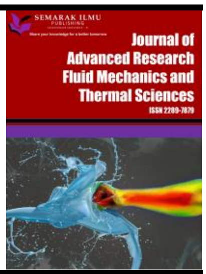
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Effect of Water Cooling and Dust Removal on Solar Photovoltaic Module Efficiency

Nik Muhammad Hazwan Nik Amran[1], Siti Lailatul Mohd Hassan[1,*], Ili Shairah Abdul Halim[1], Nasri Sulaiman[2], Noor Ezan Abdullah[1], A'zraa Afhzan Ab Rahim[1]

[1] School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2] Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia,43400 Serdang, Malaysia

ARTICLE INFO

Article history:
Received 22 December 2022
Received in revised form 25 March 2023
Accepted 2 April 2023
Available online 20 April 2023

Keywords:
Renewable energy; dust accumulation; photovoltaic cleaning; photovoltaic cooling; microcontroller

ABSTRACT

This paper is on the effect of water cooling and dust removal on solar photovoltaic module efficiency. Photovoltaic power generation suffers from low energy conversion efficiency, mainly caused by the photovoltaic module's extraordinarily high operating surface temperatures and dust collection. This paper studies the effect of overheating and dust accumulation on the photovoltaic module performance. This paper presents a cooling and dust removal automatic system to increase performance. The objectives of this paper are, first, to develop a method for the cleaning and cooling of solar modules that are fully automated; second, to investigate the effect that the cooling system has on the surface of the solar modules; and lastly, to study the impact that dust and heated panel have on the performance of the solar system. The photovoltaic module was water-cooled using a prototype with a built-in motor and water pump that operated to cool and clean the photovoltaic module. Water-cooled modules are then compared to conventional modules (no modification). For the debris build-up investigation, the traditional module is covered with 20%, 30% and 50% estimated dust coating on the module surface. The output power is compared to the module with a cleaning system (zero dust coverage). According to these findings, it takes the solar module only five weeks to lose 20% of its efficiency once it has been installed. The research found that the module had a low energy conversion efficiency when the surface temperature was relatively high. The increase in surface temperature can be attributed to the production of heat energy on the surface due to the module being exposed to intense sunlight.

1. Introduction

Renewable energy is power from renewable resources such as sunlight, wind, rain, tides, and earth heat [1,2]. One popular method of renewable energy used in modern society is photovoltaics (PV) for electricity generation [3,4]. PV modules contain photovoltaic semiconductors. These modules convert solar irradiation into direct current energy to generate power. When a substance is illuminated by light, this phenomenon is known as the photovoltaic effect. Photovoltaic power

* *Corresponding author.*
E-mail address: sitilailatul@uitm.edu.my

https://doi.org/10.37934/arfmts.105.1.184193

generation research reveals that nature, such as cloudiness and humidity, is the main factor affecting PV module efficiency [5]. The effectiveness and efficiency of PV power generation are negligible compared to a combination of factors, including ambient temperature and dust collection on PV modules. These factors impact PV power generation more. The solar industry has increasingly prioritized cooling and cleaning photovoltaic modules [6].

High-temperature sunlight hitting the PV module heats its exposed surface. Photovoltaic semiconductors usually keep a constant temperature; however, when the temperature increases, solar cell semiconductor efficiency decreases [7-15]. When the conducting material's temperature rises, its phonons get stimulated, which hinders electron movement. This impedance reduces solar module performance when it's hot. Besides that, environmental dust develops a coating on modules placed in open places to get the most direct sunlight. Dust accumulates and prevents sunlight from reaching the solar module, making the photovoltaic modules convert energy poorly. The dust layer stores heat, keeping the modules warm. High temperatures reduce the module's energy conversion efficiency [16-20].

This paper aims to increase the PV module's performance by reducing the PV surface temperature and dust collection. The objectives of this paper are, first, to develop a method for the cleaning and cooling of solar modules that are fully automated; second, to investigate the effect that the cooling system has on the surface of the solar modules; and lastly, to study the impact that dust and heated panel have on the performance of the solar system. The modifications included in this project include the addition of water cooling and the elimination of debris build-up on the surface module. A comparison of the water-cooling module's and the standard module's power output is the primary focus of this project study. With an enhanced module, there is no dust accumulation in a water-cooled module because the constant flow of water eliminates the opportunity for dust to settle and collect.

2. Methodology

The paper aims to develop an automatic, remote, self-cleaning and cooling solar panel. Debris removal is essential in ensuring that the solar system operates efficiently. Removing dirt and debris from the surface of the solar panels increases their exposure to sunlight and maximizes energy production. The cooling system design ensures that the solar panels do not overheat, which can reduce their lifespan and efficiency. The diagram in Figure 1 shown the working process of a PV module. The method of developing the PV module system begins with developing the prototype of the system. This prototype serves as the project's foundation and helps identify the necessary components and requirements for the system. The prototype is tested at the School of Electrical Engineering, UiTM Shah Alam parking lot for one month from 23 October 2022 until 24 November 2022. Experiments to test for the effect of cooling and cleaning on the solar panel are done during that time.

This paper uses an 18W monocrystalline solar panel with a 30A solar controller and a 6000W power inverter. The solar controller is used as an interface, and the power inverter is used to change the power to be used by the home appliance. In this case, the power is used to operate the cleaning and cooling system. The cooling and cleaning system consists of a temperature sensor to measure the solar panel's surface temperature. This is to determine if the solar panel's temperature has reached a critical level. In this paper, the maximum temperature is set to 45°. If the temperature exceeds that, the cooling water pump will operate. A push button is installed to manually manage and reset the cooling and cleaning system for maintenance.

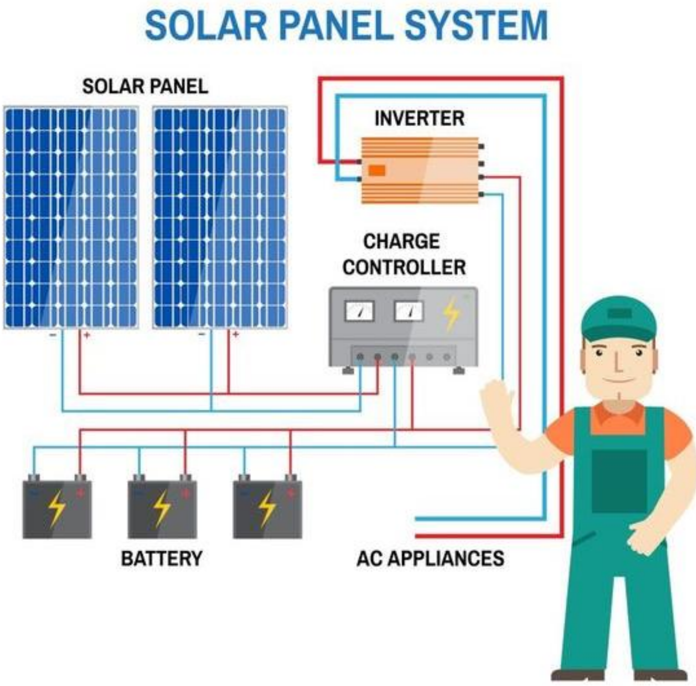


Fig. 1. PV module working diagram

The maintenance ensures the panel's surface is cleaned and cooled, maximizing energy production. The system is also connected to an IoT part to enhance further the system, which can be controlled remotely using a smartphone[21, 22]. This paper uses the Blynk application with the ESP-32's built-in Wi-Fi.

As shown in Figure 2, the Blynk application manually turns the cooling and cleaning system by turning ON or OFF the water pump and the motor. There is also a temperature reading of the PV solar module for monitoring purposes.

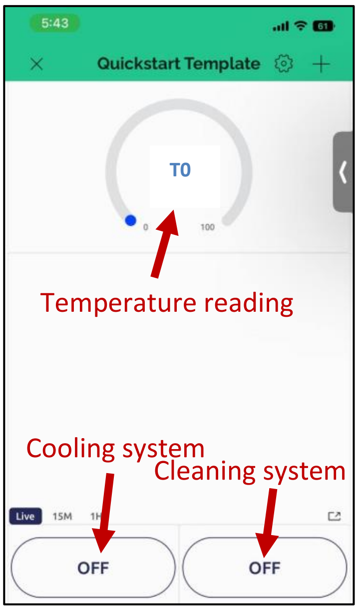


Fig. 2. Automated remote control from Blynk application

Figure 3 shows the block diagram of the solar module cooling and cleaning system. The system consists of a temperature sensor and a push button as input. The temperature sensor (DS18B20) measures the ambient temperature and sends the information to the microcontroller. The push button is used to initiate the manual operation of the system. The system's outputs are a window power lifter motor and a water pump. The window power lifter motor is used to clean the solar panel, and the water pump is used to cool the system.

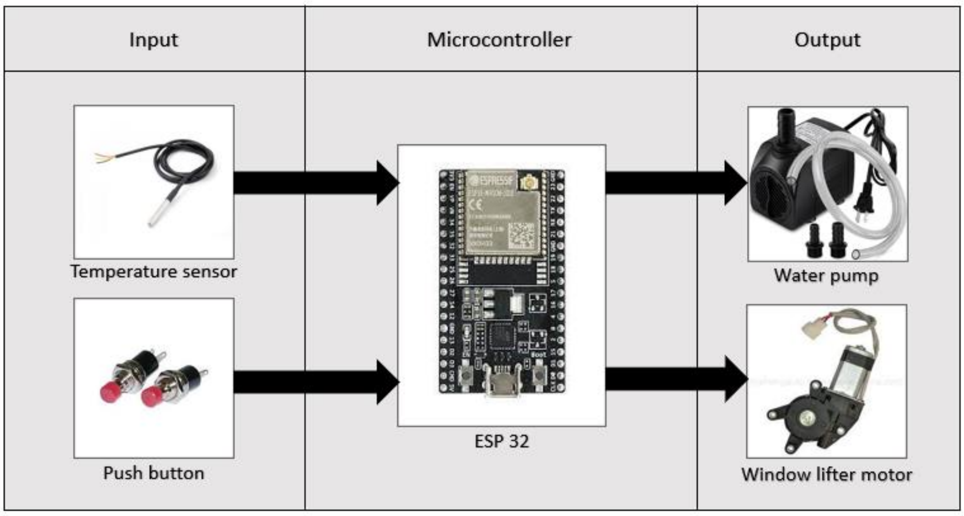


Fig. 3. Block diagram of the control box of the solar module cooling and cleaning system

Figure 4 shows the solar panel's whole cooling and cleaning system. The power obtained from the solar panel is stored in the rechargeable battery and used back to power the pump for the cooling system and move the wiper attached to the motor to clean the solar panel. The system design is self-sufficient and cost-effective as it reuses the generated power from the solar panel.

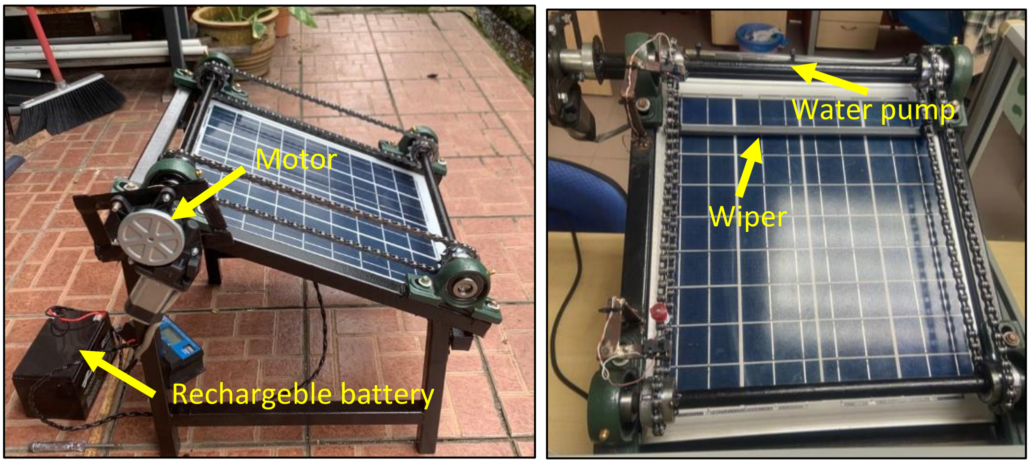


Fig. 4. The complete cooling and cleaning system for the solar panel

Figure 5 shows the simulation of dust coverage on the PV module. The dust coverage simulation by putting the dust manually on the solar panel with an estimation of coverage ranges from 20 % to 30 % to 50 %. This simulation is for the study of energy production before and after cleaning to determine the effectiveness of the cleaning system in improving PV solar panel performance.

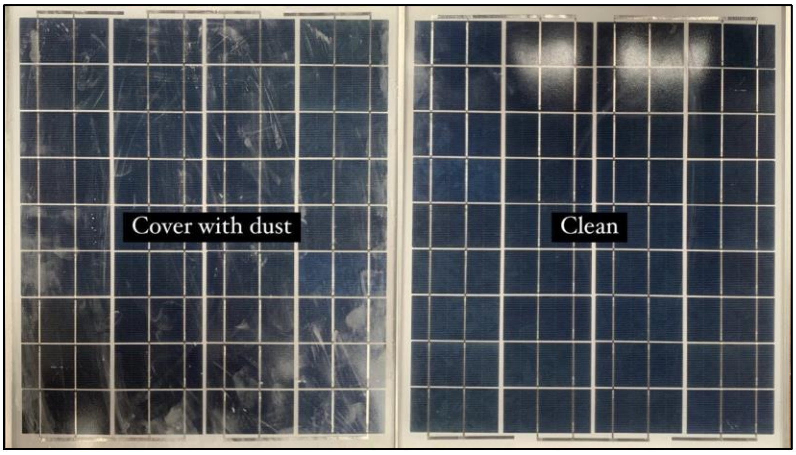


Fig. 5. The PV solar module with and without the dust

3. Results

This project aimed to design and test a solar cooling and cleaning system that can improve the efficiency of photovoltaic panels. First, the solar panel efficiency over time is studied; next is the study of the effect of water cooling on the performance and lastly, the impact of debris removal on energy production. The results of these experiments provide valuable insights into the best practices for maintaining and improving the performance of solar panels.

3.1 Solar Panel Efficiency Over Time

For the initial study, the solar panel was exposed to direct sunlight for one month. The efficiency of the solar panel was measured using a digital multimeter and recorded at regular intervals. Figure 6 shows the power output produced by a single solar module. Solar irradiation in Malaysia from October to December is between 550 to 650 for solar irradiation. The graft in Figure 6 demonstrates that output power degraded over time. Based on this finding, the solar module loses around 20% of its efficiency without the cooling and cleaning system.

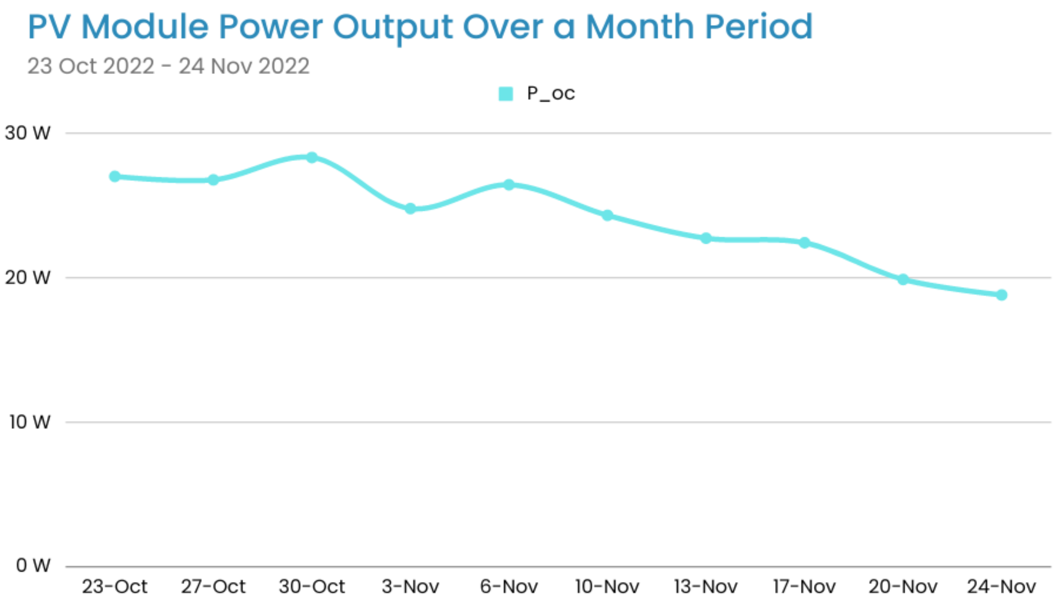


Fig. 6. PV module power output within a month without the cooling and cleaning system

Shown in Table 1 is the average reading at the beginning and end of the weeks during the observation period. G_measured represents the solar irradiation reading obtained from the solar irradiance meter, Temp_measured is the solar panel temperature reading using the temperature sensor, Isc_measured and Voc_measured is current, and voltage measured using the multimeter and Poc_measured is power calculated from the current and voltage reading of the solar panel. The same terms are used throughout this paper.

Table 1
Average reading at the beginning and end of the weeks during the observation period

Field Data	Week									
	1		2		3		4		5	
	23-Oct	27-Oct	30-Oct	3-Nov	6-Nov	10-Nov	13-Nov	17-Nov	20-Nov	24-Nov
G_measured (Wm^{-2})	599	609	614	604	606	600	578	568	601	592
Temp_measured (°C)	46.3	45.6	46.2	46.4	45.4	49.3	47.5	45.6	44.8	47.2
Isc_measured (A)	1.13	1.12	1.2	1.05	1.12	1.03	1.01	1.00	0.86	0.85
Voc_measured (V)	23.9	23.9	23.6	23.6	23.6	23.6	22.5	22.4	23.1	22.1
Poc_measured (W)	27.01	26.77	28.32	24.78	26.43	24.31	22.725	22.4	19.866	18.79

3.2 Effect of Water Cooling

Solar panel overheating due to exposure to high temperatures can significantly decrease the output of solar panels, especially during peak hours when energy production is critical. The water cooling system in this paper reduces the effect of overheating and increases the solar panel's performance. Figure 7. shows that the power of the cooled solar panel is slightly higher and more stable than the uncooled solar panel, indicating the cooling system improved the solar panel's performance.

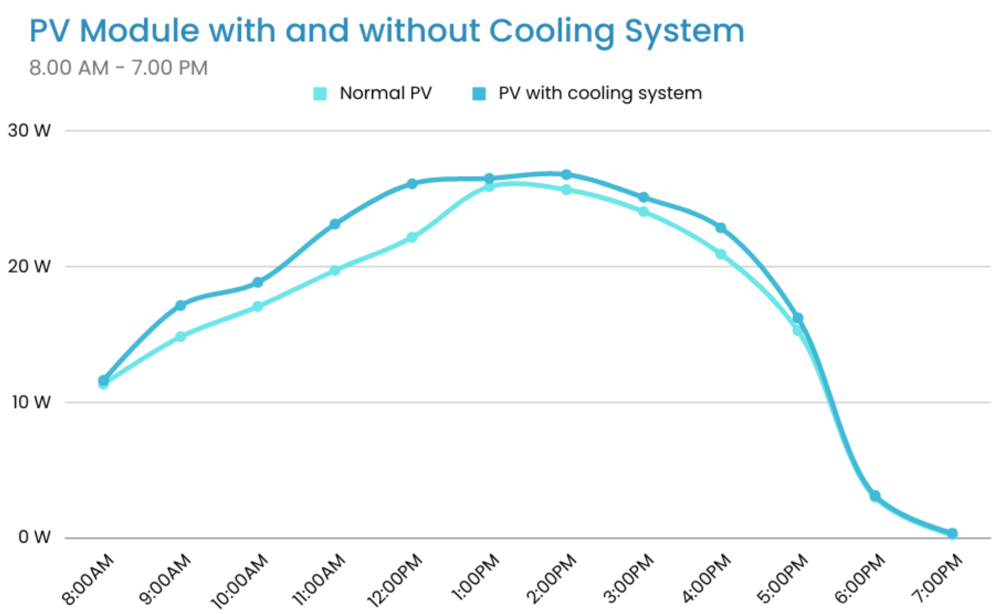


Fig. 7. Comparison of conventional with cooled system solar panels

Table 2 shows the data of two PV modules, one with a cooling system and one without a cooling system. The observation duration is for five days. After the observation, data showed that, on average, 20% more power is generated with a cooled PV solar module. With more power generated, the system is more efficient and cost-effective.

Table 2
Comparison of conventional and cooling system solar panel

	Convention solar panel (PV1)					Cooling sytem solar panel (PV2)				
Date of Experiment	27-Dec	28-Dec	29-Dec	30-Dec	31-Dec	27-Dec	28-Dec	29-Dec	30-Dec	31-Dec
Temperature(°C)	43.2	45.3	31.8	44.8	45.6	38.4	39.3	31.8	38.6	38.7
Voc_measured (V)	22.1	22.4	19.3	22.1	22.4	23.4	23.6	19.3	22.9	22.8
Isc_measured (A)	0.96	1.02	0.83	1.12	1.18	1.12	1.14	0.87	1.14	1.2
Poc_measured (W)	21.216	22.848	16.019	24.752	26.432	26.208	26.904	16.791	26.106	27.36

3.3 Effect of Dust Cleaning

The last part of this paper evaluates the impact of cleaning on the solar panel's performance. For simulation, the solar panel was covered with dust with an estimation of 20%, 30% and 50% dust covering. As shown in Figure 8. the output power decreased significantly when the panel was covered by more dust. Without the cleaning system, with dust up to 50% covering the solar module, the power produced reduces drastically, reducing the solar panel performance.

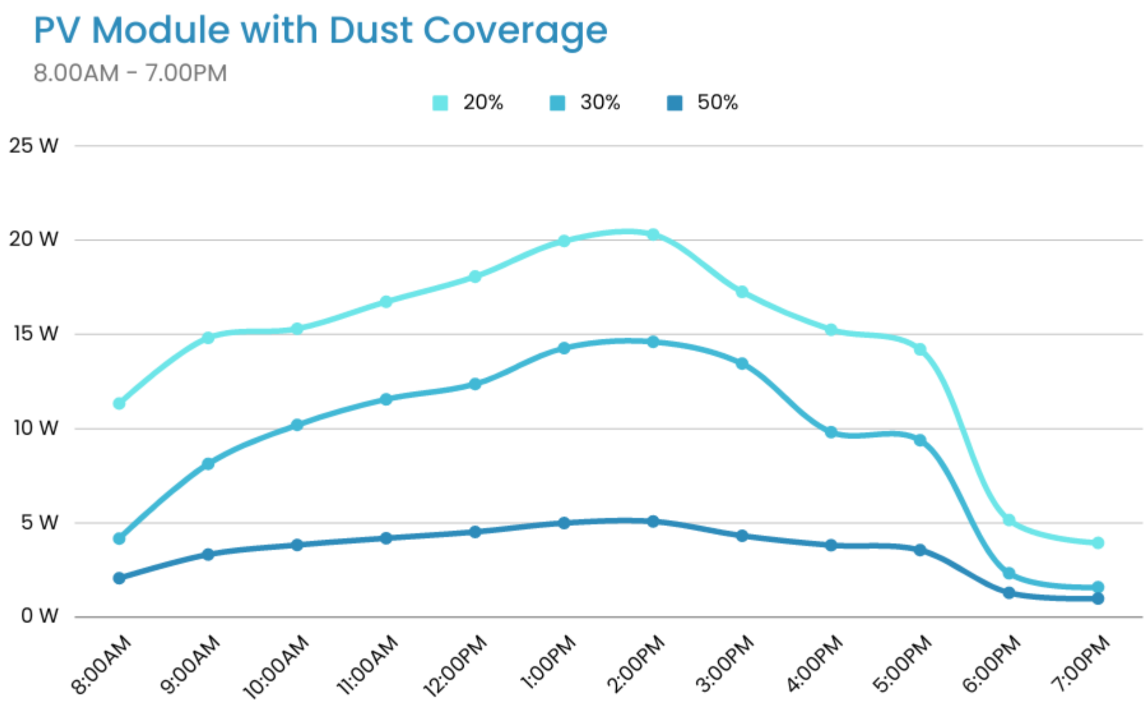


Fig. 8. Output power for different dust coverage

Shown in Table 3 is the reading for 20%, 30% and 50% dust coverage on the solar panel. 20% coverage has the highest output power compared to the rest. The results of this experiment demonstrate that even a small amount of dust and debris can significantly reduce the performance of a solar module, which is an essential consideration for the design and placement of solar modules in real-world applications [20-22]. Cleaning the PV module increased the power generated compared to PV without the cleaning system. Furthermore, the cleaning system is powered back by the solar power collected by the panel, making it self-sufficient and cost-effective.

Table 3
Dust simulation on PV module

Time	Voc_measured (V)			Isc_measured (A)			Poc_ Measured (W)		
	20%	30%	50%	20%	30%	50%	20%	30%	50%
8:00	12.5	8.4	6.25	0.66	0.495	0.33	11.32	4.16	2.06
9:00	15.8	12.9	7.9	0.84	0.63	0.42	14.81	8.127	3.32
10:00	16.1	14.3	8.05	0.95	0.7125	0.475	15.295	10.18875	3.82
11:00	16.4	15.1	8.2	1.02	0.765	0.51	16.728	11.5515	4.18
12:00	17.2	15.7	8.6	1.05	0.7875	0.525	18.06	12.36375	4.52
1:00	17.2	16.4	8.6	1.16	0.87	0.58	19.952	14.268	4.99
2:00	17.2	16.5	8.6	1.18	0.885	0.59	20.296	14.6025	5.07
3:00	15.4	16	7.7	1.12	0.84	0.56	17.248	13.44	4.31
4:00	14.8	12.7	7.4	1.03	0.7725	0.515	15.244	9.81075	3.81
5:00	14.2	12.5	7.1	1.00	0.75	0.5	14.2	9.375	3.55
6:00	10.3	6.2	5.15	0.5	0.375	0.25	5.15	2.325	1.29
7:00	8.2	4.4	4.1	0.48	0.36	0.24	3.936	1.584	0.98

4. Conclusions

In conclusion, the experiments conducted in this study demonstrated that the performance of solar panels is directly proportional to their energy conversion efficiency. The research findings suggest that an increase in surface temperature can significantly reduce the energy conversion efficiency of solar panels. The heat energy produced on the surface of solar panels due to exposure to intense sunlight reduces the amount of light energy that can be converted into electrical energy, leading to energy waste. Therefore, to improve the efficiency of solar panels, it is essential to keep them cool and prevent them from overheating. Water cooling allows excess heat dissipation, preventing the panel's surface from overheating and reducing wasted energy. With reduced energy wasted, the system is proven to be cost-effective. Therefore, the design of solar cooling systems is a practical approach to improving the energy conversion efficiency of solar panels. This paper showed that regular cleaning significantly improves the efficiency of solar panels. The accumulation of dirt, dust, and debris on the surface of solar panels can reduce the amount of light energy that can be converted into electrical energy, leading to energy waste. Therefore, keeping solar panels clean and debris-free ensures maximum energy conversion efficiency. For the recommendation for future work, implementing IoT as a monitoring system to identify areas for improvement is the best way to optimize the system.

Acknowledgement
The authors would like to acknowledge the contribution of the School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, ensuring this work's success. Thanks to Research Management Centre of University Teknologi Mara (UiTM) for providing financial support under Geran Khas Penyelidikan (GKP) grant (600-RMC/GPK 5/3 (168/2020).

References
[1] Lubis, Hamzah. "Renewable energy of rice husk for reducing fossil energy in Indonesia." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 11, no. 1 (2018): 17-22.
[2] Sharma, Prabhakar, Zafar Said, Anurag Kumar, Sandro Nizetic, Ashok Pandey, Anh Tuan Hoang, Zuohua Huang et al. "Recent advances in machine learning research for nanofluid-based heat transfer in renewable energy system." *Energy & Fuels* 36, no. 13 (2022): 6626-6658. https://doi.org/10.1021/acs.energyfuels.2c01006
[3] Karim, Abdul Razif Abdul, and Roslina Mohammad. "Meta-study of sensitivity analysis in solar renewable energy application." *Progress in Energy and Environment* (2023): 14-25. https://doi.org/10.37934/progee.23.1.1425

[4] Ilham, Zul, and Nur Aida Izzaty Saad. "Wan Abd Al Qadr Imad Wan, and Adi Ainurzaman Jamaludin." Multi-criteria decision analysis for evaluation of potential renewable energy resources in Malaysia."." *Progress in Energy and Environment* 21 (2022): 8-18. https://doi.org/10.37934/progee.21.1.818

[5] Munusamy, Arun, Debabrata Barik, Prabhakar Sharma, Bhaskar Jyoti Medhi, and Bhaskor Jyoti Bora. "Performance analysis of parabolic type solar water heater by using copper-dimpled tube with aluminum coating." *Environmental Science and Pollution Research* (2023): 1-16. https://doi.org/10.1007/s11356-022-25071-5

[6] Hasan, Khaled, Sumaiya Binty Yousuf, Mohammad Shahed Hasan Khan Tushar, Barun K. Das, Pronob Das, and Md Saiful Islam. "Effects of different environmental and operational factors on the PV performance: A comprehensive review." *Energy Science & Engineering* 10, no. 2 (2022): 656-675. https://doi.org/10.1002/ese3.1043

[7] Rebhi, Redha, Younes Menni, Giulio Lorenzini, and Hijaz Ahmad. "Forced-Convection Heat Transfer in Solar Collectors and Heat Exchangers: A Review." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 26, no. 3 (2022): 1-15. https://doi.org/10.37934/araset.26.3.115

[8] Hasan, A., J. Sarwar, H. Alnoman, and et S. Abdelbaqi. "Yearly energy performance of a photovoltaic-phase change material (PV-PCM) system in hot climate." *Solar Energy* 146 (2017): 417-429. https://doi.org/10.1016/j.solener.2017.01.070

[9] Nižetić, Sandro, Mišo Jurčević, Duje Čoko, Müslüm Arıcı, and Anh Tuan Hoang. "Implementation of phase change materials for thermal regulation of photovoltaic thermal systems: Comprehensive analysis of design approaches." *Energy* 228 (2021): 120546. https://doi.org/10.1016/j.energy.2021.120546

[10] Ali, Muzaffar, Zahida Yaqoob, Tanzeel-ur Rashid, Abid Hussain, and Zahid Suleman. "Model-based Performance Comparison of Different Configurations of Evaporative Cooling Systems in various Climates of Pakistan." *Progress in Energy and Environment* 4 (2018): 1-13.

[11] Agyekum, Ephraim Bonah, Seepana PraveenKumar, Naseer T. Alwan, Vladimir Ivanovich Velkin, and Sergey E. Shcheklein. "Effect of dual surface cooling of solar photovoltaic panel on the efficiency of the module: Experimental investigation." *Heliyon* 7, no. 9 (2021): e07920. https://doi.org/10.1016/j.heliyon.2021.e07920

[12] Haidar, Zeyad A., Jamel Orfi, and Zakariya Kaneesamkandi. "Experimental investigation of evaporative cooling for enhancing photovoltaic panels efficiency." *Results in Physics* 11 (2018): 690-697. https://doi.org/10.1016/j.rinp.2018.10.016

[13] Chandel, S. S., and Tanya Agarwal. "Review of cooling techniques using phase change materials for enhancing efficiency of photovoltaic power systems." *Renewable and Sustainable Energy Reviews* 73 (2017): 1342-1351. https://doi.org/10.1016/j.rser.2017.02.001

[14] Bayrak, Fatih, Hakan F. Oztop, and Fatih Selimefendigil. "Experimental study for the application of different cooling techniques in photovoltaic (PV) panels." *Energy Conversion and Management* 212 (2020): 112789. https://doi.org/10.1016/j.enconman.2020.112789

[15] Kazem, Hussein A., Miqdam T. Chaichan, Ali HA Al-Waeli, and K. Sopian. "A review of dust accumulation and cleaning methods for solar photovoltaic systems." *Journal of Cleaner Production* 276 (2020): 123187. https://doi.org/10.1016/j.jclepro.2020.123187

[16] Govardhanan, M. S., G. Kumaraguruparan, M. Kameswari, R. Saravanan, M. Vivar, and K. Srithar. "Photovoltaic module with uniform water flow on top surface." *International Journal of Photoenergy* 2020 (2020): 1-9. https://doi.org/10.1155/2020/8473253

[17] Derakhshandeh, Javad Farrokhi, Rand AlLuqman, Shahad Mohammad, Haya AlHussain, Ghanima AlHendi, Dalal AlEid, and Zainab Ahmad. "A comprehensive review of automatic cleaning systems of solar panels." *Sustainable Energy Technologies and Assessments* 47 (2021): 101518. https://doi.org/10.1016/j.seta.2021.101518

[18] Myyas, Ra'ed Nahar, Mohammad Al-Dabbasa, Marcos Tostado-Véliz, and Francisco Jurado. "A novel solar panel cleaning mechanism to improve performance and harvesting rainwater." *Solar Energy* 237 (2022): 19-28. https://doi.org/10.1016/j.solener.2022.03.068

[19] Salamah, Tareq, Ahmad Ramahi, Kadhim Alamara, Adel Juaidi, Ramez Abdallah, Mohammad Ali Abdelkareem, El-Cheikh Amer, and Abdul Ghani Olabi. "Effect of dust and methods of cleaning on the performance of solar PV module for different climate regions: Comprehensive review." *Science of The Total Environment* (2022): 154050. https://doi.org/10.1016/j.scitotenv.2022.154050

[20] Hassan, Siti Lailatul Mohd, Nur Asyakireen Shamsuddin, Ili Shairah Abdul Halim, and Azilah Saparon. "FPGA-based emergency traffic light controller system with IoT application." *ELEKTRIKA-Journal of Electrical Engineering* 20, no. 2-2 (2021): 103-107.

[21] Kosim, Nurul Athirah Mohd, Siti Lailatul Mohd Hassan, Ili Shairah Abdul Halim, and Noor Ezan Abdullah. "Air Quality Monitoring System using Arduino and Matlab Analysis." In *2022 IEEE 13th Control and System Graduate Research Colloquium (ICSGRC)*, pp. 225-230. IEEE, 2022. https://doi.org/10.1109/ICSGRC55096.2022.9845147

[22] Kar, Sanjaya Kumar, Atif Akhtar, Anant Singh Gambhir, J. Vignesh, and Ritesh Nair. "Design and development of waterless solar panel cleaning system." In *IOP Conference Series: Materials Science and Engineering*, vol. 912, no. 3, p. 032005. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/912/3/032005
[23] Munusamy, Arun, Debabrata Barik, Prabhakar Sharma, Bhaskar Jyoti Medhi, and Bhaskor Jyoti Bora. "Performance analysis of parabolic type solar water heater by using copper-dimpled tube with aluminum coating." *Environmental Science and Pollution Research* (2023): 1-16. https://doi.org/10.1007/s11356-022-25071-5
[24] Bakri, Mohd Azwan Mohd, J. Salmah, S. Abd Rahim, and K. Norman. "A study on Agro-Hybrid Farm Vehicle with Small Onboard Solar Photovoltaic for Herbicide Spraying in Oil Palm Plantation." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 17, no. 1 (2019): 61-77.