Study regarding the influence of environmental temperature and irradiation conditions on the performance of a photovoltaic solar module

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Abstract. In this paper the proposed study is verify to fit with the observed experimental data by choosing a correct mathematical model. The performance of the solar photovoltaic module provides a general view of the climate variables impacts and helps to find the efficiency of this module knowing the climatic parameters of a particular geographic area. The study was made when the climate is variable which is useful in developing an efficiency relationship of the photovoltaic solar module with major climatic parameters such as temperature, wind speed, humidity, dust, etc., so that the determined equations are in good correlation with measured data. The effectuate analysis shows that both variables: environmental temperature and irradiation can be used to optimize the efficiency of a photovoltaic solar module for different applications.

1. Introduction
Due to pollution and the realising of the limited fossil fuel reserves, regenerable resources for producing energy have risen constantly and have proven an adequate solution for humanity [1, 2].

Also, the technological dependency of the industrialised world on fossil fuel and the way in which these fuels have constantly degraded the terran environment in quite alarming.

Solar panels have become one of the most promising ways to meet the electrification demands of many isolated consumers around the world [3-5].

Power generation systems using photovoltaic systems located on the building surface can be combined with other functions of buildings that require electricity consumption [6-8].

Solar radiation (flux) is obviously a determining factor when it comes to studying the natural potential of solar energy as a source of renewable energy [9-10].
The efficiency of the solar photovoltaic module obtained during the day has different values. This fluctuation results from various factors that affect the performance of the photovoltaic solar module. These factors can be: latitude, altitude, temperature, humidity, wind speed, cloud cover, dust, impurities, etc., [11-15].

In this paper the average values of the efficiency, the surrounding environment temperature and the irradiation were determined experimentally. Also, the evolution of the average values of the efficiency, surrounding environment temperature and irradiation determined experimentally according to the months of the year 2014, as well as the evolution of the average values of the efficiency and of the irradiation in relation to the average values of the surrounding environment temperatures were presented graphically.

2. The system for monitoring the efficiency, irradiation and environmental temperature

The module performance provides an overview of the impacts of climate variables and helps to learn the efficiency of modules while knowing the climatic parameters of an area [16].

Solar radiation (flux) is obviously a determining factor when it comes to studying the natural potential of solar energy as a source of renewable energy. For tropical regions, on average, the potential for solar radiation is about 16.4 ± 1.2 MJ/m² per day [16], [17]. Solar flux is described by visible infrared radiation and near solar emissions, whereas the different spectra are described by their wavelength, which varies in a wide range.

Tracking of the equipment is done with a local monitoring system, but also at a distance, via the Internet. The Sunny WebBox (Figure 1) remote monitoring system acquires real-time data from the following components of the photovoltaic system [18]: from irradiation sensors, ambient temperature, photovoltaic panel temperature and wind speed; from the network inverter; from the battery inverter.

As the central communication interface, the Sunny WebBox connects the photovoltaic plant and its operator. The Sunny WebBox collects and documents all data of the connected devices, allowing continuous photovoltaic monitoring. Sunny WebBox provides the operator with all data recorded through an Internet connection.

The Flashview presentation software and the Sunny Portal site can be used to edit data or graphically display the stored data.

This means that operators can see returns both on the local network and via the Internet at any time using Flashview and Sunny Portal. The Sunny WebBox is also a powerful tool for operators when configuring cells or performing remote diagnostics via the computer. It allows continuous monitoring of photovoltaic installations and helps optimize photovoltaic cell yields [19].

Figure 1. The e Sunny WebBox connecting way to a computer

Sunny SensorBox records the relevant environmental data to monitor the performance of photovoltaic cell systems.
For this purpose, the Sunny SensorBox has an integrated irradiation sensor as well as an external temperature sensor. The operator can also optionally be connected to an ambient temperature sensor and a wind sensor at the Sunny SensorBox.

3. Measurement results
The measurements were performed during the interval January 2014 - December 2014, in Resita, Romania, at various times of the day with clear or partly cloudy skies, averaging the values of efficiency, surrounding environment temperature and irradiation.

| Table 1. Measured values in the period January-December 2014 |
|---------------------------------|-----------------|-----------------|-----------------|
| Month               | Efficiency average value | Surrounding environment temperature average value | Irradiation |
| January             | 8.53             | 3               | 535             |
| February            | 10.79            | 5               | 801             |
| March               | 9.12             | 10              | 881             |
| April               | 10.36            | 15              | 892             |
| May                 | 10.00            | 20              | 978             |
| June                | 10.12            | 38              | 928             |
| July                | 10.16            | 39.4            | 910             |
| August              | 10.66            | 33              | 954             |
| September           | 10.83            | 22.3            | 978             |
| October             | 9.36             | 14              | 697             |
| November            | 8.83             | 9.6             | 600             |
| December            | 7.90             | 20              | 473             |

The data presented in Table 1, refers to days with clear, cloudy or partly cloudy sky, averaging the values of efficiency, surrounding environment temperature and irradiation.

Figure 2 shows graphically the evolution of the average values of experimentally determined efficiency’s according to the months of 2014.

![Evolution of the average value of the efficiency depending on the months of the year 2014](image)

**Figure 2.** Evolution of the efficiency average value according the months of the year 2014
Figure 2 shows that the maximum value was determined in September and the minimum value in December.

Figure 3 shows graphically the evolution of the experimentally determined average temperature values in relation to the months of 2014.

![Evolution of the average value of the temperature depending on the months of the year 2014](image)

**Figure 3.** Evolution of the temperature average value according the months of the year 2014

The Figure shows that the maximum temperature was determined in July, and the minimum temperature in January. Figure 4 presents graphically the evolution of the average irradiation values determined experimentally according to the months of 2014.

![Evolution of the average value of the irradiation depending on the months of the year 2014](image)

**Figure 4.** Evolution of the irradiation average value according the months of the year 2014

The Figure shows that the maximum irradiation value was determined in May and September, and the minimum irradiation value in December.

Figure 5 presents graphically the evolution of the average efficiency values according to the average temperature values determined in the months of 2014.
The evolution of the average value of the efficiency depending on temperature

| Temperature [°C] | Efficiency [%] |
|------------------|----------------|
| 3                | 8.3            |
| 5                | 10.79          |
| 10               | 9.12           |
| 12               | 10.36          |
| 14               | 10             |
| 16               | 10.12          |
| 18               | 10.16          |
| 20               | 10.66          |
| 22.3             | 10.83          |
| 23              | 9.36           |
| 24               | 8.83           |

The average value of the temperature [°C]
The average value of the efficiency [%]

Figure 5. Evolution of the average efficiency value according to the temperature during the period January- December 2014

The Figure shows that the maximum yield of n = 10.83 was determined at 22.3 ° C and the minimum efficiency of n = 7.9 at 20 ° C.

The curve obtained in Figure 5 was interpolated in polynomial form in Figure 6 to obtain the mathematical representation of the average efficiency value in relation to the average temperature during January 2014 - December 2014.

The polynomial function of the efficiency according to temperature is given by the relation (1):

\[ \eta(T) = -0.0001T^8 + 0.0058T^6 - 0.1115T^4 + 1.028T^3 - 4.7256T^2 + 10.066T + 2.3794, \]

with \( R^2 = 0.7901 \)

Figure 7 shows the evolution of average irradiation values according to the average temperature values determined in the months of 2014.
The evolution of the average value of the irradiation depending on temperature

The average value of the temperature [°C]
The average value of the irradiation [W/m²]

**Figure 7.** Evolution of the irradiation average value according to the temperature in the period January - December 2014

We can see from the Figure that the maximum irradiation \( B = 978 \) [W/m²] was determined at temperatures of 20 °C and 22.3 °C and the minimum irradiation \( B = 473 \) [W/m²] at 20 °C.

The curve obtained in Figure 7 was interpolated in polynomial form in Figure 8 to obtain the mathematical representation of the average irradiation value in relation to the average temperature during January 2014 - December 2014. The polynomial irradiation function according to the temperature is given by the relation (2):

\[
B(T) = 0.0186T^5 - 0.5904T^4 + 6.3075T^3 - 22.062T^2 + 464.73T + 137.3,
\]

with \( R^2 = 0.9521 \)

**Figure 8.** Evolution of the irradiation average value according to the temperature (January - December 2014)
4. Conclusions
The study was carried out when the climate is variable, fact which is useful in developing an efficiency relationship of the photovoltaic solar module with major climatic parameters such as temperature, wind speed, humidity; dust, etc., so that the determined equations are in good correlation with measured data.

The polynomial relations obtained through interpolation are approximated relations, but can be useful in order to determine the average efficiency value, respectively of the irradiation according to the average value of the ambient temperature.

The results of this analysis indicate that the measured parameters such as: the average value of the ambient temperature.

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