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Optical Measurement and Performance Prediction of Solar PV System in Al-Khidhir Zone/Iraq

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Keywords

solar radiation, single diode model, solar cell performanc, PV system, solar energy applications.

RESEARCH PAPER

Optical Measurement and Performance Prediction of Solar PV System in Al-Khidhir Zone/Iraq

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People have tended for investing the sources of renewable energy, especially solar energy, as they are clean and environmentally friendly sources. The present work aims to invest the measured data of solar irradiance, maximum ambient temperatures and wind speed provided by Al Khidhir Meteorological Station to predict the minimum performance of photovoltaic solar systems (NT-R0E3E-SHARP) for electric power generation. The single diode model is used to calculate the minimum output power produced by solar module and its minimum conversion efficiency based on solar irradiance, maximum ambient temperatures and wind speed throughout 2020. The results indicate that the annual solar irradiance in Al-Khidhir zone on horizontal plane is 2084 kWh/m^2/year and the daily averages, approximately, range from 2500 Wh/m^2/day in January, as a minimum value, to 8000 Wh/m^2/day in July as a maximum value. Accordingly, the monthly average of peak sun hours has its minimum values in winter (3 h in January) and increases toward the summer and reaches its maximum value in July (8 h), while the annually average is 5.7 h. The results show that the behavior of predicted rates of output power of solar PV module was conforming to the behavior of solar irradiance along year. The daily averages of output power, approximately, range from 60 W to 100W along year. Due to the thermal effect of solar radiation the degradation percentage in electrical conversion efficiency of mono crystalline silicon solar cell ranges from 7.6% in winter to 24% in summer. From the results of the present work, it can be concluded that the geographical zone of Al-Khidhir and its surroundings are promising for investing solar energy to produce electricity.

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1. Introduction

The important component of the universe is energy and it represents a major form of existence. Nature produces energy which is called the renewable energy and non-nature energy is known as conventional (fossil fuel). In recent years, the world's countries have been moving towards investing in renewable energy sources, particularly the energy of solar, renewable energy sources, such as solar energy have been invested by worlds countries to produce power for the benefit of its environmental friendly. Renewable inexhaustible and contribute effectively to reducing environmental pollution caused by conventional energy sources, which are characterized by high extraction costs, as well as being sources of depletion. Iraq is among the solar-rich countries with annual rates exceeding 2000 (kWh/m2/year). As a result of the importance of this source of energy and because that the energy and basic services crisis are reflected in the suffering of citizens from the continuing interruptions in the energy supply, which is a force that has been confined to Iraq's progress and prevented Iraq from establishing its natural place in the various areas of development that have negatively affected the country's major developments and dimensions, Iraqi researchers have tended to study this type of

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energy source. They started to calculate the amount of incident solar energy [1] and its contribution to reducing environmental pollution rates [2]. The performance of solar PV systems is affected by many factors. Some of them are related to environment, particularly dust, which acts to reduce the amounts of incident solar energy [3–5], and temperature, acts to reduce the output voltage of solar modules [6,7]. Under such information, groups of researchers have studied the performance of different kinds of solar modules in conditions of the Iraqi environment [8,9]. In recent years, researchers' work in this field has progressed to include improving the performance of solar modules through the use of solar energy concentrates and joining tracking system [10–13]. The results of such research can be used to create a clear picture of the reality of solar energy in Iraq and ways to harness it and invest it in the production of electricity [14]. So, the present work aims to make use of the data which are extracted from one of Iraqi meteorological stations to predict the performance of solar PV modules instilled in this location to provide the investor with the necessary information about the feasible of investment of solar PV projects in this geographic zone.

Nomenclature

I	Output current [Amps]
I_L	The current generated by incident light [Amps]
I_D	Diode current [Amps]
I_{sc}	Short circuit current of the cell [Amps]
I_{sh}	Current through Shunt resistance, [ohm]
I_{on}	Reverse saturation current of the diode [Amps]
I_o	Saturation current of the cell [Amps]
V	Output voltage [Volts]
V_{oc}	Open circuit voltage of the cell [Volts]
V_T	Thermal voltage at operating temperature [Volts]
V_{sh}	Voltage of Shunt resistance, [ohm]
V_D	Diode voltage [Volts]
T	Operating cell temperature, [K]
A	Module area, [m^2]
ϕ	Latitude angle, [degree]
h	Hour angle of sunrise (or sunset) from noon, [degree]
P	Output power, [W]
dl	Day length, [hours]
T_r	Reference temperature, [298.15 K]
$T_{ambient}$	Ambient temperature, [K]
G	Solar Irradiance, [W/m^2]
G_r	Solar Irradiance in standard conditions, [1000 W/m^2]
R_s	Series resistance, [ohm]
R_{sh}	Shunt resistance, [ohm]
v_{wind}	Wind speed, [m/s]
N_s	Number of series connected cells [72]
E_g	Band-gap energy of solar cell, [eV]
Q	charge of electron, [1.602E-19 C]
K	Boltzmann constant, [1.381E-23 J/K]
n	Diode ideality factor, [1.2]
K_i	Temperature current coefficient of $I_{sc,}$ [/K]
P_{in}	Input power, [W]
η	Conversion efficiency, [%]
δ	Sun declination angle, [degree]
n_d	Number of days

2. The potential of solar energy in Iraq

Mesopotamia is considered abundant in solar radiation rates from south to north, compared to European countries, which have done a long way in investing in solar technologies. Iraq's solar potential is high. It has an average radiation of 6.5 kWh per square meter per day over 3000 h per year. Including the 5.3 cents per kWh (renewable energy charge) offer in 2017. If solar cells were placed on an area of 16,000 square kilometers in Western desert, for example, Iraq would be able to generate about 400 MW of electricity, a quantity of clean energy, enough to meet the needs of one of Iraq's provinces [15].

In the mid-2019, Iraq began taking a more decisive step with the help of international organizations to formulate a solar policy aiming at deploying several thousand megawatts of solar power plants, as well as 5 MW of residential PV power by 2028. The cost levels of electricity have declined significantly in the last few years, including that the cost of investing on a large scale in Iraq is still 7-5 times higher than the Middle East and other GCC countries, which have experienced faster investment growth and are expected to reach US$ 1000 billion by 2030 [16].

3. PV model

The electrical characteristics of a PV-cell are defined by using single diode models [17].The Equivalent circuit of single diode model is shown in Fig. 1, which consists of a diode, one current source, shunt resistor and series resistor. To avoid dropping voltage across transport resistances of solar cell we add the series resistor, also the effect of leakage current is represented by shunt resistor in the P–N interface diode edges, where resistance of shunt occurs across the solar cell [18]. Usually, the predicted value for resistance of shunning be very high as a comparison to the series of resistance. The current source represents the PV solar cell, where the diode is connected across the equivalent circuit, which generates current when it is illuminated. The accounts of current source for solar irradiance and accounts of diode for diffusion current [19].

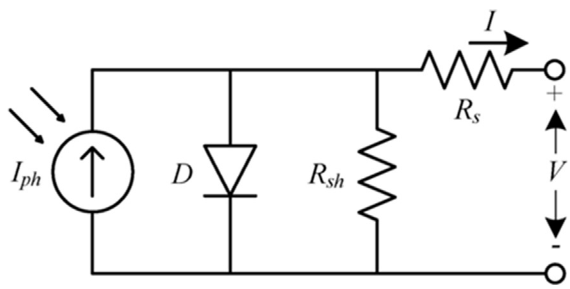

Fig. 1. PV cell single-diode electrical equivalent circuit [20].

I–V characteristic of PV cell is governed by the following equation:

$$I = I_L - I_D - I_{sh} \quad (1)$$

where I_L, I_D, I_{sh} are the current of photon, current of diode, and current through shunt resistance respectively and are given by:

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

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

$$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V_D}{R_{sh}} = \frac{V + IR_s}{R_{sh}} \quad (4)$$

The saturation current of cell I_o, which changes with change in operating temperature, is given by [21,22]:

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

The reverse saturation current of diode I_{on}, is given by:

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

Thermal voltage at operating temperature is given by:

$$V_T = N_s(kT/q) \quad (7)$$

The cell temperature T_c is calculated with wind speed v_{wind} by [23]:

$$T_{cell} = T_{ambient} + (0.32/[8.91 + (2v_{wind})])G \quad (8)$$

It is observed that the cell temperature rises with irradiance and ambient temperature. The band gap energy E_g of the semiconductor is represented by the equation [24]:

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

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

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

The output power of the PV solar module can be calculated by the following equation [25].

$$P = VI \quad (11)$$

The peak sun hours are the hours in which the solar irradiance is 1000W/m^2 and related to the output power by the following equation:

$$S\text{-}H_{Peak} = P/1000 \quad (12)$$

While the conversion efficiency of solar module is defined as the ratio of output power to incident optical power (input power) [26].

$$\eta(\%) = \frac{P}{P_{in}} \text{x} 100\% \quad (13)$$

$$P_{in} = AG \quad (14)$$

The time of sunrise and sunset for any solar declination and latitude in terms of local solar time when sunrise and sunset actually occur can be calculated as follows [26].

$$\cos(h) = -\tan(\phi)\tan(\delta) \quad (15)$$

$$\delta = 23.45\sin360\left(\frac{284 + n_d}{365}\right) \quad (16)$$

Day length in hours' changes according to different time periods in the year related to hour angle [27].

$$dl(hours) = \left(\frac{2h}{15}\right) \quad (17)$$

4. Case of study

In the present work, Al Khidhir Meteorological Station is selected for study. This Meteorological Station locates in Al-Muthana Province (see Fig. 2) at longitude 45.63° and Latitude 31.13° and above sea level by 7m. The recorded data of horizontally falling solar radiation rates, means of surrounding temperature and speed rate of wind have been used to predict the performance of the plant of Mono-crystalline solar modules type SHARB (NT-R0E3E-SHARP) that will be instilled in this zone (see Fig. 3). The characteristics of this module are listed in Table 1.

Fig. 2. Map of the main Meteorological Stations in Iraq [28].

5. Results and discussion

As it is known the number of sunny hours of the day is varying depending on the sequence of the day on the days of the year. It reaches its maximum in June and its minimum in December as shown in Fig. 4.

According to variation of incident radiation levels the means of maximum ambient temperature will be changed. These means have their maximum values in summer then tend to decrease and have their minimum values in winter as shown in Fig. 5.

The wind motion is controlled by the atmospheric thermal factor. Thus, in general, it has low speed rates which are active during summer season, as shown in Fig. 6.

The global radiation of daily falling on the horizontal surface was recalculated with units of Wh/m^2/day for all days of the year (see Fig. 7). The Figure shows an increase of radiation levels towards the summer season and reached its maximum (about 8 kWh/m2/day) in July. The Figure, also, shows that the solar radiation gets up and down in its values during winter and spring seasons due to the cloudy climate. The incident annual global solar radiation is about 2084 kWh/m^2/year in horizontal plane, which is corresponding to about 2406 kWh/m^2/year in tilt of 30 °C with the horizon.

According to the variance in the amount of incident solar radiation there was variances in the peak sun hours which represent the solar fuel as shown in Fig. 8. These values are promising for investing solar energy, especially in summer which reaches about 8 h. The annual peak sun hours were, approximately, 5.7 h.

The global radiation values were calculated in W/m^2 for each hour of the days along a year with tilt angle of 30° which represent the best annually angle in which the solar module be tilted. These values are required to predict the performance of the solar modules that will be used for generating the electric energy.

As it is customary, the rates of falling radiation are at their highest during the summer months and recede to be at the smallest of their values in winter

Fig. 3. Monocrystalline solar module (NT-R0E3E-SHARP).

Table 1. Characteristics of Mon crystalline 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% ~ 10%
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 × 46.0 mm (32.5 × 62.0 × 1.8 inch)
Weight	17.0 Kg

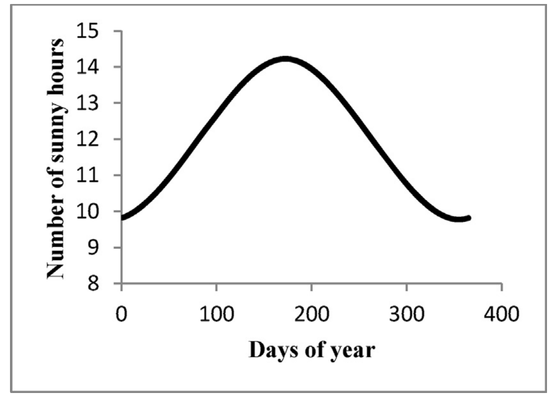

Fig. 4. Variation of number of sunny hours along year.

days, as a natural result because the number of hours of a day are greater in summer as a comparison with winter and the sun is closer to the vertical during summer days while the degree of its slope increases as we approach winter. All these facts are embodied in Fig. 9. It is induced to note from this

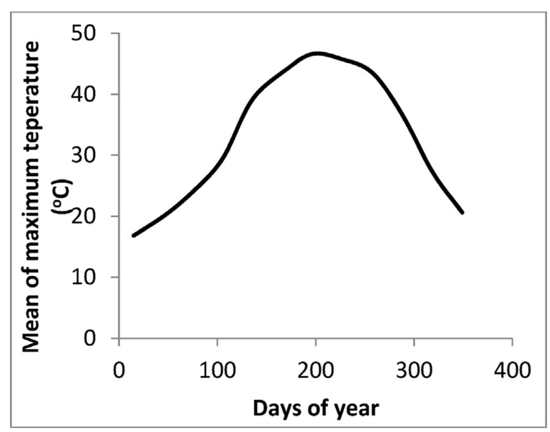

Fig. 5. Variation of means of maximum ambient temperature along year.

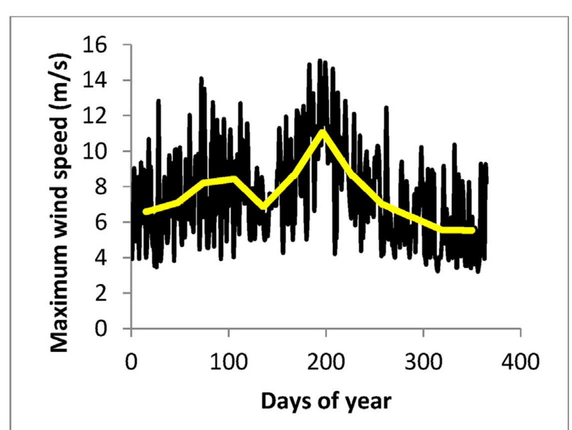

Fig. 6. Variation of maximum of wind speed along year.

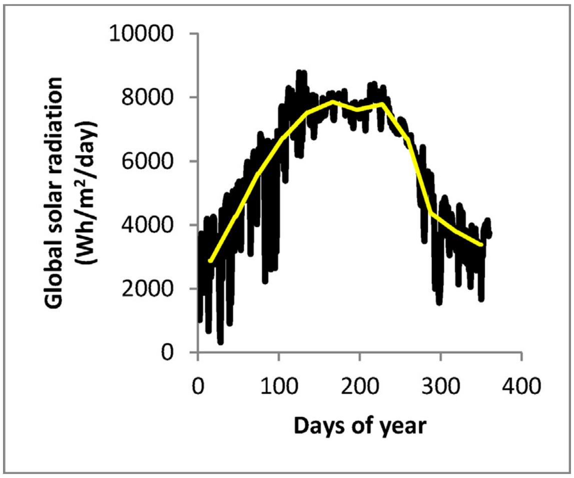

Fig. 7. Variation of incident global solar radiation rates in horizontal surface along year.

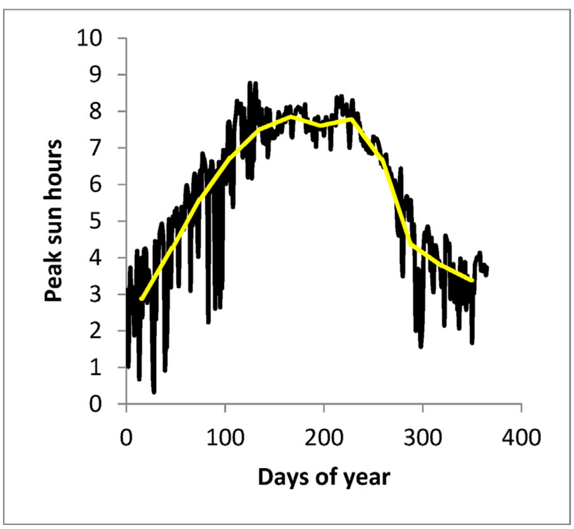

Fig. 8. Variation peak sun hours along year.

Figure that the incident solar power per unit area reached its peak at about the midday for all months of the year.

All the above results, such as global radiation of solar, surrounding temperature, and speed of wind, were utilized in prediction of performance of solar module, which is a basic unit that makes up the solar plant that will be built in this zone. Based on these results the PV model was used to calculate the predicted ones of all variables of the solar module such as cell temperature, maximum current, maximum voltage, maximum power, output power, input power, and the conversion efficiency.

In this paper the Matlab program was used to programming all equations and print only performance parameters like temperature of solar cell, output power, and conversion efficiency. It is appearing that each equation depends on the previous one. All parameters were calculated automatically and can be printed and tabulated but it may be a useless procedure, so we've just calculated the variables that show the performance of the solar panel.

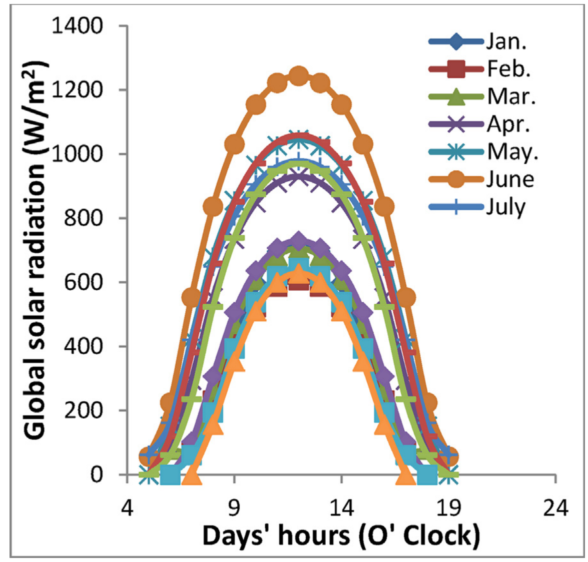

Fig. 9. Variation of daily global solar radiation received with tilt angle of 30° along year.

High radiation rates act to increase the temperature of solar cells (see Fig. 10). Figure 10 represents the maximum solar cell temperature. The high level of cell temperature causes to decrease in its performance efficiency. This result is in agreement with Hamdy K. Elminir et al., 2001 [29].

The output power increases as we move towards the summer due to the increases of the amount of

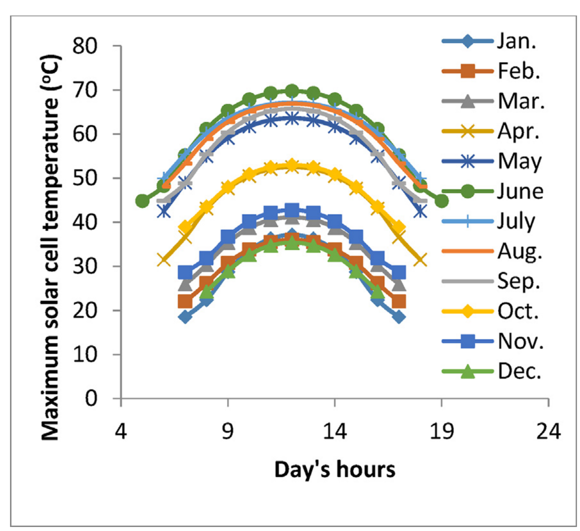

Fig. 10. Variation of solar cell's temperature rates along the year.

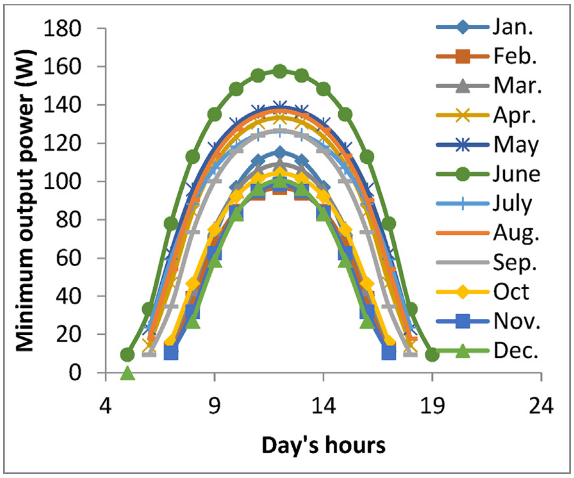

Fig. 11. Variation of daily rates of output power.

incident radiation of solar. In conjunction with the increase in amount of fallen radiation, the temperature of solar cells increases therefore decreases in the amount power produced, but this decrease is offset by a significant increase in output power resulting from increase in amount radiation of solar falling. This fact was demonstrated in Fig. 11. Figure 11 shows that the output power reaches its maximum values midday for all days of year (from 157W in July to 100W in December). Figure 12 shows the minimum rates of output power along year.

Depending on the ambient temperature, cell temperature, the electric conversion efficiency takes its minimum values in the hot days of the year (9.73% at solar noon in June) while it was 12.3% at the solar non in December. The conversion efficiency comes near to its standard condition value (13.7%) during winters' days morning (see Fig. 13).

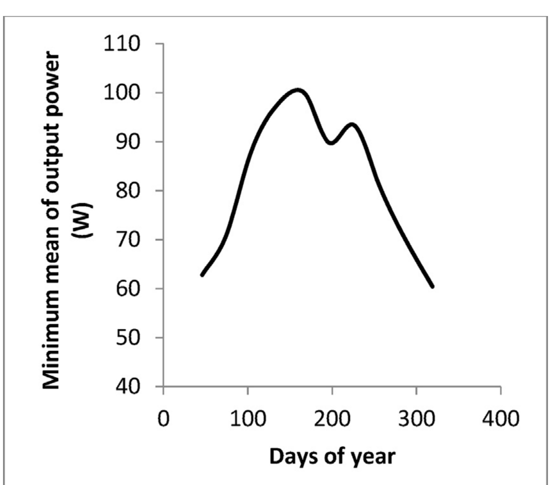

Fig. 12. Variation output power rates along the year.

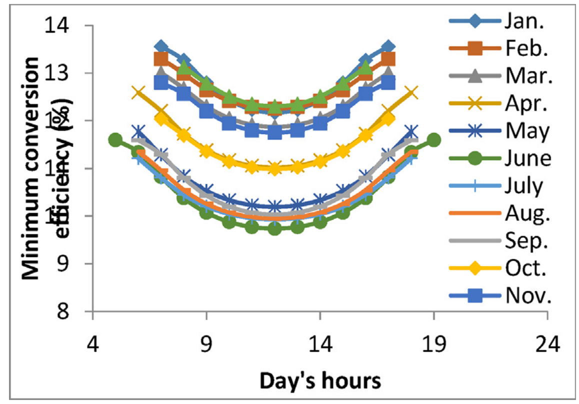

Fig. 13. Variation of daily electrical conversion efficiency along the year.

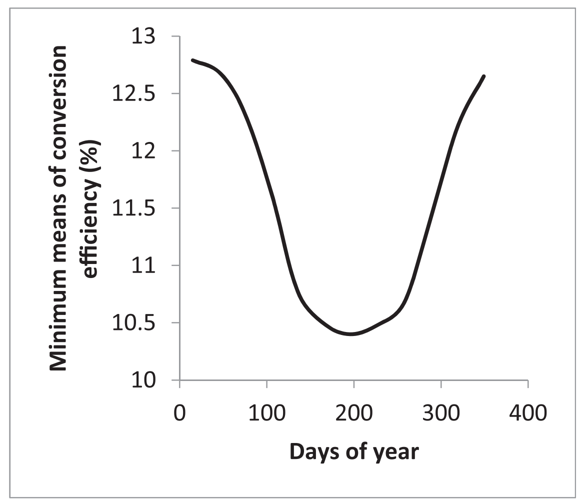

Fig. 14. Variation electrical conversion efficiency rates along the year.

Figure 14 shows the monthly electric conversion efficiency rates along the year. In this Figure the electric conversion efficiency values are between 10.4% in summer and 12.65% in winter. According to these results the degradation percentage in electrical conversion efficiency of this type of solar cell was ranged from 7.6% in winter to 24% in summer. Due to this degradation in efficiency value there is a percentage loses in output power which was, approximately, in the range of 27% in the summer. This result is agreement with that in reference [8].

6. Conclusions

From the results of the present work, it can be concluded that the PV projects are a good way to power houses far from the electricity grid with the electricity needed for lighting and operation of various household electrical devices. This energy is supplied from the sun by converting solar energy into electric power through solar modules. This technology provides emission-free electricity. It helps to reduce fossil fuel consumption in power plants, pollution and greenhouse gas emissions that cause climate damage. This work presents the guidelines for the designing of on-grid or off-grid PV solar systems. This paper appeared that there is a sufficient level of solar fuel in Al-Khidhir zone that required for production an accepTable electric energy by solar PV plant. Thus the geographic zone of Al-Khidhir and its surroundings are promising for investing solar energy to produce electricity.

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