that both of the studies have the same tendency only there are variations in the values due to the circumstances of each study, such as the ambient temperature, the value of the solar radiation and the environment and the location in which the experiments are conducted. The result will be provided in the subsequent section.

Figure 7. PV panels configuration

3.1. The Performance of Water Cooling System

The simultaneous measurement outcomes, in which all readout parameters are fully depicted in curve, can be observed in Figure 8. At 6:00 AM, as the sunlight begins to rise and illuminates the panel surface, both PV panels equipped with a cooling system (PV1) and non-cooled PV panels (PV2) commence generating less power. Consequently, the temperature of both panel types starts to increase over 20ºC. At 7:30 AM, the temperature of the panel hits 30°C, while the average output power of PV1 (P-PV1) and PV2 (P-PV2) ranges between 38 - 45 W.

The temperature of the non-cooled photovoltaic (PV) panels, denoted as T-PV2, exceeded 30°C between 07:30 and 15:20. At 13:30, it reached its peak value of 58.1°C, coinciding with a power production of 66.2 W. Simultaneously, the temperature of the photovoltaic (PV) panel equipped with a cooling system, denoted as T-PV1, is around 30.12 °C, while generating an output power of 71.6 W. The findings of the calculation indicate that there is a loss of 0.411% in the output power of photovoltaic (PV) systems for every 1°C increase in temperature, specifically in the context of crystalline silicon solar cells.

Hence, it may be inferred that the functionality of the cooling system's controller was satisfactory. The pump operates in an automated manner, activating and deactivating in response to temperature fluctuations. The duration of its operation is contingent upon the readings of the temperature sensor. At present, it is evident that the influence of photovoltaic (PV) temperature on PV output power is very

JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering
Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

discernible. Specifically, the PV power generated with a cooling system (referred to as P-PV1) surpasses the power generated by noncooled PV systems (referred to as P-PV2) as a result of the lower temperature conditions.

Figure 8 displays the mean values of all parameters during one-hour intervals of daytime testing. The total power consumed during the test, denoted as P-PV1, is measured to be 501.7 Wh. Similarly, the power consumption for P-PV2 is recorded as 425.2 Wh, resulting in a difference of 36.5 Wh between the two measurements. In this particular scenario, there exists an excess power of around 7.28% as a result of the cooling phenomenon exhibited by photovoltaic (PV) panels. The surplus mentioned does not encompass the energy utilized by the cooling system, specifically the pumps. However, the losses incurred by the controller were disregarded due to their minimal power consumption, specifically less than 1 W.

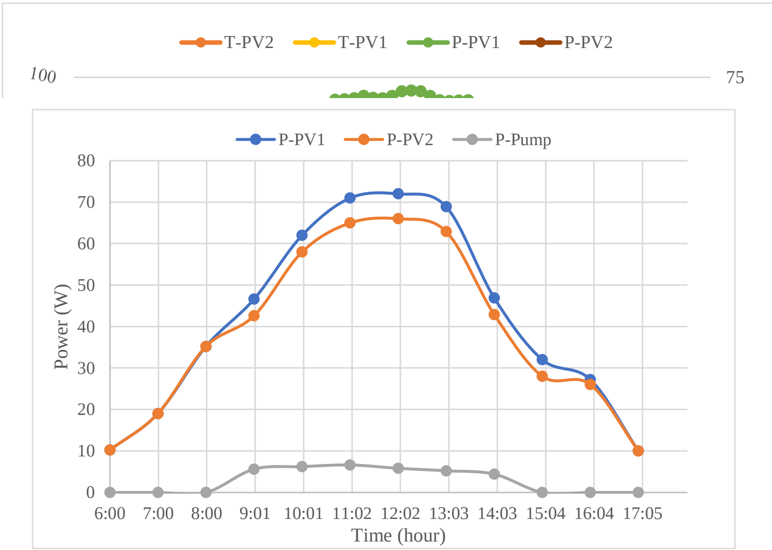

Figure 8. The hourly of measurement results

Additionally, the graph depicts the outcomes of the pump's running power measurement conducted throughout the test, shown by the gray curve. A detailed explanation of this measurement will be provided in the subsequent section.

3.2. Technical Feasibility Analysis of Water Cooling System

In addition to passive and natural cooling systems that operate without electrical power, it is important to take into account the power losses associated with the implementation of active cooling systems. The inclusion of the cooling system should be assessed in terms of its technical viability.

However, when considering the pump power, the disparity in power is observed to be 33.8 Wh, as depicted in Figure 8. The aforementioned number is derived from the computation of the disparity between the power generated by the photovoltaic (PV) system with the inclusion of the cooling mechanism (P-PV1) and the power dissipated by the cooling system. The cumulative duration of the pump's operation during the chilling procedure amounts to 3 hours, 24 minutes, and 25 seconds, leading to a total energy consumption of 40.12 watt-hours. The net output power of a photovoltaic (PV) system equipped with a cooling system, denoted as P-PV1', can be calculated as $501.7 - 40.12 = 461.58\ Wh$. When comparing the power output of cooled PV systems (P-PV2 = 425.2 Wh) to non-cooled PV systems, there is still an approximate surplus of 7.8% in power.

Figure 9 illustrates the variation in efficiency resulting from the impact of photovoltaic (PV) temperature during the experimental evaluation. Based on the photovoltaic (PV) characteristics provided in Table 1, the PV panel possesses a capacity of 100 watts peak (Wp) and occupies an area of 0.732 square meters (m2). The standard test conditions (STC) for the PV panel are defined as an irradiance of 1000 watts per square meter (W/m2) and a temperature of 25 degrees Celsius (°C). By employing equation (3), the calculated efficiency of the PV panel amounts to 13.7%.

Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

The overall performance of the cooling system controller has demonstrated its effectiveness in regulating the temperature of photovoltaic (PV) panels at 30ºC, preventing it from exceeding this threshold. However, it is important to note that the net output power of the system is still rather low. During the cooling process, the cooling system has been in operation for 3 hours, 24 minutes, and 25 seconds, and has consumed a total of 40.12 watt-hours (Wh) of power. The manual water measurement yielded a total water usage of 248.6 liters throughout the testing process, which is comparable to 1.9 liters per minute. The current pump capacity being utilized remains below the specified rate of 4 liters per minute. The potential explanation of the low net power gains observed in the planned photovoltaic cooling system is being considered. One potential improvement involves augmenting the current pump discharge capacity by a minimum of two-fold. Rationally, augmenting the cooling water capacity will result in an accelerated cooling process. This, in turn, will lead to a reduced operational length of the pump, hence mitigating power losses in the cooling system. Consequently, the net power gain will be amplified, albeit at the expense of increased water consumption. Furthermore, it is worth noting that the suboptimal cooling process may be attributed to the positioning and spacing of the PVC tube, as observed in the field. The inadequate installation of PVC tube can result in an uneven distribution of water spray across the whole surface of the panel.

Based on the findings and assessment presented earlier, it is evident that addressing these technical challenges presents an opportunity for enhancing the net output power of the photovoltaic (PV) panels in the proposed cooling system, notwithstanding the aforementioned limitations. The consideration of these many aspects is crucial while designing the photovoltaic (PV) cooling system, with particular emphasis on active water-cooling systems, to ensure long-term viability and effectiveness.

4. CONCLUSION

This research presents a comprehensive analysis and assessment of the water-cooling methods that have been designed and subsequently tested on monocrystalline PV panels with a power output of 200 W. The cooling mechanism operates by employing water on the surface of the panel in instances at the specified time and condition. The objective of this research is to increase the power performance of the PV module by using a cooling system that are practically and economically feasible. The power performance of the monocrystalline PV module was investigated experimentally by using a cooling system. The cooling system is developed based on the water flowing on the front side of the panel to keep the temperature of the water as low as possible without consuming energy. The experimental findings during daylight hours demonstrated that the photovoltaic (PV) output power exhibited a 7.8% increase when the cooling system was implemented, in comparison to the PV system without cooling. In the context of an active cooling system, it is imperative to consider the power losses associated with the system to obtain more accurate and realistic estimations. When incorporating the computation of system losses, the net gain in PV output power amounts to 5.9%. Other variables contribute to these losses, with derating being the primary cause. One significant derating issue is the water capacity, which is lower than the pump discharge capacity. Another factor that contributes to system losses is the incorrect installation of PVC tubes, specifically in terms of spacing and orientation. This leads to uneven distribution of cooling throughout the surface of panels, resulting in suboptimal cooling processes and wastage of water. By successfully addressing these challenges, the suggested cooling system holds the potential to enhance the net output power of the photovoltaic (PV) panels, hence enhancing their feasibility.

Acknowledgments

This research was fully funded by the Academic Directorate of Vocational Education, Directorate General Vocational Education Ministry of Education, Culture, Research and Technology in 2023 with the contract number : 189/SPK/D.D4?PPK.01.APTV/VI/2023.

Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

REFERENCES

[1] R. J. Mustafa, M. R. Gomaa, M. Al-Dhaifallah, and H. Rezk, "Environmental Impacts on the Performance of Solar Photovoltaic Systems," *Sustainability*, vol. 12, no. 2, p. 608, Jan. 2020, doi: 10.3390/su12020608.

[2] A. El Hammoumi, S. Chtita, S. Motahhir, and A. El Ghzizal, "Solar PV energy: From material to use, and the most commonly used techniques to maximize the power output of PV systems: A focus on solar trackers and floating solar panels," *Energy Reports*, vol. 8, pp. 11992–12010, Nov. 2022, doi: 10.1016/j.egyr.2022.09.054.

[3] S. Nižetić, E. Giama, and A. M. Papadopoulos, "Comprehensive analysis and general economic-environmental evaluation of cooling techniques for photovoltaic panels, Part II: Active cooling techniques," *Energy Convers Manag*, vol. 155, pp. 301–323, Jan. 2018, doi: 10.1016/j.enconman.2017.10.071.

[4] M. S. Ahmed, R. Karal, B. K. Das, and A. Das, "Experimental investigation of cooling, wind velocity, and dust deposition effects on solar PV performance in a tropical climate in Bangladesh," *Case Studies in Thermal Engineering*, vol. 50, p. 103409, Oct. 2023, doi: 10.1016/j.csite.2023.103409.

[5] A. Risdiyanto, Ant. A. Kristi, B. Susanto, N. A. Rachman, A. Junaedi, and E. W. Mukti, "Implementation of Photovoltaic Water Spray Cooling System and Its Feasibility Analysis," in *2020 International Conference on Sustainable Energy Engineering and Application (ICSEEA)*, IEEE, Nov. 2020, pp. 88–93. doi: 10.1109/ICSEEA50711.2020.9306133.

[6] M. R. Gomaa, R. J. Mustafa, and H. Rezk, "An experimental implementation and testing of a concentrated hybrid photovoltaic/thermal system with monocrystalline solar cells using linear Fresnel reflected mirrors," *Int J Energy Res*, p. er.4862, Sep. 2019, doi: 10.1002/er.4862.

[7] M. R. Gomaa, W. Hammad, M. Al-Dhaifallah, and H. Rezk, "Performance enhancement of grid-tied PV system through proposed design cooling techniques: An experimental study and comparative analysis," *Solar Energy*, vol. 211, pp. 1110–1127, Nov. 2020, doi: 10.1016/j.solener.2020.10.062.

[8] A. Bria, B. Raillani, D. Chaatouf, M. Salhi, S. Amraqui, and A. Mezrhab, "Evaluation of the efficiency of a cooling system using PCM materials for glazed and unglazed PV panels," in *2023 3rd International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET)*, IEEE, May 2023, pp. 1–7. doi: 10.1109/IRASET57153.2023.10152935.

[9] A. Hussien, A. Eltayesh, and H. M. El-Batsh, "Experimental and numerical investigation for PV cooling by forced convection," *Alexandria Engineering Journal*, vol. 64, pp. 427–440, Feb. 2023, doi: 10.1016/j.aej.2022.09.006.

[10] M. K. , N. M. , & O. A. N. YEŞİLYURT, "Techniques for enhancing and maintaining electrical efficiency of photovoltaic systems," *International Journal of New Technology and Research*, vol. 4, no. 4, Apr. 2018.

[11] M. Y. Abdalhamed, A. Almalih, M. Alshaikh, M. A. Hadi, and Y. Aldali, "Modeling and experimental investigation on the performance of a PV panel with water cooling system," in *2023 IEEE 3rd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*, IEEE, May 2023, pp. 836–841. doi: 10.1109/MI-STA57575.2023.10169292.

[12] S. A. Zubeer and O. M. Ali, "Experimental and numerical study of low concentration and water-cooling effect on PV module performance," *Case Studies in Thermal Engineering*, vol. 34, p. 102007, Jun. 2022, doi: 10.1016/j.csite.2022.102007.

[13] M. A. Yildirim, A. Cebula, and M. Sułowicz, "A cooling design for photovoltaic panels – Water-based PV/T system," *Energy*, vol. 256, p. 124654, Oct. 2022, doi: 10.1016/j.energy.2022.124654.

[14] P. B, V. Ravindran, M. Marimuthu, S. Ragunathan, S. K, and R. V, "Design and Implementation of PV Powered Air Cooler System Using Thermoelectric Cooler," in *2021 Innovations in Power and Advanced Computing Technologies (i-PACT)*, IEEE, Nov. 2021, pp. 1–6. doi: 10.1109/i-PACT52855.2021.9697007.

[15] V. V. Kulkarni and V. A. Kulkarni, "Performance Optimization of Photovoltaic Systems using Thermoelectric Cooling System," in *2022 International Conference on Futuristic Technologies (INCOFT)*, IEEE, Nov. 2022, pp. 1–4. doi: 10.1109/INCOFT55651.2022.10094413.

Volume 11, Issue 1, April 2024, pp. 19-28
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4442

[16] S. N. Razali *et al.*, "Performance enhancement of photovoltaic modules with passive cooling multidirectional tapered fin heat sinks (MTFHS)," *Case Studies in Thermal Engineering*, vol. 50, p. 103400, Oct. 2023, doi: 10.1016/j.csite.2023.103400.

[17] A. K. Azad and S. Parvin, "Photovoltaic thermal (PV/T) performance analysis for different flow regimes: A comparative numerical study," *International Journal of Thermofluids*, vol. 18, p. 100319, May 2023, doi: 10.1016/j.ijft.2023.100319.

[18] S. D. Prasetyo, 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, p. e13390, Feb. 2023, doi: 10.1016/j.heliyon.2023.e13390.

[19] G. Fabbri and M. Greppi, "Numerical modeling of a new integrated PV-TE cooling system and support," *Results in Engineering*, vol. 11, p. 100240, Sep. 2021, doi: 10.1016/j.rineng.2021.100240.

[20] M.-W. Tian *et al.*, "Energy, exergy and economics study of a solar/thermal panel cooled by nanofluid," *Case Studies in Thermal Engineering*, vol. 28, p. 101481, Dec. 2021, doi: 10.1016/j.csite.2021.101481.

[21] A. Aydin, I. Kayri, and H. Aydin, "The Efects of TiO_2 Nanofluid on Efficiency and Heat Transfer Indicators of an Inner-Plate Finned Collective Cooling in a PV/T Hybrid System," in *2022 Global Energy Conference (GEC)*, IEEE, Oct. 2022, pp. 368–373. doi: 10.1109/GEC55014.2022.9986908.

[22] Aldi Cahya Muhamad *et al.*, *KONVERSI ENERGI*, 1st ed. Padang: PT Global Eksekutif Teknologi, 2023.

[23] S. Bazarchi, G. R. N. Bidhendi, I. Ghazi, And A. Kasaeian, "A Techno-Economic Feasibility Study For Reducing The Energy Consumption In A Building: A Solar Energy Case Study For Bandar Abbas," *Journal of Thermal Engineering*, vol. 6, no. 4, pp. 633–650, Jul. 2020, doi: 10.18186/thermal.766463.