International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Temperature-Induced Variations in Silicon Solar Cell Efficiency and Electrical Characteristics

Mohammedain Adm Alhgabo Belal [a], Salma Elmutwakil Ali Mohamed [a], Mona Ali Abdalrasool [b], Salma Adam Hassan Ali [c] ,Alobid Ali Khalid Awad Elkareem [d] ,Sakina Ibrahim Ali Abonaib [e], and Abdalsakhi Suliman Mohammed [f]

[a] *Kordfan University -Faculty of Education- Department of Physics, Sudan*
[b] *Al-Neelain University- Faculty of Science & Technology-Department of Material Science - Khartoum, Sudan*
[c] *Nyala University -Faculty of Education - Department of Physics, Nyala, Sudan*
[d] *Gulf of Saidra University Faculty of Education - Department of Physics- Libya*
[e] *Department of Physics, Faculty of Science and Arts, Albaha University, Almakhwah, The Kingdom of Saudi Arabia*
[f] *Al Neelain University -Renewable and Alternative Energy Researches Centre & Al-Neelain University- Faculty of Science & Technology - Department of Laser & Renewable Energy, Sudan*

DOI : https://doi.org/10.55248/gengpi.6.0425.14161

A B S T R A C T

The performance of silicon solar cells largely depends upon the temperature variations, which affect significant electrical parameters such as open-circuit voltage (Voc), short-circuit current (Isc), maximum power (Pmax), fill factor (FF), efficiency (η), and current density (Jsc). In this research, the effect of temperature on silicon solar cell I-V characteristics is explored by monitoring their response within a temperature range of 24°C to 50°C. Experimental results show a significant decline in Voc and efficiency with temperature rise mainly because of high intrinsic carrier concentration and recombination loss. Though Isc experiences minor fluctuations, the net outcome is lowered power and efficiency output. The study recommends the use of good thermal management practices to fight high-temperature performance loss. Moreover, new photovoltaic materials such as low-temperature coefficient perovskite and tandem solar cells provide promising paths toward improved thermal stability. The present work advises the solar cell optimization design and cooling system for maximum performance under practical operation conditions.

Keywords: Silicon Solar Cells, Temperature Effect, Photovoltaic Performance, Open-Circuit Voltage (Voc) and Energy Conversion Efficiency

Introduction:

Silicon solar cells have several applications in photovoltaic devices owing to their stability, efficiency, and low cost. The electrical parameters are extremely sensitive to the environment, particularly to the temperature change. Temperature changes, induced by the prolonged exposure of solar cells to sunlight, impact crucial electrical parameters such as current, output power, voltage, and overall energy conversion efficiency [1,2].

It is necessary to find out the temperature effect on the efficiency of the solar cells so they can be designed to meet the requirement for optimizing the photovoltaic system design improvement for high ambient temperature applications [3,4]. The researchers have already determined that temperature variation impacts major performance parameters including open-circuit voltage (Voc), short-circuit current (Isc), maximum power (Pmax), fill factor (FF), efficiency (η), and current density (Jsc) [5,6]. It is seen to occur on an increase in temperature due to higher intrinsic carrier concentration and high recombination rates in the silicon material. Isc may, however, increase at mid-tolerant temperatures but decrease at high temperatures due to high recombination losses [7].

As photovoltaic systems operate under different climatic conditions, studies on the effect of temperature variation on solar cell efficiency are also of very high importance. Temperature variation degradation in performance can lead to efficient cooling techniques, new materials, and system design optimization for improved thermal stability [8,9]. Low-temperature coefficient photovoltaic materials such as perovskite and tandem solar cells also hold bright prospects for reducing degradation from temperature loss [10,11].

Temperature dependence of silicon solar cell I-V curves has been investigated by examining their electrical parameters at different operating temperatures. Conclusions derived from the variations of Voc, Isc, Pmax, FF, η, and Jsc are findings that result in valuable outcomes of the research as thermal limits of silicon photovoltaic technology. They can be utilized for solar cell improvement and energy efficiency method design, particularly at high temperatures.

MTHOD

For the experiment, a commercially available silicon solar cell was subjected to cyclic temperature to allow for electrical performance observation. The solar cell was integrated into an electric circuit with a voltmeter, ammeter, rheostat, and a variable light source that could emit standard solar radiation. For the study of the effect of temperature, the cell was placed under controlled heating conditions composed of a temperature-controlled heat source whose temperature setting was between 24°C to 50°C. Temperature changes were recorded and intermittent heating of the cell surface was maintained with a digital thermometer of ±0.1°C precision.

The solar cell was subjected to a continuous illumination of 1000 W/m² intensity light, the standard test condition. Current and voltage were measured at each step in temperature at 24°C, 35°C, 45°C, and 50°C using a high-accuracy digital multimeter. These tests presented the dominating electrical parameters including short-circuit current (Isc), open-circuit voltage (Voc), maximum power point (Pmax), fill factor (FF), efficiency (η), and current density (Jsc). These readings were taken three times to ensure reproducibility and accuracy, and respective averages were taken for measurement.

All measurements taken were compared by graphing I-V curves for different temperatures to search for trends and deviations in performance. Efficiency and power delivered were calculated using simple photovoltaic equations, comparing the outcome with theory as well as existing work. The paper highlights a review of the thermal performance of silicon solar cells and what effective cooling systems would need to provide improved efficiency at high levels of temperature.

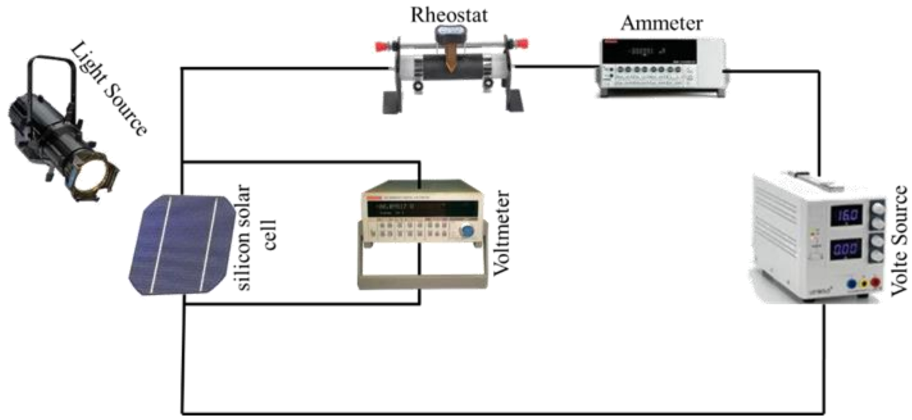

Fig. 1- Schematic diagram of IV circuit of thin film detector.

RESULT & DISCUSSION

Experimental results reveal a high interconnectedness between the temperatures and silicon solar cell performance. The most critical electrical parameters like the open-circuit voltage (Voc), short-circuit current (Isc), current density (Jsc), maximum power (Pmax), fill factor (FF), and efficiency (η) experience outstanding fluctuations at different temperatures. These fluctuations are proofs of silicon photovoltaic temperature limitations.

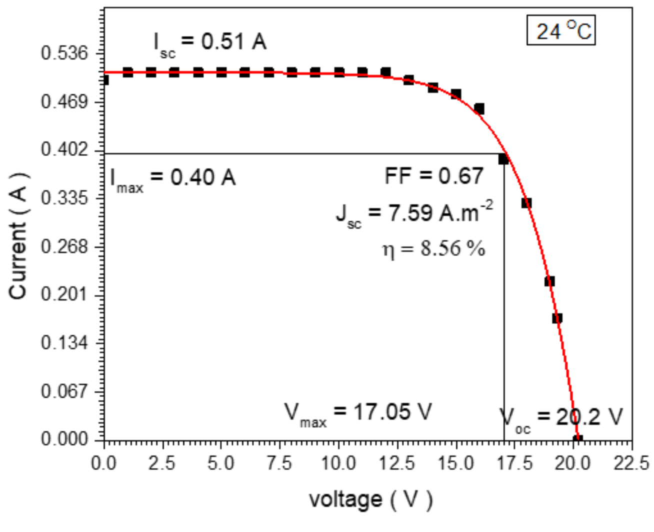

Fig. 2 - I–V curves of silicon solar cell at 24^{O}C temperature degree

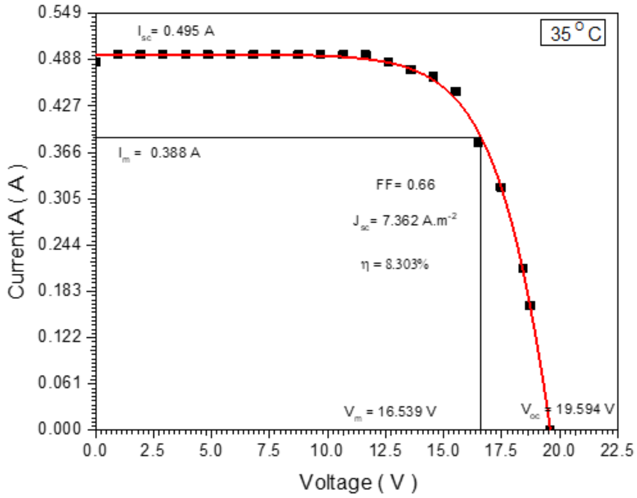

Fig. 3 - I–V curves of silicon solar cell at 35^{O}C temperature degree

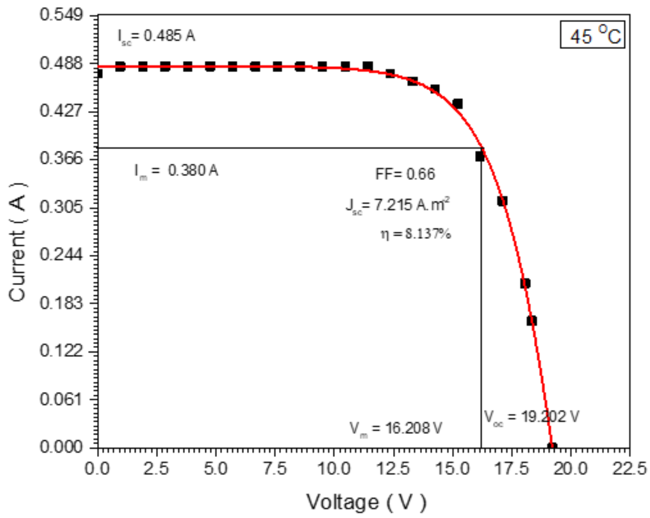

Fig. 4 - I–V curves of silicon solar cell at 45^{O}C temperature degree

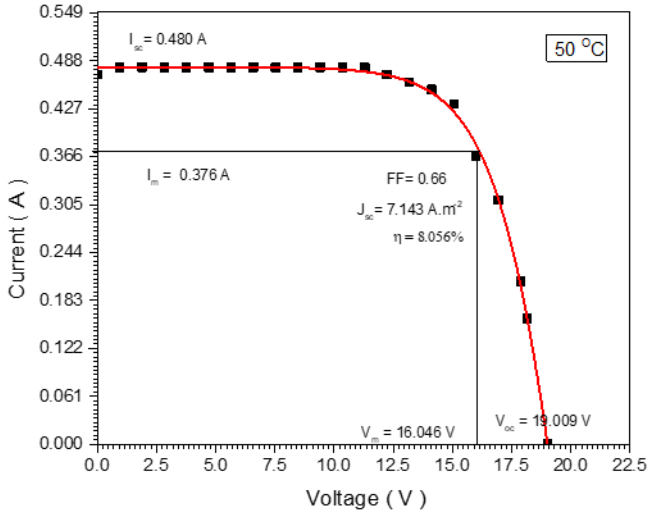

Fig. 5 - I–V curves of silicon solar cell at 50^{O}C temperature degree

Table 1 Cell Parameters effect by different temperature degrees (24,35,45 and 50) OC

	Temperature Degree (^{O}C)			
	24	**35**	**45**	**50**
Short Circuit Current Isc (A)	0.500	0.495	0.485	0.480
Maximal Current Im (A)	0.400	0.388	0.380	0.376
Maximal Voltage t Vm (V)	17.05	16.539	16.202	16.046
Open Voltage Voc (V)	20.200	19.594	19.202	19.009
Fill Factor FF	0.67	0.66	0.66	0.66
Density Current Jsc (mA.cm-2)	7.590	7.362	7.215	7.143
Efficiency η %	8.560	8.303	8.137	8.056

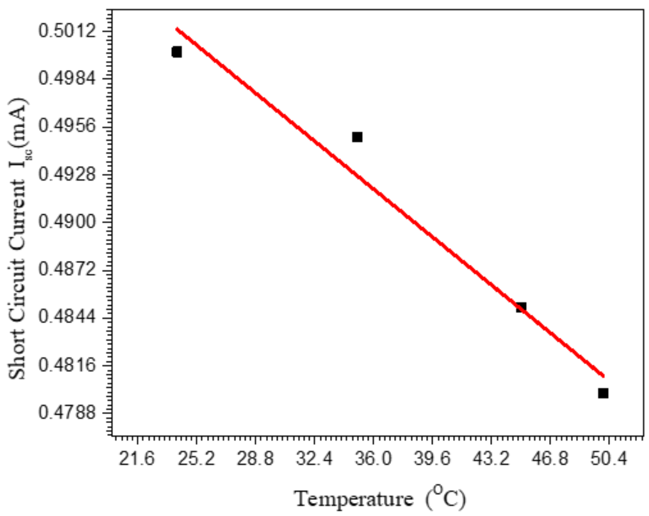

Fig. 6 - the relationship between temperature and short circuit current of silicon solar cell

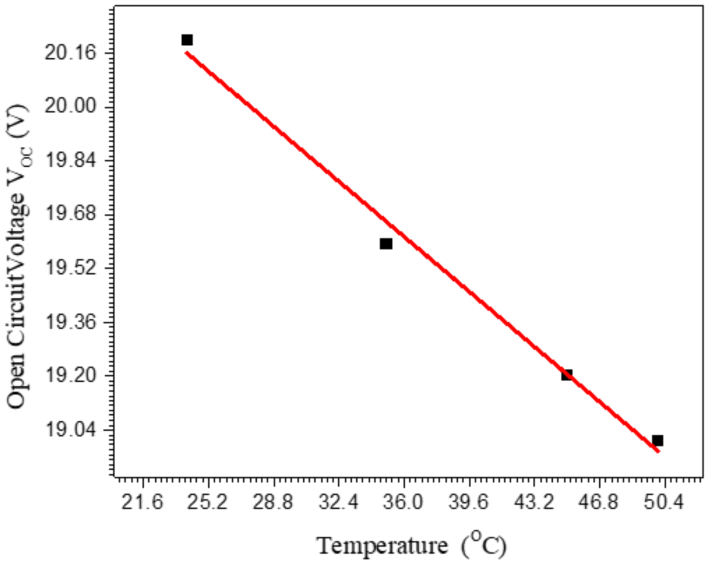

Fig. 7 - the relationship between temperature and versus open circuit voltage of silicon solar cell

DISCUSSION

The results indicate that Voc decreases linearly as temperature increases. The decrease is a result of the increased intrinsic carrier concentration; therefore, the charge carrier recombination rises, and the p-n junction built-in potential lowers [1,3]. The results confirm that Voc decreases from 20.2V at 24°C to 19.009V at 50°C, as agreed with the negative temperature coefficient of silicon solar cells. Since voltage determines the level of power being delivered, this reduction is also responsible for playing a large part in reducing the overall efficiency [13].

Isc is more dynamic in trend with the initial increase with moderate temperatures followed by the gradual fall with rising temperatures. This is to be attributed on the basis of massive generation of charge carriers due to thermal activation for small rises in temperature that is eventually dominated by rising recombination losses with rising temperatures. Although the Isc difference is of lesser magnitude than that of Voc, it also shares in the net loss of efficiency [14,15].

In contrast, Pmax reduces only when temperature increases. Since the maximum power output is a function of voltage and current, the reductions in Voc and Isc have a proportionate effect on Pmax. Methods of thermal management thus need to balance against power loss during high temperatures. The fill factor (FF), however, does not change much within the range of temperature, so resistive loss and inner impedance are not affected much by changing temperatures [16].

Efficiency (η) also decreases with increasing temperature, mainly due to the combined contribution of Voc and decrease in Pmax. The outcome reveals a decrease in efficiency from 8.56% at 24°C to 8.06% at 50°C, confirming the need for proper cooling systems in real applications. Also, Jsc decreases consistently from 7.59 mA/cm² to 7.143 mA/cm² with increasing temperature, further proving the adverse influence of excess heat on charge carrier kinetics [17,18].

These findings align with the literature, wherein silicon solar cell operation is adversely affected by temperature. Comparison to contemporary literature indicates that the existing understanding of the known temperature sensitivity of silicon photovoltaics places additional emphasis on developing new materials exhibiting improved thermal stability, such as perovskite and tandem solar cells. Cooling structure integration, material content optimization, and new photovoltaic architectures can minimize the negative effect of temperature fluctuation on the solar energy conversion process [19,20].

CONCLUSION

This study confirms temperature as a leading parameter in the electrical performance of silicon solar cells. Reduction in open-circuit voltage and overall efficiency with increasing temperature are proofs of the inherent thermal sensitivity of silicon photovoltaics. Short-circuit current didn't undergo harsh fluctuation even though, whereas the overall trend indicates reduced performance with increased temperatures. Reduction in the maximum power generated and efficiency validates thermal control mechanisms in the practical usage of solar cells.

To overcome the adverse impact of thermal fluctuation, future research has to improve coalescence of cold systems, cell design optimization, and novel photovoltaic material having improved thermal stability. Past studies on thermally stable technologies such as perovskite and tandem solar cells are maybe a treasure trove of goldmines from which the solution is waiting to make solar energy devices work at an elevated temperature.

References

[1] A. S. Joshi et al., Temperature Effects on Photovoltaic Performance: A Comprehensive Review, Renewable and Sustainable Energy Reviews, vol. 135, 2021.

[2] P. Singh and N. M. Ravindra, Temperature Dependence of Solar Cell Performance—An Analysis, Solar Energy Materials and Solar Cells, vol. 101, pp. 36-45, 2012.

[3] S. Kumar et al., The Impact of Temperature on the Efficiency of Solar Photovoltaic Cells, Renewable Energy, vol. 152, pp. 681-691, 2020.

[4] H. Durmuş et al., Experimental Analysis of Temperature Coefficients in Different Photovoltaic Technologies, Solar Energy, vol. 217, pp. 182-191, 2021.

[5] J. H. Bhosale and S. A. Kulkarni, Review on Temperature Effects on Photovoltaic Performance and Cooling Strategies, Energy Reports, vol. 6, pp. 594-604, 2020.

[6] M. D. Kempe, Control of Temperature-Induced Degradation in PV Modules, Progress in Photovoltaics: Research and Applications, vol. 25, no. 7, pp. 623-635, 2017.

[7] A. Alami et al., Performance Loss of Photovoltaic Modules under Different Temperature Conditions, Journal of Renewable Energy, vol. 2021, Article ID 6632905, 2021.

[8] Y. J. Kim et al., Comparative Study on Temperature Coefficients of Perovskite and Silicon Solar Cells, Nano Energy, vol. 84, 2021.

[9] A. K. Pandey et al., Impact of Temperature on Energy Yield of Silicon and Thin-Film Solar Cells, Solar Energy, vol. 177, pp. 219-226, 2019.

[10] M. A. Green et al., Temperature Dependence of Solar Cell Performance and Implications for Future Technology, Nature Energy, vol. 4, pp. 329-337, 2019.

[11] J. Nelson, The Physics of Solar Cells, Imperial College Press, 2021.

[12] M. S. Abolhasani et al., Cooling Strategies for PV Modules to Mitigate Efficiency Loss Due to Heat, Solar Energy Materials & Solar Cells, vol. 234, 2022.

[13] M. F. Kotb et al., Enhanced Performance of Solar Cells Using Phase Change Materials for Thermal Management, Solar Energy Materials, and Solar Cells, vol. 240, 2022.

[14] L. Zhang et al., Temperature-Dependent Performance of Tandem Solar Cells, Advanced Energy Materials, vol. 11, no. 32, 2021.

[15] G. W. Crabtree and N. S. Lewis, Solar Energy Conversion: Challenges and Opportunities, Science, vol. 438, pp. 37-42, 2021.

[16] J. A. Gu et al., Photovoltaic Performance of Silicon Solar Cells under Extreme Temperature Conditions, Solar Energy, vol. 199, pp. 314-326, 2020.

[17] X. Zheng et al., Efficiency Degradation of Solar Cells due to Temperature: Mechanisms and Solutions, IEEE Journal of Photovoltaics, vol. 10, no. 5, pp. 1312-1321, 2020.

[18] F. Yakup et al., Analysis of Fill Factor in Solar Cells Under Different Temperature Conditions, Renewable Energy, vol. 157, pp. 523-534, 2020.

[19] S. A. Kalogirou, Solar Energy Engineering: Processes and Systems, Academic Press, 2022.

[20] L. E. Mundaca et al., Mitigating the Effects of Temperature in Silicon and Perovskite Solar Cells, Materials Today Energy, vol. 18, 2021.