Scientific Research Publishing

Journal of Power and Energy Engineering, 2025, 13(4), 23-32
https://www.scirp.org/journal/jpee
ISSN Online: 2327-5901
ISSN Print: 2327-588X

Determining the Efficiency of Solar Cells at Different Temperatures

Siham Muhammed Hassan[1,2*], Manahil Mohammed Baher Eldin Omer[3], Manahil E. E. Mofdal[3]

[1]Physics Department, Faculty of Science, Hafr Al Batin University, Hafr Al Batin, Saudi Arabia
[2]Physics Department, College of Education, Peace University, Al Fula, Sudan
[3]Physics Department, Faculty of Science, Qassim University, Buraydah, Saudi Arabia
Email: *sehemm@uhb.edu.sa, mohsiham45@gmail.com

How to cite this paper: Hassan, S.M., Omer, M.M.B.E. and Mofdal, M.E.E. (2025) Determining the Efficiency of Solar Cells at Different Temperatures. *Journal of Power and Energy Engineering*, **13**, 23-32.
https://doi.org/10.4236/jpee.2025.134003

Received: March 14, 2025
Accepted: April 26, 2025
Published: April 29, 2025

Abstract

The operating temperature plays a critical role in the photovoltaic conversion process. The electric output and power output of a photovoltaic (PV) module are linearly dependent on the operating temperature. It has been proposed that short-circuit current tends to increase with temperature. The results from this study are consistent with existing literature on the subject, like temperature and intensity. A temperature is considered one of the constraints and factors that influence the efficiency of a solar cell. The objectives of this research are to study the I - V Parameters of crystalline silicon solar cells, through different temperatures in the range 303 k - 311 k, solar cell performance is determined by its parameters, viz., short circuit current (I_{sc}), the open circuit voltage(V_{oc}), and the fill factor (FF) and efficiency (η), and graphical method of the output power of a solar module determination. The result clarifies that temperature has a significant effect on the solar cell parameters and it controls the quality and performance of silicon solar cells when temperature increases at 300˚C, 320˚C, 370˚C, and 380˚C, respectively; the efficiency of the solar cell decreases as temperature increased the values were be found in the range (10.1 to 9.7)% this approve that the high-temperature effect negatively on solar cell efficiency. The results show that the open circuit voltage, maximum power, fill factor, and efficiency decrease with temperature due to a reduction in the bandgap of silicon solar cells, thereby affecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is therefore needed to break the bond. In the bond model of a semiconductor bandgap, a reduction in the bond energy also reduces the bandgap. The operating temperature plays a key role in the photovoltaic conversion process. Both the electric and the power output of a photovoltaic (PV) module depend linearly on the operating temperature. The various correlations proposed as short circuit currents increase with temperature. The results are in good agreement with the available literature.

Keywords

Silicon Solar Cell, Temperature Effect, Efficiency

1. Introduction

The trend in Saudi Arabia in the last two decades has been to optimize the power generated using fossil fuels with backup systems such as renewable solar energy. This is mainly due to the significant increase in electricity demand, the growth in population, industrialization, and urbanization. Thus, the government has decided to exploit the attractive solar energy potential of Saudi Arabia as an alternative energy source. Another reason for the shift towards renewable energy resources is the increasingly restrictive environmental regulations. Under the current circumstances, renewable energy can provide substantial environmental benefits by significantly reducing the emission of carbon dioxide and greenhouse gases. Renewable energy resources have been gaining increasing attention worldwide as the world transitions from reliance on fossil fuels to sustainable energy systems. The recent rapid growth of renewable resources in the electricity sector has been driven by several factors, including the significant reduction in system costs and the establishment of dedicated national policies and initiatives for implementing renewable energy [1]. Solar energy is one of the most effective, sustainable, available, and eco-friendly renewable energy sources, is clean, free of carbon emissions, continuous, and low cost, quickly becoming a mainstream energy supply [2]. In 1839, Becquerel discovered the PV effect. When light falls on electrolytic cells, solar cells were developed in the 1950s. Crystalline Si was used in different fields, especially in satellites, with an efficiency between 6% – 10%. During the energy crisis in the 1970s, researchers developed (R&D) for PV [3]. Solar cells are semiconductor devices, optoelectronic devices that convert solar energy directly into electricity through the phoelecrtic effect [4]. Some materials display a behavior known as the photoelectric effect that causes them to absorb photons of light and release electrons, these free electrons are captured, and an electric current results that can be used as electricity, as illustrated in **Figure 1**. Crystalline silicon solar cells (Si) have been the main material for photovoltaic (PV) cells for the previous two decades. Nonetheless, other low-cost semiconductor materials are better suited to absorb the solar energy spectrum [5]. The crystalline silicon cell is the most commonly used photovoltaic device on the market. Especially used for solar cells among low cost and a large area. There are so many technologies that produce energy, but all of these are harmful, but the only solar energy is environmentally friendly and non-toxic. In the photovoltaic industry, different materials are used in silicon, being the most popular candidate due to its easy availability, this silicon is further divided into some categories, such as amorphous, mono-crystalline silicon solar cells are made from single crystals. They are made by the Czochralski process as ingots with a maximum length of two meters and several hundred kilograms in weight, and they are made from the best silicones with high efficiency. But it's more costly, crystalline is the highest-performance solar material currently available. Conversion efficiency was found up to 40%, which is nearly double that of crystalline silicon. So it has a high prospect due to its high-efficiency disadvantage: Costly. And multi-crystalline is made from melting individual silicon crystals together. Unlike mono-crystalline-based solar panels, polycrystalline-based solar panels do not require the Czochralski process. This type of performance and lower cost made it popular and premier. Due to the lower purity of silicon, polycrystalline silicon is less effective than monocrystalline silicon. But is used as a raw material in the solar PV and electronics industry. Terrestrial applications.

Most silicon solar cells are made of crystalline material because of the excess of silicon in the earth, about 80%. These solid-state devices convert a portion of the solar spectrum into electricity [5] [6]. The trend in Saudi Arabia in the last two years has been to enhance the power generated using fossil fuels with backup systems such as renewable solar energy. This is essentially due to the significant increase in electricity demand due to population growth, and industrialization [7]. Saudi Arabia's distinct geographical and climatic locations help utilize renewable energy sources and diversify the local energy mix systems. The primary objective of this initiative is to increase this economy's share of clean energy production to satisfy its obligations toward reducing carbon emissions [8]. Many related works and research aim to study the effect of temperature on the performance of single crystalline silicon solar cells through different temperatures [9]. Also, the temperature performance of a photovoltaic (PV) silicon solar module working at constant irradiance, the graphical method of the output power of a solar module determination using photovoltaic behavior, the temperature influence on the light absorption mechanism, the spectral characteristic of the open-circuit voltage of a single crystalline silicon solar cell [10].

2. Theoretical Backroad

Solar panels generate electrical power by converting radiant energy to electricity through the photovoltaic effect. Solar panels consist of silicon-based semiconductor materials [11]. The solar cell performance is directly affected by the weather conditions, mainly the solar irradiance and temperature. The temperature coefficients of important parameters related to the cell property were discussed. Experimental results indicate that the T-coefficient of conversion efficiency (η) [12]. The silicon p-n junction exhibits its electrical properties as exposed to temperatures. This is because the band gap of the silicon solar cell is reduced by increasing its temperature. Therefore, a decrease in the band gap with temperature can increase the energy of the electrons in the p-n junction

[13]. Short Circuit I_{Sc} also increases simultaneously. In this case, the band gap of the PV cell shrinks 4, so a greater number of electrons could move easily from the valence band to the conduction band. Similar effects were observed with increases in solar irradiation. However, the open Circuit Voltage value decreases, because the solar cell p-n junction voltage effects of changing the operating temperature, and correspondingly the fill factor *FF* decreases [14]. The fill factor is the ratio of the power maximum and short current, open voltage, to the equation [15]. Solar panels generate electrical power by converting radiant energy to electricity through the photovoltaic effect. Solar panels consist of silicon-based semiconductor materials [11]. The solar cell performance is directly affected by the weather conditions, mainly the solar irradiance and temperature [12]. The silicon p-n junction exhibits electrical properties as exposed to temperatures. This is because the band gap of the silicon solar cell efficiency decreases as its temperature rises. Therefore, a decrease in the band gap with temperature can increase the energy of the electrons in the p-n junction [13]. Short Circuit I_{Sc} also increases simultaneously. In this case, the band gap of the PV cell shrinks 4, so a greater number of electrons could move easily from the valence band to the conduction band. Similar effects were observed with increases in solar irradiation. However, the open circuit Voltage value decreases, because the PV cell p-n junction voltage effects of changing the operating temperature, and correspondingly the fill factor *FF* [14]. The fill factor is calculated by the ratio of the maximum power ($P_{\max}$) and short current and open voltage of a corroding to Equation (2) and the *efficiency* of the solar cell is calculated by the ratio of maximum power generated versus incoming power obtained Equation (3). The incoming solar intensity Pin is 11,000 W/m^2 of spectrum 1.5 AM [15].

$$P_{\max} = I_{\max} \times V_{ma} \tag{1}$$

$$FF = \frac{P_{\max}}{V_{oc} \times I_{sc}} \tag{2}$$

$$Efficiency\left(\acute{\eta}\right) = \frac{V_{oc} \times I_{sc} \times F}{P_{in}} \tag{3}$$

3. Materials and Methods

In this study, data were collected by using different materials and methods to perform the experiments, it was necessary to use the required.

3.1. Materials

1) The solar panel description in Table 1.
2) Voltmeter.
3) Ammeter.
4) Connected wire.
5) Resistance box.

Table 1. Solar cell description.

Description	Value
Module Solar Module Type	*SYK* 20-18 *P*
Maximum Power (P_{max})	20 W
Open-Circuit Voltage (V_{oc})	21.24
Short-Circuit Current (I_{sc})	1.22 A
Voltage at P_{max} (V_mp)	18 V
Current at Prnax (I_(mp))	1.11 A
Power Tolerance ± 3% Maximum System	1000 V
Dimensions (mm)	480*350*25
Test condition:	$AM -1.5; E = 1000\ \text{W}/\text{m}^2$

3.2. Methods

An experimental setup is seen in **Figure 2**. Where does **Figure 3** explain the solar cell circuit of current-voltage characteristics? As the solar panel is exposed directly to sunlight, the current and voltage recording during this is controlled by the shunt resistance (R_{sh}), mainly changing the resistance. This step is repeated many times through different temperatures, 303, 305, 309, and 310 K within 2 dies; the data of the plotting is depicted in **Figure 3** and **Figure 4**, and the I - V curves are drawn below, then the short current and open voltage circuit are justified [16].

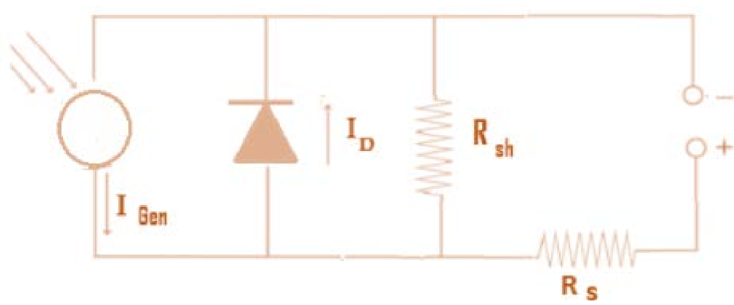

Figure 1. Equivalent circuit of a solar cell.

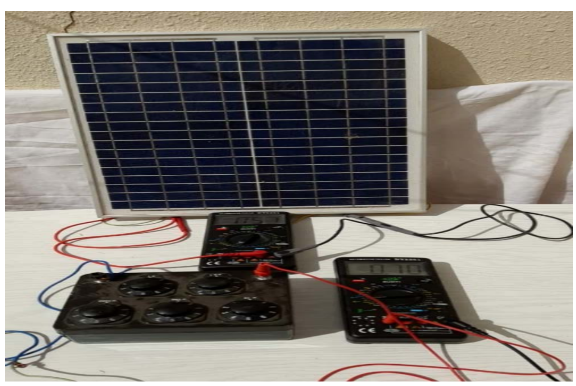

Figure 2. Experimental setup.

4. Result and Discussion

The data obtained in Table 2 and Table 3 showed the I -V characteristic and the behaviors of Silicon Solar Cell through different temperatures 30˚C, 32˚C, 37˚C and 38˚C respectively, current mainly decreased as temperature increased, corresponding to semiconductor behaviors, that agreed to [3]-[5]. Also explain the maximum value of current and volt (I_m and V_m), open voltage (V_(oc)), and short current (I_{sc}) were achieved as shown in Table 4. Regarding Figure 3, also, from Figure 4 and Table 3, the maximum power (P_max) increased slightly as the voltage increased to a certain value, then decreased, from Equation (1) the fill factor (FF) was found to be in the range of 69.1 to 74. The efficiency of silicon solar cell (η) was calculated according to Equation (3) and found that efficiency was decreased slowly as temperature increased as shown in Figure 5, this confirms the relation between intense radiation with temperature regarding to metallic behaviors of silicon, this agreement with the values of solar cell efficiency decreased as temperature increased in the range of 10.1% to 9.7% as matching to [12]. Also, from Figure 4 and Table 3, the maximum power (P_max) increased slightly as the voltage increased until a certain value then decreased.

Table 2. I - V characteristics of silicon solar cell for current at different temperatures.

Voltage (v)	Current (A)			
	I_1 (A)	I_2 (A)	I_3 (A)	I_{34} (A)
	30˚C	32˚C	37˚C	38˚C
0.5	0.48	0.43	0.38	0.37
1.1	0.48	0.43	0.38	0.36
6.6	0.43	0.48	0.38	0.36
13.8	0.47	0.428	0.38	0.36
17.3	0.46	0.42	0.35	0.34
20	0.40	0.38	0.29	0.27
20.7	0.38	0.32	0.27	0.255
21.6	0.33	0.28	0.26	0.23
22.7	0.26	0.21	0.17	0.19
22.9	0.21	0.18	0.16	0.15
22.9	0.20	0.17	0.15	0.154
23	0.19	0.16	0.15	0.14
23.1	0.19	0.16	0.15	0.14

Table 3. I - V characteristic of silicon solar cells for power at different temperatures.

Voltage (V)	power (W)			
	$P1$ (W)	$P2$ (W)	$P3$ (W)	$P4$ (W)
0.5	0.43	0.215	0.19	0.18
1.1	0.53	0.47	0.418	0.40

Continued

6.6	3.17	2.84	2.5	2.39
13.8	6.48	5.91	4.94	4.97
17.3	7.86	7.48	6.06	5.88
20	8.00	7.60	5.80	5.40
20.7	7.87	6.6	5.59	5.28
21.6	7.13	6.05	5.62	4.97
22.7	5.90	4.77	3.86	4.31
22.8	2.74	4.10	3.68	3.42
22.9	4.58	3.89	3.44	3.53
23	4.37	3.68	3.45	3.22
23.1	4.38	3.7	3.47	3.23

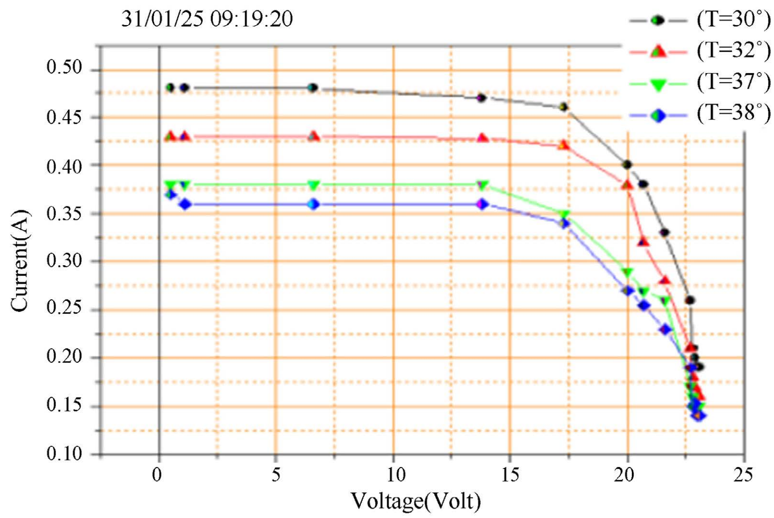

Figure 3. I - V characteristics of silicon solar cells at different temperatures.

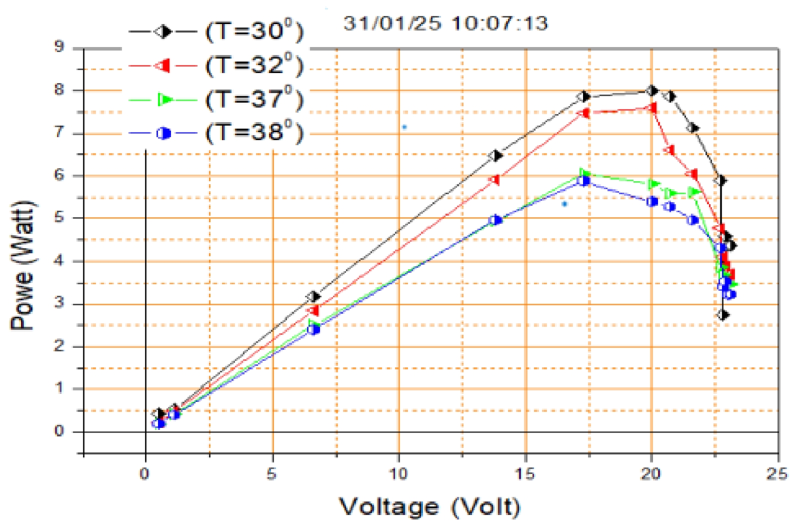

Figure 4. The power of silicon solar cells at different temperatures (t).

Table 4. Silicon solar cell parameters.

Temperature (˚C)	Solar Cell Parameters						
	I_{sc}	V_{oc}	I_{ma}	V_{max}	P_{max}	FF	η%
30	0.48	23.2	0.46	17.55	0. 807	0.73	10
32	0.43	23.1	0.42	17.51	0. 735	0.74	10.1
37	0.38	22.6	0.36	17.35	0.606	0.697	9.8
38	0.37	22.7	0.34	17.21	0. 594	0.691	9.7

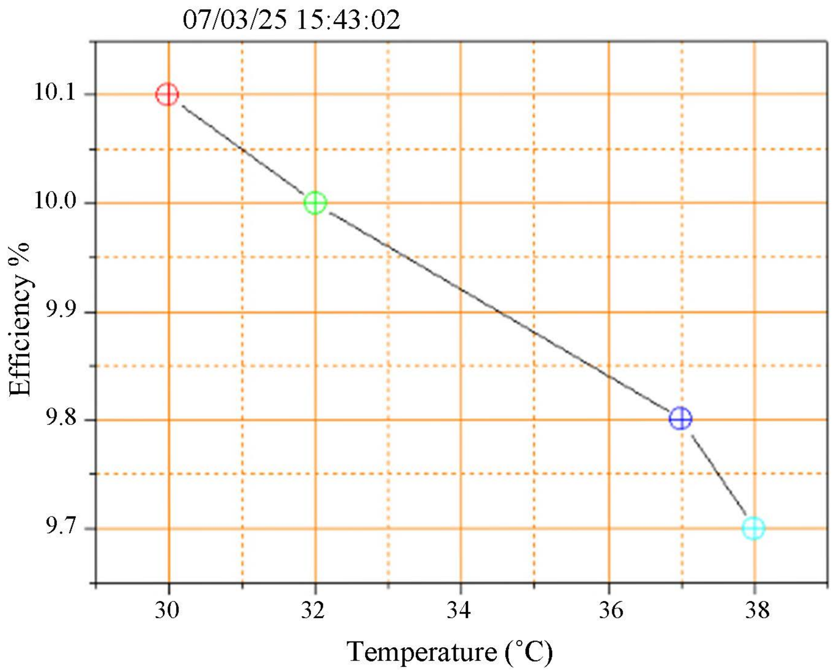

Figure 5. The efficiency of silicon solar cells through different temperatures.

5. Conclusions

The work explains the effect of temperature on the performance of the silicon solar cell and module. The heat generated, on the PV cell, due to internal resistance, affects the performance characteristics of the solar cell. The temperature coefficients of solar cells are investigated at different temperatures from 303 k to 311 k From the practical results show that temperature has a significant effect on the photovoltaics parameters and it controls the quality and performance of silicon solar cells and accurate knowledge of solar panel parameters from the measured I–V characteristics is important for the quality control and performance assessment of PV systems. The temperature dependence of performance parameters, V_{oc}, I_{Sc}, FF, and η of solar cells based on semiconductor material has been investigated in the temperature range of (30, 32, 37, and 38)˚C, verified by the experiment. The influence of temperature on the I - V characteristics, open voltage (V_{oc}), and short current (I_{sc}). With increasing temperature, I_{sc} increases, and therefore V_{oc} decreases, and hence the Solar cell efficiency as in between (9.7 - 10.1)%.

Acknowledgements

The author would like to thank and appreciate the Qassim University Faculty of Science Physics Department, great thanks to Hafer Al-Batin University College of Science and Technology of Nariyah.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] AlOtaibi, Z.S., Khonkar, H.I., AlAmoudi, A.O. and Alqahtani, S.H. (2020) Current Status and Future Perspectives for Localizing the Solar Photovoltaic Industry in the Kingdom of Saudi Arabia. *Energy Transitions*, **4**, 1-9. https://doi.org/10.1007/s41825-019-00020-y

[2] Lin, H., Yang, M., Ru, X., Wang, G., Yin, S., Peng, F., *et al.* (2023) Silicon Heterojunction Solar Cells with up to 26.81% Efficiency Achieved by Electrically Optimized Nanocrystalline-Silicon Hole Contact Layers. *Nature Energy*, **8**, 789-799. https://doi.org/10.1038/s41560-023-01255-2

[3] Razykov, T.M., Ferekides, C.S., Morel, D., Stefanakos, E., Ullal, H.S. and Upadhyaya, H.M. (2011) Solar Photovoltaic Electricity: Current Status and Future Prospects. *Solar Energy*, **85**, 1580-1608. https://doi.org/10.1016/j.solener.2010.12.002

[4] Faheem, F., Arsalan, M. and Khan, M.E. (2023) Recent Developments of Nanocomposites in Energy-Related Applications. In: Khan, M.E., Aslam, J. and Verma, C., Eds., *Nanocomposites-Advanced Materials for Energy and Environmental Aspects*, Elsevier, 111-127. https://doi.org/10.1016/b978-0-323-99704-1.00023-0

[5] Singh, P. and Ravindra, N.M. (2012) Temperature Dependence of Solar Cell Performance—An Analysis. *Solar Energy Materials and Solar Cells*, **101**, 36-45. https://doi.org/10.1016/j.solmat.2012.02.019

[6] Ghani, F., Rosengarten, G., Duke, M. and Carson, J.K. (2015) On the Influence of Temperature on Crystalline Silicon Solar Cell Characterisation Parameters. *Solar Energy*, **112**, 437-445. https://doi.org/10.1016/j.solener.2014.12.018

[7] Rashwan, S.S., Shaaban, A.M. and Al-Suliman, F. (2017) A Comparative Study of a Small-Scale Solar PV Power Plant in Saudi Arabia. *Renewable and Sustainable Energy Reviews*, **80**, 313-318. https://doi.org/10.1016/j.rser.2017.05.233

[8] Samargandi, N., Monirul Islam, M. and Sohag, K. (2024) Towards Realizing Vision 2030: Input Demand for Renewable Energy Production in Saudi Arabia. *Gondwana Research*, **127**, 47-64. https://doi.org/10.1016/j.gr.2023.05.019

[9] Fébba, D.M., Rubinger, R.M., Oliveira, A.F. and Bortoni, E.C. (2018) Impacts of Temperature and Irradiance on Polycrystalline Silicon Solar Cells Parameters. *Solar Energy*, **174**, 628-639. https://doi.org/10.1016/j.solener.2018.09.051

[10] Radziemska, E. (2003) The Effect of Temperature on the Power Drop in Crystalline Silicon Solar Cells. *Renewable Energy*, **28**, 1-12. https://doi.org/10.1016/s0960-1481(02)00015-0

[11] Chandrasiri, S. (2017) Temperature Effect on Solar Photovoltaic Power Generation. Master's Thesis, University of Sri Jayewardenepura.

[12] Adeeb, J., Farhan, A. and Al-Salaymeh, A. (2019) Temperature Effect on Performance of Different Solar Cell Technologies. *Journal of Ecological Engineering*, **20**, 249-254. https://doi.org/10.12911/22998993/105543

[13] Azimi-Nam, S. and Farhani, F. (2017) Effect of Temperature on Electrical Parameters of Phosphorous Spin-on Diffusion of Polysilicon Solar Cells. *Journal of Renewable Energy and Environment*, **4**, 41-45.

[14] Dhass, A. D., Natarajan, E. and Lakshmi, P. (2014) An Investigation of Temperature Effects on Solar Photovoltaic Cells and Modules. *International Journal of Engineering Transaction B: Applications*, **27**, 1713-1722.

[15] Singh, P. and Ravindra, N.M. (2012) Temperature Dependence of Solar Cell Performance—An Analysis. *Solar Energy Materials and Solar Cells*, **101**, 36-45. https://doi.org/10.1016/j.solmat.2012.02.019

[16] Ahmed, Y. and Manahil, E.E. (2021) The Effect of Temperature and Solar Intensity on Performance of Commercial Silicon Solar Cell as Case Study En Nahud Town. *ARID International Journal for Science and Technology*, **4**, 167-180. https://doi.org/10.36772/arid.aijst.2021.489