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Evaluation of the Impact of the Main Parameters Affecting Energy Performance in Bifacial Photovoltaic Modules in a Tropical Location.

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Abstract- Currently, photovoltaic solar energy faces the challenge of reducing the levelized cost of energy (LCOE) to compete with conventional energy sources and given the growth that bifacial technology has had in recent years and the complexity associated with estimating energy performance with respect to its monofacial counterpart. This research focuses on evaluating and comparing the energy performance of bifacial technology with respect to monofacial technology according to 4 main parameters of affectation: 1) inclination, 2) pitch, 3) albedo and 4) height from the ground, in a tropical location, using the specialized software PVsyst. The results show that the bifacial energy gain can vary according to the parameter of affectation: between 2.4% and 19.2% depending on the albedo; up to 7.44% depending on the distance between sheds or 6.1% for their height from the ground, and even not generate a bifacial gain by modifying the angle of inclination of bifacial photovoltaic modules.

Keywords: Bifacial technology, bifacial gain, energy performance, tropical location, pitch, albedo.

I. INTRODUCTION

Currently, solar PV faces the challenge of reducing the levelized cost of energy (LCOE) to compete with conventional energy sources. With this objective in mind, the manufacturers of photovoltaic modules have developed a technology that allows to capture the radiation that falls directly on the front, and at the same time allows to capture the diffuse radiation and reflected by the back of the module (albedo effect) [1], this photovoltaic module is known for The name Bifacial module and allows to obtain a higher energy production per unit area compared to monofacial modules [2]. Also, bifacial technology has a longer lifespan and sometimes a lower LCOE [3-5].

Bifacial modules began to be developed in the 80s [6], however, the cost of these modules until recently was very high, making projects with this technology unviable. Recently, the costs of bifacial modules have decreased, and their efficiency has improved, generating renewed interest in this technology in the renewable energy market. An example of this is that by 2018 bifacial technology occupied less than 10% of the market for photovoltaic modules, currently these modules occupy 30% of the market, and monofacial modules 70%. According to the International Technology Roadmap for Photovoltaic (ITRPV) it is expected that by 2030 bifacial modules will occupy 60% of the market and monofacial modules occupy 40% [5].

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On the other hand, estimating the performance of bifacial modules is more complex than doing it for their counterpart monofacial modules, since the incident irradiation at the back of the bifacial module varies depending on several parameters, such as: inclination, pitch, albedo, and height with respect to the ground [6]. To estimate the incident irradiation at the back of the bifacial module, different models have been developed, such as empirical models, ray tracing mode and the sight factor model, these models have been discussed in different investigations [8-14].

The growth that bifacial technology has had in recent years and the little knowledge we have about its performance has led to different studies being carried out in the world to understand how parameters such as albedo, inclination, height, and separation between sheds (pitch) affect its energy performance. The results of these studies [14-19] have shown that bifacial technology can obtain up to 30% more energy compared to monofacial technology. However, in tropical sites bifacial technology has not been well studied and it is unknown under which parameters bifacial technology can perform better, therefore, this research focuses on evaluating and comparing the energy performance of bifacial technology with respect to monofacial technology according to 4 main parameters of affectation: 1) inclination, 2) pitch, 3) albedo and 4) height from the ground, in a tropical location.

II. LOCATION AND PHOTOVOLTAIC SYSTEM.

This study was conducted in the city of Bucaramanga, Santander, Colombia. This city is positioned in the Northern Hemisphere, latitude 7.12539, longitude -73.1198 and a height of 975 m above sea level. The meteorological conditions of the site were obtained from the Meteonorm 8.0 database of the PVsyst software, in Fig. 1 the monthly average of direct normal irradiation in the city of Bucaramanga is presented.

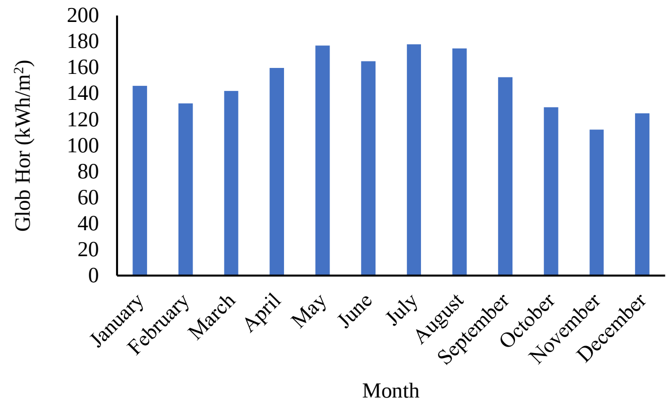

Fig. 1. Normal monthly direct irradiation from Bucaramanga, Colombia. [taken from PVsyst]

III. Photovoltaic System Design

For the research, a photovoltaic system was designed to meet a demand for electrical energy required by an industry that operates for 16 hours a day and has an average consumption of 7 MWh / month. The daily profile of electrical energy consumption is presented in Fig. 2 To cover approximately 80% of the energy demand, and given that the area available for installation is 330m^2, a photovoltaic system with an installed capacity of 46.8 kWp with monofacial technology (reference for the study) and bifacial technology was selected.

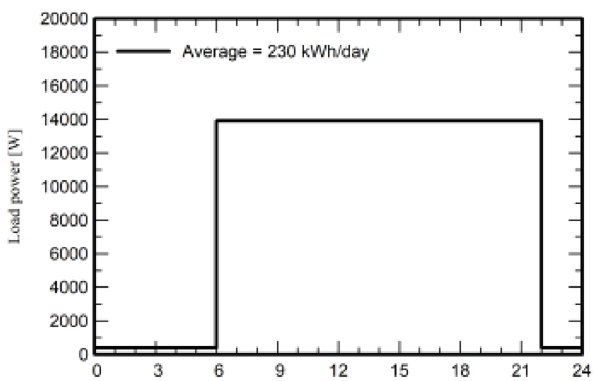

Fig. 2. Daily energy consumption profile.

For the design of the photovoltaic system, the following equipment was selected:

- Photovoltaic module: To compare the energy performance of bifacial modules with respect to monofacial modules, it was considered that the modules have the same characteristics: nominal power (450W), module size (2.2 m^2) and type of technology in the photovoltaic cell (Monoperc).

According to the manufacturer's technical sheet, TABLE 1 presents the specifications of the monofacial module in STC conditions and the specifications of the bifacial module contemplating an additional gain of 25% of energy by the back of the module. TABLE 2 presents the characteristics of the inverter selected for the PV system and TABLE 3 shows the specifications of the system connected to the grid of 46.8 kWp.

TABLE 1. Specifications of the selected module.

Technical specifications	***Photovoltaic Module***	
	Monofacial	***Bifacial Gain 25%***
Rated Power - Pmax [W]	450	544
Nominal Power Tolerance –Pmax [W]	0~+5	-
Voltage at maximum power -Vmpp [v]	41,7	40,8
Current at maximum power - Impp [A]	10,8	13,34
Open Circuit Voltage - Voc [V]	49,5	49,4
Short circuit current Isc [A]	11,36	14,05
Efficiency [%]	20,4	-

TABLE 2. 10 k W inverter specifications

Technical parameters or specifications	***Amount***
AC power [kW]	10
Minimum MPP voltage [V]	350
Maximum MPP voltage [V]	850
Nominal MPP voltage [V]	720
Absolute max PV voltage [V]	1000
Current AC nominal [A]	43.5

TABLE 3. 46.8k Wp network-connected system specifications

System Specifications	***Quantity***
Number of modules [und]	104
Serial modules [und]	13
Number of strings [und]	8
Module area [m^2]	230
Number of investors [und]	4
Rated power [kW]	46,8

IV. Simulation in Specialized PVsyst Software.

In order to evaluate and compare the energy performance of the bifacial modules with respect to their monofacial counterpart, a series of simulations were carried out using the PVsyst software in version 7.2.8. This software was selected because it allows to optimize the energy performance of the bifacial modules by modifying the main parameters of affectation: inclination, pitch (distance between sheds), height with respect to the ground and albedo. To estimate the effective irradiance at the rear of the bifacial modules PVsyst uses the "View Factor" model, this model is based on radiative energy transfer, where the factor F is the percentage of the radiation that leaves the surface A1 (albedo) and is perpendicularly intercepted by the surface A2 (back of the module).

V. PARAMETERS AFFECTING THE ENERGY PERFORMANCE OF BIFACIAL MODULES.

To evaluate the energy performance of the bifacial modules, four case studies were developed in which the parameters of affectation were modified.

Case 1 - Inclination: it consisted of varying the angle of inclination in the bifacial modules, in this case the angle of inclination defined for the latitude of the city of Bucaramanga was taken as a reference, which is 10°, and from this angle the angle of inclination was increased by 10° until reaching an angle of 90°.

Case 2 - Pitch: consisted of varying the separation distance between the sheds of the bifacial modules also known as Pitch, this distance was modified from 2.11m which is the length occupied by the module to 7.11m, in intervals of 0.5m.

Case 3 - Height: consisted of modifying the height of the modules with respect to the ground from 0m to 2.4m in an interval of 0.3m.

Case 4 - Albedo: consisted of analyzing 7 plots with different albedos: water (10%), sand (20%), concrete (25%), meadow (30%), red tiles (33%), white paint (80%) and aluminum (90%) [20].

In TABLE 4 the fixed and TABLE 4variable parameters for each case are observed.

TABLE 4. Case studies.

Parameter	***Case 1***	***Case 2***	***Case 3***	***Case 4***
Variable	Inclination	Pitch	Height	Albedo
Fixed	Pitch 4m	Tilt 10°	Pitch 4m	Pitch 4m
Fixed	Height 1.5m	Height 1.5m	Tilt 10°	Height 1.5m
Fixed	Albedo 25%	Albedo 25%	Albedo 25%	Tilt 10°

VI. RESULTS

The results obtained in the simulations show that for case 1, the angle of inclination in which the highest energy production is obtained for the city of Bucaramanga is 10° Fig. 3, this given that the latitude in which the city of Bucaramanga is located is 7°. In addition, it is observed that as the angle of inclination increases by 10° the production of the photovoltaic system decreases. This is due to the fact that at an angle greater than 10° the irradiance that directly affects the surface of the module is lower.

The results obtained in the simulations show that for case 2, the distance between sheds managed to increase energy production by 5,258 MWh/year in photovoltaic systems or s with bifacial technology with respect to photovoltaic systems with monofacial technology, this for a pitch with a value of 7.11m, representing 7.44% bifacial gain.

From another perspective, the analysis of Fig. 4 shows that the energy production in systems with conventional modules remains almost constant after the pitch has a value of 2.61m, while bifacial modules with Pitch of 4.11m are able to increase energy by 4.225 MWh / year, observing that after 4.11m the energy only increases by 1.033 MWh / year compared to the Pitch with a value of 7.11m, Therefore, with pitches above 4.61m the bifacial gain is less than 1%.

For this case, the results obtained show that raising the height of the bifacial modules to 2.4m from the ground increases energy production by 3,401 MWh/year, representing a bifacial gain of 6.1% (see Fig. 5). On the other hand, it is observed that, above a height of 1.2m, the bifacial gains obtained with respect to an elevation of 2.4m represent less than 0.6%.

In case 4, which consisted of analyzing different scenarios by varying the albedo, the results showed that energy production was increased as follows:

Fig. 6 shows that on surfaces with low albedos such as that reflected by water (albedo 10%), energy production increased by 1,685 MWh/year. On surfaces with typical albedos such as sand (albedo 20%), concrete (albedo 25%), meadow (albedo 30%) and red roofs (albedo 33%) energy production increased 3,326 MWh/year, 4,081 MWh/year, 4,869 MWh/year and 5,339MWh/year respectively. Finally, on surfaces where the albedo has a higher reflection index such as white paint (albedo 80%) and aluminum (albedo 90%), energy production managed to increase 12,241 MWh/year and 13,591 MWh/year, respectively.

On the other hand, in this case the bifacial gain obtained by different albedos was analyzed, in Fig. 6 it is observed that on surfaces with low albedos such as water and sand the gain obtained by bifacial modules with respect to conventional modules is less than 5%. On surfaces with typical albedos such as concrete, meadow and red roofs, the bifacial gain obtained with respect to monofacial modules is between 5.8% and 7.6%. Finally, on surfaces with high albedos such as white paint and aluminum, the bifacial gain obtained compared to conventional modules is 17.34% and 19.2% respectively.

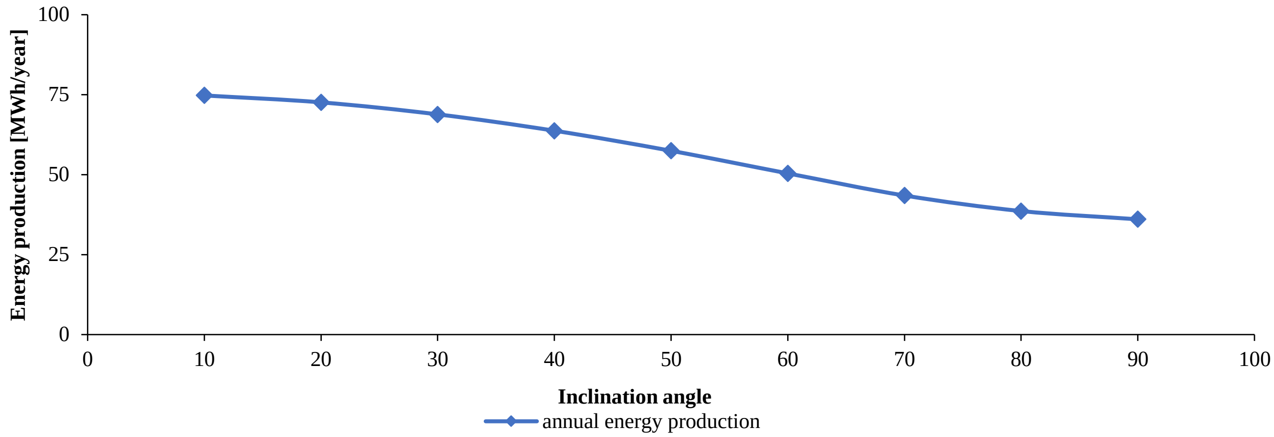

Fig. 3. Annual energy production by varying the angle of inclination in bifacial modules.

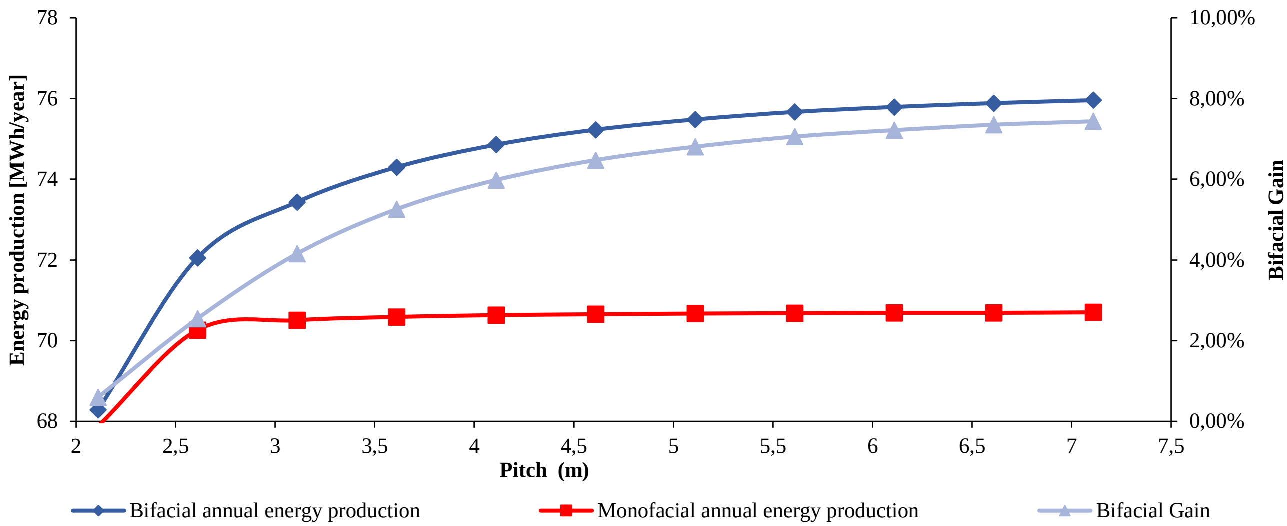

Fig. 4. Annual energy production by varying the distance between sheds.

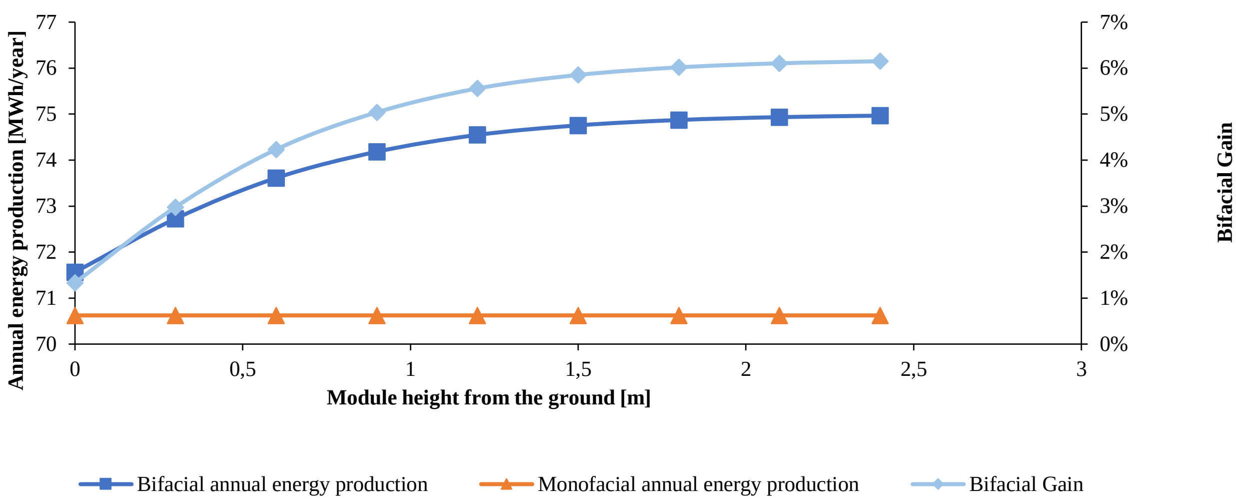

Fig. 5. Annual energy production by varying the height of the modules.

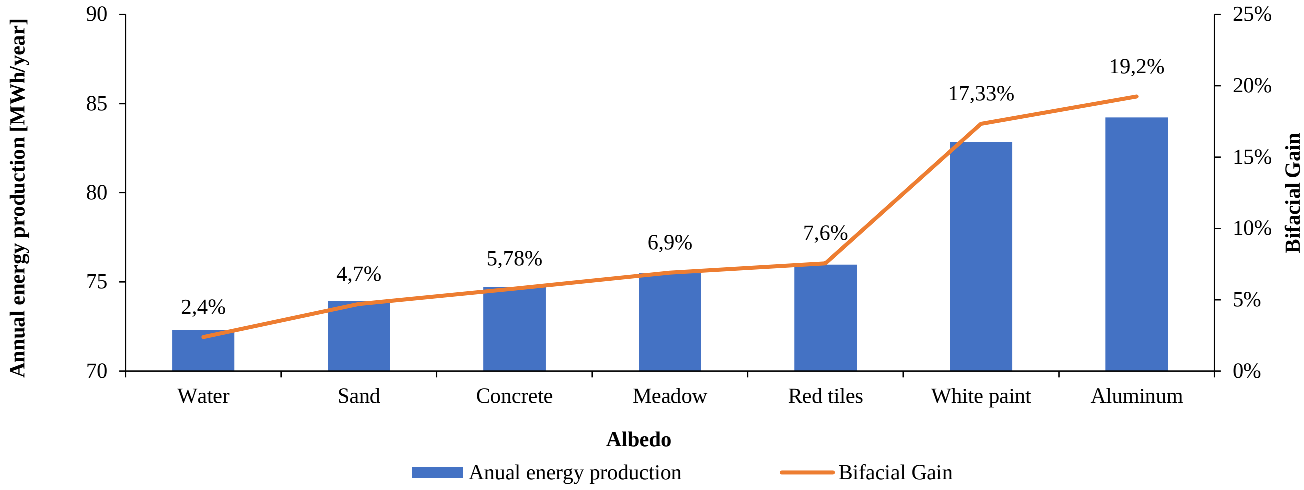

Fig. 6. Annual energy production by analyzing different albedos and their bifacial gain.

VII. Conclusions

The evaluation and comparison of the energy performance of bifacial technology with respect to monofacial technology was carried out according to 4 main parameters of affectation: 1) inclination, 2) pitch, 3) albedo and 4) height with respect to the ground, in a tropical location, using the specialized PVsyst software.

The analysis concludes that the bifacial energy gain can vary according to the parameter of affectation: between 2.4% and 19.2% depending on the albedo of the surface 10% to 90% respectively; up to 7.44% depending on the pitch or 6.1% for its height with respect to the ground, and even not generate a bifacial gain by modifying the angle of inclination of bifacial photovoltaic modules.

Bifacial modules should be oriented in the same way as monofacial modules, since in this orientation a greater benefit is obtained from the direct component that falls on the front of the module.

It was concluded that bifacial modules require a higher pitch with respect to their monofacial counterpart to achieve greater energy production, however, from a pitch of 3m the bifacial energy gain is no longer so significant. In the same way, after a height of 1.2m there is no greater benefit in the performance of bifacial modules.

VIII. Acknowledgment

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