# Decline in the performance of silicon solar cell parameters with the Ambient temperature in Baghdad

**Dr. Fouad Shaker Tahir**
**Mohammed S. Rasheed**
Applied of Science Department
University of Technology

## Abstract

In this paper, the effect of Baghdad climate ambient temperature dependence (indoor and outdoor) of the performance of solar cell in the temperatures range (5 $^{o}$C –70 $^{o}$C) had been studied. The solar cell performance is determined by its main important parameters, short circuit current ($I_{sc}$), open circuit voltage ($V_{oc}$), fill factor (F.F) and efficiency ($\eta_m$). The experimental results of the parameters of silicon solar cell showed that the conversion efficiency was decline when the temperature raised from optimal temperature.

**Keywords:** silicon solar cell, I-V characteristics, indoor parameters, outdoor parameters,

performance analysis, temperature effect.

## 1. Introduction

The basic idea of a solar cell is to convert light energy into electrical energy. The energy of light is transmitted by photons, small packets or quantums of light. Electrical energy is stored in electromagnetic fields, which in turn can make a current of electrons flow. Thus a solar cell converts light, a flow of photons, to electric current, a flow of electrons [1]. Solar cell is a semiconductor electrical junction device which absorbs and converts the radiant energy of sun-light directly and efficiently into electrical energy [2]. Solar cells may be used individually as light detectors, for example in cameras, or connected in series and parallel to obtain the required values of current and voltage for electric power generation. Most solar cells are made from single-crystal silicon and have been very expensive for generating electricity, but have found application in space satellites and remote areas where low-cost conventional power sources have been unavailable [3].

When photons are absorbed by matter in the solar cell, their energy excites electrons higher energy states where the electrons can move more freely. The perhaps most well-known example of this is the photoelectric effect, where photons give electrons in a metal enough energy to escape the surface. In an ordinary material, if the electrons are not given enough energy to escape, they would soon relax back to their ground states. In a solar cell however, the way it is put together prevents this from happening. The electrons are instead forced to one side of the solar cell, where the build-up of negative charge makes a current flow through an external circuit. The current ends up at the other side (or terminal) of the solar cell, where the electrons once again enter the ground state, as they have lost energy in the external circuit [4]. Solar cell at present furnishes the most important long-duration power supply for satellites and space vehicles. Solar cells have also been successfully employed in small-scale terrestrial applications. As worldwide energy demand increases, conventional energy resources, such as fossil fuels, will be exhausted in the not-too-distant future. Therefore, we must develop and use alternative energy resources, especially our only long-term natural resource, the sun. The solar cell is considered a major candidate for obtaining energy from the sun, since it can convert sunlight directly to electricity with high conversion efficiency, can provide nearly permanent power at low operating cost, and is virtually free of pollution. Recently, research and development of low-cost, flat-panel solar cells, thin film devices, concentrator systems, and many innovative concepts have in-creased. In the near future, the costs of small solar-power modular units and solar-power plants will be economically feasible for large-scale use of solar energy [5].

## 2. Historical review

The solar cell was first developed by Chapin, Fuller, and Pearson in 1954 using a diffused silicon p-n junction [6]. Subsequently, the cadmium-sulfide solar cell was developed by Raynolds et al [7]. To date, solar cells have been made in many other semiconductors, using various device configurations and employing single-crystal, polycrystalline, and amorphous thin-film structures. Hovel has given a comprehensive treatment on basic solar-cell characteristics [8]. Backus has compiled a volume of classic papers on solar cells prior to 1974 [9]. Pulfrey and Johnson have reviewed the photovoltaic power generations [10,11], and Bachmann has discussed the material aspects of solar cell [12]. The most current literature can be found in the conference Records of the photovoltaic Specialists Conference [13,14]. The goal of this work is to study of the effect of Baghdad climate temperature on a single silicon solar cell performance.

## 3. Voltage and Current Characteristics

Two important quantities to characterize a solar cell are:, **1.** Open circuit voltage ($V_{oc}$): The voltage between the terminals when no current is drawn (infinite load resistance), **2.** Short circuit current ($I_{sc}$): The current when the terminals are connected to each other (zero load resistance) [15]. The short circuit current increases with light intensity, as higher intensity mean more photons, which in turn mean more electrons. Since the short circuit current $I_{sc}$ is roughly proportional to the area of the solar cell, the short circuit current density, ($J_{sc} = I_{sc}/A$), is often used to compare solar cells. When a load is connected to the solar cell, the current decreases and a voltage develops as charge builds up at the terminals. The resulting current can be viewed as a superposition of the short circuit current, caused by the absorption of photons, and a dark current, which is caused by the potential built up over the load and flows in the opposite direction. As a solar cell contains a PN-junction (LINK), just as a diode, it may be treated as a diode. For an ideal diode, the dark current density is given by [16]:

$$J_{dark}(V) = J_o\left(e^{qV/K_BT} - 1\right) \quad \ldots(3.1)$$

Here $J_0$ is a constant, q is the electron charge and V is the voltage between the terminals. The resulting current can be approximated as a superposition of the short circuit current and the dark current:

$$J = J_{sc} - J_o\left(e^{qV/K_BT} - 1\right) \quad \ldots(3.2)$$

To find an expression for the open circuit voltage, Voc, we use (1.2) setting J = 0. This means that the two currents cancel out so that no current flows, which exactly is the case in an open circuit. The resulting expression is:

$$V_{oc} = \frac{k_BT}{q}\ln\left(\frac{J_{sc}}{J_o}\right) + 1 \quad \ldots(3.3)$$

## 4. Efficiency

In general, the power delivered from a power source is P = IV, i.e. the product of voltage and current. If we instead use the current density J, we get the power density [17,18,19,20]:

$$P_d = J\,V \quad \ldots(4.1)$$

The maximum power density occurs somewhere between V = 0 (short circuit) and V = $V_{oc}$ (open circuit) at a voltage $V_m$. The corresponding current density is called $J_m$, and thus the maximum power density is $Pd_{,m} = J_m V_m$. The efficiency of a solar cell is defined as the power (density) output divided by the power (density) output. If the incoming light has a power density $P_s$, the efficiency will be [16,17,21]

$$\eta = \frac{J_m V_m}{P_s} \quad \ldots(4.2)$$

The fill factor, FF, is another quantity which is used to characterize a solar cell. It is defined as [22]

$$FF = \frac{J_m V_m}{J_{sc} V_{oc}} \quad \ldots(4.3)$$

and gives a measure of how much of the open circuit voltage and short circuit current is "utilized" at maximum power. Using FF we can express the efficiency as [16,19,17,23]:

$$\eta = \frac{J_{sc}\,V_{oc}\,FF}{P_s} \quad \ldots(4.4)$$

The four quantities $J_{sc}$, $V_{oc}$, FF and η are frequently used to characterize the performance of a solar cell. They are often measured under standard lighting conditions (SLC), which implies Air Mass (AM 1.5) spectrum, light flux of 1000 $W/m^2$ and temperature of 25°C.

## 5. Equivalent circuit of a solar cell

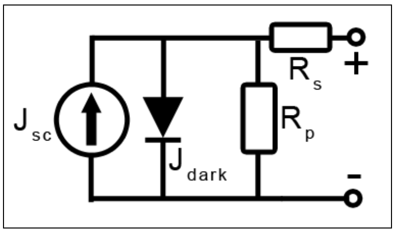



Fig. (1) Simple equivalent circuit for a solar cell [13,16,].

Fig. (1) illustrate the equivalent circuit for a solar cell, The solar cell can be seen as a current generator which generates the current (density) $J_{sc}$. The dark current flows in the opposite direction and is caused by a potential between the + and - terminals. In addition you would have two resistances; one in series ($R_s$) and one in parallel ($R_p$). The series resistance is caused by the fact that a solar cell is not a perfect conductor. The parallel resistance is caused by leakage of current from one terminal to the other due to poor insulation, for example on the edges of the cell. In an ideal solar cell, you would have $R_s = 0$ and $R_p = \infty$.

## Experimental Details

Solar cell on the building roof will suffer from the wide variety of operating temperatures [24]. Thus it is imperative to study of the effect of ambient temperature on the solar cell parameters. Also, this effect is taken into account when the solar cell parameters are determined. Reverse saturation current ($I_o$) is an important parameter which controls the change in performance parameters with temperature. Moreover, temperature changes are more suitable to describe the performance of solar cell. This solar cell has (AM 2) with conversion efficiency and the total cell was (100 $cm^2$ area). The output power extracted from the cell was delivered to the resistive load. The terminals of the load resistance nil and infinity correspond to the $I_{sc}$ and $V_{oc}$ respectively. From pW (peak watt) , $\eta_m$ was calculated and the ratio of pW and ($I_{sc}$ $V_{oc}$) represent FF was evaluated from the curve PV performance. The experimental set-up of this technique is shown in Fig. (1). All the above measurements were repeated in the indoor and outdoor at a different temperatures (T= 5.8 °C -70 °C). The equipments of this circuit were, solar cell, two digital multimeters (Victor 70C, DM-9960 utron), variable box resistance (Decade Resistance Box NV705-[1 Ω-100 MΩ]), halogen light source (100 $W/m^2$), digital light intensity meter (digital lux meter range (0-50000 Lux), Digital thermometer, (temperature meter DM68o1A). Fig. (2) shows the circuit set-up which is used in this paper.

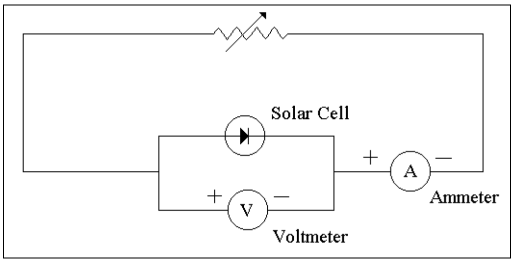



Fig. (2) gives the schematic setup for measuring the IV curve for a solar cell.

## Results and Discussion

### Solar Cell Indoor Calculations

### Solar Lab Indoor Data

This data was gathered using a 100 W halogen lamp (at high 30 cm vertical) construction workers light. The performance of solar cell is slightly variable, so the data should be approximately correct for whatever cell you are using. The calculated resistance in the 10$^{th}$ column includes the internal resistance of the solar cell. This increase in internal resistance does not occur if you use the solar cell outside. We attribute this increase in the internal resistance to the temperature increase in solar cell as a result of illumination with the halogen lamp. To monitor the effect of temperature on the solar cell, a temperature sensor was attached to the back of a couple of the cells. When illuminating the cell with the halogen lamp, the back of the cell reached approx (40 ºC to almost 60 ºC). The indoor data is shown in Table (1), and the relation between the current and voltage vs. the distance is shown in Fig (3[1-14]). In the Outdoors, the temperature cycled between approx (6 ºC with the (Rheostat at 0) to 70 ºC (Rheostat at 100%). The outdoor data obtained from the Table (2). The outdoor data is much smoother and open circuit voltage and maximum current will be higher.

Table (1): shows indoor calculations of the silicon solar cell parameters.

| Time (H) | $I_{sc}$ (mA) | $V_{oc}$ (mV) | $I_m$ (mA) | $V_m$(mV) | $P_m$ (W) | Pin (W/m$^2$) | F.F | $\eta_m$ % | $R_{cell}$ (ohm) | T cell ($^o$C ) |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.47 | 0.45 | 0.41 | 0.342 | 0.14022 | 10 | 0.663 | 1.4022 | 0.834 | 40 |
| 14 | 0.65 | 0.45 | 0.49 | 0.35 | 0.1715 | 10 | 0.5863 | 0.7149 | 0.714 | 60 |

Ten tests were performed in the month of April 2012, and results of only two of these are deplicated in table (1). Effecieny of single crystal silicon solar cell for this month ranges from (0.7 % - 0.8 %).

Fig. (4[1-2]) shows the relation between the distance

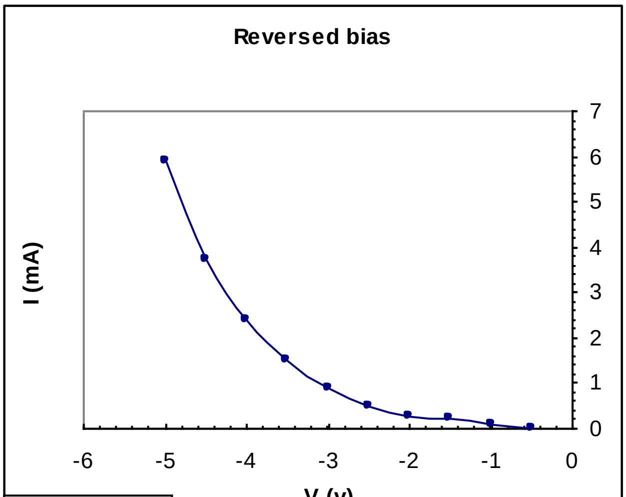



Fig. (3-1)

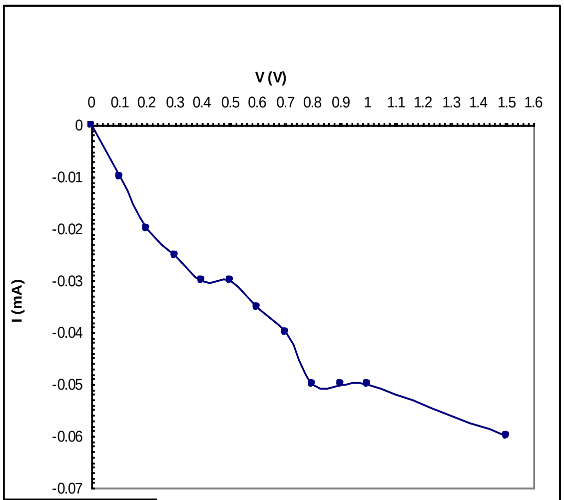



Fig. (3- Solar Cell-Reverse Bais ( I&V )

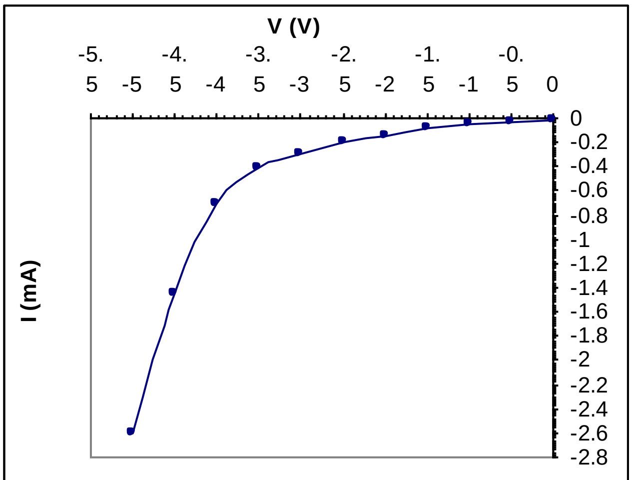



Fig. (3-3) Reversed bias

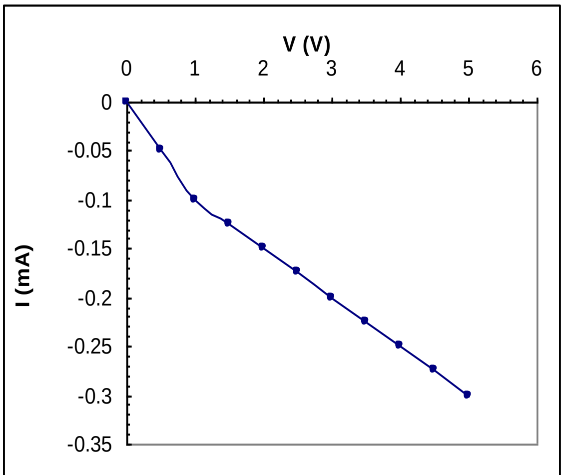



Fig. (3- Forward bias

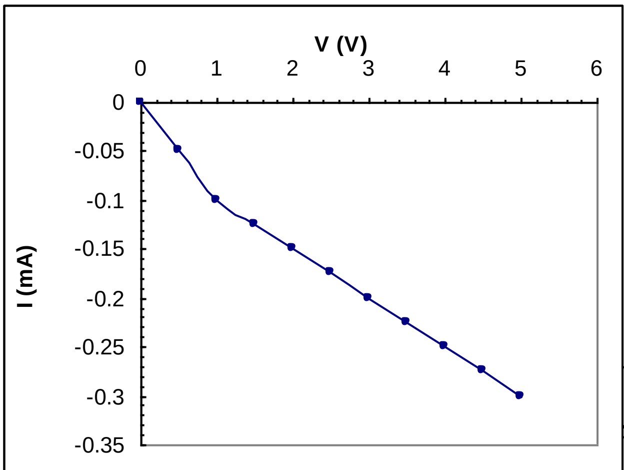



Fig. (3-5) Forward bias

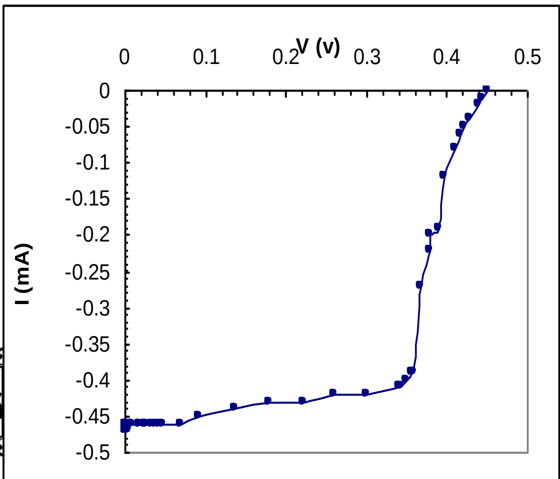



Fig. (3- Forward bias

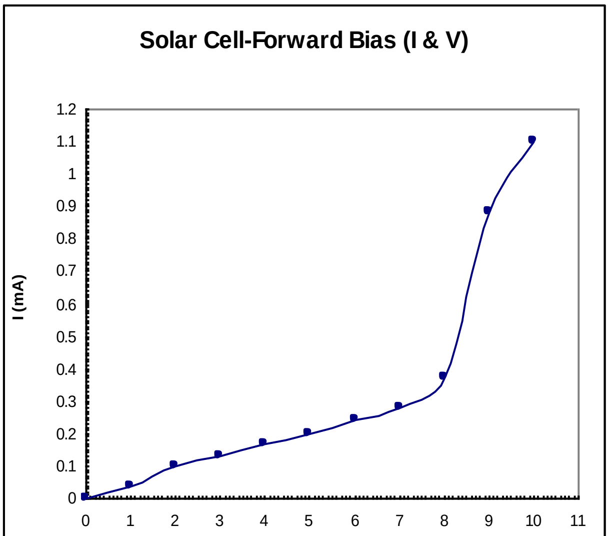


Fig. (3-7)

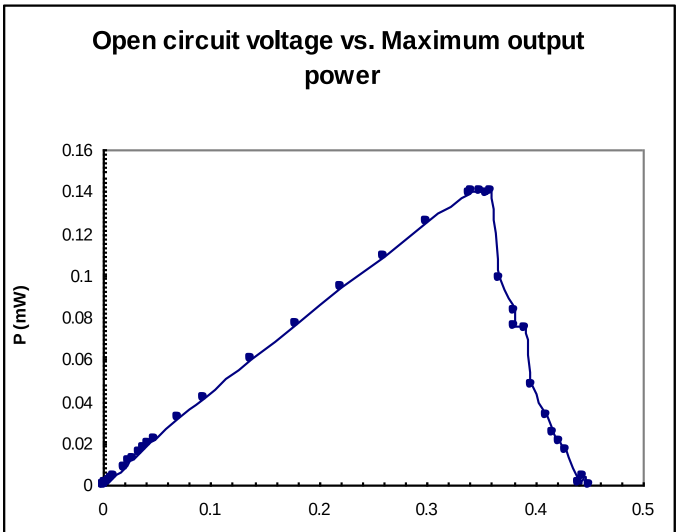


Fig. (3-8)

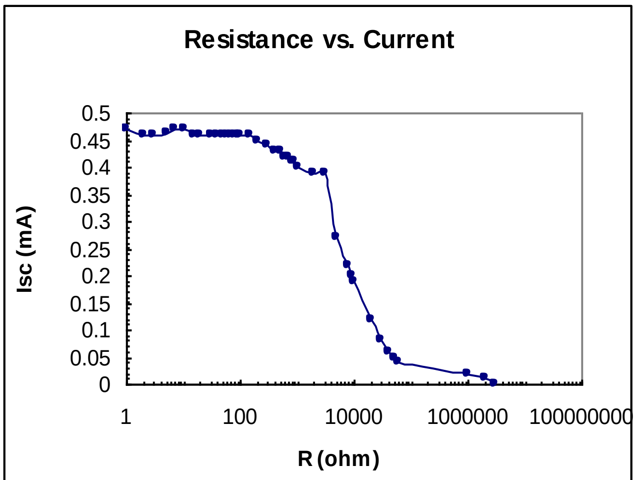


Fig. (3-11)

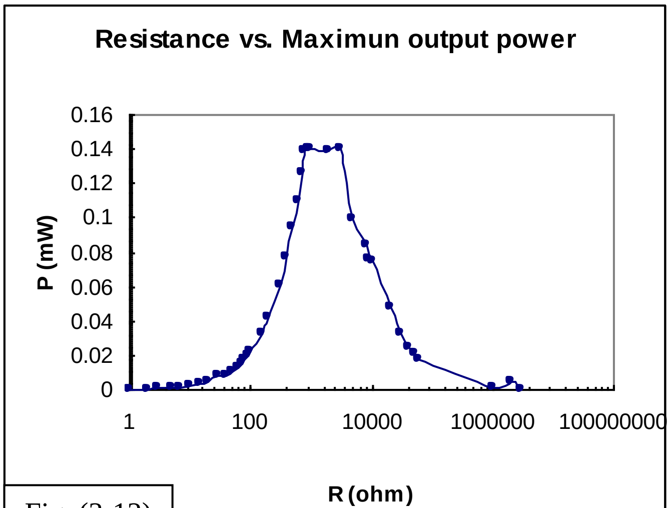


Fig. (3-12)

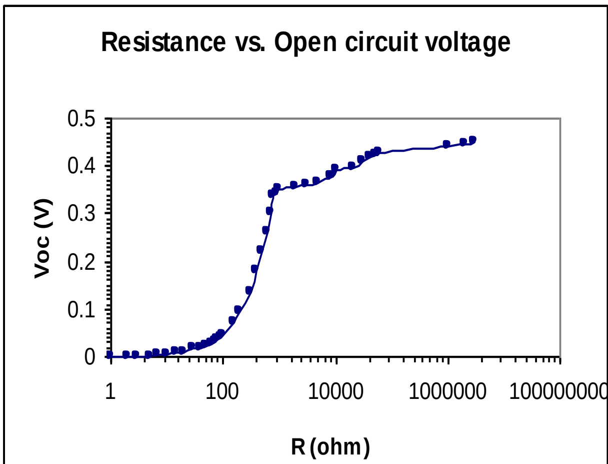


Fig. (3-9)

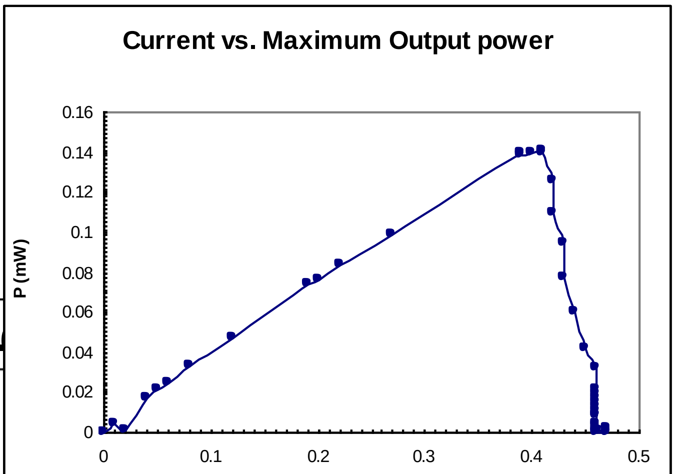


Fig. (3-10)

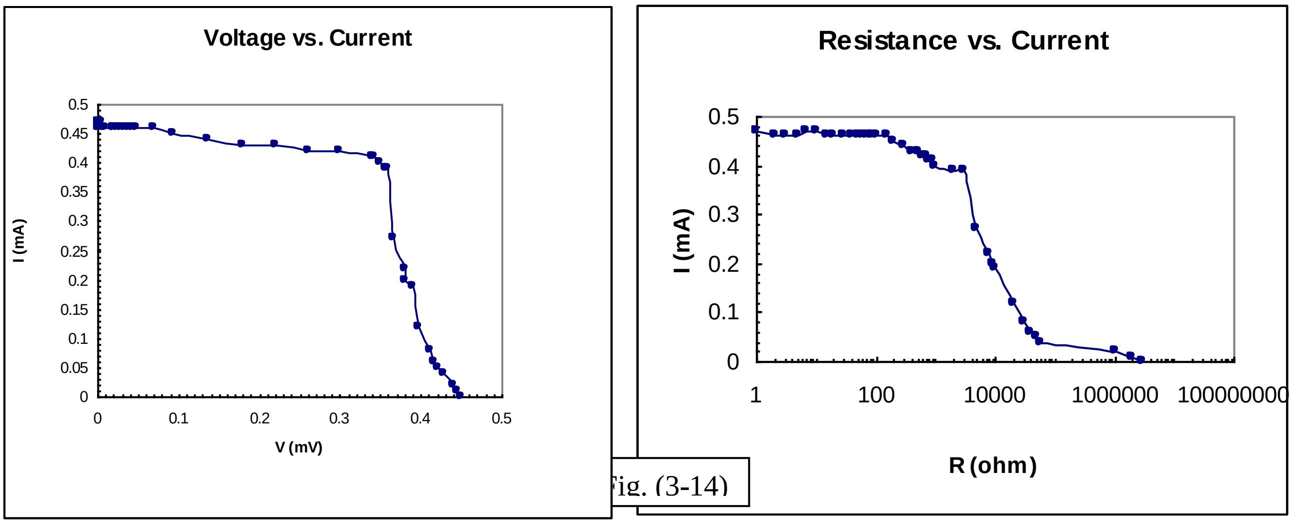



Fig. (3, [1-14]) the PV performance of the silicon solar cell, drawn in the forth quadrant to explain that the electrical power is extracted from the cell to the output circuit. The best results of $I_{sc}$ and $V_{oc}$ are obtainable at T= 5.8 °C and the input power $P_{in}$=100 mW/cm$^2$ in the outdoor calculations (see table ), Forward and reversed bias for the characteristics of the solar cell is obtained from this figure.

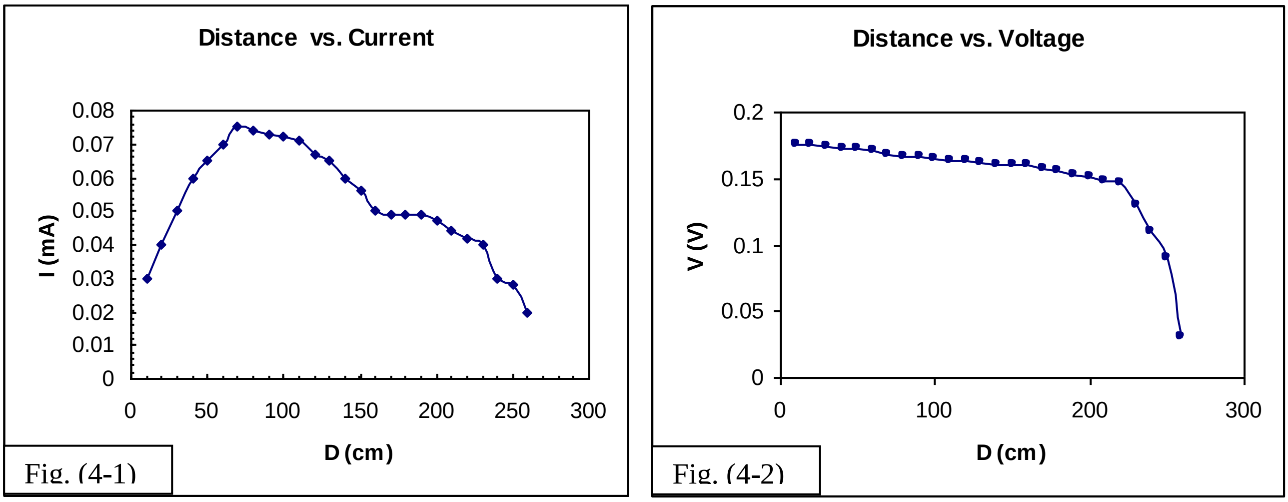



Fig. (4, [1-2]) the relation between the current and voltage with the distance from the solar cell (indoor Lab.).

## 2. Solar Cell Outdoor Calculations

The outdoor data is achieved and shown in the table (2), this table shown the main important parameters of the silicon solar cell. twenty tests were conducted in he month of April 2012. Effeciency for this month lies in the ranges (0.14 % - 2.012 %).

Table (2): shows outdoor calculations of the silicon solar cell parameters**.**

| Time (H) | $I_{sc}$ (mA) | $V_{oc}$ (mV) | $I_m$ (mA) | $V_m$ (mV) | $P_m$ (W) | Pin (W/m$^2$) | F.F | $\eta_m$ % | $R_{cell}$ (ohm) | T cell ($^o$C ) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 0.65 | 0.441 | 0.59 | 0.341 | 0.20119 | 10 | 0.7019 | 2.012 | 0.676 | 5.8 |
| 7 | 0.63 | 0.452 | 0.57 | 0.352 | 0.20064 | 15 | 0.7046 | 1.3376 | 0.717 | 10.6 |
| 8 | 0.61 | 0.473 | 0.55 | 0.373 | 0.20515 | 20 | 0.711 | 1.0257 | 0.775 | 15.7 |
| 9 | 0.52 | 0.485 | 0.46 | 0.385 | 0.1771 | 25 | 0.7022 | 0.7084 | 0.933 | 20.6 |
| 10 | 0.43 | 0.514 | 0.37 | 0.414 | 0.15318 | 30 | 0.6931 | 0.5106 | 1.195 | 27 |
| 11 | 0.37 | 0.535 | 0.31 | 0.435 | 0.13485 | 32.5 | 0.6812 | 0.4149 | 1.446 | 38.6 |
| 12 | 0.36 | 0.543 | 0.36 | 0.443 | 0.15948 | 35 | 0.8158 | 0.4556 | 1.508 | 42.5 |
| 13 | 0.35 | 0.567 | 0.29 | 0.467 | 0.13543 | 37.5 | 0.6824 | 0.3611 | 1.62 | 48.4 |
| 14 | 0.343 | 0.582 | 0.283 | 0.482 | 0.136406 | 40 | 0.6833 | 0.341 | 1.696 | 55.7 |
| 15 | 0.301 | 0.611 | 0.241 | 0.511 | 0.123151 | 36 | 0.6696 | 0.3421 | 2.029 | 60.6 |
| 16 | 0.26 | 0.622 | 0.2 | 0.522 | 0.1044 | 35 | 0.6456 | 0.2983 | 2.392 | 70 |
| 17 | 0.21 | 0.631 | 0.15 | 0.531 | 0.0797 | 32.5 | 0.6011 | 0.2451 | 3.004 | 65.3 |
| 18 | 0.14 | 0.635 | 0.08 | 0.535 | 0.0428 | 30 | 0.4814 | 0.1427 | 4.36 | 40.2 |

In this case, the relation between all (outdoor) solar cell parameters is shown in Fig. (5-[1-27]).

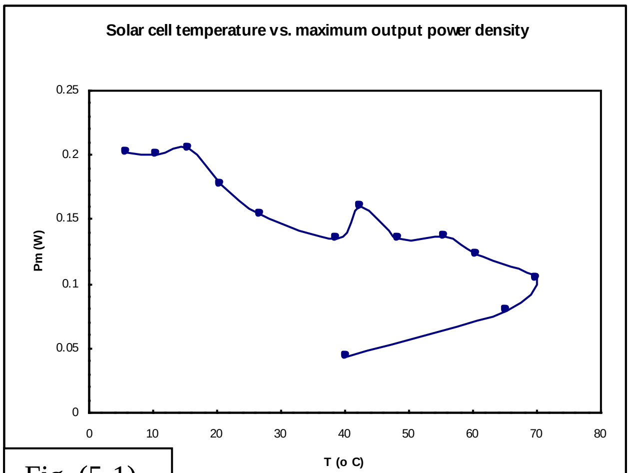



Fig. (5-1)

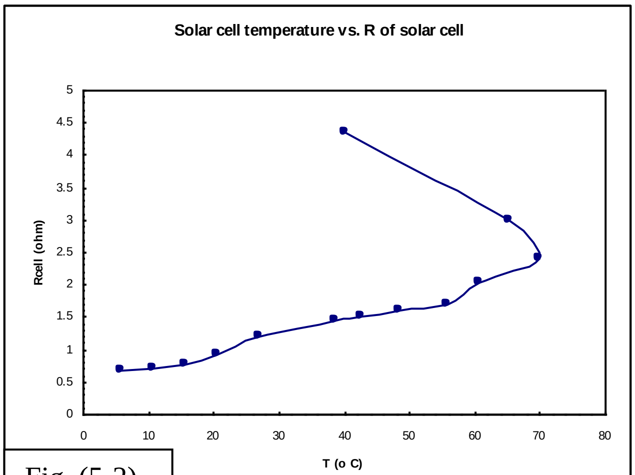



Fig. (5-2)

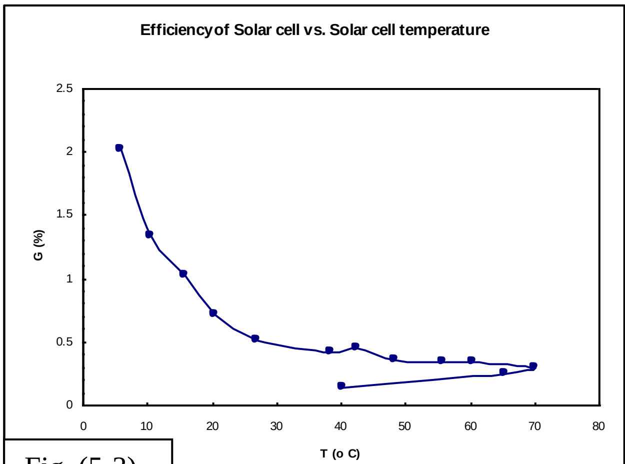



Fig. (5-3)

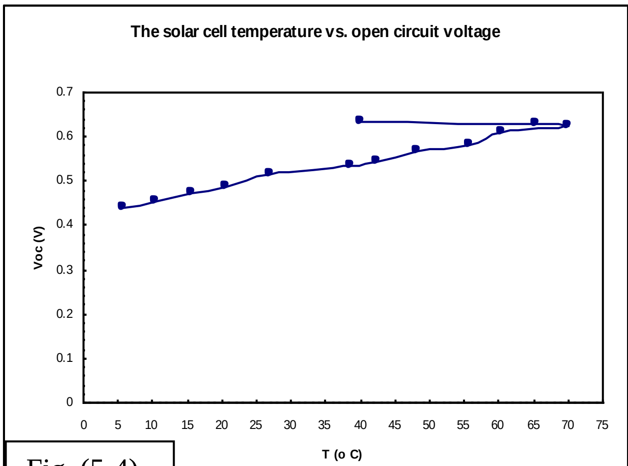



Fig. (5-4)

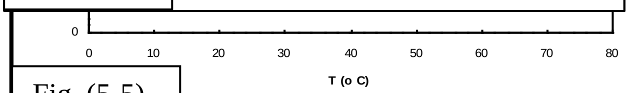



Fig. (5-5)

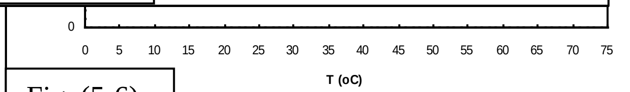



Fig. (5-6)

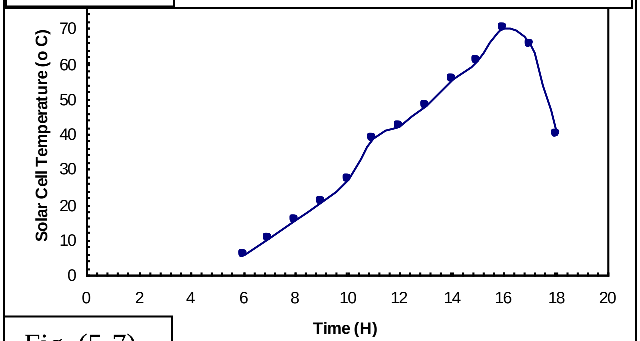



Fig. (5-7)

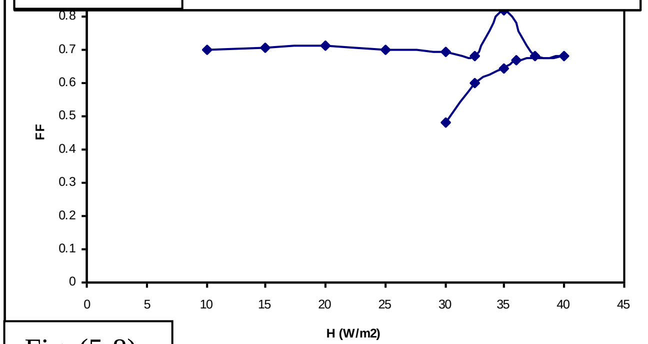



Fig. (5-8)

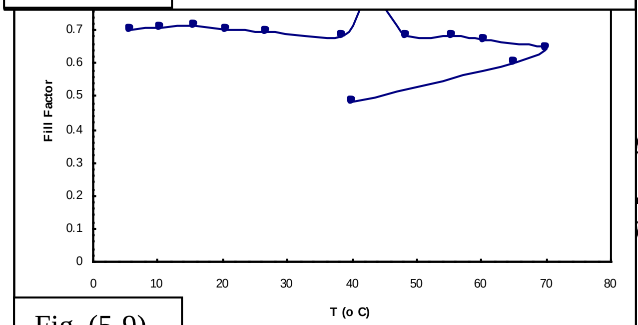



Fig. (5-9)

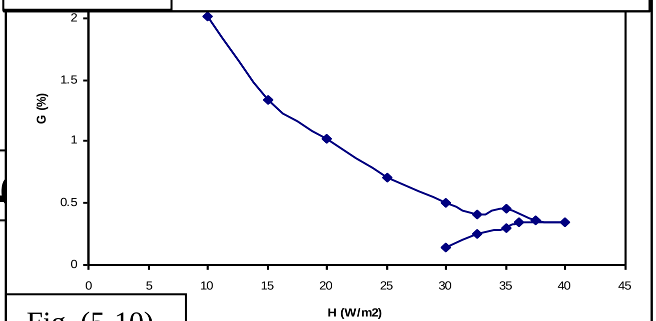



Fig. (5-10)

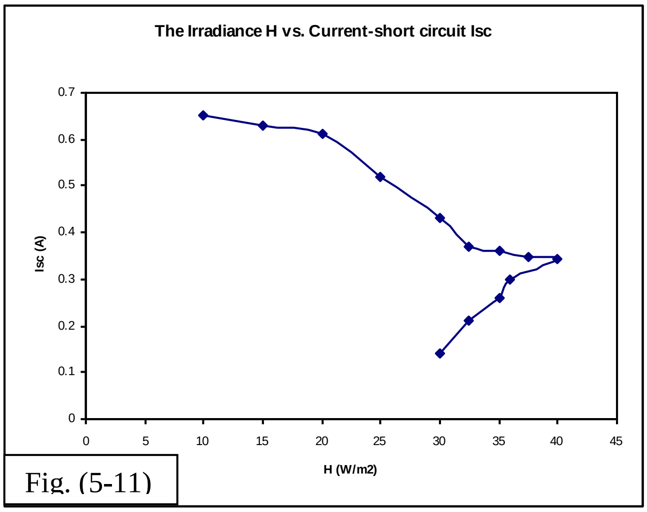



Fig. (5-11)

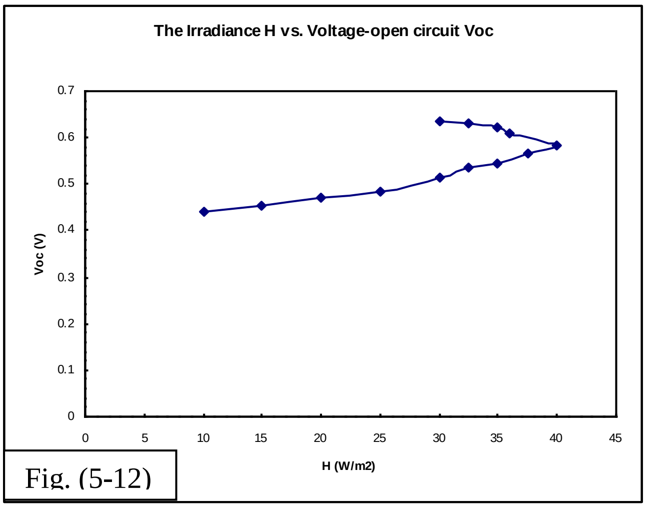



Fig. (5-12)

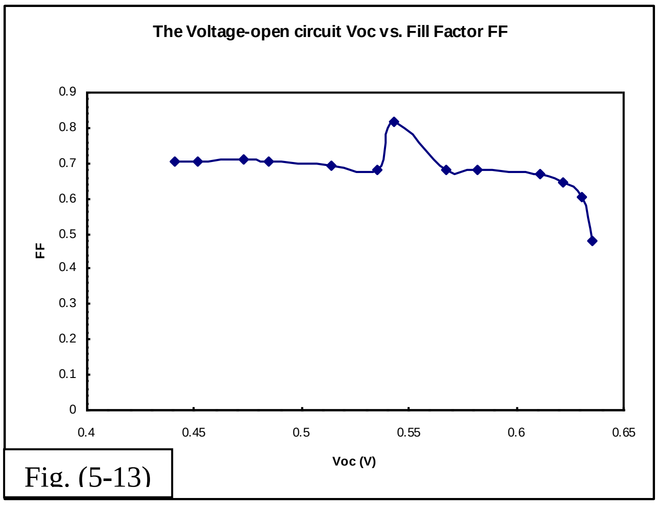



Fig. (5-13)

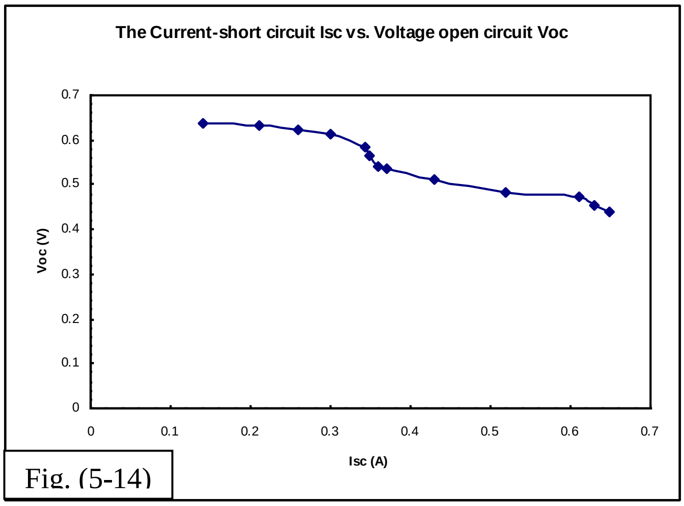



Fig. (5-14)

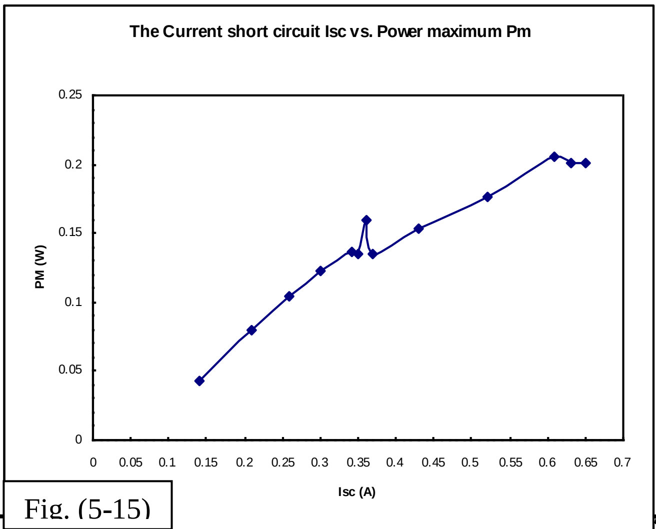
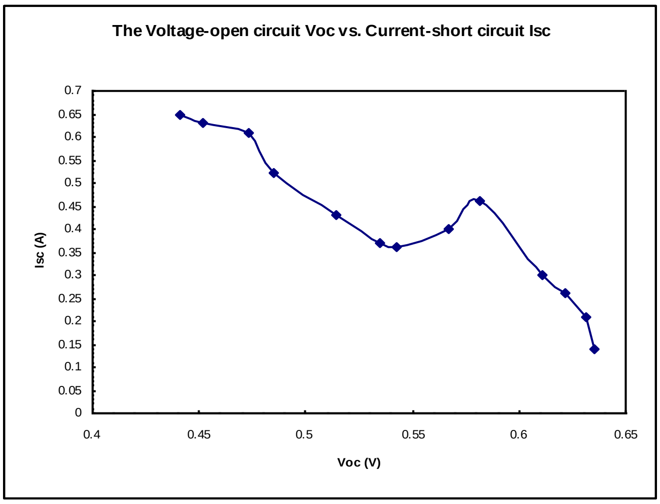



Fig. (5-15)



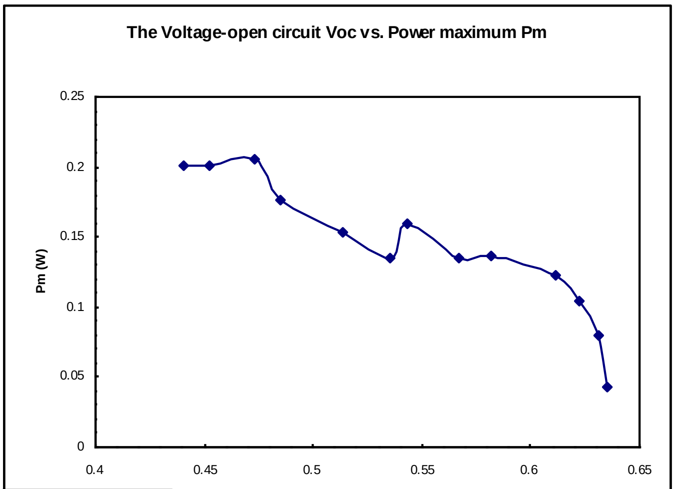
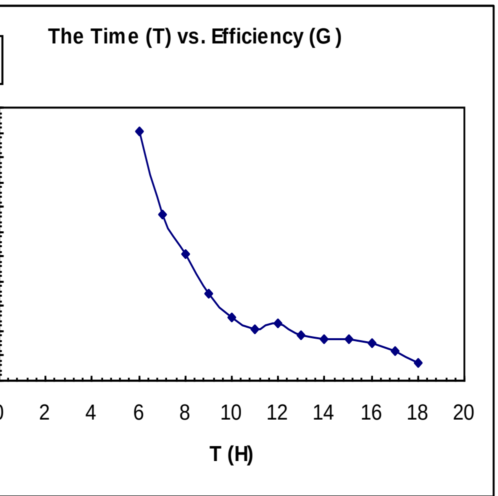




Fig. (5-16)

Fig. (5-



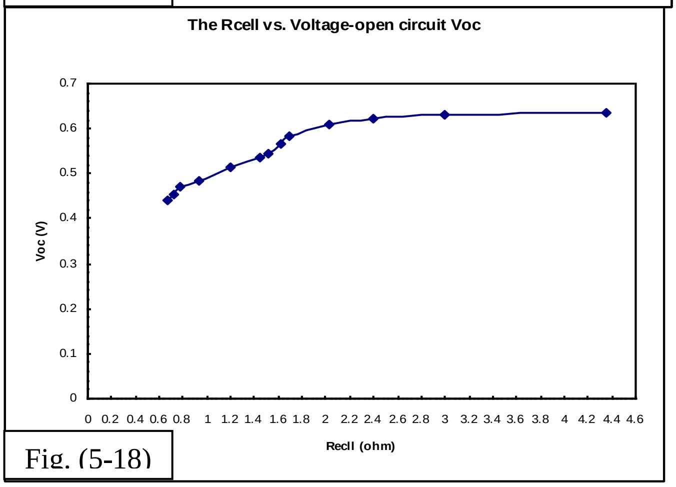
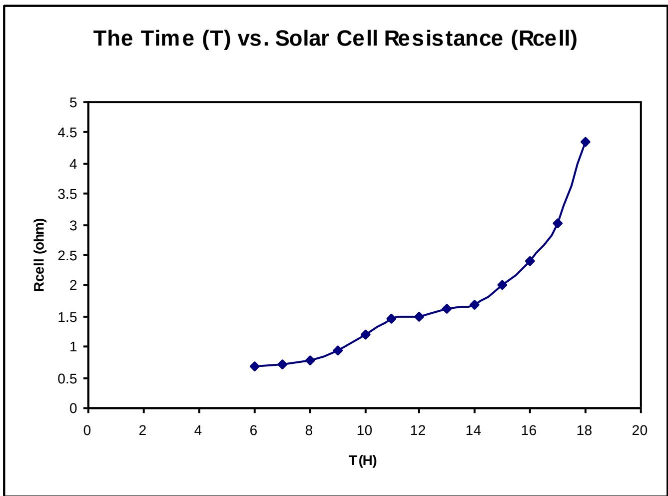
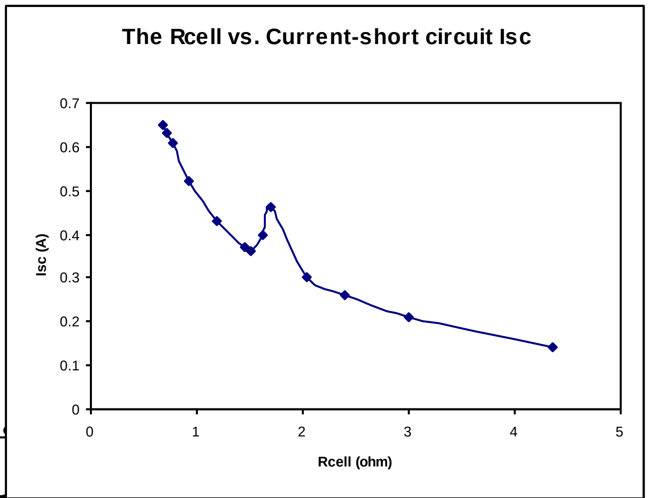



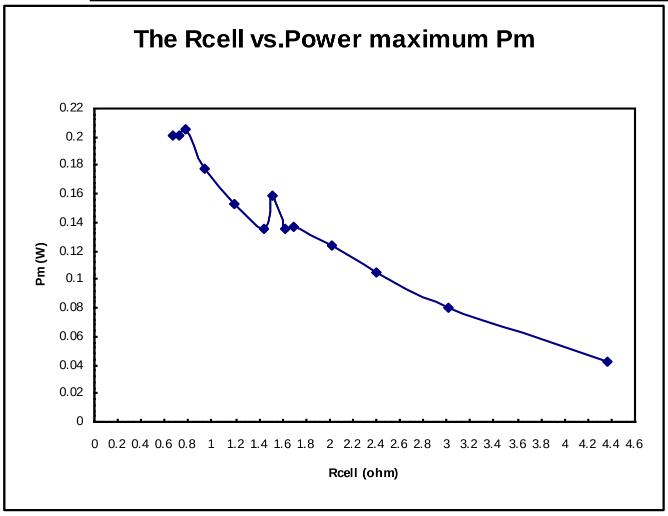

Fig. (5-18)

Fig. (5-19)

Fig. (5-20)





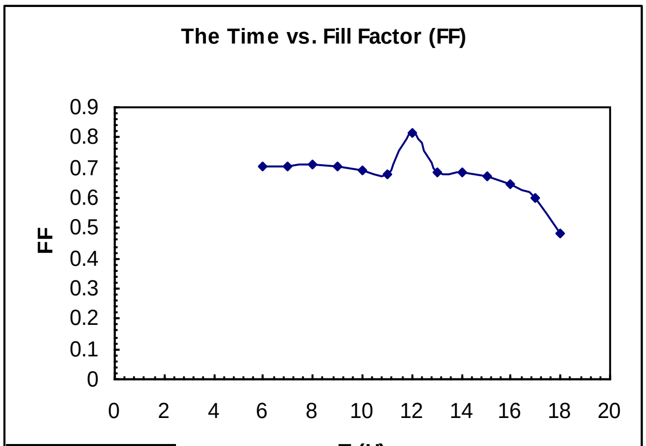




Fig. (5-22)

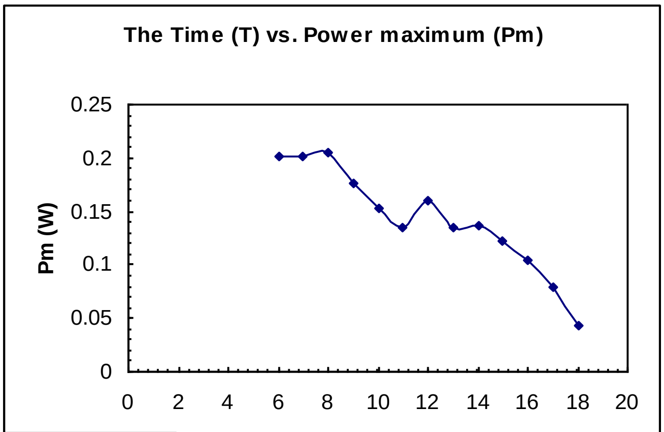
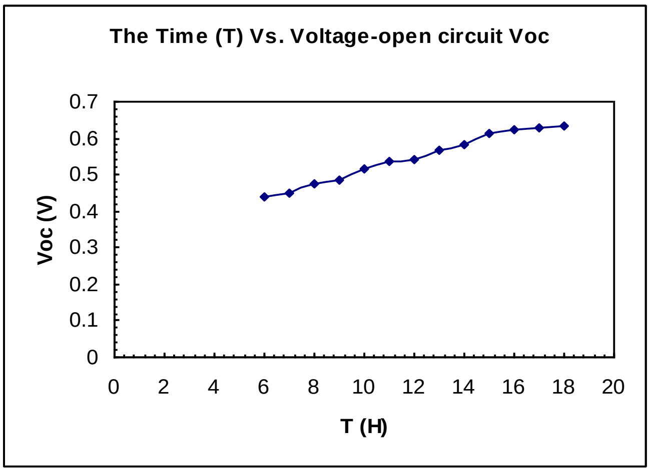



Fig. (5-25)



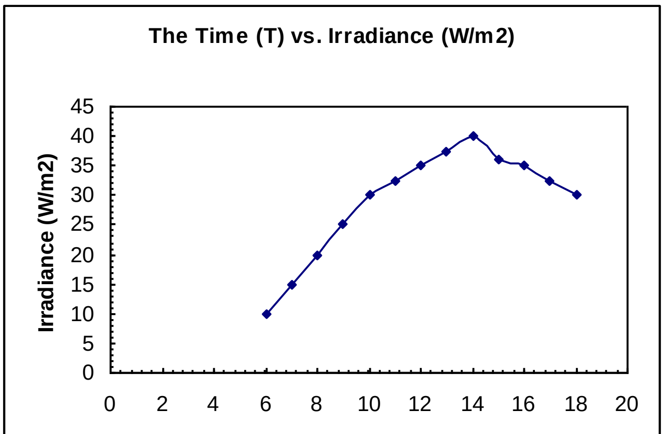




Fig. (5-27)

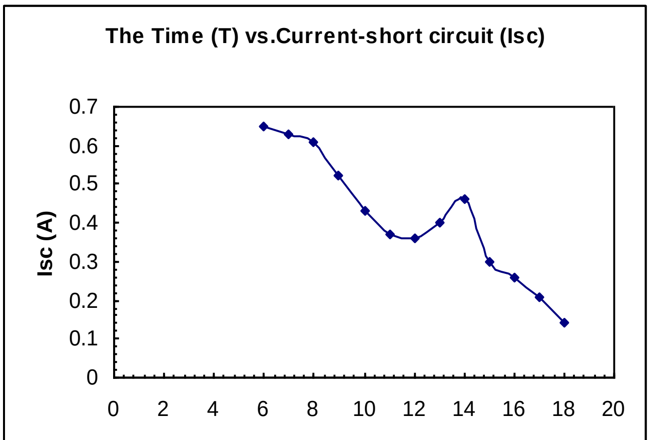



Fig. (5-26)

Fig. (5-[1-27]) Dependence of $I_{sc}$, $V_{oc}$, $P_m$, FF, $\eta_m$, on the Baghdad ambient temperature and the relation between them (outdoor). The output (I-V) characteristics of a single crystal silicon solar cell under investigation of size

(100 $cm^2$ area) on a typical day of April 2012 with various irradiations (100 $W/cm^2$ – 400 $W/cm^2$).

**Conclusions**

Like all other semiconductor devices, solar cells are sensitive to temperature. Increases in temperature reduce the band gap of a semiconductor, thereby effecting 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 band gap, reduction in the bond energy also reduces the band gap. Therefore increasing the temperature reduces the band gap. In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage. The impact of increasing temperature is shown in the figure below. The open-circuit voltage decreases with temperature because of the temperature dependence of $I_0$. Most semiconductor modeling is done at 300 K since it is close to room temperature and a convenient number. However, solar cells are typically measured almost 2 degrees lower at 25 °C (298.15 K). In most cases the difference is insignificant and both are referred to as room temperature. Occasionally, the modeled results need to be adjusted to corrolate with the measured results. Above the following conclusions the main important parameters on silicon solar cell are very sensitive to operating temperature; neither high temperatures nor low temperatures are favorite when silicon solar cell is used as a solar converter.

**Acknowledgments**

we gratefully would like to thank members of fuel and energy research center, who generously supplied numerous samples of their commercially available solar cells.

**References**

[1] D. L. Pulfrey, Photovoltaic Power Generation, Van Nostrand Reinhold, New York, (1978).

[2] W. D. Johnston, Jr., Solar Voltaic Cells, Dekker, New York, (1980).

[3] Conf. Rec. 13th IEEE Photovoltaic Spec. Conf., IEEE, New York, (1978).

[4] Conf. Rec. 14th IEEE Photovoltaic Spec. Conf., IEEE, New York, (1980).

[5] H. Lund, R. Nilsen, O. Salomatova, D. Skåre, E. Riisem, " Solar Cells", the Norwegian University of Science and Technology 2008.

[6] K. J. Bachmann, "Material Aspects of Solar Cells", in E. Kaldis, Ed., Current Topics in Material Science, Vol. 3, North-Holland, Amsterdam, (1979).

[7] William C. Dickinson, Paul N. Cheremisinoff, "Solar Energy Technology Handbook",
Part B, Applications systems Design and Economics, Marcel Dekker, Inc., USA, (1980).
[8] Sybil P. Parker, "Encyclopedia of Energy", MC Grew-Hill, Inc., 2nd edition, (1981).
[9] "Physics of Semiconductor Devices", Available in the site: WWW.Sakshieducation.com,(2011).
[10] Donald A. Neamen, "Semiconductor Physics and Devices",: Basic Principles", 3rd edition,
John Wiely & Sons, Inc., New York, (USA), (2003).
[11] G. D. Ray, "Solar Energy Utilization", India, (1980).
[12] Sze,S. M., Kwok K. Ng, "Semiconductor Devices Physics and Technology", John Wiely &
Sons, Inc., 3rd edition, Taiwan, USA, (2007).
[13] D. M. Chapin, C. S. Fuller, and G. L. Pearson, "A New Silicon p-n Junction Photocell for
Converting Solar Radiation into Electrical Power, "J. Appl. Physics., 25,676 (1954).
[14] D. C. Raynolds, G. Leies, L. L. Antes, and R. E. Marburger, "Photovoltaic Effect in Cadmium
Sulfide," Phs., Rev., 533 (1954).
[15] H. J. Hovel, Solar Cells, in R. K. Willardson and A. C. Beer, Eds., Semiconductors and
Semimetals, Vol. 11, Academic, New York, 1975; "Photovoltaic Materials and Devices for
Terrestrial Applications, "IEEE Tech. Dig. Int. Electron Device Meet., (1979), P. 3.
[16] Priyanka Singh, N. M. Ravindra, "Temperature dependence of solar cell performance-an
analysis", Department of Physics, New Jersey Institute of Technology, Newark, NJ 07901,
USA, (2012). http:// www.ivsl.org.
[17] Tomas Markvart, "Solar Electricity", 2nd edition, John Wiley & Sons, University of
Southampton, UK, (May 12, 2000).
[18] Sze, S. M., "Semiconductor Devices Physics and Technology", John Wiely & Sons, Inc.,
2nd edition, USA, (1981).

[19] Stephen T.Thornton, Andrew Rex, "Modern physics for scientists and engineers", 3rd edition,
(March 25, 2005).
[20] G. D. Rai, Bart Van Zeghbroeck , "Principles of Semiconductor Devices ", 3rd edition, Romesh
Chander Khanna, 2-B, Nath Market, Nai Sarak, Delhi-110006, (1987).
[21] C. E. Backus, Ed., Solar Cells, IEEE Press, New York, (1976).
[22] Jenny Nelson, "The Physics of Solar Cells (Properties of Semiconductor Materials)", 2nd edition,
(September 5, 2003),
[23] E. Skoplaki, J.A. Palyvos, Elias K. Stefanakos, " On the temperature dependence of photovoltaic
module electrical performance: A review of efficiency/power correlations", Solar Engineering
Unit, School of Chemical Engineering, National Technical University of Athens, 9 Heroon
Polytechneiou, Zografos Campus, 15780 Athens, Attica, Greece, (4 November 2008).
http://www.sciencedirect.com.tiger.sempertool.dk/science? www.ivsl.org.
[24] Sultan Omer A., A., Hassun Khalil I., Rasheed S., Mohammed, "Deterioration of Silicon Solar Cell
Paremeters with Ambient Temperature", Al-Mustansiriya J. Sci., Vol. 14, No. 1, 2003.

**انخفاض اداء معلمات الخلية الشمسية السليكونية مع درجة حرارة الجو في بغداد.**

**د.فؤاد شاكر طاهر**
**محمد سهام رشيد**
**قسم العلوم التطبيقية**
**الجامعة التكنولوجية**

**الخلاصة**

في هذا البحث، جرى دراسة تأثير درجة حرارة جو مناخ بغداد ( في الداخل والخارج) على كفاءة اداء الخلية الشمسية في مديات درجات الحرارة التي تتراوح بين ($5\ ^oC$-$70\ ^oC$). ان المعلمات المهمة لاداء للخلية الشمسية قيست من خلال تيار الدائرة المغلقة ($I_{sc}$)، فولتية الدائرة المفتوحة ($V_{oc}$)، معامل المليء (F.F) ، والكفاءة ($\eta_m$). ان تيار الاشباع العكسي ($I_o$) هو معلم مهم ايضاً لانه يحافظ على التغير الحاصل في المعلمات مع درجة الحرارة. علاوة على ذلك، ان التغيرات في درجة الحرارة اكثر ملائمة لوصف اداء الخلية الشمسية. النتائج التجريبية لمعلمات الخلية الشمسية السليكونية بينت ان كفاءة تحويل الخلية كانت منخفضة عندما ترتفع درجة الحرارة عن القيمة المُثلى للخلية.