ISSN: 2455-5304

Effect of Environmental Variables on Photovoltaic Performance-Based on Experimental Studies

Hussein A Kazem[1], Miqdam T Chaichan[2]

[1]Faculty of Engineering, Sohar University, Sohar, Sultanate of Oman
[2]Energy and Renewable Energies Technology Center, University of Technology, Baghdad, Iraq

Abstract— *This paper investigated the effect of environment variables on Photovoltaic PV performance.*
It is surely understood that local climate can dramatically affect the power generation from a PV system. The most obvious components are the solar radiation hitting the panels, air temperature, humidity and wind speed. The local climatic conditions and precipitation influence the extent to which the panels get to be dusty or polluted, which affects the electrical power generation.
The high air temperature caused a reduction in the PV panel output power rated from 1.85 to 20.22%, as well as, increased relative humidity where the largest decline recorded was 32.24%. The wind has a cooling effect on the PV panel that limits the power reduction due to increased solar radiation or panel back temperature. Besides, the wind blows away the accumulated dust that enhances the resulted PV panel power.
Keywords—Air movement, back panel temperature, climate condition, dust accumulation, photovoltaic, relative humidity.

I. INTRODUCTION

Most renewable energy comes from the sun either directly or indirectly. Daylight or solar power can be utilized straightforwardly to heat and lighting homes and different structures, for producing electrical energy, boiling water for warming, solar cooling, and an assortment of business and mechanical uses [1]. Likewise, the sun's warmth drives the winds, whose energy, is caught with wind turbines. At that point, the winds and the sun's heat cause water to vanish. When this water vapor transforms into rain or snow and becomes waterways or streams, its vitality can be caught to be utilized as hydroelectric energy [2].
Sunlight based photovoltaic (PV) frameworks are known for their capacity to create electric power for homes and business structures taking advantage from the retention of solar energy [3]. In the development of expanded sustainability, cleaner energy, and lower service charges, the PV systems are turning into the first sight, particularly in districts of the nation where solar energy is the most grounded [4]. In any case, this technology still needs more research and development works in buildings suction. Besides, the professional experts must introduce to their clients the better points of interest of PV systems [5].
Many researchers studied the impact of weather variables like temperature, solar radiation intensity, relative humidity, and the wind, on the productivity of the solar cells. References [6-9] studied the effect of the air temperature on the productivity of the cell and found that the increase in air temperature causes a decrease in its productivity. As references [10-15] studied the effect of relative humidity on the productivity of the PV cell and found that the effect of relative humidity less than the effect of temperature on the productivity of the cell, but it has an emphasis on a reduction in the efficiency of the cell.
References [16-22] revealed that the increase in solar radiation increases the temperature and the degree of cell in the absence of cooling them, the productivity decreases as the bulk of the solar radiation exploited in raising the cell temperature. References [23-26] indicated that the wind helps to blow dust from the surface of the cell and therefore clean it and increase the productivity of the cell. The wind also helps to calm the same cell as to help improve productivity. But high-speed winds may cause damage to the cell and lead to damage or break the base installed on them.
All the researchers agreed that the accumulation of dust and pollutants because a decrease in productivity of the cell and so you need to be cleaned periodically to rid it of dust and contaminants accumulated [27-32]. For the PV systems dust deposition case, two factors affect each other; the dust specifications and the local climate conditions. The site-local weather includes the human activities and the construction of the solar cell system properties as its type, surface finishing, installation height, and orientation. Besides, the vegetation type in the site plays a significant role in this regard. The physical,

ISSN: 2455-5304

chemical, biological, and electrostatic properties of the dust have a massive influence on the accumulation/aggregation. It is well known that dust deposition enhances more dust to settle, as the deposited particles attract and encourage more particle to settle, making the PV panel surface more willing to collect dust [30 & 32]

From the above, it is clear that weather variables play a role in the productivity of the solar cell, and the effect of these variables had studied solo or collect two variables together. Besides the fact that, weather conditions from one area to another is different, there is no fixed rule to determine the impact.

This research has investigated the effect of variables such as dust, temperature, solar radiation, relative humidity and wind on the productivity of laboratory solar cell. The goal is to represent the weather conditions and use dust from the city of Saham in Oman and a finding that the work of the solar cells in the circumstances flights. This research is part of the ongoing effort of a team of renewable energies in Sohar University for research and spread awareness regarding the use of renewables in the Arab Gulf countries and Iraq [35-73].

II. EXPERIMENTAL SETUP

The current study experimentally investigates the performance of PV panels under effect environmental variables as dust, humidity, and the wind. A PV panel which its specification is listed in Table 1 was used in the experiments. The current and voltage were measured to find the PV cell power and efficiency. The creation of the variable climatic conditions and representing it in a laboratory needed the use of solar simulator with lighting intensity ranged from 0 to 800 W/m2 with for steps of 200 W/m^2.

An air-conditioning device was used to cool the laboratory 25ºC. A fan with speed controller was used to provide a variable air speed acting as wind speed. A small boiling unit was used to generate water vapor inside the lab to control the lab humidity. Also, A glass panel of 1m2 was left for three months in the outside exposed to dust accumulation is Saham City - Oman. The accumulated dust was gathered and used in the tests.

Table 1: PV panel specifications

Typical power (Watts) at STC	20W
Nominal rated voltage at STC	12V
Maximum power (Watts)	20W
Tolerance (%)	+/- 3%
Voltage at max power	>16,0
Current at max power	1.22A
Open circuit voltage	20V
Short circuit current	1.5A

Measurements and Uncertainty

Many measuring instruments were used to measure the experimentally simulated climatic variables. All the used devices were calibrated, and their uncertainties were evaluated. The total uncertainty was less than 5% which indicated the measured results were geometrically correct and acceptable.

Test procedure

The solar simulator was fixed on the PV panel, and the solar intensity was measured to confirm the wright readings. The dust was distributed in many plastic containers of 5 grams each. In the tests, the dust was placed on the board, and it was shacked using a vibrator to distribute the dust consistently. The PV panel back temperature was measured employing four thermocouples type K.

In all tests, the air-conditioner operated till the lab temperature reached 25ºC and the relative humidity (RH) = 45% before the tests start. The representation of the relative humidity was conducted by increasing the water vapor in the lab using a steam generator. For the measurement of the effect of the wind on the productivity of the panel, the variable-speed fan had been used to generate the air movement.

III. RESULTS AND DISCUSSIONS

This study aims to determine the effect of weather conditions on the PV panel leading power through the representation of these circumstances in the laboratory to control the variables and prevent overlap from understanding the impact of each variable separately. Perhaps, the most important weather condition experienced by the solar cell is the air temperature.

Fig. 1 shows the effect of elevated air temperature on the PV output power at variable lightening intensity and constant relative humidity (RH= 45%). These figure results confirm the results of all other researchers investigated this point. The increase in air temperature from 25°C to 35 and 45°C caused reductions with about 1.85 and 20.22%, respectively. References [74 &75] manifested that if the PV panels' temperature were increased by 1 K, this would lead to a reduction of 0.4 to 0.5% in the crystalline silicon-based cells outcomes.

The relative humidity expresses the contained water in the air as moisture. Relative humidity is defined as the ratio between actual water vapor pressure in the air and the saturated water vapor pressure at the same temperature. Fig. 2 represents the effect of relative humidity on the PV panel outcomes at variable lightening intensity and a constant air temperature of 25°C. The figure confirms Ref. [11] results; the PV panel output reduced with RH increase. The reductions in the power were about 9.75, 15.24, and 32.24% for a relative humidity of 60, 75 and

90%, respectively; compared to the power at RH= 45%. The high temperature (greater than 40oC) and humidity (less than 60%) conditions that describe the Omani coast cities cause a long-term deterioration in the PV arrays and accelerate the corrosion process. Also, the wet cell surface forms a sticky surface that catches dust and dirt particles.

The wind has multivariable types of impact on the PV panel. First: a positive impact, which is increasing panel cooling by the natural and forced convection. The PV panel cooling helps in maintaining its outcomes as high as possible. Secondly: the wind adverse impact can be divided into two categories, (1) is the force exertion on the PV panel that can lead to a significant structural detriment. (2) The wind can cause dust surge and irritation in the air, which will settle and accumulate on the PV surface after the wind's sensation. In the recent tests in the lab, the wind has only a cooling effect on the solar cell and this effect is positive as Fig. 3 indicates. The solar cell absorbs the larger part of the solar radiation as heat as the Ref. [20] claimed. The air movement cools the surface of the cell by forced convection, causing a slight increase in power output as the results shows. The PV panel power increments were about 1.22, 3.35, and 3.8% for wind speeds WS of 5, 15, and 25 m/s respectively compare to WS=0 m/s.

Table.2: The measuring devices and its uncertainties

No.	Measured value	Measuring instrument name	Type	Made	Uncertainty
1	Solar intensity	Solar power meter	TM-206	Japan	0.12
2	Temperature	digital thermometer	MC-1000	China	0.68
3	Wind speed	air movement meter	PCE-007	USA	0.59
4	Relative humidity	humidistat	OMEGA	England	0.21
5	Weight	Digital balance	AGROMER	China	0.01
6	Shaker	Gemmy Orbit Shaker	VRN-480	Korea	0.34

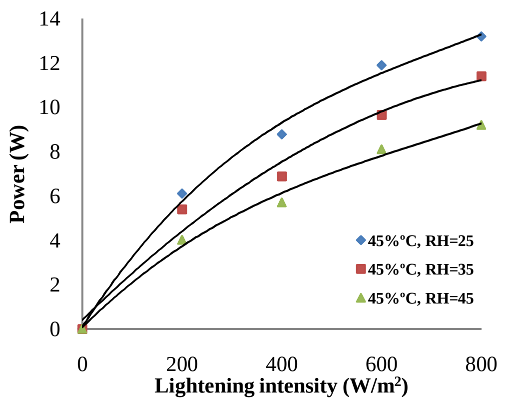

Fig.1:The Effect of PV Panel Back Temperature on the Output Power

The minute pollen, bacteria, fungi solids, and fine particles that have a diameter lower than 500 microns are called dust. Dust lowers the output power of the PV panel, and this is what was agreed with all the researchers working in this area. Fig. 4 reveals the effect of variable dust quantities accumulation on a PV panel at variable lighting intensity. The dust accumulations effect is larger at low lightening intensities, but in all conditions, it reduces the output power. The reductions in the output power were about 5.77, 7.73, 14.88, and 22.44 for 5, 10, 20 and 40 grams of deposited dust compared to clean panel case. Here we must emphasize that the dust accumulation depends on the dust chemical and physical properties, as well as, the site-specific factors, the features of the environment, the weather conditions, surface roughness, and the angle of inclination.

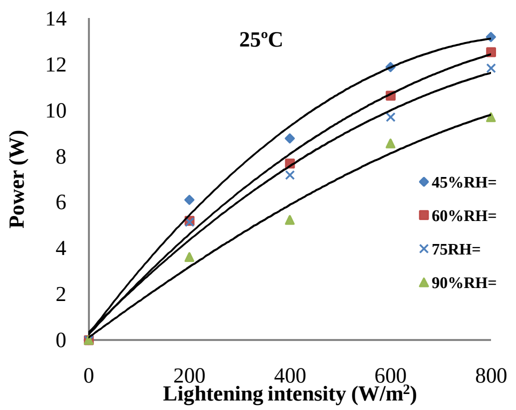

Fig. 2: The Effect of Climate Relative Humidity on the PV Panel Output Power

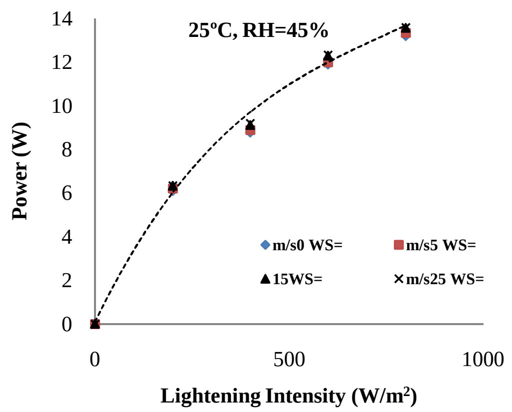

Fig. 3: The Effect of Wind Speed on the PV Panel Output Power

The air temperature can work in two directions as to cool the PV panel or to warm it. In all cases, the increase in solar radiation intensity increases the panel temperature as mentioned before. The relative humidity increase accompanied with high solar intensity as the case of the Omani coast (Saham city as it is the study subject) causes substantial reductions in the cell output power. The measured decrease, in this case, were 7.3, 14.36, and 25.6% for RHs of 60, 75 and 90% respectively compared to the baseline scenario RH=45%.

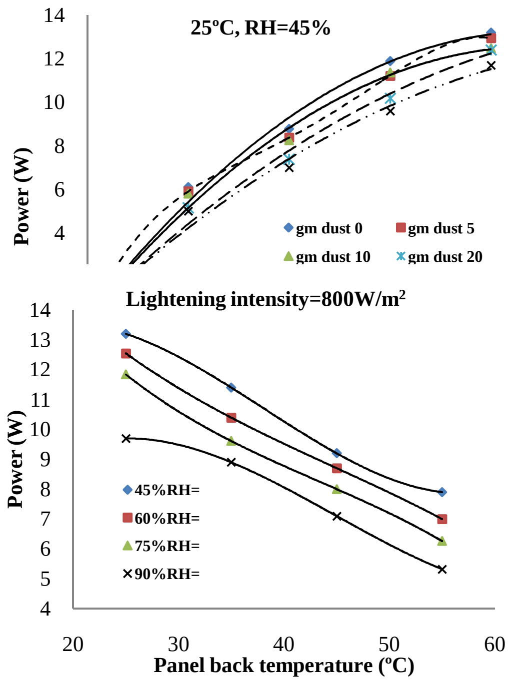

Fig. 5:The Effect of PV Panel Back Temperature and RH on the Output Power

The PV panel power increased with increasing the air movement (wind speed) at constant lightening intensity and relative humidity, as Fig. 6 manifests. The cooling effect of the increased air movement enhanced the output power of the cell by 2.87, 7.33, and 15.3% for wind speeds of 5, 15 and 25 m/s respectively compared with WS= 0 m/s.

Fig. 7 shows the impact of dust accumulation on the tested panel at elevated back temperatures. The dust accumulation and the increase in the temperature of the panel meeting caused a catastrophic decline in the resulting outcome. The dust accumulation with 5, 10, 20 and 40 grams on the panel caused reductions of 3.5, 10.8, 17.26, and 23.74% respectively compared to the clean panel.

The effect of the wind goes quietly against the impact of warmer temperatures. Increasing air speed, as shown in Fig. 8, reduced the accumulated dust and reduced the degree of solar panel temperature causing higher power when the rest variables were held constant. The reductions in the PV panel power when dust accumulated with 5, 10, 20, and 40 grams were 0.8, 2.8, 4, and 6.18%, respectively compared to clean panel.

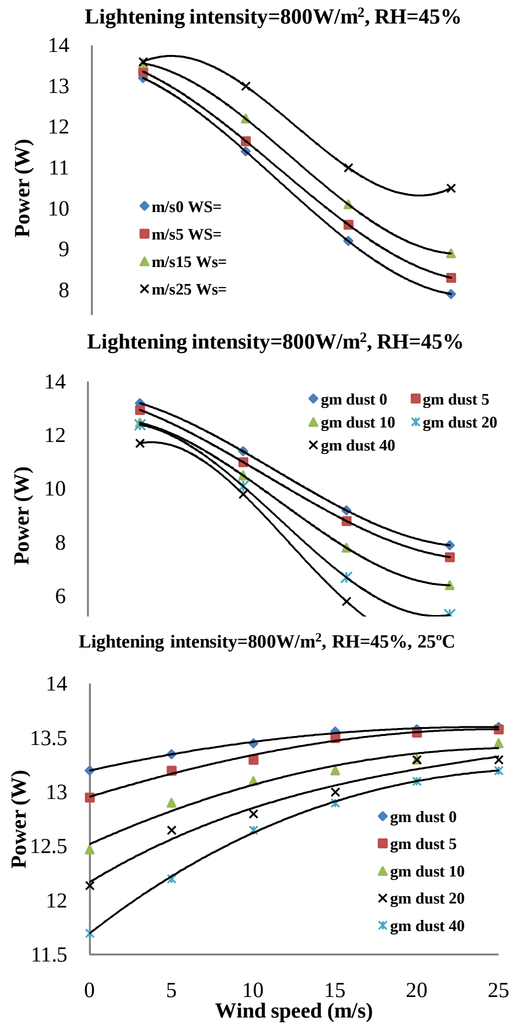

Fig. 8:The Effect of Wind Speed and Dust Accumulation onthe PV Panel Output Power

IV. CONCLUSION

The climate conditions impact the PV arrays performance, but this effect differs from area to another depending on the geographical and topographical conditions. The recent study was conducted in the Sohar University - renewable energies laboratory to investigate the mutual influence between the climatic variables as temperature, solar intensity, RH, wind speed and dust accumulation on PV panel.

The results revealed that PV panel outcomes reduced with elevated air temperature, RH, and dust accumulation. However, the reduction in increasing wind speed was limited when the other variables were remained constant. The PV panel output power was reduced in the case when high cell back temperatures and the presence high relative humidity. The wind has a cooling effect on the cell and it cause blowing the dust and prevent its accumulation on the panel surface, and therefore the resulting power decline was limited.

REFERENCES

[1] K. I. AbaasandM. T. Chaichan, "Experimental study of using solar energy storage wall for heating Iraqi houses purposes,"Wassit Journal for Science & Medicine, vol. 2, No. 2, pp. 212-221, 2009.

[2] M. T. Chaichan andH. 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.

[3] 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.

[4] H. A. Kazem, A. H. A. Al-Waeli, A. S. Al-Mamari, A. H. 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.

[5] H. A. Kazem, S. Q. Ali, A. H. Alwaeli, K. Mani and M. T. Chaichan, "Life-cycle cost analysis and optimization of health clinic PV system for a rural area in Oman," Proceedings of the World Congress on Engineering 2013, vol. II, WCE 2013, London, U.K., July 3 - 5, 2013.

[6] M. Hanif, M. Ramzan, M. Rahman, M. Khan M, M. Amin andM. Aamir, "Studying power output of PV solar panels at different temperatures and tilt angles," Journal of Science and Technology, vol. 8, No. 14, pp. 9-12, 2012.

[7] Y. Charabi, B. H. M. Rhouma, A. Gastli, "GIS-based estimation of roof-PV capacity & energy production for the Seeb region in Oman," IEEE International Energy Conference, Renewable Energy, vol. 57, pp. 635-644, 2013.

[8] B. R. Hughes, N. B. S. Cherisa and O. Beg, "Computational study of improving the efficiency of photovoltaic panels in the UAE," World Academy of Science, Engineering and Technology, vol. 5, No. 1, 2011.

[9] G.Makrides, B. Zinsser, A. Phinikarides, M. Schubert, G. E. Georghiou," Temperature and thermal annealing effects on different photovoltaic technologies," Renewable Energy, vol. 43, pp. 407-417, 2012.

[10] H. A. Kazem, M. T. Chaichan, I. M. Al-Shezawi, H. S. Al-Saidi, H. S. Al-Rubkhi, J. K. Al-Sinani and A. H. Al-Waeli, "Effect of humidity on the PV performance in Oman," Asian Transactions on Engineering , vol.2, Issue 4, pp. 29-32, 2012.

[11] 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.

[12] M. D. Kempe, "Modeling of rates of moisture ingress into photovoltaic modules," Solar Energy Materials and Solar Cells, vol. 90, No. 16, pp. 2720–2738, 2006.

[13] N. C. Park, W. W. Oh and D. H. Kim, "Effect of temperature and humidity on the degradation rate of multicrystalline silicon photovoltaic module," International Journal of Photo-energy, vol., Article ID 925280, 9 pages, 2013.

[14] H. G. Dhere and H. R. Raravikar, "Adhesion shear strength and surface analysis of a PV module deployed in harsh coastal climate," Solar Energy Materials and Solar Cells, vol. 67, No. 1–4, pp. 363–367, 2001.

[15] S. Mekhilef, R. Saidur, M. Kamalisarvestani, "Effect of dust, humidity and air velocity on efficiency of photovoltaic cells," Renewable and Sustainable Energy Reviews, vol. 16, pp. 2920- 2925, 2012.

[16] C. A. Gueymard, "The sun’s total and spectral irradiance for solar energy application and solar radiation models," Solar Energy, vol. 76, pp. 423-453, 2004.

[17] K. Thongpao , P. Sripadungtham, P. Raphisak, K. Sripapha and O. Ekkachart, "Solar cells based on the influence of irradiance and module temperature in, Electrical Engineering/Electronics Computer Telecommunications and Information Technology (ECTI-CON)," International Conference , Chiang Mai ,Thailand, pp. 153-160, 2010.

[18] A. M. Al-Salihi, M. M. Kadum and A. G. Mohammed, "Estimation of global solar radiation on horizontal surface using meteorological measurement for different cities in Iraq," Asian J. Sci. Res., vol. 3, No. 4, pp. 240-248, 2010.

[19] E. G. Dutton and et al., "Measurement of broadband diffuse solar irradiance using current commercial instrumentation with a correction for thermal offset errors," J. Atmos. Ocean. Technol., vol. 18, pp. 297-314, 2001.

[20] 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.

[21] H. A. Kazem, M. T. Chaichan, A. H. Alwaeli, and K. Mani, "Effect of Shadow on the Performance of Solar Photovoltaic,"WREN/WREC World Renewable Energy Congress, Rome, Italy, 2015.

[22] H. A. Kazem and M. T. Chaichan,"The impact of using solar colored filters to cover the PV panel on its outcomes," Bulletin Journal, vol. 2, No. 7, pp. 464-469, 2016. DOI: 10.21276/sb.2016.2.7.5.

[23] R. Siddiqui and U. Bajpai, "Deviation in the performance of solar module under climatic parameter as ambient temperature and wind velocity in composite climate," International Journal of Renewable Energy Research, vol. 2, No. 3, pp. 486–490, 2012.

[24] J. K. Kaldellis, M. Kapsali, K. A. Kavadias, "Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece," Renewable Energy, vol. 66, pp. 612-624, 2014.

[25] A. Radu and E. Axinte, "Wind forces on structures supporting solar collectors," Journal of Wind Engineering and Industrial Aerodynamics, vol. 32, pp. 93-100, 1989.

[26] G. S. Wood, R. O. Denoon and K. C. Kwok, "Wind loads on industrial solar panel arrays and supporting roof structure," Wind Struct., vol. 4, No. 6, pp. 481-494, 2001.

[27] M. T. Chaichan, H. A. Kazem, A. A. Kazem, K. I. Abaas, K. A. H. Al-Asadi, "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.

[28] H. A. Kazem, M. T. Chaichan, S. A. Saif, A. A. Dawood, S. A. Salim, A. A. Rashid, A. A. Alwaeli, "Experimental investigation of dust type effect on photovoltaic systems in north region, Oman," International Journal of Scientific & Engineering Research, vol. 6, No. 7, pp. 293-298, 2015.

[29] D. Goosens, E. V. Kerschaever,"Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance," Sol Energ, vol. 66, pp. 277-289, 1999.

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

[31] Z. A. Darwish, H. A. Kazem, K. Sopian, M. A. Alghoul and M. T. Chaichan, "Impact of some environmental variables with dust on solar photovoltaic (PV) performance: review and research status," International J of Energy and Environment, vol. 7, No. 4, pp. 152-159, 2013.

[32] M. T. Chaichan, B. A. Mohammedand H. A. Kazem, "Effect of pollution and cleaning on photovoltaic performance based on experimental study,"International Journal of Scientific and Engineering Research, vol. 6, No. 4, pp. 594-601, 2015.

[33] M. T. Chaichan, "Practical study of basement kind effect on solar chimney air temperature in Baghdad-Iraq weather,"Al Khwarizmi Eng. Journal, vol. 7, No. 1, pp. 30-38, 2011.

[34] S. T. Ahmed and M. T. Chaichan, "A study of free convection in a solar chimney sample,"Engineering and Technology J, vol. 29, No. 14, pp. 2986-2997, 2011.

[35] M. T. Chaichan andK. I. Abaas, "Practical investigation for improving concentrating solar power stations efficiency in Iraqi weathers," Anbar J for Engineering Science, vol.5, No. 1, pp. 76-87, 2012.

[36] M. T. Chaichan andH. A. Kazem, "Status and future prospects of renewable energy in Iraq,"Renewable and Sustainable Energy Reviews, vol. 16, No. 1, pp. 6007–6012, 2012.

[37] H. A. Kazem, H. S. Aljibori, F. N. Hasoon and M. T. Chaichan, "Design and testing of solar water heaters with its calculation of energy," Int. J. of Mechanical Computational and Manufacturing Research, vol. 1. No.2, pp. 62-66, 2012.

[38] M. T. Chaichan, K. I. AbaasandH. A. Kazem, "The effect of variable designs of the central receiver to improve the solar tower efficiency," International J of Engineering and Science, vol. 1, No. 7, pp. 56-61, 2012.

[39] M. T. Chaichan andK. I. Abaas,"Productivity amelioration of solar water distillator linked with salt gradient pond,"Tikrit Journal of Engineering Sciences, vol. 19, No. 4, pp. 24-34, 2012.

[40] M. T. Chaichan, K. I. Abaas, H. A. Kazem, H. S. Al JiboriandU. 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.

[41] M. T. Chaichan, K. I. AbaasandH. 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.

[42] 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.

[43] S. S. Faris, M. T. Chaichan, M. F. Sachit and J. M. Jaleel, "Simulation and numerical investigation of effect air gap thickness on Trombe wall system," International Journal of Application or Innovation in Engineering & Management (IJAIEM), vol. 3, No. 11, pp. 159-168, 2014.

[44] M. T. Chaichan andH. 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.

[45] M. T. Chaichan M T and H. A. Kazem, "Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM)," Case Studies in Thermal Engineering, Elsevier, vol. 5, pp. 151-159, 2015.

[46] M. T. Chaichan, K. I. Abaas, "Performance amelioration of a Trombe wall by using phase change material (PCM),"International Advanced Research Journal in Science, Engineering and Technology, vol. 2, No. 4, pp. 1-6, 2015.

[47] M. T. Chaichan, B. A. Mohammedand H. A. Kazem, "Effect of pollution and cleaning on photovoltaic performance based on experimental study,"International Journal of Scientific and Engineering Research, vol. 6, No. 4, pp. 594-601, 2015.

[48] M. T. Chaichan,K. I. Abaas,H. A. Kazem, "Design and assessment of solar concentrator distillating system using phase change materials (PCM) suitable for desertec weathers," Desalination and water treatment, pp: 1-11, 2015.DOI: 10.1080/19443994.2015.1069221

[49] M. T. Chaichan and K. A. H. Al-Asadi, "Environmental Impact Assessment of traffic in Oman,"International Journal of Scientific & Engineering Research, vol. 6, No. 7, pp. 493-496, 2015.

[50] M. T. Chaichan, S. H. KamelandA. N. M. Al-Ajeely, "Thermal conductivity enhancement by using nano-material in phase change material for latent heat thermal energy storage Systems," SAUSSUREA, vol. 5, No. 6, pp. 48-55, 2015.

[51] 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.

[52] H. M. S. Al-Maamary, H. A. Kazem, M. T. Chaichan, "Changing the energy profile of the GCC States: A review," International Journal of Applied Engineering Research (IJAER), vol. 11, No. 3, pp. 1980-1988, 2016.

[53] 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.

[54] 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," Environ Dev Sustain, 2016. DOI 10.1007/s10668-016-9773-z.

[55] M. T. Chaichan, A. H. Al-Hamdani, A. M. Kasem, "Enhancing a Trombe wall charging and discharging processes by adding nano-Al_2O_3 to phase changematerials," International Journal of Scientific & Engineering Research, vol. 7, No. 3, pp. 736-741, 2016.

[56] M. T. Chaichan, H. A. Kazem, A. M. J. MahdyandA. 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.

[57] M. T. Chaichan, "Enhancing productivity of concentrating solar distillating system accompanied with PCM at hot climate," Wulevina, vol. 23, No. 5, pp. 1-18, 2016.

[58] M. T. Chaichan, H. A. Kazem, A. M. J. MahdyandA. A. Al-Waeely A A, "Optimization of Hybrid Solar PV/ Diesel System for Powering Telecommunication Tower," IJESET, vol. 8, No. 6, pp. 1-10, 2016.

[59] M. T. Chaichan, H. A. Kazem, K. I. Abaas, 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.

[60] M. T. Chaichan, "Effect of injection timing and coolant temperatures of DI diesel engine on cold and hot engine startability and emissions," IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE), vol. 13, No. 3-6, pp. 62-70, 2016.

[61] H. A. Kazem,H. A. S. Al-Badi,A. S. Al BusaidiandM. T. Chaichan, "Optimum design and evaluation of hybrid solar/wind/diesel power system for Masirah Island," Environment, Development and Sustainability, 2016. DOI: 10.1007/s10668-016-9828-1

[62] M. T. Chaichan, K. I. Abaas, 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.

[63] M. T. Chaichan, K. I. Abass, D. S. M. Al-Zubidi, H. A. Kazem, "Practical investigation of effectiveness of direct solar-powered air heater," International Journal of Advanced Engineering, Management and Science (IJAEMS), vol. 2, No. 7, pp.1047-1053, 2016.

[64] H. A. Kazem, A. H. 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, DOI: 10.1007/s10668-016-9773-z, 2016.

[65] M. T. Chaichan, K. I. Abaas, F. F. Hatem, "Experimental study of water heating salt gradient solar pond performance in Iraq," Industrial Applications of Energy Systems (IAES09), Sohar University, Oman, 2009.

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

[67] M. T. Chaichan andK. I. Abaas, "Practical investigation for measurement of concentrating solar power prototype for several target cases at Iraqi summertime weathers," 1st Scientific Conference for Energy & Renewable Energies Applications, UOT, Baghdad, Iraq, 2011.

[68] M. T. Chaichan, H. I. KazemandK. I. Abaas, "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.

[69] M. T. Chaichan, K. I. Abaas, H. A. Kazem, F. Hasoon, H. S. Aljibori, A. A. Alwaeli and A. H. Alwaeli, "Effect of design variation on saved energy of concentrating solar power prototype," Proceedings of the World Congress on Engineering (WCE 2012), Vol. III, July 4 - 6, London, UK, 2012.

[70] M. T. Chaichan, K. I. Abaas, 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.

[71] H. Mazin, H. A. Kazem,H. A. Fadhil, S. Alawi, Q. Mazin and M. T. Chaichan, "Linear and nonlinear modeling for solar energy prediction on the zone, region and global," World Renewable Energy Council/Network (WREC XIII), London, UK, 3-8 August, 2014.

[72] H. Mazin, H. A. Kazem, H. A. Fadhil, S. Alawi and M. T. Chaichan, "Global linear, nonlinear and ANN-based modeling of monthly diffuse solar energy,"WREC XIV Proceedings, University POLITEHNICA of Bucharest, Romania, June 8 – 12, 2015

[73] A. H. Al-Waeli, A. S. A. Al-Mamari, A. H. Al-Kabi, M. T. Chaichan, H. A. Kazem, "Evaluation of the economic and environmental aspects of using photovoltaic water pumping system," 9th International Conference on Robotic, Vision, Signal Processing & Power Applications, Malaysia, 2016.

[74] D. T. Lobera and S. Valkealahti, "Dynamic thermal model of solar PV systems under varying climatic conditions," Solar Energy, vol. 93, pp. 183–194, 2013.

[75] E. Zambolin, D. Del Col, "Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions," Solar Energy, vol. 84, pp. 1382–96, 2010.