Iranian Journal of Electrical and Electronic Engineering

Journal Homepage: ijeee.iust.ac.ir

Impact of Temperature and Irradiance on PV Array Performance and Withstand Voltage

Jia-Wen Tang*, Chin-Leong Wooi*(C.A.), Wen-Shan Tan**, Nur Hazirah Zaini***, Yuan-Kang Wu****, Syahrun Nizam bin Md Arshad@Hashim*

Abstract: Photovoltaic (PV) energy is increasingly recognized as an environmentally friendly source of renewable energy. Integrating PV systems into power grids involves power electronic inverters, adding complexity and evolving traditional grids into smarter systems. Ensuring the reliability of decentralized PV generation is crucial, particularly as PV systems are often exposed to extreme weather conditions. This study investigates the impact of temperature and solar radiation on the performance of a PV array, focusing on key characteristics such as open-circuit voltage (V_{OC}), short-circuit current (I_{SC}), and maximum power (P_{MAX}). Using PSCAD/EMTDC simulations, the study analyses these characteristics under varying temperatures (5°C to 45°C) and radiation levels (200 W/m² to 1200 W/m²). Results indicate that V_{OC} increases with higher irradiance but decreases with higher temperatures. I_{SC} increases with both higher radiation and temperature, while P_{MAX} is optimized at high irradiance and low temperatures. The impulse withstand voltage (V_{imp}), a critical factor for PV system reliability, is assessed according to the PD CLC/TS 50539-12 standard. Findings reveal that at low temperatures and high radiation, the V_{imp} requirement is highest, emphasizing the need for robust voltage protection in PV systems. These insights underscore the importance of considering local climate conditions and implementing effective thermal management to enhance the performance and reliability of PV systems.

Keywords: Solar PV Array, Temperature, Radiation, Impulse Withstand Voltage.

1 Introduction

PHOTOVOLTAIC (PV) energy is widely regarded as one of the most environmentally friendly sources of renewable energy available, gaining widespread popularity due to government incentives globally and growing steadily [1]. PV systems interface with power electronic inverters for integration into power grids, making traditional power systems increasingly complex and evolving into smarter grids. As decentralized generation via PV plants becomes more common, ensuring system reliability is crucial, especially since PV systems are often installed in large outdoor areas like rooftops or solar farms, exposing them to extreme weather conditions [2].

Extreme weather is anticipated to have significant global impacts, such as rising temperatures year by year [3]. The Intergovernmental Panel on Climate Change indicates that from 2013 to 2022, global surface and land temperatures were 1.15°C and 1.65°C higher than in 1850-1900 in Sixth Assessment Report [4]. Malaysia, situated in the equatorial region, experiences consistently hot and sunny weather, receiving 400 – 600 MJ/m^2 of solar irradiation monthly, with an estimated maximum energy output of 6,500 MW, making it a

Iranian Journal of Electrical & Electronic Engineering, 2025.
Paper first received 24 Dec. 2024 and accepted 26 Feb. 2025.
* The author is with the Centre of Excellence for Renewable Energy, Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
E-mail: clwooi@unimap.edu.my.
** The authors are with the School of Engineering and Advance Engineering Platform, Monash University Malaysia, Jalan Lagoon Selatan, 47500 Bandar Sunway, Selangor, Malaysia.
*** The authors are with the Power High Voltage and Energy, Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, 71800 Nilai, Negeri Sembilan, Malaysia.
**** The authors are with the Department of Electrical Engineering, National Chung-Cheng University, Chiayi, Taiwan.
Corresponding Author: Chin-Leong Wooi.

viable solar energy source [5].

Solar systems predominantly use photovoltaic technology to convert solar radiation into direct current electricity. However, in hot climates like Malaysia, elevated ambient temperatures cause the surface of PV cells to overheat during operation. Climate change exacerbates this issue, potentially doubling the degradation rate of PV modules for every 10°C increase in surface temperature [6].

Many researchers have examined the impact of temperature and radiation on the output characteristics of solar cells [7-9]. However, the findings of these earlier studies and those of subsequent researchers [10-13] have often been inconsistent. For instance, study [9] found a 0.05% efficiency drop at 60°C for polycrystalline PV modules, while study [13] reported a 15.5% efficiency gain in a photovoltaic thermal system using aluminium oxide nanofluid cooling, which reduced panel temperature by 22.83%. The uncooled system, however, reached 75.5°C with 12.156% efficiency.

Generally, as temperature and radiation levels increase, the open-circuit voltage drops quickly, while the short-circuit current increases gradually. However, the characteristics observed differ widely with varying temperatures or radiation among studies due to the design differences of the intricate solar PV system.

Additionally, PV systems are increasingly vulnerable to lightning strikes due to their large, exposed installations. Lightning can cause overvoltage, disrupting operations and potentially damaging electronic components [14]. Such disruptions not only affect system functionality but also have significant economic impacts, hindering return on investment [15, 16].

Zaini *et al.,* [17] emphasized the likelihood of lightning strikes on solar PV systems, analysing their effects and highlighting the importance of lightning protection to mitigate overvoltage and protect the system. Therefore, ensuring the reliable operation of grid-connected solar PV systems is essential, addressing safety and reliable interconnection challenges in a smart grid environment. Standards or guidelines for grid-connected PV systems are crucial to safeguard against overvoltage and outages due to extreme weather.

This paper analyses key characteristics such as open-circuit voltage (V_{OC}), short-circuit current (I_{SC}), and maximum power (P_{MAX}) of the PV array under varying temperatures and solar radiation. These characteristics are essential for determining the impulse withstand voltage of solar PV systems.

2 Methodology

A PV array is conducted to obtain the system characteristics such as open-circuit voltage, short-circuit current and maximum power under different temperatures and radiation. The open-circuit voltage obtained is compared to the impulse withstand voltage according to the standard PD CLC/TS 50539-12.

2.1 PV Array Setup

A solar PV array circuit was created to measure key characteristic quantities, specifically open-circuit voltage (VOC), short-circuit current (ISC), and maximum power (PMAX) of the PV array. The circuit used for these measurements is illustrated in Figure 1. To determine these quantities, the resistance (R) in the circuit is adjusted dynamically, ranging from almost zero (0.001 Ω, simulating a short circuit) to a very high value (simulating an open circuit) over the simulation period (TIME), as depicted in Figure 1. Consequently, the terminal voltage (VPV) and current (IPV) of the PV array vary in response to changes in resistance (R).

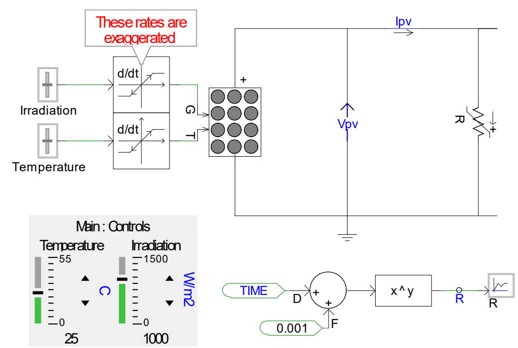


Fig. 1 PV array for measurement of open-circuit voltage, short circuit-current, and maximum power.

The PV array setup involves configuring the PV modules, cells, irradiation, and temperature settings to simulate different environmental conditions. This setup allows for the precise adjustment of the PV array's parameters to study their effects on the array's performance. Double-clicking on the PV array in the simulation environment enables modification of these parameters, as illustrated in Figure 2.

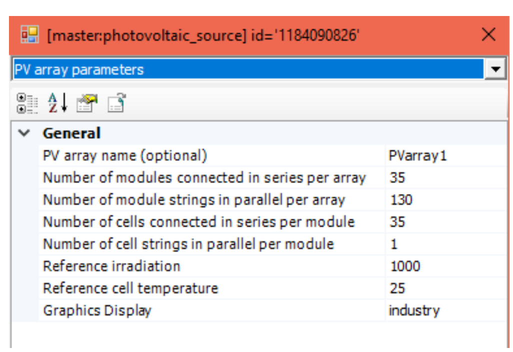


Fig. 2 PV array parameters.

The PSCAD/EMTDC simulation software was used to model the PV array's behaviour under varying temperatures and irradiance levels. The simulation was run for a duration of 2 seconds, with a solution time step of 10 µs and a channel plot step of 10 µs. This high-resolution simulation allows for accurate capture of the dynamic responses of the PV array to changing resistance, temperature, and irradiance conditions.

2.2 Impulse Withstand Voltage (V_{imp}) for Solar PV System

There are a variety of situations that can lead to overvoltage issues in hybrid solar PV systems. These include direct lightning strikes on the external lightning protection system, lightning-induced currents travelling through the electrical network, and switching events in the distribution network [18]. Impulse withstand voltage (V_{imp}) is a crucial factor to consider when evaluating the reliability and performance of electronic components used in solar photovoltaic (PV) systems. This parameter refers to the maximum voltage that a component can withstand without experiencing damage or failure when subjected to an impulse or surge.

The CLC/TS 61643-12 standard recommends maintaining a safety margin of at least 20% between the equipment's impulse withstand voltage and the protection voltage [18]. In solar PV systems, where components are exposed to various environmental issues and potential electrical disturbances [19], ensuring that the components have a high impulse withstand voltage is essential for protecting equipment, preventing downtime, reducing maintenance costs, and prolonging the lifespan of the system. By selecting components with a sufficient V_{imp} rating, system designers and installers can enhance the overall resilience and efficiency of the solar PV system, ultimately leading to improved performance and long-term reliability.

Based on PD CLC/TS 50539-12 standard, Table 1 details the impulse withstand voltage for equipment positioned on the DC side of the solar PV system such as solar PV array and inverters. This study compares the open-circuit voltage under different temperatures ranging from 5°C to 45°C and radiation ranging from 200 W/m^2 to 1200 W/m^2 with the maximum open circuit voltage in Table 1, the impulse withstand voltage for a PV generator is focused and analysed.

In this study, the impulse withstand voltage was determined for the PV array by comparing the measured V_{OC} under different environmental conditions to the maximum open-circuit voltage specified in the PD CLC/TS 50539-12 standard. The results were used to assess the adequacy of the PV array's design in terms of voltage protection and to identify any potential vulnerabilities to overvoltage conditions.

Table 1 Impulse withstand voltage for equipment of solar PV system [18]

Maximum Open Circuit Voltage, V_{OC_MAX} (V)	Impulse Withstand Voltage (V)		
	PV Generator	Inverter	Other Equipment
100	800	2500 (minimum requirement)	800
150	1500		1500
300	2500		2500
424	4000		4000
600	4000		4000
800	5000	4000	5000
849	6000		6000
1000	6000	6000	6000
1500	8000	8000	8000

3 Result

In the PSCAD/EMTDC simulation, 2 s duration of run, 10 µs solution time step, and 10 µs channel plot step were used. Figure 3 illustrates the changes in resistance (R) throughout the simulation period at a temperature of 25°C and an irradiance of 1000 W/m^2, along with the corresponding variations in terminal voltage (V_{PV}) and current (I_{PV}). The open-circuit voltage, short-circuit current and maximum power for temperature of 25°C and an irradiance of 1000 W/m^2 can be observed from Figure 3, the system's maximum power reaches approximately 254.18 kW, with an open-circuit voltage of 1.017 kV and a short-circuit current of 0.325 kA.

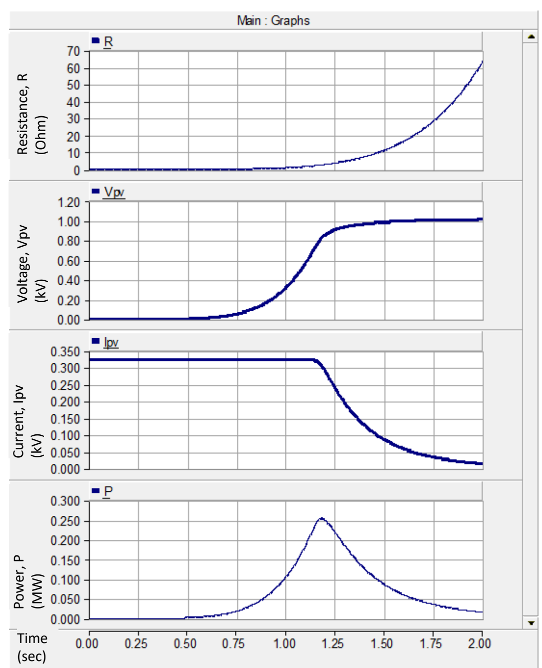


Fig. 3 Variation of the resistance (R) in the circuit at 25°C and 1000 W/m^2 and the consequence variations in current, voltage and power.

The open-circuit voltage, short-circuit current and maximum power for temperatures ranging from 5°C to

45°C and radiation ranging from 200 W/m^2 to 1200 W/m^2 are tabulated in Table 2, Table 3 and Table 4 respectively.

As radiation increases from 200 W/m² to 1200 W/m², the open-circuit voltage (V_{OC}) generally increases across all temperatures. This is expected since higher irradiance levels generate more charge carriers, leading to higher voltage. As temperature increases from 5°C to 45°C, the V_{OC} decreases for each radiation level. This is because higher temperatures increase the intrinsic carrier concentration in the semiconductor material, which reduces the bandgap energy and thus the open-circuit voltage. At 1200 W/m² and 5°C, the V_{OC} reaches a significantly higher value of 1804.79 V compared to other temperatures, indicating that low temperatures combined with high irradiance levels optimize the open-circuit voltage.

The short-circuit current (I_{SC}) increases almost linearly with radiation levels for all temperatures. This is because the number of photons incident on the PV cells increases with higher radiation, generating more electron-hole pairs and thereby increasing the current. I_{SC} slightly increases with temperature at each radiation level. Higher temperatures increase the mobility of charge carriers, contributing to a minor rise in current. At 1200 W/m² and 45°C, the I_{SC} reaches its highest value of 397.79 A, indicating that the current is most significantly affected by high irradiance, with temperature playing a secondary role.

The maximum power output (P_{MAX}) increases with radiation across all temperatures, as more sunlight directly translates to more power generation. P_{MAX} decreases as temperature increases at each radiation level. This is due to the combined effects of reduced V_{OC} and marginally increased I_{SC}, leading to an overall decline in efficiency and maximum power. At 1200 W/m² and 5°C, the P_{MAX} is highest reaching 312.43 kW, illustrating the optimal condition for power output with high irradiance and low temperature.

The trends observed in the data are consistent with the theoretical expectations for photovoltaic systems. Higher irradiance levels enhance both the voltage and current, thus increasing power output. However, elevated temperatures negatively impact the voltage more significantly than they boost the current, resulting in decreased overall efficiency. The negative impact of temperature on VOC is more pronounced than the positive impact on ISC. This results in a lower maximum power output as the temperature increases, even though the current slightly rises.

The best performance in terms of maximum power output is achieved under conditions of high irradiance and low temperature. For example, at 1200 W/m² and 5°C, the system achieves its highest power output of 312.43 kW. For optimal performance of solar PV systems, it is crucial to consider the local climate conditions. Systems installed in regions with high irradiance but moderate temperatures are likely to perform better. Additionally, thermal management strategies can be implemented to mitigate the adverse effects of high temperatures on PV systems.

The data highlights the significant influence of both irradiance and temperature on the performance of solar PV systems. To maximize efficiency and power output, solar PV installations should ideally be situated in locations with high sunlight exposure and managed to maintain lower operating temperatures. This analysis underscores the importance of comprehensive environmental assessments and effective thermal management in the design and deployment of photovoltaic systems.

Table 2 Open-circuit voltage of PV system under different temperatures and radiations

Open circuit voltage (V)	**Radiation (W/m2)**						**Temp. (°C)**
	200	**400**	**600**	**800**	**1000**	**1200**	
V_{OC}	967.08	1003.7	1023.46	1037.07	1634.64	1804.79	**5**
V_{OC}	949.45	987.16	1007.57	1021.63	1032.36	1041.05	**15**
V_{OC}	931.7	970.49	991.54	1006.06	1017.15	1026.13	**25**
V_{OC}	913.84	953.69	975.39	990.36	1001.81	1011.07	**35**
V_{OC}	895.86	936.77	959.11	974.54	986.34	995.9	**45**

Table 3 Short-circuit current on PV system under different temperatures and radiations

Short-circuit current (A)	**Radiation (W/m2)**						**Temp. (°C)**
	200	**400**	**600**	**800**	**1000**	**1200**	
I_{SC}	63.7	127.4	191.1	254.79	318.49	382.19	**5**
I_{SC}	64.35	128.7	193.05	257.39	321.74	386.09	**15**
I_{SC}	65	130	195	259.99	324.99	389.99	**25**
I_{SC}	65.65	131.3	196.95	262.59	328.24	393.89	**35**
I_{SC}	66.3	132.6	198.9	265.19	331.49	397.79	**45**

Table 4 Max power output of PV system under different temperatures and radiations

Max power output (kW)	Radiation (W/m2)						Temp. (°C)
	200	400	600	800	1000	1200	
P_{MAX}	50.67	103.74	156.82	209.44	261.35	312.43	**5**
P_{MAX}	49.83	102.18	154.59	206.55	257.82	308.26	**15**
P_{MAX}	48.95	100.57	152.29	203.57	254.18	303.96	**25**
P_{MAX}	48.05	98.91	149.95	200.5	250.42	299.51	**35**
P_{MAX}	47.12	97.2	147.46	197.32	246.54	294.93	**45**

After comparing the open-circuit voltage in Table 2 for each temperature and radiation with the Maximum Open Circuit Voltage in Table 1, the corresponding withstand voltage for the PV array is obtained and recorded in Table 5. After comparing the open-circuit voltage in Table 2 for each temperature and radiation with the Maximum Open Circuit Voltage in Table 1, the corresponding withstand voltage for the PV array is obtained and recorded in Table 5.

At 5°C and lower radiation levels (200-800 W/m²), the impulse withstand voltage is recorded as 6000 V. For higher radiation levels (1000-1200 W/m²), the impulse withstand voltage increases to 8000 V. This increase corresponds to the higher open-circuit voltages observed in Table 2 at these conditions, indicating the PV system needs to withstand higher transients.

Across all temperatures from 15°C to 45°C, the impulse withstand voltage remains constant at 6000 V regardless of the radiation level. This suggests that beyond a certain threshold, the impulse withstand voltage stabilizes, aligning with the fact that maximum open-circuit voltages do not exceed 1000 V significantly across these temperatures.

The trend indicates that radiation has a more substantial impact on the impulse withstand voltage at lower temperatures. As the temperature rises, the effect of radiation on impulse withstand voltage becomes less pronounced. This implies that at higher temperatures, the PV system's capacity to handle voltage transients remains relatively constant, whereas, at lower temperatures, high radiation levels pose a greater risk of voltage spikes, requiring higher withstand voltages.

The comparison between the open-circuit voltage and the maximum withstand voltage highlights the need for higher impulse withstand voltage ratings in PV arrays, particularly at low temperatures and high radiation levels. This ensures the PV system can handle higher transient voltages without damage. Therefore, designing PV systems with appropriate withstand voltage specifications is crucial for enhancing reliability and protecting against voltage spikes, especially under varying environmental conditions. It is also noted that transient voltages can cause degradation of electronic components that are not directly damaged by high voltage and current caused by lightning strikes [20].

4 Conclusion

This study comprehensively analyses the influence of temperature and solar radiation on the key performance characteristics of PV arrays, including open-circuit voltage (V_{OC}), short-circuit current (I_{SC}), and maximum power (P_{MAX}). The findings indicate that V_{OC} increases with higher irradiance but decreases with rising temperatures. I_{SC} shows a linear increase with both higher radiation and temperature, while P_{MAX} achieves its highest values under conditions of high irradiance and low temperatures.

One of the critical insights from this study is the importance of the impulse withstand voltage (V_{imp}) for PV systems, especially when exposed to extreme weather conditions. The analysis, based on the PD CLC/TS 50539-12 standard, reveals that PV systems require higher V_{imp} ratings at lower temperatures combined with high radiation levels to effectively handle transient voltage spikes. This is particularly crucial for ensuring the durability and reliability of PV systems installed in regions susceptible to extreme weather events.

The study underscores the necessity of incorporating robust voltage protection mechanisms and effective thermal management strategies in the design and deployment of PV systems. Proper thermal management can mitigate the adverse effects of high temperatures on V_{OC} and P_{MAX}, thereby enhancing the overall efficiency and longevity of the PV systems. Additionally, selecting components with appropriate V_{imp} ratings is essential for protecting the system against overvoltage and ensuring continuous, reliable operation.

Table 5 Impulse withstand voltage of PV array under different temperatures and radiations

Impulse withstand voltage (kV)	Radiation (W/m2)						Temp. (°C)
	200	400	600	800	1000	1200	
V_{imp}	6000	6000	6000	6000	8000	8000	**5**
V_{imp}	6000	6000	6000	6000	6000	6000	**15**
V_{imp}	6000	6000	6000	6000	6000	6000	**25**
V_{imp}	6000	6000	6000	6000	6000	6000	**35**
V_{imp}	6000	6000	6000	6000	6000	6000	**45**

In conclusion, the performance of PV systems is significantly influenced by environmental factors such as temperature and irradiance. To maximize efficiency and reliability, PV installations should be tailored to local climatic conditions, and robust protective measures should be implemented. This approach will not only improve system performance but also safeguard against potential damage caused by extreme weather, ultimately leading to more sustainable and resilient solar energy solutions.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Jia-Wen Tang: Conceptualization, Research and Investigation, Original Draft Preparation, Revision; **Chin-Leong Wooi:** Supervision, Conceptualization, Investigation, and Review; **Wen-Shan Tan:** Supervision, Idea, and Review; **Nur Hazirah Zaini:** PSCAD Guiding, Idea and Review; **Yuan-Kang Wu:** Idea and Review; **Syahrun Nizam bin Md Arshad@Hashim:** Idea and Review.

Funding

This research received no external funding.

Acknowledgement

The authors would like to acknowledge the support from the Ministry of Higher Education (MoHE) Malaysia through the Fundamental Research Grant Scheme (FRGS) under a grant number of FRGS/1/2022/TK08/UNIMAP/02/72.

References

[1] Panagoda, L. P. S. S., Sandeepa, R. A. H. T., Perera, W. A. V. T., Sandunika, D. M. I., Siriwardhana, S. M. G. T., Alwis, M. K. S. D., and Dilka, S. H. S. "Advancements in photovoltaic (Pv) technology for solar energy generation." *Journal of research technology & engineering*, vol. 4, no. 30, pp. 30-72, 2023.

[2] Zhang, Yang, Hongcai Chen, and Yaping Du. "Considerations of photovoltaic system structure design for effective lightning protection." *IEEE Transactions on Electromagnetic Compatibility*, vol. 62, no. 4, pp. 1333-1341, 2020. doi: 10.1109/TEMC.2020.2990930

[3] Di Bella, Alice, and Francesco Pietro Colelli. "Mitigation strategies can alleviate power system vulnerability to climate change and extreme weather: a case study on the Italian grid." *Environmental Research: Infrastructure and Sustainability*, vol. 5, no. 1, p. 015003, 2025. doi: 10.1088/2634-4505/ada308

[4] IPCC, 2023: *Climate Change 2023: Synthesis Report.* Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115. doi: 10.59327/IPCC/AR6-9789291691647

[5] Mekhilef, Saad, Azadeh Safari, W. E. S. Mustaffa, Rahman Saidur, Rosli Omar, and M. A. A. Younis. "Solar energy in Malaysia: Current state and prospects." *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 386-396, 2012. doi: 10.1016/j.rser.2011.08.003

[6] Kirpichnikova, Irina M., and Ilkhom B. Makhsumov. "The influence of ambient temperature on the energy characteristics of solar modules." In *2020 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, pp. 1-5. IEEE, 2020. doi: 10.1109/ICIEAM48468.2020.9112064

[7] Chegaar, Mohamed, Amer Hamzaoui, Aboubacar Namoda, Pierre Petit, Michel Aillerie, and Axel Herguth. "Effect of illumination intensity on solar cells parameters." *Energy Procedia*, vol. 36, pp. 722-729, 2013. doi: 10.1016/j.egypro.2013.07.084

[8] Daut, Ismail, Mohd Irwan Yusoff, Safwati Ibrahim, Muhammad Irwanto, and Gomesh Nsurface. "Relationship between the solar radiation and surface temperature in Perlis." *Advanced Materials Research*, vol. 512, pp. 143-147, 2012. doi: 10.4028/www.scientific.net/AMR.512-515.143

[9] Karki, Indra Bahadur. "Effect of temperature on the IV characteristics of a polycrystalline solar cell." *Journal of Nepal Physical Society*, vol. 3, no. 1 pp. 35-40, 2015. doi: 10.3126/jnphyssoc.v3i1.14440

[10] Kumar, M. Senthil, K. R. Balasubramanian, and L. Maheswari. "Effect of temperature on solar photovoltaic panel efficiency." *Int. J. Eng. Adv. Technol*, vol. 8, no. 6, pp. 2593-2595, 2019. doi: 10.35940/ijeat.F8745.088619

[11] Nadia, Mars, Houcine Lassad, Zaafouri Abderrahmen, and Chaari Abdelkader. "Influence of temperature and irradiance on the different solar PV panel technologies." *International Journal of Energy Sector Management*, vol. 15, no. 2, pp. 421-430, 2021. doi: 10.1108/IJESM-06-2020-0002

[12] Rana, Mohammad Masud, Ahnaf Tahmid Abir, Syeda Samiha Nushin, and Jaker Hossain. "Numerical investigation on the role of ZnTe back surface layer in an efficient CuInS2 thin film solar cell." *Engineering Research Express*, vol. 5, no. 4, p. 045020, 2023. doi: 10.1088/2631-8695/ad0091

[13] Ibrahim, Ali, Muhammad Raafat Ramadan, Abd EL-Monem Khallaf, and Muhammad Abdulhamid. "A comprehensive study for Al2O3 nanofluid cooling effect on the electrical and thermal properties of polycrystalline solar panels in outdoor conditions." *Environmental Science and Pollution Research*, vol. 30, no. 49, pp. 106838-106859, 2023. doi: 10.1007/s11356-023-25928-3

[14] Teja, Adimulam Rahul. "Geethanjali College of Engineering & Technology." (2025).

[15] Hu, Haize, Mengge Fang, Yufei Zhang, Liangbing Jing, and Feiyu Hu. "Dynamic lightning protection method of electric power systems based on the large data characteristics." *International Journal of Electrical Power & Energy Systems*, vol. 128, p. 106728, 2020. doi: 10.1016/j.ijepes.2020.106728

[16] Omar, Ahmed I., Abd-Allah, M. A., Ahmed Shokry, and Abdelrahman Said. "Lightning Risk Assessment, Control and Protection Scheme Design for a Rooftop Photovoltaic System in the New Capital of Egypt." *International Journal of Robotics & Control Systems*, vol. 4, no. 4, 2024. doi: 10.31763/ijrcs.v4i4.1525

[17] Zaini, N. H., M. Z. A. Ab-Kadir, M. A. M. Radzi, N. Azis, N. I. Ahmad, M. S. M. Nasir, M. Izadi, N. F. Ab Aziz, and Z. Ali. "Lightning surge on the DC and AC side of solar PV system." In *2019 11th Asia-Pacific International Conference on Lightning (APL)*, pp. 1-5. IEEE, 2019. doi: 10.1109/APL.2019.8815953

[18] The British Standards Institution (BSI). *Low-Voltage Surge Protective Devices. Surge Protective Devices for Specific Application Including D.C.-Part 12: Selection and Application Principles—SPDs Connected to Photovoltaic Installations*; PD CLC/TS 50539-12; BSI: London, UK, 2013. doi: 10.3403/30281661U

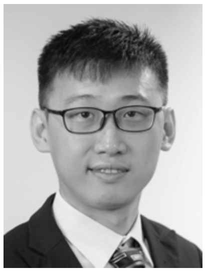
[19] Ahmad, Nor Izzati, Zaipatimah Ali, Mohd Zainal Abidin Ab. Kadir, Miszaina Osman, Nur Hazirah Zaini, and Muhammad Hakirin Roslan. "Analysis of lightning-induced voltages effect with SPD placement for sustainable operation in hybrid solar PV-Battery energy storage system." *Sustainability*, vol. 13, no. 12, p. 6889, 2021. doi: 10.3390/su13126889

[20] Jiang, Taosha, and Stanislaw Grzybowski. "Electrical degradation of Photovoltaic modules caused by lightning induced voltage." In *2014 IEEE Electrical Insulation Conference (EIC)*, pp. 107-110. IEEE, 2014. doi: 10.1109/EIC.2014.6869357

Biographies

Jia-Wen Tang is a PhD candidate in the Faculty of Electrical Engineering and Technology at the Universiti Malaysia Perlis (UniMAP) in Perlis, Malaysia. She received her B. Eng. (Hons) from the UniMAP in 2022. She was an internship student at National Chung Cheng University, Chiayi, Taiwan starting in April 2024, studying metaheuristic optimisation techniques with Matlab. Her current research is on modelling grid-connected solar photovoltaic systems and optimising the system's reliability.

Chin-Leong Wooi received his B.Eng. (honors) in Electrical and Electronic Engineering from Universiti Malaysia Sabah, Malaysia, in 2011, followed by an M.E. in Electrical Engineering from Universiti Teknologi Malaysia (UTM), Johor, in 2013. He later earned his Ph.D. in Electrical Engineering from UTM in 2017. He served as a Senior Lecturer at Universiti Malaysia Perlis (UniMAP) for eight years and currently holds the same position at the Faculty of Electrical Engineering & Technology. His research interests include lightning characterization, lightning physics, high-voltage engineering, electromagnetic field measurement, and power system engineering.



Wen-Shan Tan received the B.Eng. (honors) degree in Electrical and Electronic Engineering from Universiti Malaysia Sabah in 2011, his M. Eng. degree and Ph.D. degree in Electrical Engineering from Universiti Teknologi Malaysia (UTM), in 2013, and 2017 respectively. He is currently a Lecturer at Department of Electrical and Robotics Engineering and Centre for Net-Zero Technology, Monash University Malaysia. His research interests include power system operation and planning, power systems resilience, machine learning assisted optimization, transactive energy market, and blockchain.

Nur Hazirah Zaini graduated with a Bachelor's degree from Universiti Putra Malaysia (UPM) in 2008. She received her Master’s degree in 2014 and her Ph.D. in 2019, both from UPM. She is currently a Lecturer at the Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia (USIM), Negeri Sembilan, Malaysia. Her main research interests include high voltage engineering, lightning protection, insulation coordination, transmission and distribution systems, renewable energy, and solar photovoltaics.

Yuan-Kang Wu received the Ph.D. degree in electronic and electrical engineering from the University of Strathclyde, Glasgow, U.K., in 2004. He is currently a Distinguished Professor with the Department of Electrical Engineering, National Chung Cheng University, Chiayi, Taiwan, working in the area of renewable energy integration, modeling for modern power system components, fault diagnosis technologies, and forecasting technologies. He was the recipient of the Outstanding Research Award from National Science and Technology Council, Taiwan, in 2020.

Syahrun Nizam bin Md Arshad@Hashim is an Associate Professor at the Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis (UniMAP). He received Phd in Electrical Engineering from Universiti Putra Malaysia (UPM), Master and Degree Engineering degree in Electrical Engineering from Universiti Teknologi Malaysia (UTM), in 2008 and 2011, respectively. Previously he was an Electrical Engineer at Minconsult Sdn. Bhd. and involved in many project developments. His current research interests include Lightning Protection System and Renewable Energy.