Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: Mohammed Jawad Yaseen *et al* 2022 *J. Phys.: Conf. Ser.* **2322** 012079

Prediction of the performance of a solar PV system in Baghdad, Iraq

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Abstract. The world is actively seeking alternatives to traditional energy sources amid increasing demand for energy as a result of population growth, the development of technologies, and the environmental pollution caused by traditional energy sources and their tendency to deplete. Renewable energy sources are one of the most promising sources, mainly solar energy, which is the source of most of these sources. The goal of this work is to analyze data collected by the Al-Rashidiya meteorological station to predict the performance of solar PV modules (NT-R0E3E-SHARP) in this geographical area. Depending on the data from the Al-Rashidiya meteorological station, each of the tilted global solar radiation, cell temperature, output power, and electric conversion efficiency was calculated by using the PV model. The results indicated that the annual solar radiation incident in Baghdad with the horizontal plane was 1834kWh/m^2/year with an annual peak sun hours (solar fuel) of 5, and the degradation percentage in the electrical conversion efficiency of monocrystalline silicon solar cells ranged between 2% in winter to 11% in summer. From the results of the present work, it can be concluded that Baghdad's geographical area and surroundings are promising for investing in solar energy to produce electricity.

Keywords: Solar radiation, Meteorological Station, and Solar cell efficiency

Nomenclature

I	Output current [Amps]	T_r	Reference temperature in [298.15 K]
I_L	The current generated by incident light [Amps]	T_{am}	Ambient temperature [K]
I_D	Diode current [Amps]	G	Solar radiation, [W/m^2]
I_{sc}	Short circuit current of the cell [Amps]	G_r	The nominal irradiation [1000 W/m^2]
I_{sh}	Current of parallel resistance (shunt), [ohm]	R_s	Series resistance [ohm]
I_{on}	The reverse saturation of the diode [Amps]	R_{sh}	Shunt resistance [ohm]
I_o	Saturation current of the cell [Amps]	v_{wind}	Wind speed [m/s]
V	Output voltage [Volts]	N_s	Number of series connected cells
V_{oc}	Open circuit voltage of the cell [Volts]	E_g	Band-gap energy of solar cell [eV]
V_T	Thermal voltage at operating temperature [Volts]	Q	Electron charge [1.602E-19 C]
V_{sh}	Voltage of parallel resistance (shunt), [ohm]	K	Boltzmann constant [1.381E-23 J/K]
V_D	Diode voltage [Volts]	N	Diode ideality factor
T	Operating cell temperature in [K]	K_i	Temperature current coefficient of I_{sc} [/K]
A	Module area (m^2)	P_{in}	Input power (W)
Φ	Latitude angle (degree)	η	Conversion efficiency (%)
H	Is the hour angle of sunrise (or sunset) from noon	δ	Is the sun declination angle (degree)
P	Output power (W)	n_d	Number of days
dl	Day length (hours)	G_o	Solar constant
A_o	Atmosphere coefficient	G_{bn}	Beam normal radiation
A_1	Atmosphere coefficient	G_{dh}	Diffuse solar irradiance
k	Atmosphere coefficient	G_h	Total instantaneous solar radiation
AM	Air mass $(1/\cos(\theta_z))$	θ_z	Zenith angle
G_{bt}	Beam radiation on a tilted surface	θ	Incidence angle
β	Tilt angle		

1. Introduction

Until recently, electricity was regarded as a basic need in all parts of the world. The population's demand for electricity is increasing by the day, and it has turned into a major concern. It is going to be desperately needed in the coming years. It will be required. Traditional fossil fuels such as oil and coal are rapidly depleting, resulting in increased carbon dioxide emissions as well as global warming [1]. Solar energy is thought to be one of the most promising sources of electricity generation. The energy obtained from the sun on the earth's surface is approximately 885 million TWh of energy, which is expected to be 6200 times the world's commercial power needs [2]. Every hour, the sun emits 430 quintillion joules of energy onto the Earth [3]. Historically, the production of solar energy has been both expensive and inefficient, despite the progress made over the last two decades. This is due to a 300-fold increase in energy obtained from solar energy between 2000 and 2019 [4]. The abundance of solar energy in its current large form makes it one of the most important sources of electricity generation. The United Nations Development Program (UNDP) has indicated that the solar flood has reached 1575–49837 exajoules (EJ), which was several times more than the world's consumption in 2012 [5]. The agency stated in 2011 that the development of clean solar energy investment technology would have significant long-term benefits. It will increase energy security in countries by relying on an inexhaustible indigenous resource, most of which is independent of imports, improve sustainability, reduce pollution, lower the cost of mitigating global warming, and keep fossil fuel prices low. These advantages are universal.

The PV system is an efficient way to generate electricity because it absorbs sunlight and converts some of it into electricity. There aren't any moving parts that deteriorate over time, and there are no fluids or gases that may escape. There is no need for fuel to operate (except in hybrid systems). There is a quick response; it can reach full output immediately and it can operate at moderate temperatures [6]. In this regard, several studies have recently been conducted to assess and improve the performance of photovoltaic solar energy systems in the Iraqi environment [7-9].

However, Iraq, like a number of other nations, suffers due to a There is a severe lack of access to electricity. Frequent outages caused by a supply-demand imbalance are becoming more common as Iraqi and global populations grow, industrial activities expand, and living standards rise. Thus, the current study aims to use data on incident solar radiation levels on the Earth's surface, environmental temperatures, and wind speed measured by the Al-Rashidiya meteorological station throughout the year to forecast the performance of photovoltaic solar plants and provide the investor with the necessary information about the feasibility of solar PV projects in this geographic

2. Solar Radiation in Iraq

It is well-known that Iraq has long hours of sunshine. Studies have proved that Iraq receives solar radiation more than 3000 hours per year in Baghdad alone. In Iraq, the potential solar irradiation is 2000kWh/m^2/year [6]. The monthly average of global solar irradiation (diffuse and direct) over Iraq ranges from 2766 Wh/m^2/day in December to 6842 Wh/m^2/day in June. In Iraq, global solar irradiation on the horizontal plane ranges from 4.5 kWh/m2/day in the north to 5.7 kWh/m^2/day in the south [10], as shown in Figure1.

Because of the semi-uniform distribution of solar radiation across Iraq, PV solar technology is appropriate for the production of electricity throughout Iraq. The spatial variation of the global solar irradiation annual-daily average in Iraq ranges in the northern area between (4266 - 4700 Wh/m^2), in the middle and south (flat plains) areas are between (4750- 5000Wh/m^2), whereas in the desert area and the western plateau has the largest value between (5378-5596 Wh/m^2). Baghdad receives > 3000 h of solar radiance a year [11].

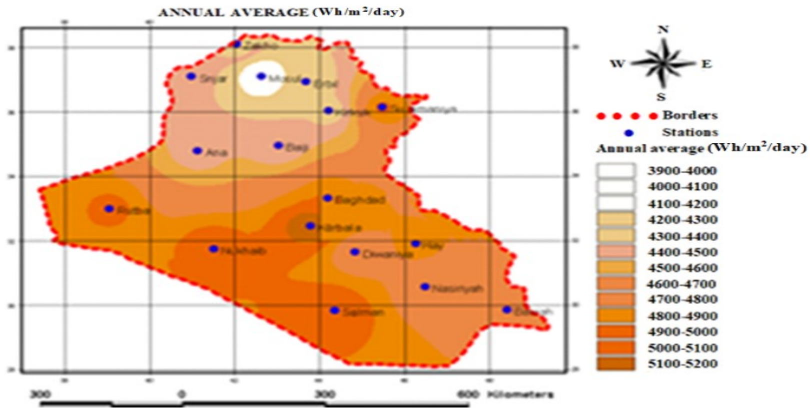

Figure 1. The annual spatial variability of total solar radiation falling on the horizontal surface of Iraq [11].

3. PV Solar Model

Single-model diodes are the most commonly used equivalent circuit models for describing the electrical properties of a PV cell [12]. In this paper, one diode model is taken into account because it's simple and accurate enough in many cases [13-15]. When a PV cell is made up of a current source and a diode that is connected across it. When illuminated, it generates current; when not illuminated, it generates no power. The solar irradiance is accounted for by this source, while the diffusion current is accounted for by the diode. [16]. Parasitic resistance is included in the equivalent circuit model., denoted by R_s, and shunt resistance, denoted by R_{sh}, as shown in Figure 2.

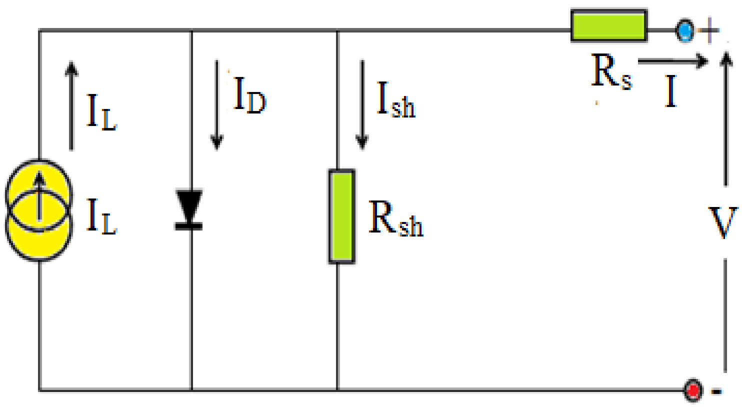

Figure 2. Equivalent circuit of a single diode model PV cell.

The series resistance, R_s, accounts for the resistance of junctions, contacts, and cables, whereas the R_{sh} accounts for charge carrier recombination and is therefore connected as a parallel element in the circuit. The governing equations for the I-V characteristics of PV cells are derived using Kirchhoff's Current Law.

$$I = I_L - I_D - I_{sh} \tag{1}$$

The photo-current dependents on the solar radiation and operating cell temperature are given by [17].

$$I_L = [I_{sc} + k_i(T - T_r)]\frac{G}{G_r} \tag{2}$$

The Shockley diode equation can be expressed as follows [18].

$$I_D = I_o\left(e^{qV/nkT} - 1\right) \tag{3}$$

The current across the shunt resistor is given by [18].

$$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V_D}{R_{sh}} = \frac{V+IR_s}{R_{sh}} \tag{4}$$

The cell saturation current (or the diode saturation current), which varies with the operating cell temperature, is given by [19, 20].

$$I_o = I_{on}\left(\frac{T}{T_r}\right)^3 \exp\left[\frac{qE_g}{nk}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \tag{5}$$

The reverse saturation current of the diode at slandered test condition (STC) or a reference is [21]:

$$I_{on} = \frac{I_{sc}}{\exp\left(qV_{oc}/nN_s kT\right) - 1} \tag{6}$$

The thermal voltage at operating cell temperature is [21]:

$$V_T = N_s\left(\frac{kT}{q}\right) \tag{7}$$

The operating cell temperature is calculated with wind speed by [21]:

$$T = T_{am} + \left(\frac{0.32}{8.91+2v_{wind}}\right)G \tag{8}$$

It is observed that operating cell temperature rises with irradiance (direct + indirect (diffuse)) and ambient temperature. The bandgap energy of the semiconductor is represented by [22]:

$$E_g = 1.6 - 4.3 \text{ x } 10^{-4}\frac{T^2}{T+636} \tag{9}$$

Now, according to equations (1), (3), and (4), I-V and P-V characteristic equations of the single diode model can be written as:

$$I = I_L - I_o\left(e^{qV/nkT} - 1\right) - \frac{V+IR_s}{R_{sh}} \tag{10}$$

The output power of the PV solar module can be calculated by the following equation [23].

$$P = V\left[I_L - I_o\left(e^{qV/nkT} - 1\right) - \frac{V+IR_s}{R_{sh}}\right] \tag{11}$$

While the solar module's ratio of output power to incident optical power is known as conversion efficiency (input power) [24].

$$\eta(\%) = \frac{P}{P_{in}}\text{x}100\% \tag{12}$$

Where P_{in} is:

$$P_{in} = AG \tag{13}$$

The time of sunrise and sunset in terms of local solar time for any solar declination and latitude when sunrise and sunset actually occur can be calculated as follows [25].

$$\cos(h) = -\tan(\phi)\tan(\delta) \tag{14}$$

$$\delta = 23.45\sin 360\left(\frac{284+n_d}{365}\right) \tag{15}$$

The length of the day in hours varies according to the time of year and the hour angle [25].

$$dl(hours) = \left(\frac{2h}{15}\right) \tag{16}$$

Extraterrestrial solar radiation is the hourly beam radiation outside the Earth's atmosphere and is given by

$$G = G_o\left[1 + 0.034\cos\left(\frac{360d_n}{325.25}\right)\right] \tag{17}$$

According to NASA, G_o it equals 1353 W/m^2 and the clear sky beam normal radiation is [26]:

$$G_{bn} = G\left(A_o + A_1 e^{-k\sec(\theta_z)}\right) \tag{18}$$

The diffuse solar irradiance on a horizontal surface may be calculated by using the following equation [27].

$$G_{dh} = G\cos(\theta_z)\left[0.2710 - 02939\left(A_o + A_1 e^{-kAM}\right)\right] \tag{19}$$

The total instantaneous solar radiation on a horizontal surface, G_h, is the sum of the beam normal radiation, G_{bn}, and the sky diffuse radiation, G_{dh}, and also denoted as the global solar radiation on a horizontal surface which is represented in the following equation [28].

$$G_h = G_{bn} + G_{dh} \tag{20}$$

Because the amount of insolation on a terrestrial surface at a given location for a given time depends on its orientation and slope, the beam radiation on a tilted surface (module) is [25]:

$$G_{bt} = G\cos(\theta)\left(A_o + A_1 e^{-kAM}\right) \tag{21}$$

From the Figure 3, we can express the cosine of the angle of inclination of the solar panel by the following formula

$$\cos(\beta) = \frac{G(\text{horizontal})}{G(\text{inclined})} \tag{22}$$

therefore, the solar radiation falling on the PV solar module inclined at an angle, β, with the horizon is:

$$G(\text{inclined}) = \frac{G(\text{horizontal})}{\cos(\beta)} \tag{23}$$

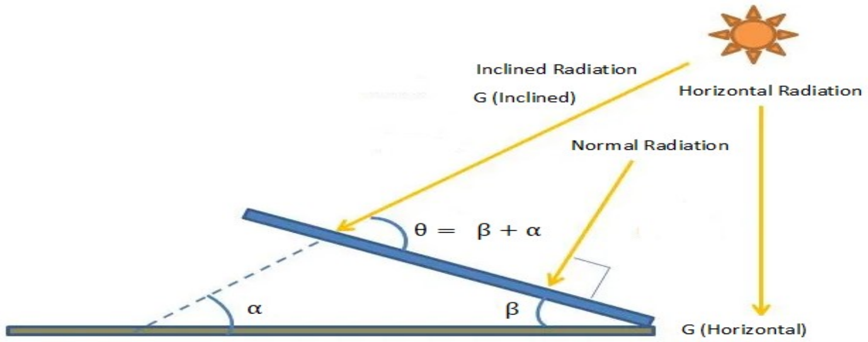

Figure 3. Horizontal and inclined Radiation diagram.

For the present work, Al-Rashidiya Meteorological Station has been selected to analyze the data obtained from it. The data includes the horizontal solar radiation rates, ambient temperature, and wind speed rates. This information is later used to predict the performance of solar module fields placed in this geographical area. Al-Rashidiya station is located in Baghdad (see Figure 1) at longitude 44.35º and latitude 33.5º with 35m of elevation level. On the other hand, a monocrystalline solar module, type SHARB (NT-R0E3E-SHARP), was used as a unit of solar plant so that its performance would be detected. The characteristics of this module are listed in Table 1.

Table 1. Characteristics of monocrystalline solar module (NT-R0E3E-SHARP).

Parameter	**Value**
STC Power Rating Pmp (W)	170
Open Circuit Voltage Voc (V)	44.2
Short Circuit Current Isc (A)	5.3
Voltage at Maximum Power Vmp (V)	35
Current at Maximum Power Imp (A)	4.86
Panel Efficiency	13.10%
Fill Factor	72.60%
Power Tolerance	-5.00% ~ 10.00%
Maximum System Voltage Vmax (V)	1000
Maximum Series Fuse Rating (A)	15
Temperature Coefficiency of Isc	0.053 %/ºC
Temperature Coefficiency of Voc	-0.35 %/ºC
Temperature Coefficiency of Pmp	-0.49 %/ºC
Cell Type	Monocrystalline Cell
Cell Size(mm)	125 × 125
Cells	6 × 12
Dimensions	1575.0 × 826.0 × 46.0mm (32.5 × 62.0 × 1.8 inch)
Weight	17.0Kg

4. Results and Discussion

In this work, the variables measured by Al-Rashidiya Meteorological Station correspond to 2019. The measured parameters are the daily radiation rates measured in mega joules per square meter that are incident on a horizontal surface, the daily ambient temperature, and wind speed rates. Regarding equation (16), the day length varies according to the sequence of the days in the year as shown in Figure 4.

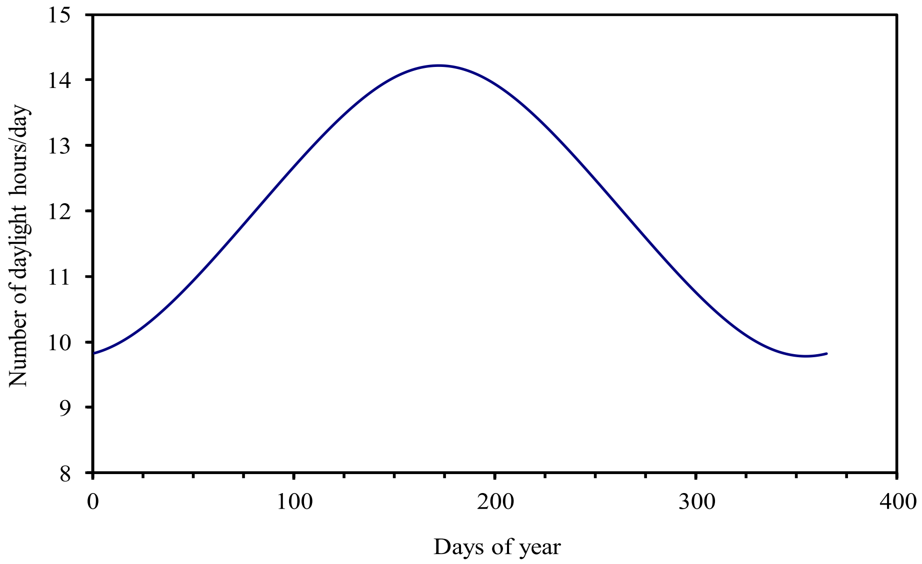

Figure 4. Variation of number of sunny hours along year.

Figure 5, represents the measured rates of ambient temperature and wind speeds at Al-Rashidiya meteorological Station during the year. This Figure shows a significant disparity in temperature rates between the winter and summer, which is the reality of Iraq's climate, while wind speeds recorded generally low values and are active in the autumn and summer due to the thermal factor.

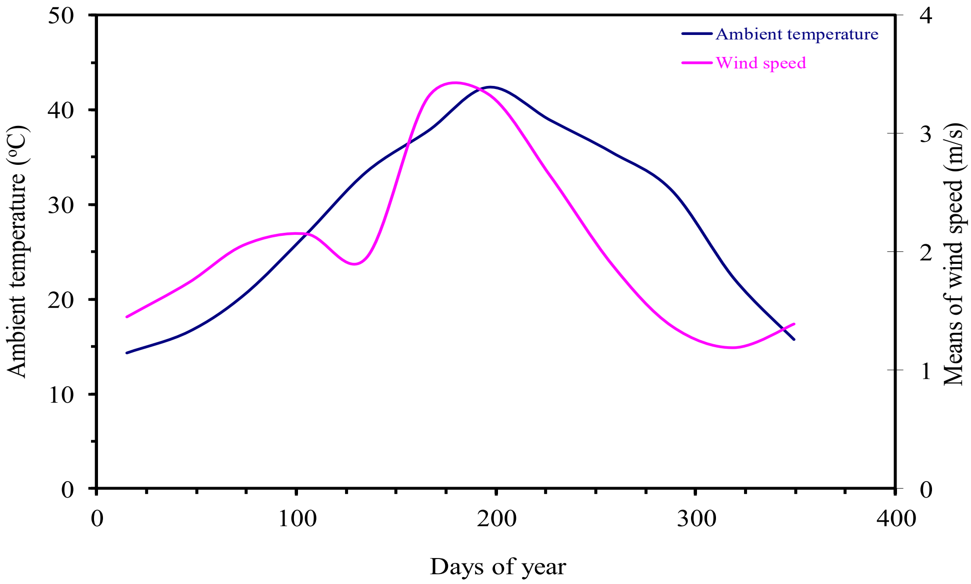

Figure 5. Variation of ambient temperature rates, and wind speed rates along year.

Figure 6 demonstrates the variation of the daily average of incident global insolation on a horizontal surface over the course of the year. This insolation reached its maximum levels in July (about 8 kWh/m^2/day). This figure also shows instability in the incident radiation levels in winter due to cloudy weather. According to the variance in the amount of incident solar radiation, there were variances in the peak sun hours, which represent the solar fuel as shown in Figure 7. These values are promising for investment in solar energy, especially in the summer, when they reach about 8 hours. The annual peak solar hours are approximately 5 hours.

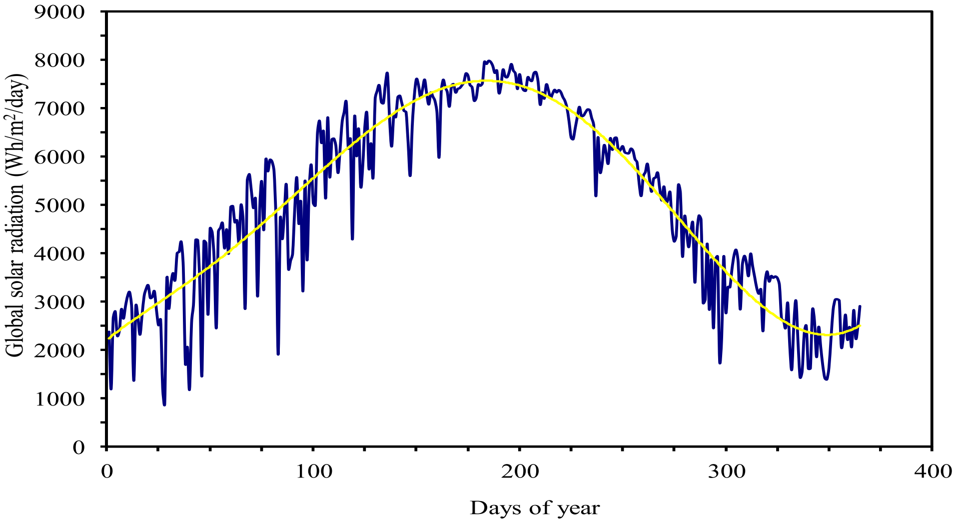

Figure 6. Variation of incident global solar radiation rates in horizontal surface along year.

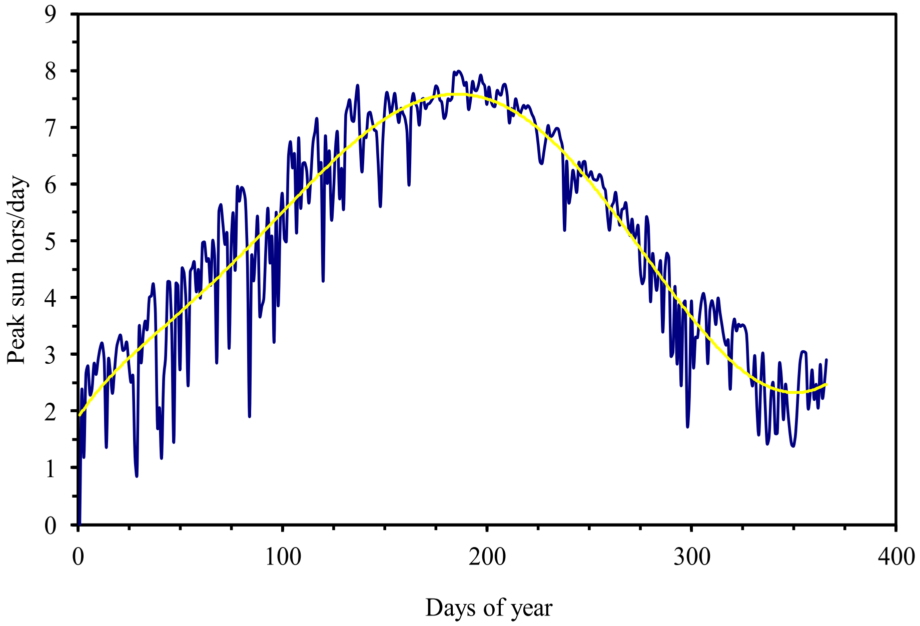

Figure 7. Variation peak sun hours along year.

The global radiation values were calculated in W/m^2 at each hour of the day throughout the year with a tilt *angle* of 30o, which represents the best annual angle at which the solar module can be tilted. These values are required to predict the performance of the solar modules in the solar plant that will be used to generate electric energy. Annual global solar radiation incident was approximately 1834 kWh/m^2/year in the horizontal plane, which corresponds to approximately 2100 kWh/m^2/year at a tilt of 30^o with the horizon.

As is customary, the rates of falling radiation are at their highest in the summer months and recede to their smallest values on winter days. This is a natural result because the number of hours of the day is greater in summer than in winter and the sun is closer to the vertical on summer days while the degree of its slope increases as we approach winter. All these facts are embodied in Figure 8. It is interesting to note from this figure that the incident solar power per unit area reached its peak at about midday for all months of the year.

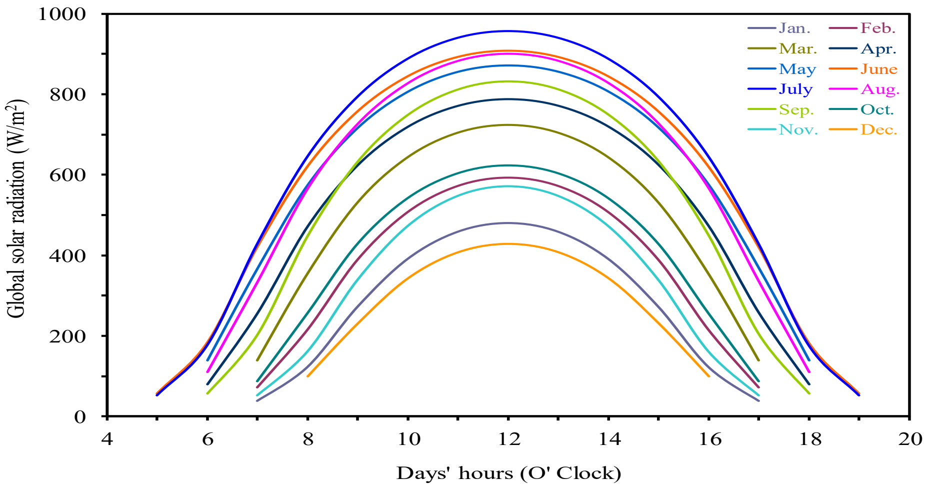

Figure 8. Variation of daily global solar radiation received with tilt angle of 30° along year.

All the above results, such as global solar radiation, ambient temperature, and wind speed, were utilized to predict the performance of the solar module, which is the basic unit that makes up the solar plant that will be built in this geographic place. Based on these results, the PV model was used to calculate the predicted values of all variables of the solar module, such as operating cell temperature, output current, output voltage, output power, input power, and conversion efficiency.
High radiation rates act to increase the temperature of solar cells (see Figure 9). Figure 9 describes the rates of solar cell temperature. The high level of cell temperature contributes to the decrease in its performance efficiency.

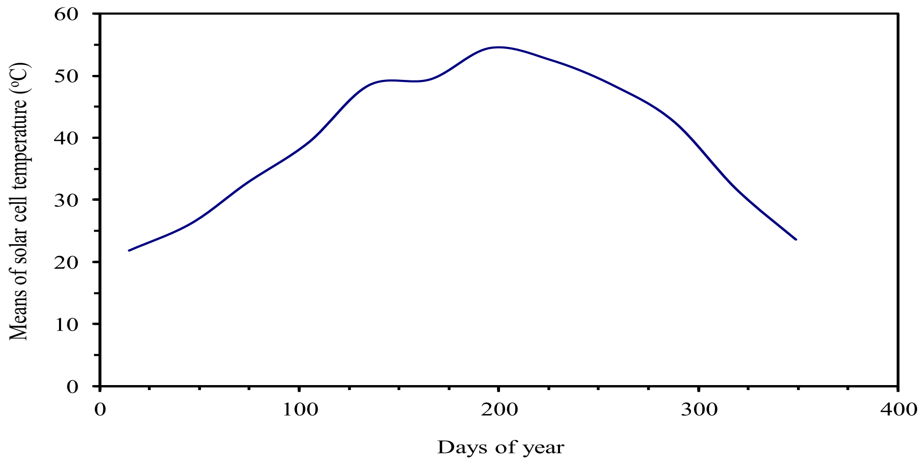

Figure 9. Variation of solar cell's temperature rates along year.

Although the increase in PV solar cell temperatures leads to a decrease in the output power, the output power increases as we move towards the summer because it depends more on the amount of incident solar radiation than the cell temperature. High temperatures affect the solar cell voltage, while the value of the photocurrent increases further by increasing the level of the incident rays and is, clearly, not affected by the increase in cell temperature. This fact is demonstrated in Figure 10. Also, it is clear that the summer days are leading the rest of the year in terms of output power generation. The output power rates are at their highest in July, as shown in Figure 11, and at their lowest in December, as shown in Figure 11.

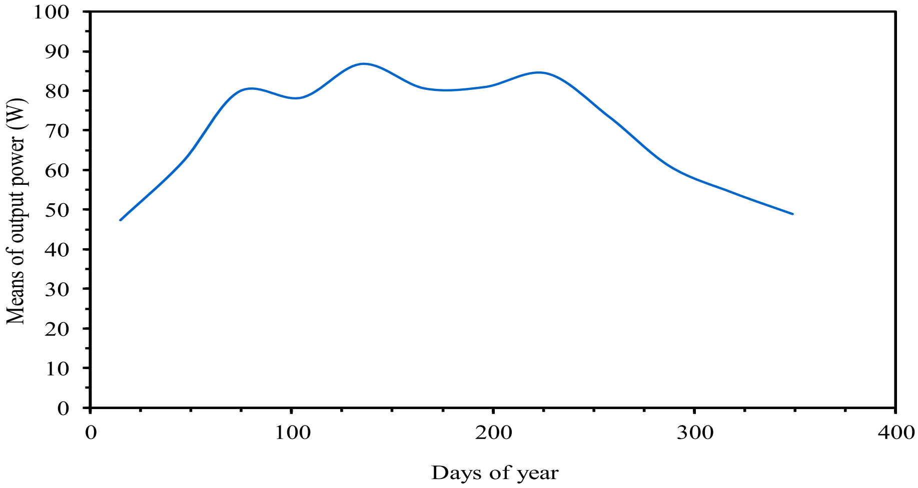

Figure 10. Variation of daily rates of output power.

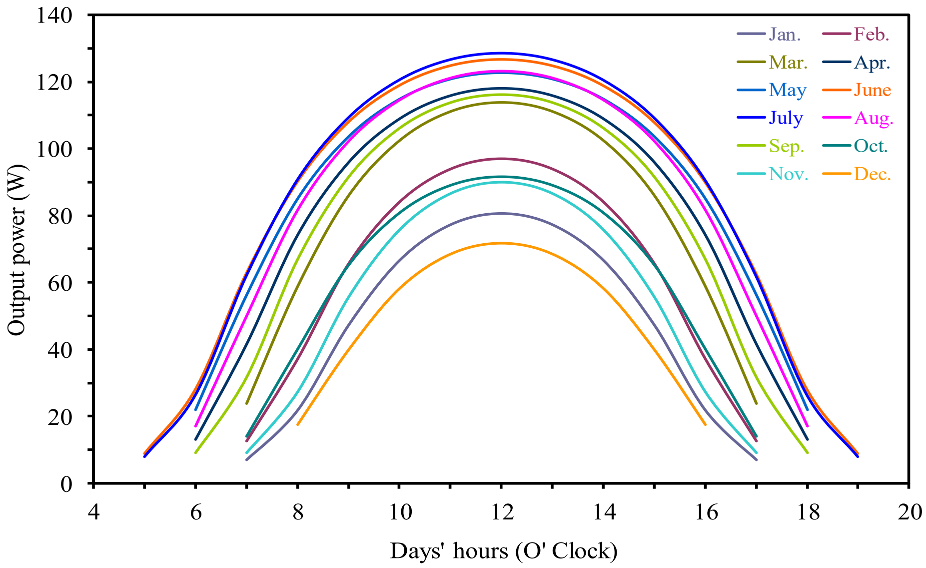

Figure 11. Variation of output power rates along the year.

Depending on the ambient temperature and thus cell temperature, the electric conversion efficiency takes its minimum value on the hot days of the year (10.7% at solar noon in August) and increases and exceeds its standard condition value of 13.7% and reaches 14% in the morning of winter days when the ambient temperature rates down to lower than 10ºC (see Figure 12). Figure 13 shows the monthly electric conversion efficiency rates throughout the year. In this figure, the electric conversion efficiency values are between 11% in the summer and 13.3% in the winter. The degradation percentage in the electrical conversion efficiency of this solar cell ranged from 2% in the winter to 11% in the summer. Due to this degradation, there are some percentage losses in output power, which were, approximately, in the range of 27% in the summer [6].

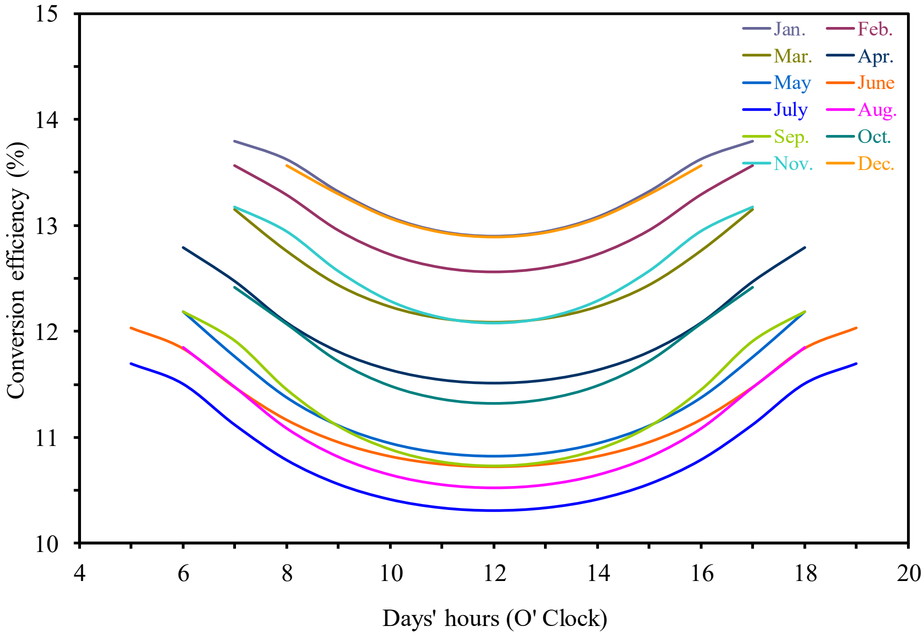

Figure 12. Variation of daily electrical conversion efficiency along the year.

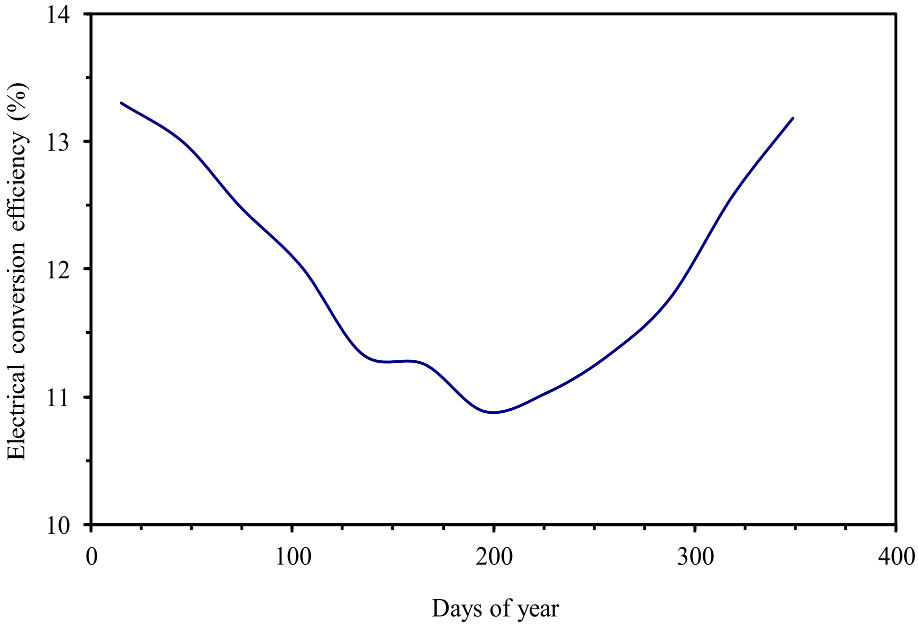

Figure 13. Variation electrical conversion efficiency rates along the year.

5. Conclusions

The results of the present work indicate that there is a sufficient level of solar fuel in the Baghdad governorate and have clearly demonstrated the importance of solar PV projects as a good way to equip off-grid houses with electrical energy. These projects work to reduce fossil fuel consumption, pollution, and greenhouse gas emissions that cause climate damage. The current work represents design guidelines for on-grid or off-grid PV solar systems, as well as guidelines for investing in solar energy to generate electrical energy.

ACKNOWLEDGEMENT

The authors would like to thank the Ministry of Agriculture's Agricultural Meteorology Center for providing us with data from most meteorological stations in Iraq, as well as Mustansiriyah University for its assistance in this work

References

[1] V. Quaschning, Understanding Renewable Energy Systems -(Malestrom), Earthscan, 2005.

[2] International Energy Agency, Solar energy perspectives2020, http://www.eng.uc.edu/~beaucag

[3] B. Online, “Nuclear fusion energy 8.1,” Online 112011,http://www.pitt.edu/~tjs120/ writing_assignment_3.pdf.

[4] “The future of solar is bright - science in the news,” 2020, http:// sitn.hms.harvard.edu/flash/2019/ future-solar-bright/.

[5] O. R. Skheel, The Improvement of The Solar Air Heater Duct by Wired Ribs Utilization, Karbala International Journal of Modern Science 5 (2019) 163-170.

[6] P. Hersch and K. Zweibel, “Basic photovoltaic principles and methods,” Antimicrobial Agents and Chemotherapy, vol. 58, no. 12, pp. 7250–7257, 1982.

[7] T. Sumaryada, A. Sofyan, H. Syafutra, Simulation of the extra-terrestrial and terrestrial performance of GaAs/Ge dual-junction solar cells, Kuwait J.Sci. 2019; 46 (4) pp. 58-65.

[8] N. K. Kasim, F. S. Zain alabdeen, J. Sh. Hameed, A. F. Atwan, Evaluation and Improvement the Performance of MCM Solar Modules in Iraqi Environments, AIP Conference Proc-eedings 2019;2144, 030011,1-7.

[9] N. K. Kasim, A. F. Atwan, F. M. Oleiwi, Performance of Solar Module with Presence of Two Types of Reflectors in Concentrator System, Iraqi Journal of computer, communications, control, & system engineering (IJCCCE), 2019; Vol. 19, No. 2, April.

[10] W. I. Al-Rijabo, S. H. Darweesh, Study of Spatial Variation of Total Solar Radiation Falling on Horizontal Surface in Iraq, Journal of Rafidain Sciences, 2011; Volume 22, Issue 4, p. 119-134.

[11] Muneer, Solar Radiation and Daylight Models, 2nd edition., Elsevier Ltd; 2004.

[12] A. M. Humada, S. Y. Darweesh, K, G. Mohammed, M. Kamil, S. F. Mohammed, N. K. Kasim, T. A. Tahseen, O. I. Awad, S. Mekhilef, Modeling of PV system and parameter extraction based on experimental data: Review and investigation, Solar Energy 199 (2020); 742–760.

[13] R. Ramaprabha, B.L. Mathur, Modelling and Simulation of Solar PV Array under Partial Shaded Conditions, in Proceedings of IEEE International Conference on Sustainable Energy Technologies (ICSET 2008), Singapore, November 24-27; 2008.

[14] H. Patel, Vivek Agarwal, MATLAB- Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics, IEEE Transactions on Energy Conversions, Vol.23, No.1(2008); pp 302-310.

[15] X. H. Nguyen, M. P. Nguyen, Mathematical modeling of photo voltaic cell/module/arrays with tags in Matlab/Simulink, Environmental Systems Research, a Springer Journal, (2015); 4:24.

[16] N. Nagaraja, Dr. T. G. Manohar, Study on Performance Characteristics of PV Array under Non-Uniform Irradiation Conditions, International Advanced Research Journal in Science, Engineering and Technology (IARJSET) ISO 3297:2007 Certified 2016; Vol. 3, Issue 11.

[17] W. Shen, Y. Ding, F. H. Choo, P. Wang, P. C. Loh, K. K. Tan, Mathematical model of a solar module for energy yield simulation in photovoltaic systems, The Eighth International Conference on Power Electronics and Drive Systems November 2-5, 2009, Taipei, Taiwan, R.O.C, 336-341.

[18] D. Rekioua, E. Matagne, Optimization of Photovoltaic Power Systems: Modelization, Simulation and Control, Springer Science and Business Media, 2012.

[19] K. Ishaque, Z. Salam, H. Taheri, Syafaruddin, Modeling and simulation of photovoltaic (PV) system during partial shading based on a two-diode model, Simulation Modelling Practice and Theory 19 (2011); 1613-1626.

[20] A. Dev, S. B. Jeyaprabha, Modeling and Simulation of Photovoltaic Module in Matlab,Proceedings of the International Conference on Applied Mathematics and Theoretical Computer Science 2013; 266-273.

[21] M, R. Rashel, M. T. Ahmed, T. Gonçalves, M. Tlemçani, R. Melicioa, Analysis of different types of obstacles for PV panel, Poster paper in Eradication Poverty through Energy Innovation Workshop, Arizona State University, poster, Tempe, Arizona, 2018, 12-14, USA.

[22] M. Kumar, N. Kumar, S. S. Chandel. Power prediction of photovoltaic system using four parameter model, International Journal of Electrical, Electronics and Data Communication, ISSN: 2320-2084 2015; Volume-3, Issue-5.

[23] T. Markvart, Solar Electricity, Wiley, Chichester; 2001.

[24] S, K. Rajput, SOLAR ENERGY- Fundamentals, Economic and Energy Analysis, first edition, 2017; p22.

[25] S. A. Kalogirou, Solar Energy Engineering Processes and Systems, 2nd edition, Copyright, 2014 Elsevier Inc, pp 54-61

[26] B. Y. H. Liu, R. C. Jordan, The Inter-relationship and Characteristic Distribution of direct, Diffuse and Total Solar Radiation, Solar Energy,1960, 4(3), 1-19.

[27] B. S. William, G. Mechael, Power from the Sun. J. T. Lyle Center for Regenerative Studies, 2001.

[28] C.C. Newton, A Concentrated Solar Thermal Energy System, M.Sc. Thesis, The Florida State University, college of engineering, 2007, p. 16.