Energy Conversion and Management 171 (2018) 778–786

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

# Analytical assessment of the outdoor performance and efficiency of grid-tied photovoltaic system under hot dry climate in the south of Algeria

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ARTICLE INFO

*Keywords:*
Grid-tied photovoltaic systems
Performance evaluation
Energy efficiency

ABSTRACT

A detailed assessment analysis of 2.5 kWp photovoltaic (PV) system located in southern Algeria (Latitude 27.88 °N, Longitude −0.27 °E, Altitude 262 m) has been carried out in this paper in order to support the growth of grid-tied photovoltaic power plant implementation in the Saharan environment. The achievement of this analysis has been done by performing an accurate evaluation of the different impacts of the environment parameters on the operating performance of the grid-tied PV system. The data set covers 12 operating months and has been collected by our team from the Research Unit on Renewable Energy (URER-MS). The collected experimental data reveal that the environmental parameters variation has direct effect on the performance of both energy conversion efficiency and system losses. The grid was supplied with a power of 4322.65 kWh during the year 2015, where the annual average temperature was 28.30 °C. An important variation in performance parameters have been observed for different months. The yield values of max/min monthly average daily reference, array and final were; 7.68/5.7 kW h/kWp/day, 6.07/4.24 kW h/kWp/day and 5.75/3.98 kW h/kWp/day, respectively. The PV module, inverter and overall system efficiency reached; 14.19/11.10%, 95.34/93.94% and 13.53/10.50%, respectively. The experimental results indicate that the performance ratio (PR) varies from 66.66% to 85.93% and the annual average capacity factor was 7.91%.

## 1. Introduction

Energy is a major foundation of modern civilization prosperity and economic development, but as the world's population grows, the demand for energy has increased significantly; the renewable energies have become an alternative solution to contribute to this development [1]. There are various forms of renewable energies such as, solar, wind, hydro, tidal, biomass, geothermal, etc. Solar energy is one of the most prominent of these renewable energies due to its abundance, pollution free and renewability for this it is considered as one of the most emerging technologies in field [2,3].

Many countries are shifting to green national energy policies, especially those who are heavily dependent on energy from fossil fuel. Their economies are vulnerable to the impacts of fluctuating oil prices in the global market. Regardless of environmental benefits, there are many other advantages of renewable energy sources, such as the improvement of the social and economic level of sub developing countries.

The multiple choice of renewable energy sources present an opportunity to the governments and investors to provide capital for the suitable type of renewable energy based on its energy potential [4,5] and reliability. Due to Algeria's geographical location and its large surface area, solar energy is considered as the most abundant source of renewable energy in the country especially in southern region where a missive solar irradiation is received yearly [6–8]. This enormous energy potential has strongly motivated Algeria's authorities to consider solar energy as an alternative source of energy to provide a comprehensive and sustainable solution to the challenges and problems like; conserving fossil fuels, reducing greenhouse gas emissions, and creating an economy of scale that consequently reducing the living costs and improves the energy market. Therefore, the government announced a new renewable energy development program that's adopted in February 2011 and amended in May 2015. The Algerian green energy program manifest an important interest to solar photovoltaic, PV grid-tied system in particular, aiming to be a leader in this type of renewable energy. Nevertheless, the performance and efficiency of photovoltaic installations are affected by two environmental factors, which are

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https://doi.org/10.1016/j.enconman.2018.06.020
Received 13 March 2018; Received in revised form 5 June 2018; Accepted 6 June 2018

meteorological conditions and geographic locations.

Grid-connected solar photovoltaic systems are quickly becoming a prevalent feature of electric power networks compared to the other installations [9–12]. A number of PV systems for electricity generation have been installed in many region in Algeria. This includes 23 photovoltaic solar plants implemented in regions of northern highlands and southern desert of the country. The performance of a grid-connected PV system depends on two different parameters, namely; technical and environmental parameters. In technical factor it includes; cell and inverter technologies, and types of installation, while in environment parameter it includes; amount of global irradiance, ambient temperature and dust accumulation [13,14] etc.

The main objective of this study is to analyze and evaluate one-year performance of a 2.5 kWp grid-connected photovoltaic system installed at the URERMS in the city of Adrar – south Algeria. The meteorological conditions have direct impact on the performance factors of the PV system, such as Efficiency (PV array $\eta_{PV}$, Inverter η_inv and system η_sys), Yield (PV array Ya, reference Yr and final Yf), Energy Losses (Array capture Lc, system Ls) and Performance Ratio (PR) [15–18].

These key performance indicators allow us to analyze and assess the overall energy performance of the photovoltaic system installation. This assessment is used to support the usage growth of grid-tied photovoltaic (PV) systems in the Sahara, southern Algeria.

## 2. Material and methods

### 2.1. Location of study

All studies presented in this paper were performed in the field of Research Unit in Renewable Energy URERMS. Adrar is a region situated in the southern-west of Algeria (Latitude 27.88 °N, Longitude −0.27 °E, Altitude 262 m). This region is characterized by [6,7,19]:

- High ambient temperature in Summer
- High solar irradiance potential
- Low humidity rate
- Large number days of clear and semi-clear sky
- Few number days of dust storm

Table 1 shows monthly average solar radiation, average ambient temperature, wind speed and relative humidity between January and December 2015 (see Table 2).

The values in Table 1 have been recorded via the meteorological station (NEAL) installed in Research Unit in Renewable Energies in the Saharan Medium (see Fig. 1).

It can be seen that the monthly average ambient temperature and PV module temperature in winter season are 15 °C and 23 °C respectively, whereas these are 38–48 °C in summer season respectively. This

**Table 1**
Monthly average meteorological parameters for year (2015).

| | Solar radiance (kWh/m$^2$) | Ambient temperature (°C) | Wind speed (m/s) | Relative humidity (%) |
|---|---|---|---|---|
| January | 5.90 | 14.73 | 2.94 | 29.39 |
| February | 6.57 | 18.10 | 3.44 | 26.78 |
| March | 7.62 | 21.05 | 3.70 | 20.25 |
| April | 7.68 | 31.88 | 3.40 | 9.23 |
| May | 7.03 | 34.08 | 3.70 | 10.02 |
| Jun | 7.85 | 38.12 | 3.95 | 9.36 |
| July | 7.48 | 39.33 | 4.17 | 11.99 |
| August | 6.47 | 37.52 | 3.60 | 16.52 |
| September | 5.80 | 35.70 | 3.04 | 21.05 |
| October | 5.83 | 30.31 | 2.76 | 26.92 |
| November | 6.19 | 22.07 | 3.41 | 32.98 |
| December | 5.70 | 16.70 | 3.58 | 36.39 |

**Table 2**
Technical characteristics of the meteorological station.

| Pyranometer sensor | Barometric pressure |
|---|---|
| Maximum operational irradiance: 4000 W m$^{-2}$ | Range: 600[a]–1100 hPa (8.7–15.95 Psi) |
| Resolution: < 1 W m$^{-2}$ | Accuracy: ± 0.5 hPa ( ± 0.007 Psi) |
| Spectral range: 310–2800 nm | Relative humidity |
| Sensitivity: 7–14 µV/Wm$^{-2}$ | Range: 0–100% RH |
| Operating temperature rate: −40 °C to +80 °C | Accuracy: ± 2% RH |
| Air temperature | Wind speed |
| Range: −40 °C to + 70 °C | Range: 1–96 ms$^{-1}$ |
| Accuracy: ± 0.3 °C | Accuracy: < 0.1 ms$^{-1}$ |

The monthly daily average temperature of both ambient and PV panel presented in Fig. 2 over a monitored period of one year.

[a] Hectopascal is one of the common units of the pascal (1 hPa = 100 Pa = 1 mbar).

large difference in temperature between ambient and PV module has been reported in Refs. [7,18], as well. The summer season shows an ambient temperature greater than winter by up to 30 °C, due to the huge solar radiation intensity during this period of year. Thus, this important amount of radiation affects both the ambient and PV module temperature. The latter is a key parameter for the current assessment of this small-scale PV plant. This is because any increase in PV module temperature will strongly affects the conversion efficiency of the PV cells.

### 2.2. The grid tied system

The grid-connected PV system used in the present study is installed on the rooftop of URERMS, as shown in Fig. 3, and has been commissioned in December 2014. The PV system consists of 10 modules. The PV cells technology used is mono-crystalline silicon model SM-250Wp from the Korean manufacturer S-Energy. The PV modules cover a total area of 15.87 m$^2$ with an installed capacity of 2.5 kWp. The modules have been tilted at a fixed angle of 28.88° and oriented northward at an azimuth angle of 12°.

The technical specifications of the PV module and inverter are depicted in Table 3 and 4, respectively.

### 2.3. Performance evaluation

To carry out an accurate and consistent assessment of the present grid-tied PV systems. International standard IEC standard 61,724 [20] published by the International Electro Technical Commission (IEC has been adopted. The performance parameters are often used to define the overall system performance taking into account; energy production, solar resource, and the overall effect of system losses [21]. In this study, we have considered the most appropriate and relevant performance parameters that define the whole system performances specifically; Efficiency (PV array $\boldsymbol{\eta_{PV}}$, Inverter $\boldsymbol{\eta_{inv}}$ and system $\boldsymbol{\eta_{sys}}$). – Yield (PV array **YA**, reference $\mathbf{Y_R}$ and final $\mathbf{Y_F}$). – Energy Losses (Array capture $\mathbf{L_C}$, system $\mathbf{L_S}$). – Performance Rate (**PR**) and capacity factor (**CF**) [7,22,23]. The collected data set covers a period of 12 months from January to December 2015.

#### 2.3.1. Energy output

The total monthly AC energy output $E_{AC,m}$ (kW h) and monthly average daily total DC output $E_{DC,m}$ (kW h) delivered by the PV system are defined as follow [16,17]:

$$E_{AC,m} = \sum_{d=1}^{n} E_{AC,d} \text{ and } E_{DC,m} = \sum_{d=1}^{n} E_{DC,d} \tag{1}$$

where n is the number of days in the month.