

Evaluation of Hot Spot Effects in Monocrystalline and Polycrystalline Photovoltaic Panels under the Climatic Conditions of Ilam

F. Darvishi¹, A. N. Lorestani^{1*}, R. Yeganeh², M. Valizadeh³

1- Department of Mechanical Engineering of Biosystems, Agriculture Faculty, Razi University, Kermanshah, Iran

2- Department of Mechanical Engineering of Biosystems, Agriculture Faculty, Ilam University, Ilam, Iran

3- Department of Electrical Engineering, Ilam University, Ilam, Iran

(*- Corresponding Author Email: lorestani@razi.ac.ir)

<https://doi.org/10.22067/jam.2026.99648.1501>

Abstract

Photovoltaic systems typically have a long service life because they contain no moving parts, making them an attractive option for both residential and industrial applications. However, several factors may reduce the service life of photovoltaic panels. This study investigates how rising temperatures from solar radiation affect different types of solar panels. One such factor is the hot spot phenomenon, in which localised regions of a photovoltaic panel experience excessive heating, potentially resulting in an irreversible reduction in power output. To assess the influence of climatic conditions on hot spot formation, a 17-week field study was conducted using monocrystalline and polycrystalline photovoltaic panels during the warm season in Ilam, Iran. The performance of the panels was also simulated in MATLAB/Simulink to obtain a more accurate analysis of the results. Additionally, infrared thermography (thermal camera) was used to evaluate the thermal characteristics of the panels during hot spot formation. The findings revealed that the power output of the damaged polycrystalline panels P1 and P2 and the damaged monocrystalline panels M3 and M4 decreased by 0.105, 0.104, 0.211, and 0.193 W, respectively, over the 17-week period. Conversely, the power output of the intact polycrystalline panels P5 and P6 and the intact monocrystalline panels M7 and M8 increased by 0.474, 0.518, 0.66, and 0.66 W, respectively. Overall, the degradation rate of the monocrystalline panels was found to be higher than that of the polycrystalline panels.

Keywords: Crystalline silicon solar panels, Hot spot, MATLAB simulation, Partial shading, Photovoltaic modules

Introduction

Population growth and rapid industrialisation have led to a steady increase in energy demand. Meeting this demand through conventional energy sources has intensified environmental pollution, affecting air, soil, and water quality. Consequently, researchers are increasingly seeking clean and sustainable energy sources and technologies that can mitigate the environmental impacts of energy production. In recent years, the deployment of renewable energy technologies has expanded considerably, although their performance and energy output depend strongly on regional climatic conditions (Kalogirou, 2023). Solar radiation is one of the primary sources of renewable energy. Solar energy is abundant, renewable, and environmentally benign, making it a promising source of sustainable energy. The amount of solar radiation reaching

a specific point on Earth varies according to latitude, longitude, altitude, and climatic characteristics (Setiabudi, Dinaryanto, Haris, & Mardwianta, 2024). Owing to its favourable solar-resource conditions, Iran has considerable potential for photovoltaic (PV) energy development. Photovoltaic panels are used at various scales and are often installed on rooftops or open spaces (Rabaia *et al.*, 2021). The installation of solar panels on buildings can significantly reduce fossil fuel consumption and associated environmental impacts (Baharin, Yahaya, & Ahmad, 2024). First-generation photovoltaic technologies are dominated by crystalline-silicon modules, which are divided into cells made of polycrystalline and monocrystalline silicon. Among these technologies, monocrystalline silicon is the most widely used and efficient technology, followed by polycrystalline silicon, which is more widely available on the market

(Gulnz, Preu, & Biro, 2012). Monocrystalline cells have advantages, such as a perfect lattice arrangement, higher material purity, lower internal resistance, and a long lifespan. They also produce more power than polycrystalline panels due to their higher efficiency in conditions where the sunlight intensity is weak (Jiang, Cui, Sun, Wang, & Yang, 2020).

Inside a solar panel, multiple strings of cells are connected. When the current of a cell is lower than that of other cells in the string due to reasons such as shading, dust, bird droppings, snow, and panel cracks, current from neighbouring cells is forced through the affected cell, causing more energy loss there. This creates a hot spot (Vishwakarma, 2017), which has a higher temperature than the rest of the panel and is usually caused by various factors, such as failures, manufacturing defects, electrical defects, uneven temperature changes, or natural parameters, which reduces carrier transport and ultimately lowers the activation of charge carriers (Ahmed *et al.*, 2023). Shaded cells can become reverse-biased and act as consumers instead of producers of electricity (Dhimish, Theristis, & d'Alessandro, 2024). With an increase in the number of bypass diodes, the intensity of the hot spots decreases, and the reverse-bias voltage and power dissipation in the shaded cells decrease; however, hot spots may still occur even with bypass diodes (Xu, Deng, Zhang, & Zhang, 2021). Keskin, Rahmati Khalejan, and Çıkkla (2021) examined the effects of shading on the performance of a grid-connected PV plant in Turkey. The size and angle of the shadow significantly impact the power loss of the solar power plant. Due to shadows from nearby buildings for 2-3 hours in the morning, a loss of 307 W was observed in a 30 kW array. Shadow effects can lead to megawatt-scale power loss over the lifetime of photovoltaic power systems. The solar irradiation time varies with the MGM values, and the long-term shadows significantly affect the performance of the PV plant and its sensitive components. Singh, Jain, and Gupta (2023) investigated the effects of partial shading at different locations on a polycrystalline PV array using simulation-

based analysis. The model incorporated cell temperature, solar irradiance, and the electrical characteristics of the PV modules. Different shading patterns were simulated, and the resulting changes in voltage, current, and output power were evaluated. The results showed that energy production and system efficiency varied according to the intensity and pattern of shading.

Oufettoul *et al.* (2023) investigated the effects of partial shading and module orientation on the performance of PV arrays using theoretical, simulation-based, and experimental approaches. Their results showed that module orientation and arrangement significantly influence energy production under partial shading and that inappropriate configurations can result in substantial energy losses. Therefore, comparing the severity of hot spot formation and the resulting performance degradation in monocrystalline and polycrystalline panels is of particular importance. Given the climatic and environmental conditions of Ilam, Iran, such a comparison can provide useful information for selecting appropriate PV technologies and improving the management and performance of solar energy systems in similar regions. The findings may also assist decision-makers and PV system designers in reducing damage, improving system reliability, and lowering maintenance costs through the timely detection of panel defects.

Materials and Methods

The experimental setup used in this study is shown in Figure 1. It consisted of four monocrystalline and four polycrystalline PV panels, each rated at 10 W and manufactured by Restar Solar. The measurement equipment included a CEM DT-9875 thermal camera, an AKBDT9208A digital multi-meter, an HT-3015 hygrometer, and a TES1333 pyranometer. Panel output power was calculated from the measured current and voltage, whereas solar irradiance, ambient temperature, relative humidity, and wind speed were recorded as atmospheric variables. The cells within each PV module were connected in series, whereas

the modules were installed independently at the experimental site. A 10 W lamp was connected

to each panel as an electrical load.



Fig. 1. a) CEM DT-9875 thermal camera, b) Digital multi-meter, c) Back view of PV modules, d) Hygrometer, e) Pyranometer, and f) Front view of PV modules

The technical specifications of these panels under standard conditions are outlined in Table 1. Wind speed and ambient temperature data were obtained from the Daily Weather online platform for the experimental location. The CEM DT-9875 infrared camera was utilised in

this study, featuring temperature measurement ranges of -20 to 400 $^{\circ}\text{C}$, measurement accuracy of ± 2 $^{\circ}\text{C}$, thermal imaging resolution of 160×120 pixels, and camera dimensions of $160 \times 103 \times 243$ mm.

Table 1- Technical specifications of the monocrystalline and polycrystalline panels used in this study

PV model	Monocrystalline	Polycrystalline
Maximum allowed power (W)	10	10
Power variation range (W)	0-5	0-5
Open circuit voltage (V)	21.18	21.60
Maximum voltage (V)	17.43	18.20
Short circuit current (A)	0.63	0.62
Maximum current (A)	0.58	0.55
Maximum system voltage (V)	1000	1000
Maximum series fuse rating (A)	15	15
Weight (kg)	0.924	0.924
Module type	Class A	Class A
Panel dimensions (mm)	350×240×17	350×240×17

Panel Installation Site

Ilam Province encompasses three major

climatic zones: cold mountainous, temperate mountainous, and hot and dry desert and semi-

desert regions. The experimental site was located at Ilam University (46.37618350° E, 33.65645445° N; elevation: 1455 m above sea level). The PV panels were installed facing south at a tilt angle of 35° (Farahmand, Nazari, Shamlou, & Shafie-khah, 2021).

Identification of the hottest cell

In the first stage, after two days of solar exposure, the hottest cells of the panels (two monocrystalline panels and two polycrystalline panels) were identified using a thermal camera (Figure 2) (Umar, Qureshi, & Nawaz, 2024).

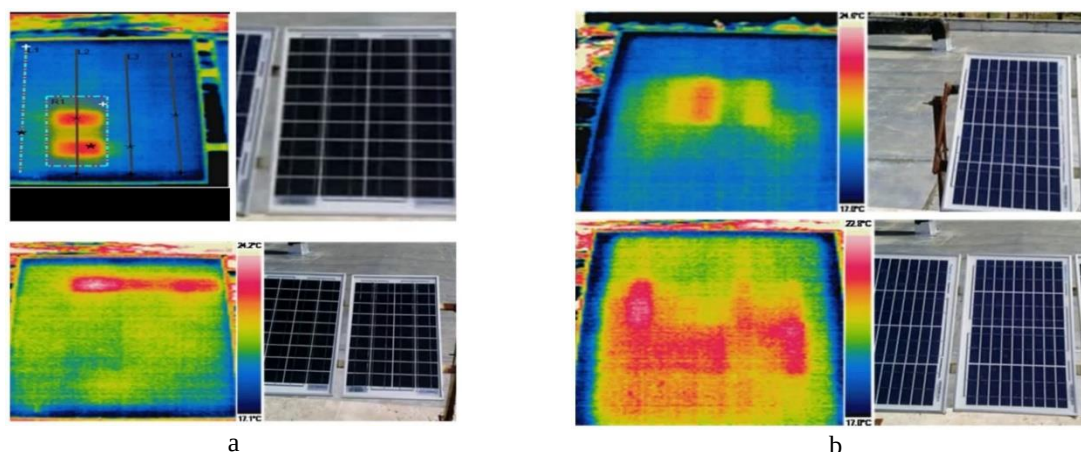


Fig. 2. The hottest cells of the (a) monocrystalline and (b) polycrystalline panels

Partial Shading of Selected Cells

From May to September, selected cells were covered to create partial shade for approximately five months, as shown in Figure 3. The aim of this method was to increase local heating and the formation of hot spots. During

the test period, meteorological variables, including solar radiation, wind speed, ambient temperature, and relative humidity, as well as the output current and voltage of all eight panels, were recorded weekly at approximately noon.



Fig. 3. Creating artificial shadow on the hot cells of the panels

Results and Discussion

According to Figures 4 and 5, over a period of 17 weeks, atmospheric parameters, including

solar irradiance, wind speed, relative humidity, and ambient temperature, were recorded simultaneously with the electrical output of the panels.

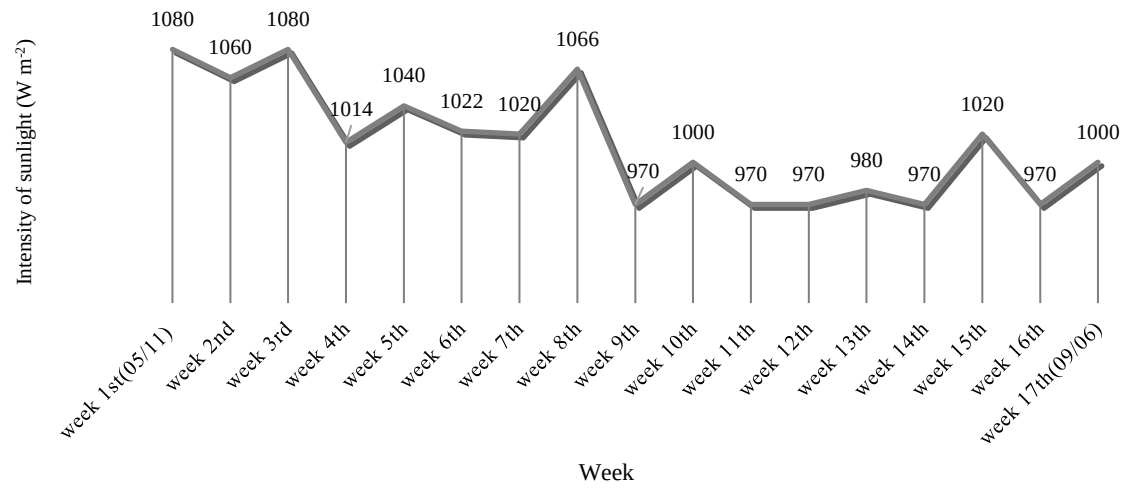


Fig. 4. Solar radiation intensity (W m⁻²)

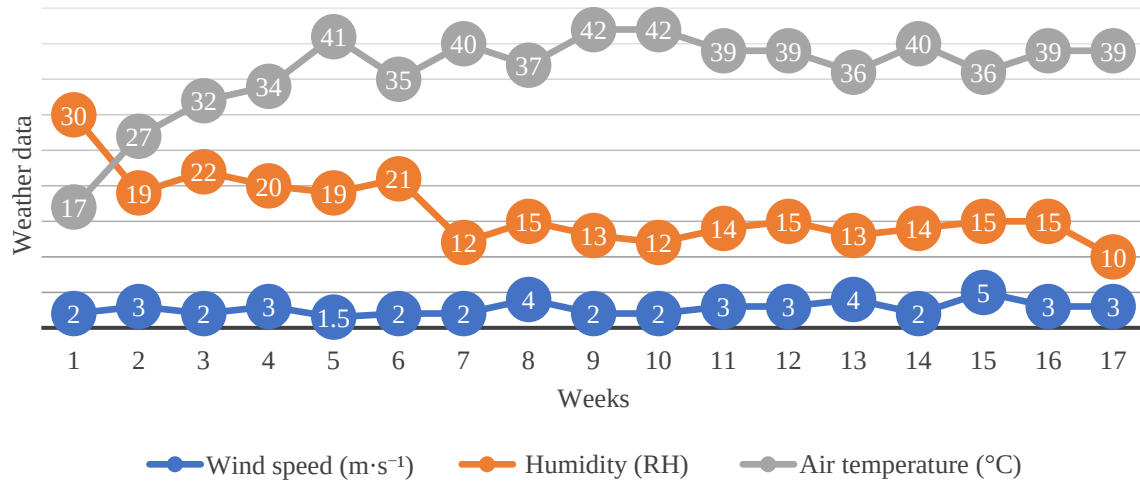


Fig. 5. Changes in wind speed (m s⁻¹), humidity (RH), and air temperature (°C) from 02/22 to 06/16

Power Output Comparison

Figure 6 displays the power output measurements of the polycrystalline silicon solar panels (P1, P2, P5, and P6) over a 17-week period from 11/05 to 06/09. Power was calculated using $P = V \times I$, where V is the measured voltage, and I is the measured current. The data analysis results indicate that

the power of panels P1 and P2, both of which were intentionally shaded, decreased by 0.105 and 0.104 W, respectively, during this period. In contrast, the power output of the unshaded control panels P5 and P6 increased by 0.474 and 0.518 W, respectively. The average power outputs of the defective and unshaded control panels were 1.54 W and 4.86 W, respectively.

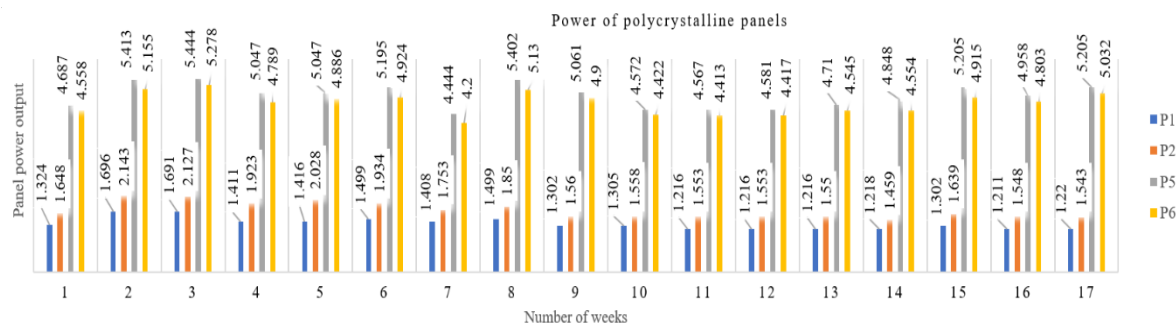


Fig. 6. Power changes of polycrystalline panels

These results indicate that partial shading promotes hot spot formation in the affected cells, which leads to an increase in the local temperature, a decrease in the voltage, and a drop in the output power. On the other hand, unshaded control panels that were not affected by shading maintained higher output power throughout the experimental period despite variations in atmospheric conditions.

The output power of the panels fluctuates depending on atmospheric parameters such as the solar radiation intensity, air temperature, humidity, and wind speed (El-Shaer, Tadros, & Khalifa, 2014; Siecker, Kusakana, & Numbi, 2017; Tripathi, Ray, Aruna, & Prasad, 2021).

An increase in the solar radiation intensity (1066 W m^{-2}) and wind speed (4 m s^{-1}) led to a notable rise in the output power. This suggests that optimal radiation conditions and natural cooling from the wind can enhance the panel's performance.

As the temperature increased to 42°C , the panel voltage decreased. This decrease is attributed to the negative effects of high temperatures on the performance of the solar cells, resulting in a decrease in the efficiency of the panels.

A reduction in relative humidity was associated with a slight increase in output voltage. This observation suggests that lower relative humidity was associated with a slight increase in output voltage under the measured conditions. Despite similar atmospheric conditions (solar radiation intensity 970 W m^{-2} , air temperature 39°C , air humidity of 15% RH, and wind speed of 3 m s^{-1}), power changes were

observed in all four panels. These differences suggest that shading contributed to the reduction in power output observed in panels P1 and P2, whereas panels P5 and P6 maintained higher power output.

These results demonstrate that partial shading of even a single cell can adversely affect the overall performance of a PV panel. In addition, solar irradiance, ambient temperature, relative humidity, and wind speed influenced panel output. Therefore, minimising shading and selecting an appropriate installation site are important for improving PV system performance and reducing shading-related losses.

Figure 7 displays the power output of the monocrystalline silicon solar panels (M3, M4, M7, and M8) over a 17-week period. Data analysis revealed that the power output of the defective panels M3 and M4, both of which were intentionally shaded, decreased by 0.211 W and 0.193 W, respectively, in the final week compared to the first week. This decline demonstrates the direct impact of shading on the occurrence of hot spots in these panels. Conversely, the power output of the unshaded control panels M7 and M8 increased by 0.66 W each, indicating a more consistent performance in conditions without shadows. The average power outputs of the damaged and undamaged monocrystalline panels were 0.91 W and 5.86 W, respectively. Both values should be interpreted in comparison with the corresponding polycrystalline results reported above.

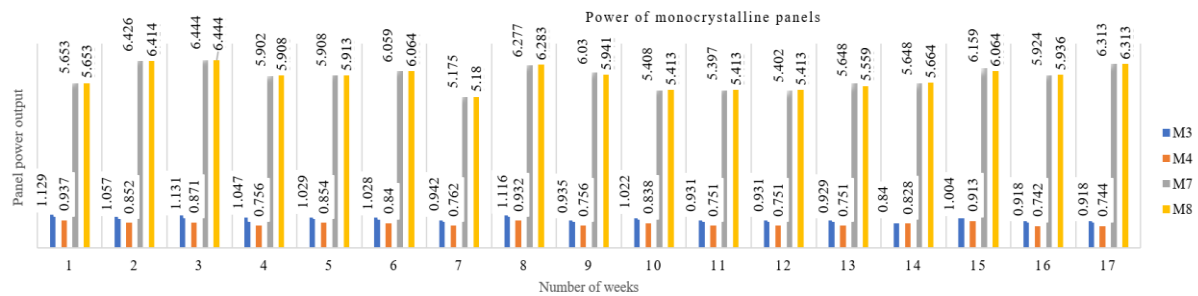


Fig. 7. Power changes of monocrystalline panels

As observed in the eighth week, the output power of the defective panels decreased due to an increase in solar radiation intensity and wind speed, while the power of the unshaded control panels increased. These changes suggest that the monocrystalline panels are more sensitive to environmental conditions. Additionally, a comparison of the data overall reveals that hot spot formation was more pronounced in the monocrystalline panels compared to the polycrystalline panels. This greater susceptibility may be related to differences in cell structure and electrical characteristics between monocrystalline and polycrystalline modules. These findings align with those reported by [Ahsan, Niazi, Khan, and Yang \(2018\)](#), who demonstrated that crystalline silicon modules, such as monocrystalline panels, typically exhibit higher efficiency but are more susceptible to hot spot formation. In contrast, thin-film modules are generally less efficient but exhibit greater resistance to hot spots.

The results of the present study are consistent with those reported by [Islam \(2019\)](#). In that study, conducted in an indoor environment at various temperatures, the performance of the panels was evaluated using thermographic images. The images indicated that the temperature difference in the hot spot regions of the monocrystalline module was greater than that of the polycrystalline module ([Islam, 2019](#)).

Overall, the results indicate that although monocrystalline panels generally offer higher conversion efficiency and power output, they

may be more susceptible to hot spot formation under partial shading and adverse thermal conditions. Therefore, minimising shading and implementing appropriate environmental and system management strategies are important for maintaining their long-term performance.

The results of this study highlight the importance of selecting the type of solar panel based on environmental conditions. In locations where partial shading cannot be avoided, the selection of PV technology should consider the shading characteristics, thermal conditions, and expected long-term performance of the system. Conversely, in areas with direct and constant sunlight, the monocrystalline panels can offer higher efficiency. Proper maintenance and techniques like installing bypass diodes to reduce the effects of hot spots are also recommended to optimise system performance.

Recent advances in 2024-2025 emphasise half-cut cell designs and advanced bypass circuits to mitigate hot spots, reducing temperatures from 55 °C to 35 °C and improving output by up to 5.3%. Machine learning models, such as Medium Gaussian SVM, achieve 99.3% accuracy in hot spot detection using thermal images ([Dhimish et al., 2024](#); [Kashika, Prem, & Vinod, 2025](#)).

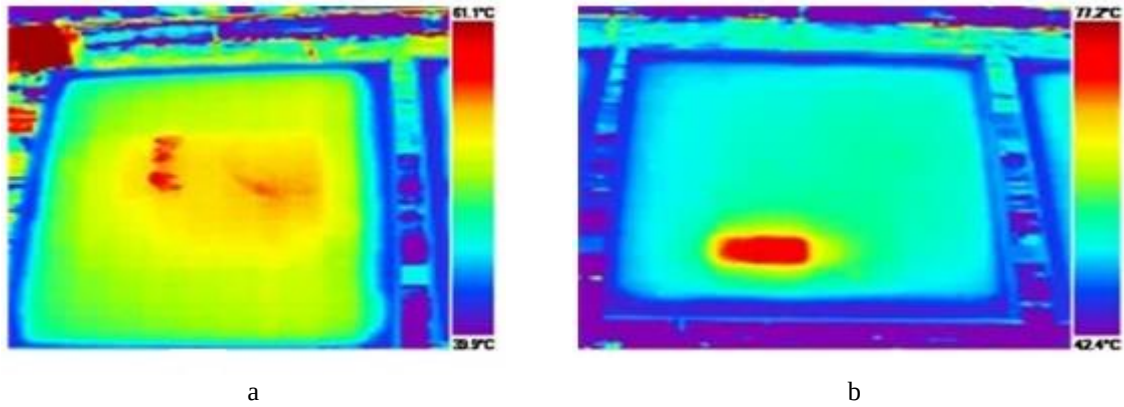
Statistical Analysis

The results of the statistical analysis, based on a three-factor factorial experiment arranged in a randomised complete block design, are presented in Table 2.

Table 2- Results of analysis of variance (degrees of freedom and mean squares)

Sources of change	Degree of freedom	I (A)	V (Volt)	P (W)
Repetition	1	0.000006 ^{ns}	0.0652 ^{ns}	0.0164 ^{ns}
Panel type	1	0.002224 ^{**}	0.2863 ^{**}	1.1136 ^{**}
Panel status	1	4.800018 ^{**}	94.7892 ^{**}	582.0469 ^{**}
Time	16	0.002785 ^{**}	0.0569 [*]	0.378 ^{**}
Panel type × Panel status	1	0.181624 ^{**}	5.3444 ^{**}	22.8739 ^{**}
Panel type × time	16	0.000157 ^{ns}	0.004 ^{ns}	0.0125 ^{ns}
Panel status × time	16	0.001016 ^{**}	0.0328 ^{ns}	0.1721 ^{**}
Panel type × Panel status × Time	16	0.000163 ^{ns}	0.0025 ^{ns}	0.0184 ^{ns}
Error	67	0.000231	0.026	0.0283
CV (%)	-	4.65	1.68	5.11

*, **, and ns indicate significance at the five and one percent levels and non-significance, respectively.

**Fig. 8.** IR image of the (a) polycrystalline and (b) monocrystalline panels

During the final week of the experiment, after the cardboard covers had been removed and under an irradiance of 1000 W m^{-2} , the hottest cells were identified using infrared thermography. Figure 8 presents thermal images of two panels: P1 (polycrystalline) and M3 (monocrystalline). As shown, hot spots have formed in the shaded cells. The maximum cell temperature in the polycrystalline panel reached 58.6°C , while in the monocrystalline panel it reached 75.5°C . These results indicate that the hottest cell in the monocrystalline panel was 16.9°C higher than that in the polycrystalline panel.

This temperature difference indicates that the monocrystalline panels are more susceptible to the phenomenon of hot spots. Although the integrated and uniform structure of the monocrystalline cells increases their efficiency, in partial shading conditions, these types of panels are prone to heat accumulation and temperature increases in certain places. In contrast, the polycrystalline panel exhibited a

lower maximum hot spot temperature under the experimental conditions.

The results of this study are consistent with the study by [Numan, Hussein, and Dawood \(2021\)](#) who also used infrared (IR) imaging technology to identify and analyse hot spots. They found that the intensity and type of shadow have a significant impact on the temperature distribution and efficiency of solar modules. The results of both studies confirm that partial shading can lead to the formation of hot spots, resulting in decreased efficiency and potential damage to the module.

Thermal imaging studies indicate that hot spots caused by partial shading not only decrease power output but can also lead to significant damage to solar panels. The monocrystalline panels are particularly sensitive to this issue; therefore, careful environmental management and the prevention of shading are essential for enhancing system performance. This research underscores the importance of addressing shading concerns in

solar panel installations. While monocrystalline panels offer higher efficiency, they are more susceptible to hot spot formation. Conversely, the polycrystalline panels demonstrate greater stability in the face of shading. Therefore, selecting the appropriate panel type should be based on environmental factors to optimise solar system efficiency and mitigate potential hot spot damage.

MATLAB/Simulink Simulation

Simulations were performed in MATLAB/Simulink to analyse the performance of monocrystalline and polycrystalline PV panels under partial shading and hot spot conditions. The simulations also took into account the panels' performance in partial shade and the occurrence of hot spots. These simulations were carried out at an ambient temperature of 39 °C and a solar irradiance of 970 W m⁻², corresponding to the

measured conditions during the twelfth and sixteenth weeks.

The effects of temperature on the current–voltage (I–V) and power–voltage (P–V) characteristics of the polycrystalline panel are shown in Figure 9. As temperature increases, the output current of the panel remains relatively stable at low voltages. However, at high voltages, the current decreases more rapidly with rising temperatures, resulting in a decrease in the open-circuit voltage. Additionally, higher temperatures lead to a reduction in the maximum power output of the panel. The consistent current values observed for voltages below 15 volts support the behavior of the panel as a current source. While temperature has minimal impact on the current and power output of the panel at low voltages, its effects become more pronounced at higher voltages, particularly near the open-circuit voltage state.

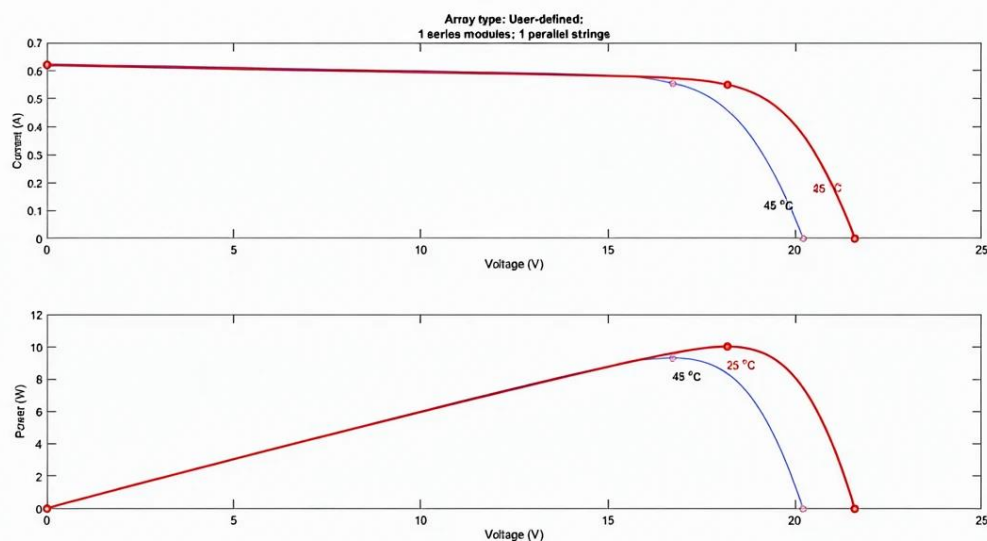


Fig. 9. Current-voltage and power-voltage diagrams of a polycrystalline panel

Under uniform irradiance and without partial shading, the cells of the polycrystalline panel operated under similar conditions. Because the cells were electrically interconnected, the voltage and current behaviour of the panel

followed the fundamental principles of circuit analysis, including Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL). Under these conditions, the panel delivered stable electrical power, as shown in Figure 10.

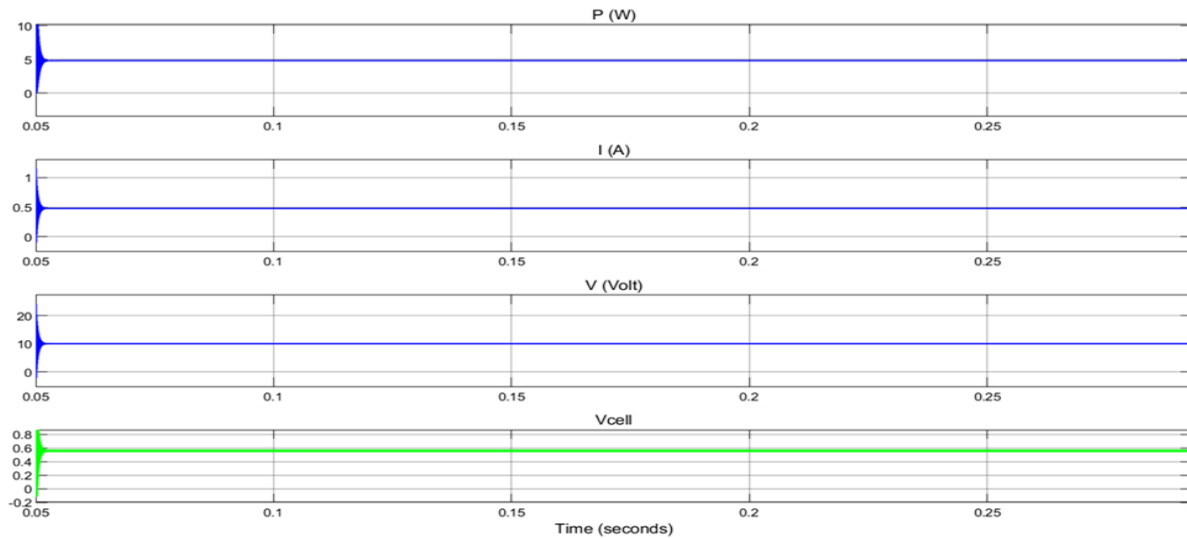


Fig. 10. Power Curves P (W), current I (A), panel voltage V (Volt), and cell voltage V_{cell} without the hot spot of the polycrystalline panel

Partial shading of a single cell reduced the overall power output, voltage, and current of the polycrystalline panel. Under the simulated hot spot condition, the voltage of the affected

cell became negative, indicating a reverse-bias operation, as shown in Figure 11, which depicts the simulation results of this scenario.

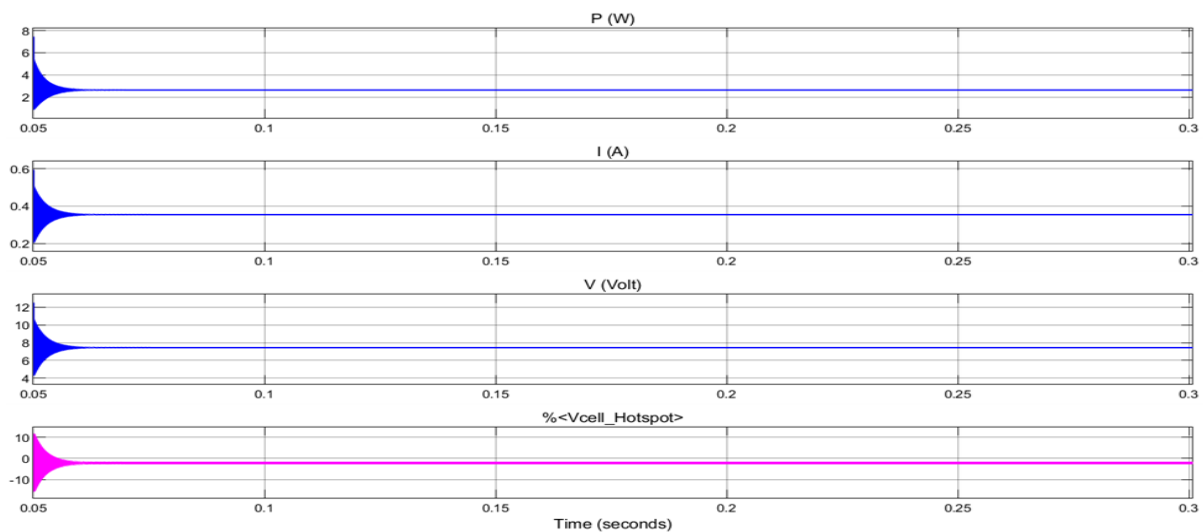


Fig. 11. Power Curves P (W), current I (A), panel voltage V (Volt), and cell voltage V_{cell} with the hot spot of the polycrystalline panel

Monocrystalline Panel

The simulated voltage, current, and power characteristics of the monocrystalline panel under normal and hot spot conditions are shown

in Figures 12 and 13. When partial shading was applied to a cell of the monocrystalline panel, the simulated power output, voltage, and current of the entire panel decreased.

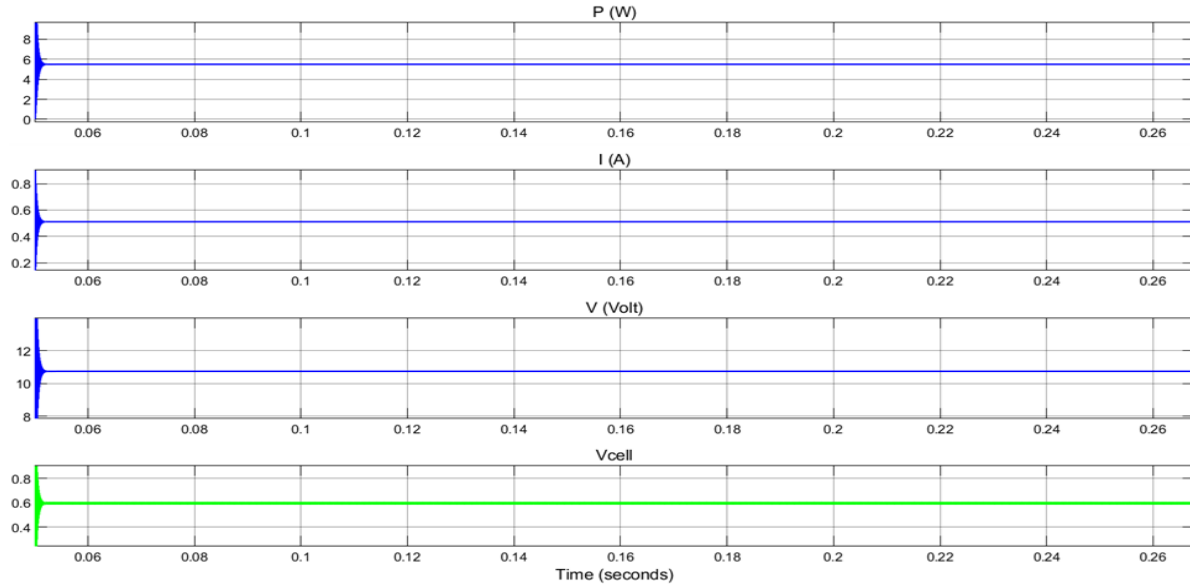


Fig. 12. Power P (W), current I (A), panel voltage V (Volt), and cell voltage V_{cell} without the hot spot of the monocrystalline panel

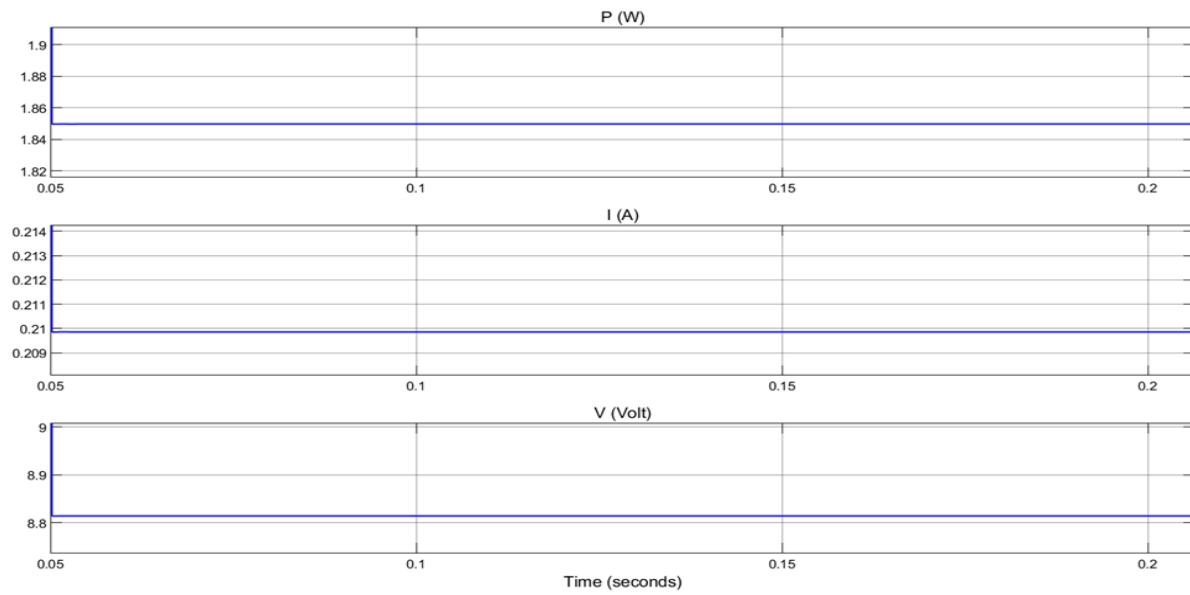


Fig. 13. Power P (W), current I (A), and panel voltage V (Volt) with the hot spot of the monocrystalline panel

Comparative Analysis of Experimental and MATLAB/Simulink Results

To explicitly evaluate the agreement between the field measurements and the MATLAB/Simulink model, a direct comparison was performed for weeks 12 and 16. These two weeks were selected because the measured environmental conditions were identical: solar irradiance of 970 W m^{-2} , ambient temperature of 39°C , relative humidity of 15%, and a wind speed of 3 m s^{-1} . The experimental power for each panel type was

calculated as the mean of the two degraded modules of the same type ($P1$ and $P2$ for polycrystalline panels; $M3$ and $M4$ for monocrystalline panels). The corresponding steady-state power values under hot-spot conditions were obtained from the existing MATLAB/Simulink plots (Figures 11 and 13). Because the raw numerical simulation output was not retained separately from the plotted results, the simulated values are reported as approximate values.

The comparison is presented in Figure 14 and Table 3. For the polycrystalline panels, the experimental mean power was 1.385 W in week 12 and 1.431 W in week 16, whereas the simulated steady-state power was approximately 2.53 W under hot-spot conditions. The resulting RMSE was 1.12 W, and the MAPE was 79.8%. For the monocrystalline panels, the experimental mean power was 0.841 W and 0.830 W in weeks 12 and 16, respectively, compared with a simulated value of approximately 1.85 W. The corresponding RMSE and MAPE were 1.01 W and 121.4%, respectively.

These results show that the MATLAB/Simulink model reproduces the

expected qualitative effect of partial shading and hot-spot formation, namely a reduction in the power output of the affected module; however, the model does not provide close quantitative agreement with the field measurements at the two selected time points. The larger difference is likely associated with the simplified representation of cell-level degradation and the difference between the idealised simulated hot-spot condition and the accumulated, module-specific degradation observed in the field experiment. Therefore, the simulation results should be interpreted as a parametric representation of hot-spot behaviour rather than as a fully validated prediction of the measured power output.

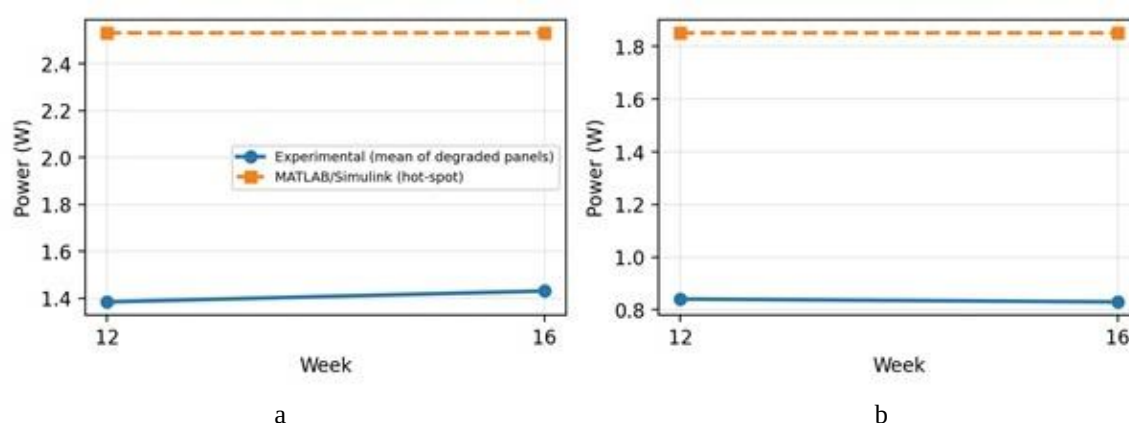


Fig. 14. Comparison of experimental and MATLAB/Simulink power at weeks 12 and 16 under identical atmospheric conditions: (a –Polycrystalline panels; b-Monocrystalline panels)

Table 3- Comparative analysis of experimental and MATLAB/Simulink power under hot-spot conditions

Panel type	Week	Experimental mean P (W)	Simulated P (W)	Absolute error (W)	Percentage error (%)
Polycrystalline	12	1.385	2.53	1.145	82.7
Polycrystalline	16	1.431	2.53	1.099	76.8
Monocrystalline	12	0.841	1.85	1.009	120.0
Monocrystalline	16	0.830	1.85	1.020	122.9

Conclusion

This study compared the severity of hot spot formation and the associated performance degradation in monocrystalline and polycrystalline PV panels subjected to partial shading for 17 weeks during the warm season in Ilam, Iran. The main findings are summarised as follows:

- Monocrystalline panels exhibited higher power output than polycrystalline panels

under normal operating conditions.

- Under the experimental shading conditions, the power output of the damaged monocrystalline panels decreased more markedly than that of the polycrystalline panels.
- Partial shading promoted localised overheating and hot spot formation in the affected cells.
- Thermal images captured using a

thermographic camera showed that the temperature of the damaged monocrystalline cells reached 75.5 °C, whereas that of the damaged polycrystalline cells reached 58.6 °C.

- Atmospheric conditions, particularly solar irradiance and ambient temperature, influenced the severity of hot spot formation and the electrical performance of the panels.
- Under the tested conditions, the presence of bypass diodes did not completely prevent hot spot formation in locally shaded areas.
- A direct comparison of the experimental and MATLAB/Simulink results at weeks 12 and 16 showed that the simulation reproduced the qualitative effect of hot-spot formation but overestimated the measured power. The RMSE was 1.12 W with a MAPE of 79.8% for the polycrystalline panels and 1.01 W with a MAPE of 121.4% for the monocrystalline panels; therefore, the model should be regarded as a qualitative/parametric representation rather than a fully validated quantitative predictor.
- Statistical analysis indicated that panel status and time significantly affected power output and current at the 1% significance level, whereas their effects on voltage were not statistically significant under the conditions examined.
- Under the climatic conditions of the experimental site, hot spot-related damage was observed earlier in the monocrystalline panel than in the polycrystalline panel.

Author Contributions

F. Darvishi: Data acquisition
 A. N. Lorestani: Supervision, Review and editing services
 R. Yeganeh: Technical advice
 M. Valizadeh: Technical advice

References

1. Ahmed, W., Ali, M. U., Mahmud, M. A. P., Niazi, K. A. K., Zafar, A., & Kerekes, T. (2023). A Comparison and Introduction of Novel Solar Panel's Fault Diagnosis Technique Using Deep-Features Shallow-Classifer through Infrared Thermography. *Energies*, 16(3), 1043. <https://doi.org/10.3390/en16031043>
2. Ahsan, S., Niazi, K. A. K., Khan, H. A., & Yang, Y. (2018). Hotspots and performance evaluation of crystalline-silicon and thin-film photovoltaic modules. *Microelectronics Reliability*, 88–90, 1014–1018. <https://doi.org/10.1016/j.microrel.2018.06.097>
3. Baharin, N. I., Yahaya, J. A. F., & Ahmad, M. Z. (2024). Reduction of hot-spot on solar PV array due to partial shading condition. *Evolution in Electrical and Electronic Engineering*, 5(1), 348–357.
4. Dhimish, M., Theristis, M., & d'Alessandro, V. (2024). Photovoltaic hotspots: A mitigation technique and its thermal cycle. *Optik*, 300, 171627. <https://doi.org/10.1016/j.ijleo.2024.171627>
5. El-Shaer, A., Tadros, M. T. Y., & Khalifa, M. A. (2014). Effect of light intensity and temperature on crystalline silicon solar modules parameters. *International Journal of Emerging Technology and Advanced Engineering*, 4(8), 311–318.
6. Farahmand, M. Z., Nazari, M. E., Shamlou, S., & Shafie-khah, M. (2021). The simultaneous impacts of seasonal weather and solar conditions on PV panels electrical characteristics. *Energies*, 14(4), 845. <https://doi.org/10.3390/en14040845>
7. Gulnz, S. W., Preu, R., & Biro, D. (2012). Crystalline silicon solar cells: State-of-the-art and future developments. In *Comprehensive renewable energy* (Vol. 1, pp. 353–387). Elsevier. <https://doi.org/10.1016/B978-0-08-087872-0.00117-7>
8. Islam, M. (2019). *A comparative study and performance analysis of poly and mono Si photovoltaic modules* (Master's thesis, BRAC University). <http://hdl.handle.net/10361/13662>

9. Jiang, L., Cui, S., Sun, P., Wang, Y., & Yang, C. (2020). Comparison of monocrystalline and polycrystalline solar modules. In *2020 IEEE 5th Information Technology and Mechatronics Engineering Conference (ITOEC)* (pp. 341–344). IEEE. <https://doi.org/10.1109/ITOEC49072.2020.9141722>
10. Kalogirou, *Solar energy engineering: Processes and systems* (3rd ed.). Academic Press. <https://doi.org/10.1016/C2021-0-02041-1>
11. Kashika, B., Prem, P., & Vinod, K. Y. (2025). Optimizing bypass diode performance with modified hotspot mitigation circuit. *Solar Energy Materials and Solar Cells*, 280. <https://doi.org/10.1016/j.solmat.2024.113281>
12. Keskin, V., Khalejan, S. H. P. R., & Çıkla, R. (2021). Investigation of the shading effect on the performance of a grid-connected PV plant in Samsun/Turkey. *Journal of Polytechnic*, 24(2), 553–563. <https://doi.org/10.2339/politeknik.701525>
13. Numan, A. H., Hussein, H. A., & Dawood, Z. S. (2021). Hot spot analysis of photovoltaic module under partial shading conditions by using IR-imaging technology. *Engineering and Technology Journal*, 39(9), 1338–1344. <https://doi.org/10.30684/etj.v39i9.841>
14. Oufettoul, H., Lamdihibine, N., Motahhir, S., Lamrini, N., Abdelmoula, I. A., & Aniba, G. (2023). Comparative performance analysis of PV module positions in a solar PV array under partial shading conditions. *IEEE Access*, 11, 12176–12194. <https://doi.org/10.1109/ACCESS.2023.3237250>
15. Rabaia, M. K. H., Abdelkareem, M. A., Sayed, E. T., Elsaid, K., Chae, K. J., Wilberforce, T., & Olabi, A. G. (2021). Environmental impacts of solar energy systems: A review. *Science of The Total Environment*, 754, 141989. <https://doi.org/10.1016/j.scitotenv.2020.141989>
16. Setiabudi, D. H., Dinaryanto, O., Haris, A., & Mardwianta, B. (2024). Increasing solar radiation energy in equipment distillation to produce fresh water for airport. In *Proceedings of the 2023 Annual Technology, Applied Science and Engineering Conference (ATASEC 2023)* (pp. 174–184). Atlantis Press. https://doi.org/10.2991/978-94-6463-358-0_18
17. Siecker, J., Kusakana, K., & Numbi, E. B. (2017). A review of solar photovoltaic systems cooling technologies. *Renewable and Sustainable Energy Reviews*, 79, 192–203. <https://doi.org/10.1016/j.rser.2017.05.053>
18. Tripathi, A. K., Ray, S., Aruna, M., & Prasad, S. (2021). Evaluation of solar PV panel performance under humid atmosphere. *Materials Today: Proceedings*, 45(1), 5916–5920. <https://doi.org/10.1016/j.matpr.2020.08.775>
19. Singh, B., Jain, A. K., & Gupta, S. (2023). Simulation based analysis of the partial shading at different locations on polycrystalline PV array. *World Journal of Advanced Engineering Technology and Sciences*, 9(1), 045–053. <https://doi.org/10.30574/wjaets.2023.9.1.0135>
20. Umar, S., Qureshi, M. S., & Nawaz, M. U. (2024). Thermal imaging and AI in solar panel defect identification. *International Journal of Advanced Engineering Technologies and Innovations*, 1(3), 73–95.
21. Vishwakarma, S. (2017). Study of Partial shading effect on solar module using MATLAB. *International Journal of Advanced Research in Electrical, electronics and instrumentation engineering*, 6(7), 5303–5308. <https://doi.org/10.15662/IJAREEIE.2017.0607011>
22. Xu, T., Deng, S., Zhang, G., & Zhang, Z. (2021). Research on hot spot risk of high wattage solar modules. *Solar Energy*, 230(4), 583–590. <https://doi.org/10.1016/j.solener.2021.10.037>

ارزیابی اثرات پدیده نقطه داغ در پنل‌های فتوولتائیک تک کریستال و چند کریستال تحت شرایط آب و هوایی ایلام

فاطمه درویشی^۱، علی نجات لرستانی^{۱*}، رضا یگانه^۲، مجید ولیزاده^۳

تاریخ دریافت: ۱۴۰۵/۰۴/۱۰

تاریخ پذیرش: ۱۴۰۵/۰۶/۰۱

چکیده

سیستم‌های فتوولتائیک معمولاً به دلیل نداشتن قطعات متحرک، عمر طولانی دارند و به همین دلیل به گزینه‌ای جذاب برای کاربردهای مسکونی و صنعتی تبدیل می‌شوند. با این حال، عوامل متعددی ممکن است عمر مفید پنل‌های فتوولتائیک را کاهش دهند. این مطالعه به بررسی تأثیر افزایش دما ناشی از تابش خورشید بر انواع مختلف پنل‌های خورشیدی می‌پردازد. یکی از این عوامل، پدیده نقطه داغ (Spot Hot) است که در آن نقاط خاصی از پنل خورشیدی به دلیل قرار گرفتن طولانی مدت در معرض نور خورشید، افزایش دما را تجربه می‌کنند و منجر به کاهش برگشت‌ناپذیر توان خروجی می‌شوند. برای ارزیابی دقیق تأثیر شرایط آب و هوایی بر وقوع نقطه داغ، یک مطالعه میدانی با استفاده از پنل‌های خورشیدی تک کریستالی و چند کریستالی در دسته‌های مختلف طی یک دوره ۱۷ هفته‌ای در ماه‌های گرم در شهر ایلام، انجام شد. عملکرد پنل‌ها نیز در MATLAB/Simulink شبیه‌سازی شد تا تحلیل دقیق‌تری از نتایج به دست آید. علاوه بر این، از یک دوربین حرارتی برای بررسی شرایط حرارتی پنل‌ها در حالت نقطه داغ استفاده شد. یافته‌ها نشان داد که توان خروجی پنل‌های چند کریستالی ۱، چند کریستالی ۲، تک کریستالی ۳ و تک کریستالی ۴ تخریب‌شده به ترتیب ۰/۱۰۵، ۰/۱۰۴، ۰/۲۱۱ و ۰/۱۹۳ وات در طول دوره ۱۷ هفته‌ای کاهش یافته است. در مقابل، توان خروجی پنل‌های چند کریستالی ۵، چند کریستالی ۶، تک کریستالی ۷ و تک کریستالی ۸ سالم به ترتیب ۰/۴۷۴، ۰/۵۱۸، ۰/۶۶ و ۰/۶۶ وات افزایش یافته است. به طور کلی، نتایج نشان داد که نرخ تخریب ناشی از پدیده نقطه داغ در پنل‌های تک کریستالی بیشتر از پنل‌های چند کریستالی بود.

واژه‌های کلیدی: پنل‌های خورشیدی سیلیکونی کریستالی، سایه جزئی، شبیه‌سازی MATLAB، ماژول‌های فتوولتائیک، نقطه داغ

۱- گروه مهندسی مکانیک بیوسیستم، دانشکده کشاورزی، دانشگاه رازی، کرمانشاه، ایران

۲- گروه مهندسی مکانیک بیوسیستم، دانشکده کشاورزی، دانشگاه ایلام، ایلام، ایران

۳- گروه مهندسی برق، دانشکده فنی مهندسی، دانشگاه ایلام، ایلام، ایران

(*)- نویسنده مسئول: (Email: lorestani@razi.ac.ir)