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Analysis of the influence of the ambient temperature on the energy efficiency of solar modules by application of empirical correlations for natural convection

Shahir Fleyeh Nawaf, Mohammad Omar Salih, Younis Nather Younis
Electrical Engineering Department, Engineering College, Tikrit University, Tikrit, Iraq

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ABSTRACT

In this paper, the effect of the ambient temperature on photovoltaic (PV) modules for different angles of inclinations and different intensities of the solar radiation on the surface of PV module is considered using empirical correlations for natural convection. The analysis used an analytical model based on the energy balance equilibrium between PV module and the environment. It has been shown that in real conditions of exploitation, the value of the solar conversion coefficient of the solar energy to be determined by the manufacturer, valid for the standard test conditions (STC) for PV module (25 °C -1000 W/m^2). The results obtained indicates that in the case a smaller number of PV modules corresponding to the required number for average household. The proposed procedure can be applied in the techno-economic analysis for PV system with uniaxial monitoring of the sun position as well as static PV systems.

Corresponding Author:

Shahir Fleyeh Nawaf
Electrical Engineering Department, Engineering College
Tikrit University
Tikrit, Iraq
Email: shahir735@gmail.com

NOMENCLATURE

T_{PV}:	The mean value of the PV modulus temperature.	[K]
α_S:	The solar radiation absorption coefficient for upper surfaces of the PV module.	
Q:	Component of solar radiation is normal on the upper surface of the PV module.	[W / m^2]
h_{UF}:	Coefficient corresponding to the natural convection between the upper surface of the PV module and the air.	[W / (m^2 · K)]
h_{DF}:	Coefficient corresponding to natural convection between the lower surfaces e PV module and air.	[W / (m^2 · K)],
$h_{r,UF}$:	Coefficient corresponding to the radiation between the upper surface of the PV module and ambient.	[W / (m^2 · K)]
Tg:	The temperature of the earth.	[K].
ε_{UF}:	Emission coefficient thermal radiation from Upper surface of the PV module.	
σ_{SB}:	Stefan-Boltzmann constant.	[W / (m^2 · K4)],
G:	Intensity of solar radiation (direct component).	[W / m^2]
Ψ:	Angle of PV module inclinations in relation to the vertical	[°]
ε_{UF}:	Emission coefficient thermal radiation from upper surface of the PV module.	
δ:	Angle between the direction of the Sun rays and normal on the upper surface of the PV module.	[°]
η_{Tref}:	Efficiency of PV modules at reference temperature T_{ref} and intensity of solar radiation of1000 W / m^2.	[%]
β_{ref}:	Temperature coefficient that describes a decrease in the efficiency of the PV module with an increase in the PV module temperature above the reference value T_{ref}.	[1 / K]

1. INTRODUCTION

The energy of solar radiation is the largest and inexhaustible source of energy on Earth available on all parts of its surface. Since this energy is free and does not affect environmental pollution, so, it is understandable why huge attention is paid to the systems for the exploitation of solar energy, especially in last two decades [1]. The direct conversion of the sun into electricity by means of PV modules today provides a small percentage of the world's electricity demand. The main reasons for this are the relatively high prices of the PV modules, but also their low efficiency, which, depending on the type of the commercial PV modules which ranges from 10 to 18%. This means that more than 80% of the energy of the solar radiation that enters the surface of the PV module is converted into heat, while the smaller part is reflected. However, the International Energy Agency (IEA) predicts that by 2050, 45% of the world's energy will be produced from the Sun's energy [1]. It is well known that the efficiency of the PV module is greatly depends on its temperature [2-4]. With the increase in the temperature of the PV module, the voltage of the PV module is reduced, resulting in a decrease in its efficiency. This problem is particularly pronounced in areas with a warmer climate such is our country (Iraq republic) [5].

There is a large number of papers in the literature dealing with the problem of the influence of different parameters on the performance of the PV modules. In there is a constant decrease in the efficiency of the PV module relative to the value prescribed by the manufacturer for the temperature of the module of 25 °C, when its temperature is higher than this value [6]. This means that it is necessary to install a larger number of PV modules in order to achieve the required power in real conditions of exploitation in relation to the STC conditions of the PV module. A set of correlations is proposed for determining the required surface of the PV module for a certain power in the function of the ambient temperature, the intensity of the solar radiation and other construction parameters of the PV module and the same is applied to the climatic conditions in [7]. Mattei *et al.* analyzed the performance of the PV module for three different variables: ambient temperature, intensity of solar radiation and wind speed without taking into account the effect of radiation and the angle of the PV module. In [8], an assessment was made of the individual influence of the intensity of the Sun's radiation, its spectrum and the temperature of different types of silicon PV modules on their performance [9]. Skoplaki *et al.* suggested semi empirical correlations for determining the efficiency of the PV modules and their power depending on the temperature of the ambient, the intensity of the solar radiation, the wind speed and the modes of PV modulation. However, the correlations in are recommended only for wind speeds greater than 1 m/s [10].

In this paper, the application of the analytical model considers the influence of the ambient temperature, the intensity of the solar radiation, the angle between the normal on the upper surface of the PV module and the incident solar radiation, the temperature of the PV module and its corresponding efficiency were analyzed [11]. On the basis of the obtained results, the expression for calculating the electric power of the PV module is proposed depending on the above mentioned parameters under the conditions of heat exchange between PV modules and ambient through natural convection and radiation. The process of heat exchange through natural convection and radiation between PV modules and the environment is modeled by empirical analytical model for the determination of temperature and electric power of PV modules. There are many models in the literature for determining the temperature of the PV modules [2]. However, all models give different results for the same values of intensity of solar radiation and ambient temperature [12]. These differences are due to the neglect of the influence of individual parameters, climatic conditions, PV module configuration and various approaches to problem solving. In this paper, an analytical model based on the equation of the energy balance between the received energy of the solar radiation, the part of this energy converted to an electric in the PV module and the exempted thermal energy from the PV module through natural convection and radiation is applied to determine the temperature of the PV module.

2. TEST EXAMPLE

In this paper, the specific PV module SUNTECH STP265-20/Wem is made of polycrystalline silicon (p-Si). Silicon Solar cells have been developed among the earliest and most used today. The PV module made of p-Si was chosen because today in the world about 60% of the electricity produced by PV modules is produced precisely in modules from p-Si [13, 14]. At today's level of development, most commercial Si modules have an efficiency of 15-18% and very uniform characteristics regardless of the manufacturer [15], so that the conclusions derived from the PV module whose data are given in Table 1.

3. MATHEMATICAL MODULE USED IN THE ANALYSIS

The model includes all the relevant values that affect the temperature of the PV module, which makes the results obtained by it very reliable. The model is described in detail and only the finite expression for calculating the temperature of the PV module in the case of heat exchange between this module and the environment through natural convection and radiation is given here [16]:

$$T_{Pv} = \frac{(1+\eta Tref \cdot (\beta ref \cdot Tref - 1))\alpha S \cdot Q + (hUF + hDF) \cdot Ta + (hr,UF + hr,DF) \cdot 0{,}0552 \cdot T_a^{1.5}}{h_{UF} + h_{r,UF} + h_{DF} + h_{r,DF} + \eta_{Tref} \cdot \beta_{ref} \cdot \alpha \cdot Q_S} \quad (2)$$

$$hr, UF = \varepsilon_{UF} \cdot \sigma_{SB} \cdot \left(T_{PV}^2 + T_{Sky}^2\right) \cdot (TPV + Tsky)$$

$$hr, DF = \varepsilon_{DF} \cdot \sigma_{SB} \cdot \left(T_{PV}^2 + T_g^2\right) \cdot (TPV + Tg) \quad (3)$$

$$Q = G \cdot cos\delta \quad (4)$$

$$Tsky = Tg = 0{,}0552 \cdot T_a^{1.5} \quad (5)$$

$$\eta e = \eta Tref[1 - \beta ref(T - Ta)] \quad (6)$$

Table 1. Illustrate the parameters description indicated in the above equations. More information on this module and the corresponding correlations used for modeling natural convection can be found in [17]. When in the iterative process the temperature of the PV module is calculated by (1) and its corresponding efficiency by (6), then the electric power of the PV module at its ends can be calculated as:

$$Pel = \eta el \cdot \alpha S \cdot Q \cdot S \quad (7)$$

where S is the active surface of the PV module in [m^2].

Table 1. Characteristics of the SUNTECH STP265-20/Wem module

Size	Value	Size	Value
Width [W]	1.00 m	Absorption coefficient for the upper surface of the PV module (αS)	0.97
Height [L]	0.64 m		
Maximum power at STC conditions [Pmax]	265 W	Coefficient of emission for the upper surface of the PV module (εUF)	0.91
Efficiency degree for STC conditions [ηTref]	16.3%	Emission coefficient for the bottom surface PV module (εDF)	0.85
Temperature coefficient [βref]	0.004 1/K	STC: Intensity of solar radiation 1000 W/m^2, PV module temperature 25 °C, R AM = 1.5	
Reference temperature [Tref	25 °C		

4. RESULTS AND DISCUSSION

Using the above-described analytical model, the electric power generated by the PV module Pel at its connection ends for different ambient temperature values, the intensity of the sun's radiation and the incident angle of the sun radiation on the top of the PV module, as the most important parameters affecting the performance of the PV module will be calculated. On the basis of the performed analyzes, it was established that for different angles of the PV modulation of the ψ and the constant value of the intensity of the solar radiation on its upper surface G and the angle between the direction of the sun's irradiance and normal on the upper surface of the PV module δ, the electric power generated Pel by the PV module is slightly changed. Therefore, all calculations are carried out for the same angle of (ψ=60°), which is the optimum tilt angle of the PV module relative to the Tikrit city and the angle δ changes in the range 0°≤δ≤60° with a step of 10° [18].

The change of the azimuth angle of the PV module slightly disturbs its electric power (only 4% in the case of the azimuth angle of the PV module of ± 45° [19]), that means the azimuth angle of PV panels considered to be constant (azimuth = 0°). Such a small change is due to the fact that solar power is not obtained only directly from the Sun, but also by the diffusion of air through the atmosphere and the reflection of air from objects on the earth. Figures 1-4 illustrate the electrical power in the panel output obtained by performing the previously described analytical algorithm in (7) for different values of δ and for three values of G (G=200 W/m^2 ^{G}=400 W/m^2 and G=1000 W/m$^{2)}$.

Based on the results obtained by performing the previously described analytical algorithm, which are shown in Figures 1-4, a correlation is proposed for determining the power of the PV module in the ambient temperature function, the intensity of the radiation, degree of efficiency of PV module specified by the manufacturer under STC conditions and the inclined angle of the panel, the output power of the photovoltaic panel can also be calculated by using the (8) [20]:

$$P_{el} = 0.0386 \,.\, \eta_{Tref} \cdot S \cdot \left[\frac{G}{1000}\right]^{0.92} .\left((cos\delta)^{0.9} . (245 - Ta\right). \quad (8)$$

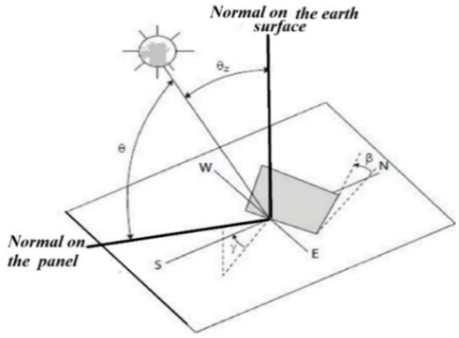

Figure 1. The angels that determine the optimum panel position [15]

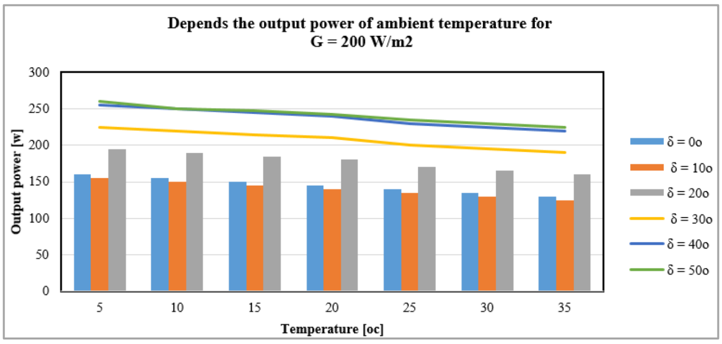

Figure 2. Power values of PV modules for different values of δ

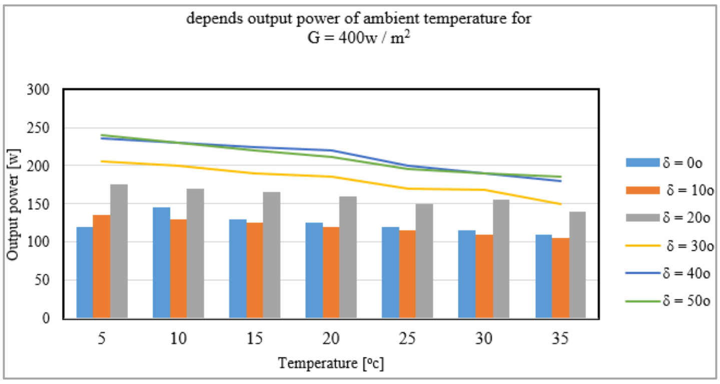

Figure 3. Power values of PV modules for different values of δ

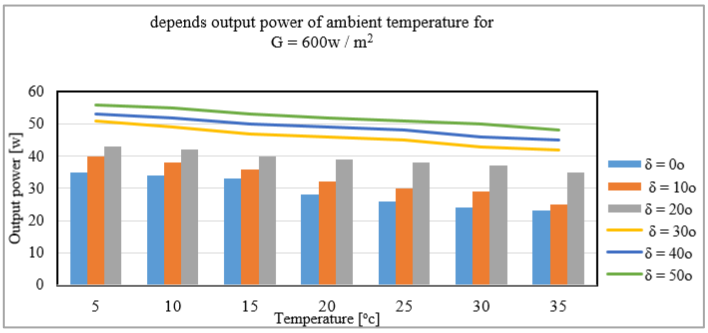

Figure 4. Power values of PV modules for different values of δ and

In the (8), the degree of efficiency of PV modules under STC conditions η Tref is expressed in [%], intensity of solar radiation G in [W/m^2], angle δ in [°C] and ambient temperature Ta in [°C]. In this way, the (8) gives the electric power in [W]. By comparing the obtained both results, it can be seen that the largest deviation between the power values obtained by the analytical model and (8) is 4.6%.

Using the (8), an analysis of the electricity production of this system will be performed for three cases of the angle of inclination of the PV module for three cases [21]: 1) when the angle of inclusion of the PV module is constant, 2) when it changes for each month; and 3) when four times daily every day (every three hours following a three-point change in the intensity of the sun's radiation and the angle at which the sun's rays fall on the horizontal surface of the earth). Table 2 gives the mean values of the intensity of solar radiation on the horizontal surface of the location of the considered place [22], as well as the mean monthly value of the angle at which the sun rays fall to the horizontal surface of the earth for the location of the Tikrit city (latitude: 29º57'47", longitude: 41º49'51") [23]. For the temperature, the mean values corresponding to the warmer part of the day when the PV modules are used are taken. All of these data are needed for the (8). Based on the data from Table 2 and using the (8) for a specific set of 8 PV modules of type AS-5M-200 W which have the following characteristics (η Tref=15.67%, Length=1.58 m, Width=0.808 m), the electrical power of the PV module can calculate and then compared with the electrical output power results obtained by the previously described module.

Table 2. The mean values of the intensity of solar radiation on the horizontal earth surface

Parameter		Jan	Feb	Mart	Apr	Maj	Jun	Jul	Avg.	Sep	Oct	Nov	Dec
G [kW/m^2]	6-9 h	0.02	0.05	0.11	0.23	0.24	0.30	0.33	0.24	0.17	0.12	0.03	0.03
δ [°]		7.71	13.35	22.45	32.6	39.72	43.01	39.57	34.91	28.42	20.65	12.89	7.855
G [kW/m^2]	9-12 h	0.21	0.30	0.42	0.36	0.45	0.63	0.67	0.61	0.53	0.36	0.22	0.19
δ [°]		23.67	31.67	42.15	53.56	62.17	66.27	64.33	57.32	47.43	36.37	26.81	22.03
G [kW/m^2]	12-15 h	0.24	0.34	0.43	0.46	0.52	0.58	0.63	0.60	0.45	0.33	0.22	0.19
δ [°]		17.27	25.1	34.05	42.16	49.21	52.9	52.23	46.33	36.53	25.67	16.29	13.66
G [kW/m^2]	15-18 h	0.04	0.09	0.16	0.20	0.26	0.33	0.24	0.68	0.07	0.06	0.03	0.06
δ [°]		0.67	3.31	7.58	12.54	18.03	21.37	21.3	15.96	8.24	2.62	0.25	n/a
T_a [°C]		5	8	13	18	23	27	29	29	23	19	12	5

According to (8), the electrical power of the PV module directly depends on the intensity of solar radiation and the degree of utilization of PV modules. It has also been confirmed that the maximum power of the PV module is in the case when it is inclined at an optimum angle (i.e., when the angle between the solar rays and the normal to the PV module is equal to zero). The member (245-Ta) actually has the form (270-Ta +25)), where 25 °C is added to the ambient temperature because it is the temperature of the PV module on which the manufacturer prescribes the characteristics under STC conditions. This is confirmed by the fact that for the temperature of the module is about 270 °C, the power generated by the PV module is equal to zero [24]. Exponents 0.92 and 0.9 in (8) take into account the influence of different parameters/phenomena on the efficiency of the PV module, such as the separation of the boundary layer along the surface of the inclined PV module which depends on the angle of inclination of the PV module, the change in the emissivity of the upper surface of the PV module with the change in the incident angle and the intensity of the solar radiation. The results are given in Tables 3-5 which illustrate the expected electrical power generation for 8 PV modules (type AS-5M-200 W) obtained by using (8). The proposed (8) will now be used to calculate the power of a series of PV modules used to supply the electrical power to the considered place. PV modules are mounted at an angle of 45° and do not have the possibility of changing the angle of inclination [25].

Table 3. Expected electrical power generation of 8 PV modules (type AS-5M-200 W) obtained by using (8) for parameter values from Table 2 when the angle of inclusion (Ψ) of the PV module is constant

Time		Output electrical power	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly production average
6-9 h	Ψ = (51°)	P[KW]	0.31	0.33	0.32	0.45	0.61	0.53	0.57	0.51	0.42	0.06	0.06	0.15	3.65 MWh / year
9-12 h		P[KW]	0.36	0.42	0.45	0.57	0.56	0.62	0.67	0.65	0.52	0.53	0.50	0.42	
12-15 h		P[KW]	0.31	0.36	0.50	0.63	0.64	0.65	0.62	0.52	0.50	0.42	0.48	0.45	
15-18 h		P[KW]	0.33	0.35	0.38	0.45	0.51	0.53	0.57	0.51	0.43	0.05	0.03	0.15	

Table 4. Expected electrical power generation of 8 PV modules (type AS-5M-200 W) obtained by using (8) for parameter values from Table 2 when the angle of inclusion (Ψ) changes for each month

Time	Output electrical power	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Yearly production average
6-9 h	Ψ [°]	21	28	38	48	56	59	58	52	42	31	22	32	3.70 MWh / year
	P [kW]	0.07	0.18	0.36	0.61	0.82	0.90	0.84	0.68	0.49	0.33	0.14	0.08	
9-12 h	Ψ [°]	21	28	38	48	56	59	58	52	42	31	22	18	
	P [kW]	0.73	0.96	1.25	1.36	1.57	1.67	1.73	1.68	1.41	1.11	0.77	0.64	
12-15 h	Ψ [°]	21	28	38	48	56	59	58	52	42	31	22	18	
	P [kW]	0.79	1.08	1.31	1.36	1.49	1.62	1.73	1.66	1.31	1.03	0.71	0.06	
15-18 h	Ψ [°]	21	28	38	48	56	59	58	52	42	31	22	18	
	P [kW]	0.14	0.29	0.46	0.53	0.64	0.74	0.81	0.68	0.45	0.25	0.07	0.06	

Table 5. Expected electrical power generation of 8 PV modules (type AS-5M-200 W) obtained by using (8) for parameter values from Table 2 when the angle of inclusion (Ψ) changes four times daily every day (every three hours)

Time	Output electrical power	Jan.	Feb.	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Yearly production average
6-9 h	Ψ [°]	8	13	22	33	40	42	40	35	28	21	13	3	3.87 MWh / year
	P [kW]	0.08	0.18	0.37	0.63	0.85	0.94	0.82	0.71	0.50	0.36	0.15	0.08	
9-12 h	Ψ [°]	24	32	42	54	62	66	64	57	47	36	27	22	
	P [kW]	0.73	0.96	1.26	1.37	1.58	1.68	1.74	1.69	1.42	1.12	0.77	0.64	
12-15 h	Ψ [°]	17	25	34	43	49	53	52	46	36	25	17	14	
	P [kW]	0.79	1.08	1.32	1.37	1.50	1.63	1.74	1.66	1.31	1.07	0.71	0.64	
15-18 h	Ψ [°]	1	3	8	13	18	21	21	16	8	3	0	0	
	P [kW]	0.15	0.32	0.53	0.63	0.79	0.91	0.98	0.82	0.53	0.24	0.07	0.07	

From the comparison of the results obtained for three cases, it can be seen that the difference in the annual production of electricity, in the case where PV modules do not have the possibility of changing the angle of inclination and the case when this angle is changed for each month, it is very small (only 50 kWh/year), while in the third case, production is expected to be the highest. However, for the third case a complex mechanism for uniaxial monitoring of the position of the sun is necessary. Using the single-axis monitoring system of the sun position, 232 kWh of energy can be produced in a year more than a system that does not have the possibility of changing the angle of inclination of the PV module. However, in order to monitor the position of the sun and adjust the angle of inclination of the PV module, among other things, an actuator (motor) and a solar positioner is required [20]. In the unidirectional monitoring system of the sun position, an additional mechanism for rotating the PV module is needed, and the maintenance costs due to more frequent system failures and higher own consumption for the operation of the engine are also higher. Therefore, in order to achieve the required power of the PV system, in this case, it is much more economical to invest in a larger number of PV modules with constant angle inclinations than in a unidirectional monitoring system for the position of the sun.

5. CONCLUSION

In this paper, it has been shown that the power of the PV module depends on the ambient temperature. This dependence is linear in contrast to the dependence of the power of the PV module on the intensity of the sun's radiation and the angle between the sun's irradiance and the normal on the upper surface of the PV module. The proposed (8) for calculating the power of the PV modules in function of the parameters considered is very simple and very useful for calculating the expected production of electricity and the techno-economic optimization of the PV system both static and those that have the ability to monitor the position of the sun. Formula applies to the worst case of cooling PV modules when the wind speed is zero. The same was applied on a system of a series of 8 PV modules installed in the University of Tikrit and which serve to supplement the electrical power supply of consumers in this place. From the results obtained, it has been shown that in the case of a smaller number of PV modules corresponding to the required number for an average household, it is more economical to invest additional resources in increasing the PV module's surface area than in case of the sun tracking system. Of course, this applies to the ambient conditions of micro location at which the PV modules are being exploited or planned.

REFERENCES

[1] H. A. Kazem, A. Al-Waeli, M. Chaichan, A. Al-Mamari & A. H. Al-Kabi, “Design, Measurement and Evaluation of Photo-voltaic Pumping System for Rural Areas in Oman," *Environment Development and Sustainability,* vol. 19, pp. 1041-1053, 2016.

[2] 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.

[3] A. Kazem, A. H. Al-Waeli, A. S. A. Al- Mamari, A. K. Al-Kabi, M. 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.

[4] Kazem & M. 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.

[5] H. M. Al-Maamary, H. Kazem & M. 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.

[6] Khosravi A., Koury R. N. N., Machado L. and Pabon J. J. G., “Energy, Exergy and Economic Analysis of a Hybrid Renewable Energy with Hydrogen Storage System,” *Energy*, vol. 148, pp. 1087-1102, 2018.

[7] A. Kazem, M. Chaichan & H. Kazem, "Effect of Dust on Photovoltaic Utilization in Iraq: Review Article," *Renewable and Sustainable Energy Reviews*, vol. 37, pp. 734-749, 2014.

[8] Khalid F., Dincer I., Rosen M. A., “Techno- Economic Assessment of a Renewable Energy Based Integrated Multigeneration System for Green Buildings,” *Applied Thermal Engineering*, vol. 99, pp. 1286-1294, 2016.

[9] M. Chaichan & H. Kazem, "Water Solar Distiller Productivity Enhancement Using Concen- trating Solar Water Heater and Phase Change Material (PCM)," *Case Studies in Thermal Engineering Elsevier*, vol. 5, pp. 151-159, 2015.

[10] M. Chaichan & K. 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.

[11] Cheviron B., Vervoort R. W., Albasha R., Dairon R., Le Priol C., Mailhol J. C., “A framework to use crop models for multiobjective constrained optimization of irrigation strategies,” *Environ. Modell. Softw.,* vol. 86, pp. 145-157, 2016.

[12] Dinesh H., Pearce J. M., “The potential of agrivoltaic systems,” *Renew. Sust. Energ. Rev.,* vol. 54, pp. 299-308, 2016.

[13] Emmanuel I., Andrieu H., Leblois E., Janey N., and Payrastre O., “Influence of rainfall spatial variability on rainfall? Runoff modelling: benefit of a simulation approach?,” *J. Hydrol*., vol. 531, pp. 337-348, 2015.

[14] Harinarayana T., Sri Venkata Vasavi K., “Solar energy generation using agriculture cultivated lands,” *Smart Grid Renewable Eng*., vol. 5, pp. 31-42, 2014.

[15] IPCC: Climate Change, “Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,” *Cambridge University Press*, New York, 2014.

[16] Martello M., Ferro N., Bortolini L., and Morari F., “Effect of incident rainfall redistribution by maize canopy on soil moisture at the crop row scale,” *Water*, vol. 7, pp. 2254-2271, 2015.

[17] Pujol G., Iooss B., Janon A., “Global Sensitivity Analysis of Model Outputs (Version, 1.14.0), Package “sensitivity”, 2017.

[18] Ravi S., Lobell D. B., and Field C. B., “Tradeoffs and synergies between biofuel production and large solar infrastructure in deserts,” *Environ. Sci. Technol.,* vol. 48, pp. 3021-3030, 2014.

[19] Pakdaman M. F., Lashkari A., Tabrizi H. B., Hosseini R., “Performance evaluation of a natural-convection solar air-heater with a rectangular-finned absorber plate,” *Energy Conversion and Management*, vol. 52, no. 2, pp. 1215-1225, 2011.

[20] Bahrehmand D., & Ameri, M. (2015). Energy and exergy analysis of different solar air collector systems with natural convection," *Renewable Energy*, vol. 74, pp. 357-368, 2015.

[21] Rahimi A., Kasaeipoor A., Malekshah E. H., “Natural convection analysis by entropy generation and heatline visualization using lattice Boltzmann method in nanofluid filled cavity included with internal heaters-Empirical thermo-physical properties,” *International Journal of Mechanical Sciences*, vol. 133, pp. 199-216, 2017.

[22] Singh Y. A., Kumar T. M., “Artificially roughened solar air heater: experimental investigations,” *Renewable Sustainable Energy Reviews*, vol. 36, no. 370-411, 2014.

[23] Farhan A. Ammar, “Theoretical and experimental studies for a double pass solar air heater,” *International journal of computer applications*, vol. 161, no. 2, pp. 1-6, 2017.

[24] Manuel R., Shivkumar P., “Power flow control model of energy storage connected to smart grid in unbalanced conditions: A GSA-technique-based assessment,” *International Journal of Ambient Energy*, vol. 440, no. 4, pp. 417-426, 2017.

[25] Askarzadeh A., “A memory-based genetic algorithm for optimization of power generation in a microgrid,” *IEEE Trans. Sustainable Energy,* vol. 9, no. 3, pp. 1081-1089, 2018.