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Comparative experimental analysis of the annual energy production of a 72kW*n* photovoltaic solar power plant installed on a roof for self-consumption in the city of Monteria using PVsyst, PVGIS and SAM

Análisis experimental comparativo de la producción anual de energía de una planta solar fotovoltaica de 72kWn instalada sobre techo para autoconsumo en la ciudad de Montería utilizando PVsyst, PVGIS y SAM

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Abstract: The present work developed the comparative experimental analysis of the actual power production data of a $72kW_n$ solar PV plant, with simulations done in PVsyst, PVGIS, and SAM. The measurement period was divided between March 2021 to February 2022 and March 2022 to February 2023. It was found that the developed SAM simulation presented the lowest mean square error for the entire measurement period compared to PVsyst and PVGIS, presenting respective values of 1621.1 kWh for SAM, 1680.9 kWh for PVGIS, and 2337.8 kWh for PVsyst. It was also concluded that an increase in ambient temperature can influence the production of a photovoltaic system.

Keywords: Solar, Photovoltaic, Simulation, Software.

Resumen: El presente trabajo desarrolló el análisis experimental comparativo de los datos reales de producción de energía de una planta solar fotovoltaica de $72kW_n$, con simulaciones hechas en PVsyst, PVGIS y SAM. El periodo de medición fue dividido entre marzo de 2021 a febrero de 2022 y de marzo de 2022 a febrero de 2023. Se encontró que la simulación desarrollada en SAM presentó el error cuadrático medio más bajo para todo el periodo de medición en comparación con PVsyst y PVGIS, presentando valores respectivos de 1621.1 kWh para SAM, 1680.9 kWh para PVGIS y 2337.8 kWh para PVsyst. Además, se concluyó que un aumento en la temperatura ambiente puede influir en la producción de un sistema fotovoltaico, así también el uso de bases de datos ambientales actualizadas puede resultar en cálculos más precisos de la producción proyectada.

Palabras clave: Solar, Fotovoltaica, Simulación, Software.

1. INTRODUCTION

Solar energy is one of the most widely used renewable energies in the world, as well as the most accessible, which makes it a viable option for the development of the global energy transition [1]. However, in order to achieve the goals of sustainable development, especially the vision of zero emissions, there must be a significant increase in the growth of annual power generation, and the development of better models for the design of photovoltaic installations is key [2]. On the other hand, modeling and simulation are essential to understand the overall feasibility of photovoltaic plants in terms of environmental and technological economics [3].

1.1 Case study.

The study system is installed on the roof of a building in the city of Monteria, Colombia, at location 8.803750, -75.850125, and is connected to the facility's power grid through an indoor type substation on the roof of the building see Fig. 1. According to the literature, meteorological factors do not significantly affect the performance of the system at this location [4], but the city's high relative humidity, which ranges from 76% to 82%, [5], could influence efficiency [4]. The plant consists of 240 panels with a capacity of , reaching a peak power of 96kWn. The DC to AC conversion system includes two inverters of 36kWn each with a total capacity of 72kWn., see Fig. 2.

1.2 Software used.

A software program frequently used in simulations of solar photovoltaic plants is PVsyst, which is used to estimate the energy yield of composite and conventional systems [6]. PVsyst has been used for the analysis of losses due to shading, and the Photovoltaic Geographic Information System (PVGIS) for the comparison and inclusion of tracking systems, as has SAM [7]. Among the most important technical indicators that can be considered to measure the energy yield of a photovoltaic plant are the performance ratio and the energy production [8].

Fig. 1. *Photovoltaic solar plant located on the roof of the building.*
Source: *own elaboration.*

Fig. 2. *Solar inverter No. 1 of the plant.*
Source: *own elaboration.*

PVGIS can be used to calculate how much energy you can get from different types of PV systems almost anywhere in the world [9]. The coverage of the solar radiation database used by PVGIS 5.2 is shown Fig. 3 [10].

The System Advisor Model (SAM) is a free techno-economic software model that facilitates decision making for renewable energy professionals. SAM can model many types of renewable energy systems, including, for example: (i) photovoltaic systems, from small residential rooftops to large commercial-scale systems; (ii) lithium-ion, lead-acid or flow battery storage for front- or back-of-meter applications; and (iii) concentrating solar systems for electric power generation., including parabolic trough, power tower and linear Fresnel collectors [11].

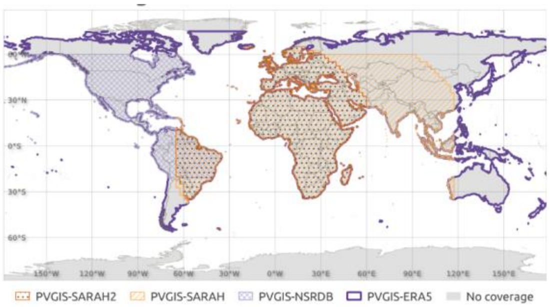

Fig. 3. *PVGIS 5.2 Solar Radiation Database Coverage.*
Source: *Based on [10].*

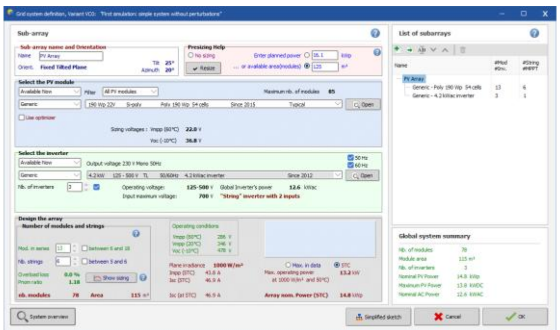

Fig. 4. *PVsyst General Dashboard.*
Source: *Based on [9].*

PVsyst is designed for the development of photovoltaic systems. PVsyst can import weather data as well as personal data from many different sources [12]. ***Fig. 4*** the PVsyst general board can be seen in which the characteristics of the panels, the inverter and the array design are indicated in order to simulate a simple photovoltaic system without disturbances.

1.3 Purpose of the analysis.

Currently, many PV system analyses are developed using simulation programs such as PVsyst, PVGIS and SAM, among others [13], but these studies take periods of one year for most of them [7]. However, environmental conditions may be different from one year to another, either due to natural or human effects [14], what may affect the temperature of the photovoltaic panel [15] and, therefore, the performance of the system [16]. The main purpose of this paper is to make a comparative analysis with real data of 24 months of energy production of a rooftop solar PV plant with simulations made in PVsyst, PVGIS and SAM, in order to measure the deviations from the real data, and to study the relationship between environmental temperature conditions and energy production.

2. METHODOLOGY

For the development of the analysis, it was necessary to develop four stages, see ***Fig. 5***:

2.1. Processing of plant and environmental data

In this stage, plant data were collected via GSM through the inverter's own communications system, see Fig. 6 , which sends the operating data to a cloud platform, from which the data is downloaded in .csv format. The ambient temperature data were downloaded from the meteostat.net platform for the Los Garzones Montería weather station, in .xls format. The measurement period was from March 2021 to February 2022 (period 1) and from March 2022 to February 2023 (period 2).

2.2. Development of PVsyst, PVGIS and SAM simulations on the study plant

For the development of this stage, the plant design data were taken and simulated in SAM version 2017.9.5, PVGIS version 5.2 and PVsyst version 7.4, to obtain the annual energy production data of the system in kWh. The databases used were: PVGIS-NSRDB for PVGIS; Meteonorm 8.1 for PVsyst; and NSRDB for SAM.

2.3. Comparative analysis and data correlation

At this stage, the data from the plant's annual energy production measurements and the simulations for each software program expressed in kWh were compared and the program with the lowest root mean square error was identified. Correlations between actual and simulated energy production data and correlations between ambient temperature in the measurement period were compared.

2.4. Discussions and conclusions

At this stage, discussions on the results were held.

3. RESULTS

After processing the production data of the solar photovoltaic plant and environmental factors, there was a decrease in energy generation from period 1 to period 2, going from 127211 kWh per year to 100645 kWh per year, which coincided with an increase in the ambient temperature for period 2 of 0.7ºC. The increase in ambient temperature causes an increase in the temperature of the photovoltaic module, which results in a decrease in the efficiency of the photovoltaic modules and, consequently, in the entire system. It is also observed that for the months of October and September 2021 and 2022, the energy production was very similar see

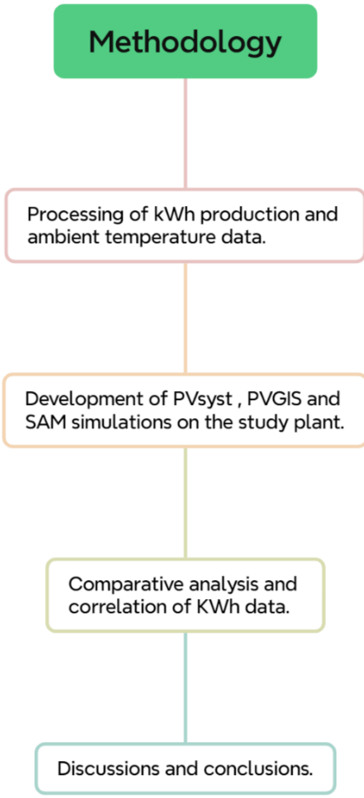

Fig. 5. *Methodology of the analysis.*
Source: *own elaboration.*

Fig. 6. *Inverter communications system.*
Source: *own elaboration.*

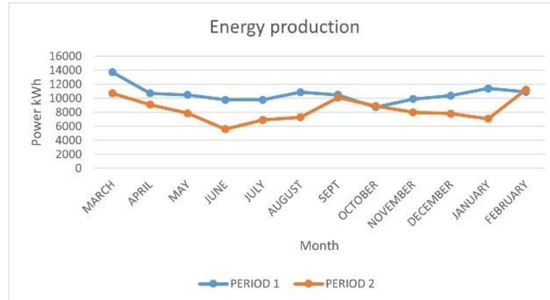

Fig. 7. *Comparación de producción de energía.*
Fuente: *elaboración propia.*

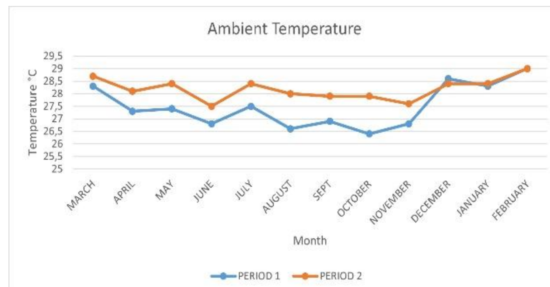

Fig. 8. *Ambient temperature comparison.*
Source: *own elaboration.*

The correlation between ambient temperature and production is 0.55 for period 1 and 0.53 for period 2, which is assessed as a moderate positive correlation according to Pearson's correlation coefficient. The correlation between the ambient temperature data for the measurement periods is 0.85, which is valued as a high positive correlation according to Pearson's correlation coefficient. The behavior of the ambient temperature during the observation periods is shown in the Fig. 8.

The development of the PVsyst, PVGIS and SAM simulations resulted in a predicted energy production of 152 432 kWh per year for PVsyst, 100 299 kWh per year for PVGIS and 117 321 kWh per year for SAM. The highest correlation between the simulations was between PVGIS and PVsyst with a correlation of 0.65, which is valued as a moderate positive correlation according to Pearson's correlation coefficient.
Fig. 9 the results of the energy production simulation using PVGIS, PVsyst and SAM are shown.

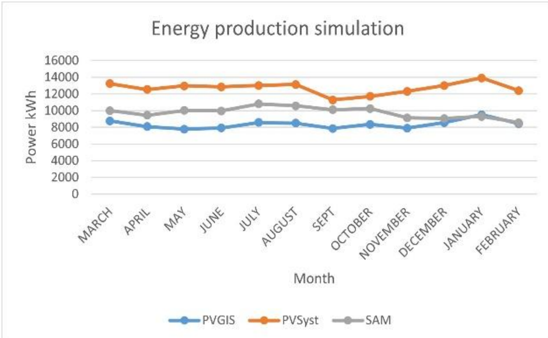

Fig. 9. *Comparison of simulated energy production.*
Source: *own elaboration.*

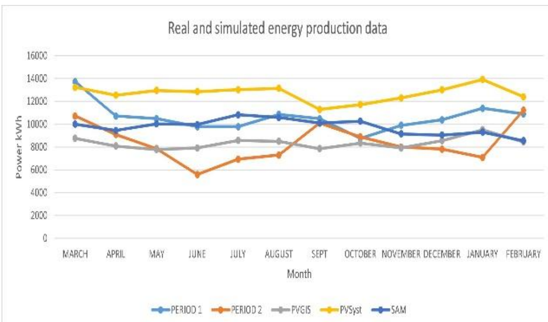

Fig. 10. *Comparison of actual and simulated energy production.*
Source: *own elaboration.*

Table 1: *Mean square error per program.*

	PVGIS	PVsyst	SAM
Period 1	2472.3	2337.8	1621.2
Period 2	1681.0	4754.5	2366,2

Source: *own elaboration.*

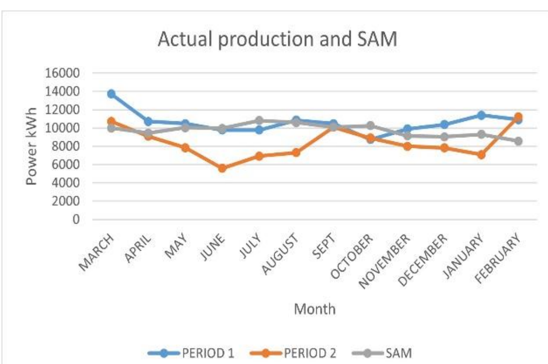

Fig. 11. *Actual plant production compared to the simulation performed in SAM.*
Source: *own elaboration.*

A comparison of the actual production data for the measurement periods with the data obtained from the PVGIS, PVsyst and SAM simulations shows periods in which the data are very similar see ***Fig. 10***. The mean square error between the actual data and the simulation results showed that for period 1, the lowest error was for the simulation developed in SAM with a value of 1621.1kWh and for period 2, the lowest error was for the simulation developed in PVGIS with a value of 1680.9kWh see **Table 1**. The lowest error calculated for the analysis periods was for SAM. The SAM simulation deviated in the first year about 8% below the actual production value and 16% above the second year of measurement see ***Fig. 11***.

4. CONCLUSIONS

After analyzing the mean square error value for the entire measurement period, the simulation that comes closest to the actual 24-month energy production is the one obtained with SAM.

The simulations obtained offer an approximation of the real behavior of the plant and allow estimating the energy production for annual periods. However, a factor of losses in the system caused by the aging of the components within their useful life must be considered. The similarity between SAM and PVGIS may be due to the fact that both have a NSRDB (National Solar Radiation Database) database, so their computations may converge in some data.

Changing environmental conditions lead to alterations in the production of solar photovoltaic energy. This could be evidenced from the analysis of the correlation between energy production and ambient temperature, which suggests that the ambient temperature can influence the operating temperature of the solar module, this can significantly impact the output of the PV system, in addition to solar radiation. In addition, it is worth mentioning that an increase in ambient temperature can also alter the operating temperature of an inverter, provided it is not protected in a temperature-controlled installation. Excessive operating temperature in the inverter can produce a phenomenon known as temperature derating, which decreases the efficiency of the inverter.

For future work, the operating temperature of the inverters can be considered to determine how it would affect production over operating periods longer than 5 years.

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