Development of an IoT-Monitoring and Control System for Solar Panel Surface Temperature Regulation Utilizing Water-Cooling Techniques

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Abstract—**As the world's energy needs escalate and the availability of finite natural resources diminishes, there is an urgent need to explore sustainable alternatives. Renewable energy sources, including solar power, hold great promise due to their abundance, cost-effectiveness, and environmental friendliness. Solar panels, a cornerstone of renewable energy, have the potential to provide clean electricity, but their efficiency depends on temperature control. This research addresses this challenge by implementing an Internet of Things (IoT) monitoring and control system using the Blynk platform to regulate solar panel surface temperatures. The system's smart design uses water pumps to mitigate excessive temperatures, improving performance and energy efficiency. Extensive testing demonstrated the system's effectiveness, particularly in mitigating temperature spikes, improving system efficiency and sustainability. Our results demonstrate the remarkable potential of water-cooled systems and IoT technology to revolutionize solar energy harvesting, marking a significant step toward a sustainable energy future.**

***Keywords*—Temperature, Solar Panel Surface, IoT, Water Pump**

I. INTRODUCTION

The energy needs of the human population are undeniably vital in the realm of contemporary energy demands [1]. The escalation of this energy demand is directly correlated to the dwindling availability of finite natural resources [2]. Consequently, there is an urgent need to explore and utilize alternative and sustainable sources of energy [3]-[4]. One such resource is renewable energy, which includes elements such as water [5]-[6], air [7]-[8], solar radiation (solar panel) [9]-[11], and biomass [12]-[13]. Renewable energy sources offer several inherent advantages, including their inexhaustible nature, abundant supply, cost-effectiveness, and environmental friendliness [14].

Solar energy, a prominent member of the renewable energy family, has significant potential to meet long-term energy consumption needs [15]. It can be harnessed as a clean and environmentally friendly source of electrical power [16], [17]. Solar panels, which consist of an array of solar cells carefully designed to maximize sunlight absorption, use photovoltaic technology to convert solar radiation into electrical energy [18]. However, it is important to recognize that the temperature of solar panels plays a critical role in determining their efficiency [19]. For every 1°C increase in panel temperature above the standard 25°C, there is a corresponding decrease of approximately 0.4% in total power generation [20]-[21]. This issue underscores the importance of managing and optimizing solar panel temperature for sustained performance.

Efforts to improve the efficiency of solar panels have included various cooling methods, such as the implementation of heat sink fans [22]-[23], air cooler system using thermoelectric cooler [24]-[25], water-based cooling systems with pipes under the panels [26], and the integration of Internet of Things (IoT) technology for remote monitoring [27]-[28]. In this context, this research seeks to design and implement a monitoring and control system for monitoring the surface temperature of solar panels using water systems via the Internet of Things using the Blynk platform. Blynk, a versatile application designed to interact with microcontrollers through Wi-Fi, or IoT connectivity, provides a means to remotely monitor solar panel temperatures. The primary goal of this research is to reduce unnecessary power consumption by solar panels when their temperature exceeds a pre-defined limit. In such cases, a water pumping system is activated to cool the solar panel surface until the temperature returns to an optimal range. This innovation is an important step toward increasing the efficiency and sustainability of solar energy use.

II. METHOD

This research begins with the design of a system in the form of software design, hardware design, and system circuit design. Then system testing is carried out by testing the ability of the sensor to read the output value obtained and the pump can flow water when the temperature exceeds the specified limit. The software design then the flow chart of the desired tool work system can be seen from Fig. 1 below.

Fig. 1 shows the system flowchart for monitoring and controlling solar panel surface temperatures using Internet of Things (IoT) technology and a Blynk application. This flowchart outlines the intricacies of how the system works to monitor and control several critical parameters in real time. These parameters include Temperature 1, Temperature 2, Temperature 3, Temperature 4, Average Temperature, Panel Voltage, Battery Charge Current, Battery Voltage, Current Consumption, and Power Consumption.

Temperature management within the system is achieved through an automated control mechanism. When the Blynk application detects an average temperature value above 35°C, it activates a relay system, which in turn triggers the water pump to initiate water flow onto the solar panel surface. This mechanism is implemented to mitigate the temperature rise. Conversely, when the Blynk application registers an average

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temperature value below 35°C, the relay system deactivates the water pump, stopping the flow of water onto the solar panel surface [29]. Hardware design starts with making a system design scheme, the system design block diagram can be seen in Fig. 2.

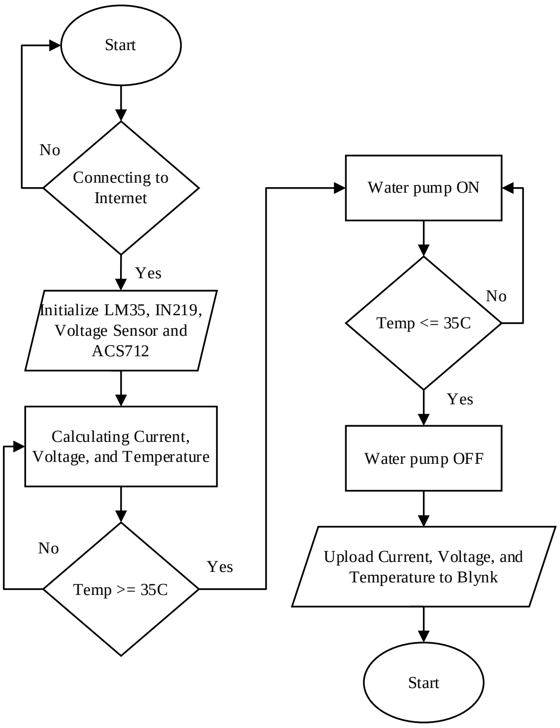


Fig. 1. System flowchart

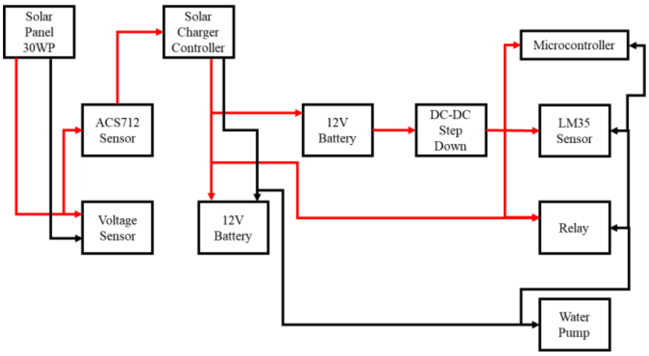


Fig. 2. Block diagram system

Fig. 2 shows the block diagram of the design of the monitoring and control system to regulate the surface temperature of the solar panels. The system includes a 12V DC battery to power relays and water pumps to ensure efficient temperature control. In addition, a NodeMCU microcontroller is used to interface with four sensors, all of which require a 5V power supply. To facilitate this voltage transition, a step-down module is integrated to convert the 12V DC battery power to 5V DC [30]. The sensors collect data, which is then transmitted to the NodeMCU microcontroller. Finally, the NodeMCU communicates this data to the Blynk software, which serves as a real-time monitoring application.

The block diagram illustrates the key components and their interconnections in the system, showing the flow of data from the temperature sensors to real-time monitoring by the Blynk application. The systematic integration of these components allows for efficient temperature control to ensure optimal solar panel performance.

The design of the Internet of Things (IOT)-based solar panel surface temperature monitoring and control system can monitor temperature, panel voltage, battery charging current, battery voltage, current used by the system, and power used by the system. The pump can turn on and flow when the average temperature exceeds 35 °C, and the pump can stop flowing water when the average temperature is less than 35 °C. The series of components of the Internet of Things-based solar panel surface temperature monitoring and control system can be seen in Fig. 3.

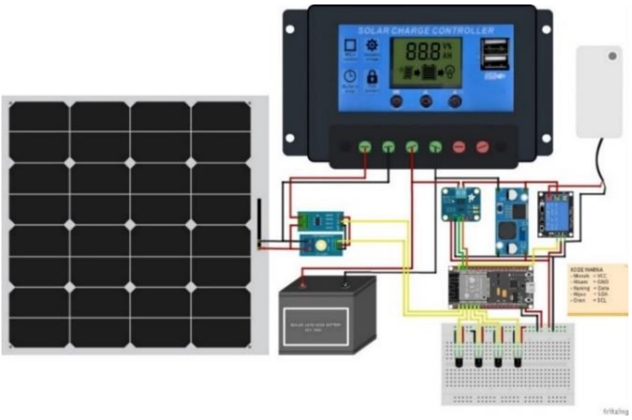


Fig. 3. Wiring diagram system

III. RESULTS AND DISCUSSION

In this research, we actively explore the management and regulation of solar panel temperature by leveraging the capabilities of water pumps and IoT technology. Shifting our focus from light intensity management, we turn our attention to actively controlling the temperature on the surfaces of solar panels.

Our research systematically examines the application of control methods to actively ensure a consistent and optimal temperature on solar panel surfaces. An essential element of this research is in-depth research of the parameters involved in temperature control and their direct impact on overall system performance.

The primary objective of this research is to actively develop a deep understanding of the effectiveness and practicality of using water pumps and IoT technology for active temperature control of solar panels. The empirical findings derived from this research will actively promote the wider adoption of these techniques in solar panel temperature control. This research, in turn, is actively leading to significant improvements in energy efficiency, system adaptability, and overall reliability, thereby promoting the sustainable and efficient use of solar energy resources.

Fig. 4 and Fig. 5 show the results of the system components and the solar panel frame assembled into one. In the system circuit there are ESP32 components, INA219 sensors, voltage sensors, ACS712 current sensors, step down, relays, and in the solar panel frame there are water pumps, 12V batteries, SCC and LM35 sensors behind the solar panel.

In Fig. 6, we show the results of the Blynk online display, actively connected to a Wi-Fi network, displaying real-time data including parameters such as Temperature 1, Temperature 2, Temperature 3, Temperature 4, average temperature, panel voltage, battery charging current, battery voltage, current system usage, and system power consumption.

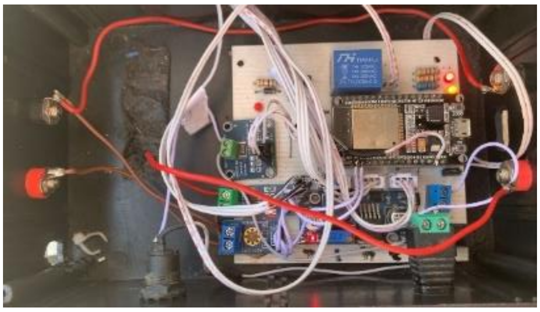
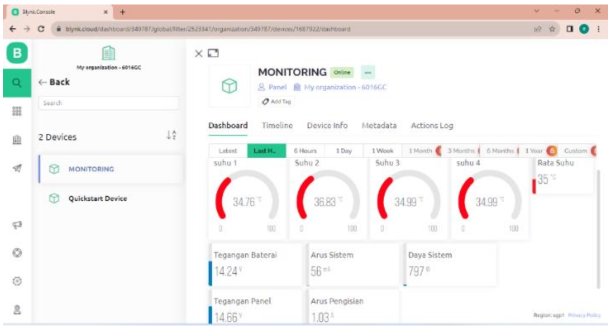


Fig. 4. System component circuit

Fig. 5. Solar panel framework from rear view

The seamless integration and functionality of the Blynk platform is a key achievement, providing instant access to key operational insights for the solar panel temperature control system. These real-time measurements play a critical role in evaluating the efficiency of the system and the effectiveness of its control mechanisms. The graphical representation in Fig. 6 underscores the Blynk system's ability to collect, display, and actively communicate critical data, contributing to a deeper understanding of system performance and informing potential improvements, thus promoting the sustainable and efficient use of solar energy resources.



suhu 1 34.76 °C

Suhu 2 36.83 °C

Suhu 3 34.99 °C

suhu 4 34.99 °C

Rata Suhu 35 °C

Tegangan Baterai 14.24 V

Arus Sistem 56 mA

Daya Sistem 797

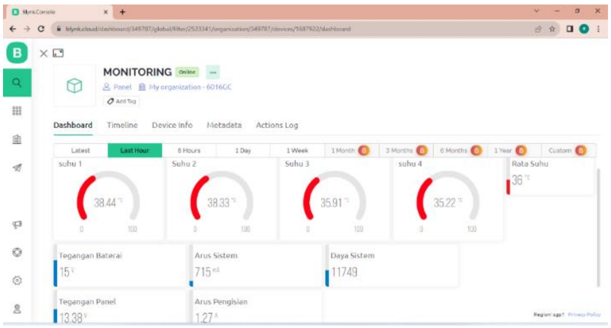
Tegangan Panel 14.66 V

Arus Pengisian 1.03 A

Fig. 6. Blynk online view

In Fig. 6, the online data shows an average temperature of 35°C, a battery voltage of 14.24 V, a system current of 56 mA, a solar voltage of 14.66V and a charge current of 1.03A.

Fig. 7 and Fig. 8 show the Blynk display actively indicating that the average temperature has exceeded 35°C. In immediate response to this condition, the water pump is activated, actively initiating the flow of water onto the surface of the solar panel. This active temperature control mechanism ensures that the solar panel operates within an optimal temperature range, improving overall energy efficiency and sustainability.



suhu 1 38.44 °C

Suhu 2 38.33 °C

Suhu 3 35.91 °C

suhu 4 35.22 °C

Rata Suhu 36 °C

Tegangan Baterai 15 V

Arus Sistem 715 mA

Daya Sistem 11749

Tegangan Panel 13.38 V

Arus Pengisian 1.27 A

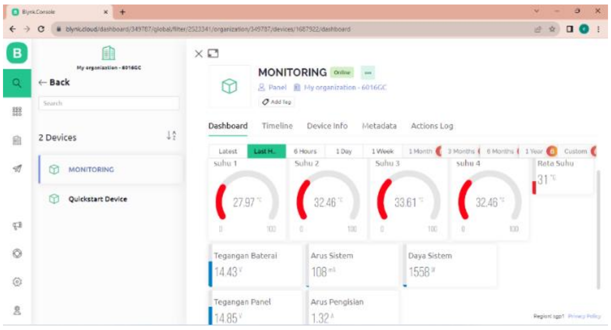
Fig. 7. Blynk display while the pump is on

Fig. 8. System view with water pump on

In Fig. 7, the temperature data collected from all four sensors consistently register values above the critical 35°C threshold, culminating in an average temperature of 36°C. This collective temperature spike triggers the orchestrated activation of the water pump subsystem, causing a noticeable spike in the system's electrical current, which quickly escalates to 715 mA. This increase in electrical current inevitably triggers a concomitant increase in overall system power consumption, which eventually peaks at 11.749 mW. This intricate cascade of events underscores the effective temperature control mechanism, which promptly initiates cooling measures in response to elevated panel temperatures. This active temperature control strategy is a critical means of ensuring that the solar panel consistently operates within an optimal temperature envelope, thereby increasing the system's energy efficiency and sustainability.

Fig. 9 and Fig. 10 clearly show the Blynk display indicating that the average temperature reading has dropped below 35°C. In immediate response to this condition, the water pump shuts off, effectively stopping the flow of water onto the solar panel surface. This active temperature control mechanism ensures that the solar panel continues to operate within an optimal temperature range, further improving overall energy efficiency and sustainability.

Fig. 9 demonstrates that all four temperature sensors register temperatures below 35°C, with an average temperature of 31°C. Therefore, the water pump remains. inactive due to the average temperature below the 35°C threshold.



suhu 1 27.97 °C
Suhu 2 32.46 °C
Suhu 3 33.61 °C
suhu 4 32.46 °C
Rata Suhu 31 °C
Tegangan Baterai 14.43 V
Arus Sistem 108 mA
Daya Sistem 1558 W
Tegangan Panel 14.85 V
Arus Pengisian 1.32 A

Fig. 9. Blynk display while the pump is off

Fig. 10. System view with water pump off

Table 1 presents data collected during a 5 Hour data collection period beginning at 09:00 am and ending at 14:00 pm. This time frame allowed for a comprehensive examination of various parameters associated with the solar panel system.

In particular, the system reached a maximum temperature of 37°C and the average temperature is 34.83°C. The charging current reached a maximum of 1.73 A at 14:07, while maintaining an average charging current of approximately 1.32 A. These variations in charging current levels can be attributed to the dynamic interplay of solar radiation and changing environmental conditions throughout the data collection period. A key aspect of this investigation focuses on the power parameters, where the system demonstrated its peak power generation capability by reaching an impressive 25.555W (25.555 mW) at 14:07. At the same time, the average power output over the duration of the research consistently hovered around 19.72252W (19.722.52 mW). These fluctuations in power output underscore the water pump activity and solar panel performance, which are inherently affected by varying external factors such as solar irradiance and temperature and water pump activity.

Of particular importance is the effect of the water-cooling system on current draw. When the water pump is activated, the system's power requirements increase significantly, reaching levels of approximately 750-850 mW. This significant increase in system power is due to the active operation of the water pump, which is primarily used to cool the solar panel surface. The water-cooling system plays a critical role in actively regulating the temperature of the panel, thereby improving overall system performance. Table 2 shows the data collected without water cooling system. As a result, the system currently experiences a significant increase, reaching 715 mA. This elevated current system subsequently leads to an increase in system power, reaching 11.749 mW.

During sensor testing, we found that the sensors used were effective at reading and displaying output values. The LM35 sensor accurately measures and displays temperature values and activates the relay to begin water flow on the solar panel surface when the temperature exceeds 35°C. Conversely, if the temperature drops below 35°C, the relay de-energizes, stopping the water flow. The INA219 sensor deftly reads battery voltage, current draw, and power consumption, and immediately relays this data to the Blynk application. The voltage sensor accurately reads and displays panel voltage values within the Blynk application, while the ACS712 current sensor efficiently captures and transmits values to the same application.

Table 1. Data results with using water cooling

Time (WIB)	Average Temp (C)	Panel Voltage (V)	Current Charging (A)	Power Charging (mW)	Battery Voltage (V)	System Current (mA)	System Power (mW)	Water Pump
09:01	36	12.97	1.27	16471	12.88	824	10616	ON
09:07	32	14.83	1.14	16906	14.36	62	890	OFF
09:31	36	14.96	1.30	19448	14.43	109	1573	ON
09:35	33	14.91	1.08	16102	14.40	63	907	OFF
10:04	36	13.96	1.48	20660	13.74	132	1933	ON
10:18	33	15.25	1.28	19250	14.65	64	879	OFF
10:30	35	13.71	1.44	19742	13.51	772	10429	ON
10:31	34	14.10	1.52	21432	13.85	64	886	OFF
11:34	36	13.15	0.44	5786	12.92	731	9447	ON
11:41	34	15.41	1.38	21265	14.76	61	900	OFF
12:01	37	14.63	1.55	22676	14.18	748	10606	ON
12:25	34	15.24	1.03	15697	14.43	110	1423	OFF
12:26	37	14.54	1.57	22827	14.19	805	11423	ON
12:41	34	15.92	1.39	22128	15.00	60	902	OFF
13:06	36	14.89	1.53	22781	14.37	772	11094	ON
13:07	34	15.96	1.24	19790	15.00	106	1597	OFF
13:33	36	15.16	1.41	21375	14.52	857	12441	ON
13:36	34	15.72	1.25	19650	14.91	110	1640	OFF
14:03	34	15.92	1.33	21173	15.00	107	1607	OFF
14:04	35	15.84	1.37	21700	14.98	106	1588	OFF
14:04	36	14.72	1.34	19724	14.34	815	11682	ON
14:07	35	14.77	1.73	25555	14.27	733	10456	ON
14:08	34	16.15	1.33	21480	15.00	107	1621	OFF

Table 2. Data results without using water cooling

Time (WIB)	Average Temp (C)	Panel Voltage (V)	Current Charging (A)	Power Charging (mW)	Battery Voltage (V)	System Current (mA)	System Power (mW)
09:30	39 ℃	12. 77 V	0.72 A	9194 mW	12.62 V	68 mA	858 mW
10:00	43 ℃	13.55 V	0.57 A	7723 mW	13.37 V	66 mA	1551 mW
10:30	46 ℃	13.34 V	0.44 A	5869 mW	13.18 V	118 mA	1554 mW
11:00	55 ℃	13.78 V	0.5 A	6890 mW	13.51 V	65 mA	878 mW
11:30	57 ℃	13.64 V	0.45 A	6138 mW	13.46 V	117 mA	1561 mW
12:00	59 ℃	13.55 V	0.39 A	5284 mW	13.3 V	66 mA	877 mW
12:30	62 ℃	13.45 V	0.34 A	4573 mW	13.28 V	119 mA	1580 mW
13:00	57 ℃	13.76 V	0.35 A	4816 mW	13.52 V	118 mA	1594 mW
13:30	48 ℃	14.27 V	0.62 A	8847 mW	13.79 V	128 mA	1787 mW
14:00	45 ℃	14.53 V	0.67 A	9735 mW	14.12 V	112 mA	1581 mW
14:30	40 ℃	14.79 V	0.56 A	8282 mW	14.3 V	112 mA	1601 mW
15:00	38 ℃	14.94 V	0.72 A	10756 mW	14.43 V	111 mA	1601 mW

It is important to note that this research relies on the availability of ample sunlight, as the sensors rely on solar panel absorption to measure data. Consequently, during the rainy season, data collection becomes a challenging task, making the research unprofitable at such times. Table 1 presents research data on the performance of solar panels with water coolers and Table 2 without water cooler shedding light on the influence of temperature control mechanisms on system efficiency.

Table 2 presents data collected during 5 hour and 30 minutes data collection period beginning at 09.30 am and ending at 15.00 pm. The results allowed for a comprehensive examination of various parameter associated with the solar panel system and comparing current charging, power charging, system current, and system power on the system that using water colling.

During observation, the system exhibited dynamic temperature fluctuations with a peak temperature of 62°C and an average temperature of 49.08°C. These fluctuations indicate the system's responsiveness to environmental factors, particularly solar radiation and ambient conditions. Accurate temperature control is critical to optimizing the efficiency and lifetime of solar panel systems.

Charging current fluctuated, with peaks of 0.72A at 09:30 and 15:00, while maintaining an average charging current of approximately 0.53A. These variations in charging current levels were influenced by the dynamic interplay of solar radiation and evolving environmental conditions during the data collection period. In addition, the investigation focused on power parameters, revealing the system's capacity for peak power generation, reaching 10.756W (10.756 mW) at 15:00, with an average power output consistently around 7.34225W (7.342.25 mW). These power fluctuations underscore the system's adaptability to external factors such as changes in solar irradiance and environmental conditions. The effect of water cooling on system performance was also evident. Without water cooling, the system exhibited lower current consumption in the range of 65-128 mA. This reduction in power consumption was due to the inactivation of the water pump, which significantly reduced power consumption. The water-cooling system is critical to temperature management, contributing to optimized power efficiency and sustainability.

Analysis of Table 1 and Table 2 reveals a significant advantage in favor of the water-cooled system, where it consistently maintains lower temperatures. The maximum temperatures in the water-cooled system were 40.323% cooler, while the average temperatures were 29.05% cooler compared to the non-water-cooled counterpart. This significant reduction in operating temperatures has significant implications for solar panel performance, especially in the face of extreme weather conditions. Lower temperatures not only contribute to increased efficiency, but also serve as a safeguard against overloading the solar panel system.

In addition, when examining the charging current parameters, the water-cooled system showed remarkable improvements. The maximum charge current showed an impressive increase of 240.278%, while the average charge current showed a significant increase of 268.169% compared to the without water cooled system. These results underscore the remarkable improvements in system efficiency made possible by the implementation of water cooling.

Conversely, when considering the maximum system current, the water-cooled system showed a striking increase of 669.53%, with the average system current experiencing a significant increase of 361.65% compared to the without using water cooler system. However, it is important to emphasize that this increase in current demand is a transient event that coincides exclusively with the active phase of the water pump. During the periods of inactivity of the water pump, the current and power consumption levels are the same as those of a system without water cooling.

IV. CONCLUSION

In this extensive research, we have delved into the active management and control of solar panel temperature using water pumps and IoT technology, shifting our focus from light intensity control to dynamic temperature control of solar panels. Our research has systematically explored the implementation of control methods to maintain consistent and optimal surface temperatures on solar panels, deepening our understanding of the parameters governing temperature control and their direct impact on overall system performance. The primary objective of this research was to gain in-depth insight into the effectiveness and feasibility of using water pumps and IoT technology for active solar panel temperature control, with the expectation of wider adoption of these methods in the context of solar panel temperature management. The integration of the Blynk platform has played a crucial role in real-time monitoring and data display, facilitating the evaluation of the system efficiency and the effectiveness of the control mechanisms. The empirical results highlight the system's ability to actively regulate temperature, optimizing energy efficiency and sustainability.

The research also highlights the importance of sufficient sunlight for data collection, with rainy seasons challenging this process.

In addition, the research underscores the significant advantages of the water-cooled system in maintaining lower temperatures and improving system efficiency and sustainability, especially during extreme weather conditions. Fluctuations in charging currents, power outputs and system currents demonstrate the adaptability of the system to external factors. In addition, the role of water cooling in temperature management is evident, significantly reducing power consumption when the water pump is inactive, thereby improving energy efficiency and sustainability. This research contributes to solar panel temperature management, promoting more resilient and efficient use of solar energy in diverse environmental conditions, furthering our progress toward a sustainable energy future.

REFERENCES

[1] M. Sookhak, H. Tang, Y. He and F. R. Yu, “Security and Privacy of Smart Cities: A Survey, Research Issues and Challenges,” *IEEE Communications Surveys & Tutorials*, vol. 21, no. 2, pp. 1718-1743, 2019, https://doi.org/10.1109/COMST.2018.2867288.

[2] R. Ostadian, J. Ramoul, A. Biswas and A. Emadi, “Intelligent Energy Management Systems for Electrified Vehicles: Current Status, Challenges, and Emerging Trends,” *IEEE Open Journal of Vehicular Technology*, vol. 1, pp. 279-295, 2020, https://doi.org/10.1109/OJVT.2020.3018146.

[3] M. H. Rehmani, M. Reisslein, A. Rachedi, M. Erol-Kantarci and M. Radenkovic, “Integrating Renewable Energy Resources Into the Smart Grid: Recent Developments in Information and Communication Technologies,” *IEEE Transactions on Industrial Informatics*, vol. 14, no. 7, pp. 2814-2825, 2018, https://doi.org/10.1109/TII.2018.2819169.

[4] Y. Saleem, N. Crespi, M. H. Rehmani and R. Copeland, “Internet of Things-Aided Smart Grid: Technologies, Architectures, Applications, Prototypes, and Future Research Directions,” *IEEE Access*, vol. 7, pp. 62962-63003, 2019, https://doi.org/10.1109/ACCESS.2019.2913984.

[5] H. A. Illias, N. S. Ishak, H. Mokhlis and M. Z. Hossain, “IoT-based Hybrid Renewable Energy Harvesting System from Water Flow,” *2020 IEEE International Conference on Power and Energy (PECon)*, pp. 204-208, 2020, https://doi.org/10.1109/PECon48942.2020.9314412.

[6] Y. Xu, C. Li, Z. Wang, N. Zhang and B. Peng, “Load Frequency Control of a Novel Renewable Energy Integrated Micro-Grid Containing Pumped Hydropower Energy Storage,” *IEEE Access*, vol. 6, pp. 29067-29077, 2018, https://doi.org/10.1109/ACCESS.2018.2826015.

[7] S. P. Bihari et al., “A Comprehensive Review of Microgrid Control Mechanism and Impact Assessment for Hybrid Renewable Energy Integration,” *IEEE Access*, vol. 9, pp. 88942-88958, 2021, https://doi.org/10.1109/ACCESS.2021.3090266.

[8] A. U. Rehman et al., “An Optimal Power Usage Scheduling in Smart Grid Integrated With Renewable Energy Sources for Energy Management,” *IEEE Access*, vol. 9, pp. 84619-84638, 2021, https://doi.org/10.1109/ACCESS.2021.3087321.

[9] E. Du et al., “The Role of Concentrating Solar Power Toward High Renewable Energy Penetrated Power Systems,” *IEEE Transactions on Power Systems*, vol. 33, no. 6, pp. 6630-6641, 2018, https://doi.org/10.1109/TPWRS.2018.2834461.

[10] F. M. Guangul and G. T. Chala, “Solar Energy as Renewable Energy Source: SWOT Analysis,” *2019 4th MEC International Conference on Big Data and Smart City (ICBDSC)*, pp. 1-5, 2019, https://doi.org/10.1109/ICBDSC.2019.8645580.

[11] E. Du et al., “The Role of Concentrating Solar Power Toward High Renewable Energy Penetrated Power Systems,” *IEEE Transactions on Power Systems*, vol. 33, no. 6, pp. 6630-6641, 2018, https://doi.org/10.1109/TPWRS.2018.2834461.

[12] V. Brych, O. Borysiak, N. Yushchenko, M. Bondarchuk, I. Alieksieiev and N. Halysh, “Factor Modeling of the Interaction of Agricultural Enterprises and Enterprises Producing Green Energy to Optimize the Biomass Supply Chain,” *2021 11th International Conference on Advanced Computer Information Technologies (ACIT)*, pp. 424-427, 2021, https://doi.org/10.1109/ACIT52158.2021.9548463.

[13] S. Paul, T. Dey, P. Saha, S. Dey and R. Sen, “Review on the development scenario of renewable energy in different country,” *2021 Innovations in Energy Management and Renewable Resources (52042)*, pp. 1-2, 2021, https://doi.org/10.1109/IEMRE52042.2021.9386748.

[14] A. F. Güven, N. Yörükeren, E. Tag-Eldin and M. M. Samy, “Multi-Objective Optimization of an Islanded Green Energy System Utilizing Sophisticated Hybrid Metaheuristic Approach,” *IEEE Access*, vol. 11, pp. 103044-103068, 2023, https://doi.org/10.1109/ACCESS.2023.3296589.

[15] B. Chen *et al.*, “Distributionally Robust Coordinated Expansion Planning for Generation, Transmission, and Demand Side Resources Considering the Benefits of Concentrating Solar Power Plants,*” IEEE Transactions on Power Systems*, vol. 38, no. 2, pp. 1205-1218, 2023, https://doi.org/10.1109/TPWRS.2022.3171515.

[16] X. P. Nguyen and A. T. Hoang, “The Flywheel Energy Storage System: An Effective Solution to Accumulate Renewable Energy,” *2020 6th International Conference on Advanced Computing and Communication Systems (ICACCS)*, pp. 1322-1328, 2020, https://doi.org/10.1109/ICACCS48705.2020.9074469.

[17] R. M. Elavarasan *et al.*, “A Comprehensive Review on Renewable Energy Development, Challenges, and Policies of Leading Indian States With an International Perspective,” *IEEE Access*, vol. 8, pp. 74432-74457, 2020, https://doi.org/10.1109/ACCESS.2020.2988011.

[18] F. Hyder, K. Sudhakar, and R. Mamat, “Solar PV tree design: A review,” *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 1079–1096, 2018, https://doi.org/10.1016/j.rser.2017.09.025.

[19] C. Sen *et al.*, “Assessing the Impact of Thermal Profiles on the Elimination of Light- and Elevated-Temperature-Induced Degradation,” *IEEE Journal of Photovoltaics*, vol. 9, no. 1, pp. 40-48, 2019, https://doi.org/10.1109/JPHOTOV.2018.2874769.

[20] J. Oh *et al.*, “Reduction of PV Module Temperature Using Thermally Conductive Backsheets,” *IEEE Journal of Photovoltaics*, vol. 8, no. 5, pp. 1160-1167, 2018, https://doi.org/10.1109/JPHOTOV.2018.2841511.

[21] H. Sainthiya, N. S. Beniwal, and N. Garg, “Efficiency Improvement of a Photovoltaic Module Using Front Surface Cooling Method in Summer and Winter Conditions,” *J. Sol. Energy Eng.*, vol. 140, no. 6, p. 061009, 2018, https://doi.org/10.1115/1.4040238.

[22] Z. K. Hussein, J. Ayad, H. J. Abdulkareem and H. J. Hadi, “Enhancing the Power and Efficiency of Photovoltaic Panel Using Heat Sinks with fans,” *2021 3rd International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*, pp. 096-101, 2021, https://doi.org/10.1109/ICHVEPS53178.2021.9601060.

[23] L. Xie, X. Yuan and W. Wang, “Thermal Modeling of Fan-Cooled Plate–Fin Heatsink Considering Air Temperature Rise for Virtual Prototyping of Power Electronics,” *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 10, no. 11, pp. 1829-1839, 2020, https://doi.org/10.1109/TCPMT.2020.3009156.

[24] 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,” *2021 Innovations in Power and Advanced Computing Technologies (i-PACT)*, pp. 1-6, 2021, https://doi.org/10.1109/i-PACT52855.2021.9697007.

[25] L. Xie, X. Yuan and W. Wang, “Thermal Modeling of Fan-Cooled Plate–Fin Heatsink Considering Air Temperature Rise for Virtual Prototyping of Power Electronics,” *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 10, no. 11, pp. 1829-1839, 2020, https://doi.org/10.1109/TCPMT.2020.3009156.

[26] A. Saxena, S. Deshmukh, S. Nirali, and S. Wani, “Laboratory based Experimental Investigation of Photovoltaic (PV) Thermo-control with Water and its Proposed Real-time Implementation,” *Renew. Energy*, vol. 115, pp. 128–138, 2018, https://doi.org/10.1016/j.renene.2017.08.029.

[27] N. M. Kumar, K. Atluri and S. Palaparthi, “Internet of Things (IoT) in Photovoltaic Systems,” *2018 National Power Engineering Conference (NPEC)*, pp. 1-4, 2018, https://doi.org/10.1109/NPEC.2018.8476807.

[28] G. Bedi, G. K. Venayagamoorthy, R. Singh, R. R. Brooks and K. -C. Wang, “Review of Internet of Things (IoT) in Electric Power and

Energy Systems," *IEEE Internet of Things Journal*, vol. 5, no. 2, pp. 847-870, 2018, https://doi.org/10.1109/JIOT.2018.2802704.

[29] H. Durani, M. Sheth, M. Vaghasia and S. Kotech, "Smart Automated Home Application using IoT with Blynk App," *2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT)*, pp. 393-397, 2018, https://doi.org/10.1109/ICICCT.2018.8473224.

[30] Z. Hosseinzadeh, N. Molavi and H. Farzanehfard, "Soft-Switching High Step-Up/Down Bidirectional DC–DC Converter," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 6, pp. 4379-4386, 2019, https://doi.org/10.1109/TIE.2018.2863216.