International Journal of Trend in Research and Development, Volume 6(3), ISSN: 2394-9333
www.ijtrd.com

# Solar Panel's Current-Voltage Characteristics

[1]Khaleel I Abass, [2]Ali A K Al-Waeli and [3]Kadhem A N Al-Asadi,
[1]Mechanical Eng. Dept., University of Technology-Iraq
[2]Ibn Rushed College, Baghdad University, Iraq
[3]Education College for Human Science, University of Basra, Iraq

***Abstract***-This article checks the relation between current-voltage characteristics, to evaluate the impact of solar radiation and temperature on the productivity of a solar photovoltaic module. Photovoltaic systems have become an urgent requirement to reduce dependence on fossil fuels and reduce air pollutants from burning. In Iraq, this rich country in fossil fuels such as natural gas and crude oil, is suffering from a shortage of electricity supplies and long hours of disruption. It seems that the solution using natural gas or diesel plants is no longer feasible and switching to photovoltaic stations is the best option to this day. The results of the study showed that the current is affected slightly by the increase in the radiation intensity whilethe module voltages is affectedhighly by the intensity of radiation, especially when the load on the cell is increasedcausing an increase in power produced.

***Keywords** - PV Module, Solar Radiation, Temperature, Voltage, Current.*

## I. INTRODUCTION

Iraq (a country rich in natural resources such as oil and natural gas) suffers from significant problems in the processing of electricity to citizens. The power outages for long hours caused the Iraqi citizens to rely on generators running by diesel and gasoline [1]. The use of these generators has been aggravated by air pollution (already contaminated and hard). The extraction of crude oil has caused significant pollution in the atmosphere of Iraq because of the spread of oil wells throughout the country [2]. Rainfall lack for more than two decades has caused the Fertile Crescent (Mesopotamia) to turn into a source of dust to Iraq and neighboring countries [3]. It also increased the salinity of water in the rivers and thus reduced the large cultivated areas [4].Also, Iraq has suffered from many wars that caused the destruction and deterioration of services, especially for power generation facilities [5].

The shift towards the use of renewable energies in electricity production has become very vital in Iraq to reduce the environmental impact of excessive combustion of fossil fuels [6]. Some may consider wind power to be limited in certain parts of Iraq, making it useless [7]. Many consider the use of solar energy to produce heat and electricity in Iraq necessary and successful, as Iraq's environment is characterized by high solar radiation is very high because of the country is located next to the solar belt [8]. Solar heat can be used to heat domestic water [9], solar distillation [10-13], heating air for comfort purposes [14, 15], and heating Trombe wall for ventilation and heating rooms [16-18].Electricity can be produced using solar chimney [19], concentrated solar power plants [20], and photovoltaic cells [21]. Among these applications, photovoltaic cells are considered the most acceptable, because of their high elasticity, which can be operated in various areas of Iraq topography, desert, mountains, and green plains [22]. It can also work in areas far from the national grid [23].

In addition to the possibility of installation PV modules in different areas, its applications are multiple, for example it can be set for street lighting [24], health clinics [25], electricity telecommunication towers [26], pumping systems [27], and lighting cars parking [28]. Dependence on electricity produced from photovoltaic cells is determined by the weather conditions as they are affected by solar radiation [29, 30], air temperature [31, 32], relative humidity [33, 34], wind [35], shadow [36], dust [39, 40], and other factors such as air mass [41], and tilt angle [42].

The current-voltage (I-V) characteristics of a particular photovoltaic (PV) cell module or array are giving a detailed description of its solar energy conversion ability and efficiency. Knowing the electrical I-V characteristics (more importantly (Pmax) of a solar cell, or panel is critical in determining the device's output performance and solar efficiency[43].

The main electrical characteristics of a PV cell or module are summarized in the relationship between the current and voltage produced on a typical solar cell I-V characteristics curve[44]. A large part of the solar radiation falling on the solar cell turns into heat while the smaller part of the radiation turns into electricity. Increasing the intensity of solar radiation to the photovoltaic cell turns into (I), while increases in the temperature of the solar cell reduce its voltage (V).

In this study, I-V and P-V properties were tested for an in-vitro photoelectric unit to assess the possibility of using such techniques in the solar radiation environment in Iraq. Iraq is characterized by high solar radiation, which is an average of 460 W/m$^2$ in winter and reaches 1000 W/m$^2$in summer.

## II. EXPERIMENTAL SETUP

### *A. Effect of Light Intensity*

Figure 1 shows the characteristics of the I-V curve of a photovoltaic cell system with a light intensity of 1000, 800 and 500 W / m 2. The figure shows a significant difference in the characteristics of V-I

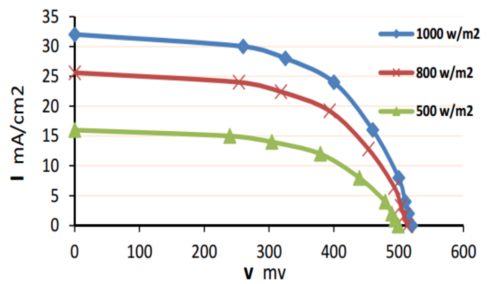


Figure 1: V-I Characteristics of Solar Cell under Several Solar Radiation Intensity

Photovoltaic cells change as the intensity of the solar radiation reaches them. The resulting current is proportional to the flow of photons of light energy, while the difference of the open circuit voltage increases logarithmically as the light intensity increases.

To evaluate the performance of an array of PV cells, attention should be paid to the sequence and transition resistors, which can be considered very important in this assessment because of their direct effect on the solar cell filler (FF). The filler is defined as the power ratio at the maximum power point (MPP) divided by the short circuit current (Isc) and the voltage of the open circuits (Voc). From this definition, the refill factor (FF) can be considered as a measure of a distinctive I-V curve, and by moving away from this curve, the efficiency of the PV array becomes impaired.

The internal losses of the semiconductor layer resulting from communication describe the RS resistance series. These losses directly affect the forward shape of the I-V solar system around the MPP and thus fill the filler. The effect of degradation on short circuit current (Isc) by increasing the chain resistance is obviuos. This is evident when the radiation density is high, while the open circuit voltage remains unaffected. This feature is undesirable as it causes a reduction in peak power and results in degradation of the efficiency of the PV system.

The RP (or parallel) resistivity represents the currents of the leakage of electrons from the surface of the solar cell via PN junctions. This transformation affects the slope of the characteristic I-V curve near the short circuit current point and results in the deterioration of the FF. This deterioration in general has a practical effect on the efficiency of the solar cell system less than the resistance of the chain. Low conversion resistance results in higher open loop decay especially under low voltages, and there is no effect on short circuit current in this case. Resistivity is directly affected by solar radiation absorbed in the short circuit current. When the absorbed radiation is increased, the slope of the characteristic I-V curve decreases near the short circuit current point and the effective conversion resistance decreases proportionately.

### *A. Simulation and experimental results*

Figure 2 represents the characteristic curves of I-V and P-V for a 250V-rated PV system when changing the intensity of solar radiation and cell temperature. In this case, the temperature was set at 25 ° C and the intensity of the solar radiation was changed by 200, 600, 1000 W/m$^2$. Experimental data obtained using current and voltage measurement devices enabled the I-V curve to be plotted for the studied units.

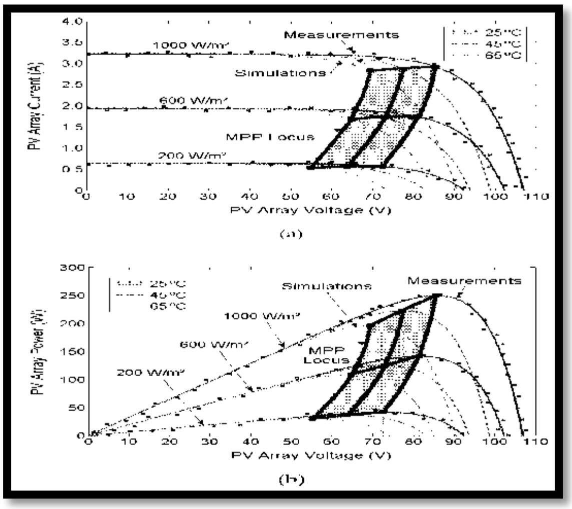


Figure 2: V-I and P-VCharacteristics of Solar Cell Affected by Different Temperature and Solar Radiation

Using the curves of Fig. 2, a specific point is found where the MPP is maximized. This point depends entirely on the maximum or optimal solar radiation intensity. The PV output characteristic curve is divided into two parts: the left part: The source at which the output current approaches the constant, and the right part: the voltage source area where the output voltage is barely changed. The MPP point changes by changing the intensity of the solar radiation, the angle of the cell's tilt, and the temperature of the cell itself. It is always recommended to operate PV systems in MPP (shaded area) mode to optimize the system output. This method requires constant modification to face the solar cells and perpendicular to the sun to reach maximum power output.

### *B. Equipment*

The solar panel used in the tests incorporates a module of (85 W, 12 V). It contains a sensor for the Irradiation and Temperature. These sensors are Red and Black; to provide the solar panel power output. Also, the 5-pin terminal provides irradiation and temperature data. To make it easy to be handled, the light weight solar module is placed on wheels. Side of the panel contains a meter for measuring the angle of the solar panel inclination towards the horizontal surface.The solar irradiation intensity and the PV temperature sensors used in the tests were type DELLENZO. These sensors are used to transfer the heat and the irradiation from the Solar Source using the connections to the DL Solar device.

Figure3: Solar Panel Equipment Used.

### *D. Tests procedure*

1. Change the light from (100 ,75, 50, and 25)
2. Change the resistances from 0 to 1000 Ω and take reading of power, current, and voltage.
3. Draw a relationship between current and voltage.
4. Draw a relationship between power and voltage.

## III. RESULTS AND DISCUSSION

The tests were conducted to evaluate the impact of temperature and radiation on PV module inside the laboratory. Table 1 shows thedaily generated power with changing the light intensity (25, 50, 75 and 100 W).The PV module outcomes are positively affected by solar radiation intensity while the temperature effect is negative.The tests results reveals that the impact of solar radiation increase voltage with increasing the load resistance on the module while its effect on current is low. Figure 4 is known as an I-V curve, it shows how current and voltage relate to each other in each of the four colors lines is describes the behavior of radiation, the above graph shows I/V curves for four different time that is the current presents a slightly descending behavior until it reaches to down and its decreases quickly into reach to zero, also we found the maximum current is 0.22 amps. On the other hand, Figure 5 known as a P-V curve where we get the maximum power is equal to 3.2 Watts, we noted when the power is increased the voltage will increase for four different lights intensities. In general, the PV module output power is increased with elevated solar radiation intensity. This outcome power increase is related tovoltage increase.

Table 1: data from experiment

| Light at (100) | | | | Light at (50) | | | |
|---|---|---|---|---|---|---|---|
| **Ω** | I | V | P | Ω | I | V | P |
| **0** | 0.21 | 0.4 | 0 | 0 | 0.15 | 0.04 | 0 |
| **1** | 0.22 | 0.2 | 0 | 1 | 0.15 | 0.13 | 0 |
| **2** | 0.22 | 0.44 | 0.1 | 2 | 0.15 | 0.25 | 0 |
| **3** | 0.22 | 0.57 | 0.1 | 3 | 0.15 | 0.31 | 0 |
| **5** | 0.22 | 0.84 | 0.2 | 5 | 0.15 | 0.45 | 0.1 |
| **10** | 0.22 | 1.98 | 0.4 | 10 | 0.15 | 1.05 | 0.2 |
| **20** | 0.22 | 3.76 | 0.8 | 20 | 0.15 | 2.17 | 0.3 |
| **30** | 0.22 | 5.13 | 1.1 | 30 | 0.15 | 2.87 | 0.4 |
| **50** | 0.22 | 9.42 | 2 | 50 | 0.15 | 5.37 | 0.8 |
| **100** | 0.2 | 15.39 | 3.1 | 100 | 0.15 | 9.28 | 1.4 |
| **200** | 0.16 | 17.81 | 2.8 | 200 | 0.14 | 14.08 | 2 |
| **300** | 0.12 | 18.58 | 2.2 | 300 | 0.11 | 16.71 | 1.9 |
| **500** | 0.1 | 18.81 | 1.9 | 500 | 0.1 | 17.16 | 1.7 |
| **1K** | 0.08 | 18.98 | 1.6 | 1K | 0.08 | 17.61 | 1.5 |
| Light at (75) | | | | Light at (25) | | | |
| **Ω** | I | V | P | Ω | I | V | P |
| **0** | 0.19 | 0.04 | 0 | 0 | 0.11 | 0.03 | 0 |
| **1** | 0.19 | 0.21 | 0 | 1 | 0.11 | 0.08 | 0 |
| **2** | 0.19 | 0.4 | 0.1 | 2 | 0.11 | 0.12 | 0 |
| **3** | 0.19 | 0.47 | 0.1 | 3 | 0.11 | 0.19 | 0 |
| **5** | 0.19 | 0.69 | 0.1 | 5 | 0.11 | 0.25 | 0 |
| **10** | 0.19 | 1.55 | 0.3 | 10 | 0.11 | 0.53 | 0.1 |
| **20** | 0.19 | 3.12 | 0.6 | 20 | 0.11 | 1.14 | 0.1 |
| **30** | 0.19 | 4.22 | 0.8 | 30 | 0.11 | 1.55 | 0.2 |
| **50** | 0.19 | 7.73 | 1.5 | 50 | 0.11 | 2.88 | 0.3 |
| **100** | 0.18 | 13.16 | 2.4 | 100 | 0.11 | 5.24 | 0.6 |
| **200** | 0.16 | 16.84 | 2.6 | 200 | 0.11 | 8.22 | 0.9 |
| **300** | 0.12 | 17.84 | 2.1 | 300 | 0.11 | 13.4 | 1.4 |
| **500** | 0.1 | 18.15 | 1.8 | 500 | 0.1 | 15.35 | 1.4 |
| **1K** | 0.08 | 18.41 | 1.5 | 1K | 0.08 | 16.37 | 1.3 |

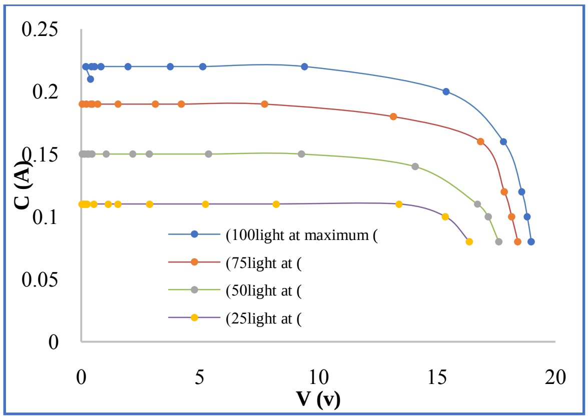


Figure 4: I-V Characteristic of Different Solar Radiation

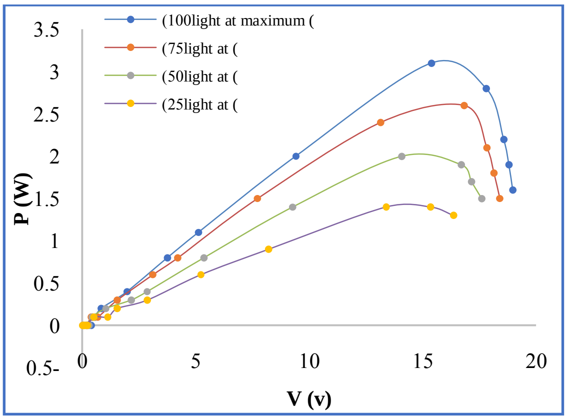


Figure 5: P-V Characteristic of Different Solar Radiation.

## CONCLUSION

Iraq suffers from a severe shortage of electricity supplies, and to this day, this problem has not been solved because of the decision makers prefer to establish high-cost steam power stations, which run with fossil fuels. Although Iraq has one of the world's largest reserves of oil and natural gas, such stations emit millions of tons of pollutants into the air every year. Therefore, the shift towards the use of photovoltaic stations has been introduced as an alternative to these stations. In this study, the behavior of the photovoltaic cell was understood when solar radiation was increased. The solar cell was tested by exposing it to four light intensities (25, 50, 75, 100 W) and found that cell productivity was increased by light intensity, as the intensity of the radiation increased the energy. There was a noticeable effect on solar module due to temperature.

## References


[1] A. A. Al-Waeely, S. D. Salman, W. K. Abdol-Reza, M. T. Chaichan, H. A. Kazem and H. S. Al-Jibori, "Evaluation of the spatial distribution of shared electrical generators and their environmental effects at Al-Sader City-Baghdad-Iraq," International Journal of Engineering & Technology IJET-IJENS, vol. 14, No. 2, pp. 16-23, 2014.

[2] K. A. Al-Aasadi, A. A. Al-Waeelyand H. A. Kazem, "Assessment of air pollution caused by oil investments in Basra Province-Iraq," J Nov. Appl Sci., vol. 4, No. 1, pp. 82-86, 2015.

[3] A. A. Kazem, M. T. Chaichan &H. A. Kazem, "Effect of dust on photovoltaic utilization in Iraq: review article," Renewable and Sustainable Energy Reviews, vol. 37, pp. 734-749, 2014.

[4] B. R. Yaseen, K. A. Al Asaady, A. A. Kazem, M. T. Chaichan, "Environmental impacts of salt tide in Shatt al-Arab-Basra/Iraq," IOSR Journal of Environmental Science, Toxicology and Food Technology, vol. 10, No. 1-2, pp. 35-43, 2016. DOI :10.9790/2402-10123543

[5] A. A. Al-Waeely, H. N. Al-qaralocy, K. A. Al-Aasadi, M. T. Chaichan, H. A. Kazem, "The environmental aftermath resulted from chemical bombardment of Halabja Territory for the period 1988-2014," International Journal of Scientific & Engineering Research, vol. 6, N0. 9, pp. 40-44, 2015.

[6] H. A. Kazem, M. T. Chaichan, "Experimental analysis of the performance characteristics of PEM Fuel Cells," International Journal of Scientific & Engineering Research, vol. 7, No. 2, pp. 49-56, 2016.

[7] A. M. J.Mahdy, A. A. Al-Waeely, K. A. Al-Aasadi, "Can Iraq use the wind energy for power generation?" International Journal of Computation and Applied Sciences IJOCAAS, vol. 3, No. 2, 2017.

[8] M. Walker, "Climate of Iraq,"translated by A. A. Al Waeli, K. A. Al-Aasadi, F. S. Rahem, M. T. Chaichan, Zaki Printing Office Baghdad-Iraq, 2018.

[9] M. T. Chaichan, K. I. Abass&H. M. Salih, "Practical investigation for water solar thermal storage system enhancement using sensible and latent heats in Baghdad-Iraq weathers," Journal of Al-Rafidain University Collage for Science, Issue 33, pp. 158-182, 2014.

[10] M. T. Chaichan, H. A. Kazem &K. I. Abass, "Improving productivity of solar water distillator linked with salt gradient pond in Iraqi weather," World Congress on Engineering 2012, London, UK, 4-6 July, 2012

[11] M. T. Chaichan, H. A. Kazem, K. I. Abass, A. A. Al- Waeli, "Homemade solar desalination system for Omani families," International Journal of Scientific & Engineering Research, vol. 7, No. 5, pp.1499-1504, 2016.

[12] M. T. Chaichan, H. A. Kazem, "Single slope solar distillator productivity improvement using phase change material and Al2O3 nanoparticle," Solar Energy, vol. 164, pp. 370-381, 2018. https://doi.org/10.1016/j.solener.2018.02.049

[13] M. T. Chaichan &H. A. Kazem, "Using aluminum powder with PCM (paraffin wax) to enhance single slope solar water distillator productivity in Baghdad-Iraq winter weathers," International Journal of Renewable Energy Research, vol. 1, No. 5, pp. 151-159, 2015.

[14] M. T. Chaichan, K. I. Abass, H. A. Kazem, "The impact of thermal storage materials on the heating and storage efficiencies of a solar air heater," World Wide Journal of Multidisciplinary Research and Development, vol. 4, No. 6, pp. 121-128, 2018.

[15] M. T. Chaichan, K. I. Abass, M. A. Rasheed and H. A. Kazem, "Using paraffin wax as a thermal storage material in a solar air heater," International Conference for Renewable Energies, UOT, Baghdad, Iraq, 2013.

[16] M. T. Chaichan, K. I. Abass, R. S. Jawad, A. M. J. Mahdy, "Thermal performance enhancement of simple Trombe wall," International Journal of Computation and Applied Sciences IJOCAAS, vol.2, No. 1, pp. 33-40, 2017.

[17] M. T. Chaichan, K. I. Abass, D. S. M. Al-Zubidi, "A study of a hybrid solar heat storage wall (Trombe wall) utilizing paraffin wax and water," Journal of Research in Mechanical Engineering, vol. 2, No. 11, pp. 1-7, 2016.

[18] M. T. Chaichan &K. I. Abass, "Experimental study to improve thermal performance of simple solar energy collecting wall," Industrial Applications of Energy Systems (IAES09), Sohar University, Oman, 2009.

[19] M. T. Chaichan &H. A. Kazem, "Thermal storage comparison for variable basement kinds of a solar chimney prototype in Baghdad - Iraq weathers," International journal of Applied Science (IJAS), vol.2, No. 2, pp. 12-20, 2011.

[20] M. T. Chaichan, K. I. Abass, H. A. Kazem, H. S. Al Jibori&U. Abdul-Hussain, "Novel design of solar receiver in concentrated power system," International J. of Multidispl. Research &Advcs. in Eng. (IJMRAE), vol. 5, No. 1, pp. 211-226, 2013.

[21] M. T. Chaichan, H. A. Kazem, "Generating Electricity Using Photovoltaic Solar Plants in Iraq," Springer, ISBN: 978-3-319-75030-9. https://doi.org/10.1007/978-3-319-75031-6

[22] A. H. A. Al-Waeli, H. A. Kazem, M. T. Chaichan, "Review and design of a standalone PV system performance," International Journal of Computation and Applied Sciences IJOCAAS, vol. 1, No. 1, pp. 1-6, 2016.

[23] H. A. Kazem, F. Hasson and M. T. Chaichan, "Design and analysis of stand-alone solar photovoltaic for desert in Oman," The 3rd Scientific International Conference, Technical College, Najaf, Iraq, 2013

[24] A. A. Al-Waeely, K. A. Al-Aasadi, "Analysis of stand-alone solar photovoltaic for desert in Iraq," International Research Journal of Advanced Engineering and Science, International Research Journal of Advanced Engineering and Science, vol. 3, No. 2, pp. 204-209, 2018.

[25] M. T. Chaichan, H. A. Kazem, A. M. J.Mahdy&A. A. Al-Waeely, "Optimal sizing of a hybrid system of renewable energy for lighting street in Salalah-Oman using Homer software," International Journal of Scientific Engineering and Applied Science (IJSEAS), vol.2, No. 5, pp. 157-164, 2016.

[26] H. A. Kazem and M. T. Chaichan, "Design and analysis of standalone solar cells in the desert of Oman," Journal of Scientific and Engineering Research, vol. 3, No. 4, pp. 62-72, 2016.

[27] M. T. Chaichan, H. A. Kazem, A. M. J.Mahdy&A. A. Al-Waeely, "Optimization of hybrid solar PV/ diesel system for powering telecommunication tower," IJESET, vol. 8, No. 6, pp. 1-10, 2016.

[28] H. A. Kazem, A. H. A. Al-Waeli, M. T. Chaichan, A. S. Al-Mamari, A. H. Al-Kabi, "Design, measurement and evaluation of photovoltaic pumping system for rural areas in Oman," Environment Development and Sustainability, vol. 19, No. 3, pp. 1041-1053, 2017. DOI: 10.1007/s10668-016-9773-z, 2016.

[29] H. A. Kazem, A. H. A.Al-Waeli, A. S. A. Al-Mamari, A. H. K. Al-Kabi, M. T. Chaichan, "A photovoltaic application in car parking lights with recycled batteries: A techno-economic study," Australian Journal of Basic and Applied Science, vol. 9, No. 36, pp.: 43-49, 2015.

[30] M. T. Chaichan, H. A. Kazem, "Experimental analysis of solar intensity on photovoltaic in hot and humid weather conditions," International Journal of Scientific & Engineering Research, vol. 7, No. 3, pp. 91-96, 2016.

[31] M. J. B.Buni, A. A. Al-Waeely, K. A. Al-Aasadi, "Effect of solar radiation on photovoltaic cell," International Research Journal of Advanced Engineering and Science, Volume 3, Issue 3, pp. 47-51, 2018.

[32] H. A. Kazem, M. T. Chaichan, "Effect of environmental variables on photovoltaic performance-based on experimental studies," International Journal of Civil, Mechanical and Energy Science (IJCMES), vol. 2, No. 4, pp. 1-8, 2016

[33] M. T. Chaichan, H. A. Kazem, A. A. Kazem, K. I. Abass, K. A. Al-Aasadi, "The effect of environmental conditions on concentrated solar system in desertec weathers," International Journal of Scientific and Engineering Research, vol. 6, No. 5, pp. 850-856, 2015.

[34] H. A. Kazem and M. T. Chaichan, "Effect of humidity on photovoltaic performance based on experimental study," International Journal of Applied Engineering Research (IJAER), vol. 10, No. 23, pp. 43572-43577, 2015.

[35] R. T. A. Hamdi, S. A. Hafad, H. A. Kazem, M. T. Chaichan, "Humidity impact on photovoltaic cells performance: A review," International Journal of Recent Engineering Research and Development (IJRERD), vol. 3, No. 11, pp. 27-37, 2018.

[36] C. Schwingshackla, M. Petitta, J.E. Wagner, G. Belluardo, D. Moser, M. Castelli, M. Zebisch and A. Tetzlaf, "Wind effect on PV module temperature: Analysis of different techniques for an accurate estimation," Energy Procedia, vol. 40, pp. 77 – 86, 2013.

[37] H. A. Kazem, M. T. Chaichan, A. H. Al-Waeli, K. Mani, "Effect of shadows on the performance of solar photovoltaic," Mediterranean Green Buildings & Renewable Energy, pp.379-385, 2017, DOI: 10.1007/978-3-319-30746-6_27

[38] R. S.Jawad, K. I.Abass, A. A. Al-Wailie, D. S M Al-Zubaidi, "Dust effect on PV outcomes at five different sites around Baghdad," Journal of Scientific and Engineering Research, vol.4, No. 7, pp. 93-102, 2017.

[39] R. T. A.Hamdi, S. H. Hafed, M. T. Chaichan, H. A. Kazem, "Dust impact on the photovoltaic outcomes," International Journal of Computation and Applied Sciences, vol. 5, No. 2, pp. 385-390, 2018.

[40] K. S.Rida, A. A. Al-Waeely, K. A. H. Al-Asadi, "The impact of air mass on photovoltaic panel performance", EngSci Rep; vol. 1, No. 1, pp. 1-9, 2016.http://dx.doi.org/10.18282/ser.v1.i1.41.

[41] A. A. Al-Waeely, K. A. Al-Aasadiand A. M. J.Mahdy, "Effect of tilt angle and temperature on PV performance," Elixir Elec. Eng., vol. 113,pp. 49334-49340, 2017.

[42] J. P. Rama, H.Manghania, D. S. Pillai, T. S.Babu, M.Miyatake, N. Rajasekar, "Analysis on solar PV emulators: A review," Renewable and Sustainable Energy Reviews, vol. 81,pp. 149–160, 2018.

[43] A. H. A. Al-Waeli, K. Sopian, H. A. Kazem, M. T. Chaichan, "Nanofluid based grid connected PV/T systems in Malaysia: A techno-economical assessment," Sustainable Energy Technologies and Assessments, vol. 28, pp. 81-95, 2018. https://doi.org/10.1016/j.seta.2018.06.017

[44] A. H. A. Al-Waeli, K. Sopian, H. A. Kazem and M. T. Chaichan, "Photovoltaic thermal PV/T systems: A review," International Journal of Computation and Applied Sciences IJOCAAS, vol. 2, No. 2, pp. 62-67, 2017.

[45] A. H. A. Al-Waeli, K. Sopian, J. H. Yousif, H. A. Kazem, J. Boland, M. T. Chaichan, "Artificial neural network modeling and analysis of photovoltaic/thermal system based on the experimental study," Energy Conversion and Management, vol. 186, pp. 368–379, 2019.

[46] A. H. A. Al-Waeli, M. T. Chaichan, H. A. Kazem, K. Sopian, "Evaluation and analysis of nanofluid and surfactant impact on photovoltaic-thermal systems," Case Study in Thermal Engineering, vol. 13, 100392, 2019.

[47] A. H. A. Al-Waeli, M. T. Chaichan, K. Sopian, H. A. Kazem, "Influence of the base fluid on the thermo-physical properties of nanofluids with surfactant," Case Study of Thermal Engineering, vol. 13, 100340, 2019. https://doi.org/10.1016/j.csite.2018.10.001